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Message from Deputy Vice-Chancellor, Academic, SLIIT

I am delighted to provide a congratulatory message to the Proceedings of SICET 2022. The Faculty of Engineering at SLIIT is known for its high-quality academic programs and innovative research. SICET 2022 is the inaugural international conference organized by the Faculty of Engineering under the leadership of Professor Saman Thilakasiri, Dean of Engineering. The Conference Chair, Associate Professor Niranga Amerasinghe and the Technical Program Chair, Dr. Anton Hettiarachchige, deserve credit for producing very high -quality proceedings based on the presentations made at the conference.

The proceedings of SICET 2022 covers established and emerging topics of engineering. It is, therefore, an excellent collection of papers that will have a significant archival value. The world is slowly recovering from the Covid-19 pandemic, which reminds us of the importance of both basic and applied research. The pandemic has also reinforced the need to advance the frontiers of knowledge through international collaborations and multidisciplinary approaches. The papers in the proceedings demonstrate these key features.

I am pleased to note the interest of local and international scholars in the conference. SICET 2022 has set the foundation to become a highly recognized venue for research examining innovative solutions to complex problems of today and tomorrow. I look forward to participating in future SICET conferences.

I wish all authors and the editorial team continued success with their scholarly endeavours.

Professor Nimal Rajapakse, FCAE,FEIC,FCSCE,P.Eng. (BC)
Deputy Vice-Chancellor, Academic, SLIIT

Message from Dean, Faculty of Engineering, SLIIT

I give this message for the conference proceeding of the SICET 2022 with immense pleasure. At the outset, I thank the conference chair of SICET 2022 and the organizing committee for excellent job they did by organizing the first ever conference by Faculty of Engineering (FoE), Sri Lanka Institute of Information Technology (SLIIT) successfully. The conference was organized by the organizing committee with the advice of the conference technical committee and the advisory committee. I thank them all for the support extended. This will be beginning of new era and this conference will be an annual event of the FoE.

We at FoE are dedicated to educate and train each student to the highest standard and prepare them for employment across many levels. During their undergraduate studies, we provide them with compulsory on-the-job training, which will give them valuable hands-on experience within their respective fields of study. Our highly qualified and experienced full-time academic staff and excellent in-house state-of-the-art laboratory facilities will ensure that the students one day will leave the faculty with the best learning experience with national and international recognition. We enhance their research capabilities through compulsory research project and comprehensive design projects (CDP).

In parallel with the development of our undergraduate program, we develop our Postgraduate research programs leading upto MPhil and PhD degrees, for which we were given permission by Ministry of Higher Education (MoH), Sri Lanka in 2015 after a thorough inspection of our facilities and quality assurance system we followed. We take a genuine effort to publish our research in indexed journal and conference proceedings, and have a very good publication record over the past few years. We started this conference with the idea of developing further research collaborations with the industry and other research institutions, and in the near future to index this conference with international bodies. This conference is an excellent start and I wish my warm congratulation for its future success!

Professor Saman Thilakasiri
Dean – Faculty of Engineering

Message from Conference Chair, SICET 2022

Welcome to the proceedings of the SLIIT International Conference on Engineering and Technology- volume 1 (2022). The studies presented during the conference, which focused on different field of Engineering and technology are included into these proceedings. This conference is organized to offer a platform for academics, students, and industrial participants to disseminate their recent findings and discuss them with prominent engineering professionals.

A total of 153 papers were submitted to SICET2022. Each submission was reviewed by at least two experts in the relevant field. The papers were judged according to their originality, validity of research design, clarity, soundness of research output, readability and organization, and relevancy to the conference tracks and beyond. This resulted in the selection of 59 papers for presenting at the conference (38% acceptance rate) in which 20 papers received with oversees affiliations. Out of the selected papers, fourteen manuscripts were selected by the faculty journal publication committee to publish in the Journal of Advances in Engineering and Technology. The remaining 45 manuscripts are published in this volume. As the chair of the technical program committee, I feel that these proceedings inspire future research and create an intense following.

Furthermore, the conference features with three key-note speeches and a panel discussion from prominent experts. It also facilitates with six pre-conference workshops in different disciplines of Engineering and Technology for creating knowledge and sharing opportunities.

I would like to express my heartiest appreciation to the authors of the submitted papers and all the attendees, panels of reviewers, track chairs for their dedication and assistance in turning the conference into a success. Producing this book would not have been possible without the continuous contribution of Co-editor Anton Hettiarachchige-Don.

I hope you will enjoy the papers in the proceedings.

Professor Niranga Amarasingha
Co-Editor & Conference Chair, SICET 2022

Message from Publication Chair, SICET 2022

It is my pleasure to welcome you to the proceedings of the first SLIIT International Conference on Engineering and Technology (SICET2022). This multi-disciplinary engineering conference featured scientific publications from a wide range of interests. I provided authors, researchers and industry experts an excellent platform to interreact and exchange ideas about the latest developments in their fields.

All papers in this publication have gone through double blind peer review process conducted by reviewers who are area expects. Papers not meeting our expectation of quality in terms of innovation and originality have been rejected to perverse the overall quality of the conference.

I am thankful for the authors for these contributions as well as the reviewers and conference organizers for all their effort. It is my hope that the papers contained in this publication offers readers with a valuable trove of knowledge and helps to further the knowledge base in multiple disciplines of engineering.

Dr. Anton Hettiarachchige-Don, PhD.
Co-Editor & Publication Chair, SICET 2022

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Journal Publications

The following papers presented at SICET 2022 and published in the journal of advances in engineering and technology.

Published in the Journal of Advances in Engineering and Technology.

Application of Sentinel-2 Satellite Data to Map Forest Cover in Southeast Sri Lanka through the Random Forest Classifier
By: Thakshila Gunawansa (University of Southern Queensland/Uva Wellassa University), Kithsiri Perera (University of Southern Queensland), Armando Apan (University of Southern Queensland), Nandita Hettiarachchi (University of Ruhuna)

Experimental Identification of Alkali-Aggregate Reaction in Concrete.
By: Rashean Baddeliyanaralalage Don (Curtin University), Nihal Somaratna (SLIIT)

Factors Affecting to Red-Light Running of Pedestrians at Signalized Intersections
By: Chamara Herath (SLIIT), Niranga Amarasingha (SLIIT)

Evaluating the Effectiveness of Speed Humps related to Speed Profile and Noise Profile
By: K.G. Dilanka Gamlath (SLIIT), Niranga Amarasingha (SLIIT), Vasantha Wickramasinghe (University of Peradeniya)

Attributes of ADR in Sri Lankan construction industry
By: Vajira Edirisinghe (SLIIT), Dianne Marsh (LJMU), Fiona Borthwick (LJMU), Mohan Siriwardena (LJMU), Cotgrave, Alison Cotgrave (LJMU)

Strategies Used by the Sri Lankan Construction Industry to Overcome the Challenges Posed by the COVID -19
By: Piyumi Fernando (LJMU), Nishanthi Gunarathna (SLIIT)

Design and dynamic modelling of knee exoskeleton for disabled people through ADAMS-Simulink co-simulation
By: Jivindu P. Ranaweera (Curtin University), Malika Perera (SLIIT)

Neural Network based automated hot water mixture
By: F.N.M Firsan (Curtin University), G.M Herath (SLIIT), T.D Thilakanayake (SLIIT)

Efficient Ventilation Configurations for an Isolation Ward in view of Reducing the Potential Contamination of Its Occupants
By: Hasitha Durage (SLIIT), Prof. Rahula Attalage (SLIIT), Dr R.M.P.S. Bandara (KDU)

Vertical Axis Wind Turbine for Sri Lanka Southern Highway
By: Samidu Perera (SLIIT), Dilumi Nandasena (SLIIT), Dilini Wijayakumara (SLIIT), Kasuni Guruvita (SLIIT)

A Review on Sub-Synchronous Resonance Damping with Thyristor Controlled Series Compensators
By: D. R. Weerakoon (University of Manitoba), U. D. Annakkage (University of Manitoba), C. Karawita (Trans Grid Solutions (Pvt.) ltd.)

Understanding the characteristics of the heatwaves using temperature as the only variable – A case study on heatwave in 1994 in South Korea
By: Sewwandhi S. K. Chandrasekara (University of Peradeniya/Sejong University), Hyun-Han Kwon (Sejong University)

Data Science to Determine Mechanical Properties of Low Carbon Steel During In-Process Inspections
By: K. G. Alahapperuma (University of Vocational Technology), D. D. D. Suraweera (University of Vocational Technology), N.Nandhakumar (Ashok Steel Private Limited Company)

Developing a Rubber Based Nanocomposite
By: Muhamed Ismaeel Faisal Sadique (Curtin University), Migara Liyanage (SLIIT), Chitral Angammana (University of Waterloo)

SICET 2022 Plenary Session

Topic: Engineering aspects in dealing with COVID-19 pandemic

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Keynote Address 1:

Converter Control for Integration of Renewable Energy into the Grid

Udaya Annakkage
Professor, Department of Electrical and Computer Engineering,
University of Manitoba, Canada

Abstract:

Generation of electricity using renewable sources of energy will be the only option available to us soon. This may happen within the next two decades. In the meantime, we make the transition form traditional synchronous generator driven power systems to fully renewable energy-based power systems where the energy source is integrated through power electronics converters. We must start thinking in a new way. This presentation will address the technological challenges associated with connecting renewables to the grid through converters and the options available to meet those challenges. While the ability of the converters to respond fast is an obvious advantage, unlike the synchronous generator, it does not have a rotating mass that stores kinetic energy. The short-term overcurrent rating of the converter is much less than that of a synchronous generator unless the converter is overdesigned. Addressing these engineering challenges will be discussed in the presentation.

Speaker Biography:

Dr. Annakkage is a professor in Electrical and Computer Engineering Department at the University of Manitoba. He has more than 30 years of experience in teaching, research and consulting. His main strength is in power system stability and security assessment. He received the B.Sc. (Eng.) degree from University of Moratuwa, Sri Lanka, in 1982 and the M.Sc. and Ph.D. degrees from the University of Manchester Institute of Science and Technology (UMIST), Manchester, U.K., in 1984 and 1987, respectively. He has supervised more than twenty PhD students and several MSc students at the University of Manitoba (Canada) and the University of Auckland (New Zealand). He has served on IEEE and CIGRE working groups. He was an editor of IEEE Transactions on Power Systems from 2009 – 2012, and the Head of Electrical and Computer Engineering Department at the University of Manitoba from 2008 January – 2012 December, and Acting Head from 2005 July – 2006 June and 2020 July – 2021 June. He has published over 125 articles including 60 articles in peer-reviewed journals. He was the convenor of the IEEE Task Force on "Dynamic System Equivalents" (2009-2012), the convenor of CIGRE Working Group on "Application of Phasor Measurement Units for monitoring power system dynamic performance" (2013-2017) and the Technical Committee Program Chair representing the Power System Dynamic Performance Committee of IEEE Power and Energy Society (2015-2017). Currently he is the secretary of the CIGRE Working Group on "Guidelines for Sub-synchronous Oscillation Studies in Power Electronics Dominated Power Systems" and the convener of joint CIGRE/IEEE Working Group on "Evaluation of Voltage Stability Assessment Methodologies in Transmission Systems".

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Keynote Address 2:

Intelligent Robotics—Misconceptions, Current Trends and Opportunities

Clarence W. de Silva
Professor of Mechanical Engineering
The University of British Columbia
Vancouver, Canada

Abstract:

The concepts of "Robots" have been of interest to humans from the historical times, initially with the desire to create "artificial slaves." Since the technology was not developing to keep up with the "dreams," initially Robotics was primarily of entertainment value, relegated to plays, movies, stories, and so on. The practical applications started in the late 1950s and the 1960s with the development of programmable devices for factories and assembly lines, as flexible automation. However, since the expectations were not adequately realized, the general enthusiasm and funding for Robotics subsided to some extent. With subsequent research, developments, and curricular enhancement in Engineering and Computer Science and with the resurgence of Artificial Intelligence (AI), particularly machine learning, Robotics has found numerous practical applications today, in industry, medicine, household, the service sector, and the general society. Important developments and practical strides are being made, particularly in Soft Robotics, Mobile Robotics (Aerial—drones, Under Water, Ground-based—autonomous vehicles in particular), Swarm Robotics, Homecare, Surgery, Assistive Devices, and Active Prosthesis.

This talk will start with a brief history of Robotics while indicating some associated myths and unfair expectations. Next it will outline key developments in the area. In particular, some important practical applications of Intelligent Robotics, as developed by groups worldwide including the Industrial Automation Laboratory at the University of British Columbia, headed by the author, will be indicated. Some misconceptions and shortcomings concerning Intelligent Robotics will be pointed out. The main shortcomings concern the mechanical capabilities and the nature of intelligence. The talk will conclude by mentioning future trends and key opportunities available in Intelligent Robotics, for both developed and developing counties.

Speaker Biography:

Clarence W. de Silva received his primary education at B/Morahela Maha Vidyalaya, under the loving care, coaching and guidance of his parents who were teachers. His mother in particular, with her remarkable foresight, self-learned English and Algebra and taught him those subjects even before Grade 5 even though those subjects were not taught in her village school. Subsequently he was sent to St Bede's College, Badulla, St Thomas' College, Gurutalawa, and finally Ananda College, Colombo from where he entered the then University of Ceylon (now University of Peradeniya) after winning the Dr. Erwin de Silva Gold

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Medal. He graduated from the University obtaining First Class Honors and the Dr. C. H. Hewavitarana Prize in Engineering. After working several years at Arpico Factory in Nawinna, Maharagama (now defunct) as an Assistant Works Engineer, he went overseas. He obtained an MASc degree from University of Toronto, PhD degrees from MIT and University of Cambridge, and recently, the ScD degree, the so-called “Higher Doctorate,” from University of Cambridge. He is a Fellow of: IEEE, ASME, Canadian Academy of Engineering, and Royal Society of Canada. Also, he has been a Senior Canada Research Chair, NSERC-BC Packers Chair in Industrial Automation, Mobil Endowed Chair, Lilly Fellow, Senior Fulbright Fellow, Killam Fellow, Erskine Fellow, Professorial Fellow, Faculty Fellow, Distinguished Visiting Fellow of the Royal Academy of Engineering, UK, and a Peter Wall Scholar. He has authored 25 books and about 600 technical papers, approximately half of which are in journals. He has attempted to pay back to his motherland through such activities as: providing scholarships to two dozen Sri Lankan students for post-graduate studies in Canada; developing curricula and course material in Mechatronics and conducting courses for educational institutions in Sri Lanka, including the Open University; endowing an award for the top student in Mechatronics; and developing computer facilities, roads, mentoring network, health clinics, and hospital cafeteria in a rural area .

Keynote Address 3:

Aspects of Structural Vulnerability against Tsunamis

Priyan Dias
Senior Professor, Faculty of Engineering,
Department of Civil Engineering,
University of Moratuwa, Sri Lanka

Abstract:

Using historical data, it is shown that tsunamis may not occur for earthquake magnitudes even up to Mw = 8. Field data can be used to arrive at generalized fragility curves for different materials of construction as functions of inundation depth. Such curves can also be integrated into vulnerability curves that can be characterized by simple negative exponential equations. It is also possible to create synthetic fragility curves generated by Monte Carlo simulation, which were found to have a reasonable fit with the empirical ones. While most simulations focus only on the structural frames in buildings, partitions can also play a significant role in damage mechanisms. There is also a role for simplified indices of either risk or robustness, based ideally on physics rather than expert opinion. Such indices can also be used to consider risk to an entire system, for example buildings, functions and backup services that are spread across adjacent coastline hospitals.

Speaker Biography:

Priyan Dias has a doctorate from Imperial College London and is an Emeritus Professor in Civil Engineering at the University of Moratuwa, Sri Lanka, where he was the founder Director of Research (2014-17). He has also held research fellowships at the University of Bristol, Carnegie Mellon University, the University of Melbourne and the National Technical University of Athens. He is now attached to the Sri Lanka Institute of Information Technology as a part time Consultant and Professor. He is currently the Sri Lanka Representative for the Institution of Structural Engineers, UK; and the President of the National Academy of Sciences of Sri Lanka. He is also an associate editor of Civil Engineering & Environmental Systems, and has authored a book with Springer Nature in 2019 titled Philosophy for Engineering: Practice, Context, Ethics, Models, Failure. In 2020 and 2021, he was included in a database of the top 2% of researchers worldwide, prepared by authors from Stanford University and Elsevier.

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Effects of Manufactured Sand on the Properties of Normal and High Strength Concrete

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ABSTRACT

Manufactured Sand (MS) has been introduced as a very effective fine aggregate and is being widely used in various construction activities. Large amounts of Manufactured Sand Fines (MSF) that are less than 75 µm in particle size, are produced during the production process. Costs are incurred in separating these fines from the crushed stone and are then dumped in landfills, thus causing serious environmental issues. Studies on MSF are not well established and a handful has been done on High Strength Concrete (HSC). The key objectives of this study were to study and compare the effects that MSF have on the properties of Normal Strength Concrete (NSC) and HSC and to propose effective fines percentages that could be incorporated in them. Tests were carried out by partial replacement of MS with fines in proportions of 10%, 15% and 20% for C30 and C60 concrete and were compared with the control mixes that contained 3.36% MSF. It was identified that a 15% replacement of MSF produced effective results with the highest compressive, splitting tensile and flexural strength results and minimum water absorption in both NSC and HSC. At 15% fines content, a strength of 35.3 MPa and 63.3 MPa was achieved by the C30 and C60 concretes respectively. However, the increment of fines decreased the workability significantly. The microstructure analysis proved the densification of the microstructure at 15% MSF content. The cost analysis showed that the availability of high fines content can deduct the cost of NSC by 1.8% and HSC by 1.6%. The 10% - 15% range was identified as the most effective fines content range that can be incorporated in NSC and HSC. Results of this study can contribute to develop concrete with better performance while addressing several environmental and cost issues related to the concrete industry.

KEYWORDS: *Manufactured sand, fines, partial replacement, normal strength concrete, high strength concrete.*

1 INTRODUCTION

Concrete is considered to be the most widely used construction material all over the world. Depending on the compressive strength of concrete, concrete can be categorized into NSC and HSC. Concrete compressive strength of 60 MPa is considered as the lower limit for HSC (Al-Oraimi et al., 2016). Among the various materials used as fine aggregates in the industry, River Sand (RS) is considered to be the most prominent material that has been used in concrete over many decades. With the scarcity of RS and the restrictions towards mining, the prices of RS have vastly increased, bringing RS to be unaffordable and not economical. Thus, there arose a need for the use of alternative materials for RS for the use as fine aggregates.

In the search for alternatives, MS has been introduced as a very effective alternative for RS. Unlike RS which is naturally occurring, MS is artificially produced by the mechanical crushing of the parent rock under controlled processes. Therefore, due to this reason, MS appears to have different compositions, shapes, gradation and fines content (particles smaller than 75µm) when compared to RS. One of the components of MS that has extensive effects on the properties of concrete is the amount of fines content incorporated in MS. The percentage of MSF that can be incorporated in concrete is usually limited to specific ranges due to several reasons. One of the reasons is due to the decrement of workability of the fresh concrete due to the large surface area that has to be wetted. This as a result will

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lead to the increment of the water content in order to maintain the workability, and as a result, the concrete being more susceptible to shrinkage and cracking. These fine particles have a high tendency of attaching to the surfaces of the larger particles thus preventing proper bonding among the cement paste and aggregate. Another reason is due to the availability of clay particles among the MSF which are less than a few micrometers. The hardened concrete is more susceptible to have more sensitivity to cracking due to the volume changes that occur in the clay particles by water absorption and drying out. This will result in a decrease in the strength of the concrete. As a result of the above-mentioned restrictions, various methods such as washing are used to separate MSF and are discarded to landfills. Since the entire number of fines will not be removed from these processes and due to the above-mentioned restrictions, several standards have been put up to limit the quantity of fines that can be used in concrete.

However, studies done on NSC have proved that the use of high levels of MSF in concrete have both favorable and adverse effects on the mechanical and durability properties of concrete.

As investigated in Ahmed and El-Kourd (1989) using both MS and RS in NSC, with the replacement of MSF, an increase in the compressive strength was observed for the concrete with MSF whereas an approximately constant variation was observed for the concrete with natural sand. It was observed that the slump drastically decreased with the increase in fines. In the studies done on Grade 35 concrete in Katz and Baum (2006), it is further confirmed that the fresh concrete properties such as the slump are greatly affected by the increase in fines content. It was observed in the study that with the increase in the MSF content, the amount of High Range Water Reducing Admixture (HRWRA) that was added in order to maintain a constant slump increased. It was further studied that the fineness of the fines, that is, the decrease in the particle size of the MSF had a major impact on the workability of the concrete. It was observed that the demand for the HRWRA was doubled when the median size of the fines in the concrete decreased. In Beixing et al., (2009), it is discussed that the compressive strength of the concrete increases with the addition of limestone fines. It is mentioned that limestone fines act as nucleation sites for the calcium silicate hydrates accelerating the hydration of clinker minerals at the early stages. Carbo-aluminates are formed by the reaction between limestone fines and tricalcium aluminates further improving the strength. Çelik and Marar (1996) have investigated on the effects of crushed rock fines on the mechanical and durability properties of NSC. It is shown in the study that the flexural strength and the impact resistance are at the maximum at 10% and 5% replacement of fines respectively. In the study, a minimum water absorption has been observed at 15% fines replacement as well. The water permeability continuously decreased with the increment of fines, indicating that the addition of fines improved the durability properties of concrete. In the microstructure studies as discussed in Yang et al., (2018), the filler effect of MSF in concrete was justified since it was observed that the limestone fines that were incorporated in the concrete, densified the pore structure and the Interfacial Transition Zone (ITZ) of concrete. The studies clearly indicated the effectiveness of incorporating high content of fines in concrete.

Though there exists several studies that have been done to study the effects of MSF on the properties of NSC, a handful has been done on the effects of the MSF on the properties of HSC. Furthermore, no proper study has been done comparing the effects that MSF have on the properties of both NSC and HSC. Therefore, it is observed that there exists a gap that requires more investigation on the effects that MSF have on the properties of HSC. There also exists a gap that requires a comparison between the effects of MSF on the variation of the properties and determining the most effective fines content that can be used in NSC and HSC.

The objectives of this study were to study and compare the effects of MSF on the properties of normal and high strength concrete by partial replacement of MS by MSF and to determine an effective amount of fines content in manufactured sand to be used in normal and high strength concrete that would have better properties and be cost effective.

2 METHODOLOGY

2.1 Materials

Ordinary Portland Cement (OPC) of the strength class 42.5 N was used for all the experimental tests that were done. Natural coarse aggregates with a maximum aggregate size of 20 mm were adopted. Properly graded MS was used in all experimental aspects. The dry sieving method was adopted for the sieve analysis test. The MSF were obtained by mechanically sieving the MS using the 75 μm British Standard test sieve (BS 812 – 103.1: 1985) with the aid of a sieve shaker. Water used in concreting was potable water (Babu et al., 2018). A Polycarboxylate based super plasticizer with a relative density of 1.11 was used for the HSC and no admixtures were used for the NSC.

Throughout the experimental process, the quality of the materials was ensured to maintain the consistency and accuracy of the results. Aggregate properties are shown in Table 1.

Table 1. Aggregate properties

Aggregate	**Specific Gravity**	**Water Absorption (%)**	**Aggregate Impact Value**
Coarse Aggregate	2.73	1.6	21.2
Manufactured Sand	2.6	2.75	-

2.2 Test Variables

Table 2 indicates the percentages of partial replacement that was done for the total manufactured sand quantity by MSF. The replacement percentages were decided based on the data analysis of past research data. Gaining insight from the analysis, a replacement range of 10% - 20% was used. It should be noted that the control mix contained a fines content of 3.36%. Table 3 and Table 4 indicate the mix proportions that were used for the Grade 30 and Grade 60 concretes respectively.

Table 2. Test variables

Concrete Grade	**Materials**	**Percentage of Use (%)**			
30	MS (Particle size < 75 μm)	3.36	10	15	20
	MS (Particle size > 75 μm)	96.64	90	85	80
60	MS (Particle size < 75 μm)	3.36	10	15	20
	MS (Particle size > 75 μm)	96.64	90	85	80

Table 3. Mix proportions of Grade 30 concrete

Grade 30				
Fines Content	**3.36%**	**10%**	**15%**	**20%**
Cement	409	409	409	409
Water	225	225	225	225
MS (> 75 μm)	708.4	659.7	623.1	586.4
MS (< 75 μm)	24.6	73.3	109.9	146.6
Coarse Aggregate	1013	1013	1013	1013
Superplasticizer	0	0	0	0
w/c	0.55	0.55	0.55	0.55

Table 4. Mix proportions of Grade 60 concrete

Grade 60				
Fines Content	**3.36%**	**10%**	**15%**	**20%**
Cement	490	490	490	490
Water	157	157	157	157
MS (> 75 μm)	730.2	682.2	644.3	606.4
MS (< 75 μm)	27.8	75.8	113.7	151.6
Coarse Aggregate	1091	1091	1091	1091
Superplasticizer	5.98	5.98	5.98	5.98
w/c	0.32	0.32	0.32	0.32

Note: Concrete mix proportions are in kg/m^3

2.3 Test Program

The test program was set up to test the properties of the materials and the concrete. The outcomes of these tests were analyzed and used to discuss the outcomes of the research.

Materials tests, fresh concrete tests, hardened concrete tests and a microstructure study was conducted. Material tests such as sieve analysis test, specific gravity test, water absorption test and aggregate impact value test were conducted for the aggregates.

The fresh concrete was tested for initial slump and wet density.

Hardened concrete tests namely compressive strength test, splitting tensile test, flexural strength test and water absorption test was conducted. 150 x 150 x 150 mm cubes, cylinders with a 150 mm diameter and a depth of 300 mm and 100 x 100 x 400 beams were used for the compressive, splitting tensile and flexural tests respectively. The samples for the hardened concrete tests were tested after 28 days of curing. The compressive strength was tested at both 7 and 28 days of curing.

2.4 Microstructure Study

To study the microstructure, a Scanning Electron Microscope (SEM) analysis was done. A ZEISS EVO18 SEM was used for this purpose. Concrete samples from mechanically tested concrete specimens after 7 days of curing was used for the analysis. The samples were properly washed and oven dried at 60℃ prior to the analysis.

3 RESULTS AND DISCUSSION

3.1 Initial Slump

Figure 1 demonstrates the variation of initial slump with fines content in the C30 and C60 mixes.

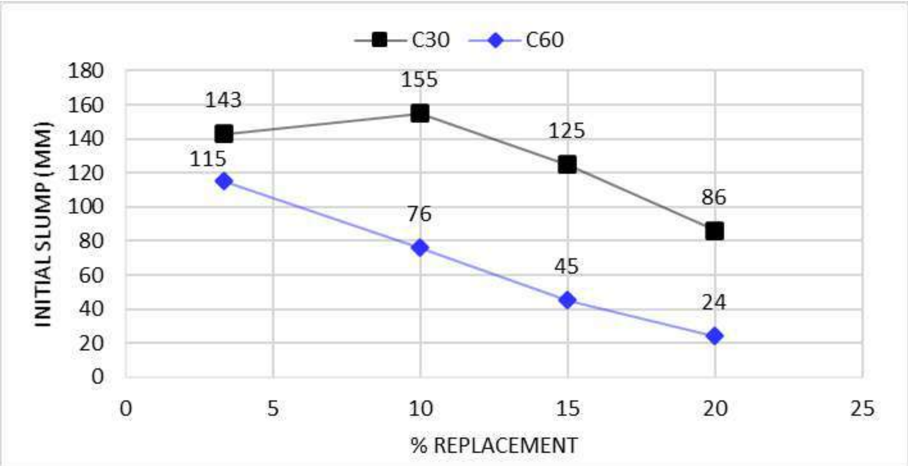

Figure 1. Variation of initial slump with fines content

As illustrated in Figure 1, slump decreases in both the concretes indicating that the increment of fines had a similar effect on the workability. Though there was an increment in the slump at 10% fines in the C30 concrete, no such observation was observed in the C60 concrete. All in all, increment of fines had negative effects on the workability of both, C30 and C60 concretes.

In the C30 concrete, an increase in the slump could be observed at 10% replacement. According to Shen et al., (2018), this behavior could be due to the contribution of the fines in filling the gaps in the packed aggregate and improving the fluidity of the mortar, thus improving the workability. This decrease in workability beyond the 10% replacement can be explained in relation to the specific surface area of the fine aggregates. As discussed in Katz and Baum (2007), with the increase of fines in mixtures, the fineness of the fine aggregates increases, thus increasing the specific surface area. The increase in specific surface area increases the demand for water to wet the increased surface area, thus decreasing the workability of concrete.

3.2 Concrete Densities

Figure 2 shows the variation of wet and dry densities of the C30 and C60 mixes with MSF.

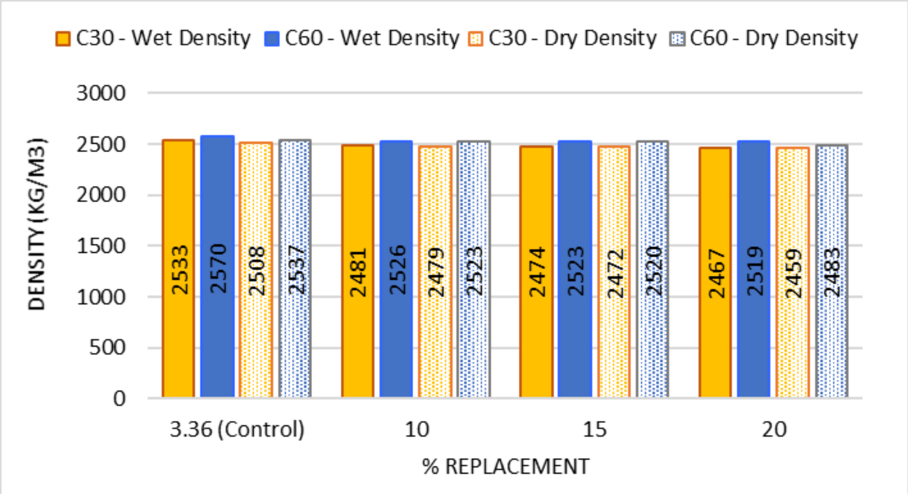

Figure 2. Variation of densities with fines content

As shown in Figure 2, though there appears to be a negative trend in the densities, the percentage reduction doesn't appear to be significant indicating that the increment of fines doesn't have a significant effect on the wet and dry densities of C30 and C60 concretes and that the above trends are not much notable. It was also observed that the difference between the wet and dry densities at the 10% - 15% MSF replacement range were less when compared to the other mixes. This could be due to the minimum water desertion from the concrete.

3.3 Compressive Strength

Figure 3 given below is an illustration of the variation of compressive strength at 7 and 28 days with the fines content in the C30 and C60 mixes.

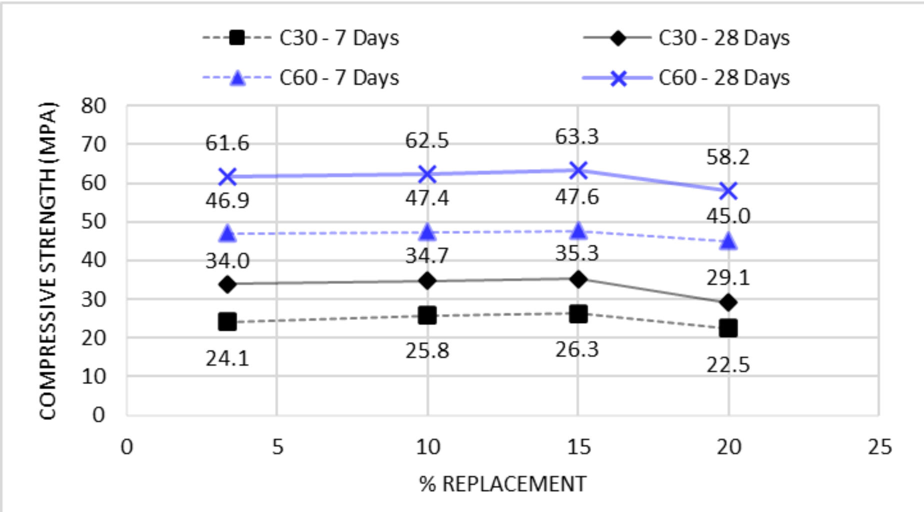

Figure 3. Variation of compressive strength with fines content

As shown in the above figure, the maximum compressive strength of both the grades have been achieved at 15% MSF replacement. Replacement of 20% fines showed negative effects on the compressive strengths of both the grades indicating that a 20% fines content is not an effective amount to be incorporated in both normal and high strength concrete. No sign of early strength gain at 7 days was observed in both the concrete grades. Increment of MSF had a similar effect on the compressive strength of both the C30 and C60 mixes, Since the 10% - 15% fines content produced effective compressive strength results, it could be considered as an effective fines percentage range for both normal and high strength concrete.

The reason for the increase in the compressive strength with the increase in MSF could be due to the filler effect of the fines. As discussed in Goldman and Bentur (1992), the addition of micro-fillers to the concrete significantly enhances the strength of the paste – matrix and also densifies the interfacial transition zone, thus improving the strength of the concrete.

The decrease in the compressive strength at the 20 % replacement can be explained in relation to the water film thickness and the high water demand that occurs due to the increased surface area with the availability of high fines content. As explained in Kwan and McKinley (2014), there lies an optimum water film thickness that corresponds to good strength properties. Due to the availability of high fines content, there would be a decrease in water film thickness due to the increased water demand as a result of the high surface area, thus leading to insufficient water to fill the voids. This would result in high air entrapment within the paste thus leading to a decrease in strength.

All in all, it could be identified that the effective MSF range to be used in NSC and HSC in relation to the compressive strength is 10% - 15%.

3.4 Splitting Tensile Strength

Figure 4 demonstrates the variation of the splitting tensile strength with the fines content.

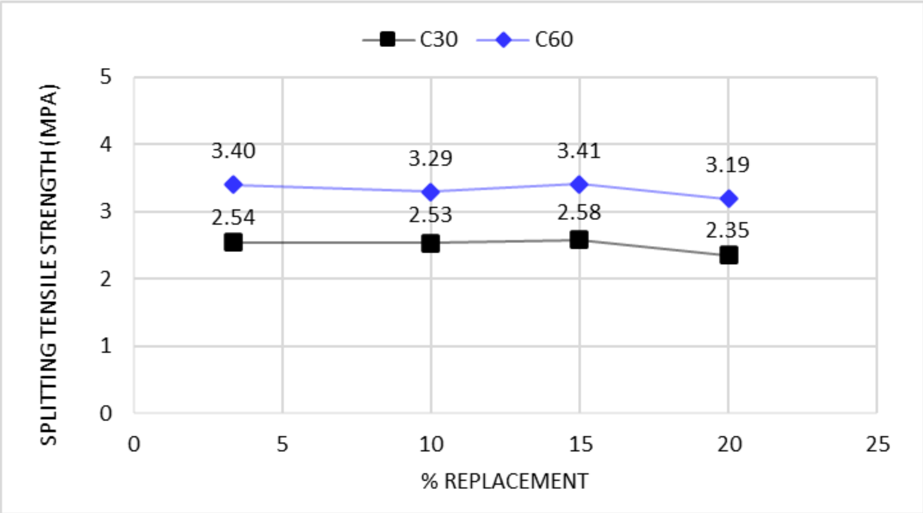

Figure 4. Variation of splitting tensile strength with fines content

The highest splitting tensile strength was observed at 15% fines replacement while the lowest was observed at 20% fines for both the C30 and C60 mixes. Increment of MSF appeared to have a similar effect on both the types of concrete. Though there was a slight drop in splitting tensile strength at 10% fines replacement in the C60 concrete, the drop did not appear to be significant and the 10% - 15% fines percentage could be considered as an effective range in terms of the splitting tensile strength for both the normal and high strength concrete.

3.5 Flexural Strength

Figure 5 illustrates the variation of the flexural strength with the fines content in C30 and C60 concretes.

The highest flexural strength was observed at 15% fines replacement for both the C30 and C60 mixes. Increment of MSF appeared to have a similar effect on both the types of concrete. However, the samples with 20% MSF had higher flexural strengths than the control mix. Availability of up to 20% fines content could be considered as an effective percentage in relation to the flexural strength of concrete.

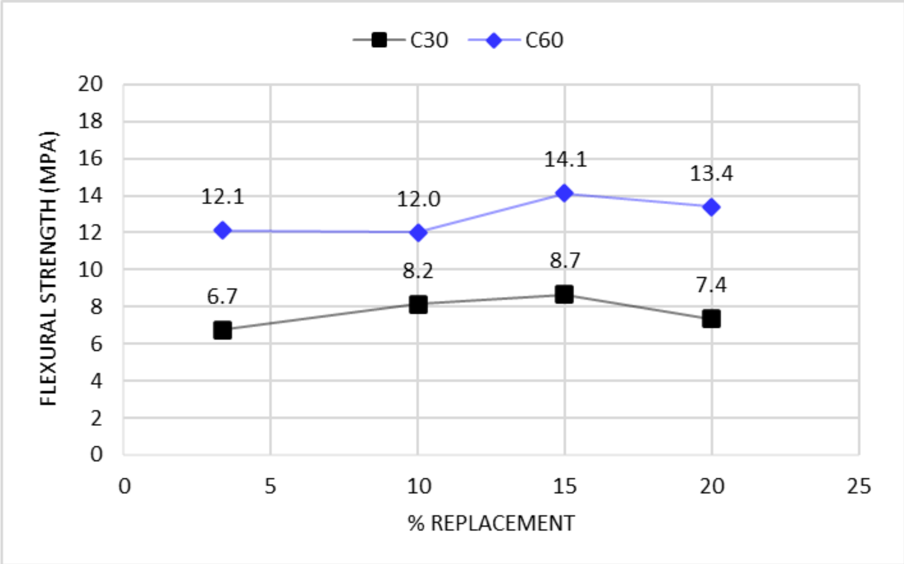

Figure 5. Variation of flexural strength with fines content

3.6 Water Absorption

Figure 6 shows the variation of water absorption with fines content in C30 and C60 concretes.

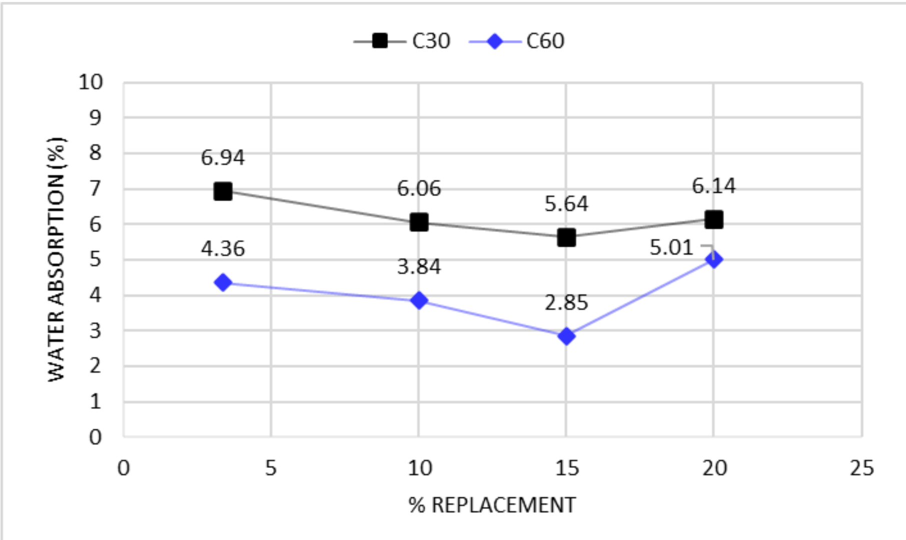

Figure 6. Variation of water absorption with fines content

As shown in Figure 6, both the concrete grades showed low water absorption at 15% fines content. Though there wasn't a significant difference in the water absorption in the C30 concrete at 10%, 15% and 20% fines content, there appeared to be a significant difference between the 10% - 15% range and 20% fines content in the C60 concrete. Therefore, 10% - 20% fines content for C30 concrete and 10% - 15% fines content for C60 can be considered as the effective ranges in terms of water absorption.

The decrease in water absorption could be due to the filler effect of MSF. The fines have decreased the porosity in the concrete, thus reducing the voids that can be filled with water which ultimately has reduced the water absorption of the concrete. Yang et al., (2018) has explained by microstructure studies that the fines fill the micro cracks and pores in concrete and thus reducing the porosity and densifying the microstructure. The increase in water absorption at 20% MSF replacement could be due to the domination of the high water demand over the filler effect which ultimately would increase the water absorption of the concrete. However, even with 20% MSF, the water absorption was less than the control mix.

3.7 Microstructure Study (Scanning Electron Microscope Analysis)

Concrete samples from the control mixes and the mixes with 15% MSF of the C30 and C60 concretes were used for this purpose.

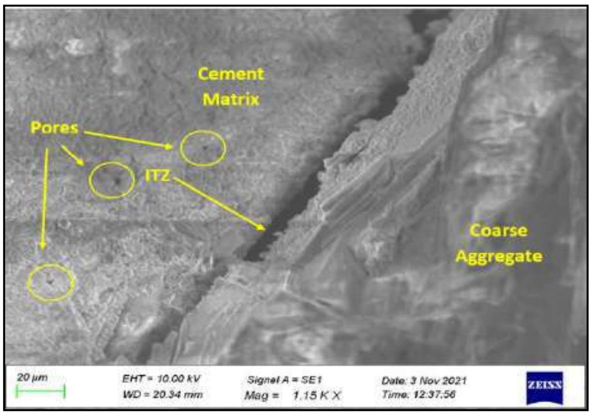

Figure 7. SEM image of C30 concrete with 3.36% fines content

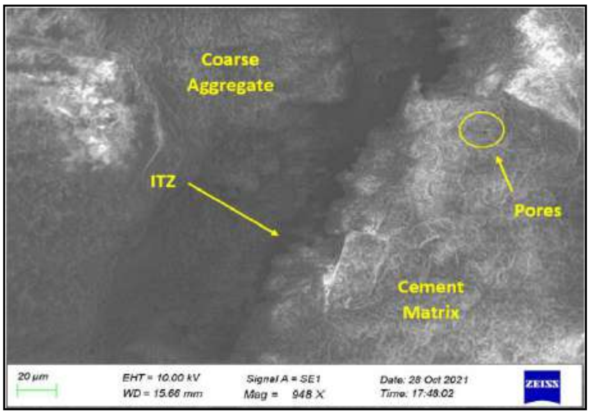

Figure 8. SEM image of C30 concrete with 15% fines content

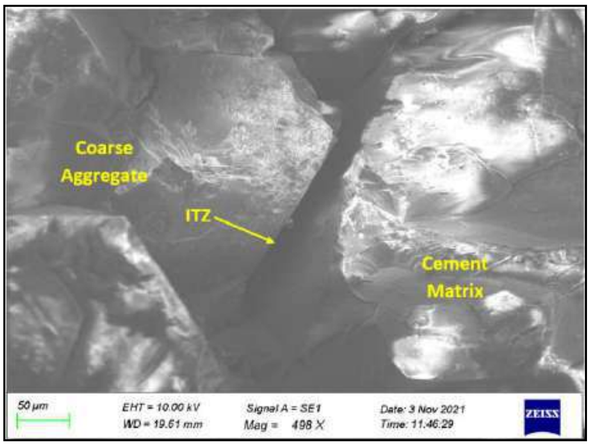

Figure 9. SEM image of C60 concrete with 3.36% fines content

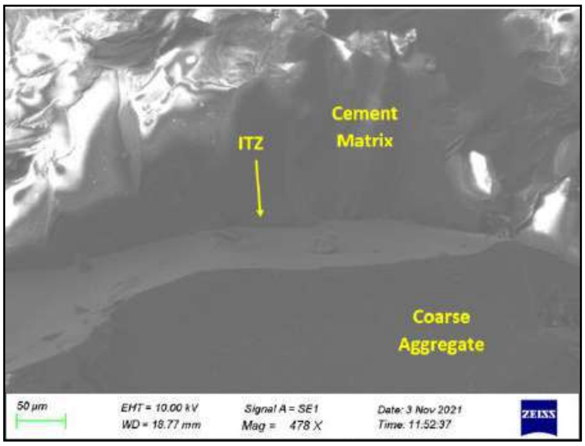

Figure 10. SEM image of C60 concrete with 15% fines content

By observing Figure 7 and Figure 8, it is evident that the concrete with 15% MSF had a dense microstructure. Less number of pores had developed in the mortar in the samples with 15% MSF compared to the control mix. This is likely due to the filler effect of fines that has made it possible to densify the microstructure by filling majority of the pores. No micro cracks had been developed, even close to the ITZ between the coarse aggregate and the cement mortar, which is an indication that the microstructure was dense enough to prevent the development of micro cracks. As observed in Figure 8 and Figure 10, it is evident that the ITZ between the coarse aggregate and the cement mortar of the C30 and C60 concretes had densified compared to the control mixes which showed that the MSF had contributed to densify the ITZ as well. Overall, it could be concluded that the concrete microstructure showed clear signs of densification with the introduction of MSF which justifies the reasons for the improved strength and low water absorption.

3.8 Cost Analysis

A cost analysis was performed in order to determine a cost-effective mix with effective concrete properties. The cost calculations were performed for 1 m^3 of the mixes of the C30 and C60 concretes. The variations in costs were expressed in the form of a ratio in proportion to the cost of the control mix. The main resource rates were obtained using the existing market prices, both locally and overseas. The variable in the cost was considered to be manufactured sand subjected to different washing rounds.

Manufactured sand that is double washed, single washed and non-washed were considered. The fines percentage ranges were as follows:

- Double washed manufactured sand: less than 10% fines
- Single washed manufactured sand: less than 15% fines
- Non - washed manufactured sand: greater than 15% fines

Key points in the cost analysis:

- Labour, tools/machinery and wastage costs were not included.
- The cost reduction depending on the washing trials was determined based on overseas prices and was considered to be 16.67%.

It should be noted the cost analysis was determined based on the cost ratio and the cost ratio is the ratio between the cost of concrete with a particular MSF to the cost of concrete of the control mix

The generated Cost Ratio vs Fines Replacement Percentage graph was the same for both C30 and C60 concretes. Figure 11 given below illustrates the graph.

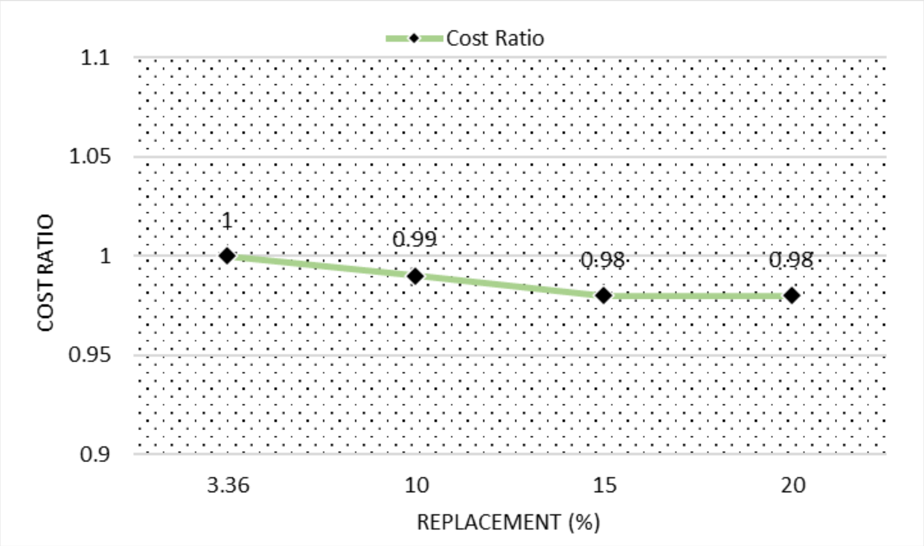

Figure 11. Variation of cost ratio with fines content

The reduction in costs compared to the control mix in C30 concrete was 0.98%, 1.8% and 1.8% at 10%, 15% and 20% replacements respectively. The reduction in costs compared to the control mix in C60 concrete was 0.88%, 1.6% and 1.6% at 10%, 15% and 20% replacements respectively. The least cost can be obtained when the fines replacement is 15% - 20%. Since both normal and strength concretes produced the most effective strength results at 10% - 15% MSF, the 10% - 15% fines content could be considered as the most effective fines percentage in manufactured sand, strength and cost wise.

4 CONCLUSION

The research study was conducted to study the effects of manufactured sand fines on the properties of normal and high strength concrete. Partial replacement of manufactured sand by fines was done at 10%, 15% and 20% and the test results were compared with the control mix that contained 3.36% fines. Grade 30 and Grade 60 concrete were casted to study on the normal and high strength concretes respectively.

Fresh and hardened concrete properties were tested to study the effects of fines. Mixes with 15% fines content produced effective results in both the concrete grades. Mixes with 15% fines content had 3.82%, 1.57% and 15.53% higher compressive, tensile and flexural strength results than the control mix respectively in the C30 concrete. C60 concrete with 15% fines content had 2.76%, 0.29% and 22.99%

higher compressive, tensile and flexural strength results than the control mix respectively. Water absorption of the specimens with 15% fines content was 18.73% and 34.79% lower than the control mixes in the C30 and C60 concretes respectively. The increment of fines showed negative effects on the concrete properties beyond 15% fines content in most of the properties. However, the slump of both the concrete grades decreased with the increment in fines indicating that the fines had detrimental effects on the workability of the concrete.

The microstructure analysis on the concrete with 15% fines showed a dense microstructure with minimal pores and dense interfacial transition zones which confirmed that the fines acted as a filler material and thus contributed to densifying the microstructure.

It was identified from the cost analysis that incorporating about 15% fines can reduce the cost of C30 concrete by 1.8% and C60 concrete by 1.6%. This concluded that cost effective MS concrete can be produced by using high MSF.

All in all, a 10% - 15% fines replacement range appeared to be an effective replacement range in both normal and high strength concrete. Concrete with high fines content can not only generate concrete with better properties, but also reduce the unnecessary costs in washing manufactured sand and reduce the environmental issues that arise due to the dumping of the washed fine sand in landfills. Recommendations for future research would be to study the effect of manufactured sand fines on ultra-high strength concrete, to study the effects of chemical admixtures on MS concrete with high fines content, to study on the effects of MSF on the durability properties of HSC and to research on the effects of blended fines on the properties of manufactured sand concrete.

5 ACKNOWLEDGEMENTS

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The Properties of Lime/Soil Concrete

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ABSTRACT

The investigation of materials for replacing cement in concrete manufacturing has garnered steady interest from experts in recent years. However, the majority of past researches have only focused on the use of lime as a cement substitute in producing Lime Concrete. The reason for this is that lime concrete can be made easily and cheaply while still providing a durable material that can minimize negative environmental impacts. Even though lime is used as an alternative material the integration of a new material as a replacement for conventional aggregates has been limited. As a result, this study will attempt to examine the various compositions of hydraulic lime as a partial replacement of cement while completely replacing the coarse and fine aggregate with a soil to find the influence on the physical characteristics of Lime/Soil concrete. This will also help in decreasing the ecological imbalance caused due to the excess use of conventional aggregates. Locally available reddish-brown laterite soil was used in this study without any modifications. C30 concrete mixes containing 0%, 10%, 15% of hydraulic lime replaced with OPC and complete replacement of aggregate with laterite soil were casted before subjected to water curing. Workability, compressive strength, splitting tensile strength and water absorption test were conducted in accordance with the existing standard. Based on the results obtained from the study it has shown that even with complete replacement of aggregate with laterite soil it was able to produce workable concrete with satisfactory strength that can be employed for ground improvements in pavement design and to manufacture economical non-load bearing concrete blocks. The targeted strength still can be achieved with replacement of 15% hydraulic lime for a lower cost. With the accomplishment from the composition, future studies will be able to better assess the long-term effects of construction operations on the environment.

KEYWORDS: *Compressive strength, lime concrete, physical properties, hydraulic lime, laterite soil.*

1 INTRODUCTION

1.1 Background

In the recent years the importance of ecological and sustainable design of structures in the development of the construction industry has played a major role. Due to this reason many alternative materials like soil and lime in the production of concrete which contain proportions of various ecological components are expected to be developed rapidly. Generally concrete is an artificially built hardening mixture which includes a binding agent, coarse aggregate, fine aggregate, and water with or without a suitable admixture. Concrete is mainly used in construction of columns, beams and slabs which are components of buildings. Most of the structures which are made are designed to withstand usually more than 50 years. This is half the amount of a life span of a human being. Therefore, these structures should be properly built to withstand any kind of loading which can alter the safety during its life period. Similarly, it is important that the materials used in constructing these structures are eco and man friendly.

This research aims to optimize the compositions of lime as partial replacement of cement to find the influence on the physical characteristics of concrete made by completely replacing the fine and coarse aggregates with a soil. Another purpose of this research is to produce concrete with the express

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objective of reducing the production of greenhouse gas emission. When considering lime, it does not generate as much CO2 in its production as it does in the production of Portland cement. Lime is a durable, abundant, and versatile material which has been used as a binder widely in constructions like lime concrete and lime mortar. Natural hydraulic lime which is the lime type that is intended to be used in this research has hydraulic properties where it sets with the help of water.

When soil-based constructions are considered, they go back centuries. In the recent years, use of soil for construction has attract lots of attention due to the eco-friendly nature of the material. Most of the early research have studied the mechanical properties of soil-based concrete which can be used in modern constructions and buildings. Furthermore, the characteristics of the buildings that were constructed in the early stages using concrete made from soil has shown lower temperatures in the summer and also higher temperature in winter. This has inspired several modern researchers to study the properties of concrete by introducing soil into lightweight conventional concrete. The 28-day compressive strength of laterite and clay-based concrete ranged from 8 to 22 MPa for densities of 1500–2350 kg/m^3. (Ma Cong & Chen Bing, C, 2015)). Compressive strength and thermal conductivity ranged from 0.95–3.85 MPa and 0.201–0.281 W/m K for densities of 843–1038 kg/m^3.

Natural coarse aggregate depletion, pointing out that the natural resource is depleting while the demand for aggregate for concrete manufacturing remains strong. The depletion of this substance may lead to its extinction in the future, resulting in a rise in the cost of concrete. One approach to tackle this problem is to modify the concrete ingredients. This is one way to reduce granite usage. Concrete made from alternative components may reduce the amount of natural aggregate used.

Most of the physical properties of concrete, especially the compressive strength mostly depends on the mix design of the concrete. Although, the mix design plays a major role in the characteristics of concrete it is also affected by the factors like the methods of mixing, placing, curing and quality of the ingredients which are used in the concrete. The compressive strength of concrete is defined as the maximum stress that the solid material can sustain without causing any fracture when a load is applied gradually.

The building materials used in the modern-day constructions are very sensitive to humidity. Therefore, the measure of water absorption plays a major role in the durability of the porous materials. The movement of water in to concrete mainly depends on the diameter of pores, the distribution, and the continuity of the pores.

1.2 Objectives

- To identify the material properties of soil to be used as an aggregate in concrete production.
- To investigate the physical properties of lime/soil concrete.
- To propose the most suitable mix design for the production of lime/soil concrete.

2 LITERATURE REVIEW

The connection between lime and soil was initially reviewed, annotated, and summarized by Herrin and Mitchell in the year 1960 (H. Moreland & M. Henry, 1961). The review has indicated the valuable effects of the use of lime as a stabilization on the factors like workability, plasticity, and strength properties of soil. It has been found that in most of the case the strength has been increased and also the workability characteristic was improved. According to the studies made by Herrin and Mitchell at that time, the work they have published was primarily concerned on the various physical properties due to the effects of different types and various quantities of lime on the soils. With the amount of work done by these two researchers since 1960 it has involved in the nature of lime soil reaction products and the influence of the properties of natural soil properties on the reactions between lime and soil.

Dr. A. Anbuchezian et al. (A. Anbuchezian & Kumar, 2018) has studied the experimental work on Splitting Tensile Strength, Flexural Strength, and the Compressive Strength of concrete. In those experiments the cement has been replaced with lime powder and fine aggregates has been replaced with groundnut shell. In this research they have partially replaced the content of fine aggregate with groundnut shell varying in the range of percentages 5%- 20%. And the lime powder has been replaced instead of cement in general ration of 20%. They have concluded that for the groundnut shell contents of 5% and 10% the concrete has achieved a higher strength. Lime concrete with 20% of lime has achieved more strength than normal concrete.

B. T. Sapna et al. (B. T. Sapna & M. Aravindhraj, 2018) has also discussed the physical properties like Compressive and Splitting Tensile Strength of concrete by replacing the cement content with 0%, 5%, 10%, 15%, 20% of red mud and also with 5% of hydrated lime. Their conclusion has shown that the compressive strength of concrete has increased to a percentage of 17% by replacement of cement with 15% of red mud and for hydrated lime it has been 5% compared to normal concrete. The authors have seen that the compressive strength of the test cubes and the splitting tensile strength of the test cylinders have achieved the highest values for the optimum percentages of red mud and lime with 15% and 5% replacements.

Awodiji Chioma Temitope Gloria et al. (Gloria, Ogbonnaya, & Olujide, 2017) has investigated the Tensile and Flexural strengths of concrete by replacing cement with hydrated lime. In this recent study they have replaced cement with hydraulic lime with the percentages ranging from 5% to 30%. They have concluded that the highest value for Tensile and Flexural strengths have been recorded for the replacement of cement by 13.83% of hydrated lime and the strengths have been achieved after 28 days of casting.

K.Muthusamy et al. (K.Muthusamy & N.W.Kamaruzaman, 2012) integrated a new soil material as a partial replacement for coarse aggregate to reduce the high dependency on conventional aggregate in concrete production. Results of the study have showed with replacement of aggregate to an appropriate content the strength of concrete was achieved up to a considerable extent. The optimum amount of aggregate replacement was identified as 10% to produce a mix with comparable strength to plain concrete. Even with 30% of laterite replacement the target strength could be achieved according to the results from the study.

3 METHODOLOGY

3.1 Materials

Ordinary Portland Cement of strength class 42.5 N was adopted in all the experimental procedures. Hydrated lime was used as the cement replacement in the study. The soil selected for this study was Reddish Brown Laterite with a maximum aggregate size of 20mm which is locally available and easily accessible. The bulk density of this varied from 1500kg/m^3 – 1600kg/m^3. This soil has a past of being used for compressed earth blocks and a subgrade material in road constructions. These Laterites are formed as a result of a long-term tropical weathering process. It is classified as A-2-7 (0) in the AASHTO soil classification system. The soil was used without any modifications.

3.2 Mix Design

The mix design used in the process was the mix design for M30 grade of concrete using 42.5 grades Ordinary Portland cement that is used in the study. This mix design was performed as per BS Standard. The water/cement ratio for the mix was .55 Aggregates was used with a saturated dry condition of the surface, and this was helpful in calculating the water requirement more accurately and adjusting the amount of water according to the moisture content.

3.3 Aggregate Tests for Laterite Soil

Material tests were conducted on the laterite soil to compare the results with conventional aggregates and to determine the reasons for the deviations in soil concrete results with normal concrete. A sieve analysis was conducted on a sample of laterite soil according to BS 882 - 1992 to determine the distribution of particles because this will help in giving an idea to determine the compliance with the concrete design and the strength of concrete. Usually for a soil sample a wet sieve analysis is done to eliminate the fine particles as they contain more fines. But in this case since the soil is used as an aggregate a normal sieve analysis was done. The sieve sizes used for the test ranged from 20mm – 0.075mm. The AIV test was conducted on laterite particles passing the 14mm sieve and retaining on 10mm according to BS 812 – 113: 1990 to measure the resistance to sudden impact or shock. Water absorption test for the laterite soil was conducted according to BS 822 - Part 2 - 1995 to get an idea on the internal structure of the particles in the soil. This will provide the suitability of the material as an aggregate by the porosity of the sample in nature. The specific gravity of the laterite soil was found according to BS 822 - Part 2 – 1995 to measure the indirect density of the material. This parameter is required to identify the strength and quality of the aggregates. The following Table 3.1 shows the results obtained for Laterite Soil properties.

Table 3.1. Physical and mechanical properties of laterite aggregates

Property	Value
Specific Gravity	2.8
Bulk density	1500 - 1600kg/m^3
AIV	29.83%
Water absorption	8.60%

3.4 Fresh Concrete Tests

Slump, Temperature and Wet density was measured according to BS EN 12350 - 2: 2009 and BS 1881- 130: 2013 standards to make sure that the condition of the fresh concrete was maintained in the required standards.

3.5 Test Variables

A cost and strength analysis were done in order to find the most effective range of lime for replacing the cement. The strength analysis was done using the results of the past studies and the cost analysis was done by determining the percentage of cost saved from addition of lime compared to cement. Percentage range 10 – 20% can be selected as the most optimum variation of lime. The below Table 3.2 shows the variable percentage of lime used in the study.

Table 3.2. Test Variables

Concrete designation	Concrete Type	
	Cement	Lime
Soil / LC-0	100%	0%
Soil / LC-10	90%	10%
Soil / LC-15	85%	15%
Soil / LC-20	80%	20%

3.6 Casting

Test cube casting is usually done with two types of specimens either cubes of 15cm x 15cm x 15cm or using 10cm x 10cm x 10cm. This will be mostly dependent on the size of aggregates which are been used in the test. But under this case the cubic moulds of size 15cm x 15cm x 15cm was used.

A hardened soil cement mixture's primary structural criterion are appropriate strength and durability. Mixing proportions for soil cement was according to the BS test standards. Lime was used as a partial replacement for cement, and it was used in different percentages. For this study amount of lime used was 10%, 15% and 20% by the weight of cement. For each percentage at least three cubes were casted and three each for the testing days.

The concrete was poured into the moulds and properly tampered so that it will ensure to not have any voids in the mix. Each cube was marked with a proper identification on the top of the test cubes. After casting the test cube samples were left undisturbed for 24 hours. After 24 hours the moulds were open, and the test cubes were immersed in water for curing until the cubes are taken for testing. Top face of the test cubes should be made even and smooth. This can be done by applying cement paste on top of the face and spreading them smoothly on the whole area of the specimen. The water used for the curing purpose was tested every seven days, this is done to ensure the temperature of the water and it was maintained at 27 +- 2^{o}C.

The specimens for splitting tensile tests were prepared using a cylinder. The length of the cylinder shall not be less than that of the diameter and also should be less than twice the diameter. The dimensions of the cylinder used in this case was 150mm in diameter and 300mm in length. Moulds used for this, and cube casting were coated with mould oil to prevent adhesion of concrete. Figure 3.1 briefly demonstrate the above processes.

Figure 3.1 Concrete Casting and Curing

3.7 Harden Concrete Tests

Compressive strength, splitting tensile strength, Water absorption and Dry density tests were conducted accordance with to BS 1881 - 116: 1983 and BS EN 12390 – 6: 2009 standards to determine the physical properties of soil concrete.

4 RESULTS AND DISCUSSION

4.1 Fresh Concrete Test Results

Table 4.1 Fresh Concrete Test Results

Fresh Concrete Test Results				
Concrete Designation	**Concrete Type**	**Slump (mm)**	**Temp.**	**Wet density (kg/m^3)**
C30 Normal	Cement 100%	143	25.7	2489.0
Soil / LC-0	Cement 100%	45	26.4	2055.3
Soil / LC-10	Cement 90%, lime 10%	40	26.3	2074.1
Soil / LC-15	Cement 85%, lime 15%	30	25.6	2288.9
Soil / LC-20	Cement 80%, lime 20%	30	24.6	2362.9

The above Table 4.1 shows the variation of Slump, Temperature, and the Wet density of the soil concrete with the increase of lime. When the slump value of normal concrete mix is compared with the control mix of soil concrete there can be seen a significant drop in the workability. This shows that the laterite soil aggregate is less workable than the normal concrete even with the equal amount of water cement ratio. This implies that the soil aggregate requires more amount of water to gain the required workability probably due to high rate of water absorption than the conventional aggregates. The water absorption results obtained for the soil supports to the consistency of the concrete. Number of voids in the aggregate or the higher porosity may have result in the decrease of slump.

Similar results can be seen when the slump of different percentages of lime is compared. When the amount of lime increases the slump decreases. This is because lime is produced from limestones which has the property of hydration and high-water absorption, and this means that to gain the binding property of lime it requires more water in the reaction thus decreasing the workability of concrete.

When the temperature of normal concrete mix and the soil mix in the Table 4.1 is compared a rise in temperature can be observed. The rise in temperature might have been since when the laterite is mixed with cement it releases more amount of heat than the normal aggregates. Usually, the temperature is expected to increase with the addition of lime as the reaction is exothermic and more heat is generated due to the reaction of lime with water. But in this case the change might have occurred due to the properties of soil affecting in the lime mixture. High temperature values in the mix can cause to loss in workability and can severely affect the durability of the concrete by increasing the number of voids. This will also results in the decrease in slump. With addition of 15% of lime the results have shown a similar temperature value to the normal concrete. This is an advantage in the process of lime addition to decrease the negative impacts from temperature rise in the soil concrete mix. Ambient temperature may also have affected in these results.

When the results of wet density of the soil concrete in the above Table 4.1 is compared with the C30 normal concrete the values have decreased. A sudden drop can be seen in 0% lime mix but gradually increased with the lime percent increasing. This shows that lime has positively affected the soil and cement mix in the initial stage of concrete. The addition of lime has increased the wet density of concrete therefore that will also affect the durability and the water absorption of the harden concrete. But this cannot make any conclusion on the strength of the soil concrete but with these results it can be concluded that when soil is used for concrete less voids are formed in the concrete mix making the wet density low.

4.2 Compressive Strength

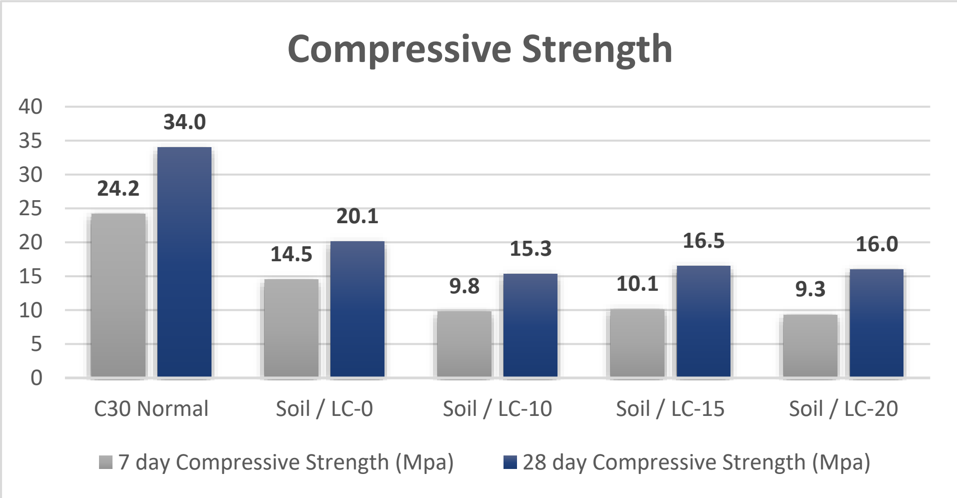

Figure 4.1 Compressive Strength Test Results

As shown in the Figure 4.1 from the results obtained a clear trend can be seen for the different values of lime. All the samples have shown a continues development in the strength as the curing age increases. Similar results can be seen from both 7 and 28 days. The maximum strength for the soil concrete is seen in the mix with 0% lime and the optimum lime content can be observed as 15%. The replacement of lime beyond 15% has caused strength reduction in the concrete. Addition of too much lime has resulted in losing the bonding ability of the mix. The continuous water supply has not affected the soil by enhancing any clay properties thus decreasing the strength. Initially in the strength gain a 50% strength from the final expected value was gained in 7 days and only 15% was gained in the next 14 days. This shows that soil concrete has a high initial strength gaining capability. According to the standard the 7-day strength is within the range of 70 – 75%. Therefore, this value is considerably satisfied for a soil concrete. A maximum value of 20.1MPa was obtained for the lime replacement of 0% in 28 days and the least was obtained for 10% replacement of lime with a value of 15.3MPa. The main reason for these values is due to the physical properties of the laterite aggregate compared to the traditional aggregate in denseness, surface texture, hardness, and shape. With further improvements or modifications of the laterite aggregate better results could be obtained compared to normal concrete.

4.3 Splitting Tensile Strength

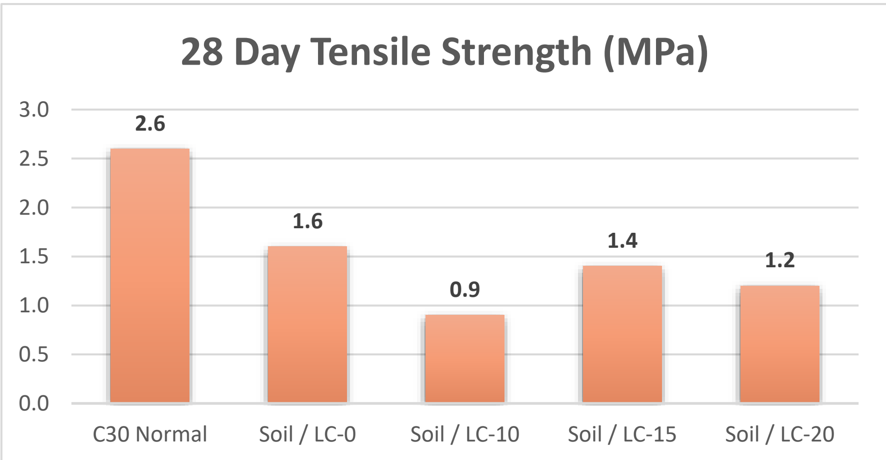

Figure 4.2 Splitting Tensile Strength Test Results

According to Figure 4.2, obtained results for tensile strength shows a similar variation to the compressive strength. The results are comparatively low when compared with the C30 normal concrete mix. But as the rule of thumb for tensile strength of concrete is 5% to 10% of its compressive strength, the obtained tensile strength values for all the mixes are in the acceptable range. When the lime replacements are compared with each other the results show that for 0% replacement of which has produced the maximum results of 1.6MPa even for the optimum lime percentage the strength is almost similar with a value of 1.4MPa. this shows that addition of lime has not affected the tensile strength as for the compressive strength. Also, the strength decrease percentage is lower than that of compressive strength for the comparison between normal concrete mix and soil concrete mix. The results may have slightly varied due to the preloading micro cracks that could have developed in cylinders.

4.4 Water Absorption

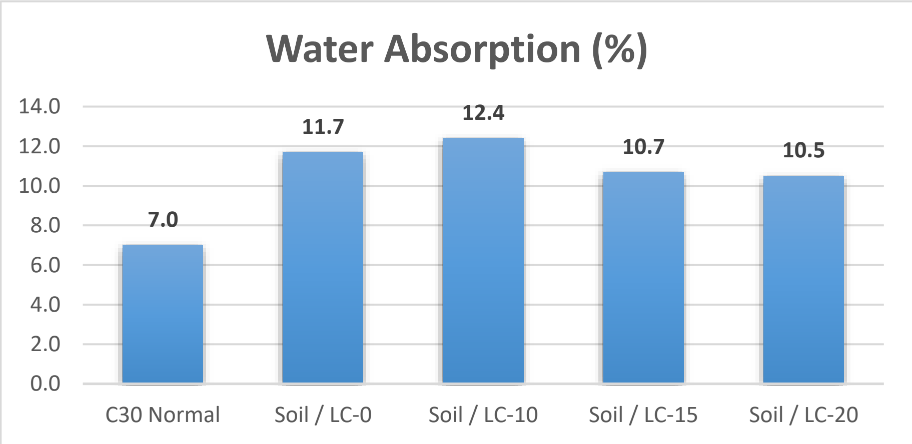

Figure 4.3 Water Absorption Test Results

As shown from the above results in Figure 4.3 the C30 normal concrete mix has the lowest water absorption percentage which depicts the fact that lower the water absorption better the results. When the soil concrete results are compared with each other addition of more lime decrease the water absorption and therefore increase the durability of concrete. Mix with 0% lime has a higher water absorption and the lowest can be seen in 20% lime replacement. This shows that soil only will not give overall results for the durability of concrete, but lime have the ability to stabilize the soil cement mix thus increasing the durability. When considering the tensile and compressive strength results the most suitable lime content can be identified as 15% which has given the optimum results in this study

4.5 Dry Density

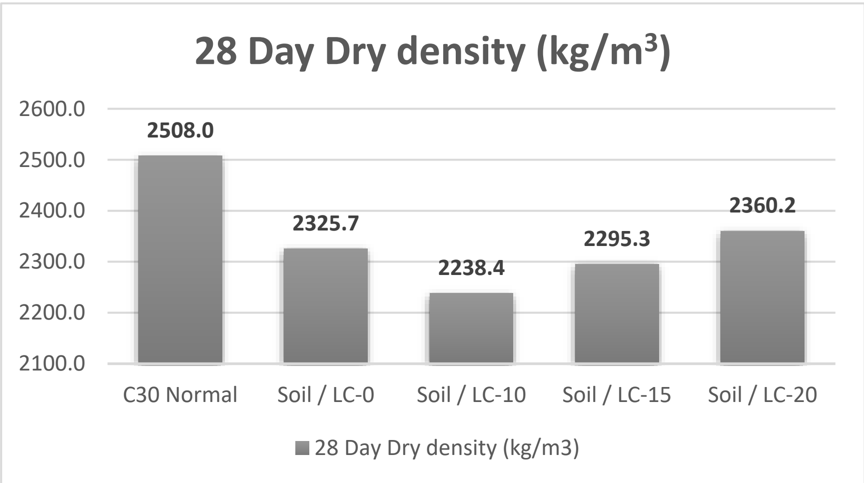

Figure 4.4 Dry Density Test Results

According to the results shown in the Figure 4.4 the density of C30 normal concrete was more than the average value. When the soil concrete values are compared with the control mix value a significant drop can be observed. This is due to the unit weight of the aggregate used. Soil contains more finer particles than sand and metal which can lead to lesser weight in concrete. Among the results of the varying lime percentages, initially 10% lime has decreased the density more than just soil concrete. But with the increase of lime percentage the dry density values have increased. This shows that lime contributes more on the weight than cement when mixed with soil. Lime has the ability to positively influence the density of soil concrete which can result in providing higher strength and decreasing the number of voids and porosity. When the number of voids in concrete decreases, it becomes less permeable to water and other soluble elements. This property in Lime/Soil concrete can contribute to increasing the durability where its lower in than normal concrete. The water absorption property also gets reduced due to this reason. In conclusion it can be understood that even though soil can decrease the unit weight of concrete, lime can maintain an acceptable weight in soil concrete.

5 CONCLUSIONS

This aim of this research was to optimize the compositions of lime as partial replacement of cement while completely replacing the coarse and fine aggregates with a soil to find the influence on the physical characteristics of concrete. Production of concrete can be done using different types of alternative materials specially for cement. The aggregate type and the bonding material are the most important concerns in physical characteristic of concrete. Lime has become a cheap and ecofriendly material from the early stages. Even though lime is used as an alternative material the integration of a new material as a replacement for conventional coarse and fine aggregate has been limited. The cost for concrete production and the ecological imbalance due to the high dependency of the conventional aggregates has been the leading factor in conducting this type of a research.

According to the results of this study it was able to produce concrete with a soil aggregate that could provide a Compressive strength 20MPa and a tensile strength of 1.6MPa. Material testing of the laterite soil aggregate has shown satisfactory results compared to the conventional aggregates. But the acceptable workability was not obtained from soil aggregate therefore the water cement ratio is required to be increased in order to maintain a proper workable concrete. The optimum lime content was found as 15% as it gave the maximum mechanical properties among the lime replacements. Even though addition of lime slightly decreased the strength results, from some of the test it was concluded that the lime was able to enhance the properties of concrete which was reduced due to the soil aggregate. The rate of increase of compressive strength was higher at early ages as the lime content is increased.

Concrete produced in this study has shown satisfied properties which can be used in application like ground improvements in pavement design and producing an economical Non-Load Bearing Concrete block which would increase the ecological value and the sustainability of future constructions. With the initial investigation of the soil aggregate and the results obtained from this research the future studies will be able to better assess the long-term effects of construction operations on the environment.

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Structural Behavior of Two Major Concrete Dams in Sri Lanka Under Earthquake Loads

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ABSTRACT

Dams are built for a variety of purposes including hydropower generation, irrigation, water supply, and flood mitigation. Concrete and earth dams are common types of dams in Sri Lanka. Concrete dams can be categorized as Gravity dams and Arch dams. Gravity dams are most common in Sri Lanka. Dams can also pose safety hazards. Failure of a dam can cause serious damages to both people and property downstream. One of the major threats to dams is earthquakes. They can have significant impacts on the stresses within the dams. In extreme cases this can cause even failures of dams. These possibilities can be investigated using finite element analysis.

In this study Rantambe and Moragahakanda concrete gravity dams were selected for 2-D finite element analysis under the action of suitable earthquakes. For each case linear time history analysis was performed using SAP2000 software. The stresses were examined for potential failures. Important considerations in this process were selection of dams, selection of suitable earthquake records, and identification of an appropriate failure criterion. The selection of earthquake records was based on proximity and geological conditions. Koyna earthquake was used to develop suitable earthquake loadings. Peak ground acceleration was varied from 0.05g to 0.15g. Westergaard method was used to assign hydrodynamic loads. Coulomb-Mohr criterion was employed to investigate potential failures in concrete.

Stresses in dam models during the earthquakes was scrutinized for potential failures. Significant stress increases were observed in some areas of the dams. These critical areas and corresponding values of earthquake parameters were identified. It was concluded that the dams were unlikely to suffer material failures under earthquake loads even with a peak ground acceleration of 0.1g (which is the value recommended for use for critical structures in the areas concerned).

KEYWORDS: *Concrete gravity dams, Finite element model, Coulomb-Mohr criterion, Time history analysis, Westergaard method*

1 INTRODUCTION

Sri Lanka is situated in the Indo-Australian tectonic plate but far away from the plate boundaries. So it is considering a non-seismic country. Past records indicate only a few minor earthquake events in the country. Earthquakes can be defined as sudden slips or sudden movements on earth surface in the tectonic plates of the earth's crust. (Bolt, 2021)

Sudden movement of earth surface creates inertia forces in structures. This may cause variations in structural responses such as stresses. Such increased stresses may pose hazards for the safety of structures such as high-rise buildings and dams. Potential dam failures might imply threats perhaps even more significant than building failures. If a dam fails under an earthquake it can cause serious damages to properties and people in downstream areas. This is a situation that has much relevance to Sri Lanka.

Sri Lanka has more than 350 medium and large dams. (Samarajiva, Goswami, and Ennen, 2006). There are two main types of dams in Sri Lanka: concrete dams and earth and rockfill dams. Concrete dams have been used more frequently for medium and large dams in modern times due to some advantages such as cost effectiveness, feasibility of large heights and of large reservoir capacities. Arch type and gravity type are the two main types of concrete dams found in Sri Lanka. Most of them are gravity dams. Therefore, it is important to examine the risks for gravity dams under earthquakes.

Analysis of a dam's structural response to earthquake loads is important to identify potential threats to the dam. This can be conveniently done using finite element method which is a computerized procedure for structural analysis under static and dynamic loads. (Ghanaat, 2004). In 2017 Karunananda and Tharmarajah performed a seismic analysis of Victoria arch dam in Sri Lanka using SAP 2000 finite element software package.

Response Spectrum analysis and time history analysis are the two main methods for finite element analysis of dams under seismic loads. They involve a few main steps such as preparing finite element model, assigning loads and boundary conditions, analyzing, and interpretation of results. (Yaghin, and Hesari, 2008)

2D or 3D finite element models can be used for analysis. Long and straight concrete gravity dams with approximately uniform cross-sections can usually be analyzed satisfactorily with 2-D finite-element models. But curved arch dams require 3-D models. (Ghanaat, 2004).

An earthquake load can be applied to a finite element model as a time history function to represent loads varying with time. Static analysis methods are not suitable for these seismic loads. (Salamon, 2015). Ground acceleration and frequency are the most important parameters in an earthquake. Time history analysis can be done for dams using acceleration records that reflect these earthquake parameters.

Water pressure on a dam during an earthquake also should be considered. Westergaard has proposed a method to determine the hydrodynamic pressure of the water on an upstream vertical side of a concrete dam during an earthquake event. (Zhou et al., 2017). Approximate form of Westergaard equation is normally used for calculating hydrodynamic loads in finite element analysis. The approximate form is a convenient way to calculate hydro dynamic forces, and results are not much different from what is obtained using the actual Westergaard equation. (Salamon, 2015)

Strictly speaking, for an accurate analysis the foundation (usually rock) on which the dam sits also should be included in the finite element model. However, it has been shown that, if the ratio of the elastic modulus of foundation material to that of the material of the dam body is high, foundation does not significantly influence the structural behavior of the dam. In such cases the dam foundation need not be included in the finite element model. Instead, the dam body can be treated as fixed at its interface with the foundation. (Zeidan, 2015)

In order to assess the likelihood of material failure in a dam under seismic loads it becomes necessary to use a failure criterion for the dam material which is usually concrete. Concrete is a brittle material. There are a few failure criteria for identifying material failure in concrete. Coulomb-Mohr criterion and Drucker-Prager criterion are good for identifying failure of concrete in linear time history analysis. (Malm, 2016).

In the present work structural behaviors under earthquake loads of two important concrete gravity dams in Sri Lanka was examined. Time-history analysis using SAP2000 finite element package was performed for each of the two dams under appropriate seismic loads and the results were examined for potential material failure in the dams.

2 METHODOLOGY

2.1 Selection of two dams

Rantambe and Moragahakanda concrete gravity dams were selected for this study. This was mainly based on consequences of failure and safety considerations. Selected dams are located in hilly areas which would be affected more severely in the event of an earthquake near Sri Lanka. The presence of large populations downstream of each dam amplifies the severity of consequences to life and property in the case of a potential failure of the dams.

2.2 Selection of an earthquake parameters

There are no detailed past records of any major earthquakes in close proximity to Sri Lanka. This necessitates the use of earthquake records form other locations or the use of synthetic earthquake records. For the present study the former approach was adopted

Koyna earthquake (M 6.3) recodes were selected for the analysis. It had happened in Maharashtra in India in 1967 (Figure 1), This area also is located on the Indo-Australian tectonic plate. Most of topographical conditions of Koyna area are similar to Sri Lankan topographical conditions. Another advantage is that detailed and accurate data are available for Koyna earthquake. In the PEER data base SEISMOSIGNAL software was used to scale earthquake records to correspond to different peak ground acceleration values.

Figure 1. Locations of Koyna earthquake

The blue color lines in Figure 1 show tectonic plate boundaries near Sri Lanka and the Koyna earthquake location

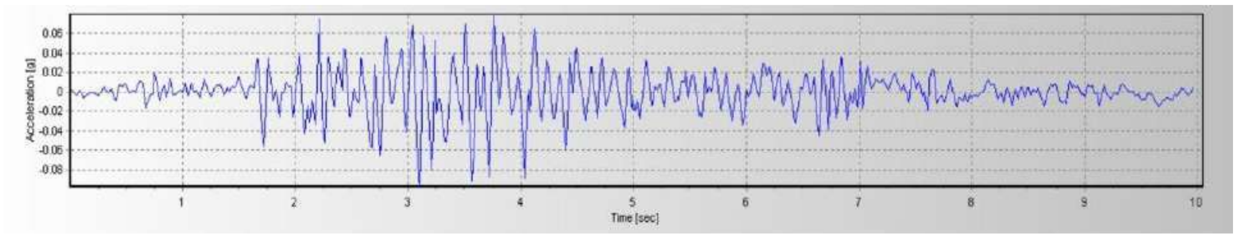

Figure 2. Seismograph of Koyna earthquake (PGA 0.1g)

The Koyna earthquake duration is 10s and each time period is 0. 01s.Therefore the time history record consists of 1000 time steps.

2.3 Dimensions and material parameters.

Table1. Important dam dimensions

Dimension	Rantambe Dam	Moragahakanda dam
Height (m)	39	55.2
Crest width (m)	5	8

Details of the dam configuration for finite element modelling was obtained from the Mahaweli Authority. Sections with the highest value of body height were selected for each dam. The relevant dimensions are given in Table 1. As material parameters, tensile strength was estimated following IS 456-2000.

Tensile strength (MPa) $=0.7\sqrt{f_{ck}}$ (1)
Modulus of elasticity (MPa) $= 5000\sqrt{f_{ck}}$ (2)

where f_{ck} = Compressive strength of concrete (MPa)

Compressive strength of concrete in Rantambe dam is 15 MPa and Moragahakanda dam has concrete of two different compressive strengths – 15 MPa and 20 MPa. (Figure 3).

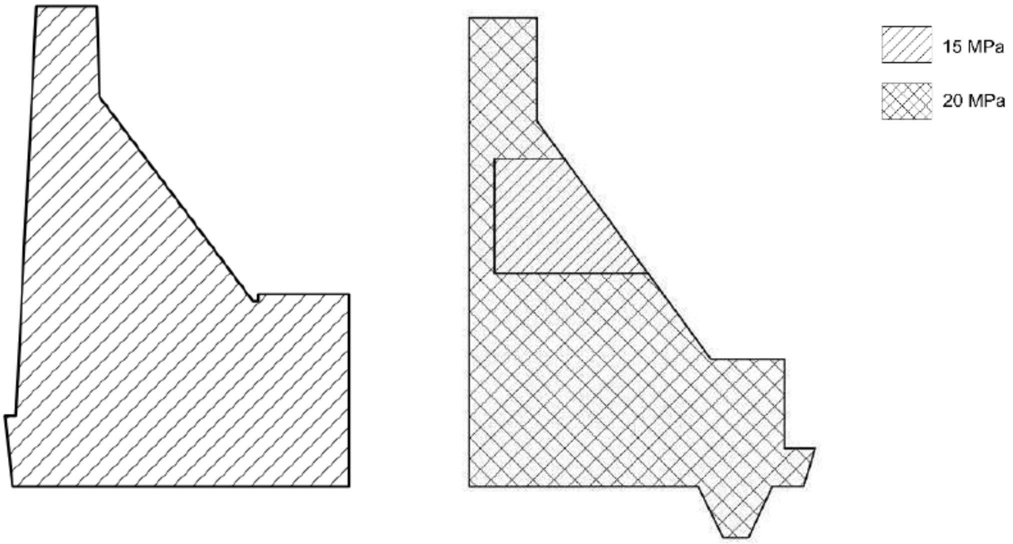

Figure 3- Compressive strengths of concrete layers on dams
(Left: Rantambe, Right: Moragahakanda.)

2.4 2D finite element models of the dams

The axes of both Rantambe and Moragahakanda dams are straight. Their cross-sections are also approximately uniform. Therefore, 2D finite element models were adequate for reasonably accurate results. (Ghanaat,2004). 2D finite element models were developed for the two dams using SAP2000. Quadrilateral elements were used in each mesh. All elements were developed with aspect ratio close to one and the meshes were refined to check convergence of results. Foundations of the dams were assumed to be much stiffer than the dams and not included in the models. Fixed boundary conditions were applied on the dams at their interfaces with the foundations. The two models are shown in Figures 4 and 5.

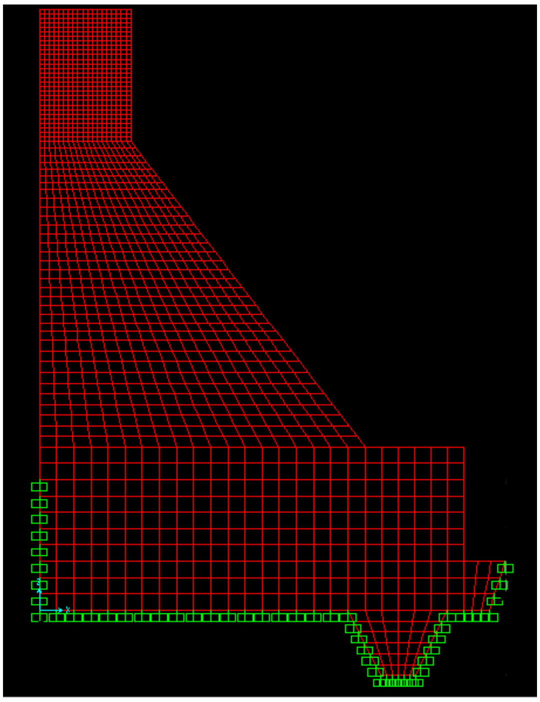

Figure 4. 2D Model of Moragahakanda dam

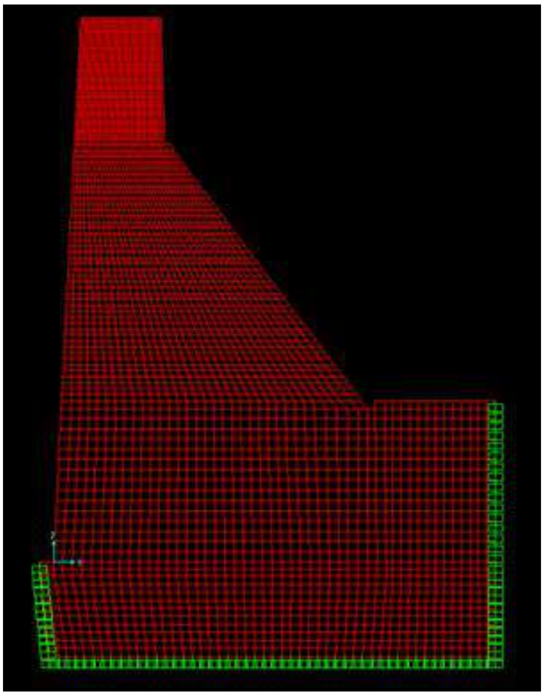

Figure 5. 2D Model of Rantambe dam

2.5 Assigning boundary conditions and loading

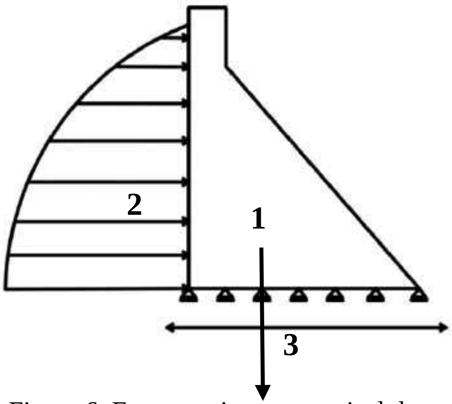

Figure 6. Forces acting on a typical dam

1 = Self weight of dam.
2 = Westergaard hydrodynamic pressure.
3 = Earthquake loads

Earthquake load was applied as a time history function. Koyna earthquake parameters were used and analysis was done by changing peak ground acceleration values as 0.05g, 0.1g and 0.15g. The possibility of an earthquake happening in Sri Lanka is low. So, these moderate peak ground acceleration values were used (Seneverathne et al, 2020)

Westergaard hydrodynamic load was assigned as hydrodynamic pressures acting on the dams under an earthquake event. The following Westergaard approximate equation was used for this purpose. (Salamon, 2015)

$$P_d=0.875\ W_0.\ k\sqrt{(H.h)} \quad (3)$$

P_d = Westergaard hydrodynamic pressure.
W_0 = Unit weight of the water (kN/m).
k = Design seismic coefficient. (0.1).
H = Height from reservoir water surface to the foundation level (m)
h = Depth from water surface to calculated point (m)

Several assumptions had been used to derive Westergaard equation. Reservoir was assumed to contain water to maximum capacity and dam's upstream surface was considered as Vertical. Loads were applied to each node on the upstream side of the dam.

2.6 Failure criterion

To represent the brittle behavior of concrete, Coulomb- Mohr failure criterion was used to examine the failures of the material under earthquake loads. In terms of the principal stresses σ_1 and σ_3, Coulomb - Mohr criteria can be defined as shown below. The corresponding failure curve is illustrated in Figure 7.

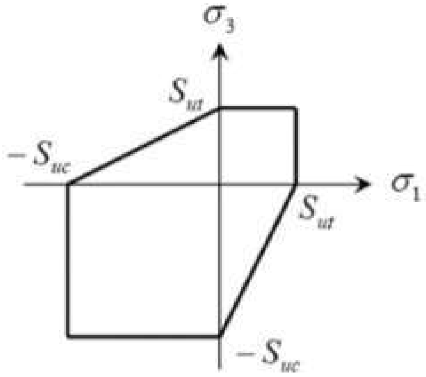

Figure 7. Coulomb-Mohr failure plane

$(\sigma_1 / S_{ut}) \leq 1$; if $0 \leq \sigma_1 \leq \sigma_3$. (4)
$(\sigma_1 / S_{ut}) - (\sigma_3 / S_{ut}) \leq 1$; if $\sigma_3 \leq 0 \leq \sigma_1$. (5)
$(\sigma_3 / -S_{uc}) \leq 1$; if $\sigma_3 \leq \sigma_1 \leq 0$. (6)

S_{uc} = Compressive strength
S_{ut} = Tensile strength

3 RESULTS

Coulomb-Mohr failure factors were calculated at each node of the finite element mesh in each time interval. For safety this factor should be less than 1. A factor equal to 1 or higher is an indication of possible material failure. The risk of material failure gets reduced as the value of this failure factor decreases towards 0. Risk gets increased when failure factor increases towards 1. The critical failure factors were 0.45 and 0.34 respectively for Rantambe and Moragahakanda dams during an earthquake with 0.1g peak ground acceleration. Figure 8 shows contour maps of Coulomb-Mohr failure factor at the time when the critical value of the factor occurs.

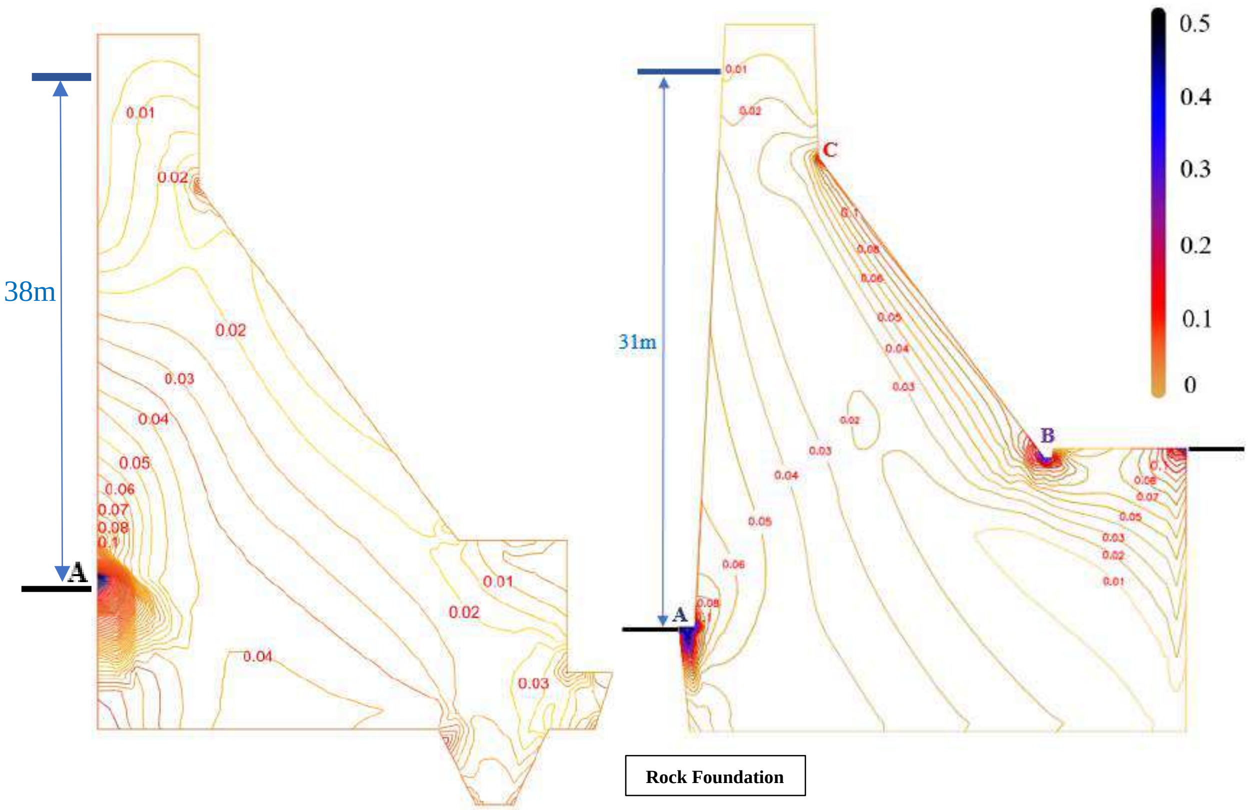

Figure 8. Coulomb-Mohr failure factor distribution on dam at the time interval which critical failure factor occurs at peak ground acceleration of 0.1g
(Left -Moragahakanda and Right -Rantambe)

For Rantambe dam, critical failure factor of 0.45 occurred in location A in Figure 8 (31 m below water level) and 2nd and 3rd largest values of 0.24 and 0.14 in locations B and C respectively. For Moragahakanda dam, the critical failure factor that occurred in location A in Figure 8 (38 m below water level) is 0.34.

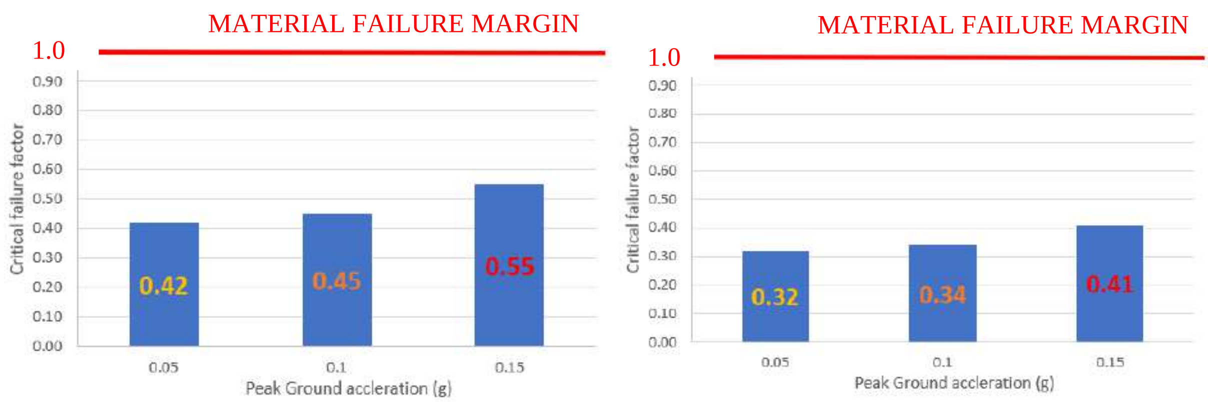

Figure 9– Critical Coulomb-Mohr failure factor variation with Peak Ground acceleration
(Rantambe-Left, Moragahakanda –Right)

The calculations were repeated for peak ground accelerations of 0.05g and 0.15g. The variation of the critical failure factor is shown in Figure 9. Even with peak ground acceleration of 0.15g the critical failure factor in Rantambe dam and Moragahakanda dam did not exceed the limiting value of 1. Therefore, material failure is unlikely in both dams for peak ground acceleration values up to 0.15g. In this connection it should be noted that the maximum peak ground acceleration recommended by Senevirathne et al. (2020) for critical structures in the relevant areas is 0.1g.

4 DISCUSSION

Rantambe dam is unlikely to experience material failures under earthquake loads having peak ground acceleration values up to 0.15g. Critical Mohr-Coulomb failure factor is 0.55 for Rantambe dam. (Figure 9). Moragahakanda dam also is unlikely to suffer any material failure up to a peak ground acceleration of 0.15g. Critical Mohr-Coulomb failure factor is 0.41 for Moragahakanda dam. These values are well within the allowable value 1.

In Rantambe dam the critical values were generated at sharp corners in the model where stress concentrations are likely to occur.

In Moragahakanda dam, critical failure factor occurs at the location A where different material layers meet. In such places also stress concentrations are likely to occur due to discontinuities in material properties.

Actual failure factor values might be slightly higher than the estimated values in both cases because some external forces were not considered in the analysis. Examples are tail water pressure, uplift pressure, and silt pressure. However the effects of these forces would be quite small.

When analyzing the stress distribution on the dam body, it is clear that critical stresses on the dam surface rapidly decrease when moves deeper into the structure of the dam. As a result, the middle of the dam has extremely low failure factors.

5 CONCLUSION

Sri Lanka is considered a non-seismic country. However, the possibility of an earthquake cannot be totally disregarded. Therefore, seismic analysis of dams is an important aspect of disaster preparedness. In the present work seismic analyses were performed for Rantambe and Moragahakanda dams under earthquake loads with peak ground acceleration values up to 0.15g. 2D finite element models were developed for both dams and time history analyses were carried out using SAP2000 software. Resulting stresses were examined using Coulomb-Mohr failure criterion.

The results indicate that both Rantambe and Moragahakanda dams are unlikely to have material failures even with a peak ground acceleration value of 0.15g. However, these results should be treated with caution. The analyses were performed using only one earthquake record. The results are preliminary at best. For a more definitive conclusions further comprehensive analyses need to be carried out under several different earthquake records and appropriate variations of time history analysis parameters.

6 ACKNOWLEDGMENT

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INVESTIGATION MECHANICAL & DURABILITY PROPERTIES OF CRUMBED RUBBER CONCRETE CONTAINING RECYCLED CONCRETE AGGREGATE

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ABSTRACT

The concrete construction industry requires huge amount of natural resources. Currently natural resources are depleting while demand for concrete is increasing. Several studies are focused to solve this issue. The waste rubber has become a huge environmental issue worldwide. Researchers identified a sustainable way of reusing waste rubber by recycling it to Crumbed Rubber and partially replacing that for fine aggregate in concrete. However, with introduction of this crumbed rubber to concrete, the compressive strength of developed concrete was decreased. Therefore, the main aim of this research is to improve compressive strength in Crumbed Rubber Concrete using recycle concrete aggregate. Other than that, some fresh properties, mechanical & durability properties were investigated. 15 percent of replacement of fine aggregate by rubber has been identified as an optimum replacement level by other studies. Therefore, this study was conducted for 15% volume based fine aggregate replacement. As recycle aggregate act as a cementitious binder, it was added in 10,15,20,30 percent of weight basis for cement. The w/c ratio was kept constant at 0.57. Maximum 10 mm aggregate was used in the study. The crumbed rubber replacement resulted in 60 percent decrement in compressive strength and recycled aggregate in all levels resulted in a higher compressive strength than rubber-only concrete but got optimum increment in 20 percent and starts to decrease. Same as compressive strength, splitting tensile, flexural strength increased to optimum values with 20 percent of recycled aggregate. The available design codes were used to calculate theoretical values using experimental values to investigate adequacy of these mixes. The investigate revealed that available standard guidelines cannot be used to predict the behavior of crumbed rubber concrete containing recycled concrete aggregate. This study proves that addition of recycle aggregate to crumbed rubber concrete improves its strength. However, the durability and dynamic properties of this developed concrete needs to be investigated.

KEYWORDS: *crumbed rubber concrete, recycled concrete aggregate, mechanical properties*

1 INTRODUCTION

The increase of discarded rubber products has turned into a global problem for the environment currently. The poor waste management is the main reason for this observation. Waste tire Rubber is one of such waste which challenge the environment. Every year, a huge number of tires go to disposal, but only about 50% of them get recycled, and the remaining go to landfills. Therefore, there is an urgent need to address this issue. One sustainable solution to waste tires is to use them as an alternative to conventional aggregate in concrete.

However, countries like Sri Lanka are facing difficulties when it comes to maintaining and reusing or recycling this rubber to maintain a green environment and keep the industry pollution free. On the other hand, along with the accelerated development activities, demand for concrete is increasing worldwide, and the concrete industry is already facing huge difficulties when it comes to finding a satisfactory amount of material. The natural fine aggregate (NFA) used for concrete is river sand. Which is a nonrenewable natural, depleting resource. As we know, waste rubber disposal has become a big environmental problem worldwide. Treatment processes also face many difficulties due to the huge amount of rubber material disposed of. These tires pose an economic, health, and environmental risk by releasing toxic waste into water, air, and soil. Rubber tires act as long-term storage for water due to their specific shape and nature of resistance to water. Hence, they provide a breeding ground for mosquitoes and various other pests as well. The easiest way of disposing of rubber tires is tire burning, but it causes serious fire hazards to the environment. It has been found that, overall, 1000 million tires reach their end of life every year. By 2030, the amount of waste tires from motor vehicles is expected to be 1200 million, on behalf of nearly 5000 million tires that will be disposed of on a regular basis (Sofi, 2016). Therefore, there is an urgent need to address this issue (Roychand et al., 2019). Countries like Sri Lanka are facing difficulties when it comes to maintaining and reusing or recycling this rubber to promote a green environment and keep the country pollution free. Nowadays, researchers have found a sustainable solution to waste tires. That is using waste rubber tires as an alternative to aggregates in conventional concrete. Also, for the investigation, rubber can be used in three forms, which can be listed as rubber chips, molded rubber, and rubber powder. Generally, rubber chips are larger than 6 mm and crumbed rubber is less than 6 mm. The cost of shredding increases with the reduction of particle size, and the particles influence the strength of concrete. Larger particles would decrease the compressive strength and small particles would increase it relative to large particles (Mendis, Deen, & Ashraf, 2016).

Crumbed rubber (CR) concrete is a good solution to the overuse of river sand. So far, rubber concrete has only been used for non-structural applications because it has several disadvantages. Research studies have shown that crumbed rubber can be used as a partial replacement for both natural coarse aggregate (NCA) and natural fine aggregates (NFA). However, it was shown that mechanical and durability properties had changed, and hence, it would not be suitable for direct use in construction work. With the addition of rubber into concrete, the following disadvantages occurred: relatively low compressive strength, low tensile strength, low workability, low stiffness, early cracking, and low young's modulus of elasticity, found by these researchers (Jokar, Khorram, Karimi, & Hataf, 2018), (Bisht & Ramana, 2017). However, as advantages, replacement for natural materials, as a good method of reusing rubber tires, increased ductility, increased energy dissipation, higher damping ratio, non-biodegradable material, and reduced concrete density can be highlighted (Mendis et al, 2016). According to Mousavimehr and Nematzaded (2019),It was found that by replacing 15% and 30% of the rubber with fine aggregate, the CS decreased by 35% and 52%, respectively. (Xie et al, 2019) found that by replacing rubber with fine aggregate 10% and 20% with 1.5% of steel fiber, compressive strength decreased relatively by 8% and 19% in concrete cubes, but in cylindrical concrete, it decreased the compressive strength by 7% and 15% compared to control concrete (CC).

To overcome the above-mentioned decrement in compressive strength, many researchers have found various materials and various methods of treatment. Studies have found that 25–50% of RCA on concrete does not show a big difference in the mechanical properties of concrete compared to CC (Hossain, Shahjalal, Islam, Tiznobaik, & Alam, 2019). As mentioned in rubber, researchers have found RCA has higher absorption capacity and low density. However, the RCA can be used as a replacement or additional material for both natural fine aggregates, NCA. Ali, Zidan & Ahmed (2020) state The mechanical properties of concrete were investigated using 0%, 25%, 50%, and 100% RCA as a replacement for natural aggregate. The results have shown that replacing up to 50% will not have a huge effect on mechanical properties. However, when RCA is increased by up to 100%, there will be higher compressive strength and a tensile strength decrease. Evangelistaa & Brito (2005) state that using 30% of RCA does not have a considerable effect on the mechanical behavior of concrete. Etxeberria, Vazquez, & Barra (2005) state that it was also found that the rough texture of RCA and proper bonding of cement paste could result in good compressive strength in concrete. Ali et al (2020) state In conclusion, it can be decided that RCA can be used up to 30% of its replacement efficiently. Boudali, Kerdal, Ayed, Abdulsalam, & Soliman (2015) state that the incorporation of RCA in the mixture will give a better performance than pozzolan in CC. According to Hossain et al. (2019), it was noticed that there was an increase in compressive strength when replacing 10% of RCA. Compressive strength decreases with each increment of RCA and crumbed rubber. The addition of polypropylene fiber has increased compressive strength, but the maximum 27% of compressive strength increment was achieved in 30% of RCA and 2% of fiber without crumbed rubber. Xie et al (2018) state that replacing 100% of

RCA with a partial percentage of crumbed rubber showed a result of strength decrement due to the addition of RCA and a further strength decrease due to the addition of crumbed rubber. Similarly, Xie et al (2014) state that a decrement of strength occurred due to the addition and increment of crumbed rubber and the addition of constant RCA. In his 5th edition of the Properties of Concrete book, A. M. Neville mentioned the following things: Which means the strength of concrete will depend on the cohesion of the mixture of cement and the bond it carries with aggregates and the strength of the aggregate carried itself. By increasing aggregate size, strength can be increased. Due to the contribution of old mortar in RCA unit weight, concrete made with RCA will have a lower value. Similarly, higher absorption and porosity can be expected. The absorption can be reduced by saturated RCA before use. The strength of concrete mainly depends on the W/C ratio and the degree of compaction. And the penetration depth is negatively proportional to the strength of the concrete.

Therefore, considering the above facts, this study investigates the possibility of using crumbed rubber as a substitute for fine aggregates in concrete and alleviates the inherent adverse effects of crumbed rubber on concrete's compressive and tensile strength, workability, low stiffness, etc. by adding recycled concrete aggregates. An experimental study was conducted to investigate the mechanical, durability, and fresh properties of each concrete mix. Basic tests like compressive strength (CS), splitting tensile strength (STS), and modulus of rupture (MR), density, water absorption (WA), and volume of voids (VV) are performed.

Considering the above facts, the potential research area in this sector was identified. In the research, it would be investigated whether crumbed rubber concrete has RCA. Usually, with the addition of rubber, the compressive strength of concrete decreases. However, in concrete cast, using RCA, higher mechanical properties have been shown by some researchers. But in this research, RCA was added as an additional material, and it won't be replaced with any material. Here, RCA is assumed to be a cementitious material, and by increasing cementitious materials, it is aimed to improve the strength of concrete. This study will use a maximum size of 10 mm NCA, a maximum size of 4 mm natural fine aggregate, a constant 15% crumbed rubber replacement, and a 0–30% RCA replacement. Hence, in this research, experiments will be conducted to find a solution to this compressive strength decrement and ways of improving it by changing mixed proportions in concrete like RCA. Basic tests like compressive strength tests, tensile strength tests, workability, water absorption, volume of voids, etc. will be initially carried out, and as the research goes on, more tests will be conducted to obtain proper results and meet the ultimate objectives of this study.

1.1 Materials and methodology

A. Materials and mixtures

A detailed description of all the ingredients used in this study to prepare concrete mixtures is provided below. Mainly Crumbed rubber was used as a replacement for natural fine aggregate content by 15% of its volume. Recycled concrete aggregate was used in various percentages to increase cement content in this concrete production.

Portland Limestone Cement (PLC) of grade 42.5 was used in this concrete production. Concrete industry tends to use PLC over OPC due to the environmental benefits of PLC. PLC can be directly used in the same mix designs as OPC. Locally available, well-graded natural river sand with a nominal maximum grain size of 4.75 mm, Locally available, well-graded natural gravel with a maximum of 10 mm, crumbed rubber with a maximum of 2 mm, and recycled concrete aggregate, which was collected from a demolished building and crushed manually with a maximum aggregate size of 10 mm, were used in this study. The sieve analysis and gradation of recycled concrete aggregate were done using ASTM C136–19 standards. The figures depict the gradation curves of all aggregates and demonstrate that the aggregates were within the ASTM upper and lower bound ranges. The material characterization of the recycled concrete aggregate was performed using the same procedure as for natural coarse aggregate. In order to achieve a similar distribution as fine aggregate, the final crumbed rubber mixture contained 70% of rubber passing through # 30 mesh and 30% of rubber passing through # 10 mesh. In order to achieve the required workability of concrete, a locally available high-range water-reducing admixture (MasterRheobuild 1000) was used. The natural fine aggregate and crumbed rubber density are 1700 and 532.5 kg/m3 respectively.

Figure 1 shows the particle distribution of natural fine aggregate (NFA), natural coarse aggregate (NCA), crumbed rubber (CR), and recycled concrete aggregate (RCA).

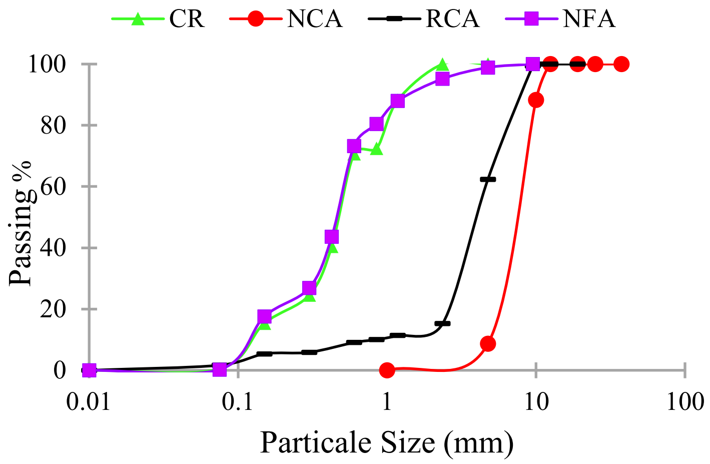

Figure 1. Particle distribution of aggregates

B. Mixture proportions

Six different concrete mixes were prepared for this study to support proportional analysis. A target compressive strength of 25–35 MPa in 28 days is commonly used in designing reinforced concrete structures in Sri Lanka, depending on the construction. The total Portland limestone cement content and the effective water cement ratio were kept constant at 405 kg/m3 and 0.57, respectively. It was assumed that coarse and fine aggregate used in this study were in saturated surface dry conditions. The percentage of crumbed rubber replacement was kept at a constant value of 15 throughout the study. Crumbed rubber was replaced by a volume of fine aggregate. Therefore, crumbed rubber was replaced by 15% by volume of sand and recycled concrete aggregate was added additional by weight of cement up to 30% as addition cementations material. To improve workability, the high water reducing admixture "MasterRheobuild 1000" was used. With the introduction of admixture, 20% of water content was reduced as a standard. The remaining 80% of water was divided into 4 parts. At first, 3 parts of water were added to the concrete, and finally the remaining part was added after properly mixing it with the admixture. 1 L of admixture was added for every 100 kg of cement (1% of admixture). The specimen identification description is shown in Table 1. For illustration, ($C_{15}R_{20}A_1$) describes 15% crumbed rubber replacement, 20% recycled concrete aggregate added along with 1% admixture (MasterRheobuild 1000).

Table 1. Concrete mixture proportions per meter cube.

Refer No	**w/c ratio**	**Cement Kg/m³**	**Water Kg/m³**	**Sand Kg/m³**	**Metal Kg/m³**	**CR Kg/m³**	**RCA Kg/m³**	**Admixture L**
$C_0R_0A_0$	0.58	405.8	233.3	761.59	969.29	0	0	0
$C_{15}R_0A_0$	0.58	405.8	233.3	647.35	969.29	5.76	0	0
$C_{15}R_{10}A_0$	0.58	405.8	233.3	647.35	969.29	5.76	40.58	0
$C_{15}R_{15}A_1$	0.58	405.8	186.7	647.35	969.29	5.76	60.87	4.06
$C_{15}R_{20}A_1$	0.58	405.8	186.7	647.35	969.29	5.76	81.16	4.06
$C_{15}R_{30}A_1$	0.58	405.8	233.3	647.35	962.29	5.76	121.74	4.06

C. Experimental program

In order to evaluate the fresh, mechanical, and durability properties of concrete, the following standard experiments were conducted, and the results were compared with control concrete. Standard ASTM C143 was used to measure slum value. Frustum of a cone was used for the slum test, which has a 300 mm height and 100 mm and 200 mm diameter openings. The apparatus was placed on a smooth surface with a smaller opening at the top and was filled with concrete in three layers. Each layer was tamped 25 times with a standard 16 mm diameter steel rod. Immediately after filling, the cone was slowly lifted, and unsupported concrete slumped. The decrement in the height was measured to the nearest 5 mm. The uniaxial compressive strength test was conducted according to ASTM C39. A constant load of 0.25 ± 0.05 Mpa/sec was applied. The splitting tensile strength test was conducted according to ASTM C496 & a constant load of 0.011 to 0.023 Mpa/sec was applied. The flexural strength test of concrete prims was conducted according to ASTM C78 & BS EN 12390–5: 2000, which suggests a prism size of 100 mm × 100 mm × 500 mm for concrete that uses less than 25 mm of aggregates. To investigate water absorption capacity, density, and volume of voids, the standard ASTM C642 test was conducted.

D. Comparison with standard code of practice

Various design guidelines and standards exist for predicting the mechanical and durability of concrete using various properties like compressive strength and flexural strength. In this study, present design guidelines and standards from Eurocodes (EC2), fib, ACI, and CSA were used to predict the different response parameters of the concrete specimens. Then predicted behaviors were compared with experimental values. A ratio (ξ) between experimental and predicted values was calculated for comparison, where a ξ value greater than 1 indicates an over-prediction, while a value less than 1 indicates an under prediction of the result.

fib2010 & EC2 recommend using Eqs (1) & (2), and taking respective measures. AS3600 is also used, but there is another relation between Eqs (3). ACI 318-14, ACI 363-92 provide direct reflection between Eqs. (4) and (5). Where, is splitting tensile, tensile, mean compressive strength, respectively. Guidelines by fib2010, AS3600, ACI 318-14, and ACI 362-92 have proposed a relationship between CS and modulus of rupture by Eqs (6)–(9) respectively. Where, modulus of rupture, compressive strength & depth of prism.

$$f_{ctm,sp} = f_{ctm}/\alpha_{sp} = 0.3\left(f_{cm}\right)^{\frac{2}{3}}/\alpha_{sp} \tag{1}$$

$$f_{ctm} = \alpha_{sp} f_{ct,sp} \tag{2}$$

$$f_{ctm,sp} = f_{ctm}/\alpha_{sp} = 1.4 \times 0.36\sqrt{f_c^{'}}/\alpha_{sp} \tag{3}$$

$$f_{ctm,sp} = 0.556\sqrt{f_c^{'}} \tag{4}$$

$$f_{ctm,sp} = 0.59\sqrt{f_c^{'}} \tag{5}$$

$$f_r^{'} = \frac{0.3(f_c^{'})^{\frac{2}{3}}}{\alpha_{fl}} \; where, \alpha_{fl} = \frac{0.06h_b^{0.7}}{1+0.06h_b^{0.7}} \tag{6}$$

$$f_r^{'} = 0.6\sqrt{f_c^{'}} \tag{7}$$

$$f_r^{'} = 0.62\sqrt{f_c^{'}} \tag{8}$$

$$f_r^{'} = 0.94\sqrt{f_c^{'}} \tag{9}$$

1.2 Results and Discussion

A. Workability

The average slump value recorded for each of the six mixes is shown in Table 2. The addition of 15% crumbed rubber resulted in a lower slump value. Recycled concrete aggregate also decreased the slump value.

Due to the very low workability of 15%, admixture was introduced to the remaining mixes. But in 15% and 20% recycled concrete aggregate mixes, there was enough workability without 20% required water. But 30% recycled concrete aggregate mix requires 100% water. The slump value highly depends on the properties of raw materials used in the relevant concrete mix and some environmental facts as well. Crumbed rubber is a porous material and requires more water to overcome friction, recycled concrete aggregate has a higher water absorption and higher surface roughness. Because of those reasons, workability was reduced. Another reason behind this dramatic workability reduction is that adhered mortar with crumbed rubber and recycled concrete aggregate entraps air in the mixture and creates air bubbles. Decrement of particle size of rubber reduces workability of concrete because it increases surface area of angular shape particles.

B. Compressive strength

A summary of hardened concrete Compressive strength test results of cube and cylindrical specimens at 7day and 28day are presented in Table 2. It was observed that in the 7-day compressive strength test for cube and cylinder, a higher strength was achieved than control concrete for all mixes except for rubber-only mix ($C_{15}R_0A_0$) and 10% recycled concrete aggregate mix ($C_{15}R_{10}A_0$). Approximately 59% of design characteristic strength was achieved in the 7-day test for control concrete. The lowest compressive strength resulted in a 15% replacement of crumbed rubber over natural fine aggregate.

Introducing recycled concrete aggregate resulted in an increment in compressive strength. Further to that, from 15% recycled concrete aggregate mix onwards, it showed higher compressive strength than control concrete. But the optimum compressive strength is received in 20% recycled concrete aggregate mix and a little lower value is received in 30% recycled concrete aggregate mix. Replacement of 15% rubber resulted in 57% and 54% compressive strength decrements in cubical and cylindrical specimens, respectively, at the 7-day test. When it comes to the 28-day test, replacement of 15% rubber resulted in a 59% and 61% compressive strength decrement in cubical and cylindrical specimens, respectively. Compared to control concrete, the addition of 10% recycled concrete aggregate resulted in a 27%, 34%, 38%, and 49% strength decrement in the 7-day cube and cylinder and 28-day cube and cylinder, respectively. When it comes to the cylinder at 28 days, only 20% recycled concrete aggregate mix achieved a 3.8% increment in compressive strength compared to control concrete. But all recycled concrete aggregate mixes showed higher compressive strength values compared to crumbed rubber only concrete mixes.

The cement used in this study was PLC, since it is a slow strength gain cement. The results showed a slow strength gain over 7 days. The addition and increase of recycled concrete aggregate increased strength gain, but was not continuous till 28 days. The decrease in compressive strength in crumbed rubber only mix happens due to the weaker bond created by crumbed rubber with aggregate and cement paste. The transition zone gets weaker due to the higher amount of free water in the concrete mix because of the crumbed rubber. Crumbed rubber has very low strength compared to natural fine aggregate. Therefore, crumbed rubber is unable to achieve some strength results with natural fine aggregate itself. This crumbed rubber contains a lot of impurities like sulfur and zinc, and they result in low bonding capacity with the cement matrix. The crumbed rubber has a very low elastic modulus and hydrophobic properties that increase the porosity, which results in a lower compressive strength. Another reason behind this strength decrement is deformability. Crumbed rubber particles relative to the cement matrix developed crack pattens similar to the air void created by crumbed rubber. In this study, a huge amount of crumbed rubber was used, which clearly means that the concrete contains a huge number of air voids as well. Due to these voids, we can see sudden failures in loading time. Figure 2 & 3 Present failure patterns and (a) $C_0R_0A_0$ (b) $C_{15}R_0A_0$ (c) $C_{15}R_{10}A_0$ (d) $C_{15}R_{15}A_1$ (e) $C_{15}R_{20}A_1$ (f) $C_{15}R_{30}A_1$ represent respectively.

. The increment of compressive strength with the increase of recycled concrete aggregate may occur by better/optimal internal curing provided by a higher amount of water that is absorbed by the recycled concrete aggregate and thus the w/c ratio gets a lower value at the interfacial zone. Thus, the bond between the attached old mortar in the recycled concrete aggregate surface and the new cement paste will improve. But strength increases by up to 20% with recycled concrete aggregate and decreases by 30%. This may happen due to the higher amount of porosity introduced by recycled concrete aggregate. The strength reduction may happen due to the multiple layers of interfacial transition zone (ITZ)

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Figure 2. Cubes after failure in 7 days

Figure 3. Cylinders after failure in 7 days

C. Splitting tensile strength

A summary of the hardened concrete splitting tensile strength test results is presented in Table 2. It can be seen that maximum splitting tensile occurred in control concrete at 28 days. 20% recycled concrete aggregate addition gets a splitting tensile strength value of 2.62 MPa, which is closer to the control concrete value of 2.77 MPa. But when it comes to the 7-day test, maximum splitting tensile strength was achieved in 20% recycled concrete aggregate mix and it was equal to 2.53 MPa while control concrete got 1.64 MPa. As mentioned in compressive strength, PLC cement shows low strength gain, but addition and increment of recycled concrete aggregate increase the strength gain in 7 days, but it is not continuous to 28 days. Compared to control concrete, crumbed rubber's only concrete splitting tensile strength was decreased by 37%. 10% Recycled concrete aggregate mix splitting tensile strength value was decreased by 16%, but in recycled concrete aggregate 15%, 20%, and 30% samples, splitting tensile strength was increased by 16%, 54%, and 8%, respectively in 7 days. But when it comes to the 28-day test, splitting tensile strength decreased compared to control concrete by 47%, 32%, 13%, 5%, and 17%, respectively, in 0%, 10%, 15%, 20%, and 30% recycled concrete aggregate mixes.

The control sample failed gradually. The rubber-only sample also failed gradually, but the increment of recycled concrete aggregate up to 20% gave more sudden failure with a slight increment of failure sound. Figure 4 presents failure specimens after a splitting tensile strength test. Crumbed rubber has low elastic modulus, and it is fragile in tension. The bond between crumpled rubber and cement paste was weak. Therefore, it broke suddenly more than control concrete. The reason behind this tensile strength reduction in the concrete containing crumb rubber is that small rubber particles isolate other solid constituents of the mix from each other and act as voids that induce stress concentration, leading to a quicker concrete failure in tension.

D. Modulus of rupture

After taking out the specimens from the curing tank and preparing them by removing surface water using a towel, measurements of prism height, width, and diameter were taken. Support points were marked 50mm apart from each end. Therefore, the clear distance between supports is equal to 400 mm, and it was divided into 3 equal sections, and symmetrical loading points were marked. BS EN 12390–5:2000 suggests a beam size of 100 mm × 100 mm × 500 mm for less than 25 mm of aggregate concrete. A summary of the hardened concrete flexural strength test results of prisms after 28 days is presented in Table 2. All failures occurred in the middle third of the distance (in between loading points as shown in Figure 5). All concrete mixes had higher flexural strength than control concrete, except rubber only concrete. Flexural strength was decreased by 36% in the rubber-only concrete mix.

The highest flexural strength resulted from a 20% recycled concrete aggregate mix, which was equal to 5.68 MPa, and flexural strength was increased by 20% compared to the control mix. The flexural strength of the recycled concrete aggregate 10% mix was equal to the control concrete mix. The flexural strength of 15% and 30% recycled concrete aggregate mixes increased by 3% and 4%, respectively. The 15% crumbed rubber replacement created a weaker ITZ and a weaker bond between the aggregate and the cement matrix. Due to its low density, it was not uniformly distributed within the cement matrix. As in the compressive strength and splitting tensile strength tests, strength increased to an optimum value in 20% recycled concrete aggregate and 30% recycled concrete aggregate concrete mix, but resulted in a lower strength.

Figure 4. Cylinders after failure at 7 days

Figure 5. (a) Failure point (b) dimension check

Table 2. Material properties of various mixes at 7 day and 28 da

Ref No	Compressive strength (MPa)				Splitting tensile strength (MPa)		Modulus of rupture (MPa)	Slump (mm)
	Cube		Cylinder					
	7 days	28 days	7 days	28 days	7 days	28 days	28 days	
$C_0R_0A_0$	17.65	27.62	14.28	23.13	1.64	2.77	4.75	200
$C_{15}R_0A_0$	7.53	11.12	6.55	9.00	1.04	1.46	3.04	175
$C_{15}R_{10}A_0$	12.8	17.12	9.42	11.70	1.38	1.89	4.75	110
$C_{15}R_{15}A_1$	24.47	32.71	18.22	22.65	1.91	2.48	4.88	90
$C_{15}R_{20}A_1$	28.22	36.50	20.5	24.02	2.53	2.62	5.68	80
$C_{15}R_{30}A_1$	20.67	28.09	14.79	20.14	1.77	2.29	4.93	115

E. Water absorption, Density, Volume of voids

Four different weights were selected as: dry weight, saturated weight, weight after boiling, and apparent mass in water collected. Water absorption capacity increased in rubber-only concrete compared to control concrete. With the addition of recycled concrete aggregate, water absorption decreased to 4%

in the 15% and 20% recycled concrete aggregate mixes but got a slightly higher value in the 20% recycled concrete aggregate mix.

Overall, all mixes in which recycled concrete aggregate was included gave a low water absorption rate compared to control concrete. In all mixes, density values had a similar variation as follows: Bulk density dry < Bulk density after immersion < Bulk density after immersion and boiling < Apparent density. In Crumbed rubber only concrete, dry density was decreased by 16% and with addition of Recycle concrete aggregate, the density was increased compared to Crumbed rubber only concrete. 15% from recycled concrete aggregate mix onwards, the density reached a similar value compared to control concrete. In the other 3 densities also, a similar variation to dry density was observed. Voids increased by up to 21% in rubber-only concrete compared to control concrete, but with the addition of recycled concrete aggregate, it decreased to 11% in the 15% recycled concrete aggregate mix. 20% Recycled Concrete Aggregate Mix got a slightly higher value than the 15% Recycled Concrete Aggregate Mix, but it was decreased again in the 30% Recycled Concrete Aggregate Mix. A summary of test results regarding water absorption, density, and volume of void is presented in Table 3.

Table 3 Variation in Water Absorption, Density, and Volume of Void in each mix

Ref No	**Water absorption (%)**		**Bulk density (Mg/m3)**			**Apparent density (Mg/m3)**	**Volume of voids (%)**
	After immersion	**After immersion & boiling**	**Dry**	**After immersion**	**After immersion & boiling**		
$C_0R_0A_0$	7.45	8.17	2.36	2.53	2.55	2.92	19.24
$C_{15}R_0A_0$	8.11	10.01	2.12	2.29	2.29	2.69	21.22
$C_{15}R_{10}A_0$	6.72	7.21	2.17	2.32	2.33	2.58	15.68
$C_{15}R_{15}A_1$	3.69	4.69	2.38	2.47	2.5	2.69	11.2
$C_{15}R_{20}A_1$	5.03	5.81	2.38	2.51	2.51	2.77	13.87
$C_{15}R_{30}A_1$	4	5.03	2.33	2.43	2.45	2.64	11.73

F. Comparison with standard code in practice

Standard available guidelines (EC2) were used to predict 28-day compressive strength values using 7-day values and to get the ratio between the experimental value and the calculated value. Using this method, compressive strength was calculated for both cylinder and cube specimens. Figure 6. Shows a summary of the ratio between the experimental and calculated values of compressive strength in cube & cylinder. Figure 7 presents the calculated tensile strength values. The ratio between experimental and calculated values of splitting tensile strength is presented in Figure 8. The ratio between experimental and calculated values of flexural strength is presented in Figure 09.

Figure 6 shows that the experimental value of the compressive strength of concrete gets a higher value than calculated values from EC2. When it comes to crumbed rubber and concrete, the difference in strength can be neglected. With the introduction of recycled concrete aggregate to concrete, the calculated value of strength gets a higher value than the experimental value. The variation between experimental and calculated values is greater in cylinder specimens up to a 20% addition of recycled concrete aggregate. The 30% recycled concrete aggregate mix variation was much closer. Due to addition of Recycle concrete aggregate, concrete strength gain increased. But all the variations were in the 15% range.

The tensile strength of concrete was calculated using AS3600, fib2010, and EC2. In all concrete mixes except crumbed rubber only mix, the highest tensile strength was shown for AS3600. EC2 showed the second highest strength, and fib2010 showed the lowest strength values. In the crumbed rubber only mix, the highest tensile was shown by fib2010 and the lowest tensile strength was shown by AS3600. EC2 showed an in between value (Figure 7). For normal concrete, strength values showed a small variation for all design codes, which was approximately equal to 2.6 MPa. Crumbed rubber only mixes got the lowest tensile strength and addition of 10% Recycle concrete aggregate increased the strength values, but it was still less than the control concrete. From the addition of 15% recycled concrete aggregate onwards, tensile strength increased compared to control concrete for AS3600 and fib2010 standards. But EC2 still shows less value compared to control concrete.

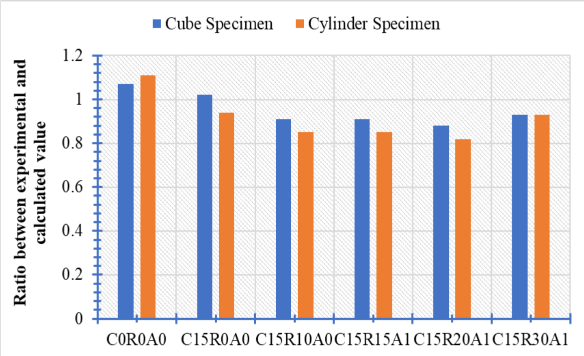

Figure 6. Ratio of experiment & calculate values using EC2

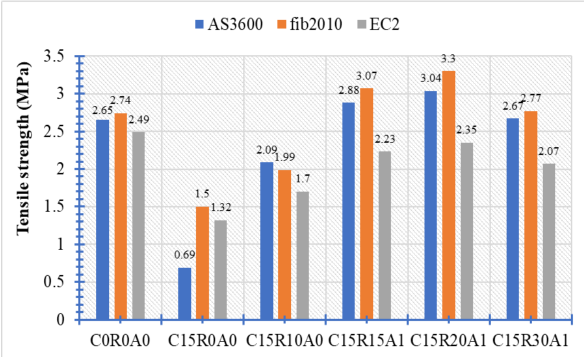

Figure 7. Calculated tensile strength for 28 days

Figure 8 shows the ratio between the experimental and calculated values of splitting tensile strength using available codes. The result shows that control concrete achieved all splitting tensile strength values within a 10% range. For all other mixes, AS3600 shows less than 23% variation. ACI codes shows less than 37% variation. fib2010 shows much closer value to experimental values in control mix, Crumbed rubber only mix and 10% Recycle concrete aggregate mix, but variation goes up to 21% in 15%, 20%, 30% Recycle concrete aggregate mixes. All calculated values show a higher splitting tensile strength value than the results achieved in the experiment. Due to this large variation in all mixes, further studies must be carried out to check the adequacy of crumbed rubber concrete with recycled concrete aggregate.

Figure 9 shows the ratio between the experimental and calculated values of flexural strength using available codes. The control concrete shows 1.51 and 1.46 variations in experimental and calculated values, as calculated by AS3600 and ACI 318-14 standards. ACI 363-92 and fib2010 show small variation ratios. Crumbed rubber only concrete mixes and 15%, 20%, and 30% recycled concrete aggregate concrete mixes show approximately similar ratios as control concrete. But in 10% recycled concrete aggregate, a higher variation in ratios can be seen.

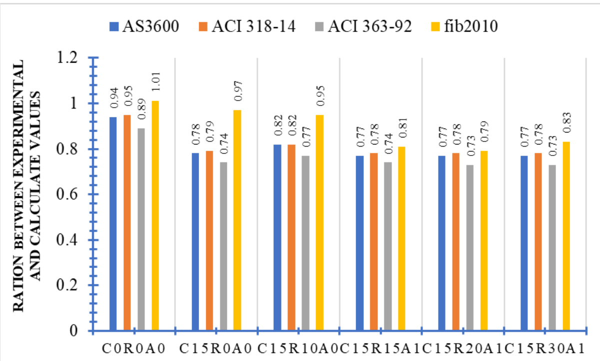

Figure 9. Ratios of splitting tensile strength

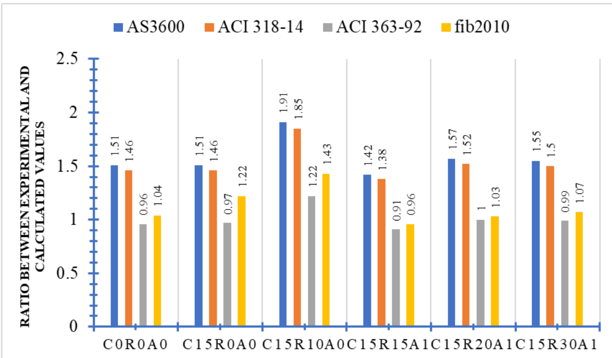

Figure 8. Ratios of flexural strength

2 CONCLUSION

This study was conducted to investigate the mechanical and durability properties of CR concrete, which contains RCA. 15% of CR was replaced by fine aggregate and different RCA was added to the developed concrete. The result of this study can be summarized as follows:

- Workability decreased with replacement of Crumbed rubber, and it further reduced with increase of level of Recycled concrete aggregate.
- Compressive strength decreased by 59% due to the replacement of 15% Crumbed rubber. Addition of Recycled concrete aggregate. in each level increased Compressive strength but the optimum value was received in 20% Recycled concrete aggregate.
- A maximum Compressive strength of 36.5 MPa was achieved in a 20% Recycled concrete aggregate. mix. Compared to Control, it is a 32% increment.
- Splitting tensile decreased by 47% with the replacement of 15% Crumbed rubber. and increased in each level of Recycled concrete aggregate. But reached an optimum value of 2.62 in 20% Recycled concrete aggregate. The reduction in splitting tensile strength compared to Control concrete was 5% in the 20% Recycled concrete aggregate. mix.
- Flexural strength of concrete decreased by 36% in 15% of Crumbed rubber replacement. It increased with the addition of Recycled concrete aggregate. at each level and got an optimum value at 20% Recycled concrete aggregate mix. The flexural strength increment in the 20% Recycled concrete aggregate. mix was 20%.
- Based on the mechanical behavior of concrete, a 20% Recycled concrete aggregate. Addition can successfully improve loosen strength due to a 15% Crumbed rubber replacement.
- But existing design guidelines cannot be directly used with these concrete mixes. There are rapid changes in strength values that were achieved using Recycled concrete aggregate.
- Existing guidelines cannot be directly used with these concrete mixes. There are rapid changes in strength values that were achieved using Recycled concrete aggregate.

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Effective Waste Management Strategies of Bentonite in Sri Lanka

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ABSTRACT

One of the greatest challenges of Bentonite usage in construction industry is, managing the wastage created in sites thus, it has to be given attention. Therefore, the study would be conducted focusing on the domestic piling construction sites and the process followed by them. Although it is a chemical, it is recognized to be safe for both the environment as well as mankind in an ecological and health protection perspective. However, a proper disposal method in order to reduce the further issues as excessive waste in sites is needed.

Therefore, this study aims to explore an effective method regarding the waste management strategies for Bentonite in Sri Lanka. The objectives of the study are, identifying the wasting methods of Bentonite, identifying causes of disposing Bentonite and determining the most suitable method for Bentonite disposal. Data for the objectives one and two were collected through a literature survey and analyzed by using NVivo which was validated using a questionnaire by majority of 5-10 years experienced professionals aligning to mixed method approach. Data for the third objective was found by aegis of the same questionnaire. Noticeably, it was validated through interviews by the industry experts with more than 30 years of experience.

The study found that, site conditions are the most relatable reason for the Bentonite waste. Apart from that 'weather' and 'manual handling errors' can be additional reasons for the wastage. Moreover, most sites consider either 'when the slurry forms into a cake' or 'silos are full' as the causes for disposal. Furthermore, it has identified that the majority of sites dispose the waste to disposable lands using bowsers as of the disposal method after reusing 3-4 times. The suggested method appears to be cost effective and efficient in comparison to the others. Furthermore, it can be rather safe and environmentally friendly.

KEYWORDS: *Bentonite, Waste Management, Wastage, Sri Lanka, Pile Construction.*

1 INTRODUCTION

Construction is the process of constructing buildings or infrastructure. This particular process differs from manufacturing. (Eve, 2007) In order to complete the procedure, following the Royal Institute of British Architects (RIBA) plan of work is the current practice. This particular plan consists of a brief idea about the process and operation of building projects into eight stages. Further, it gives detailed tasks and output required at each and every stage. Since there were some editions of the RIBA plan, currently it is using the revised plan in 2013. (RIBA, 2021) In order to construct high-rise buildings and large-scale infrastructure projects, the base should be strong. Considering that point the construction industry has an important solution, which is strong enough to bear the weight of those constructions. That is to provide a strong, steady foundation for a structure regardless of soil quantity or harsh environment engineers came up with Piles as a solution (Agyekum, Blay & Opoku, 2019). Pile use in construction is done on unstable soil layers, such as, terminals and refineries which are often located near rivers and gulfs, etc. There are a few pile driving methods as follows: Dropping weight; a hammer with approximately the weight of the pile is raised an appropriate height in a guide and released to strike the pile head. This is a simple method of the hammer in this process. Under this procedure to make the pile stronger, Bentonite clay is used as a hardening material. Bentonite is the chemical substance that is widely used in, current construction. Bentonite is an absorbent clay that concludes with aluminum

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properties formed out of volcanic ash. When liquefied into a slurry, it should be disposed carefully and properly without exposing it to people because there may be security issues. The liquefied Bentonite is used in massive quantities and once all the reusing cycles are done, the bulk of liquid will no longer be in use. Thus, it needs to dispose (Arif, Bendi, Toma-Sabbagh & Sutrisna, 2012). Due to the increase of environmental awareness from utility companies as well as municipal bodies, the intense attention has been focused on drilling fluids and their disposal. That induces challenging conditions on constructions including piling operations. Therefore, the research gap is identified as, the waste management practice in relation to Bentonite in the context of Sri Lanka is not applying in the industry. Hence, it is important to develop new waste management strategies to achieve the proper construction environment (Yean Yng Ling & Song Anh Nguyen, 2013).

Therefore, this study aims to explore an effective method regarding the waste management strategies for Bentonite in Sri Lanka. The objectives of the study are, identifying the wasting methods of Bentonite, identifying causes of disposing Bentonite and determining the most suitable method for Bentonite disposal.

2 LITREATURE REVIEW

Burj Khalifa, Shanghai Tower, Abraj Al-Bait clock tower are some of the tallest towers around the world of which infrastructures facilitate to play a key role in their economies. In line with those developments, the construction industry has obtained an incredible development around the world (Xia, Olanipekun, Chen, Xie & Liu, 2018). With the development, most of the construction projects are large scale projects such as high-rise buildings with underground basements, large-scale infrastructure projects such as underwater tunnels, railways due to its economies of scale (Karunasena, Rathnayake & Senarathne, 2016).

Strong and well-structured sub structure or foundation is a key element to construct large buildings and to provide sound passage to transfer its weight to the subsoil (Lin, Hanna, Sinha & Tirca, 2017). Jarkas has found that, design and scale of foundation depends on various factors such as type of soil, height and weight of the building, and so on (Jarkas, 2010). Especially for high rise buildings and infrastructure projects, modern technology uses Piles (Agyekum, Blay & Opoku, 2019). In modern civil engineering, piles are driven deep into the ground to support super-structure as well as sub-structure. On unstable soils, piles will provide indispensable scaffold to the building and may also be used on stable ground when exceptionally large structural loads are involved (Ahmed, Emira & Tawfik, 2013). Therefore, construction of pile is a key element of construction process, especially those built in locations that are not suitable for freestanding buildings.

There are number of piling types in the construction industry. They are categorized according to various guidelines considering its characteristics such as, mechanism of load transfer, method of installation and type of material (Liyanapathirana, Deeks & Randolph, 2000). Continuity of pile shaft is a mandatory requirement of the successful pile and collapse of pockets of sand into borehole resulting in discontinuity of pile shaft (Adviser, Filtraci, 2012). Bentonite is considered as a highly plastic clay and a widely used commercial application to avoid collapses in to borehole (Chen, Xia, Liu & Wang, 2014).

Past researchers have provided evidence-based prediction of significant increment in global use of Bentonite in the future (Kong, Wang, Ge, Su & Li, 2019). Technological advancements in Bentonite production and increasing demand through exports are identified as major underlying factors anticipated in the growth of Bentonite market in the Asia Pacific Reagan between 2016 to 2025 (Wang et al., 2019).

The construction industry generates a large quantity of waste due to inferior application of waste management systems and inefficient material utilization (Malik, Ahmad, Chen, Altaf & Al-Hussein, 2019). Useless output or the materials and equipment from the construction process is identified as construction waste (Hwang & Bao Yeo, 2011). Therefore, the construction industry has become more interested in moving towards implementing a sustainable construction process to reduce waste and minimal environmental impact during the construction process (Jalaei, Zoghi & Khoshand, 2019). When consider the piling processes, there are several kinds of waste management systems relating to various materials and Bentonite waste management is one of them (Arif, Bendi, Toma-Sabbagh & Sutrisna, 2012).

In the current practice seven causes for waste can be determined which are Design, Workers, Management, Handling, Procurement, Site Conditions, and External factors (Nagapan, Rahman, Asmi, 2012). Under these main causes there are number of wasting types which are commonly observed in construction sites (Rose & Stegemann, 2018). Five major causes of waste and their wasting types are illustrated in the table 1.

Table 1 - Causes of waste

Causes of waste	Reasons of waste
Design	Waste due to inexperience design, lack of design information, poor design quality and design errors, last minute client requirements, frequent design changes
Workers	Lack of awareness, Workers mistakes during the construction, incompetent workers, poor workmanship, and lack of experience
Management	Errors during planning, controlling and supervision, poor in site management, unavailability of effective and efficient equipment
Handling	Wrong material storage, poor material handling, equipment failures, delays during handling
Procurement	Wrong material delivery and purchase, material/items are not compliance with specifications or requirement, use of different methods to estimate, Supply errors and errors occurred during shipping

Source -(Arif, Bendi, Toma-Sabbagh & Sutrisna, 2012), (Nagapan, Rahman & Asmi, 2012), (Alhumoud & Al-Kandari, 2008), (Faniran & Caban, 1998), (Hwang & Bao Yeo, 2011)

In construction industry, waste of materials and equipment is one major problem leading to a reduction of profit. During the piling construction process, there are number of waste items (Arif, Bendi, Toma-Sabbagh & Sutrisna, 2012). Since Bentonite is a material which becomes a waste at the end of pile driving process and there is a process to identify Bentonite as waste material (Faniran & Caban, 1998). Therefore, it is important to develop a new waste management strategy to manage waste of Bentonite to ensure sustainable construction (Yean Yng Ling & Song Anh Nguyen, 2013).

Construction wastage is a subject for many research studies carried out all around the globe, as well in Sri Lanka (Rosado, Vitale, Penteado & Arena, 2019). Commonly, researchers have discussed on wastage of concrete, cement, timber and like, as materials which represent major portion of wastage in construction industry. There is lesser number of studies carried out on the waste of material in the process of pile construction. Thus, this research has been carried out on use of Bentonite clay in process of pile construction, which will be using during the process of pile boring. To focus on Bentonite wasting types and management, a literature survey was done to figure out the general waste types in construction industry, referring to the past literature.

On the other hand, final outcome of successful waste management system is to minimize generation of waste throughout the process. A system's perspective of waste management allows an integrated approach to the five basic functional elements of waste management. That is to say, generation, reduction, collection, recycling, and disposal. Moreover, interfaces with the management of energy, nature conservation, and environmental protection, economic factors like unemployment and productivity are benefitted (Sushil, 2006).

Summary of the survey is shown in below table 2 while the strategies that are commonly used are illustrated in table 3. Table 2 describes various types of wasting methods. Hence, it includes the result of twenty number of various researchers regarding the wasting types in the construction industry.

Table 2 - Types of wastes

Waste types	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
Wrong material storage	x	x	x			x	x	x		x		x		x	x	x		x	x	
Poor material handling	x	x		x	x		x	x		x					x		x	x		x
Poor quality of materials	x	x		x		x				x				x				x	x	
Equipment failure		x		x		x	x	x			x	x		x			x			x
Tools not suitable used		x			x	x					x				x					
Materials supplied in loose form		x		x					x		x		x			x		x	x	
Inefficient methods of unloading	x	x	x				x				x			x	x	x	x			
Workers' lack of awareness					x			x				x	x		x			x	x	x
Workers' mistakes	x		x						x				x				x			x
Incompetent workers	x				x			x				x	x	x		x		x		
Damage caused by workers		x						x	x		x	x	x				x			x
Inappropriate use of materials	x	x		x		x	x				x		x		x					
Long project duration	x	x			x			x		x		x			x	x	x		x	
Construction methods	x		x		x	x		x	x					x	x		x			x
Poor information quality	x	x		x		x				x		x	x	x		x		x		x
Poor site management	x	x			x		x		x	x	x					x		x	x	x
Poor controlling	x	x	x	x					x	x	x	x	x	x	x		x	x	x	
Poor supervision	x	x	x	x	x	x	x	x		x	x	x		x		x	x		x	
Rework	x			x								x				x	x	x	x	
Wrong material delivery	x	x	x			x					x		x					x		x
Effect of weather			x					x	x								x	x		
Unpredictable local conditions			x	x				x	x						x	x			x	
Ordering errors	x				x	x				x	x	x	x	x						x

A1 -(Nagapan, Rahman & Asmi, 2012), A2 -(Meghani, Vyas & Bhavsar. 2011), A3 - (Kamaruddin, Yusoff & Ahmad, 2015), A4 - (Domingo & Batty, 2021), A5 - (Wu, Zhang & Zhou, 2019), A6 - (Saka, Olaore & Olawumi, 2019), A7 - (Pérez & Costa, 2018), A8 - (Yuan, Shen & Wang, 2011), A9 - (Yates, 2013), A10 -(Yates, 2013), A11 - (Udawatta, Zuo, Chiveralls & Zillante, 2015), A12 - (Udawatta, Zuo, Chiveralls & Zillante, 2015), A13 - (Park & Tucker, 2016), A14- (Poon, Yu, Wong & Cheung, 2004), A15 - (Hwang & Bao Yeo, 2011), A16 - (Hao, Tam, Yuan & Wang, 2011), A17 - (Rodríguez-Robles, García-González, Juan-Valdés, Morán-del Pozo & Guerra-Romero, 2014), A18 - (Al-Hajj & Hamani, 2011), A19 – (Islam, Raihan, Chowdhury & 2016), A20 – (Muhwezi, Chamuriho & Lema, 2012)

Table 3 - Waste management strategies

Strategy	Explanation
Prevention	Prevention is the best method in waste management. Giving attention to the technical information about construction process helps in preventing construction waste.
Minimization	Minimizing is the second most preferred method. Reducing the waste generating factors from the beginning helps in reducing the ultimate amount of waste.
Reuse	Thirdly, reusing before the disposal is known to be an effective way as well.
Recycle	Recycling comes fourth factor that helps in waste management.
Recovery	'Recovery' helps in removing materials or components and making it reusable.
Disposal	Disposal is the last option it is mostly used among construction sites in many countries

Including Piling, construction processes use Bentonite, either for horizontal drilling or slurry wall construction. After Bentonite slurry utilized or labeled as "spent", there is a need for disposal because the remaining beneficial properties at the completion of pile driving process has not been identified (Lawson, Douglas & Garvin, 2011). Therefore, it has been a major concern of identifying the existence of beneficial properties after the use of Bentonite (Chatziaras, Psomopoulos & Themelis, 2016).

In most scenarios, it tends to dispose Bentonite after few cycles. Whilst few other construction companies tend to follow some in-site tests to check the properties which appears to be effective. Depending on the results and comparing them with the specification, it is decided to dispose or to keep continue.

Another major issue is inconsistent use of Bentonite. Moreover, storing for days would result in settling and caking if not agitated (De Silva and Vithana, 2008). In addition, the very property of swelling in water upon which are useful applications of Bentonite lead to serious problems in the handling, delivery, and transportation of Bentonite clays (Hwang & Bao Yeo, 2011).

3 AIMS AND OBJECTIVES

In considering the background study of the case, research question is what the effective uses and waste management strategies of Bentonite in Sri Lanka are. To figure out the answer for this question, the research aims 'To identify the effective uses and waste management strategies of Bentonite in Sri Lanka'.

In fulfilling the aim, research had been carried out to achieve three main objectives. First and foremost, it is needed to identify the causes of Bentonite waste. Second objective is identifying the causes for disposal of Bentonite. That is to say, the reasons for the disposal should be known. Thirdly, identifying the most suitable disposal method for Bentonite in Sri Lanka should be identified.

4 RESEARCH METHODOLOGY

Any research needs the related data which are in either qualitative form or quantitative form. To collect essential data that appears in both types, this research has used the 'mixed-method' which consisting of both the data.

As a primary stage, background study has been carried out based on past studies amalgamating with "NVivo 12". Literature review has been carried out with the aid of books and past research articles those are in line with the subject matter. In second phase, a questionnaire has been drafted based on past studies. Thereafter, a pilot test has been conducted with the support of industry experts to check the effectiveness of the draft questionnaire. Then the questionnaire has been finalized accordingly.

Following that, the questionnaire had been circulated among 30 no of industry professionals. Collected data had been verified by using face to face interviews with 10 no of senior professionals of the industry.

5 DATA COLLECTION AND ANALYSIS

In the first section of the questionnaire, demographical data of the participants were analyzed. In order to do so, the profession, age, educational background and experience in related aspects were given attention. Mostly, engineers, quantity surveyors, project managers and construction workers from the age groups between 21-50+ have responded to the questionnaire. Both aspects of educational background and experience in this particular area has varied among the responders. Evidently, the duration of experience too has varied resulting in different point of views relating to the subject matter. Especially, experience in construction industry and piling were given attention.

Table 4-Position at Company

Position	No of responds
Engineer	13
Quantity Surveyor	5
Consultant	4
Project Manager	4
Other	3
T.O.	1
Architects	0

Table 5- Experience in Construction Industry

Experience in Construction Industry	No of responds
1-5	18
6-10	7
11-15	1
16-20	2
21-30	2
31-40	0
41-50	0
51+	0

Table 6- Experience in piling

Experience in Piling	No of Responds
1-5	27
6-10	0
11-15	2
16-20	1
Above 20	0

Out of the 30 responders, 13 of them are engineers whereas 5 are QS, 4 responds were coming from both categories of PM and consultants. Most of the responders are from the age groups of 21-25 and 31-35 mostly with experience in construction industry from 1-5 years. 27 responders claimed to have 1-5 years of experience in 'piling' while only two people had it for 11-15 years. On the other hand, 40% of the responders are bachelor's degree holders whereas less people have other educational qualifications such as PhDs. During the research, the responses given by these respondents with both professional and educational background who are experienced in the construction industry were analyzed. Thus, the concluded data analysis contains the ultimate result found within the responses.

Afterwards the contextual data has been analyzed in terms of qualitative and quantitative forms which directly affect the main objectives of the research. First concern has been whether the responders have experience in using Bentonite.

Table 7- Bentonite usage

Usage	No of Responds
High	11
Moderate	14
Less	3

Table 8- Number of cycles

Number of Cycles	No of Responds
1-2 Cycles	10
3-4 Cycles	17
5-6 Cycles	3
More than 6	0

It can be concluded that majority has a moderate experience in using Bentonite. Along with that, the number of reuses was concerned thus found that most sites go with 3-4 cycles of reusing. It was also found that additional chemicals are not mixed with Bentonite slurry in most instances but rarely cement and pipe-clay are used as additional chemicals or materials.

Table 9- Bentonite Wastage

Wastage	No of Responds
High	4
Moderate	14
Less	12

In the questionnaire it was also asked the responder's opinion on Bentonite wastage which appears to be a moderate wastage according to most of them. While most of the QSs found it to be 'less', engineers, PMs and consultants found it to be on a 'moderate' scale.

Table 10- Reasons for Bentonite waste

Type of Cause of Waste	No of Responds				
	Least	Less	Moderate	More	Most
Calculation Errors	5	7	3	0	0
Manual Handling Errors	1	6	12	4	1
Site Conditions	0	1	6	16	3
Weather	1	4	9	10	1
Wrong Material Storage	5	3	4	0	0
Poor Quality of Materials	4	3	5	0	0
Long Project Duration	4	6	6	1	0
Management Errors	4	6	1	1	0

When the reasons are concerned, site condition appears to be the major reason for Bentonite wastage according to the opinion of most of the experienced people in this matter. That is to say, 24 out if the 30 respondents have agreed on this. Moreover, 'weather' and 'manual handling errors' are some other major reasons according to the opinions of the responders which is 21 and 16 respectively. If consider the severity of reasons, it shows that site condition affects the wastage the most while manual handling errors affect moderately. Similarly, 'poor quality of materials' and 'long project duration' has a moderate effect on this matter. While calculation errors effects lesser wrong material storage has the least effect on Bentonite wastage.

The below set of tables indicate the figures which were analysed by the data collected in relation to the process of disposal.

Table 11- Time of disposing

Time of Disposing	No of Responds
When silos are full	18
When slurry is forming to a cake	17
When the system is malfunctioning disposing factor	10
When too old.	17

Table 12- Severity of disposing factor

Type of Disposing factor	No of Responds				
	Least	Less	Moderate	More	Most
When silos are full	2	6	5	6	4
When slurry is forming to a cake	0	0	5	9	5
When the system is malfunctioning disposing factor	3	5	7	3	0
When too old.	3	2	5	8	4

Table 13- Procedure of disposing.

Procedure of Disposing	No of Responds
Dispose by bowser to disposable lands	24
Direct disposal into sewer canal	6

Process of disposal also was given attention in the questionnaire. Evidently the disposal is done only after reusing the Bentonite mixture. According to the research, the disposal of the slurry is decided when the silos are full. Severity factors are mostly when the slurry forms a cake or if it is too old. When it comes to the disposal methods only two are recognized thus it is done either by disposing to a disposable land by a bowser or directly disposing into sewer canals. Moreover, opinions regarding Bentonite wastage were collected from each individual which is based on their profession and experience on this subject area.

According to the analysis 80% of participants identified, site conditions are the most relatable reason for Bentonite wastage. Position wise majority of this 80% was Engineers, second and third highest are respectively Quantity Surveyors and Consultants, and they belong to age category of 31-35 years mostly with 1-5 years of experience in pile construction.

Under second objective, most of the participants, as s number 60% selected when silos are full as the reason for disposing Bentonite. Majority of them are Engineers with 1-5 years of experience in pile construction and age category of 26-30 years.

According to the responses of the participants for the question which is the currently using disposing procedure large count of them identified the method of disposing by bowser to disposable lands. As a figure it is 80%.

Participants were asked to suggest the most suitable disposing method for Bentonite according to their point of view. Participants were come up with a few ideas and for reasons for it.

Table 14- Summary of suggested disposal method

Dispose with bowser into disposable lands	60%
Dispose of sewer canals/ lines	16%
Form into polynomial compounds and recycle	20%

As per the above summary table most of the participants are suggested disposing using a bowser into disposal lands as the most suitable disposing method for Bentonite. As a percentage, it is about 60%. As well as participants are suggested form into polynomial compounds and recycle in second place and dispose of sewer canals/ lines in the third place.

Table 15- Summary of reasons for suggested method

Environmentally friendly and less pollution	40%
Cost effective & Time management	43%
Easy to handle	17%

Participants of this study have come up with the above suggestions due to various reasons such as efficiency, cost-effective, time management and environmental reasons, since Bentonite is not very much environmentally friendly. It may occur cautions if it mixes up with groundwater as well as drinking water. The summary of the reason is in the above given table.

6 CONLUSION

This study focusses on exploring an effective methods for waste management strategies of Bentonite in Sri Lanka, under three specific objectives. Data was collected and analyzed using the mixed method.

The first objective of the research was to identify the Bentonite wasting methods. Albeit the several ways the Bentonite are being wasted, responders have suggested that 'site condition' is the major reason when it comes to Bentonite wastage. Methods such as calculation errors, management errors and long duration of a project has a lesser impact on the Bentonite wastage.

The second objective has been identifying causes for disposal of Bentonite. It was recognized disposal is most appropriate when the silos are full. However, there is also a possibility of it being disposed due to the slurry turning to a cake or being old.

The third objective was to identify the most suitable disposal method for Bentonite in Sri Lanka. It was suggested that since Bentonite is not eco-friendly, disposal by bowser to a disposable land would be a safer option rather than disposing into sewer canals. Moreover, a less number has suggested a third option that is considered to be cost-effective.

7 RECOMMONDATIONS, LIMITATIONS AND WAY FORWARD

On a final remark, among many reasons for the Bentonite to be wasted site condition can be recognized as the major reason. The research targeted in finding out a strategy that would be effective in managing Bentonite wastage in Sri Lanka. Considering the fact that site condition is the major reason for increasing the wastage amount the research suggests that sites should be more considerate on the condition of it. Moreover, working on the improvement of site condition and managing it in a proper manner can be a help in both minimalizing Bentonite wastage as well as cost control. In the disposal procedure, it is suggested that using a bowser to transport disposing Bentonite to be effective. In addition to that reuse and recycle can be seen as alternatives that help in improving the waste management of Bentonite.

Furthermore, limitations figured out of this research are as follow; most of the experts as well as workers are slightly less experienced on pile construction and the construction sites considered to collect data was in middle range and the leftover of Bentonite was minimal. Hence, applying the waste management strategies are somewhat difficult due to the point. Other than that, the research was conducted within six months of period.

In addition, this research can be done in more effective way considering the large-scale pile construction sites.

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Critical Supply Chain Problems In Contractor - Subcontractor Interface Of Sri Lankan Building Construction Projects

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ABSTRACT

As a developing country, construction industry provides considerable contribution to the Socio-economic growth of Sri Lanka. However, successful completion of a construction project is yet a challenging task. It requires coordination, collaboration and management of different stakeholders with different objectives. While achieving the objectives of a construction project, a proper management of supply chain is vital as improper management of the supply chain impacts negatively on the construction project delivery process.

Prior studies have identified several interfaces which impact on the successful project delivery. The mechanism related to contractor-subcontractor interface highly impacts the ultimate project outcome as it is directly linked with the delivery of the project. This study set out to identify the critical supply chain problems in contractor-subcontractor interface in Sri Lankan building construction projects.

The study was derived through a mix method approach. Semi structured interviews were carried out among the industry expertise to identify the supply chain related problems. Thereafter, to identify the critical problems of supply chain, a questionnaire survey was carried out among the industry practitioners in the building construction projects. The data was analyzed using Relative Important Index in order to rank and identify the severity of each identified problem in the contractor – subcontractor interface.

The study indicates that, using verbal information, lack of reference to the main contract and non-responsible responses as the critical problems in the Information flow. In terms of the Material flow: deliveries are not according to the plan, poor labour management and noncompliance with material and components are ranked as the critical problems. Delay in payments, back-to-back payments and payment interest charging as the critical problems under the Capital flow. These findings may assist the industry practitioners to identify the criticality and monitor supply chain problems in contractor- subcontractor interface and to minimize them in building construction projects.

KEYWORDS: *construction industry, construction supply chain, supply chain management, contractor subcontractor interface, interface problems.*

1 INTRODUCTION

The construction industry plays a significant role as a fundamental economic division of a country's development. Also, it has been acknowledged as a highly fragmented industry with both positive and negative impacts on the industry itself. Few of them are low productivity, cost and time overruns, conflicts and disputes resulting in claims and time-consuming litigations. According to Karunasena & Sanjeewa (2010), the construction industry has been regarded as a highly insufficient sector, in terms of the process of project delivery. Further, they highlight, improper management, lack of coordination, unjustifiable relationships among members, poor information flow throughout the construction supply chain and law quality output as causes of failure in project delivery (Karunasena & Sanjeewa, 2010).

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Among these causes, many researchers have identified construction supply chain related issues initiated by different parties and functions as one of the major reasons for failures in delivery of construction projects (Vrijhoef, et al., 2001; Vrijhoef & Koskela, 2000; Papadopoulos, et al., 2016; Battula, et al., 2020). Therefore, to achieve the set goals in a construction project, proper integration among the project team has become an essential fact for a proper supply chain in every construction project. Thus, the management of supply chain has become a very promising approach to achieve integration among clients, consultants, contractors, subcontractors and suppliers (Papadopoulos, Zamer, & Gayialis, 2016) for a successful completion of a construction project.

The construction supply chain consists of activities and functions associate with transforming raw material to a stage where clients can accept it as a product or a service. Based on the functions and the different parties involved, supply chain problems can be classified into several interfaces (Papadopoulos, Zamer, & Gayialis, 2016). They are, ***End user/ Client Interface:*** This phase can be introduced as the concept phase of the construction project which consists of knowledge transfer, information exchange, financial and contractual relationship of end user and client. This end user may be client.; ***Client/ Design Interface*** The phase consist of completion of concept designs, full designs and specifications**,** the relationships between client and architects and consultants come into play during this phase. (Behera, Mohanty, & Prakash, 2015); ***Design/ Procurement Interface:*** the second phase of the construction project which includes procurement of the project. The Architects, Consultants and main Contractor are the key players involved in this phase; ***Main Contractor/ Subcontractor Interface:*** the phase consists of the tasks related to fabrication of elements on site or off site. The main Contractor and subcontractor play the main roles of this phase; ***Main Contractor/ Indirect Suppliers Interface:*** the phase dedicated for parts manufacturing and material production for the construction project. The relationship between the main contractor and indirect supplier is addressed at this interface; ***Production/ Organising Interface:*** tasks related to organizing of manufactured and fabricated materials on site is the main activity of this phase; ***Organising/ Handing-over Interface***: as per the Figure 1 below, this phase denotes both phase 4 and phase 5 which are installation and winding up respectively. It is also include the project handing over to the end user who undertakes the maintenance of the project time to time after the successful project completion of the project (Behera, Mohanty, & Prakash, 2015).

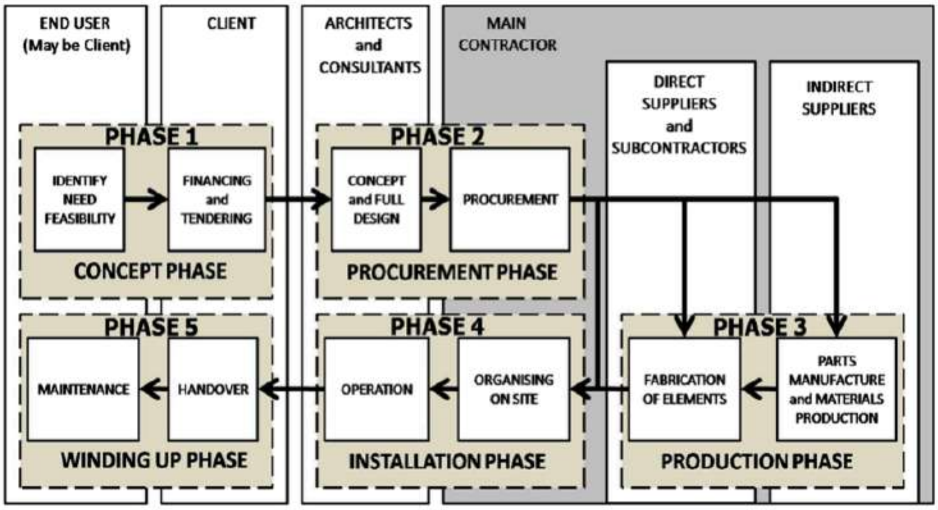

Figure 1: Phases in a typical Construction project (Behera, Mohanty, & Prakash, 2015)

Among these interfaces, supply chain problems in the contractor-subcontractor interface makes a significant impact on the construction project as these parties play a vital role in delivering the project objectives successfully (Jraisat, Jreisat, & Hattar, 2016). Throughout these years, researchers have taken attempts to identify construction supply chain related problems in different countries and regions. In terms of the global context, Critical factors affecting contractor- subcontractor relationship in Chinese construction industry (Tan, Xue, & Cheung, 2017), critical success factors, which need to achieve best Supply chain management in the construction process (Tan, Xue, & Cheung, 2017), alternative interpretations of the problems and remedies to construction supply chain (Vrijhoef, Koskela , & Howell, 2001), major problems in different interfaces in construction projects (Behera et. al., 2015), problems in defferent interfaces based on composite façade elements (Vrijhoef & Koskela, 2000). Major causes of problems between contractors and subcontractors in Gaza Strip Enshassi, Arain, & Tayeh, (2012) can be highlighted.

Even though many researchers have revealed supply chain problems of construction projects in the global context, considering the local context, there are only few researches conducted to examine the situation with Sri Lankan building construction projects (Kesavan, Gobidan, & Dissanayake, 2015; Karunasena & Sanjeewa, 2010; Sivarajah, 2021). However, the research conducted on local context, have revealed that supply chain problems are not an exception but a common experience for every construction project and for its stakeholders (Sivarajah, 2021; Kesavan, Gobidan, & Dissanayake, 2015). Hence it is important and there is a need to address the critical supply chain related problems in contractor- subcontractor interface in Sri Lankan building construction projects. However, implementing innovative systems to overcome supply chain problems relating to construction projects are still a question in the local context as it follows 'by different consequences which may affect the construction projects in numerous ways. Therefore, there is a need to identify and address the critical supply chain related problems of construction projects in the local context. Thus, this study attempts to identify the critical supply chain problems in contractor- subcontractor interface of building construction projects in Sri Lanka.

2 LITERATURE REVIEW

2.1 An introduction to construction supply chain

Supply chain is "the network of organisations consists of upstream and downstream linkages, during different processes and activities that produce value in the form of products or services in the hands of the ultimate customer" (Vrijhoef & Koskela, 2000). The main goal of construction supply chain management is to integrate the clients' requirements with the materials and information flows along the process of supply chain, until achieving the balance between client satisfaction and the cost (Papadopoulos, Zamer, & Gayialis, 2016). There are critical supply chain characteristics in construction. Few of them are, final construction product is for a single client, unique products, change in location, equipment, production method, high rotation of construction professionals between projects, impossibility of storing all the required material and parts at construction sites (Papadopoulos, Zamer, & Gayialis, 2016). Construction supply chain includes the activities which transform raw materials into a client accepted product or service (Karunasena & Sanjeewa, 2010) with the involvement of different stakeholders in the construction supply chain such as Clients, Architects, Engineers, Contractors, Sub-contractors and Material suppliers etc. To integrate with stakeholders, construction projects use different platforms. These platforms can be defined as interfaces or connectors which connect clients, consultants, contractor and suppliers, comprise with knowledge transfer, information exchange, financial and contractual relationships (Behera, Mohanty, & Prakash, 2015). However, depending on the project function which need to be performed, these networks can be transitory and these flows may subjected to continuous linking and disconnections. Therefore, construction supply chains can be regarded as convergence, temporary and made-to-order chains (Vrijhoef, Koskela , & Howell, 2001).

The construction supply chain can classify into three levels as, ***primary supply chain***: refers to chain which delivers the materials incorporate into the final product, ***support chain***: chain provides equipment, expertise, materials which facilitate the construction and the ***human resource supply chain***: supply of labour (Butković, Kaurić, & Mikulić, 2016). Moreover, in terms of flows, Construction Supply Chain consist of three flows, Information ***flow***: Information flows include orders, rules and regulations, schedules, forecasts, drawings, specifications, invoices, etc., ***Material flow***: consist with supplies, production, deliveries, etc. and ***Capital flow:*** payments for products (Souza & Koskela, 2014).

2.2 Contractor- subcontractor interface of construction supply chain

The Contractor- subcontractor interface makes a significant impact on the process of project delivery (Karunasena & Sanjeewa, 2010; Zeng, et al., 2018). Karimet al. (2006) have highlighted that the Main Contractors highly rely on large number of subcontractors to get specific parts of the project done (Karim et. al. , 2006). Therefore, in order to get the project done, many Subcontractors or specialists are hired by the Main Contractor with an intention of saving time and reducing risk of the project (Daoor, Fanoona, Lulu, & Shanty, 2020). According to Tan and his team (2017), both the main contractor and subcontractors interdepend with each other for a successful project completion. However, the alliance of these two parties creates more problems in the contractor and subcontractor interface in the construction supply chain which may create a significant impact on the project delivery. Hence, identifying these problems and addressing them properly would minimise the impact on the successful completion of projects as well as strengthening the relationship of these two parties.

2.3 Supply chain related Problems in contractor- subcontractor interface

Supply chain problems related to contractor-subcontractor interface has become one of the key problems in construction projects (Vrijhoef, Koskela , & Howell, 2001). According to Papadopoulos, Zamer, & Gayialis (2016) majority of problems are not generated in the conversion process but in the interfaces within the supply chain (Papadopoulos, Zamer, & Gayialis, 2016). The below Table 1 shows a summary of supply chain problems in contractor subcontractor interface regarding construction projects.

Table 1: Supply chain related problems identified in Contractor-Sub Contractor Interface

Problems retrieved from literature	Reference
Subcontracted work not delivered according to main design	(Vrijhoef, Koskela , & Howell, 2001)
Contract and planning	(Vrijhoef, Koskela , & Howell, 2001)
Design problems (many changes and inconsistent information).	(Serpell & Heredia, 2004)
Deficient communication and information transfer.	(Serpell & Heredia, 2004)
Poor quality of materials and components.	(Serpell & Heredia, 2004)
Inadequate management within the supply chain, mainly poor planning and control	(Serpell & Heredia, 2004) (Papadopoulos, Zamer, & Gayialis, 2016)
Poor training of contractor's suppliers, subcontractors and workers	(Serpell & Heredia, 2004) (Papadopoulos, Zamer, & Gayialis, 2016)
Lack of effective methods for measuring the performance of the different parties within the supply chain.	(Serpell & Heredia, 2004)
Inaccurate data	(Behera, Mohanty, & Prakash, 2015)
Information needs not met,	(Behera, Mohanty, & Prakash, 2015)
Adversarial bargaining and other changes.	(Behera, Mohanty, & Prakash, 2015)
Deliveries not according to planning	(Papadopoulos, Zamer, & Gayialis, 2016)
Late deliveries of permanent materials	(Papadopoulos, Zamer, & Gayialis, 2016)
Wrong and defective deliveries	(Papadopoulos, Zamer, & Gayialis, 2016)
Interfaces with several subcontractors and suppliers	(Papadopoulos, Zamer, & Gayialis, 2016)
Delay in payments	(Xie, et al., 2019) (Ramachandra & Rotimi, 2012)

3 METHODOLOGY

At the beginning of the study, a comprehensive literature survey was conducted to identify the problems in contractor- subcontractor interface related to construction supply chain. 15 number of problems were identified based on literature. After a comprehensive Literature survey, the research was carried forward with the mixed method approach to explore the critical problems of construction supply chain in the building construction projects in Sri Lanka. Since the supply chain problems related to building construction projects differ from country to country and context to context, semi-structured interviews with industry experts who possess over 20 years of experience in building construction projects followed by a questionnaire survey were carried out to identify the critical problems in supply chain in building construction projects in Sri Lanka.

To identify the problems in Sri Lankan context, five number of semi-structured interviews were caried out. The focused group was deputy general managers of leading construction companies (1), Project managers (2) and Chief quantity surveyors (2).The data which provided by them, was considered as reliable as they possess over 20 years of experience in building construction projects in Sri Lanka. Based on comments given by the professionals, the questionnaire was developed. The questionnaire was distributed only among the Contractors with CS2-C4 grading under CIDA registration and Subcontractors in building construction projects. small-scale contractors possess less administrative experience with subcontractors and was not considered in this study. However, no any limitation was set for subcontractors. The questionnaire survey was planned to examine the critical supply chain problems in contractor- subcontractor interface in Sri Lankan building construction projects. Therefore, Close-ended questions were incorporated in order to identify the critical supply chain problems and their causes in contractor subcontractor interface. The questionnaire consists of 10 numbers of closed- ended questions. For proposed questionnaire survey, 55 questionnaires were distributed among the focused group. However only 34 responses were received. To identify the critical problems of supply chain in building construction projects and their frequency of occurrence, two different Likert scales were introduced to the respondents as shown in Tables 1(a) and 1(b) respectively.

Table 1(a): Likert scale for identifying the criticality of different problems in construction supply chain

	Value
Not critical at all	1
Low	2
Moderate	3
High	4
Very Critical	5

Table 1(b): Likert scale for assessing the frequency of occurrence of construction supply chain problems

	Value
Very rare	1
Rare	2
Moderate	3
Often	4
Very often	5

Responses of the questionnaire survey were analyzed and ranked using RII (Relative Importance Index) method.

$$\text{Relative Important Index} = \frac{\sum w}{AN} \quad (1)$$

Where "w" is the weighting given to each factor by the respondents, (ranging from 1 to 5)

"A" is the highest weight (i.e.,5 in this study) "N" is the total number of respondents. RII ranges from 0-1.

$$Relative\ Importance\ Index = \frac{\sum \mu}{A \times N} = \frac{1n_1 + 2n_2 + 3n_3 + 4n_4 + 5n_5}{5N} \quad (2)$$

$n_1 = Number\ of\ respondents\ rate\ on\ 1\ (1 - not\ critical\ at\ all)$
$n_2 = Number\ of\ respondents\ rate\ on\ 2$
$n_3 = Number\ of\ respondents\ rate\ on\ 3$
$n_4 = Number\ of\ respondents\ rate\ on\ 4$
$n_5 = Number\ of\ respondents\ rate\ on\ 5\ (5 - very\ critical)$

According to the responds received, Relative Importance Index were calculated similar to the above calculation.

Table 3: Respondents' Profile

Organizational Background	Level of Experience	Sample
Contractor	< 5 years	7
	5-10 years	12
	10-15 years	6
	>15 years	2
Sub-contractor	< 5 years	2
	5-10 years	4
	10-15 years	1
	>15 years	0

According to the Table 2, the majority contractors and Sub-contractors participated in this questionnaire possessed 5-10 years of experience in the construction industry which proved that the industry practitioners

4 ANALYSIS AND RESULTS

This section focuses on the main three areas of the study; Problems in information flow, Problems in product flow and problems in capital flow. In each section, RII score was calculated followed by a brief discussion. Problems related to orders, regulations, schedules, forecasts, drawings, specifications, invoices and contracts were included under information flow category. Problems include supplies, productions and deliveries were categorized under product flow. Payment problems related to products, services and supplies were categorized under capital flow.

4.1 Problems in Information flow

From literature and expert interviews, 17 number of problems of construction supply chain in the interface of contractor- subcontractor were identified. Those problems were categorised into three main areas as scope definition, communication and design. Problems identified in information flow are shown in Table 3.

Table 3: Problems in Information flow

No.	Identified Problem in Information flow	Reference
1.0	**Scope Definition**	
1.1	Unclear specification	Respondent 01, 04
1.2	Unclear written subcontract scope	Respondent 01, 02, 04, 05
1.3	Lack of reference to the main contract written scope	Respondent 01, 02
1.4	Lack of signed subcontractor-contractor agreement with clear deliverable and deadlines	Respondent 03
1.5	Lack of finer scope definition (interface marked in the drawings or written)	Respondent 02
1.6	Unable to obtaining Guaranties warranties	Respondent 05
2.0	**Communication**	
2.1	Non-responsible responses	Respondent 01
2.2	Using verbal information	Respondent 01
2.3	Unnecessary communication	Respondent 01
2.4	Deficient communication and information transferring	(Serpell & Heredia, 2004)
2.5	Copyrighting issues	Respondent 01
2.6	Information need not met	(Behera, Mohanty, & Prakash, 2015)

2.7	Unclear responsibility matrix	Respondent 01
2.8	Lack of periodic progress review meetings	Respondent 03
3.0	**Design**	
3.1	Subcontractors' Design responsibility	Respondent 01
3.2	Property product and patent rights	Respondent 05
3.3	Design changes	(Serpell & Heredia, 2004)

However, out of these various problems, it is necessary to identify the most critical problems in information flow. Therefore, based on the questionnaire survey, the study identifies the most critical problem in information flow.

Table 5, shows the problems ranked in the order of criticality with the RII score under information flow. Using verbal information was ranked as the most critical problem in information flow with Relative Importance Index (RII) of (0.953). Lack of reference to the main contract written scope was ranked as the second most critical problem in information flow, with RII of (0.947). non-responsible responses, Lack of finer scope definition (interface marked in the drawings or written and design changes (0.924), unclear specification (0.718), copyrighting issues (0.724) respectively were raked in a descending order by the professionals.

Table 5: Relative important Index Calculation for problems in Information Flow

Problems in Information flow	RII	Rank
Using verbal information	0.953	1
Lack of reference of the main contract written scope	0.947	2
Non responsible response	0.941	3
Lack of finer scope definition (interface marked in the drawings or written)	0.924	4
Design changes	0.924	4
Information needs not met	0.906	5
Lack of signed subcontractor-contractor agreement with clear deliverable and deadline	0.900	6
Lack of periodic progress review meetings	0.888	7
Deficient communication and information transferring	0.876	8
Unclear written sub-contract scope	0.865	9
Unclear responsibility metrix	0.859	10
Unable to obtaining guaranties warranties	0.841	11
Sub-contractors' design responsibility	0.818	12
Unnecessary communication	0.806	13
Proprietary products and patent rights	0.794	14
Copy righting issues	0.724	15
Unclear specification	0.718	16

The above Table 5, indicates that in the construction supply chain, of building construction projects in Sri Lanka, the most critical problem under information flow is relying on verbal information which reflects the informal behaviour shown by the industry practitioners during the process of acquiring goods and services.

4.2 Problems in product flow

11 problems in contractor- sub contractor interface in Sri Lankan building construction industry were identified. Problems in product flow is shown in Table 6

Table 6: Problems in Product flow

No.	Identified Problem in Product flow	Reference
1	Non-compliance with the material and components	Respondent 01, 02, (Serpell & Heredia, 2004), (Papadopoulos, Zamer, & Gayialis, 2016)
2	Poor workmanship and lack of performance subcontractors	Respondent 01, 05,
3	Delays in defect rectification	Respondent 03
4	Poor Labour Management	Respondent 03
5	Issues in contractor subcontractor facilities	Respondent 04, 05
6	Non adherence to the safety procedures	Respondent 05
7	Subcontractors work not delivered according to the main design	(Vrijhoef, Koskela , & Howell, 2001)
8	Late deliveries of permanent material	(Papadopoulos, Zamer, & Gayialis, 2016)
9	Deliveries not according to the plan	(Papadopoulos, Zamer, & Gayialis, 2016)
10	Lack of effective methods for measuring the performance of the different parties within the supply chain	(Papadopoulos, Zamer, & Gayialis, 2016)
11	Interfaces with several subcontractors and suppliers	(Papadopoulos, Zamer, & Gayialis, 2016)

Table 7 Reports the ranks for the problems in product flow. As shown in Table 7, “Product and services deliveries are not according to the plan’’ was perceived as the most critical problem in the product flow with RII of (0.741). Similarly, Papadopoulos (2016) and his team have stated “deliveries are not according to the plan” as one of general supply chain problems in the construction industry (Papadopoulos, 2016). With the RII of (0.735), Poor labour management was indicated as the second most critical problem in product flow. Non-compliance with material and components and poor workmanship and lack of performance of subcontractors were ranked as the third most critical problem in product flow with the RII of (0.724). Similarly, Serpell & Heredia (2004), Papadopoulos, et al., (2016) have stated that poor quality materials as well as components and wrong and defective deliveries as one of general supply chain related problems in construction industry (Serpell & Heredia, 2004). “Issues in contractor- subcontractor facilities” was ranked in the last position by the respondent with RII of (0.624).

Table 7: Relative Importance Index Calculation for Problems in Product Flow

Problems in product flow	RII	Rank
Deliveries not according to the plan	0.741	1
Poor labour management	0.735	2
Non-compliance with material and components	0.724	3
Poor workmanship and lack of performance subcontractors	0.724	3
Late deliveries of permanent material	0.706	4
Delays in defect rectification	0.688	5
Non adherence to the safety procedures	0.682	6
Subcontractors work not delivered according to the main design	0.682	6
Interfaces with several subcontractors and suppliers	0.653	7
Lack of effective methods for measuring the performance different parties with supply chain	0.653	7
Issues in contractor-subcontractor facilities	0.624	8

According to the Table 7, the most critical problem of the product flow is indicated as contradictory of delivery and plan which reflects poor coordination and communication attempts taken by the industry practitioners.

4.3 Problems in Capital flow

During the literature review and by the Interviews conducted, 6 problems were identified under capital flow and they are shown in Table 8.

Table 8: Problems in Capital flow

No	Identified Problems in Capital flow	Reference
1	Payment interest charging	Respondent 01, 04
2	Payment Terms and conditions	Respondent 01, 02
3	Disputes arising from claims	Respondent 03
4	Delay in payments	Respondent 04, (Xie, et al., 2019) (Ramachandra & Rotimi, 2012)
5	Back-to-back payment	Respondent 01, 05
6	Adversarial bargaining and other changes	(Behera, Mohanty, & Prakash, 2015)

Table 9 shows problems in Capital flow related to Sri Lankan building construction projects according to their criticality. Delay in payments and Back-to-back payment were perceived as the most critical problem in capital flow with RII of (0.635). Similarly, Xie, et al., (2019) have stated that, payment delays are common in construction supply chain and it is a key factor leading to overall project delays (Xie, et al.2019). Further, Ramachandra & Rotimi, (2012) have revealed that payment delays are more frequent in New Zealand construction projects (Ramachandra & Rotimi, 2012). With RII of (0.624), payment interest charging, payment terms and conditions, adversarial bargaining claim the similar importance in the ranking. changes were perceived as the second most critical problem in capital flow. Similarly, Behera and his team (2015) have stated that "adversarial bargaining and other changes" is a general problem in construction supply chain (Behera et. Al, 2015). Disputes arising from claims were ranked in the last position with RII of (0.600).

Problems in capital flow	RII	Rank
Delay in payments	0.635	1
Back to-back payment	0.635	1
Payment interest charging	0.624	2
Payment terms and conditions	0.624	2
Adversarial bargaining and other changes	0.624	2
Disputes arising from claims	0.600	3

4.4 Overall occurrence of problems in each flow

According to the survey results, as shown in table 10, the occurrence of problems in information flow was perceived as the highest with RII of 0.682. Occurrence of problems in product flow was perceived as higher than the capital flow with RII of (0.671).

Table 10: Relative Importance Index for Occurrence of Problems

Flows in supply chain	RII	Rank
Information flow	0.682	1
Product flow	0.671	2
Capital flow	0.665	3

Survey results reveal that, the construction supply chain of building construction projects in Sri Lanka suffers from problems under information flow than the problems related to product flow and capital flow respectively. Considering each of these flows separately, the top ranked critical supply chain problems which reveal from the survey are listed with their respective rank in Table 11.

Table 11: Top ranked critical supply chain problems

Rank no.	Information flow	Product flow	Capital flow
1	Using verbal information	Deliveries are not according to the plan	Delay in payments Back-to-back payments
2	Lack of reference to the main contract	Poor labor management	Payment interest charging Payment terms and conditions Adversarial bargaining and other changes
3	Non responsible response	Noncompliance with material and components	Disputes arising from claims

5 CONCLUSION

Construction supply chain can consider as one of key factors which effect the delivery of construction projects. Maintaining proper supply chain in a construction project is a necessity for the successful completion. Construction supply chain consist with various interfaces. Among these interfaces contractor- subcontractor interface directly impact the end product of development projects. Therefore, problems which arise in contractor subcontractor interface significantly effect the project completion. Thus, in order to maximise the efficiency of building construction projects, it is important to identify and address these critical problems in construction supply chain to complete the construction project successfully. e.

This study has identified supply chain related problems in contractor subcontractor interface of construction industry followed by the identification of, supply chain problems in contractor-subcontractor interface of building construction projects in Sri Lankan context through semi- structured interviews with construction industry professionals. Initially, critical problems were identified using questioner survey. Based on the survey results, RII has been calculated to rank the identified problems. The top most critical problems in contractor- subcontractor interface were concluded through the ranking results. According to the results, using verbal information for communication, lack of reference to the main contract written scope, non-responsible response, lack of finer scope definition (interface marked in the drawing or written), design changes and information needs not met are the top five critical problems in information flow. Deliveries not according to the plan, poor labour management, noncompliance with material and components, poor workmanship and lack of performance of subcontractors, late deliveries of permanent material and delays in defect rectification are the top five critical problems related to the product flow. Delays in payments, back-to-back work acceptance are the top ranked critical problems in capital flow. These findings may assist the industry practitioners to identify the criticality and monitor supply chain problems in the interface and help to minimize them in building construction projects. Since this research was focused only on the comminuty of Contractors with CS2 and C4 gradings, further research can be carried out focusing the other grades of Contractors., The research finding were limited to the problems related to contractor-subcontractor interface only. However, further research can also be carried out focusing the critical problems regarding the other interfaces related to the Sri Lankan building construction projects. However, deep and detailed research developments are necessary to identify solutions for the problems relating to this area.

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Fire Safety Performance of High-rise buildings in Sri Lanka

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ABSTRACT

Fire safety is the most critical aspect of high-rise building safety. As human life is essential than other aspects, analysis of a reliable building fire safety performance is more critical than ever. Whenever an actual fire incident occurs, the active firefighting systems in the building would be activated first. As a result, it is necessary to identify the operation of active firefighting systems as well as proper service and maintenance of the systems.

The research problem was identified as, people tend to fulfill the minimum fire safety requirements imposed by regulations. Therefore, the condition of fire safety performance in most high-rise buildings are very poor. The aim of this research is to identify suggestions to improve the fire safety performance in high-rise buildings in Sri Lanka. Consequently, three objectives have been established to fulfill the research aim. In the first objective, building design features, human behaviors, equipment failures, and underperformance of fire regulations are highlighted as contributing factors to building fire events. The second objective evaluates fire safety precautions implemented in high-rise buildings, such as alarm activation, communication and evacuation procedures, service and maintenance periods of live fire systems, and fire evacuation drills. In the third objective, suggestions to improve the fire safety performance in high-rise buildings are recognized as, maintaining proper coordination between the fire brigade and building fire maintenance department at all times. Since the interpretivism philosophy used in this inductive qualitative research, the data was collected through conducting ten interviews with professionals who are primarily engaged with achieving reliable fire safety performance in high-rise buildings.

In conclusion, recommendations such as, establish a coordination center to maintain proper coordination with fire brigade, air force and building maintenance staff and introduce a trained air force squad with helicopters and firefighting equipments can be implemented in Sri Lankan high-rise buildings.

KEYWORDS: *fire safety, high-rise buildings, construction*

1 INTRODUCTION

With the growth of the economy, increased population density and demand for building spaces, it is unavoidable that buildings in large cities will have to rise higher and higher (Chow, 2005). In Sri Lanka, a high-rise building is described as one that is between 30m up to 60m in height and super high-rise building is defined as one that is more than 60m in height (Colombo Municipal Council, 2017). High-rise structures have 3 unique features: first, the structure is complex due to its height and number of floors, second, the operations are complex, and the population size is large and third, combustible is massive, and the fire load is great (Liu et al., 2012).

The goal of Architects and builders is to develop a structure that will last for more than 60 years (Rathnayake et al., 2020). However, the aim fails for a variety of reasons, the most important of which

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is fire. Although, in terms of working or living in high-rise buildings, large scale fires have not been widespread in recent history of Sri Lanka, so the emphasis on fire safety may not be as high as desired (Aluthwala et al., 2007). Since Sri Lankan fire brigade is not equipped with modern technologies when compared with developed countries, it is an important part in high-rise buildings to install and maintain a proper fire and safety systems to minimize risks of life.

Every building has a fire risk. Therefore, it is a mandatory requirement to take fire system requirements from Fire Service Department before commencement of any construction project (Urban Development Authority, 2018). Typical fire requirements are as follows: fire detection system, fire hydrant system, sprinkler system, fire suppression system, one way communication system, two-way communication system, portable fire extinguishers, staircase pressurization system and evacuation system (Colombo Municipal Council, 2017a) .

The research problem was identified as, people tend to fulfill the minimum fire safety requirements imposed by codes and regulations due to the high cost of installation and maintenance of fire safety systems in high-rise buildings. Therefore, the condition of fire safety performance in most high-rise buildings are very poor. As a result, to achieve the research problem, the aim of this research is more focused on fire safety performance in high-rise buildings. The aim of this research is to identify suggestions to improve the fire safety performance in high-rise buildings in Sri Lanka. Three objectives have been set to achieve the aim. The first objective is to identify factors contributing to building fire incidents, second objective is to analyze fire safety precautions implemented in Sri Lankan high-rise buildings and the third objective is to identify suggestions to improve the fire safety performance in Sri Lankan high-rise buildings. The objective one was achieved by reviewing a literature review. The second and third objectives were completely achieved by conducting expert interviews. Conclusions and recommendations were based on the findings from the third goal.

2 LITERATURE REVIEW

A detailed review of the literature was conducted to examine the factors that have the greatest impact on building fire events. Therefore, to enhance the fire safety performance in high-rise structures, it is necessary to analyze the factors that contribute to fire incidents in high-rise buildings.

2.1 The connection between High-rise buildings and Fires

Accordingly, why is it such a critical criterion to be concerned about fires in high-rise buildings? Since there are so many stairways, elevators, pipelines, air passageways, cables as well as other vertical shafts in a high-rise structure, fire spreads quickly than low-rise structures (Liu et al., 2012). As there is so much combustible material around, if it takes fire, it will spread rapidly. All these factors make evacuation more difficult due to the high population density and limited evacuation time in high-rise buildings.

When concerning about the high-rise buildings fire safety, the following systems must be operated properly, otherwise high-rise buildings become more vulnerable in case of a real fire. Fire safety systems include staircase pressurization system, sprinkler system, alarm system, two communication system as well as properly marked evacuation paths and proper operation of firefighter lifts will help to save human lives. Therefore, to enhance the fire safety performance in high-rise buildings, it is necessary to analyze the factors that contribute to fire incidents in high-rise buildings.

2.2 Building Design Features

Building design features have a major impact on fire safety. Architect is the person who mainly responsible for the building's design features. In fact, from the perspective of an architect, fire safety would most probably be a less considerable factor compared to the aesthetic appearance of the building. Fire safety is a critical need that is sometimes given a lesser value than other design requirements because of its inherent qualities and the low degree of danger experienced by fire. Grenfell Tower, a 24-storey residential building in London, that caught fire in 2017, killing 72 people, is a great example of a fire caused by building design features (Mohamed et al., 2019). The main reason for the Grenfell Tower fire is the exterior modern wall cladding, which is a key factor to the fast spread of the fire. Moreover, after a fire incident at the Crowne Plaza Hotel in Denmark reported that firefighters took approximately

8 minutes to find the door to the fireman's elevator (Rathnayake et al., 2020). At the investigation process, investigators discovered that the reason for taking a long time to find a door was due to the absence of proper naming on the fireman's elevator, as well as the fact that the door and its background walls had the same colour, which make difficult to identify the door. However, if a fire occurs, this design error causes a significant delay in the rescue process.

2.3 Human Behavior

Fires in high-rise structures may be caused by wrong human behavior. The Hong Kong fire incident in a high-rise building further revealed that the floor at the bottom of the lift shaft was suspected to include garbage, papers, and waste materials, posing a significant fire risk (Wong and Lau, 2007). In addition, when it comes to the long-term operation of high-rise buildings, some repairs may be necessary, therefore welding works with electric discharges was identified as a source of ignition with highly combustible components. Human errors include wrong waste disposal, careless electrical tool maintenance, faulty wiring, irresponsible workers etc. Furthermore, failing to use the facility for its intended purpose was recognized as a fire cause in high-rise buildings. A fire destroyed a 28-story Shanghai apartment building in China on November 15, 2010, killing at least 53 individuals and injuring 90 others (Barboza, 2010). According to the investigation, the cause of the fire was identified as sparks from welding work being carried out by unlicensed welders on the building.

2.4 Equipments Failures

Equipment failures, such as failures in cooking equipments, heating equipments and electrical and lighting devices are another leading cause for high-rise building fires. (Ahrens, 2016). When concerning the buildings with cooking equipments, fires occur due to excessive cooking temperatures, explosive oils and grease and the busy environment of commercial kitchens. Furthermore, depending on the climate, high-rise buildings may require heat for several months of the year, putting them at risk of fire due to overheating. Not only that, but also old and defective circuits, heavily loaded circuits, defective fuses, poor connections, unbalanced electrical equipments and variety of other electrical and lighting issues, can result in overheating or sparks, which can start a fire. The 42-story Polat Tower in Istanbul, which contains apartments as well as shops and businesses, caught fire on July 17, 2012 (Goodenough, 2012). The fire, which was reported to have been started by a faulty air conditioner, was successfully extinguished by firemen who had battled the flames for hours and incredibly no one was injured from the fire.

2.5 Underperformance of Fire Regulations, Policies and Building Codes

Fire safety regulations and building codes are primarily responsible for maintaining building fire safety. However, landowners and responsible parties tend to fulfill the minimum fire safety standards outlined in rules or regulations due to the high capital cost of fire safety systems (Li and Zlatanova et al., 2007). As a result, attempting to comply with the provisions without recognizing the logical basis behind the regulations would result in ineffective building fire safety. In order to further clarify this factor, policies expect that occupants will use the nearest emergency exit to escape, but occupants will generally escape by familiar exit routes, rather than using emergency exits, as it has been proven that known escape routes are shorter than unknown escape routes. The Markham Tower, a 10-story building in Norwich, was affected by a fire in February 2011 (Maxwell, 2017). The reason of the incident was discovered as the flats were equipped with battery-operated smoke detectors and the building had an up-to-date fire risk assessment but was not equipped with a sprinkler system.

3 RESEARCH METHODOLOGY

This section identifies the appropriate research methods for fulfilling the research aim and objectives (Langkos, 2014). This research is based on fire safety performance of high-rise buildings in Sri Lanka. Initially it is important to review the literature in order to identify factors contributing to building fire incidents. Then, define the research problem by identifying the research gap from previous research studies. After defining the research problem, formulate research aim and objectives that will specify what should be investigated and provide a framework for the scope of research study. In the next stage, preparation of the research design which is a blueprint that lays out the methods and techniques for collecting, processing and analyzing the relevant data. Accordingly, identify data collection methods and then set data analysis methods to determine whether the research aim, objectives and research question has been properly achieved. Finally, suggest recommendations and conclude the research study.

Research design outlines the process for gathering and analyzing the required information, as well as how all of this will be used to address the research question (Boru, 2018). Semi-structured interviews were used to obtain data for this research study in order to recognize real, human experiences based on achieving proper fire safety performance in high-rise buildings. In this research study, data will be collected through the qualitative approach to research design. Whereas interviewing is a technique used to understand the experiences of construction industry professionals, which is considered as a method for conducting qualitative research. In the research approach section, there are two types of approaches: inductive and deductive (Priya Chetty, 2016). As qualitative data is obtained for this research study, inductive approach is selected to analyze the data. Inductive approach is based on knowledge from expert interviews that leads to the generalization of a theory about the fire safety performance of high-rise buildings in Sri Lanka. Saunders (2009) has recognized five major research philosophies: positivism, critical realism, interpretivism, postmodernism and pragmatism. Interpretivism was selected as the most appropriate research philosophy for this research study, based on the reason that expert interviews were conducted to develop theory using participants' perceptions and meanings, as well as how they differ from those of other participants. Subsequently, they are two types of sampling methods: probability sampling and non-probability sampling (Shona McCombes, 2019). The sample group for this research study is made up of individuals with more than ten years of experience and knowledge in the area of fire safety in high-rise buildings. As a result, non-probability sampling was selected, since every construction industry professional is not knowledgeable of high-rise building fire safety. Therefore, individuals are selected based on non-random factor, and not every individual has a possibility of being included. The qualitative data obtained through expert interviews with ten respondents will be evaluated in the data analysis section. In this study, ten interviewees with more than ten years of experience in the field of fire safety, participated to share their knowledge about fire safety performance in high-rise buildings.

Table 1. Profile of the Interviewees

Interviewee ID	Profession	Professional Qualifications	Experience in the Construction industry
R1	Chief Fire Officer	FIFireE(UK)	30 years
R2	Fire Consultant	FIFireE(UK)	48 years
R3	Fire Chief	GIFireE(UK)	40 years
R4	General Manager in MEP Division	B.Sc.Eng(Hons) in Mechanical, CEng	30 years
R5	Contracts and Procurement Manager	B.Sc.QS(Hons), Chartered QS	11 years
R6	Mechanical Engineer	B.Sc.Eng.(Hons) in Mechanical	16 years
R7	Facility Manager	Dip.in Fire Engineering (SABIC)	25 years
R8	Senior MEP Manager	Dip.in Fire Engineering (UK)	15 years
R9	MEP Project Manager	B.Sc.Eng.(Hons) in Mechanical	16 years
R10	MEP Project Manager	HND in Mechanical Engineering	12 years

4 FIRE SAFETY PRECAUTIONS IMPLEMENTED IN SRI LANKAN HIGH-RISE BUILDINGS

This section mainly focuses on achieving the second objective in the research study. As a result, data collected from semi-structured interviews with industry professionals are used to achieve this objective.

4.1 Alarm activation and communication steps in case of a fire in particular floor of the high-rise building

In case of a fire, the fire alarm tone may be activated manually by a pull station or manual call point, or automatically through the use of heat and smoke detectors, which then sound the evacuation alarm, alerting the people in that zone to the risk of a fire. In the event of a fire, the fire alarm panel indicates the correct location of the fire, assisting emergency personnel as well as the fire brigade in locating the fire as soon as possible. Then trained emergency personnel would evaluate the situation and broadcast specific orders through emergency voice communication system to the occupants. If it is a small fire, extinguish the fire using portable fire extinguishers or fire hose. If the fire cannot be extinguish using extinguishers, tenants of the fire floor, as well as those immediately above and below, should use the exit stairs to move to a safe location as soon as possible. People on other floors may be advised to remain in place and await further instructions. If the emergency increases in scale, the warnings can be expanded to evacuate the entire building. R8 interviewee highlighted that if there will be a partial or full evacuation will be decided by the progress of the fire, and the maximum evacuation time in a high-rise building should be three minutes.

4.2 Service and maintenance period of live fire systems

Sprinkler system should be checked weekly by the user, and annual testing should be carried out for the complete system by a competent person and certified by Authority having Jurisdiction (AHJ). The user should test the hydrant system on a monthly basis and conduct a visual inspection every six months, in addition to annual testing and certification by AHJ. Fire alarm system should be tested weekly by the user, and a competent person should test the alarm system every six months and carry out the annual testing and certified by the AHJ. Live fire systems should be checked every week by an in-housed building maintenance team.

R8 interviewee stated that “select a competent agent authorized by the manufacturer for the services and enter into a comprehensive maintenance agreement with the agent. All live fire systems must have minimum two comprehensive services within one year and service reports should be submitted for proper record by the service provider.”

4.3 Recommendations on how often high-rise buildings should conduct fire evacuation drills

A fire evacuation drill is a planned emergency process designed to imitate the procedures that would be followed in the case of a fire or other emergency that necessitates evacuation. It is important to conduct fire evacuation drills every three months in a workplace with serious fire hazards, such as high-rise buildings, while every six months is adequate in other workplaces. Announced drills are preferred by employees and supervisors may find it easier to organize the event and limit workflow disturbance while unannounced drills provide more realistic assessment of evacuation preparedness.

4.4 Fire evacuation procedures currently practicing in high-rise buildings

In the event of a fire in a high-rise building, occupants should first proceed to the corridors or lobbies, then either escape through a protected stairway to a fire assembly point or move to a refuge floor, which is located in every 10 floors. During the time when occupants are reported to the assembly point, fire warden should check to see if anyone is still inside the building premises. In the event of a fire, all elevators should be landed to the ground floor, since it would prevent occupants from using elevators as a means of escape, which is functioned by the fire alarm system. However, firefighters lift should be operated normally to rescue people who may be caught on upper floors and to suppress the fire.

According to R2 interviewee, staircase pressurization is a mandatory requirement for high-rise buildings that provide a smoke-free evacuation path and maximize occupant evacuation speed in the event of a fire. Hence, the issue is that as people escape during a fire, they must open the door to the stairway for a longer period of time, allowing smoke to enter the stairway. If the stairways are filled with smoke, evacuation may be difficult. If the staircase pressurization method is used, the higher pressure in the stairway pushes the smoke back onto the floor when the doors open, clearing the escape route of smoke.

R1 interviewee highlighted that, high-rise buildings are now equipped with a refuge floor at each ten stories for the disabled occupants and persons who need help should be directed to a refuge floor until fire fighters can remove those disable people. Furthermore, sounder strobes are installed for those with hearing problems, so that in an emergency, people with hearing difficulties can see the light emerging from the sounder strobe.

4.5 Suggestions to avoid panic conditions due to false alarm incidents frequently

In order to avoid false fire alarm incidents, install sounder to the Main Panel which is located at the Fire Command Center and programmed with the Main Alarm Panel to activate the sounder when there is a fire. Once sounder is activated, monitor the location of the fire by Main Panel and immediately inspect the location to find whether it is really a fire or any fault signal. If it is a real fire, activate all sounders by switch and if it is a fault signal, reset the panel. R1 interviewee commented that, fire alarm systems need regular testing and maintenance by a qualified technician as early protection against false fire alarm events and always maintain good communication with the fire service provider in the event of a false fire alarm incident. Additionally, to avoid panic conditions due to false fire alarm incidents, conduct awareness programs repeatedly, provide advance notice for the occupants regarding the participation of fire drills and train fire wardens or building maintenance staff to respond in such incidents.

4.6 Safety measures need to take if there are areas of special risk in high-rise buildings

A boiler room, generator room or transformer room or any other area of special risk should be separated from the rest of the building by a compartment that is fire resistant for at least 4 hours. Generators and associated fuel supplies should be protected by an automatic fire suppression system other than the basement or ground floor level in buildings. Furthermore, if there are storage facilities inside buildings, they should be made of non-combustible materials with a fire rating of not less than one hour and there must be at least one meter of clear space on all sides of the racks.

In order to prevent kitchen fires in high-rise residential structures, user should take below mentioned methods, such as install fire suppression system in the kitchen hood, keep a wet chemical fire extinguisher in the kitchen and use a fire blanket for chip pan fires or wrapping around a person whose clothing is on fire. According to R2 interviewee, always have a qualified person to check heat detectors for proper function of the detectors in case of a kitchen fire.

5 SUGGESTIONS TO IMPROVE THE FIRE SAFETY PERFORMANCE IN SRI LANKAN HIGH-RISE BUILDINGS.

This section mainly focuses on achieving the third objective in the research study. As a result, data collected from semi-structured interviews with industry professionals are used to achieve this objective. It is necessary to identify drawbacks between fire regulations and actual fire safety measures before providing suggestions to improve fire safety performance in high-rise buildings.

5.1 Drawbacks identified between fire regulations and actual fire safety measures in high-rise buildings

It is critical to analyze the drawbacks between fire regulations and actual fire safety measures in order to take corrective actions to address such concerns. If we can overcome those problems, primarily we can save human lives as well as time and money in the event of a fire.

- Building users use a variety of materials to improve the attractiveness of high-rise buildings, but most of them are combustible materials that do not comply with fire resistant ratings.
- Due to the high cost of fire safety systems in the buildings, building users reduce the quantity and use inferior quality equipments that does not comply with fire safety standards.
- According to regulations, fire pumps must be UL listed and consist with positive suction; however, some high-rise buildings, they do not comply with this standard and have negative suction arrangement.
- When a fire breaks out in a high-rise building, people will gather on the basement floor. According to the regulations, smoke extraction systems must be installed in basement floors. However, smoke extraction systems in some high-rise structures are not appropriately designed to extract smoke.
- When gas pipes run through the concealed areas, gas detectors should be installed to detect fires caused by gas leaks. However, in some instances they are not properly placed in those concealed areas.
- As per regulations, there must be a refuge floor at every ten stories in high-rise buildings, but due to architectural concerns, the entrance location is not properly located to enter the refuge area.
- In some high-rise buildings, evacuation path is not clearly marked.
- Sprinkler and a detector are needed in every room in high-rise residential buildings, although some buildings do not install them in required locations due to the high cost of firefighting systems.
- Fire equipment failures, due to lack of proper maintenance.
- Poor management in government apartment buildings.
- Specification provided for each high-rise building is not being followed.

5.2 Suggestions to improve the fire safety performance in high-rise buildings

Since we are living in a rapidly developing technological world, we should update day by day. As a result, when it comes to high-rise building fire safety, we should implement new concepts, practices, and technologies in Sri Lankan high-rise buildings. Therefore, following suggestions are recommended by interviewees in order to improve the fire safety performance in high-rise buildings.

- Introduction of a coordination center for the proper coordination between fire brigade and building fire maintenance department in case of an actual fire.
- It is always advisable to get a service of a qualified fire consultant.
- In order to maintain the quality of firefighting equipments, fire brigade should register the relevant brands or all firefighting systems in the building should comply with NFPA (National Fire Protection Association) or IFE (Institution of Fire Engineers) standards.
- Conduct regular trainings for the maintenance staff.
- Introduction of trained air force squad with helicopters and firefighting equipments.
- Introduction of firefighting drones that can carry four missiles of dry powder to extinguish the fire.
- Aerial firefighting training for firefighters.
- Always adhere to the fire-resistant ratings imposed by fire regulations to minimize the spread of fire in high-rise buildings.
- Qualified person should carry out the regular fire safety inspections in high-rise structures.
- With the connection of the fire brigade, a competent person should conduct regular fire safety awareness programs and building evacuation drills for the occupants.
- Any changes to the elemental structure (additions or alterations) or the nature of the occupancy should be informed to the fire service department and take necessary actions to comply with the changes.

- The necessary fire safety requirements for high-rise buildings should be designed by a qualified designer.
- Ducts and cable tray openings between floors should be closed to prevent fire spread.

5.3 Proposals for proper coordination between fire brigade and building fire maintenance department in case of an actual fire

According to R1interviewee, in the event of a fire, inform the firefighters about water sources within the premises, or if they are insufficient to suppress the fire, inform them about the available water sources around the premises and inform the fire brigade team about the hazardous areas within the premises. R2 interviewee commented that, if there is a proper coordination with the fire brigade, it will be easy to control the fire in a short period of time, as firefighters are familiar with the building fire protection and detection systems. Furthermore, the building maintenance department should coordinate with the fire brigade once in every three months or six months and obtain their assistance in advance. R3 interviewee highlighted that, building fire maintenance department should appoint a single coordination officer to deal with the fire department, as that officer is accountable for any emergency situation in the high-rise structure.

6 CONCLUSION AND RECOMMENDATIONS

This section represents an outline of the research findings. The aim of the study is to identify suggestions to improve the fire safety performance in high-rise buildings in Sri Lanka. This section describes how each research objective is achieved through findings in order to achieve the research aim.

Initially, it is important to identify the factors that contribute to building fires. Failure to consider these factors may lead to under-performance of existing building firefighting systems. Therefore, literature review is mainly focused on achieving this research objective. The identified factors are building design features, human behavior, equipment failures and underperformance of fire regulations, policies and building codes. The second objective is achieved by conducting semi-structured interviews with industry professionals. Most of the professionals stated that fire detection system, fire hydrant system, sprinkler system, fire suppression system, one-way communication system, two-way communication system, portable fire extinguishers, staircase pressurization system and evacuation system are the currently implemented fire safety precautions in high-rise buildings.

The third objective is also achieved by conducting semi-structured interviews with industry professionals. The following suggestions are recommended by most professionals in order to enhance the fire safety performance in high-rise buildings: get a service of a qualified fire consultant for high-rise buildings, register relevant brands by fire brigade in order to maintain the quality of firefighting equipments, maintain proper coordination with the fire brigade and building fire maintenance department, introduce trained air force squad with helicopters and firefighting equipments, conduct regular fire safety awareness programs and evacuation drills for the occupants with the connection of the fire brigade, introduce firefighting drones that can carry four missiles of dry powder to extinguish the fire.

In recommendations, most of the professionals suggest that maintain proper coordination with the fire brigade at all times, use high-quality firefighting equipments recommended by the fire brigade, conduct regular fire evacuation drills and awareness programs with the building occupants and introduce trained air force squad with helicopters and firefighting equipments are the most appropriate suggestions to enhance the fire safety performance in high-rise buildings, which primarily helps to save human lives and property.

There are always limitations in any research paper. This research is limited to fire safety in high-rise buildings in Sri Lanka. As a result, fire safety requirements differ based on the building’s height category and the country.

Further research can be focused on following research areas to find solutions to the gaps between fire regulations and actual fire safety measures, examine the differences in fire responses of structural materials and use of innovative firefighting equipments and systems in high-rise buildings.

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Improving Psychological Health of Junior Professionals in the Construction Organisations in Sri Lanka

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ABSTRACT

Construction is a volatile and highly uncertain industry that faces several challenges in terms of poor image, skills and labour shortage, exposure to adverse weather, macho culture, and stressful environment. The labour-intensive nature of construction industry leads to vertical and horizontal segregation within the workforce. This study focuses on the psychological health experienced by junior professionals from the time they join until they settle down in Sri Lanka. It is vital to keep the junior professionals in their best psychological position to ensure their continuity in the job. This study investigated the risk factors that contribute to psychological health of junior professionals in construction industry and proposed strategies to address such risk factors. The research adopted a qualitative survey strategy, where 24 semi-structured qualitative interviews, including 18 junior and 6 senior construction professionals, were conducted. The research identified 26 factors under five categories such as adverse nature, apprenticeship, company culture, competition and opinions. While conforming to the existing factors from literature, the research revealed new factors too. Few to name are some common factors such as lack of leisure events, deadlines, job uncertainty; some personal factors such as human behaviour, illegal activities, personal agendas, lack of belongingness, educational background, personal bias, and lack of confidence and some dependency factors such as lack of support from seniors and task-oriented training. The senior professionals, while agreeing to most of these factors, claimed these are mainly due to the limited subject specific knowledge and lack of awareness on the nature of the job including regulations and policies by junior professionals. Appointing a mental health monitoring officer, implementing stronger human resource management policies, investing on training and development, counselling and support systems and encouraging more social activities were some of the key strategies proposed to improve the psychological wellbeing of the junior professional.

KEYWORDS: *Psychological Health, Junior Professionals, Human Resources Management, Construction Organisations.*

1 INTRODUCTION

The construction industry is an uncertain and risky industry with the third most stress affected workforce in the world following mining and police while exposing employees and different stakeholders to mentally uncomfortable situations that create psychological issues (De Silva et al., 2017; Campbell, 2006; Bowen et al., 2013; Fordjour et al., 2020). There are two types of employees in the construction industry such as professional workers and trade workers (Fordjour et al., 2020). The level of psychological conditions of professionals, directly and indirectly, contributes to the increase or decrease of job performances of employees (Fordjour et al., 2020).

In this research, focus has been given on the negative impact of the psychological health of junior professionals of the construction industry in Sri Lanka. Several psychological researchers guarantee that the psychological needs of construction professionals differ on age (Bowen et al., 2013; Cardoso et al., 2015; Bukhari et al., 2021). Lack of support, family imbalances, qualitative work demands without prior knowledge, minimised opportunities to learn new skills, lack of experience to cope with stress, doubt about the correct utility of skills and not having proper recognition are the problems faced by junior professionals which may direct them towards psychological ill-health (Senaratne & Rasagopalasingam, 2017; Bowen et al., 2013; Love et al., 2010; Fordjour et al., 2020; Bowen et al., 2013; Cohen-Callow et al., 2009; Bukhari et al., 2021). *"Side-bet theory of Becker (1960) suggests that even though an employee is highly dissatisfied with their job, a high tenure employee may find it more challenging and disruptive to resign from the job, as they have some side bets, sunk costs, or investment in their present organisation"* (Dodanwala & Santoso, 2021, P 09).

Construction sector-related psychological health comes under the major area of occupational psychology. The research related to occupational psychological health in construction industry is limited (Fordjour et al., 2020). Among little-explored psychological health related studies in construction, there is a dearth of knowledge specifically focusing on the psychological wellbeing of junior professionals in Sri Lankan construction industry (Senaratne & Rasagopalasingam, 2017). Hence this paper aims to investigate the psychological health experienced by junior professionals of Sri Lankan construction industry from the time they join until they settle down. Hence, the objectives of the research are,

1) to identify the risk factors that are contributing to the psychological health of junior professionals in construction organisations; and

2) to suggest organisational strategies to overcome the risk factors in order to reduce the impact of such factors on the psychological health of junior professionals in construction organisations.

The period from the beginning of the training period, up to 5 years since the first job appointment is considered as the period during which the junior professional will comparatively undergo more stress and anxiety. Hence both trainee professionals and junior professionals are included within the scope of the study. As psychological issues are personal to a particular individual, psychological conditions and factors that contribute to that of junior professionals may differ from person to person. Further junior professionals not willing to speak their heart out unless they feel safe and confident was a limitation.

Accordingly, the next section explores the existing literature related to career related issues faced by construction junior professionals, then the research methodology is presented, followed by research findings and discussion. Finally, the conclusions are drawn.

2 LITERATURE REVIEW

Critical early careers of construction junior employees should be structured to develop junior's skills and knowledge with a boost to carry on the journey in the construction industry (Senaratne & Malewana, 2011; Senaratne & Rasagopalasingam, 2017; Bukhari et al., 2021). Improving the psychological health of junior professionals will increase the confidence to perform well and ultimately results in the quality of organisational outcomes (Bukhari et al., 2021). When an employee is psychologically ill, the organisation bears the cost directly (wrong decisions, losses, faulty construction, loose of employees, legal issues) and indirectly (inefficiency, moral downness, loss of goodwill, loss of motivation) (Bowen et al., 2014; Fordjour et al., 2020; Martino, 2003; Dodoo & Al-Samarraie, 2019; Fordjour & Chan, 2019)

Research studies partially represent construction junior professionals through an entire group of professionals that were focused. In addition to that, past researchers deemed to include any significant factor regarding the psychological health of junior professionals if that came across. Panojan et al., (2019) graphically represented factors that contribute to poor work-life balance and the impact of that on the junior quantity surveyors compared to senior quantity surveyors. Bukhari et al., (2021) discussed the early career of construction professionals and mentioned 46 risk factors on the motivation of construction professionals. Psychological health exists among humans as conditions like stress, anxiety, emotional distress, fatigue, frustration, depression etc. (Fordjour et al., 2020). They have found 42 working environment related psychological risk factors that contribute to the psychological health of construction professionals. Accordingly, the critical factors which could be driven to psychological problems are high task demand (high volume of work), high role demands (complex responsibilities), poor interpersonal working relationships (poor relationship among colleagues), poor working conditions (limited time, risking and unsatisfied exposure in work), lack of autonomy (possessing enough power to utilise) and lack of feedback (not being appreciated enough). Psychological indicators can be used to recognise psychological conditions. (Fordjour & Chan, 2019) classified psychological indicators of construction employees into four categories which are individual lifestyle, psychosocial symptoms, physiological conditions, and work attitudes.

Ethically, employees in the construction sector expect the human resource (HR) department of the construction organisation to care about their needs but the construction sector is little known for the care the HR department has given to their human resources (Bukhari et al., 2021; Senaratne & Rasagopalasingam, 2017). An extensive number of research studies shows that what has been taught in academics has been a major pillar to retain in the industry (Farrow et al., 2017; Lucas, 2017; Leathem & Mcglohn, 2017; Simons et al., 2021). There should be a valuable reason for research studied in the past to identify the necessity of soft skills like team working, collaborative working skills, leadership, decision making, etc. alongside technical and theoretical knowledge (Ahn et al., 2012; Banik, 2008; Simons et al., 2021). In literature, professionals have asked for psychological training programmes from the organisation (Chan et al., 2012).

Stress is one of the key contributors to have psychological ill-health. De Silva et al., (2017) introduced a stress management framework consisting of primary secondary and tertiary strategies. Primary strategies are to reduce factors contributing to stress, secondary strategies are to respond immediately, and tertiary ones are to reduce the long-term impact. Literature in the context suggest that leisure activities, parties, trips, coaching and monitoring schemes, career development, long term career planning, family travel fees, medical subsidies compensation plans, assignment bonuses, employee benefits plans, living allowances, fairness of pay, incentives, financial rewards, on-time payment, good working facilities, and safety at work were recommended as advanced requirements to experience a stress-free career (De Silva et al., 2017; Dodanwala & Santoso, 2021; Senaratne & Rasagopalasingam, 2017; Zakeri et al., 1997; Bukhari et al., 2021; Chan et al., 2012).

2.1 Risk Factors contribute to psychological health of junior professionals

Risk Factors that contribute to the psychological health of junior professionals which are identified from the literature have been included in Table 1.

Table 1. Risk Factors contribute to the psychological health of junior professionals

Factors	Resources
Lack of autonomy	(Bowen et al., 2013)
Job description / not having a specific job role	(Bukhari et al., 2021; Chan et al., 2012; Fordjour et al., 2020; Bukhari et al., 2021)
Job uncertainty	(Bowen et al., 2013)
Complexity	(Dodanwala & Santoso, 2021; De Silva et al., 2017)
Deadlines	(Bowen et al., 2013; Fordjour et al., 2020)
Irregular work schedule	(Bowen et al., 2013)
Lack of support from seniors	(Senaratne & Rasagopalasingam, 2017)
Poor HR management strategies	(Chan et al., 2012)
Lack of management	(Bowen et al., 2013)
Lack of experience	(Dodanwala & Santoso, 2021)
Lack of knowledge	(Love et al., 2010; Fordjour et al., 2020)
Personal agenda	(Ruthankoon & Ogunlana, 2003; Bukhari et al., 2021).
Abuses	(Fordjour et al., 2020)
Addictions	(Fordjour et al., 2020)
Relation with supervisor and workmates	(Bowen et al., 2013; (Bukhari et al., 2021)

As indicated in Table 1, the risks factors identified are related to the job itself (unclear job description, job uncertainty, complexity), working schedules (deadlines and irregular schedules), the support offered (both from senior staff and from the management), personal factors (knowledge, experience, personal agenda), and social factors (abuses, addiction, relationship with supervisors).

In overseas research, racial classifications are more precise (Bowen et al., 2013). Trends and patterns differ between labour markets in different countries (Bowen et al., 2013). Some overseas research was conducted in a background in which their governments had recognized psychology is a priory in occupational health which is unlikely in Sri Lanka (Commission of European Communities, 2002). The construction policy of a country also very precise on the topic. Lack of autonomy can differ on work demands being qualitative or quantitative (Bowen et al., 2013).

Cultural influence is effective upon the psychological well-being of construction employees (Ki et al., 2010; Chan et al., 2014; Senaratne & Rasagopalasingam, 2017). Udayanga, (2020) emphasised the unique attitudes of Sri Lankans to resolve stress-related issues with the beliefs of mixed religious blessings. As same as the uniqueness from every other aspect, risk factors that contribute to the psychological health of junior professionals may differ from other contexts as well. In addressing the context-specific risk factors, primary data was employed to the research using the methodology discussed in the next section.

3 RESEARCH METHODOLOGY

In this chapter, the methodology adopted to this research to achieve the objectives is described. Knowledge regarding risk factors on the psychological health of junior professionals and strategies to overcome those psychological risk factors are limited in the context of Sri Lankan construction industry. Hence the knowledge capturing across a wider context is more useful. This justifies the selection of a survey strategy (Punch, 2003).

As psychological health is a sensitive and subjective phenomenon, and due to the limited existing studies in psychological health of junior professionals in Sri Lankan construction industry, this research adopted a qualitative approach. Qualitative approaches are primarily concerned with understanding, explaining, exploring, discovering, and clarifying a group of people's situations, feelings, perceptions, attitudes, beliefs, and experiences (Saunders, Lewis, and Thornhill, 2019).

Hence, the research strategy adopted was a qualitative survey as the objectives have an exploratory nature where a wider capture of knowledge is needed before going for an in-depth analyses. The qualitative type of survey does not aim at establishing frequencies, means or other parameters but at determining the diversity of some topic of interest within a given population (Jansen, 2010). As there is no specific sample size is required for qualitative studies (Naderifar, Goli, and Ghaljaie 2017), 24 semi-structured interviews were conducted among 18 junior professionals and 6 senior professionals to capture significant risk factors contributing to their psychological health and the appropriate strategies to address such risks factors. The number of interviews was limited to 24 after realising a data saturation. Though the study focuses on the issues faced by junior professionals, few senior professionals were also contacted mainly to minimise the biasness involved with having a single perception. The experience that senior staff faced when they were in their first few years of employment were captured. In addition, as the senior professionals have gone through the similar situation as junior professionals, the strategies to overcome the risk factors were mainly collected from senior professionals. Hence a single tool was used for the primary data collection and both junior and senior professionals were included to have a better data triangulation (Carter et al. 2014). Purposive sampling, which is a non-probability sampling technique, was used to select the interviewees to best enable the achievement of the objectives (Saunders et al., 2019). The profile of the respondents is provided in Table 2.

Table 2: Participants' Collection

ID	Gender	Age	Sector	Experience	Job	Project Sector	Education Level
JP01	M	24-28	Private	below 3 years	QS	building	BSc
JP02	F	24-28	Private	below 3 years	Asst. QS	building	BSc
JP03	F	24-28	Private	below 3 years	Asst. QS	building	BSc
JP04	M	24-28	Private	below 3 years	Asst. QS	civil	BSc
JP05	M	24-28	Private	3-5 years	QS	civil	BSc
JP06	F	24-28	Private	below 3 years	Asst. QS	civil	BSc
JP07	F	24-28	Private	below 3 years	Asst. QS	building	BSc
JP08	M	24-28	Private	3-5 years	QS	civil	BSc
JP09	M	24-28	Gov	below 3 years	Eng	civil	BSc
JP10	F	24-28	Private	below 3 years	Asst. Eng	building	BSc

JP11	M	24-28	Private	below 3 years	Asst. Eng	building	BSc
JP12	M	24-28	Private	below 3 years	Archi	building	MSc
JP13	M	24-28	Private	3-5 years	Eng	building	BSc
JP14	M	24-28	Private	3-5 years	Eng	building	BSc
JP15	M	24-28	Private	3-5 years	Eng	building	BSc
JP16	M	24-28	Private	3-5 years	Eng	building	BSc
JP17	M	24-28	Private	below 3 years	QS	civil	BSc
JP18	M	24-28	Private	below 3 years	Asst. Eng	building	BSc
SP01	M	29-35	Gov	8-10 years	Eng	civil	BSc
SP02	M	29-35	Private	8-10 years	Archi	building	BSc
SP03	F	36-45	Gov	10-20 years	QS	civil	BSc
SP04	M	29-35	Private	8-10 years	Eng	civil	BSc
SP05	F	45-55	Private	above 20 years	QS	civil	BSc
SP06	M	29-35	Private	8-10 years	Archi	civil	Dip

Using the semi-structured qualitative interviews conducted among the respondents, the risk factors that are contributing to the psychological health of junior professionals were identified. Then, the strategies to overcome the risk factors to reduce the impact and in turn to improve psychological health of junior professionals in Sri Lanka were proposed. The interviews were recorded after obtaining permission from the respondents. The interview transcripts were prepared for further analysis. A qualitative content analysis was employed to analyse the primary data collected through qualitative interviews. Content analysis can be identified as the frequently used technique of data analysis method in qualitative research approaches (Wahayuni, 2012). The next section discusses the results in detail.

4 RESULTS AND DISCUSSION

This section discusses the risk factors contributing to the psychological health of junior professionals and the strategies to overcome such risk factors.

4.1 Risk factors contributing to the psychological health of junior professionals

Table 3 presents the 26 risk factors contributing to the psychological health of junior professionals identified through the semi-structured interviews. The factors identified were classified under 5 main categories as adverse nature; apprenticeship; company culture; competition and personal opinions. Table 3 presents these risk factors along with the discussion from primary data within the table itself.

Table 3 Responses on Psychological health risk factors of junior professionals

Risk Factors	**Qualitative Discussions**
Adverse nature	
Human behavior	JP02 mentioned that rejecting any work would lead to face long-term trouble in the workplace. JP06 highlighted the responsiveness of site staff and as juniors, she has nothing to do about it. JP09 says that “labour handling is difficult because, while respecting them and we also need to get work done from them”.
Irregular work schedules	JP04 emphasised that it needs good psychological health to adjust to a critical situation to work more time than normally do. For JP11 working at weekends was a complete surprise. JP05 mentioned that “when critical works arrive, there are irregular working schedules arranged at a very short notice”.
Illegal human activities	JP06 mentioned that at site she had a lot of tension that she could have been misled and site stuff would be robed without her awareness. One junior quantity surveyor mentioned that he came across project corruption and was threatened to keep silent about it. Another junior quantity surveyor mentioned that his organisation forces him to go against his ethical adherence to his governing body.

Personal agendas	A junior engineer highlighted that working under someone is something he didn't like since his first few years. Government campus graduates (JP05, SP01) have felt that their job is not that exciting unless they face some challenging tasks.
Industry behaviour	JP06 has felt that she must show some improvement daily to survive in the job. Most of the juniors view that the well-being of employees is just a document in the HR department and not getting implemented.
Apprenticeship	
Lack of experience	JP03 mentioned that doing document work is very stressful. SP01 mentioned that they felt like "There are a lot of bosses. We don't know to whom we need to discuss and report". Further, lack of experience leads to doubts like "are we treated well or not?"," am I overdoing or underdoing my work?". On a positive note, JP07 advised "Just keep teamwork. Don't keep problems with colleagues and just solve them before it is too late".
Lack of time management	JP02 mentioned the struggle she has been going through because of being unable to keep work life balance. JP02 highlighted that being unable to take a leave at an urgent notice is psychologically effective. SP12 mentioned that "during the first training, I felt like missing home for too long, but now I am used to the timing".
Lack of knowledge	JP10 mentioned that "first job as a graduate is quite stressful that we do not have prior knowledge about those tasks". When we don't get our qualification-related to the task, it makes us feel like we are at the wrong place". Senior professionals who have also undergone the similar struggle when they first joined, are now realising, knowledge is something they can gather by learning by doing.
Deadline	Without any doubt, government and private sector junior professionals emphasised that deadline is a huge stressor in their working environment.
Company Culture	
Autonomy	Senior professionals mentioned that certain professionals have limited autonomy comparatively when making decisions, running committees and meetings. Organisations should realise that taking good ideas from anyone, irrespective of whether he/she is a junior or senior, will be always beneficial to the company.
Lack of demand	SP03, "in the government sector, engineers usually dominate. As a junior when she was not demanded in the workplace, she felt like her dedication on education was a wasteful end". Now she thinks that she has established a position in her organisation that is recognised. In agreement JP16 mentioned that "getting relevant professional affiliations in the industry is important".
Health and safety	The majority of the junior professional are in the view that the health and safety of employees are at a stake. JP07 expressed her view saying, "management only wants their work done and they don't think about workers' health". Two years experienced engineer from essential services mentioned that "we don't get proper accessories to execute our work. Safety facilities are not in place". Few senior professionals also confirmed that the health and safety culture should be improved in the industry.
Lack of support from seniors	Two of the quantity surveying graduates who are working in the private sector mentioned that they need a senior to consult while they are working but they don't get help often. An engineer from the government sector emphasised that "when conflicts happen with top management it would be very difficult to get solved". Senior professionals are also in agreement on the lack of support from seniors when they were juniors. But they also added, the juniors were quite reluctant to ask for help, if they seek help, there will be a way to support them.
Lack of monitoring	JP02 mentioned that "it is very disappointing that workers who work in pandemic situations are not getting any promotions". JP07 determined that "when we don't get the necessary care from organisations, even can lead to high staff turnover".
specific job role	JP02 mentioned that they are not provided proper work scope to do. JP01 mentioned that "seniors put a lot of supporting work to do".

Task-oriented training	Junior professionals have a lot of complaints against task-oriented training. Here task-oriented training means providing training focused on the task company expects rather than the potential of the employee.
HR management activities	JP07 mentioned that she has not received an appointment letter for nearly 2 years of practicing in the organisation. JP16 highlighted HR management of the company tended to neglect the wellbeing of junior engineers who had health related issues. JP08 mentioned that he faced a lot of injustice from the HR management of his organisation. JP05 from the road sector mentioned that he was not supported to do his postgraduate degree. JP04 highlighted that he is not allowed to go to take care of his parents who contracted with COVID-19. The senior professionals are also in agreement with most of these statements.
Lack of leisure events	Government sector juniors suffer from being lack of connection between seniors and juniors. Junior professionals in the government sector believe that there should be some get together, sporting events and leisure activities to get more collaboration. In contrast, the junior staff in private sectors do have comparatively more opportunities for leisure and networking.
Lack of belongingness	Most of the juniors and seniors experienced lack of recognition during their first few years. JP14 mentioned that he was not added to society once he enrolled. After helping seniors for a long time, he has gained it. An engineer mentioned that he thinks everyone in the company must be work-friendly and otherwise the company is inefficient. Participant JP16 mentioned that "I like when there is a good culture and environment in the organisation. Salary is important but, in a place, not suitable for a professional is not suitable ever".
Competition	
Job uncertainty	Irrespective of sectors and educational background, all the junior professionals mentioned the risk of not having a job in the Sri Lankan construction industry is still pertaining due to high competition and economic issues.
Educational background	JP06 mentioned that she would advise her successors to do something none other than a degree to support CV.
Lack of confidence	SP06 mentioned that "depending on the competency gained, salary increases. But employee should update themselves to request something first". Juniors do not seek to improve themselves due to their lack of confidence.
Personal issues	
Personal involvement	SP02 mentioned "Our supervisor wanted to find what we are doing after office hours, which I feel like I don't have a personal space in my life".
The personal bias	JP11 mentioned that there was a comparison between trainees from different backgrounds in the first training. Junior professional from a private organisation highlighted that consultant officers are not respectful to him.
Extremism	JP06 mentioned that "seniors don't like their juniors doing good with others in the workplace and I was a junior, stay unbiased at those situations". SP02 highlighted that "some seniors micromanage juniors and he has involved in verbal arguments with seniors". SP06, a draftsman, mentioned that he was told to learn himself studying at workplace. he has not received any support from his senior".
Abuses	JP06 says "Seniors, sometimes, scold us and use us to cover their fault".

When psychological risk factors are considered, without a gap, 80% of factors share similarities among each study (De Silva et al., 2017; Fordjour et al., 2020; Fordjour & Chan, 2019; Panojan et al., 2019; Bukhari et al., 2021). In contrast to the lack of psychology-related research studies and the uniqueness of Sri Lanka, a minimum of 70% of psychological risk factors of junior professionals have similarities to risk factors of other contexts. In Contexts like Ghana, Pakistan & China, Psychological risk factors have been further divided into a bigger number of factors in contrast to this research possess a more clustered overview of factors (Fordjour et al., 2020; Bukhari et al., 2021; Chan et al., 2012)

That the tasks are easy, hard, long, interesting, boring or short is dependent on the mental well-being of the employee animates "personal agendas" in this research (Ruthankoon & Ogunlana, 2003;

Bukhari et al., 2021). "lack of capacity" identified in the study can be related to stressors or stress making factors (Bowen et al., 2013; Gmelch,1982; Selye, 1982, cited at Isabelle et al., 2012; Dodanwala & Santoso, 2021). In literature, "lack of demand" which has been addressed in this study was mentioned in a different term like "not having a proper job description". It is acceptable that juniors have a "lack of knowledge" since some technical matters are not taught at the academic level. In the industry above factors affect, every professional as each project is unique in the nature of the construction industry (Enshassi & Al. Swaity, 2014; Dodanwala & Santoso, 2021; De Silva et al., 2017).

Maladaptive behaviours like alcoholism were not mentioned by junior professionals as a psychological problem though, in research studies of other contexts, that is available (Panojan et al., 2019; Chan et al., 2012). Professionals have mentioned consequences to family relationships due to ill psychological health (Chan et al., 2012). But in the context of junior professionals in Sri Lanka, that issue wasn't spoken in the interviews and the reason could be most of the junior professionals who participated were below 25 years of age and not married. Deadline tops psychological health risk factors when it comes to other contexts (Panojan et al., 2019; De Silva et al., 2017; Fordjour et al., 2020). Junior professionals in interviews mentioned "lack of knowledge", "bad HR management practices", and "lack of capacity" are the critical factors compared to the deadline factor. Sexual harassment, male-dominated discrimination was not mentioned by junior professionals as such incidents are relatedly limited in the Sri Lankan context due to strong cultural barrios (De Silva et al., 2017).

Mobile phone usage and being caught in traffic were mentioned by professionals in the Sri Lankan context in literature as stressors that were not highlighted by juniors in this research (De Silva et al., 2017). The reason for that could be juniors are not mature enough to understand that deep down, mobile phone drains their future and productive time in the workplace. Minimum approximately 80% of early-career professionals were allocated full time at remote locations for accommodation and work. Due to that, stress due to traffic on road shall not affect the early-career professionals in Sri Lanka.

Several results, unique to the context, were found like illegal human activities, poor HR management activities, and extremism despite the similarity of 80-90% in other aspects. A reason for that uniqueness could be the economic impact of the country on the construction industry. From in researchers' point of view devaluation of the Ceylon currency is the major problem. While implementing strategies in long term to survive from inflation in the industry, organisational policies, ethics, cultures also change. Since other countries don't possess similar settings, factors like "Poor HR Management Activities" are considered unique to Sri Lanka and another similar context as Sri Lanka. Further critical reasons for that factor were revealed as "not providing offer letters", "lack of care on health", and "not offering leaves for personal matters". The social and cultural setting also will add to the uniqueness of this factor. Senior professionals highlighted that the personal beliefs of seniors are adopted when executing organisational policies. As mentioned by one of the junior professionals in the interviews, in other contexts, rules and regulations are established to treat equally all employees but unfortunately organisations in Sri Lanka bias employees whom they consider as an asset to company. Hence, factors like "extremism" and "illegal human activities" are unique to Sri Lankan and other similar contexts.

4.2 Strategies to overcome risk factors contributing to psychological health of junior professionals

The strategies were collected individually from the junior professionals but mainly from senior professionals. After combining the strategies collected from both groups of professionals, Table 4 presents the strategies to be considered in addressing the risk factors contributing to psychological health of junior professionals in the construction industry. As per Table 4, several strategies were proposed to address most of the risk, though certain risk factors are difficult to address at the organisational level.

Table 4. Strategies to overcome risk factors contributing to the psychological health of junior professionals in the construction industry

Risk Factors	Organisational Strategy
Adverse nature: The junior-senior relationship is culturally bound which is not the problem only in construction but in the country as a whole. Therefore, the risk factors under this category are either difficult to address or will take a longer time to address as per the respondents' view. The professionals proposed the following strategies for risk factors.	

Human Behaviour Irregular Work Schedules Illegal Human Activities Personal Agendas Industry behaviour	- Allocate juniors to suitable streams to make them satisfied in the job - Establish verbal discipline in the organisation - Strictly enforcing rules and regulations to minimise non-legal practices - Juniors to be encouraged to freely share their viewpoints with the higher authority and hold psychological health training and workshops - Encourage junior professionals to work for the benefit of the organization in the first few years which will help them to be recognised - Company ethics need to be enforced to address the behaviour of employees to be respectful and closely monitor any unusual activities
Apprenticeship: The risk factors under this category are all related to personal development and profile building, hence the strategies are proposed to achieve the personal development	
Lack of experience Lack of time management Lack of knowledge Deadlines	- Establish organisational level policies to support the settling process for newly recruited employees and provide short and long term career plans - Monitor the appropriateness of supervisors allocation - Provide psychological training to junior professionals - Assign the tasks based on their capability first and gradually assign them new tasks while providing incentives for meeting deadlines - Being patient and supportive with junior professionals during the first few months to give them space to study and adapt to the working culture and environment while encouraging them to learn by doing - Encourage them to reveal and prove their talents - Provide sufficient opportunities for them to learn new knowledge - Provide necessary support when the jobs are assigned at a short notice
Company Culture: This acts a greater contributor One should understand that anyone joining construction should be given space and time to adapt to the organisational culture.	
Autonomy Lack of demand Health and safety issues Lack of support from seniors Lack of monitoring Not having a specific job role Task oriented training Poor HRM Activities Lack of Leisure Events Lack of belongingness	- Organisational policy level changes to strengthen the support to be provided for employee's career development - Making the job description clear in the offer letter, including the additional responsibilities that are expected from junior professionals - Provide an offer letter with a proper job description - Map the employee capabilities with the job demand - Establish a proper hierarchy for employee evaluation and monitoring - Assign senior professionals as mentors for juniors - Provide medical allowance and follow proper standards, policies, and ethics enforced by relevant professional bodies - Strengthen the HR management policies to support junior professionals - Training and development programme to be resigned to focus beyond the task-oriented and converting skills oriented - Training the juniors to learn the culture of learning by doing - Assign innovative team works and balance the workload across juniors - Organise monthly social and leisure activities for the employees to opportunities for networking, collaboration and have fun - Celebrate employees' personal events such as birthdays
Competition: This factor is highly influenced by external factors such as economic and pandemic related issues in the country. At times these factors are beyond the control of the organisation	
Job Uncertainty Educational Background Lack of Confidence	- Improve the recruitment policies and training policies to reduce high staff turnover - Assign personal mentors for junior staff
Personal issues: There haven't been direct strategies as the seniors had both in agreement and against with these claims. However, the strategies proposed are mostly related to ethics and policies.	
Personal Involvement	- A fair policy for conflict management - Close monitoring on the ethical behaviours of the staff

Personal Bias	- A mechanism to report personal issues with a high level of confidentiality
Extremism	- A fair enquiry process to address personal issues faced by the staff members and the appointment of a mental health monitoring officer
Abuses	

SP05 mentioned that the quality of the training provided to juniors depends on the training policy of the company. A senior (SP04) from a short and medium scale entrepreneur construction firm mentioned that due to a junior being just late to the industry, he is not allocated to rapid programmes but if they have completed the competency levels. Further he mentioned that it is impossible to always provide juniors with a job at the start of a project because employees leave jobs regularly in the middle of projects. To fill such vacancies, new employees must be recruited and assigned to tasks to continue with the already progressed projects. Hence the senior professionals emphasised that the juniors should understand the practical issues faced by the organisations in giving them the fullest training and opportunities in a project. Answering the question regarding lack of defence from out of scope works, SP04 mentioned that “in almost all the companies, there is conflict resolution. Junior must only report to the line manager. When juniors are assigned tasks by someone other than their line manager, the best approach is to first check with the line manager, as the manager will have a better understanding on their overall workload. If they can take additional tasks, it will always add to their experience,”.

Participant SP03 mentioned that “there is no provision to upgrade psychological health of professionals in construction organisations in Sri Lanka”. SP05 mentioned that employees including junior professionals have suffered from a lack of jobs in this period due to the pandemic situation and economic crisis. Answering the factor of job uncertainty SP05 mentioned that to the reduction of jobs available, economic issues and number of students who graduated from universities, there is a reduction in the number of juniors allowed to have trained under construction organisations. According to SP04, some companies are dependent on trainees. But companies have settled with many employees nowadays. Middle scale companies don’t have the financial strength to launch training programmes. SP06 and SP05 mentioned that even juniors are not allowed to go for further education with almost 80% of local construction companies. In the past, organisations provided financial support for their employees to get an education but now in the industry, there is no such influence. Instead of educating their employees and getting benefits for a long time, companies demand professionals with necessary qualifications to fulfil their jobs as there is generally a higher supply of employees available in the job market. SP3 mentioned that juniors are not getting well-monitored training if they are engaged with a C3 graded company as per the Construction Industry Development Authority (CIDA) ratings, due to lack of resources for the companies to invest on good training programmes. To get a proper training, juniors should join a C2 or above graded company. According to SP06 in private companies, trainees are overlooked as potential campaigners in the construction industry. But once become a professional, if they are not successful, he or she is going through a tough time. But finally, transfer to a section he can survive or attempt to improve. As such the support system for juniors highly depends on the culture of the organisation, financial strength and management policies and grading of the organisation.

5 CONCLUSIONS

This research contributes to the knowledge gap on the psychological health issues faced by junior professionals of the Sri Lankan construction industry. There are 26 risk factors that are contributing to the psychological health of junior professionals identified under 5 major categories such as adverse nature; apprenticeship; company culture; competition and personal issues. Organisational strategies were proposed to address the risk factors identified and key strategies are appointing a mental health monitoring officer; implementing stronger HR management policies; investing on training and development; counselling and support systems and encouraging more social activities. Improving the psychological health of junior professionals will increase the confidence to perform well and ultimately will result in the quality of organisational outcomes and high staff turnover. This research emphasises the need to strengthen the development and monitoring of policies related to psychological health in the construction sector. In terms of practical implications, the strategies proposed will help to improve the status of junior staff members in the construction industry. As such system changes and a new thinking pattern needed to be cultivated to grow a sound psychological health care policy in an organisation.

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Mitigation Practices for Frequent Accidents in High Rise Building Construction

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ABSTRACT

High-rise building construction accidents are observed within the construction industry in Sri Lanka. These accidents represent a significant loss for the construction industry in terms of lives, cost, time, and the reputation of the construction company. To overcome those losses, this research aimed to develop the framework as guidance to mitigate frequently happening accidents in high-rise building construction in Sri Lanka. It was achieved by three main objectives, identify the frequent accidents in high-rise building construction, investigate the causes of frequent accidents happen and analyze the strategies to minimize them. The first two objectives were completed by literature review, and the third objective was completed by data collection while developing the second objective. The data collection was done through semi-structured interviews with 12 professionals who work as health and safety officers, project managers, engineers, and quantity surveyors in high-rise building construction. Only those who work in the Colombo area were considered here as a limitation. Under the first objective, scaffolding accidents, struck by falling objects, plant, and machinery accidents, falling from a height, and fire accidents were identified as frequent accidents in high rise building construction, and causes were listed below the human factors, material, and equipment factors, environmental Factors, safety technology factors, and management failures as the second objective. Essentially risk assessment, developing the site conditions, conducting training programs establishing safety system with the procedure control system, and establishing penalty procedure were the discoveries of the third objective, and those are categorized separately in the pre-construction stage and post-construction stage. According to all these findings, the framework was developed to identified relevant mitigation practices for the causes of high-rise building construction accidents, and this research recommended for government to introduce new regulations for safety while strictly following up the safety system of the high-rise building construction sites to reduce the accidents.

KEYWORDS: *Construction. High Rise Building, Accidents, Causes, Mitigation*

1 INTRODUCTION

The construction industry is one of the major developing industries in the whole over the world(Brito & Saikia, 2012). It makes a large job market, instead of these contractions have to do with the big effort of different employers. However, these construction industry employers have to face down these unpredictable situations as the industry circumstance (Kasapoğlu, 2018). Especially, high-rise buildings' construction remains predominant in the high accident rates recorded annually, and it is important to accurately estimate safety matters (Md Sofwan et al., 2016).

High-rise buildings can define generally as the building which has more than 7 floors (Ahrens, 2016). These high rises buildings works are contained different machinery and conceivably dangerous building materials (Sikora, 2016). Therefore, the cost in terms of human life in the man-made accident will be a huge amount, and safety of life must become the main consideration, beginning from the conceptual phase in high rise buildings (Perera et al., 2017b). These accidents related to high-rise buildings have taken place in Sri Lanka as well. Mr. Koneswaran Nidharshan died due to falling from the Lotus Tower's 13 floor is one example of it. According to the news he had fallen down the lift shaft of the building (Teenage worker falls to his death from Lotus Tower : mirrorcitizen.lk, 2018). In the early hours of 29 December 2019, Mr.Kokila Samandaperuma, was killed in the elevator of the Green Lanka Towers at Nawam Mawatha in Colombo. The reason for it was the elevator stalled on the ground floor and fell underground. At that time elevators were in the construction stage (Mudugamuwa, 2019). In addition to that most nearly, there was a fire accident which happened in a high-rise building at Hyde Park in Colombo, and that building was collapsed due to the fire (Daily Mirror - Fire breaks out at Hyde Park Corner, 2020).

According to those previous cases, which happened nearly illustrate that still there are happening accidents in high rise buildings. In order with that, high rise building accidents became a problem that wants a proper accident mitigation method immediately in Sri Lanka. As the solution for that issue, the research aim was to develop a framework for aimed to develop the framework as guidance to mitigate frequently happening accidents in high-rise building construction in Sri Lanka with the three objectives, identify the frequent accidents in high-rise building construction, investigate the causes of frequent accidents happen and analyze the strategies to minimize them.

2 LITERATURE REVIEW

2.1 Construction Industry

The construction industry is an important role in the socio-economic development of all over the world while providing infrastructure facilities, sanctuary facilities, and employment(Fu et al., 2019). This industry has various sectors that produce immobile, unique, heavy, bulky, complicated, durable, and costly heterogeneous products (Mohamed Babikir Ibrahiem, 2015). To cater to the nature of the product and service, the construction industry is a dangerous industry that has a considerable amount of firms while making a large job market(Faizal, 2010). Due to a large number of participants in the construction industry in general, the complexity of their cooperation, and the relationships between workers, their tools and machines, and materials and operations, the number of occupational accidents outperforms other industries (Radosavljević & Vukadinović, 2020). Furthermore, these accidents in the construction industry can make the danger in terms of valuable lives, time, cost overruns, which be the black mark to the construction industry reputation (Perera et al., 2017a).

2.2 Accidents

According to the International labor department (2019), over two million people die from work-related diseases and 321,000 people die each year from occupational accidents. Furthermore, there are at least 60,000 fatal accidents occur each year on construction sites around the world, and one of every six fatal accidents happens at the construction sites (International labour organization, 2019). In industrial countries, 25% to 40% of work-related deaths happen in construction sites, even there is only 6% to 10% of the workers (Somavia, 2005). Furthermore, As the Labor Department's Industrial Safety Division in Sri Lanka, normally 2500 to 3000 accidents were reported while been 40% to 60% were fatal and 30% were construction accidents among them. In the construction work zones there happen two different types of accidents such as work area and traffic near to site accidents near to site area (Mohan & Zech, 2005). In this research, focusing is happening with work area accidents. That accident can categorize into four types according to the Workmen's Compensation Ordinance No. 19 of 1934. There are death, Permanent total disablement, permanent partial disablement, and Temporary disablement (Legislative Enactment of Democratic Socialist Republic of Sri Lanka., 1980). As this is a dangerous industry all four accidents can happen. To that, health and safety practice is mandatorily considered in the construction industry.

2.3 Health and Safety

Health and safety is a public health field that investigates trends in illnesses and injuries in the worker community and suggestions and implements strategies and rules to avoid them (Correll, 2020).

Furthermore, this system of health and safety should be responsible and accountable for the potential hazards and it should be included with the procedures of eliminating the hazards and identification of factors that make the path for uncertain accidents (Muiruri & Mulinge, 2014). In the construction industry, the contractor must make sure the encourage the medical staff, first aid equipment, and store persons at the site throughout the contract period (FIDIC, 1999). However, most of the construction companies use only mandatory standards as the health and safety management strategy even despite the high cost of accidents at work (Shibani A et al., 2013). Even though, simply adhering to these regulations may not be enough to ensure perfection in the performance of health and safety. (Shibani A et al., 2013). To that, the health and safety issues like accidents have to manage while identifying the injuries, evaluating the risk posed by these injuries, and controls for risks are chosen according to a risk control (Medilife, 2012). However, accidents caused in High Rise building construction are one of the major areas that should have managed the accidents instead of high-rise buildings having more danger than the construction of the small building (Rajendran et al., 2009).

2.4 High Rise Building Accidents

High-rise buildings are the recent demand in the construction industry these days instead of lack of land space (Giyasov & Giyasova, 2018). These High-rise buildings can define as buildings that have more than seven floors and those can categorize into four such as 7-12 floors, 13-24 floors, 25- 49, and 50 floors or more (Ahrens, 2016). It is typified by continuous variations, use of many various sources, lack of working conditions, stable work failure, harsh environments such as vibration, noise, dust, load handling, and denudation to stochastic fundamentals such as conditions of weather, soil types, and road accidents (Zaini et al., 2015). To that performing the safety of the workers while preventing accidents is a major challenge with these circumstances.

The previous researchers identified the types of high-rise building accidents as below.

Table 1 - Types of High-rise building construction accidents

Author	**Types of High-rise building construction accidents**
(Zhou & Pang, 2013) (Goh et al., 2016)	Scaffolding accidents People falling from a height Struck by falling objects Plant and machinery accidents
(Alam, 2015)	ladders Falling debris Falling from height Electrical shock and Machinery Trips and Slips Crane and hoist operation
(Su, 2014)	Falling height Object against accidents machine, and crane accidents electric shock accident Fire

By adhering to those categorizations, the types of high-rise buildings are taken as scaffolding accidents, falling from a height, plant and machinery accidents, struck by falling objects, and fire accidents.

2.4.1 Scaffolding Accidents

Scaffoldings are used for support to carry out the building works which are done at height but also places that have poor access (Błazik-Borowa & Szer, 2015). General needs for scaffolding are capacity, scaffolding platform construction, suspended scaffolding criteria, Supported Scaffolds Criteria, entry requirements, usage requirements, fall protection requirements, and protection against falling objects (U.S. Department of Labor, 2002). There can happen hazardous incidents which are related to the uncertain activity that makes dangers the worker in the scaffolding areas such as injuries (Abas, Noridan, et al., 2020). To that Scaffoldings have to prepare with considering sustainability for accidents and encourage skilled laborers while considering documentation about the preparation of scaffolding, selection of the assembly elements of the scaffolding, assembling the scaffolding, scaffolding exploitation, and disassembling the scaffolding has to be done correctly with proper knowledge. (Błazik-Borowa & Szer, 2015).

2.4.2 Struck by a falling object

Most of the construction sites are full of people or ancillary activities without sufficient space and it makes a path for most common accidents like striking against or being struck by objects (Fung et al., 2010). The research done in Johor shows that the percentage of the striking which related to materials is 65% while which related to equipment is 35%. (Abas, Heong, et al., 2020) According to Wu et al (2013), most hazardous strikes happen while hoisting or lifting. Furthermore, it is 41% percentage from including all the types of struck objects (Wu et al., 2013)**.** Struck can be happened by the equipment, private vehicle, falling materials, vertically hoisted materials, and horizontally transport materials (Goh et al., 2016).

2.4.3 Plant and machinery accidents

Plant and machinery are some of the most significant resources that need to complete the construction stage of a project (Manaf & Razali, 2007). Especially earthmoving and carrying machinery are more important machinery among them which can handle various soil and materials (Dadhich et al., 2016). However, according to the factory ordinance in 1942 the parts of the machinery must be guarded or protected while moving or in service, except when those parts are inevitably exposed for examination and any lubrication or adjustment as soon as possible required by that examination (Department of Labour, 1942). Furthermore, As per Occupational Safety and Health Administration (OSHA) requirement, employers are only allowed to purchase machines that have capable guard and security measures in place to protect workers from amputation accidents (Az, 2017).

2.4.4 Falling from height

A fall can be defined as a movement towards the ground and that kind of physical hazard that happens while the worker's body balance is lost (Liy et al., 2016). As a result of the main hazard in high-rise buildings is correlated with working at height and vertical transportation of materials, falling objects or the fall of the worker accident can happen (Fung et al., 2010). However, these accidents mainly happen in construction as the reason for construction characterized by long-term production cycle, large mobility, heavy labor, and complex operations (Zhou & Pang, 2013). Falling from height is can happen in the area of scaffolding, structure, or working structure (Arifuddin et al., 2020). The suggestion for the system of fall protection should be flexible, passive, simple, feasible, protective while maintaining less cost (Cecen & Sertyesilisik, 2013).

2.4.5 Fire accidents

In high-rise building construction, a large number of hazard elements are used which can simply make a path for fire accidents. This difficulty is forward to the usage stage from the construction stage (Chen et al., 2012). Most of the High rise buildings are covered with combustible materials which spread the fire than the other buildings (Lamont & Ingolfsson Sigurjon, 2018). The reason for it is high-rise buildings are consist of staircases, elevator shafts, pipe shafts, cable shafts, and many other verticals shafts than the others which can act as the passage to spread the fire if there have not proper fire separations (Liu et al., 2012).

2.5 Causes of frequent accidents happen

Most of the time these accidents happen because the people did not give the priority to safety well compared to the size of the workload, searching for easy methods to save the times and unfair thinking such as that accidents never happen to me (Haslam et al., 2005). Furthermore, they elaborated that causes of accidents can be classified as the operation of the workers and material factors. Other than that causes of the accident can divide into human and physical factors (Gibb et al., 2001). In addition to that Zhou and Pang (2013), they classified the accident causes as human factors, environmental factors, material and equipment factors, and safety technology factors. Here the causes are going to discuss mainly under those four causes. Other than that, according to Hamid et al, there is a cause called management failures and it also going to consider here.

2.5.1 Human factors

This human error can categorize into two types such as the individual approach and the systematic approach (Selby et al., 2000). The individual approach focuses on dangerous actions, which are mainly seen as a result of abnormal mental disorders problems such as inattention, neglect lack of motivation, and recklessness while the systematic approach considers human error as a consequence than a cause (Ye et al., 2018).

2.5.2 Environmental Factors

The site environment is the victim of an accident operates. Effect of sunshine on the summer season, Possibility for Slipping from scaffolding on the Rainy season, inadequate light at the night while constructing and there is no sign to identify the dangerous areas which are excavated can be causes for these accidents happen in high rise buildings under environmental factors (Zhou & Pang, 2013).

2.5.3 Material and equipment Factors

Building materials were the main source of injuries from construction accidents in this category, with metal building materials, pipes, channels, and pipes, and lumber being the main culprits (Jones, 2017). According to Zhou and Pang (2013), the quality or damaged materials such as safety nets, safety belts, safety helmets, and ladders and not having proper safety and job requirement are the causes of these high-rise buildings accidents.

2.5.4 Safety Technology Factors

Certify about the good technical skills and experience should have to take as the very much important to workers (Haslam et al., 2005). Lacking the knowledge to use technological innovation to expand safety ineffective and lack of technical advice when carrying out construction work causes are lead to happen accidents under this safety technology factor (Memon et al., 2017).

2.5.5 Management Failures

Accidents are symptoms of mismanagement and safety goals must be consistent with business goals if good safety performance is to indicate successful management (Häkkinen, 1995). Furthermore, Hamid et al (2019) said that, under incorrect or nonexistent work procedures, structural failure, unsafe working methods or circumstances, and lack of supervision are the most ordinary contributing causes to fatal accidents can happen.

All the causes under these factors should have been understood to find the proper way to reduce the number of accidents that happen in high-rise building construction.

2.6 Available Mitigation Practices in the construction industry at Sri Lanka

According to research about the Study of construction accidents in Sri Lanka, contractors could develop safety programs, if the Industrial Safety Division of Sri Lanka does the analysis and distributed the data about the accidents (Rameezdeen et al., 2006). Furthermore, they said that Work order and approaches to performing certain work activities can be changed to reduce the risk that can be done under that. Other than that construction accidents can mitigate by making sure the wearing safety equipment is mandatory at the site (Perera et al., 2017a). In addition to that, there should be prestart briefing meetings by the supervisor and there should be proper permit systems to carry out the difficult areas such as excavation and hot work as per their findings. According to Darshana (2017), there should be a systematic performance review based on independent monitoring and audit data from the system of the entire health and safety management. In addition to that, there should be an engagement in continuous development including risk management policies, systems, and techniques (Darshana, 2017). However, all the accidents can mitigate through administrative controls, engineering control, and by using the PPE other than accidents that happen due to unsafe behavior and unsafe acts (Mudiyanselage et al., 2016).

3 METHODOLOGY

To carry out this research the philosophy was taken as Interpretivism. To this interpretivism, the paradigm theoretical approach was taken as inductive with the qualitative research design. This qualitative research design is mainly used to collect answers about the thoughts and feelings of research participants, which can help to understand the meaning people attach to their experiences (Sutton & Austin, 2015). Under that, objective one was competed with related literature to identify frequently happened accidents in high rise building construction. The Second Objective, to investigate the causes of frequent accidents was achieved through a literature review once the first objective had been completed. The final objective was achieved through primary qualitative data collection by using semi-structured interviews while developing the second objective through it. These semi-structured interviews were used here to gather in-depth insights into high-rise building construction accidents. These interviews were done with the participation of 12 professionals who had more than 5 years of experience in high-rise building construction such as health and safety officers, engineers, project engineers, and quantity surveyors while developing the second objective through it. Other than that, the factory ordinance act which is published in 1942 ad previous findings were considered and, did the data analysis and discussion by using NVivo 12 software while selecting the most suitable mitigation practices as per the participants recommended according to their experience. At the end of the discussion, the framework was buildup based on it.

4 DATA ANALYSIS AND DISCUSSION

The data were collected through open-ended semi-structured interviews with the professional bodies who are involved with the high-rise building construction Colombo area in Sri Lanka. There were 12 interviews in different construction organizations' high-rise building projects. The findings of the research had analyzed and explained accurately in a logical systematized manner.

The basic information about Causes of frequent accidents in high rise building construction which collect through interviews categorized as the Human Factors, Environmental Factors, Material and equipment factors, Safety technology Factors, and Management failures as per the literature findings. Table number 2 is used to shown analyze the obtained data from the semi-structured interviews, literature, and factory ordinance in 1942 as below.

Table 2. Causes of high-rise building accidents

Factor	Causes
Human Factor	• Negligence of the workers • Unconfidently about safety equipment • Poor Supervision • Unsafe Behavior • human stress level • Human disaster
Environmental Factor	• Changes in weather • Unsafe condition at the site • Site space • salinity of wind
Material and Equipment Factor	• Low quality of the material and equipment • Wrong material Usage
Safety technology Factor	• Lack of knowledge • Safety measures do not implement
Management Failure	• Focusing only about target only • Poor human resource management

As per the result regarding the causes of accidents of high-rise building construction the mitigation practices were identified with the collected data. According to them, the mitigation has to be done with both the pre-construction stage and the post-construction stage.

Risk assessment is important to mitigate all accidents and it can mitigate the hazard level of the project as per the participants in the pre-construction stage. Furthermore, preventive measures could be drawn up and implemented per it. Other than that, there had five participants mentioned that **studying the health and safety standards and the conditions of the contract** in this pre-construction stage is a must and the contractor should check the safety precision which was given by the client is adequate or not and if not have to discuss for establishing the systems for mitigating got prevent the accident. Furthermore, as their thoughts, the client party should check the safety records of the contractor and the local and international health and safety standards followed by the contractor.

In the post-construction stage, **giving proper training** for the workers was mentioned by all the participants. Other than that, according to the Factory ordinance part III, no young person may work on a machine unless is fully aware of the hazards associated with the machine and precautions that must be observed and adequately trained to work the machine. . To that training is a must and the fairest decision among given answers about training sessions, is conduct the safety training should be once a week and there should be an instruction session daily basis. Other than that, they proposed to have special training for the special tasks once the time it has to do. In order with that, this can use to improve the knowledge of workers and guide the workers on the correct path which can use for mitigating the safety technology causes of high-rise building construction. As parral wit that, **handling awareness program** was proposed as mitigation practice by the five number of participants. As the fairness decision from their experiences, it should be happening daily basis for workers and once a month for the management. As per that this is considered a good mitigate practice for resolving human causes and management failures. **Providing the PPE** is mentioned as compulsory to mitigate the accidents by all the participants and there should have to use safety helmets, eye protection, gloves, safety footwear, high-visibility clothing, and safety harnesses under that. Furthermore, those PPE must be in accordance with the standard. This will be beneficial to mitigate the accidents due to the human factor, material and equipment factor, and environmental factors.

Appointed role of safety supervisor also mentioned by all the participants and they thought certified about the quality level and standards of material, plant, and equipment, maintain a tool checklist, ensure about safety system establishment, conduct safety training and awareness programs, certified about workers training and investigate health and safety complaints the duties that safety supervisors should follow. The factory ordinance also mentions maintaining the standards of plant and machinery. In order with that, this appointment of safety officer role can mitigate the all the causes than the management failures. Other than that, five participants mentioned that there should be used **only the skill laborers for dangerous work** like working at height to prevent from the safety technology causes like lack of knowledge. Furthermore, they recommend involving technological knowledge workers such as those who take proper training from technical colleges. If the contractor uses this skill labors, they can mitigate the human causes and safety technology causes that lead to accidents due to their knowledge.

Implementing the safety systems are mitigation practices that are very important to reduce accidents due to safety technological causes as all responders thought. Under that, they mentioned there should have to be a guard rail system, warning line system, control access zone, safety net system. Positioning device system, personal fall arrest system, canopy system, and fall restraint system are the system that looks forward to that total safety system. Other than that, ten participants mentioned accidents can happen due to turbulent movement when the other accident happens, and there should be a technical solution for it like a dedicated vehicle for emergency cases, intercom system, maintain first aid facilities, establish fire extinguishers, displaying emergency numbers, trained for casual canteen were the proposed **procedure control systems** for it. The factory ordinance in 1942 also showed about first aid facilities, as those have to maintain inaccessible boxes or cupboards. However, this was taken as mitigate practice that can use to reduce the damage of the accident. In addition to that, **develop of site conditions** is one proposed mitigation practice by the two participants for environmental causes. Furthermore, the factory ordinance mentions that there should be proper cleanliness to manage the overcrowding, temperature, ventilation, and lighting at the site.

As the last mitigation practice, three participants nominate the **penalty procedure** and they proposed to have given only the 3 chances for the workers. As their thoughts, the first time there should have given a warning letter and the second time there should have to give a signing letter through management. Although if it is the third time the workers should have to resign from the job. The researcher proposed that it is better to establish in every construction company and it can mitigate the human causes which lead to high rise building accidents.

4.1 Suitable Mitigation Practice Framework for high rise building accidents in Sri Lanka

This Framework was prepared as the final step to achieve the aim of the research while given a Suitable Mitigation Practice Framework for causes that lead to high-rise building accidents in Sri Lanka.

4.1.1 Steps for the development of the proposed framework

This section is included with the steps which were followed by the researcher for the final objective according to the data analysis outcome.

Step 1: Identifying the frequent high-rise building through the literature review.
Step 2: Investigate the causes for those frequent accidents semi-structured interview.
Step 3: Analysis of the strategies to minimize the causes from the interview.

4.1.2 Use of the proposed framework

These are the steps to use the framework that the contractor must follow to select a suitable mitigation practice. The framework is attached in figure 1.

Step 01: Identified the accidents that can happen in high-rise building construction.
Step 02: Investigate the causes that lead to those accidents.
Step 03: Identify the factor it was to categorize.
Step 04: Select the mitigation practices which can apply to it

However, according to the organization's strategies and location, these practices can be changed.

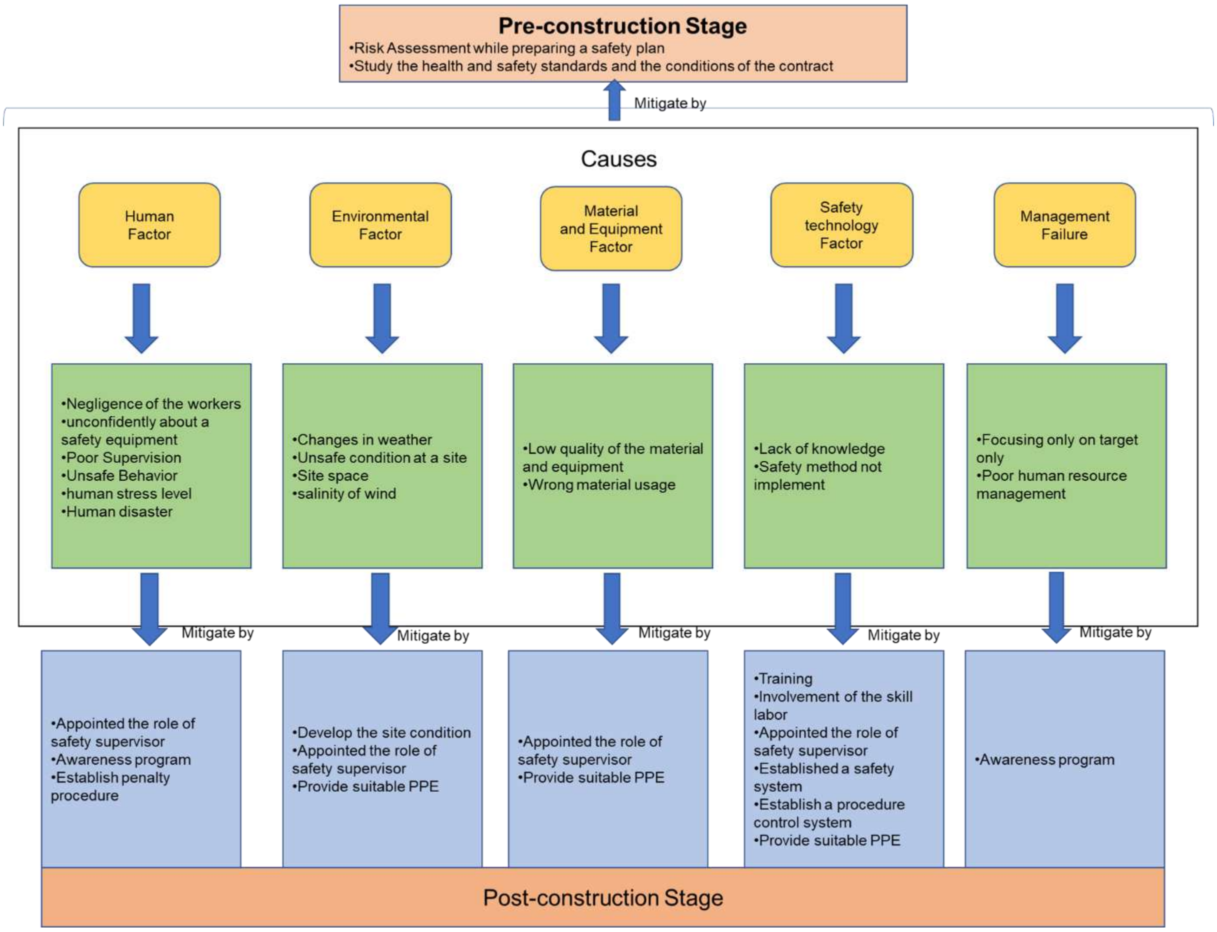

Figure 1-Mitigation Practices for Causes of High-rise Building Accidents

5 CONCLUSION

The number of accidents happening in the high-rise building construction industry is higher than the number of small building constructions. Due to that, finding the mitigation practices for those accidents is very important, and in order with that, this research aims to develop the framework to mitigate frequently happening accidents in high-rise building construction in Sri Lanka. To overcome that aim the high-rise building accidents were identified under the first objective such as falling from a height, struck by falling objects and scaffolding accidents, plant and machinery accidents, and fire accidents and the causes for those accidents classified under human factors, material and equipment factors, environmental Factors, safety technology factors, and management failures under the second objective. As the outcome of this research, the way of mitigating those causes was present through the framework and it consists of the mitigation practices such as the risk assessment, study the safety standard and conditions of the contract, developing the site conditions, conducting the training and awareness program, the involvement of the skill labors, establish penalty procedure safety system and procedure control system, appointed the role of safety supervisor and provide suitable PPE which analysis under the third objective. The data was collected through the literature review, factory ordinance act, and semi-structured interviews to achieve the aim. To develop this research area gap the researcher proposed to do further research on the topic of analysis of government involvement for health and safety regulations in the construction and comparison between low rise building accidents and high-rise building accidents

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REGULARITIES AND PATTERNS OF CONSTRUCTION COSTS UPON POLITICAL EVENTS

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ABSTRACT

Though the market prices change before and after political events were often speculated, if such changes could be systematically accounted for in construction cost forecasting was unknown. This study aimed to bridge this knowledge gap by identifying the regularities and patterns of the construction costs upon political events. A decade of period was selected in which the scope of the study started in 2010. Time series analysis was used along with regression analysis, assuming a linear relationship between construction costs and time. After a comprehensive literature review, CIDA construction cost indices were chosen as the most appropriate cost representation for the local context, and these were taken as the dependent variables. All indices were plotted in diagrams and long-term trends were observed, then indices were carried for further analysis of cycles. Major political events were collected through a document survey and the findings were plotted on the time series analysis output. It was noticed that in 2013 indices were changed mostly, where three provincial elections were held, and some more pattern changes had occurred close to the local government elections which took place in 2011 and 2018. The study concluded that there is neither pattern nor regularity in construction costs upon political events where it cannot be systematically incorporated into construction cost forecasting. However, the findings did not deny the impact of political events on construction costs, and novel areas were found where further explorations are required.

KEYWORDS: *Construction Costs, Political Events, Sri Lanka, Time Series Analysis.*

1 INTRODUCTION

The impact of political changes towards construction industry costs has been in common interest among industry stakeholders. There has been varying expectation and speculations in advent of political events such as the presidential election. However, these speculations were not based on scientific evidence, but mostly based on personal knowledge and experience. This research is conducted to find if and how past political changes affected construction costs in Sri Lankan construction industry. The study was interesting because its findings will help to make better informed predictions at future political events.

Politics have been one of the main branches in an economy and its movements were to be considered as risky in general. It was because of the inability to guarantee the outcome beforehand. According to the findings by Bekr, (2017) unstable political and security conditions caused high cost incurrence in construction projects in Iraq. Similarly, Bussy and Kelly (2010) showed that the gulf between stakeholders' salience legitimacy and political decision makers as attempting to be in power was resulted in an unstable and interrupted economy in Western Australia. In 2013, Silva, Rajakaruna and Bandara stated that political instability forms breakneck changes in policy decisions which reduced the productivity of the industry in Sri Lanka. Having said that, the interference of politics towards the construction industry has been lasted for a considerable period.

Figure 1.1 shows the percentage change in Gross Value Added (GVA) & Gross Domestic Product (GDP) of the construction industry from 2010 to 2020 in Sri Lanka.

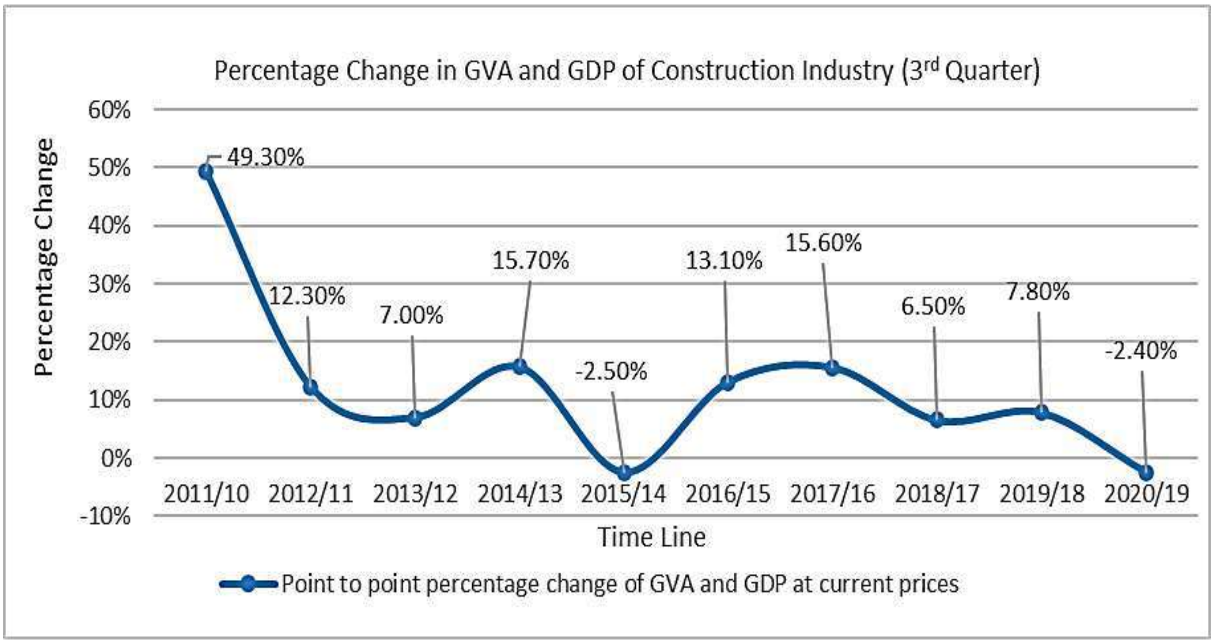

Figure 1.1 Percentage change in GVA & GDP of construction industry (3rd Quarter)
Source: Statistics and Census Department, 2021

From figure 1.1, change in GVA & GDP of the construction industry had fluctuated from 49.3% to -2.5%. There was a dramatic drop on the same in 2015/14 and 2020/19, where the 7th & 8th presidential elections were held. As appeared in Elinwa and Buba's (1993) paper, professionals had recorded 70% - 74% of severity on influence in government policies on construction costs' prices. Substantially, Enshassi, Al-Hallaq and Mohamed (2006) had mentioned that, construction industry highly relied on the economic cycles and political surroundings. McDonald and Kendall (1994) had found that sudden change of political events in the defense industry, had impacted its' stock prices with positive values in United States which admitted the general perception about uncertainty that may create from the date of announcement of an election. Thus, if sudden political changes could have an impact towards the construction industry, it can be assumed that, political events could affect the construction industry and its' related costs figures. Yet, any findings had not observed on such trends and regularities in history which left it alone as a supposition.

At the same time, cost estimation is crucial to the construction activities where, both over-budgeting and under-budgeting, have been rejected due to the creation of loss in strategic opportunities in the industry. Akintoye (2000) stated that, the accuracy of cost estimation had been very important for all parties to the Contract. Inappropriate Engineer estimates could make unsustainable and ineffective financial injections from the Employer to the project. On the other hand, the contractor would cling on the winner's curse. As per the study of indirect cost estimations published by Tah, Thorpe and McCaffer (1994), professionals were not using the risk analysis to accumulate the risks for estimates in United Kingdom, where a provisional margin was kept from the profit based on their experience, due to the uniqueness on each event. In Sri Lanka as current practice, everyone was used to allow inflation risks when preparing estimations. This was included even in the Standard Bidding Document – Major Works (SBD/CIDA/02) published by the Construction Industry Development Authority (CIDA). However, in absence of such provisions (or the deletion of it in contract), necessitates the inclusion of potential fluctuation in the price quoted. Even during budgeting, specific contingencies to accommodate cost fluctuations due to oncoming political events were not observed. The limitation could be primarily attributed to lack of proper knowledge on how political events affect the market price changes of construction inputs. This then limits the proper accounting of the related risks in cost estimating, and also leads to limit the professional advice to clients on the subject.

If an established regularity in pattern of changes exists, it could have been systematically incorporated into cost forecasts of construction projects. The absence of such knowledge results in speculative adjustments to price forecasts making them less accurate.

1.1 Aim of the Study

In order to address the above-mentioned problem, the study aimed to identify if there are regularities and patterns of the construction costs upon political events that can be systematically incorporated into construction cost forecasts.

1.2 Scope of the Research

In Sri Lanka, the presidential election is the foremost election with respect to the 1978 constitution. From 26th January 2010, a new presidential term was started whilst a fresh start of the post-war chapter of the country (30 years of Sri Lankan civil war was ended in May 2009).

Recent past, certain interesting and unique political events have happened in Sri Lanka. For example:

- Being the president for second consecutive time
- Being the presidential election candidate for the third time
- Unexpected political party changes
- Unity government
- Severe allegations on ruling parties
- Two prime ministers at the same time etc.

By looking at such events that occurred in the past, the period from 2010 to 2020 was selected as the scope of this study.

2 POLITICS AND CONSTRUCTION COSTS

Many professionals had identified risks associated with the construction industry and presented the risks analysing frameworks, and then various mitigation plans were illustrated. Kishan, Bhatt and Bhavsar (2014) formed risks into ten categories namely, Design, Physical, Logistics, Legal, Environmental, Construction, Management, Cultural, Financial and Politics. In political and financial risks, the mentioned causes were overlapped. Arguably, the majority of those financial risks were shadows of political risks on decision making. It was still unclear to group each risk into separate baskets due to the linkage on each other as above. Especially in political risks, the linkage to other risks were not addressed clearly so far. Thus, the criticality is kept silent along with the hidden background.

2.1 Political Events' Impacts

Apart from that, the effect of political events had not been cornered only to the construction industry but in every industry at large. However, the impacts on political events were seemed more popular in stock market price analysis in other countries. Though some had found that stock prices were affected by political events, the used definitions of political events were different. Niederhoffer (1971) had considered major political events based on the headlines of newspapers whilst Reilly and Drzycimski (1973) had selected seven political events concerning previously determined quantitative measures. Interestingly, the Niederhoffer (1971) considered illness and death of politicians, etc. also as political events whereas others did not. Meanwhile in Pakistan, Nazir et al (2014) showed the autocratic and democratic governments' impacts using events collected from several news channels for a period of decade. Because of the dependability and high interaction with minor changes in governing systems, the cut-off line on political events could not be well defined. According to the study of McDonald and Kendall (1994), the impact of political events had caused even before the event occurred, although the significance was low. It was addressable that, breakthrough or sense of future action would cause it. The majority of past literary works were conducted in narrow time bands when assessing the impact on a particular event. But the concern was, whether the actual impact would account within the specified period.

2.2 Political Risk in Construction Industry

The direct political intervention was already identified as a risk on economic growth and infrastructure expansions in many cases but not the political events. Among the construction industry vagueness, mostly the international construction had looked on the political risks independently. Gunhan and Ardith (2005) were shown that the international construction business was impacted by political risks. Nevertheless, Ashley and Bonner in 1987 presented an approach for contractors to evaluate those risks. Xiaopeng and Pheng (2012) presented the top ten variables which were affected for the level of political risks. In that study, the degree on stability of government was recorded in peak by both academia and practitioner, followed by the host country's willingness and policy uncertainty. Under the host government influencers, upcoming elections, level of democracy, degree of consensus in policymaking were included out of forty factors from an extensive literature review in three means. Though, those were not recorded at top, such variables were already identified as impactors in international construction industry by 2012. At the end of the study, it was recommended to either deal or mitigate this risk, which indicated that, it is not a risk that could avoid. As Deng et al (2014) mentioned, the extent of applicability on those findings and recommendations was doubtful for other countries because of the tailoring nature of politics. For example, Viswanathan and Jha (2020) have found that political risk in Indian international construction as one of the risks but it was ranked the lowest. However, politics have been interpreted as a risk in both national and international contexts.

2.3 Construction Costs and Political Risk

Since the past, construction cost and time overruns were seemed to be very famous research interesting areas in construction industry, including in Sri Lanka. It was shown that, construction costs exceeded 100% of budget usually (Memon, Rahaman and Aziz, 2011). For many countries, fluctuation of material prices was a significant influencer on such cost overruns (Arditi, Akan and Gurdamar, 1985; Olawale & Sun, 2010; Memon et al, 2011). Other than that, Olawale & Sun (2010) found that fluctuation of currency, unstable government policies and weak regulations & controls were impacted negatively for construction costs. Arditi, Akan and Gurdamar, (1985) revealed the critical behaviour of a country's government and the significant role of responsible leadership. Similarly, Niazi and Painting in 2017 recommended a strong leadership in future projects to overcome this construction cost overflow. As well as, Wijekoon and Attanayake (2013) recommended to have necessary national policies and amendments to acts to reduce the road construction projects cost overruns when acquisitioning lands in Sri Lanka.

In the study of Prabowo, Hooghiemstra and Van (2017) in Europe, found that labour cost stickiness was strong when elections occurred. Besides that, Rosenbaum (1997) had identified the risks of political instability, corruption, fluctuations in interest rates and currency and problems in material availability were the causes of cost overruns in privatised infrastructure projects in developing countries. Many research had reviewed corruption and allege under the umbrella of politics as a cause for financial problems, where this has become a common concern in the industry. In Sri Lanka, Hiroshan and Hadiwatte (2014) had recorded 16% of political influence on total construction costs in the industry. In their study, the cost of material was ranked for 1st on severity scoring of 84%. Though they have mentioned that 16% of political influence, they were silent on the rationality behind it. Hence, the truth behind political behaviour to construction cost was not revealed yet.

2.4 Construction Cost Representatives

Most of the above-mentioned research papers' variables were identified through comprehensive literature review, questionnaire surveys or pool discussions. Some had presented the statistics of past cost overruns and cost indices to support the interpretations of their study (Damnjanovic et al, 2009). However, it was noticed that, cost indices published by authority bodies, were heavily used to produce estimated cost predictions. Yet, the uses of these indices were not restricted to that. Son, Jang and Lee in 2014 had used construction indices in Korea to study the productivity of workers' operating rates. In the local context, Ruddock et al in 2011 directed the study of post-tsunami reconstruction through construction cost indices published by the Institute of Construction Training and Development (ICTAD) present as CIDA. Similarly, some others also had used the construction cost indices to advocate their explorations (Weddikkara and Devapriya, 2001). CIDA has a rich, past construction costs database for Sri Lanka which consisting all costs of materials, labour, plants and machinery. As well as they have indices for types of constructions.

However, some researchers had argued that those indices were not accurate and realistic. In international context, academic journalists have used similar measures combined with the more sensible and less estimating error techniques of statistical models (Shahandashti, and Ashuri, 2013; Ilbeigi, Ashuri and Joukar, 2017; Zhang et al, 2017). Though it was debatable, indices were provided to use in both academic and industrial applications, which were published by an authorised national entity – CIDA, and interestingly, no one had in fact proved the inaccuracy of these indices. Even if they could have inaccuracies, that would not significantly affect this study as the expectation was not to estimate cost, but to identify the changes in cost trends. As construction costs were the base impactor in all causes, it was taken as the variable of this study. Construction cost indices published by CIDA were identified as the appropriate data to represent construction cost fluctuations in Sri Lanka.

3 METHODOLOGY

As mentioned above, CIDA cost indices, the most applicable and reliable cost representation were chosen in literature review. Using that cost representator, the study was carried forward for the data analysis.

Positivism was followed as the research problem was tested using statistics aiming to either reject or not reject the hypothesized patterns. Past statistical data were collected to observe the behaviour and regularities of the variable. Using the observations of trends and patterns, a critical discussion regarding the involvement of political background was built. The study accompanied the mixed method on both qualitative and quantitative approaches. The beginning of the study was carried on quantitative style but based on the findings, latter part of the analysis followed the qualitative approach which had to construct the theory purely on interpretations based on observations. Strategy of inquiry was a documentary survey because, the variable data and details on changes in political events were collected from a variety of published documents. Data collection strategy was built on the findings of literature review. The method of data collection was unobtrusive due on the borrowed statistical data. Accordingly, the following research method was adopted.

Both qualitative and quantitative studies were carried out simultaneously. For the qualitative analysis, details on political events were picked from newspapers, websites, government reports, and other available and reliable sources of published documents in public. These details were on past elections, amended acts, past economic statistics, infrastructure developments, policy changes, acts of politicians, etc. After a desktop study, elections were chosen as the best fitted benchmark to project the political events in Sri Lanka for the study. Qualitative analysis was continued further to identify the timeline pins which were required to observe the patterns and trends in quantitative analysis.

On the other hand, construction cost indices were extracted from the Bulletin of Construction Statistics published by CIDA. Since the scope of this research lasted a decade, two hardcopy bounded bulletins were used. One was published in December 2014 and other was published in December 2019. Published data were on 55 materials, 3 types of each labour, plant and machinery. As well as those bulletins have given the indices based on 11 types of constructions. These data were calculated with respect to a base year or base month and these base months and years were not identical for all indices. Since the study focused on changes in patterns, dissimilarity of base years and months would not disrupt the results. Moreover, these statistics were directly obtained through either observations or experiments by CIDA. Hence, the collected variable data was primary data though it was from an institute. To observe the fluctuations over the period, this study followed a time series analysis method for construction cost data. A longitudinal time series analysis was conducted through spreadsheet-based data analysis software. The independent variable was the time and the dependent variable was the construction cost indices. Firstly, data were recorded to spreadsheets and average quarterly data were computed in each year to observe long-term patterns and regularities while excluding the distraction of short-term influencers in the trends which could appear on monthly or quarterly basis. Initially, all 72 indices were represented in graphs and long-term trends were observed. Out of them, unresponsive graphs were dropped, and significant waves were taken for further analysis. Thereinafter the regression analysis was conducted to get the best fit estimated line for each index, assuming the linear relationship between construction costs along with the time. Given that, the assumption was more likely to be real when compared to the long-term trend on actual data. Then, the cycles were formed considering the difference between actual cost index and cost index predicted by long term linear trend. Because of that, periodical trends and cycles were formed without the seasonality. An extensive analysis was conducted on formed cycles while detecting patterns, turning points and dispersions in every graph. Furthermore, smoothing techniques of moving average on double (2), triple (3) and quintuple (5) in time series analysis, were drawn on cycles when necessary to highlight the trends and cyclical regularities. Out of drawn moving averages on cycles most accountable trendline was taken to the next analysis. As to reduce the complexity of presenting the findings, similar trends and patterns were grouped by considering significant familiarities as in whole, even when patterns were not exactly the same. The number of formed groups was twenty. Aside from that, materials were further evaluated along with the related products and raw materials, importing and regulated materials.

Finally, the identified political events' timeline was pinned on grouped graphs. In findings, the results of the quantitative analysis were discussed and interpreted with the identified timeline pins in qualitative analysis.

4 ANALYSIS AND DISCUSSION

The study was focused on 'major' political events in Sri Lanka. Since there has not any other clean bottom line of defining such political events that happened within the country, the events given in Table 4.1 were used as the major events for the analysis. The overall findings of the study were given later.

Table 4.1 Major Political Events

Ref. No.	Major Political Events	Date
I.	6th Presidential Election	26.01.2010
II.	Parliamentary Election	08.04.2010 & 20.04.2010
III.	Local Government Election	17.03.2011, 23.07.2011 & 08.10.2011
IV.	Eastern Provincial Election	08.09.2012
V.	North Central Provincial Election	08.09.2012
VI.	Sabaragamuwa Provincial Election	08.09.2012
VII.	Central Provincial Election	21.09.2013
VIII.	Northern Provincial Election	21.09.2013
IX.	North Western Provincial Election	21.09.2013
X.	Western Provincial Election	29.03.2014
XI.	Southern Provincial Election	29.03.2014
XII.	Uva Provincial Election	20.09.2014
XIII.	7th Presidential Election	08.01.2015
XIV.	8th Parliamentary Election	17.08.2015
XV.	Local Government Election	10.02.2018
XVI.	8th Presidential Election	16.11.2019

Analysis was executed on several stages to get the best outcome at last. Initially the long-term trend was considered. Almost many graphs had overall upward trends throughout the decade except the followings.

Table 4.2 Downward Trend Materials

Type	Duration (Q = Quarter)
Hume Pipe	1st Q 2010 -1st Q 2012
Zink Aluminium Sheets	4th Q 2015 – 4th Q 2016
Bitumen 80/100 (Using Drum Price)	4th Q 2010 – 3rd Q 2011 3rd Q 2014 – 2nd Q 2016
Fuel	3rd Q 2014 – 1st Q 2018

As per the world bank inflation data, 2012 and 2017 were critical years where the inflation rate soared. And 2014 year had a lower inflation rate in Sri Lanka. Therefore, it was likely to be that, materials which had been occurred a downward trend like in Bitumen, Hume Pipe and Fuel may because of the inflation. Specially for Cement, it was mainly floated with policy changes as it has been a regulated price in Sri Lanka. That could have been the reason for drastical drop in 2015, where a new government was appointed. Similarly, the fluctuation of Fuel would be caused due to the same fact that acts of the government.

Apart from the aforementioned, Cement and related products were recorded sudden decline of price by 1st Q 2015. Similarly, below types of construction prices were shown dramatic shifts in long run upward trends.

Table 4.3 Shifts Along Long Term Trends

Type of Construction	Period
Water Supply and Drainage	4th Q 2011 – 4th Q 2012
Road Works	4th Q 2011 – 1st Q 2016
All Civil Works	4th Q 2011 – 1st Q 2016

Especially for Road Works and All Civil Works, the middle part of the trend could be considered as a shift to the usual, comparing the besides two end paths' trends. However, all these shifts were occurred due to the emergent rise and dip. Those were happened in long term because of the political background as mentioned earlier. As a result of the developments of infrastructure projects in the areas which were affected by terrorism, the demand for construction was arisen by 2011. And this was continued to the commercial city of Colombo latter, but with a different perception of developments (tourism) while commencing landmark projects and road development projects in urban and suburban areas. This boom was represented even in cycles of some building materials with a shock.

Following indices were dropped from further analysis as they have been levelled off for more than three years even without being regulated by the government nor logically justifiable trends.

- Electrical Wiring
- Cadjan
- Geo-Textile
- Small Equipment
- Heavy Equipment

By perceiving the results of overall cyclical trends, the indices were grouped together in which mix of degree of smoothing in one group. This would not cause doubts in reliability, because smoothing was done only to achieve the best fit trendline of scattered indices' prices.

Table 4.4 Grouped Elements

Type of Index	Group No.	Included Indices
Materials	Group 01	Sand, Bricks (Hand cut), Bricks (Machine cut), Calicut Tiles, Formwork Timber, Electrical Fittings, Earth
	Group 02	Cement Blocks, Rubble, Metal, Sanitaryware (Imported), Timber Products, Terrazzo, Floor Tile, Granite Tiles, Coloured Pigment, Ready Mixed Concrete, Metal Dust
	Group 03	Reinforcement Steel, Wall Tiles, High Tensile Steel Wire, Pre-stressed Bridge Beams, Chain Link Fence
	Group 04	Glass, Wall Paint
	Group 05	GI Sheets, General Timber, Aluminum Ceiling, Concrete Lamp Post, ABC Road Metal
	Group 06	Cement (Local – Exfactory Prices), Cement (Imported), Cement (Local – Market Price), Cement (Weighted Average), Cement Concrete Roof Tile
	Group 07	Asbestos Roofing Sheets, Asbestos Ceiling, Door & Window Fittings
	Group 08	Lime, Sanitaryware (Local), Wood Paint
	Group 09	Structural Steel, PVC Pipes, Aluminium Doors, Windows and Partitions, Stainless Steel
	Group 10	Precast items for Bridges, Roads and Building Components, Hume Pipe
	Group 11	Bitumen 80/100 (Using drum price), Bitumen 80/100 (Using bulk price), Bitumen 60/70 (Using drum price, Bitumen 60/70 (using bulk price)
	Group 12	Zink Alum Sheets
	Group 13	Ductile Iron Pipe
	Group 14	Gabion Box, Road Marking Paint
Labour	Group 15	Skilled labour, Semi-Skilled Labour, Unskilled Labour
Plant and Machinery	Group 16	Fuel
Types of Constructions	Group 17	Modern Housing, All Housing, Non-Residential Building, Irrigation Minor
	Group 18	Irrigation Major, Other Civil Works, All Civil Works
	Group 19	Road Works, Water Supply and Drainage
	Group 20	Semi-Permanent Housing

The observations of line graphs of above Grouped Elements in Table 4.4 were listed below.

- Group 01 had recorded changes around in 2011 and 2012 last quarters, and mid of 2015 and 2018 years. Only Electrical Fittings' prices had changed in the year 2017 out of all group members.
- Group 02 indices' prices were got changed mainly in 2011, 2013, 2017 and 2018.
- High Tensile Steel Wire and Pre-stressed Bridge Beams' indices stayed stable in 3rd quarter of 2015 to 1st quarter of 2016. All materials in Group 03 had a significant turning at 3rd quarter of 2018. However, in 2014 and 2015 had no directional changes in graphs.
- Prices of Wall Paints were more fluctuated than prices of Glass while all Group 04 materials had turning points in every year from 2011 to 2018 except 2014.
- Rubble in 3rd quarter of 2015 to 2nd quarter of 2016 and Terrazzo in 3rd quarter of 2016 to 2nd quarter of 2017 recorded a slight deviation from the regular long-run pattern of prices.

- In Metal, it was noted that graphs were switched mostly in 2013 and 2018. Another significance was that all graphs maintained the long-term trend in 2014 and 2015 without altering. As well as, all asbestos related materials had alike pattern changes.
- Precast items for Bridges, Roads and Building Components, Hume pipe presented very much similar patterns.
- All bitumen related materials took the same graph but Bitumen 80/100 (using bulk price) had slightly dropped in 2nd quarter of 2013.
- Ductile Iron pipe and ABC Road Metal had totally different graph compared to all other materials. Hence, those two were left alone.
- Gabion box and Road marking paint materials were started to use recently. Therefore, both graphs started late in 2011 and early 2014 respectively.
- All labour indices were taken in the same pattern.

Aside from the above-grouped graphs following diagrams were plotted to study further on noticed, and critical observations.

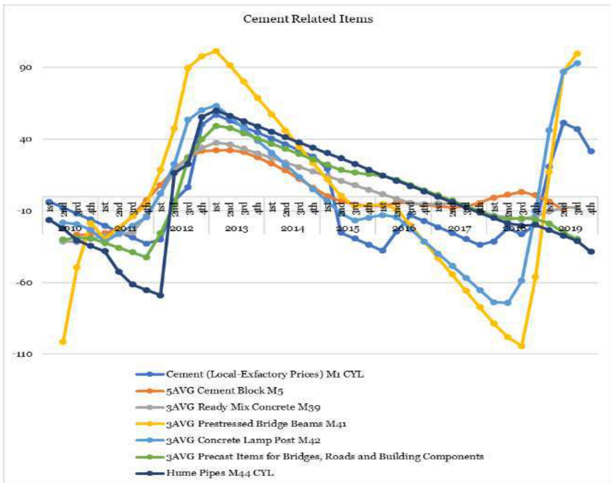

Figure 4.1 Cycles on Cement Related Products

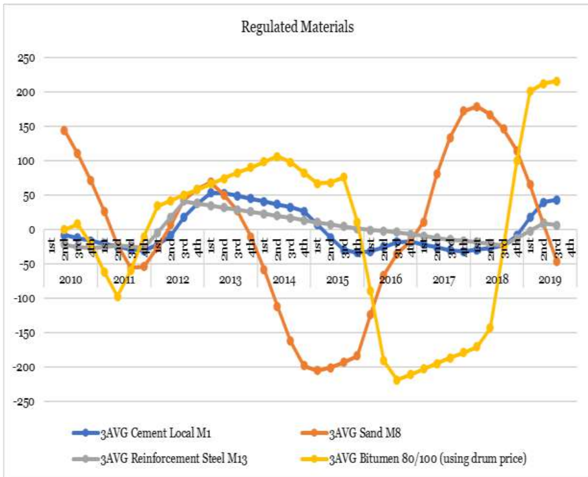

Figure 4.2 Cycles on Regulated Materials

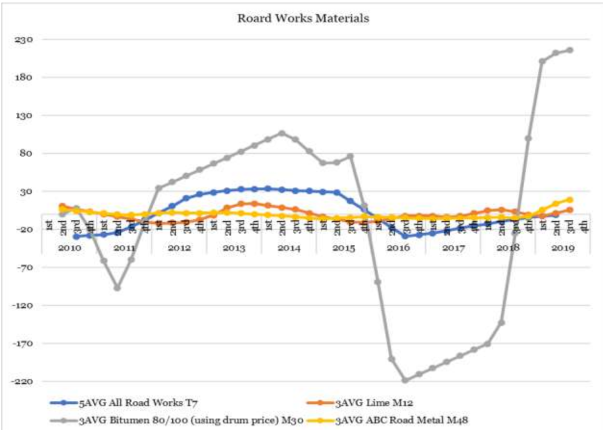

Figure 4.3 Cycles of Road Works Materials

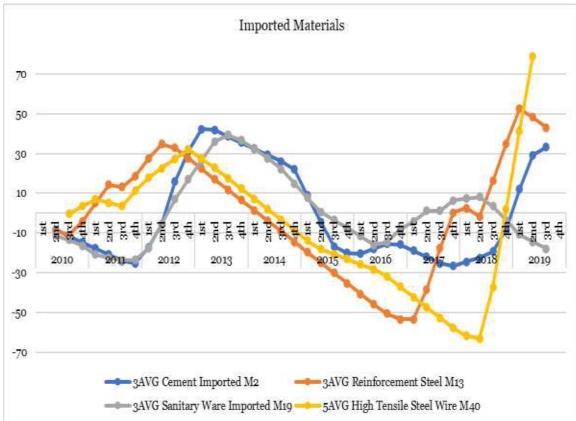

Figure 4.4 Cycles of Imported Materials

Figures from 4.1 to 4.4 shows various relationships among indices. In figure 4.1, though the M44 had followed M1 pattern changes in 2012 to 2013 and it was not continued from 2015. Both graphs in figure 4.2 and 4.4 did not provide a clear indication of the relationship, even those were labelled under two general categories. This would be again because of the policy and regulatory changes, with the changes in ruling party, the policies and acts that get updated from time to time. Even though the changes in indices occurred due to policy changes, it can be argued that, these policy changes have happened as a result of the political events (changing in government).

Apart from that, many materials had a likelihood boost from last quarter in 2018 to early 2019. At this period the political situation in the country was not stabled because of that upheaval political event on the bond scam. The local currency value was steadily fallen during the period and citizens were got impacted. It seemed that a country like Sri Lanka would react to the occurrence of such political events either directly or indirectly which can be stated out that, it is not necessarily only to be happened because of policy changes.

The results from time series data analysis were observed along the pinned timeline of major political events. As a holistic view of outcomes of the above data analysis, it was observed that most of the indices' patterns were swapped in 2011, 2013 and 2018. Both in 2011 and 2018 the local authorities' elections were held island-wide. Overall results in both elections terms were not changed with the comparison of right before previous election results but in 2018 winning party was neither from president nor prime minister's party. In 2013 provincial election was happened for the provinces of Central province, Northern province and Northern Western province. The majority party was unchanged in all provinces, in both the terms but some elected minorities were changed in both years. Whereas Northern province was not called out for an election in 2008 to 2009 as there was a civil war.

5 CONCLUSIONS AND REFLECTIONS

With the findings of the study, it can be concluded that, there are no specific patterns and regularities of the construction costs upon political events in Sri Lanka that can be systematically incorporated into construction cost forecasts in the local industry. Therefore, to the practice of Quantity Surveying, it is not recommended to make any specific construction cost or price adjustments on account of political events, but include them within undefined contingencies. However, it could be highlighted that cyclical patterns lasted for 4 to 6 (i.e. on average 5) years' time spans, and some fluctuations within these cycles have significantly deviated from the average trend. Hence, the significant cyclical fluctuations that seems to be occurred over the average trend shall be carefully attended in making forecasts for the improvement of accuracy in pricing and budgeting.

Therefore, the findings however do not deny the impact of political events on construction costs. The observed average cycle of construction costs was found to be 5 years. Interestingly, the political cycles in Sri Lanka are also 5 years on average. Since current literature also points to a potential link, though indirect. The academic interest should continue to better understand this complex causal mechanism. A qualitative study would help deeper understanding of this complexity. Due to lack of generalizability, it may not offer a direct solution to the research problem in this study, yet it may present a pathway to find an appropriate solution.

As a spill over knowledge, the study showed interesting relationships in price fluctuation patterns among some construction inputs. This knowledge can be expanded further to improve the accuracy of construction cost forecasting.

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Conflicts Handling Styles Used by Professionals at Pre-Contract Stage of Building Construction Projects in Sri Lanka

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ABSTRACT

Conflicts between design team professionals is a common experience in building construction projects in Sri Lanka. Depending on the way they are been handled, these conflicts bring either positive or negative impacts to the project. Thus, this paper investigates the conflict-handling styles that the professionals use to handle different types of conflicts among themselves at pre-contract stage of construction projects in Sri Lanka.

The study on different types of conflicts and handling styles were derived through quantitative approach by a questionnaire survey designed incorporating Rahim's Organisational Conflict Inventory-II (ROCI-II) with the participation of 42 number of professionals engaged during the pre-contract stage of building construction projects in Sri Lanka. The scope of the study was limited to the building construction projects and only to the conflicts among professionals at the same level. The collected data were analysed using descriptive statistics.

The research findings revealed that there are four types of conflicts: task, relationship, process and status conflicts, occur in different frequencies among the professionals. The task conflicts occur very often, and process conflicts occur often whilst relationship and status conflicts occur rarely among professionals during the pre-contract stage. This study revealed that professionals use different conflict handling styles to handle these four types of conflicts among themselves during the pre-contract stage of building construction projects in Sri Lanka. Further, majority of professionals use integrating style often to handle conflicts among themselves, and they use avoiding style very rarely to handle the conflicts among themselves except for relationship conflicts. However, to handle relationship conflicts, professionals use dominating style as the last option.

The study would assist the industry practitioners to identify their personnel conflict handling style and the outcome of using each style with their supervisors when handling conflicts during the pre-contract stage.

KEYWORDS: *Conflicts, Conflict-Handling Styles, Conflicts With Professionals, Construction Industry, Pre-Contract Stage.*

1 INTRODUCTION

Conflicts have been developed as a fundamental behaviour of human beings (Slabbert, 2004) and they are inevitable in the human lifestyle (Rahim, 1986). Conflicts have an impact on individuals, teams as well as organisations. In an organisational context, conflicts reduce the productivity, the satisfaction of the employees and impact the routines of production. However, it also enhances the quality of decision making, performance and the creativity of the products by contributing to the progress of the productivity and the organizational culture (Jehn, 2005). In contrary, unaddressed conflicts lower the moral, job satisfaction and increase the tension between individuals resulting a poor working environment (Hastings, Kavookjian, & Ekong, 2018). Thus, in an organisational view, recognising and

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addressing conflicts properly may bring benefits to the organisation as well as to the personals involved (Silverthorne, 2005).

With the unique nature of construction projects, conflicts appear as a common problem (Zhu, Wang, Yu, & Yang, 2020) in every construction project. It compels the project stakeholders to accept conflicts and manage them (Zhang & Huo, 2015). Improper management of conflicts could lead the construction workforce to cause loss of opportunities (Brown, 1983). On the other hand, ignorance of conflicts could lead to problems with serious impacts on the project as well as on the relationships maintained throughout the years (Augsburger, 1992). However, a study on Chinese construction projects revealed that inter-organisational conflicts with moderated conflict management strategies add value to construction projects (Wu, Zhao, & Zuo, 2017). Another study has shown that intra-group conflicts boost innovation, constructive decision providing, learning and development opportunities for different levels of construction industry (Senaratne, Udawatta, & Gunasekara, 2013).

There are many dynamics to construction conflicts. Recognizing these dynamics and signifying the relationships among them at the beginning may assist the project stakeholders to study the conflicts and address them accordingly (Charkhakan & Heravi, 2019). Therefore, as a phase that decide the fundamentals and a stage that arrive at important decisions, hassle free environment during pre-contract stage of a construction project is very crucial. Thus, the multidisciplinary team engaged in pre-contract stage has a great influence over the success of the project (Senaratne, Udawatta, & Gunasekara, 2013).

However, when handling conflicts, the management has to choose the most suitable conflict handling style that brings the best solution to the conflict (Ogunbayo, 2013), as it assists to meet the set goals and objectives as planned. Therefore, each conflict should be handled carefully by using the suitable conflict handling style. In comparison with other sectors, due to complex nature, construction industry has become a fertile ground for conflicts. However, only few studies have been offered investigations on construction conflicts and conflicts handling styles, identifying their impacts on different aspects both in global and local construction contexts.

In terms of global construction context, impact of conflicts on cross-functional project team innovation (Guo H. , Zhang, Huo, & Xi, 2019), impacts of conflicts on project team motivation in Nigerian construction industry (Ogunbayo, 2013), impacts of conflicts on construction project added values in Chinese construction industry (Guangdong, ZhaoJian , & Zuo, 2017) can be identified. Considering the local context, conflicts and management styles in Sri Lankan commercial building sector (Gunarathna, Yang, & Fernando, 2018) and intragroup conflicts in the pre-contract stage of construction projects (Senaratne, Udawatta, & Gunasekara, 2013) can be highlighted.

With the alliance of professionals in different disciplines, conflicts in pre-contract stage, can heavily impact the success of the project. Considering the Sri Lankan construction projects, conflicts have become a common experience (Senaratne, Udawatta, & Gunasekara, 2013). In terms of Sri Lankan construction industry, three types of conflicts, i.e., task conflict, process conflict and relationship conflict are highlighted by the previous research (Gunarathna, Yang, & Fernando, 2018; Senaratne, Udawatta, & Gunasekara, 2013).

In spite of time-tested conflict management styles that use to handle these conflicts, in the local context, the sensibleness, pertinence, and appropriateness of each style in each project get varied as they may cause different consequences that affect the progress of the project. Among the research conducted on construction conflicts, a gap is observed in examining the conflict handling styles that address different types of conflicts during the pre-contract stage of Sri Lankan building construction projects. Thus, this study aims to investigate the conflict-handling styles used by professionals at pre-contract stage of building construction projects in Sri Lanka.

2 LITERATURE REVIEW

2.1 An introduction to conflict

Conflict is a common phenomenon to every individual's life and unable to avoid at any cost (Hussein, Al-Mamary, & Hassan, 2017). Throughout these years, many authors have taken attempts to define the concept of conflict using different parameters. Different interests, technical proficiency, environment and precedence of stakeholders, a conflict can mold with different framework, political and statutory influence, economic, cultural and social background to name a few (Irfaan, Thaheem, Gabriel, Malik, & Nasir, 2019). However, the modern model identifies the conflict as a concept that deals with functionality of the person or the organization that impacts to its growth (Alper, Tjosvold, & Law, 2000). Considering the fact, based on their outcomes and processes, several researchers have introduced different classifications of conflicts.

Conflicts can be natural and functional. At the same time, it can be constructive or unnatural. In contrast, it can also be dysfunctional, destructive and unproductive (Gardiner & Simmons, 1992). Conflicts among individuals and groups can appear as an interpersonal conflict, intrapersonal conflict, intra-group conflict or intergroup conflict (Axley, 1996). Adding more to this classification, it was found that except for the above four types, it can also appear as an inter-organizational conflict (Thakore, 2013). In another perspective, conflicts can be collaborative and competitive (De Dreu, 2007). It also can be classified as cognitive and affective (Amason & Sapienza, 1997) or functional and dysfunctional (Gorse, 2003). Conflicts can bring either a positive or a negative impact depend on the way they are being handled (Johari, Morni, Bohari, & Sahari, 2013). In terms of organizational conflicts, addressing these conflicts consist of a series of tasks that begins with diagnosis, intervention at different levels and use of conflict handling styles to handle them (Rahim, 2003).

Considering the different sectors of the world, construction industry and the construction projects are also considered as vulnerable grounds for conflicts. Thus, these temporary multi-organizations can be impacted constructively or destructively by different types of conflicts (Tabassi, Abdullah, & Bryde, 2019). Among the attempts taken to classify construction conflicts, one of the classifications that widely used is task conflicts, relationship conflicts and process conflicts (Jehn & Mannix, 1997; Senarathna and Udawatta, 2013; Gunarathna, Yang, & Fernando, 2018). Adding more to this classification, Bendersky and Hays, (2012) identified the fourth type as status conflicts (Bendersky & Hays, 2012). The speedy development of construction industry had led itself into interorganizational conflicts (Tabassi, Abdullah, & Bryde, 2019) and branded as being vulnerable to conflicts (Ofori, 2013).

2.2 Types of conflicts

A ***task-based conflict*** can create due to a disagreement on a decision taken, due to different perspectives and opinions, personnel insights among the members of the group or individuals (Rahim, 2002; Suifan, Alhyari, & Sweis, 2019). It assists wise decisions, strategic planning (Amason, 1996), improves innovation (Kiernan, Ledwith, & Lynch, 2020) and facilitates information flow among the group members whilst enhancing the group's effectiveness (Zhang & Zhang, 2012; Kiernan, Ledwith, & Lynch, 2020). However, task conflicts could make serious impacts on the satisfaction of team members. They could also strengthen the conflict and reduce the functionality of the team as they are not directly associated with affective reactions (Jehn, 1995). ***Relationship conflicts*** are sequential and re-occur very often among parties to the conflict (Jehn, 1995). They are linked to the disagreements or incompatibilities of individuals on emotional grounds (Suifan, Alhyari, & Sweis, 2019). It negatively impacts the ability of thinking and analyzing new information (Jehn, 1995). Individuals with relationship conflicts feel destructive, doubtful, annoyed, or angry (Rahim, 2002). therefore, it can delay the performance (Shawa , Lello, & Ntiyakunze, 2018) and bring irresolvable issues, affect decision quality and reduce the commitment to the group (Roloff, Miller, & Malis, 2007). ***Process conflicts*** create due to mismatch of opinions on the method of the work to be carried out (Suifan, Alhyari, & Sweis, 2019). Poor communication, failure to obey rules and regulations, unable to agree on methods of work, distribution of workload, issues in scheduled work are the key causes of process conflicts that mainly related to contractual documents (Gunarathna, Yang, & Fernando, 2018). Process conflicts could lower satisfaction (Suifan, Alhyari, & Sweis, 2019) and lead the group to inefficiency. ***Status conflicts*** occur due to the attempts taken to secure or promote individual's own status. (Bendersky & Hays, 2012). The key reason for status conflict is the disagreement on the extent of dominance experience in the social life of an individual (Gould, 2003). Since a construction project is considered as a temporary multi-organization (Gonzalo, de Blois, & Latunova, 2011), these four types of conflicts that describes the behavior of individuals in an organizational context is used for further analysis of conflict handling styles used by the professionals during per-contract stage of building construction projects in Sri Lanka.

2.3 Conflicts in Pre-contract stage

In the perspective of construction industry, a construction project creates more conflicts among the different stakeholders assigned and within the project itself from the beginning to its end (Irfaan et. al, 2019; Zhu et. al, 2020). These conflicts create different forms in different stages throughout its life cycle (Wu, Zhao, Zuo, & Zillante, 2017). Among these conflicts, the conflicts between design entities can make a significance impact on the performance schedule (Safapour, Kermanshachi, Nipa, & Kamalirad, 2019). In exchanging of resources, knowledge and information, due to the complexity and multidisciplinary involvement, the project participants get into various conflicts during the project implementation stage (Wu, Zhao, & Zuo, 2017). Conflicts can occur due to stakeholders of the pre-contract activities (Shin, 2005). The effect of these conflicts on the members of the team can impact the construction project either positively or negatively (Tabassi et. al, 2019). Poor communication, lack of trust and misinterpretation of contract, unawareness of their roles and responsibilities, poor risk management in the contract, mainly lead the construction projects and its team to conflicts in the pre-contract stage (Shin, 2005).

2.4 Conflict handling styles

Conflicts can be handled using different conflict handling styles (Rahim & Magner, 1995). Depending on the conflict management style used, the outcome can either be positive or negative (Wang, Wu, Gu, & Hu. L., 2021). However, the general idea of all these management styles is to minimize the negative effects whilst maximizing the positive effects on the parties engaged (Rahim & Magner, 1995). Examining its' nature, outcome and impacts, many researchers have introduced different techniques to control these conflicts (Johari, Morni, Bohari, & Sahari, 2013). Corporation and Competition Model by Deutsch (1949), Knudson, Sommers and Golding Theory (1980), Mary Follet Theory (1940), Putnam and Wilson Theory (1982), Blake and Mouton Managerial Grid (1964), Thomas and Kilmann Two-dimensional Model (1976), Rahim Model (1985) and Pruitt and Rubin Model (1986) to name a few. Among them, Rahim's two-dimensional model developed referring the theory of Blake and Mouton managerial grid (1964) and Thomas-Kilman two-dimensional model (1976), analyses the concern on our self against on others with five conflict handling styles. They are ***integrating style:*** trying to arrive at a solution by valuing both goals and relationships, ***obliging style:*** arriving at a solution valuing relationship over goals, ***avoiding style:*** *v*alue avoiding the conflict over their goals or relationship, ***compromising style***: attempting to arrive at a solution concerning both their goals and relationships moderately and ***dominating style:*** trying to find a solution valuing their goals over relationships (Rahim, 1985). Among them, significant number of researchers of conflict management regard the Rahim's two-dimensional model as a successive mode of discussing the behavioural pattern of individuals as it claims user friendliness, unambiguous interpretation and fruitful predictions comparing to other theories. It provides a clear picture as well as firm yet flexible approach for conflict management (Gunarathna, Yang, & Fernando, 2018). Thus, this study used the Rahim's two-dimensional model to analyze the usage of conflict handling styles by the professionals during the pre-contract stage of building construction projects in Sri Lanka.

2.5 Conflict handling instruments

To study the behavioural patterns of individuals and groups against set of conflict handling styles discussed in different models, many researchers have developed conflict handling instruments. Hall's Conflict management survey (Hall, 1969), Thomas and Kilmann's MODE: Management of Difference Exercise (Thomas and Kilmann, 1974), Putnam and Wilson's Organizational Communication Conflict Instrument (Putnam and Wilson, 1982), Ross and DeWine's Conflict Management Message Style Instrument (Ross & DeWine, 1982), Rahim's Organizational Conflict Inventory (ROCI) (Rahim,1983) to name a few. Among these, the commonly used Rahim's Organizational Conflict Inventory-II (ROCI-II) measures how the members of the organization handle conflict with Supervisor, peers and subordinates through a questionnaire consist of 28 phrases. The questionnaire discloses the personnel conflict handling style that an individual would naturally use to handle conflicts with others (Rahim,1983). Hence, this research used the well established ROCI-II as the basis for the data collection to achieve the research aim.

3 METHODOLOGY

With the knowledge gathered through a comprehensive literature survey on conflict types, conflict handling styles and instruments, the research was continued further with the quantitative approach to examine the resistance of different types of conflicts against the frequency of usage of conflict handling styles established by Rahim (1985). The study was focused on the conflict types and their handling styles used by the professionals during the pre-contract stage of building construction projects in Sri Lanka. Since conflict is a global concept and solely depend on the individual preference, a questionnaire was developed to identify the individual preference of conflict handling styles. The questionnaire was designed, incorporating the ROCI-II, Form C – handling conflicts with professionals at the same level (peers), a pre-defined and time-tested questionnaire on the behaviour of individuals in handling conflicts. It is designed to measure the conflict handling styles in an organizational context. Further, ROCI-II is a simple and a time saving instrument that a reader can easily fill out.

The questionnaire was distributed among 67 construction industry professionals (Adjudicator, Architects, Cost Managers, Engineers, Project Managers and Quantity Surveyors) engaged in pre-contract stage of building construction projects in Sri Lanka, selected through purposive sampling. However, only 42 out of 67 questionnaires returned back. In assessing the occurrence of different types of conflicts and usage of different conflict handling styles when handling conflicts between peers during the pre-contract stage of building construction projects, two different 5-point Likert scales were introduced as shown in Tables 1(a) and 1(b) respectively.

Table 1(a): Likert scale for assessing occurrence of different types of conflicts

	Value	Range
Never	1	1.00 – 1.80
Very rare	2	1.81 – 2.60
Rare	3	2.61 – 3.40
Often	4	3.41 – 4.20
Very often	5	4.21 – 5.00

Table 1(b): Likert scale for assessing usage of different conflict handling styles

	Value	Range
Strongly disagree	1	1.00 – 1.80
Disagree	2	1.81 – 2.60
Moderate	3	2.61 – 3.40
Agree	4	3.41 – 4.20
Strongly agree	5	4.21 – 5.00

The collected data were analyzed using mean, standard deviation (SD), frequency and percentage counts to study the usage of conflict handling styles used by professionals to handle different types of conflicts with other professionals in the same level during the pre-contract stage of building construction projects of Sri Lanka.

4 DATA ANALYSIS

4.1 Demographic Information of Respondents

The respondents were professionals of construction industry engaged in the pre-contract stage of building construction projects in Sri Lanka. Table 2 shows the classification of respondents and their number of years of experience in construction industry.

Table 2: Classification of professionals against the years of experience in construction industry

Experience	Engineer	Architect	Quantity Surveyor	Project Manager	Cost-Manager	Adjudicator
< 5 Years	3					
5 - 10 Years	3	2	12		1	
11 - 15 years	3		5			
16 – 20 years	1		4	1		
> 20 Years	1		4		1	1

According to Table 2, the highest number of (42%) of professionals possess, 5 to 10 years of experience in the construction industry followed by 19%, 16%, 14% and 7.14% possess 11-15 years, 16-20 years, over 20 years and below 5 years of experience, respectively.

From the collected data, the experience of different professionals in pre-contract stage of the construction industry is graphically illustrated in Figure 1.

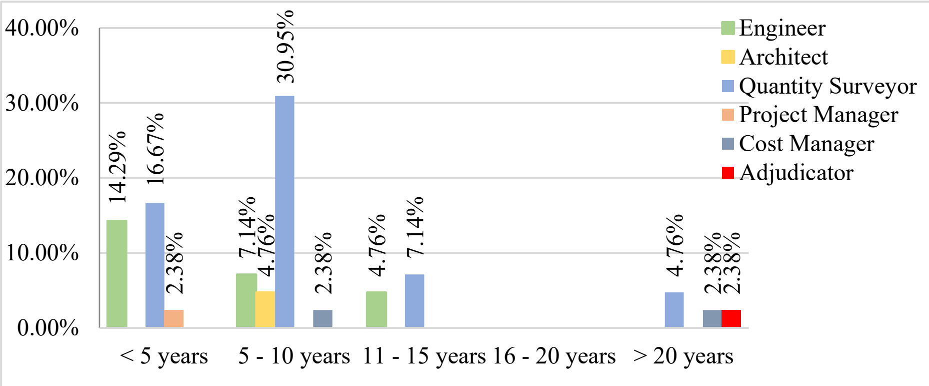

Figure 1: Classification of professionals against the years of experience in pre-contract stage

Figure 1 indicates that the majority of 45.23% of professionals possess 5-10 years of experience in the pre-contract stage of building construction projects. However, no professional possesses 16-20% years of experience. Further 9.52% of the professionals have more than 20 years of experience in the pre-contract stage.

According to Table 3 given below, 78% of professionals experience conflicts with their peers and over 90% of professionals have experience in resolving the conflicts with their peers.

Table 3: Experience of having conflicts and resolving with peers

	Experience of having conflicts	**Experience in resolving conflicts**
With Peers	78.57%	90.48%

4.2 Handling disagreements of conflicts with peers

To investigate the behaviour of the construction industry professionals engaged in pre-contract stage, when handling conflicts with their peers, ROCI-II - Form C was used. ROCI-II contains 28 phrases that study the behaviour of professionals handling conflicts with their peers. To determine the general conflict handling style, by score, a scoring key with five independent dimensions is given. The observations of professionals' behaviour during handling the conflicts with their peers is summarised in Table 4.

Table 4: Average agreement for usage of ROCI-II phrases against conflict-handling styles

Phrase		Mean	SD
Integrating			
1	I try to investigate an issue with my other party to find a solution acceptable to us	4.02	0.30
5	I try to work with my other party to find solution to a problem that satisfies our expectations	3.90	0.39
12	I exchange accurate information with my other party to solve a problem together	4.07	0.40
22	I try to bring all our concerns out in the open so that the issues can be resolved in the best possible way	4.24	0.41
23	I collaborate with my other party to come up with decisions acceptable to us	4.10	0.40
28	I try to work with my other party for a proper understanding of a problem	4.14	0.39
Obliging			
2	I generally try to satisfy the needs of my other party	4.00	0.38
11	I give in to the wishes of my other party	3.14	0.34
13	I usually allow concessions to my other party	3.17	0.42
19	I often go along with the suggestions of my other party	2.74	0.33
24	I try to satisfy the expectations of my other party	3.24	0.38
Dominating			
8	I use my influence to get my ideas accepted	3.12	0.36
9	I use my authority to make a decision in my favor	3.17	0.35
18	I use my expertise to make a decision in my favor	2.93	0.28
21	I am generally firm in pursuing my side of the issue	2.71	0.30
25	I sometimes use my power to win a competitive situation	3.26	0.33
Avoiding			
3	I attempt to avoid being "put on the spot" and try to keep my conflict with my other party to myself	3.26	0.36
6	I usually avoid open discussion of my differences with my other party	3.07	0.28
16	I try to stay away from disagreement with my other party	3.31	0.33
17	I avoid an encounter with my other party	2.69	0.35
26	I try to keep my disagreement with other party to myself in order to avoid hard feelings	3.24	0.36
27	I try to avoid unpleasant exchanges with my other party	3.33	0.37
Compromising			
4	I try to integrate my ideas with those of my other party to come up with a decision jointly	2.95	0.33
7	I try to find a middle course to resolve an impasse	3.43	0.40
10	I usually accommodate the wishes of my other party	3.64	0.41
14	I usually propose a middle ground for breaking deadlocks	3.52	0.41
15	I negotiate with my Supervisor so that a compromise can be reached	3.81	0.41
20	I use "give and take" so that a compromise can be made	3.40	0.38

Table 4, to handle conflicts between them and their peers , professionals use all five styles of Rahim's two-dimensional model during the pre-contract stage of building construction projects in Sri Lanka. Moreover, the phrases under integrating style claim over all high mean values comparing to the phrases under other conflict handling styles.

4.3 Frequency of the occurrence of types of conflicts during the pre-contract stage of a construction project

Figure 2 and Table 5 show the frequency of occurrence of conflicts during pre-contract stage of construction projects.

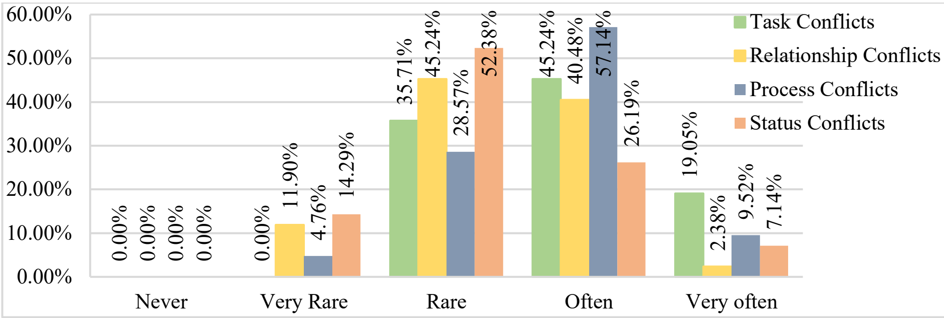

Figure 2: The occurrence of types of conflicts during the pre-contract stage of Sri Lankan building projects.

Table 5: Average of occurrence of different types of conflicts during pre-contract stage of Sri Lankan building construction projects.

Type of Conflict	Average of occurrence during pre-contract stage (w.a.)
Task Conflicts	3.83
Relationship Conflicts	3.33
Process Conflicts	3.71
Status Conflicts	3.26

During the pre-contract stage of building projects in Sri Lanka, task conflicts are the most common types of conflicts that occur very often. The process conflicts occur often. However, the data reveals that the status and relationship conflicts are rare during the pe-contract stage.

4.4 Frequency of conflict-handling styles used to resolve the types of conflicts with Peers

Table 6 shows the frequency of usage of different conflict handling styles used to handle different types of conflicts by the professionals during the pre-contract stage of building construction projects.

Table 6: Frequency of conflict-handling styles used to handle status conflicts.

Type of conflict	Integrating style	Obliging style	Dominating style	Avoiding style	Compromising style
Task Conflicts (w.a.)	3.67	2.88	2.71	2.45	2.74
Relationship Conflicts (w.a.)	3.38	2.90	2.50	2.52	2.83
Process Conflicts (w.a.)	3.67	2.88	2.71	2.43	2.81
Status Conflicts (w.a.)	3.52	2.74	2.71	2.48	2.69

Table 6 indicates that professionals often use integrating style to handle task conflicts with their peers. Moreover, it signifies that obliging style, compromising style and dominating styles are rarely used in the pre-contract stage. However, avoiding style is rarely used in handling task conflicts. In terms of relationship conflicts, professionals rarely use integrating, obliging and compromising styles and very rarely use avoiding and dominating styles to handle conflicts with their peers during pre-contract stage.

According to data, to resolve process conflicts with their peers, professionals often use integrating style and very rarely use avoiding style. However, data indicates obliging style, compromising style and dominating styles are used rarely to handle conflicts during the pre-contract stage. In terms of status conflicts, professionals use integrating style often, whilst they use obliging, dominating and compromising styles rarely. Moreover, the data indicates that they very rarely use avoiding style to handle status conflicts with their peers.

5 DISCUSSION

Construction industry is a pool of conflicts and they are common in every construction project. It also indicates that professionals experience different types of conflicts with their peers during the pre-contract stage of building construction projects. Reinforcing the research findings, the literature proved that the term conflict and many of the associated concepts and ideas appear as a part of the nature of a construction project (Gardiner & Simmons, 1992). According to the literature, conflicts are classified in terms of their sources, causes, organisational levels of organisations, based on groups, their performance which are relevant to the construction industry. Among these classifications, task conflict, relationship conflicts, process conflicts and status conflicts can identify as a classification that attracts the attention of researchers and also the construction industry practitioners (Bendersky & Hays,2012). Similarly, the research findings indicate that the professionals experience task, relationship, process and status conflicts in different frequencies during the pre-contract stage of building construction projects in Sri Lanka. Furthermore, the research findings indicate that task conflicts occur very often during the pre-contract stage. Accordingly, the literature showed that the members of the team never hesitate to oppose the others believe, attitudes and ideas of tasks related to design and innovation (Kiernan, Ledwith, & Lynch, 2020). Further, the findings indicate that, process conflict occur often among the professionals at the same level. The literature proved that, throughout the task fulfillments, process conflicts emphasize the process differences (Kiernan, Ledwith, & Lynch, 2020). However relationship conflicts and status conflicts appear to be rare in building construction projects in Sri Lanka. Similarly, Gunarathna and team (2018), revealed that due to task related matters, Sri Lankan construction industry faces relationship conflicts (Gunarathna, Yang, & Fernando, 2018).

Moreover, the research findings revealed that, during the pre-contract stage of building construction projects , professionals use all five conflict handling styles of Rahim's two-dimensional model: integrating style, obliging style, avoiding style, compromising style and dominating style in various instances during the pre-contract stage to handle conflicts with their peers. Similarly, the literature indicates that all these five styles are being used to handle conflicts in the Sri Lankan construction industry (Gunarathna, Yang, & Fernando, 2018).According to research findings, the mean scores that include each of five styles in form C (Conflict handling with peers) respectively are integrating: 4.07; obliging: 3.10; dominating: 3.05; avoiding: 3.16; and compromising: 3.60. Similarly, the norm established by Rahim (1983) confirms the mean scores as integrating:4.24; obliging:3.24; dominating:3.16; avoiding:2.72; and compromising:3.59 (Rahim,1983).

In terms of the relationship between conflict-handling styles and types of conflicts with peers, the research findings indicate, professionals use integrating style frequently to handle task, relationship, process and status conflicts with their peers during the pre-contract stage of building construction projects in Sri Lanka. Similarly, the literature proved that integrating is an opportunity of problem solving where every team member is respected by each other that open negotiations (Cheung & Chuah, 1999). It shows the keenness of professionals to maintain their relationships with their peers and at the same time whilst valuing their goals. The professionals use avoiding style seldom to handle task, process and status conflicts with their peers. However, to handle relationship conflicts, the results indicate that professionals use avoiding and dominating styles seldom.Similarly, the literature proved that, compromising, competing and avoiding styles highly distract fruitful results in negotiating (Cheung, Yiu Yiu, & Yeung, 2006). Thus, the statement reinforces the behaviour shown by the professionals when handling conflicts with the same level professionals (peers) during the pre-contract stage of building construction projects in Sri Lanka. Further, the literature indicates that the acceptance of conflict handling styles increases in the scale of dominating, compromising, avoiding, obliging and integrating (Cheung, Yiu Yiu, & Yeung, 2006).

The following Table 7 shows the summary of frequency of usage of conflict handing styles by professionals to handle different conflict types with their peers during the pre-contract stage of Sri Lankan building construction projects.

Table 7: Frequency of usage of conflict-handling styles to handle different conflict types

Conflict Type	Integrating Style	Obliging Style	Avoiding Style	Compromising Style	Dominating Style
Task Conflicts	Often	Rare	Very rare	Rare	Rare
Relationship Conflicts	Rare	Rare	Very rare	Rare	Very rare
Process Conflicts	Often	Rare	Very rare	Rare	Rare
Status conflicts	Often	Rare	Very rare	Rare	Rare

Table 7 indicates the varied preference of professionals of conflict handling styles in Rahim's two-domensional model to handle different types of conflicts with their peers during per-contract stage of building construction projects.

6 CONCLUSIONS AND RECOMMENDATIONS

Immaterial of the extent of experience, conflict is a common concept among every individual and group. Temporary endeavours such as building construction projects can easily create variety of conflicts at the pre-contract stage as it claims the alliance of multidisciplinary professionals at the initial stages to design and plan the building project. The analysis conducted between the different conflict types and different conflict handling styles of professionals at the same level, may assist the professionals to identify their personnel conflict handling style they prefer when handling conflicts with their peers and assess each style and use during different occasions where they are applicable. Further, the study elaborates the behavioral pattern of professionals with different types of conflicts and different styles of conflict handling during the pre-contract stage of building construction projects. Moreover, the study reveals what kind of an impact that they could make on the project by using each style in different situations. Additionally, it confirms that integrating is the best style for a fruitful solution for a conflict occurs between peers. It is believed that the findings would assist the construction professionals to identify the conflicts they encounter with their peers and to go for a fruitful solution by using an effective conflict handling style whilst minimizing the impact on the building construction project.

During the study it was found that there are many research gaps yet to be filled related to conflicts and conflict handling styles. The research findings and conclusions in this research are moderately biased towards the behavioral pattern shown by Quantity surveying professionals during the pre-contract stage of building construction projects in Sri Lanka as the majority of 59.25% of questionnaires received, represents the community of Quantity Surveying. Therefore, the research can also be performed for other design team professionals for further research. As of other areas, Investigation of conflict-handling styles used during the construction stage of building construction projects in Sri Lanka, Investigation of the effect of conflict-handling styles on the satisfaction of design team members during the construction stage of building construction projects in Sri Lanka, can be identified.

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Relationship between procurement systems and payment methods in assuring financial safety in Sri Lankan building projects

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ABSTRACT

The Construction industry is a place where the parties to a project frequently face various risks throughout the project life cycle. Financial risks are one of the aforementioned risks that have a significant impact on parties, and more studies should be conducted to investigate the possibility of minimizing these financial risks and assuring the financial safety of projects. Thus, this research aims at identifying the relationship between procurement systems and payment methods towards assuring the financial safety of construction projects. Researchers selected government funded building projects to limit the scope because such projects frequently deal with financial risks. Frequent financial risks in a Government Funded Building Projects (GFBP) were identified as material shortages, fluctuation of inflation rate, legislation changes. The study used a mixed method approach, and data was gathered through semi structured interviews and questionnaires. Data was analyzed using manual content analysis and basic statistics. Common procurement systems and payment methods available in a GFBP were identified through interviews. Accordingly traditional, design and build, management oriented and collaborative procurement systems were identified and lumpsum, measure and pay, Guaranteed Maximum Price (GMP) and cost reimbursement were identified as payment methods. Furthermore, findings revealed that there are six common combinations between procurement systems and payment methods in GFBP. The identified combinations were further tested for their ability to minimize financial risks of GFBP and it was revealed that the combination consisting of Lumpsum with Design and Build was the best combination to assure financial safety in GFBP. Other combinations are traditional with measure and pay, design and build with lumpsum, design and build with GMP, management oriented with lumpsum, management oriented with measure and pay. Ultimately, a framework has been developed by harmonizing all the research findings in which parties can select the most viable combination to assure the financial safety of their project.

KEYWORDS: *Financial safety, Government funded building projects, Procurement systems*

1 INTRODUCTION

The construction industry is a very complex and unpredictable industry. According to the nature of the construction industry, procurement plays an important role in balancing the expenses of a construction project. Procurement means the process of capturing the goods or services needed to run a business or complete a project successfully (Leadership, 2019). Basically, there are four number of procurement systems. The traditional system, design and build system, management-oriented system and the collaborative system are those systems (Richards, 2006). Proper selection of the procurement system as well as the payment method also affect the success of the project. Payment is described as the

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exchange of money, goods, or services in proportions agreed upon by all parties (Kenton, 2021). Accordingly, there are a few payment methods used in the construction industry namely lump sum, measure and pay, cost reimbursement, and Guaranteed Maximum Price are examples of that (Rodriguez, 2019). Proper payment method selection helps to reduce the cash flow problems in the industry and in absence of such will create a financial risk to the parties. A financial risk is the probability of losing money on an investment or business venture (Hayes, 2021). Furthermore, financial risks are type of threats that could result in monetary losses for those involved (Hayes, 2021). If a project can move forward with less financial risks, it can be identified as a project is with good financial safety.

The government funded building projects in Sri Lanka are frequently experiencing financial risks (Scalisi, 2021). Thus, there is a need to find a mechanism to establish a financial safety net for parties in those projects. Hence, the authors established the research question as, whether a properly allied procurement system and payment method enhance the financial safety of government-funded building projects in Sri Lanka.

Research aim of this study was to identify the relationship between procurement systems and payment methods in assuring financial safety in Sri Lankan government-funded building projects. Research objectives were set as to identify the financial risks in Sri Lankan government-funded building projects, to identify the available procurement systems and payment methods in Sri Lankan government-funded building projects, to identify the most appropriate procurement system and payment method which minimize the financial risks in Sri Lankan government-funded building projects and to propose a framework for identifying the relationship between procurement systems and payment methods in assuring financial safety in government-funded building projects in Sri Lanka.

2 LITERATURE REVIEW

2.1 Financial risks faced by the main parties in a construction project

The construction projects are having different kinds of financial risks and Kolhatkar (2013) identified a few types of financial risks such as, bankruptcy of a project partner, fluctuation of interest rates, fluctuations in the inflation rate, fluctuation of the exchange rate, insurance risk, liquidity risk, variations in material prices, and material shortages. Bankruptcy is the legal status of a company or individual that is unable to repay its debts to creditors (Kolhatkar, 2013). The cost of borrowing money is expressed as an interest rate (Kolhatkar, 2013). Inflation is the gradual loss of a currency's buying value over time (Fernando, 2021). The definition of the exchange rate is, the value of one country's currency in relation to the currency of another country (A. Chen, 2020). If the contractor party or employer party fails to pay the insurance, it becomes a risk for the opposite party (Barone, 2021). As simply, cash in hand means a liquidity risk. The difference between the standard price and the real price for the actual quantity of materials used in manufacturing is known as material price variation (Barone, 2021). In economic terms, a shortage occurs when the amount demanded exceeds the quantity available at the market price (J. Chen, 2021). The payment works in the construction projects is unusual, and it puts a lot of financial risk on the shoulders of construction companies (Budde, 2016).

2.2 Payment methods in construction projects

Payment is defined as the exchange of money, products, or services for goods and services in proportions that have been agreed upon by all parties concerned (Kenton, 2021). There are a few payment methods used in the construction industry. Those are lumpsum, measure and pay, cost reimbursement and guaranteed maximum price. The most basic sort of construction payment is known as lump sum and contracts using these methods are known as "lumpsum fixed price contracts." The lumpsum method provides a single fixed price for every work completed (Finity, 2021). Remeasurement contracts are another type of contracts under payment methods. In remeasurement contracts it basically does the work, measures the work done, and makes the payments. It's useful when the design can be specified in acceptable detail but the amount cannot (Jeyakumar, 2016). A GMP is a cross between a cost-reimbursable and a fixed lumpsum. Contractors are reimbursed for costs incurred when they are incurred, which helps with cash flow (Herbert Smith Freehills, 2015). In cost reimbursement, it allows a contractor to get the personnel and materials needed to complete a project without having to fit those resources into a predetermined price range (Landau, 2021). The payment method selection is linked with the procurement system selection. To ensure an effective construction process, it is essential to select the appropriate payment method in line with the appropriate procurement system.

2.3 Procurement methods in construction projects

Procurement means the process of acquiring the goods, resources, or services needed to run a business or finish a project successfully (Leadership, 2019). When choosing a procurement system, time, cost, and quality parameters should be considered, and the most appropriate procurement system that is safe for contractual parties should be chosen (Rashid et al., 2006). There are four types of procurement systems (Davis et al., 2006). Those are, traditional system, design and build system, management-oriented system and collaborative system. The most prevalent procurement system utilized in the building sector is traditional procurement. Design Bid Build is another name for it (Davis, 2008). This procurement system is mostly used in projects that do not have any special features in their design, like school buildings and hospital buildings etc. Here, the design and construction work are done separately, and the contractor is responsible for only the construction work (Gowrinath, 2016). Design and build system is one of the procurement approaches that is rapidly gaining popularity in order to meet the needs of today's construction employers who want to have a built facility (Gambo & Gomez, 2015). In here, the design and construction stages are overlapped. It has four variants as turnkey, novated design and build, package deal and develop and construct (Luenendonk, 2014). The management-oriented system divided in two types. Those are, management contracting and contract management. Collaborative procurement is a system allowing more than one client, consultant, contractor, or supplier to work together to procure work, services, or goods, share expertise, increase efficiency, and create value for money savings in the performance of projects or service objectives (Burnand, 2009).

2.4 Procurement systems and payment methods in Sri Lankan construction industry

All construction projects were procured via the traditional system in the early 1900s, and it still is with some variations today. The Sri Lankan construction industry has been using "measure and pay" under traditional system domains since the 1970s (Ariyachandra, 2018). That relationship contributes to the success of construction projects. Also, this traditional with measure and pay combination stand with high popularity in Sri Lanka. The design and build procurement system is identified as the second most popular system in the Sri Lanka and the lumpsum payment method is better to use with that (Ariyachandra, 2018). That relationship helps to avoid the unfair excessive profits earnings for all parties. Those are the most popular procurement method and payment method relationships in the construction industry. So, the correct selections help to achieve a successful construction project while avoiding financial risks.

2.5 Assuring financial safety in Government funded building projects in Sri Lanka

Sri Lankan construction industry has strong linkages with other sectors of the economy like urban development, public and private housing, land development, water supply and sewerage, telecommunications, etc. are a few examples of those sectors (Rameezdeen & Ramachandra, 2008). Sri Lankan government was involved in a number of residential, commercial, and mixed-use development projects during the past few years (Nandasena et al., 2021). Most of these projects were affected due to the instability of the country’s economy and the major parties involved for the project suffered financially (Gurtner, 2010).

Thus, it is paramount important to investigate strategies to minimize this financial risk in GFBP for the successful completion of the project. As the procurement system and the payment method of a project plays a vital role in a project success it is worth to examine whether there is any impact for assuring financial safety of the GFBP through a proper selection of procurement systems and payment methods.

3 RESEARCH METHODOLOGY

This research is basically about the relationship between procurement systems and payments in assuring financial safety in Sri Lankan government-funded building projects.

A comprehensive literature review was conducted to identify the financial risks, basic procurement systems and payment methods practicing in the construction industry and in order to identify the applicability of such methods in Sri Lankan context, expert's opinions were required. Since the authors intended to identify the most suitable procurement system and payment method combination to minimize the financial risks in GFBP in Sri Lanka the opinion of industry practitioners was collected. Thus, this research followed a mixed method approach.

Qualitative data was collected through semi-structured interviews. Basically, 10 semi-structured interviews were conducted. The semi-structured interviews were conducted with only chartered quantity surveyors and chartered engineers because, they have good knowledge of procurement systems,payment methods, financial risks, etc. and some of them have lots of experience in Sri Lankan government-funded building projects. Table 1 shows the profile of the interviewees.

Table 1. Profile of the interviewees

Interviewee ID	Profession	Experience in the construction industry
EI 1	Charted Quantity Surveyor	6 Years
EI 2	Charted Quantity Surveyor	5 Years
EI 3	Charted Quantity Surveyor	7 Years
EI 4	Charted Civil Engineer	35 Years
EI 5	Charted Quantity Surveyor	20 Years
EI 6	Charted Quantity Surveyor	35 Years
EI 7	Charted Quantity Surveyor	10 Years
EI 8	Charted Quantity Surveyor	15 Years
EI 9	Charted Quantity Surveyor	5 Years
EI 10	Charted Quantity Surveyor	8 Years

Quantitative data was gathered through a questionnaire survey. The questions were prepared by using the financial risks, procurement system and payment method combinations identified during the expert interviews. Thirty (30) responses were received and the answers were given based on a three-point Likert scale which offers highly suitable, averagely suitable and less suitable options for answering questions. Basically, undergraduates, quantity surveyors and engineers were selected as the sample and the highest priority was given to quantity surveyor's responses. Quantity surveyors are the people who are mostly involved in the procurement and payment processes, and they are highly knowledgeable in those areas. Therefore, the authors gave the priority to the quantity surveyors' responses.

As this is a **mixed method** research project, both qualitative and quantitative were analyzed. Data analysis and discussion was done by following both deductive and inductive approaches.

4 DATA ANALYSIS AND DISCUSSION

Eight (8) common financial risk factors were already identified through the literature review. By conducting expert interviews, it was determined which risk factors are applicable for the Sri Lankan government-funded building projects. In addition, three new financial risks were highlighted by the interviewees and with those three factors, completely ten factors were listed out through the expert interview's findings. Accordingly, fluctuation of inflation rate, fluctuation of exchange rate, variations in material prices, material shortages, legislation changes, payment delays, importation restrictions, liquidity risk, fluctuation of interest rate and absence of proper insurances selected as financial risk factors which can be there in the Sri Lankan government funded building projects.

Four procurement systems and four payment methods were already identified through the literature review. By conducting expert interviews, it was determined which procurement systems and payment methods are available in the Sri Lankan government-funded building projects. The answers of interviewees are shown in the figure 1 and figure 2, respectively.

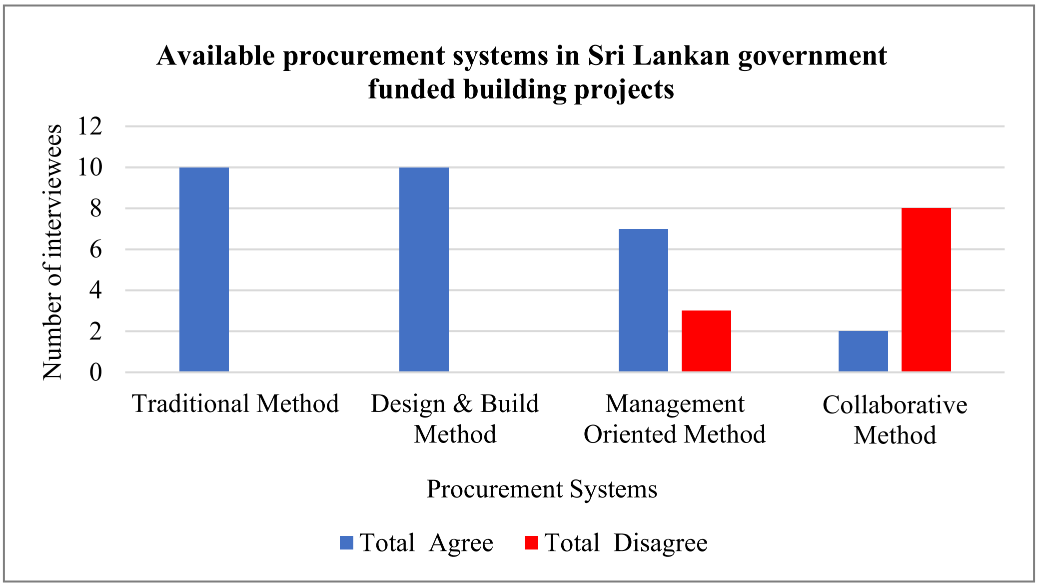


Figure 1. Responses of the available procurement systems in Sri Lankan GFBP

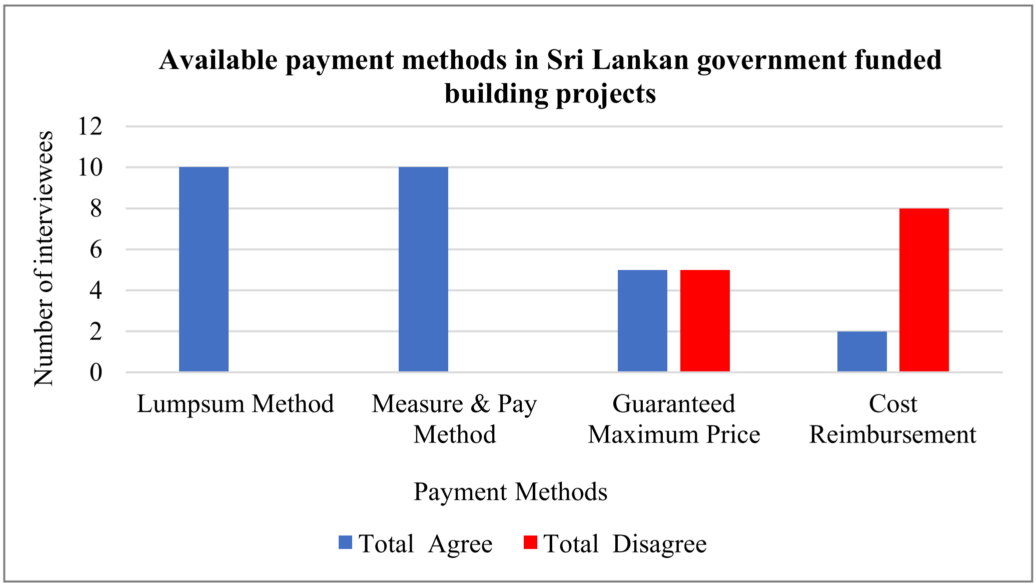


Figure 2. Responses of the available payment methods in Sri Lankan GFBP

As per opinions of the participants of the expert interviews, there are sixteen payment method and procurement system combinations which can be observed in the Sri Lankan government funded building projects. The combinations which were identified by more than 50% of the participants were considered as the most viable combinations, and those were taken to further analysis to check the most suitable combination to minimize financial risks in Sri Lankan government-funded building projects. Accordingly, design and build with lumpsum (100%), traditional with measure and pay (100%), traditional with lumpsum (60%), management oriented with lumpsum (70%), design and buildwith GMP (60%) and management oriented with measure and pay (80%) were selected for the further analysis.

The third objective of the research was to identify the most appropriate procurement system and payment method combination which minimizes the financial risks in Sri Lankan government-funded building projects. The said objective was achieved through the questionnaire findings. The questionnaire survey sample size was fifty (50) and there were thirty (30) responses received from the respondents. According to the respondents in questionnaire survey, the majority of the respondents are quantity surveyors. There are 15 respondents who have more than fifteen years of experience and as a percentage it is 50%. Only thirteen respondents have experience in the government-funded building projects.

Analysis of the questionnaire data were caried out using the **"mean values"** of the responses.

Steps of the analysis

1st step

The "mean" of all possible procurement system and payment method combinations was found by following the explanation given in the table 2.

Table 2. Sentiment level and numerical level

Sentiment Level	Numerical Values
Less Suitable	1
Averagely Suitable	2
Highly Suitable	3

Mean calculations were done according to the equation given in figure 3. It presents the nomenclature of all the variables used for calculations (A, B, C, D).

$$\text{Mean} = \frac{(A \times 1) + (B \times 2) + (C \times 3)}{D}$$

In this equation,
A = Number of responses for less suitable
B = Number of responses for averagely suitable
C = Number of responses for highly suitable
D = Total responses

Figure 3. Sample calculation for the mean

2nd step

Got the collection of "means" separately, for each of the combination against minimizing all ten (10) risk factors. Afterwards, the sum of the "means" for each of the six combinations in minimizing financial risks was obtained.

3rd step

In order to identify the most viable combination to minimize financial risks, individual means calculated as in the second step were added and divided by ten. This gives the "average mean value" of the particular combinations separately.

4th step

Afterwards, those "average mean values" were organized in descending order. Accordingly, the most suitable combination to minimize the financial risks in Sri Lankan government-funded building projects was identified.

The table 3 presents the mean values as according to the 1st step and calculated sum of those mean values as according to the 2nd step.

Table 3. Total of the "mean values" for six combinations

No	Financial Risk	Mean of the combinations					
		C1	C2	C3	C4	C5	C6
01	Fluctuation of Inflation Rate	2.07	2.17	2.23	1.77	1.83	1.73
02	Fluctuation of Exchange Rate	2.03	2.17	2.30	1.77	1.90	1.77
03	Variation in Material Prices	2.13	2.30	2.23	1.83	1.87	1.70
04	Material Shortages	1.90	2.13	2.33	1.87	1.77	1.77
05	Legislation Changes	1.93	2.10	2.10	1.80	1.87	1.70
06	Payment Delays	2.00	2.23	2.37	1.70	1.80	1.80
07	Importation Restrictions	2.10	2.43	2.30	1.90	1.97	1.80
08	Liquidity Risk	2.20	2.40	2.33	1.83	2.10	1.90
09	Fluctuation of Interest Rate	2.10	2.23	2.33	1.87	1.97	1.90
10	Absences of Proper Insurances	1.97	2.13	2.27	1.90	1.83	1.67
Total		**20.43**	**22.29**	**22.79**	**18.24**	**18.91**	**17.74**

The nomenclature of the combinations from the C1 to C6 is as below.

C1 – Traditional with lumpsum
C2 – Traditional with measure and pay
C3 – Design and build with lumpsum
C4 – Design and build with GMP
C5 – Management oriented with lumpsum
C6 – Management oriented with measure and pay

There are ten financial risk factors. Therefore, in order to calculate the 'average mean value', sum of the mean values in table 3 were divided by ten (As per the 3rd step). After that those values are set in descending order (According to the 4th step) as shows in the table 4.

Table 4. Descending order for "average mean values" in six combinations

Combination No	Combination Name	Average Mean Value
C 3	Design and Build with Lumpsum	2.28
C 2	Traditional with Measure and Pay	2.23
C 1	Traditional with Lumpsum	2.04
C 5	Management Oriented with Lumpsum	1.89
C 4	Design and Build with GMP	1.82
C 6	Management Oriented with Measure and Pay	1.77

According to the table 4, the highest "average mean value" is for the C3 combination. It means **the Design and Build Procurement system with Lumpsum Payment Method combination is the most suitable for minimizing majority of the financial risks in Sri Lankan government funded-building projects.**

As the final outcome of this research, a framework was developed by harmonizing all the findings. It shows the relationships between procurement systems and payment methods in assuring financial safety in government-funded building projects. It can be easily understood by following steps.

First of all, need to identify the color codes which used in the content lines here. This framework is based on the 'mean values' of the procurement system with payment method combinations. Table 5 presented the 'mean values' and color codes.

Table 5. Mean values of the combinations with color code

No	Financial Risk	Mean Values of the combinations					
		Traditional + Lumpsum	Traditional + Measure & Pay	Design & Build + Lumpsum	Design & Build + GMP	Management Oriented + Lumpsum	Management Oriented + Measure & Pay
01	Fluctuation of Inflation Rate	2.07	2.17	2.23	1.77	1.83	1.73
02	Fluctuation of Exchange Rate	2.03	2.17	2.30	1.77	1.90	1.77
03	Variation in Material Prices	2.13	2.30	2.23	1.83	1.87	1.70
04	Material Shortages	1.90	2.13	2.33	1.87	1.77	1.77
05	Legislation Changes	1.93	2.10	2.10	1.80	1.87	1.70
06	Payment Delays	2.00	2.23	2.37	1.70	1.80	1.80
07	Importation Restrictions	2.10	2.43	2.30	1.90	1.97	1.80
08	Liquidity Risk	2.20	2.40	2.33	1.83	2.10	1.90
09	Fluctuation of Interest Rate	2.10	2.23	2.33	1.87	1.97	1.90
10	Absences of Proper Insurances	1.97	2.13	2.27	1.90	1.83	1.67

Here, the color code is determined by the 'mean value' of the combinations associated with each financial risk.

Suitability level 1 – Row wise, the highest 'mean values' are presented in Red

Suitability level 2 – Row wise, secondly highest 'mean values' are presented in Orange

Suitability level 3 – Row wise, thirdly highest 'mean values' are presented in Green

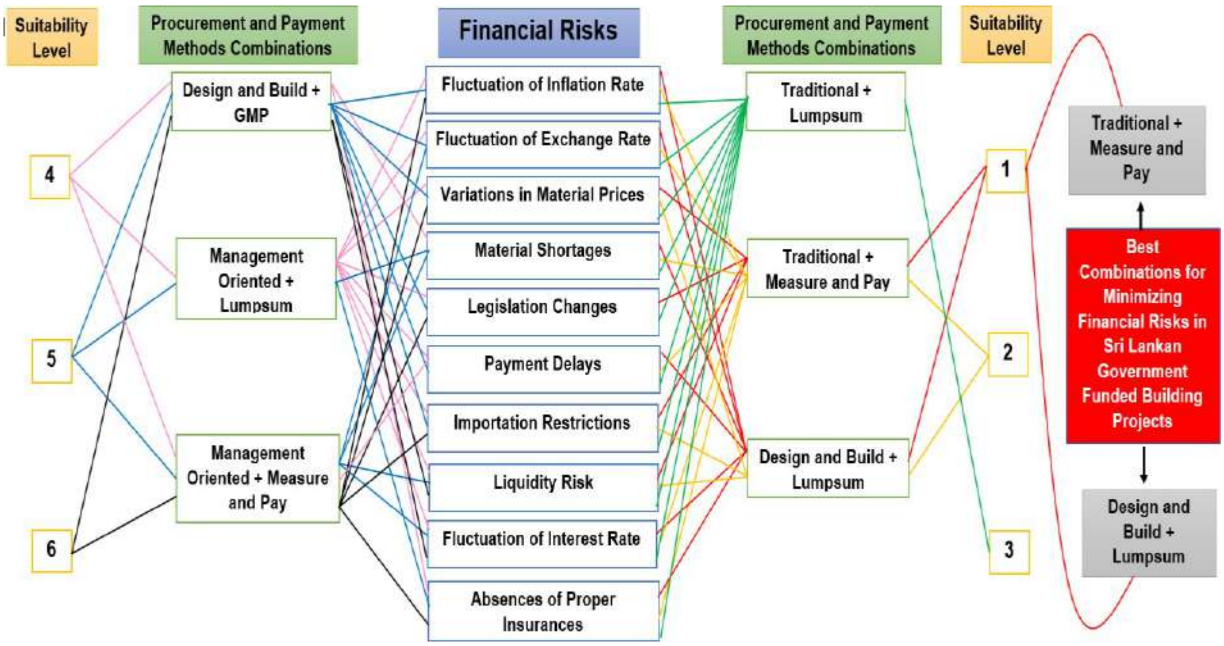
Suitability level 4 – Row wise, fourthly highest 'mean values' are presented in Pink

Suitability level 5 – Row wise, fifthly highest 'mean values' are presented in Blue

Suitability level 6 – Row wise, sixthly highest 'mean values' are presented in Black

The combination with the highest 'mean value' for each financial risk, considered as the highest suitable combination to minimize that financial risk. Similarly, combination with the lowest 'mean value' for each financial risk, considered as the lowest suitable combination to minimize that financial risk.

This framework should be observed from the middle to the sides. The lines, point from the financial risks to the procurement system + payment method combinations on either side (the colors of the lines are based on the table 4). There are suitability levels on both sides of the combinations. Suitability level 1,2,3 is in the right-hand side and suitability level 4,5,6 is in the left-hand side. Many lines points to the combinations and only one line from those (according to the color code), points to the matching 'suitability level'. It is then clear how appropriate it is to minimize that financial risk by using that combination. Both lines drawn from traditional with measure and pay combination and design and build with lumpsum combination, points to the suitability level 1 and the color code of the line is red. Hence, both combinations are the most suitable for minimize the risks of government funded building projects.



By using this framework, financial risks in government-funded building projects can be easily identified and procurement system with payment method combinations that can be used to minimize them also can be easily identified. Not only that, this framework explains the suitability level of each combination to minimize each financial risk. Therefore, this will be useful for Sri Lankan government-funded building projects to avoid the unnecessary failures in financial things.

5 CONCLUSION AND RECOMMENDATIONS

The aim of this research was to "Identify the relationship between procurement systems and payment methods in assuring financial safety in Sri Lankan government-funded building projects". Accordingly, there were four objectives to be achieved.

The first objective is to identify the financial risks in Sri Lankan government funded building projects. Eight common financial risk factors in construction industry were identified through the literature review and through the expert interviews the same were checked against the applicability of such factors in Sri Lankan government-funded building projects. Accordingly, ten number of financial risk factors were confirmed through the interviews, and those are, fluctuation of inflation rate, fluctuation of exchange rate, variations in material prices, material shortages, legislation changes, payment delays, importation restrictions, liquidity risk, fluctuation of interest rate and absence of proper insurances.

The second objective is to identify the available procurement systems and payment methods in Sri Lankan government funded building projects. Similarly, available procurement systems and payment methods in construction industry were identified through the literature review and through theexpert interviews the same were checked against the applicability of such factors in Sri Lankan government-funded building projects. Accordingly, four number of procurement systems were confirmed through the interviews, and those are, traditional, design and build, management-oriented and collaborative system. Also, four payment methods were confirmed through the interviews, and those are, lumpsum, measure and pay, GMP and cost reimbursement method. But according to the interviewee's opinions, traditional, design and build procurement systems and the lumpsum, measure and pay payment methods were mostly available in the government-funded building projects. Furthermore, the procurement system with payment method combinations in the government funded building projects were identified through the interviews. Many of the interviewees said that these combinations could be happened. There are, design and build with lumpsum, traditional with measure and pay, traditional with lumpsum, management oriented with lumpsum, design and build with GMP, management oriented with measure and pay.

To identify the most appropriate procurement system and payment method which minimize the financial risks in Sri Lankan government funded building projects is the third objective. According to the results of the questionnaire survey, design and build with lumpsum combination was identified as the most suitable combination for minimizing financial risks in Sri Lankan government-funded building projects. In addition, it is advisable to use traditional with measure and pay combination, traditional with lumpsum combination, management oriented with lumpsum combination, design and build with GMP combination and management oriented with measure and pay combination respectively to minimize those risks.

According to the research findings, design and build with lumpsum combination can be recommended to use if there are financial risk such as, fluctuation of inflation rate, fluctuation of exchange rate, material shortages, payment delays, fluctuation of interest rate and absence of proper insurances. As well as, traditional with measure and pay combination can be recommended to use if there are financial risks such as, variations in material prices and material shortages. To minimize the financial risk of legislation changes in government-funded building projects, can be recommended both design and build with lumpsum combination and traditional with measure and pay combination as the most appropriate combinations. Accordingly, design and build with lumpsum combination can be recommended to use in Sri Lankan government funded building projects to minimizes financial risks.

As well as, secondly can be recommended, traditional with measure and pay combination to those projects.

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Review on Use of End-Area-Rule for Volume Calculations in Highway Pavements

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ABSTRACT

Volume estimation of highway pavements is very important in planning and design of highways, in order to calculate the amount of materials and hence for cost analysis. It is also used to investigate the workmanship and quality of construction in post analysis. End area rule is the simplest and most widely used technique in volume calculation as it can be used with the cross sections generated at a suitable interval. The theory being used for road segment between two consecutive cross sections assuming there exists a linear variation of cross sectional areas within the interval. Validity of the application of end area rule depends on this assumption and accuracy also varies when the linear variation does not exist. This study was carried out to analyze the validity of the application of end area rule due to the non-linearity of variation of cross sectional areas in highway pavements. The scope of the study was limited to straight segment with rectangular cross section. Road width and height of the cross section were selected as variables and the volumes were compared using different models with coaxial centroids and skew sections. Numerical models with different angles of centroids were used in the study and the results were verified using digital models created with AutoCAD 3D software. The interval between sections was also investigated and it was determined that the perpendicular distance between sections should be used in the end area rule. Finally it was concluded that the area variation is not linear when there are more than one variable affect the cross section. The modification to end area rule was also developed in order to increase the accuracy.

KEYWORDS: *end-area-rule, non-linearity, volume estimation, sectional interval*

1 INTRODUCTION

The volume calculation is a very important event in the design stage of an engineering project as the sustainability begins with proper design. Accuracy of the volume calculation effects the estimation of material volume, workmanship and finally the total project cost. Estimation of the earth work volume of road construction project is the most crucial factor on which the highest weight of the total cost depends on. It is a challenging issue to calculate the exact volume since the amount of field measurements increases as the variation of the terrain becomes rugged. There is no any method to calculate this volume in a perfect way, but many approaches are used to approximate the result.

The accuracy of the final volume depends on the compatibility of the basis of the method and the field conditions. The most widely used method to calculate the volumes in road construction is the use of cross sections. It advances other methods by ease, time consumption and also the economy. The ability to conduct the method using contour maps is also an additional advantage. The same technique is used to calculate the volumes in reservoirs by using area enclosed by depth contours instead of cross sectional areas. There are several equations used to calculate the volume between two consecutive cross

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sections and end-area-rule is the most widely used method among them. According to the end-area-rule, the volume is calculated as the multiplication of the average sectional area and the perpendicular distance between the sections. The two major assumptions in the theory are the parallelism of the cross sections and the linear variation of the sectional areas which is considered as the basis of the equation. Both of the above conditions must be sacrificed to obtain a closer result but the method is applied in road constructions without paying adequate consideration for these criterions. It is obvious that the use of parallel cross section is not possible while taking the cross sections along a selected center line and the factor is deliberately skipped in the calculation stage.

This study was conducted to analyze the effect of linearity between the two cross sections when the end-area-rule is used for volume calculations. The variation of cross sectional areas was categorized as one dimensional and two dimensional according to the number of directions they are varying. Initially, rectangular, parallel sections were selected and the variation of centroid parallel to the edge of the section is considered as one dimensional variation. A numerical model was developed using basic mathematical operations and the results were confirmed using digital model generated using computer software. The above results deployed that the volume calculated by the direct application of end-area-rule deviates from the actual volume and a correlation factor can be generated to modify the final result.

2 LITERATURE REVIEW

It is a basic requirement to estimate the area and volumes in most of the engineering schemes such as route, alignment, reservoirs, construction of tunnels. The most significant and costly aspect of such schemes are excavation and hauling of material on which the majority of project cost is depend on. Many researches have been conducted to develop a method to calculate volumes perfectly but no perfect solution is derived. The closure approximations can be achieved by careful investigations on the field conditions as well as the theory used for the calculation.

Prismoidal method (Hickerson 1964) is one of the very basic methods used to calculate earthwork volumes in very early stage which considers the average end area concept. This method was conventionally used and became the most widely used method among these as it requires simple linear measurements. But the main disadvantage of the method is the assumption of linear variation between the sections. The average end area methods require cross-section areas to be of the same type as either cut or fill.

End area rule for cross sections with different configurations was developed by Epps and Corey (1990) to estimate earthwork volumes differently. Cheng (2005) introduced a mechanism to solve the inaccuracy problem caused by average end-area method and prismoidal method used for the calculation of roadway earthwork volume. The feasibility of average-end-area method for earthwork volume was reconfirmed by Cheng and Jiang (2013) and the difference of accuracy between 3D method and average-end-area method was analysed. It depicted that the critical value of interval distance between two consecutive cross sections is 30m for average-end-area method.

According to Khalil (2015), the average end area method is identified as tedious and time consuming technique. This literature study was intensively conducted on many models for accurately estimating earthwork volumes. The average end area model and prismoidal model were commonly employed for estimating earthwork volumes. The prismoidal model gave an exact volume for linear profiles, while the average end area model generally overestimated the volume. Cheng and Jiang (2013) further stated that a reliable and accurate earthwork volume calculation is one of the most important components in roadway engineering that can influence the choosing of roadway alignment, the cost and construction.

Roadway design has stepped into 3D era as the appearance and wide use of application of Digital Terrain Model (DTM) and accordingly 3D method for earthwork volume calculation is also developed. But the concept of adopting average-end-area method which is considered as 2D method is deep-rooted in roadway design. It has been further investigated the accuracy comparison of Roadway Earthwork Computation between 3D and 2D Methods. Weighted ground elevation was introduced by Goktepe et.al (2009) which is a method that considered the material properties in grade line selection to balance the cut and fill volume. All these researches were conducted by average-end-area method.

Easa (1992) introduced improvements in average-end-method when the studies on imprecision and limitations of 2D method in volume calculation are considered. Aruga and Akay (2005) developed a forest road design program based on a high-resolution Digital Elevation Model (DEM) from a light detection and ranging (LIDAR) system. After a designer had located the intersection points on a horizontal plane, the model firstly generated the horizontal alignment and the ground profile, and then it could precisely generate cross-sections and accurately calculate earthwork volumes using a high-resolution DEM. A shortage of this model was the incapability of properly optimizing horizontal and vertical alignments simultaneously. The researchers further used DTM to calculate cross section area, but still completed volume computation by 2D rule. These programs had begun to bring DTM into roadway design and volume calculation, but actually it can not be considered as pure 3D concept as they still use average-end-area or prismoidal method to compute earthwork volume finally.

Even though this rule is developed for the sections with parallel sections, its applicability for the curved road sections have been investigated (Wanasinghe et.al, 2018) and concluded that the end-area-rule can be used with modifications applied according to the skew angle. All these studies prove that this rule is a valid tool to calculate the volumes in construction industry despite that the ideal conditions are not satisfied.

3 METHODOLOGY

This study was carried out to investigate the factor of linearity of the variation of cross sectional area and the scope of the study was limited to parallel rectangular sections. The edges of the rectangles were kept parallel and the width of each section was kept constant while only the lengths are different which is called the one dimensional variation. The situation where the both length and width of the two surfaces are different is termed as two dimensional variation.

Two models called numerical model and digital model were generated to calculate the volumes for different dimensions and to confirm the calculated volume. The calculated volumes were compared with the conventionally calculated volume by end area rule.

3.1 Numerical Model

The volume of the pavement section was calculated by developing a mathematical equation using integration. Two parallel rectangular sections having dimensions ***c*** and ***d*** at the top and ***a*** and ***b*** at the bottom which are distance ***H*** apart is considered as shown in Figure 1. The one dimensional variation was obtained by considering the situation where the dimensions ***a*** and ***c*** become identical.

It is proved with the fundamentals that the linearity of the variation of end areas exists in this situation and the volume of the section become identical with the end-area-rule which is given in equation (1)

$$V = h(ab + cd)/2 \tag{1}$$

The existence of the above condition is very rare in the practical applications and the two dimensionally varied modules were selected with the same dimensions but no edges in same vertical plane. The equation derived using basic mathematical integration is given in equation (2).

$$V = h(2ab + 2cd + ad + bc)/6 \tag{2}$$

3.2 Digital Model

The volumes of the sections used in numerical models were determined by generating the similar models using computer software Auto Cad 2019 which allows measuring the volume directly. Figure 2 illustrates a digital model used to measure the volume using Auto Cad 2019.

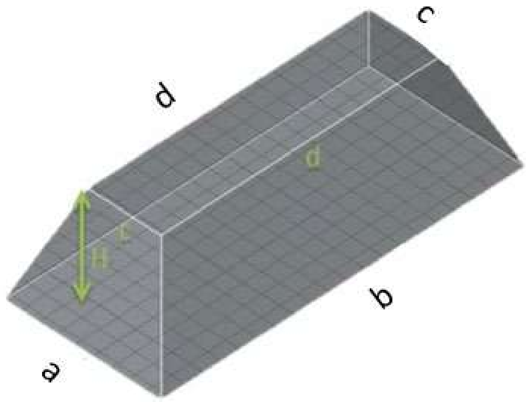

Figure 1. Details of the numerical model

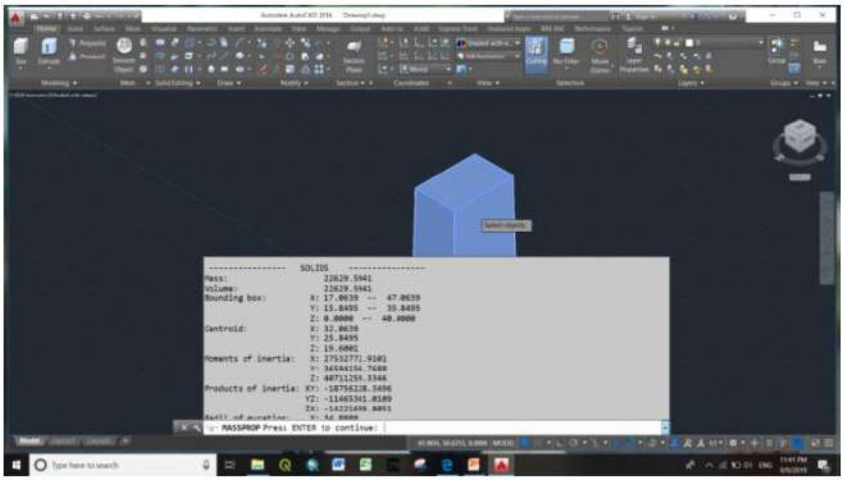

Figure 2. Digital Model and its details

4 OBSERVATION AND RESULTS

12 samples were used in this investigation whose dimensions are depicted in Table 1.

Table 1. Dimensions of the samples

Trial No.	Dimensions (m)				
	a	b	c	d	h
1	30	20	44.1062	34.1062	40
2	30	20	36.9991	26.9991	40
3	30	20	35.5941	25.5941	40
4	30	20	34.1926	24.1926	40
5	30	20	32.6937	22.6937	40
6	30	20	31.3964	21.3964	40
7	30	20	28.6036	18.6036	40
8	30	20	27.3063	17.3063	40
9	30	20	25.8074	15.8074	40
10	30	20	24.4059	14.4059	40
11	30	20	23.0009	13.0009	40
12	30	20	15.8938	5.8938	40

Volumes of each sample were calculated using traditional end-area-rule, the derived formula of equation (2) and using the digital model. The values were compared with each other and the comparison is illustrated in Table 2.

Table 2. Volume calculated by different methods

Trial No.	Volume (m^3)		
	Numerical method	Digital Model	End-area-rule
1	40759.33	40 759.27	42085.89
2	31652.27	31 652.26	31978.84
3	30011.35	30 011.40	30219.98
4	28426.97	28 427.00	28544.16
5	26790.45	26 897.72	26838.82
6	25422.40	25 422.40	25435.40
7	22629.60	22 629.59	22642.60
8	21403.05	21 310.40	21451.42
9	20041.77	20 041.75	20158.96
10	18823.15	18 823.11	19031.78
11	17654.07	17 654.07	17980.65
12	12546.93	12 546.96	13873.50

It is clearly identified that the numerical and digital models resulted very close volumes but end area rule always generated over estimations. The error analysis was conducted by considering the numerical method as the absolute value. The errors of end area rule were calculated and the corresponding values are illustrated in Table 3. To investigate the relationship between the error and the geometry of the section, the differences of the dimensions in each side was calculated and the multiplication of dimensional deviations were considered. It showed proportionality to the error as shown in the Table 3.

Table 3. Error analysis

Trial No.	Error	a-c	b-d	(a-c)(b-d)=α	Error/ α
1	1326.566	14.1062	14.1062	198.985	6.667
2	326.5827	6.9991	6.9991	48.987	6.667
3	208.6264	5.5941	5.5941	31.294	6.667
4	117.186	4.1926	4.1926	17.578	6.667
5	48.37346	2.6937	2.6937	7.256	6.667
6	12.99955	1.3964	1.3964	1.950	6.667
7	12.99955	-1.3964	-1.3964	1.950	6.667
8	48.37346	-2.6937	-2.6937	7.256	6.667
9	117.186	-4.1926	-4.1926	17.578	6.667
10	208.6264	-5.5941	-5.5941	31.294	6.667
11	326.5827	-6.9991	-6.9991	48.987	6.667
12	1326.566	-14.1062	-14.1062	198.985	6.667

5 CONCLUSION

From the above results, it can be concluded that the end area rule is valid only for one dimensionally varying sections. It can be verified through the error analysis since the error become zero when either ***a*** and ***c*** or ***b*** and ***d*** become identical.

The equation 2 provides better approximations than end area rule for two dimensionally varying sections. The variations in side dimensions can be used to determine a correction factor and the end-area rule can be modified to achieve more accurate volume estimations.

However for this correction factor cannot be applied for non-rectangular sections. Therefore this should be further studied and related and it is supposed to be investigated in future.

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REGIONAL RELEVANCY OF THE CIDA PRICE INDICES UNDER THE RESTRICTIONS URGED BY THE COVID-19 PANDEMIC

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ABSTRACT

CIDA price fluctuation formula and price indices provide considerable relief to the estimators in mitigating the risk due to the fluctuation of the price of construction inputs during project execution. But there is a huge outcry that the CIDA indices does not appropriately reflect the actual fluctuation of market prices especially during the period of pandemic. The aim of this research was to identify the appropriateness of CIDA indices in ascertaining the price fluctuation of construction material prices across the regions especially under the restrictions imposed by the Covid-19 pandemic.

The study was limited to analysis the regional behavior of material prices based on the significant materials. Market price of construction materials was collected from suppliers, constructors, and construction professionals who are currently involved in construction projects. The market prices were collected from nine provinces of the country for eight different types of significant materials during the period of pandemic.

Collected data were first observed for its behavior within and across the provinces to check the appropriateness to be represented by country wide common indices. This was done through the analysis of variance and through the checking of null hypothesis i.e., "always there is no difference in means between the provincial prices of a given material".

Thereafter the fluctuation of provincial prices of given inputs were compared to the variation of respective CIDA indices with the corresponding time to check the parallelism and correlation.

In this research, it has been concluded that, there is a requirement for establishing regional monthly indices for construction inputs.

KEYWORDS: *CIDA indices, Construction materials, Province, Regional*

1 INTRODUCTION

Cost of construction materials is the highest component of the input and may vary from 40% - 60 % depend on the type of construction. Price fluctuation of construction materials is a risk associated with bidding and implementation of construction projects.

Generally, the price fluctuation risk is accepted by the employer through the introduction of price fluctuation formula to overcome difficulties faced by constructors. The price fluctuation calculation is based on the formula which associate with the indexation (Saman WijewardenaS, n.d.). CIDA publish countrywide index for the different construction inputs. The CIDA, former ICTAD, introduced bulletin of price and cost indices in the year 1990, capitalized it as the base year. CIDA indices reflects price fluctuation in each month and all the indices are expected to reflect the fluctuation of the actual market price of any given time. But there is a huge outcry that the CIDA indices does not appropriately reflect the actual fluctuation of market prices especially during the period of pandemic.

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Furthermore, there are concerns about using of single index for the entire country may not appropriately compensate the regional fluctuation of material prices.

Limited number of studies are available in Sri Lanka on regional variation of the construction materials prices. During this research prices for selected construction materials were collected from different regions in Sri Lanka. The objective of the research is to study, how regional prices of construction materials varied during the period of pandemic compared to the CIDA indices. It is also important to study the variation of regional prices to ascertain the validity of using single price indices. The specific objectives of this research are,

- Collect construction material prices for selected materials from various regions.
- Identify region to region price variations and analyze the price variance of each material across the regions.
- Find the correlation in-between CIDA national indices variation patterns and regional price variation patterns.

Study area was limited to building construction materials due to restriction imposed as a result of Covid19 pandemic situation (L.P.D.S, 2020). Collecting data from various suppliers and contractors was a challenge due to prevailing pandemic and lockdown situation in the country and therefore sample size was limited.

2 LITERATURE REVIEW

The price increase of construction materials, machineries and manpower is a major challenge and risk faced by constructors during the execution of projects. The challenge is mainly attribute to the estimation in forecasting the future trends in market prices of construction materials, manpower, machineries etc. This unpredictability can lead to greater prices and increased risk for suppliers, contractors, and owners, putting all parties engaged in the construction process in financial instability (Justin E. Weidman MSCM, Kevin R. Miller Ph.D, 2011). Construction expenses are always subject to changers. Estimated costs are predicted using construction cost indices (Alaloul et al., 2021).

It is very important to understand and seen market behaviors at the time of bidding by estimators. Inaccurate and estimate errors will finally result budgetary issues for contractors. As a result, material price fluctuation and shocks can be devastating (Al-Zarrad & Moynihan, 2015). Losses incurred because of pricing changes should be shared between the contractor and the owner (Ph.D., Minsoo Choi, Jinu Kim, 2006).

In any event of price increase or decrease, there are strategies that can be deployed to recover or compensate the price changes for the client or the contractor. There are no attempts to calculate or estimate the exact amount of the volatility or loss that occurred. The sums recovered using the formulas technique differ from those obtained using traditional methods. As a result, the traditional technique is thought to be superior to the formula method (Jayasinghe et al., 2015). CIDA price fluctuation formula is a simplified method to determine the escalation of contract prices. Saman Wijewardena, S. A. Y. B. Jayasinghe have done the study on actual price fluctuation and the amount determined using the ICTAD formula to evaluate the sensitivity of it with respect to various variables and how it has affected the contract price.

The indices in the bulletin are to be used in calculations to determine the ultimate cost difference between actual and estimated costs. In the recent past, it was highlighted that the reported indices differed from actual price differences in building projects based on inflation, Covid-19's impact, and restrictions imposed by government for import and exports. The accuracy of the indices needs to be revisited, so that stakeholder's could be protected from the financial shocks due to the current pandemic (Notoatmodjo et al., 2014). Supply and demand are always altering, raw material prices fluctuate because of various elements colliding. As an example, weather conditions - political upheavals, and hydrocarbon prices are all short-term influences, while economic policies - trade policies, and technological innovation are long-term issues. As an example, factors that affect the short term – may be the dollar exchange rate, while economic conditions and technological growth are long-term variables (Trader, 2018).

Escalations are defined as an increase in the cost of construction items that are required for the initial contract during the construction phase (Awad S. Hanna, Unv of Wisconsin-Madison, Madison & Andrew N. Blair, Unv of Wisconsin-Madison, Madison, 1993). The ICTAD price adjustment is hugely reliant on the appraised valuation, input percentages, PI, and fixed coefficient (FC) - 0.966. The latter is directly affected by the cost adjustment factor (CAF) and the rest adjustment factor (RAF) (Jayasinghe et al., 2015). Most countries consider location index, Sri Lanka has failed to do so and instead utilizes a single cost index that only considers the time factor, although location index is critical. To reduce that it is important to analysis and check the location factor (Parameswaran et al., 2019).

Location indices in Sri Lanka are necessary to increase the accuracy and efficiency of tender pricing (Abeysinghe, 2010). To identify the primary location elements that influence construction costs, investigate the impact of location factors on building construction costs in Sri Lanka, and a mechanism to investigate the impact of location factors on building construction costs in Sri Lanka are important in investigating the applicability of location factor (Parameswaran et al., 2019). Price fluctuation is a major risk factor in any construction project market. It's impossible to avoid, and difficult to forecast. The amount calculated using the CIDA price fluctuation formula approach and the real price fluctuation, however, are usually argued to be different (Janardana et al., 2021).

Individual industries, of course, have different locational needs in terms of processing and transfer costs. Regional disparities in processing costs, whether of labor or power, have a significant impact on the placement of some firms. Other factories are best positioned near raw material suppliers to reduce total transportation expenses (Harris, 2008). It was identified that regional relevancy will depend on geography of the country, resource availability and availability of infrastructure facilities (Transportation), Regional Wage differences etc. Construction prices are a function of many factors beyond pure material costs (Dr. Douglas D. Gransberg, 2008).

3 METHODOLOGY

CIDA indices for construction materials have been established based on collected data from various suppliers and contractors for previous 12 months. The same methodology was adopted for collecting regional prices. and basically, two methods were applied. Industry experts were method one is conducting interviewed gather views on suitability of CIDA indices.

The data collection was done through a questionnaire survey among contractors and suppliers. The goal of the study was to examine the relationships reginal prices and CIDA indices. Statistical method was used for the analysis of data. The research method type adopted in this regional relevance of the CIDA pricing indices investigation is quantitative research.

Participants were selected using non-probability Sampling methods. The snowball method is used for data collecting. Market prices of different inputs were collected through the questionaries. Only 30 responses were managed out of 40.

Selected materials were considered for the evaluation of price variation during the period of 2020 August to July 2021 from collected data from various suppliers and contractors. The collected data was processed by using Excel software. Selected research philosophy was pragmatism method. Deductive theory is used for theoretical approached and exploratory research design was selected to study the curiosity and better understanding of the applicability of CIDA single indices for entire country.

4 ANALYSIS AND DISCUSSION OF RESULT

4.1 Analysis of market price behavior

The analysis was carried out to check the price variation of selected samples within the region and across the regions. To compute the mean value and standard deviations from the collected data, the following formulas were used to compute the mean and standard deviation.

$$\bar{x} = \frac{x_1+x_2+x_3+\cdots+x_n}{n} \quad (1)$$

$$s = \sqrt{\frac{(x_1-\bar{x})^2+(x_2-\bar{x})^2\ldots+(x_n-\bar{x})^2}{n}} \quad (2)$$

4.1.1 Price behavior pattern of construction materials within the province

Below table 1 shows the statistical data of construction materials in all provinces.

Table 1. Standard deviation and mean

Material		Nothern Province	Nothern Central Province	Nothern Western Province	Central Province	Easten Province	Uva Province	Western Province	Sabaragamuwa Province	Southern Province
SAND	Mean	13187.50	10604.17	13250.00	14687.50	9270.83	12416.67	15777.78	14104.17	13760.42
	Standard deviation	649.52	445.41	923.19	501.42	561.13	243.86	686.57	310.03	614.01
RUBBLE	Mean	3737.50	4603.13	3395.83	4875.00	3802.08	3447.92	3090.28	3822.92	3632.81
	Standard deviation	22.61	227.27	128.73	376.89	90.11	158.64	300.38	64.37	144.82
¾"METAL	Mean	6427.08	7209.72	6291.67	7093.75	6770.83	6958.33	5548.61	6347.92	6343.75
	Standard deviation	495.60	245.51	396.48	297.36	380.02	462.62	351.87	286.53	267.17
RED EARTH	Mean	1250.00	1240.28	991.67	2229.17	1366.67	956.25	1744.44	1054.17	1383.33
	Standard deviation	0.00	31.95	36.93	198.24	55.05	38.62	745.50	78.21	41.74
ABC	Mean	7500.00	6080.21	6187.50	6037.50	5447.92	5416.67	4905.56	5541.67	5927.08
	Standard deviation	0.00	52.08	386.20	369.27	64.37	257.46	137.31	257.46	321.83
BRICKS	Mean	18354.17	10970.83	9250.00	17166.67	8020.83	8895.83	13312.50	9520.83	12791.67
	Standard deviation	568.67	288.87	261.12	1094.06	249.05	128.73	892.68	198.24	257.46
RAINFORCEMENT STEEL	Mean	6859.17	6849.17	6837.92	6841.67	6856.67	6856.67	6829.17	6837.92	6856.67
	Standard deviation	1376.83	1376.83	1376.83	1376.83	1376.83	1376.83	1376.83	1376.83	1396.89
CEMENT	Mean	42300.00	41200.00	40850.00	41650.00	42450.00	43850.00	41150.00	41300.00	41150.00
	Standard deviation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

From the above table, it is shown that how material prices are varied from province by province and price volatility of construction materials province to province.

4.1.2 Price variation behavior patterns across the provinces

Interpretation of standard deviation and mean across the provinces

Analysis reported to observe the price behavior across the province. And it was analysis based on the market prices of different materials.

Observation of average prices across the provinces

The average of the annual prices within the provinces of each material were analyzed through the Standard Deviation and mean to observe the behavior.

The average of the annual prices within the provinces of each material were analyzed through the Standard Deviation and mean to observe the behavior.

Table 2. Observation of average prices across the provinces.

Material	Avarage Standerd deviation	Avarage mean value
SAND	548.35	13006.56
RUBBLE	168.20	3823.05
¾"METAL	353.68	6554.63
RED EARTH	136.25	1357.33
ABC	205.11	5893.79
BRICKS	437.65	12031.48
RAINFORCEMENT STEEL	1379.06	6847.22
CEMENT	0.00	41766.67

Below box charts shows the spread of the standard deviation. Figurer 1 reinforcement shows equal standard deviation in all province and red earth under figure 2 shows high standard deviation in western province. Wide array of standard deviations reported for sand as per figure 3 sand box chart.

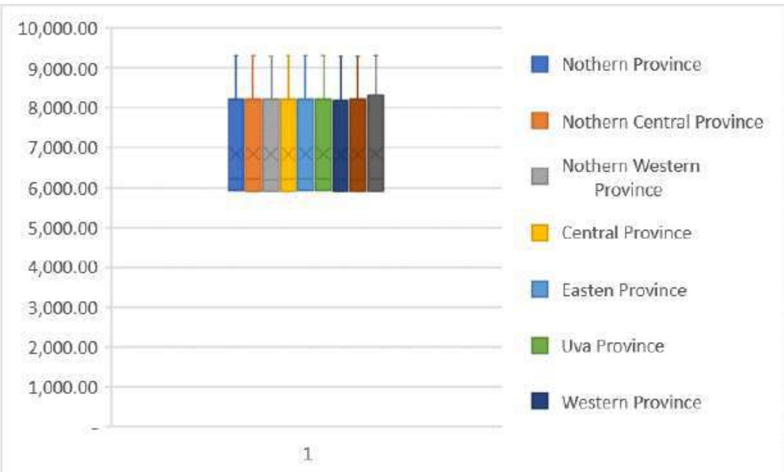

Figure 1. Reinforcement, box chart

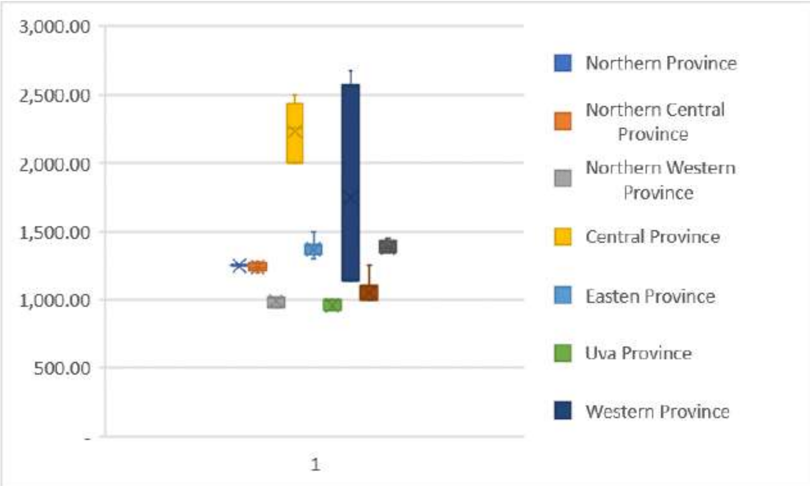

Figure 2. Red earth, box chart

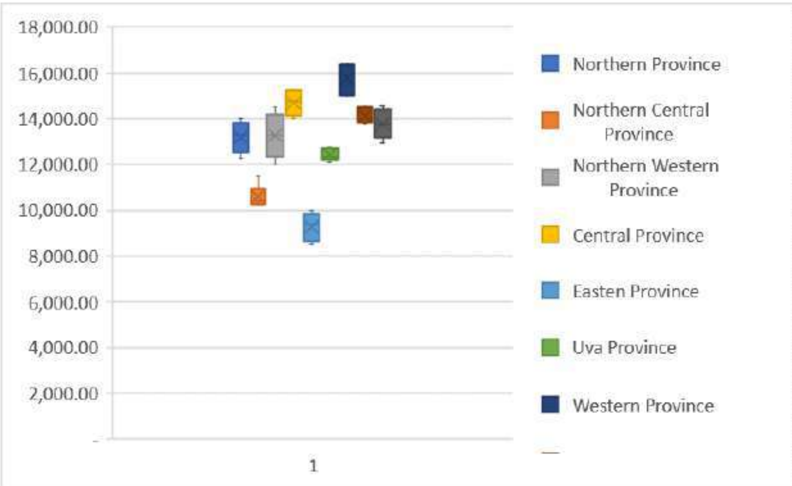

Figure 3. Sand, box chart

From the above Table 2. standard deviation and mean values analysis, the results may not appropriately represent the actual variance since the analysis was done for the average prices of the provinces. Therefore, in order to derive a batter analysis of the realistic behavior across the provincial prices, for the study was done based on ANOVA as deiminated under subtopic of analysis of variance.

4.1.3 Analysis of Variance (ANOVA)

To verify the results of standard deviation and slope described in previous chapters, Analysis of variance test (ANOVA) is used to make a confident and reliable decision. ANOVA test is a statistical technique that is used to check if the means of two or more groups are significantly different from each other. ANOVA checks the impact of one or more factors by comparing the means of different samples.

The F value is used in ANOVA and is calculated by dividing two mean squares. It determines the ratio of explained variance to unexplained variance. F critical is obtained from F table to determine given parameters effects are significant or not.

The P value is defined as the probability under the assumption of no effect or no difference (Null hypothesis). P value can take any value between 0 and 1. Table 3 shows the F, F crit and P value of the data set.

Table 3. F and P- value

Material	*F*	*F crit*	*P-value*
Cement	65535	2.033295	#DIV/0!
Sand	143.9502	2.033295	5.35E-51
3/4" Metal	24.04067	2.033295	4.23E-20
6" X 9 " Rubble	98.38396	2.033295	1.23E-43
ABC	104.8125	2.033295	7.69E-45
Red earth	29.27446	2.033295	6.59E-23
Bricks	557.9417	2.033295	9.6E-79
Reinforcement	0.000745	2.033295	1

The null hypothesis, (H0) is that all provinces have same mean. H1 is at least one province is different from other provinces with respect to means.

From above table F < F crit is only for reinforcement and P value is 1. Refer to the figure 1 box chart, mean value has almost equal value hence null hypothesis fail to reject.

P value for cement is an infinity value and F value is larger than F crit. The reason for is the government control price cement for the whole of the country. Under such, can reject the null hypothesis significantly.

All materials except reinforcement, F value is larger than F critical and P value is almost close to zero hence null hypothesis failed to reject.

As per the above analysis that there are significant evident to reject null hypothesis and to accept the alternative hypothesis. We can conclude that a common index may not reflect the price fluctuation of the different provinces. which urge the requirement of reginal indices.

4.2 Observation of CIDA indices against the provincial price behaviors

The comparison of monthly price changers and monthly changers of the CIDA indices done based on the slope (to check the parallelly) and correlation comparison is done based on the relative price changers within different month compared to the average price or average index (in case of CIDA index) this is done in order to make the comparison on same platform.

4.2.1 Slope

Array formula method was deployed to derive the slope, and intercept of each data set taking the month as the independent variable (months are label as 1 to 12).

Table 4. Slope

Material		Northern Province	Northern Central Province	Northern Western Province	Central Province	Easten Province	Uva Province	Western Province	Sabaragamuwa Province	Southern Province
SAND	Slope	0.0125	0.0106	0.0178	0.0091	0.0160	0.0051	0.0103	0.0056	0.0121
	CIDA indicers Slope	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083
RUBBLE	Slope	0.0010	0.0124	0.0090	0.0197	0.0056	0.0115	0.0231	0.0040	0.0095
	CIDA indicers Slope	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165
¾" METAL	Slope	0.0201	0.0086	0.0164	0.0113	0.0127	0.0181	0.0151	0.0101	0.0114
	CIDA indicers Slope	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096
RED EARTH	Slope	0.0000	(0.0048)	0.0085	0.0231	(0.0046)	(0.0096)	(0.1006)	(0.0141)	0.0073
	CIDA indicers Slope	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222
ABC	Slope	0.0000	0.0022	0.0148	0.0139	0.0028	0.0113	0.0067	0.0110	0.0129
	CIDA indicers Slope	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128
BRICKS	Slope	0.0080	0.0068	0.0023	0.0169	0.0019	0.0005	0.0171	0.0054	0.0007
	CIDA indicers Slope	0.0137	0.0137	0.0137	0.0137	0.0137	0.0137	0.0137	0.0137	0.0137
RAINFORCEMENT STEEL	Slope	0.0464	0.0464	0.0465	0.0465	0.0464	0.0464	0.0466	0.0465	0.0469
	CIDA indicers Slope	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239
CEMENT	Slope	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CIDA indicers Slope	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

$$m = \frac{(Y2-Y1)}{X2-X1} \tag{3}$$

From table 4, it is showing variance slope variance from province to province with respect to the CIDA indices slopes except for cement which is with control price. This mean that at least one province doesn't vary on par with other provinces. Which means a common index may not reflect the price Fluctuations of different provinces, which proves the requirement of provincial indices

4.2.2 Correlation

The relationship between CIDA indices and each provincial prices are plotted on scatter graph, and it is shown in below figure numbers. It shows relationship between two variables of CIDA indices and provincial price variation. A scatter graph indicates the strength of the co-relationship between two variables of CIDA indices.

$$r_{Xy} = \frac{\sum(X_i-\bar{X})(y_i-\bar{y})}{\sqrt{\sum(X_i-\bar{X})^2\sum(y_i-\bar{Y})^2}} \tag{4}$$

Positive Correlation

Figure number of 4 for construction material of sand and other ¾" metal, Rubble and Bricks in Northern, Southern, Uva and Northern Provinces respectively shows positive gradients which shows one variable increase the other increases. All points lie close to the straight line.

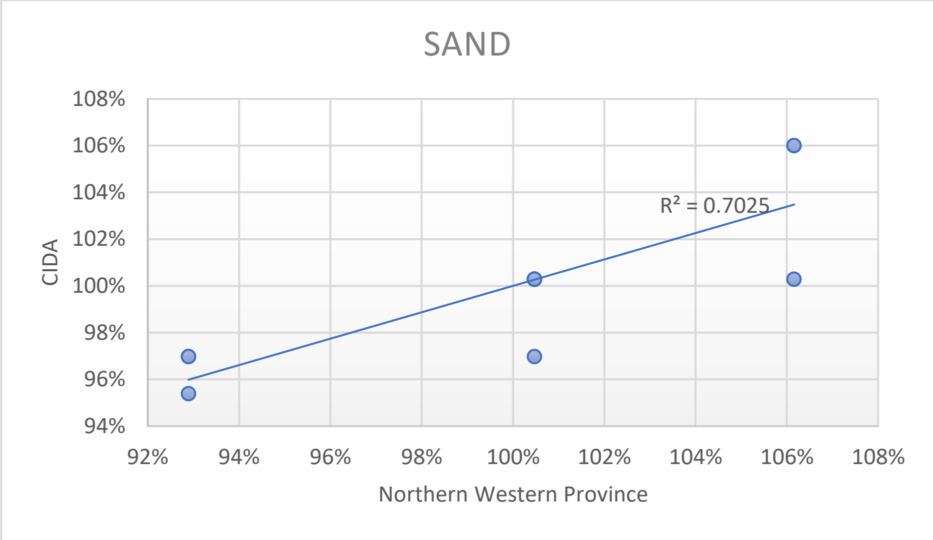

Figure 4. Sand

Negative Correlation

Figure number of 5 and for construction material of red earth in Western and Sabaragamuwa Provinces respectively shows negative gradients which shows one variable increase the other decreases. All points lie close to the straight line.

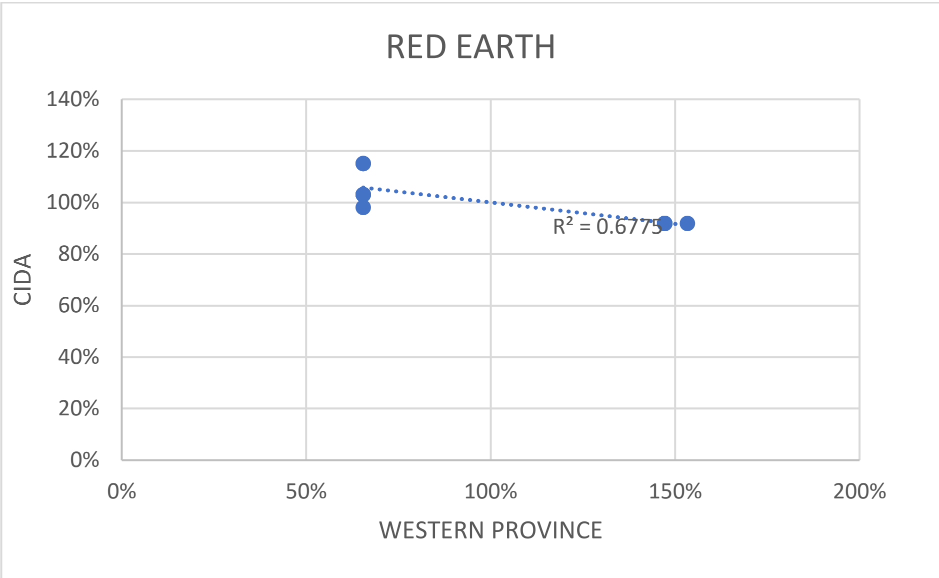

Figure 5. Red earth

Corelation is shown in below Table number 5 numerically as coefficient of corelation, slope and interception respective construction materials in each province. From the table corelation coefficient varies from -1 to +1. A corelation of -1 indicates a perfect negative corelation, that means one variable goes up other goes down. A corelation of +1 indicates a perfect positive corelation, that means one variable goes up, the other goes up.

Table 3. Interception, slope, and correlation

Material		Nothern Province	Nothern Central Province	Nothern Western Province	Central Province	Easten Province	Uva Province	Western Province	Sabaragam uwa Province	Southern Province
SAND	Interception	0.919	0.931	0.884	0.941	0.896	0.967	0.933	0.963	0.922
	Slope	0.013	0.011	0.018	0.009	0.016	0.005	0.010	0.006	0.012
	CORREL	0.838	0.865	0.851	0.818	0.864	0.830	0.714	0.791	0.852
RUBBLE	Interception	0.994	0.919	0.941	0.872	0.963	0.925	0.850	0.974	0.938
	Slope	0.001	0.012	0.009	0.020	0.006	0.012	0.023	0.004	0.009
	CORREL	0.572	0.920	0.838	0.840	0.838	0.895	0.838	0.838	0.838
¾"METAL	Interception	0.870	0.944	0.893	0.927	0.918	0.882	0.902	0.934	0.926
	Slope	0.020	0.009	0.016	0.011	0.013	0.018	0.015	0.010	0.011
	CORREL	0.775	0.841	0.775	0.859	0.732	0.844	0.807	0.618	0.828
RED EARTH	Interception	1.000	1.031	0.945	0.850	1.030	1.062	1.654	1.092	0.952
	Slope	0.000	-0.005	0.008	0.023	-0.005	-0.010	-0.101	-0.014	0.007
	CORREL		-0.606	0.689	0.869	-0.420	-0.824	-0.823	-0.705	0.882
ABC	Interception	1.000	0.986	0.904	0.910	0.982	0.927	0.957	0.928	0.916
	Slope	0.000	0.002	0.015	0.014	0.003	0.011	0.007	0.011	0.013
	CORREL		0.886	0.833	0.772	0.833	0.833	0.833	0.833	0.833
BRICKS	Interception	0.948	0.956	0.985	0.890	0.988	0.997	0.889	0.965	0.996
	Slope	0.008	0.007	0.002	0.017	0.002	0.000	0.017	0.005	0.001
	CORREL	0.850	0.778	0.538	0.896	0.492	0.406	0.897	0.810	0.406
RAINFORCEMENT STEEL	Interception	0.699	0.698	0.698	0.698	0.699	0.699	0.697	0.698	0.695
	Slope	0.046	0.046	0.047	0.046	0.046	0.046	0.047	0.047	0.047
	CORREL	0.974	0.974	0.974	0.974	0.974	0.974	0.974	0.974	0.969
CEMENT	Interception	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Slope	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CORREL									

Reinforcement

Slope of reinforcement in all provinces are almost at constant value with a positive trend and CIDA indices in all provinces are also at a constant value with a positive trend. Slope of the CIDA indices in reinforcement shows a lesser slope than provincial prices and therefore both lines are not parallel in each other. As such in actual scenario CIDA indices are not matching with provincial prices.

Bricks

Slope of CIDA indices is at a constant value of 0.0137 for all provinces. From the table its highlighting that slope of brick prices is showing less gradients in Northern. North Central, Northwestern, Eastern, Uva, Sabaragamuwa and Southern Province with a positive trend and showing higher gradient in Western and Central Provinces with a positive trend. In this case also, it is observed that CIDA indices are not reflecting the actual scenario of price variation in all provinces.

Except for Northern Province, all other provinces exhibit a perfect positive correlation. And ¾" metal is having relatively perfect positive correlation except for Eastern and Sabaragamuwa Provinces. In Eastern and Sabaragamuwa Province also shows relatively positive perfect correlation. The table shows red earth is having positive perfect correlation only in southern province, perfect negative co-relationship. ABC has a perfect positive correlation across all provinces according to the correlation calculations. Bricks is having relatively perfect positive correlation in northern and eastern provinces and strong correlation in all other provinces. And according to the table the reinforcement is having perfect positive correlation in all provinces. And cement also having a perfect positive correlation in all provinces.

4.3 Analysis summary

Analysis of collected data were carried out by using following methods.

1) Analyzing price variation from region to region with standard deviation and mean values
2) Comparing Price behavior pattern of construction materials within the province with respect to the standard deviation.
3) Comparing price variation behavior patterns province to province with respect to the mean value.
4) Analyzing CIDA national indices pattern and regional price variation patterns with the slope.
5) Analyzing correlation between the CIDA indices and provisional variations of the prices across the different provinces.
6) Analyze of Variance (ANOVA) Test

5 CONLUSION

Following finding were identified during the research on the variation of prices from region to region and with respect CIDA material indices.

1) As described in 4.1 and Table 1, it is evident, significant variance can be identified in the price fluctuation patterns of the different regions for construction materials selected in this research.
2) According to the derived data in Table 1 and figures no 1, 2 and 3, it showed that there is low papalism in price variation compared to the CIDA indices in many regions.
3) With the data analysis of the slope shown in Table 4, it is shown that there are positive and negative trends in price volatility with respect to the CIDA indices other than Cement in all provinces.
4) Correlation analysis also showing positive and negative trend in price volatility with respect to the CIDA indices in all regions.
5) ANOVA test proved that there are significant evident to reject null hypothesis other than cement. It is possible to conclude that government regulatory price of cement may be the reason for the no price volatility of cement all over the island.

It is clearly shows that the mere determination of price fluctuation with single price index for the whole country is not accurate representative for different regions. Weightage of province to province price volatility varies. This analysis leads to conclude that, there is a significant requirement to establishing in regional indices.

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Queue Length Prediction at Un-Signalized Intersections with Heterogeneous Traffic Conditions

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ABSTRACT

Increasing queue lengths while reducing average vehicle speeds is a notable criterion in intersections with heterogeneous traffic conditions. Such queue lengths vary with different intersection controls. This study aimed to estimate the queue length at un-signalized intersections with heterogeneous traffic conditions. The study was done for un-signalized intersections in Peradeniya and Weliwita, Sri Lanka and the data were collected through video recordings. The queue lengths in an un-signalized intersection with mixed traffic conditions have an instantaneous aggressive variation due to the uncontrolled movements. Thus, a time series analysis with the aid of Vector Auto Regression (VAR) model was used in order to estimate the queue length. Variables considered in this study were arrival flow rate, discharge flow rate, number of conflicts for 15 seconds time intervals as independent variables and queue length at the end of each 15 seconds as the dependent variable. For the modelling, the procedure of "Box-Jenkins" method was followed. After the confirmation of the variables are stationary, Cointegration check and Granger causality tests were done to check the cointegration between variables and the granger causality between variables. Then, VAR models were developed using 80% data from the total data set for both locations. The remaining 20% of the data set was used to validate the model using the MAE, MAPE, and RMSE error values between the actual and predicted queues. Among both models, 0.94 of higher R^2 value and Durbin Watson value as 2 was obtained for the developed model using raw variables for Weliwita junction. Furthermore, the observed MAE, MAPE, and RMSE values for Weliwita model were 3,5 and 6%, respectively. Thus, the results of this study can be used to reduce traffic congestion while enhancing the safety of the users at un-signalized intersections in Sri Lanka.

KEYWORDS: *heterogeneous traffic, queue length, time series analysis, un-signalized intersections.*

1 INTRODUCTION

Increasing traffic congestion during peak hours has become a major problem in developing countries like Sri Lanka. This traffic congestion has led to increase potential parameters such as queue length, vehicle delay, travel time while decreasing the travel speed (Anusha et al., 2013). Intersections within the cities are congested frequently during peak hours (Vajeeran and Silva, 2019). Thereby, the excessive road traffic congestions result in reduced average vehicle speed while increasing the vehicle queue lengths at intersections in urban areas.

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Intersections can be classified into two categories. Signalized intersections and un-signalized intersections are the two types of intersections. The heterogeneous traffic condition at the signalized intersection can be controlled but at the un-signalized intersections, the traffic cannot be controlled. It's upon the driver's behavior. In the present scenario of ever-growing traffic congestion at the intersections, increasing the use of road transportation has led to reduce the vehicle speed, this arises the need of a queue prediction model to predict queue length at intersections (Anusha et al., 2013). Thereby, queue length can be recognized as an essential factor to measure the performance of both signalized and un-signalized intersections (Comret, 2016). This study was aimed to predict the queue length at un-signalized intersections while identifying the governing parameters that cause to queue lengths and to develop a time series model to predict the queue length at un-signalized intersections.

As per the authors' knowledge, no research has been conducted based on queue length prediction at un-signalized intersections with the aid of time series analysis but there is research that has been conducted for the queue length prediction at signalized intersection using the other methods. Those are tabulated in Table 1.

Table 1. Queue length predictions and the theories used in previous studies.

Country and the study	Theory	Type of intersection	Condition of traffic
China (Li et al., 2018)	LWR shockwave theory	Signalized intersection	Heterogeneous traffic condition
India (Parmar et al., 2020)	Multi Linear Regression Analysis	Signalized intersection	Heterogeneous traffic condition
USA (Comret., 2016)	Poisson model with analytical expressions	Signalized intersection	Heterogeneous traffic condition
China (Gao et al.,2020)	Shockwave theory	Signalized intersection	Heterogeneous traffic condition
Canada (Khan and Ali, 2010)	Shockwave theory	Signalized intersection	Heterogeneous traffic condition
USA (Anusha et al., 2013)	Queue polygon method	Signalized intersection	Heterogeneous traffic condition
Sri Lanka (Vajeeran and Silva., 2019)	Trial-and-error process using VISSIM simulation	Signalized and un-signalized intersections	Heterogeneous traffic condition
Germany (Heidemann and Wegmann.,1997)	Renewal queueing theory	Un-signalized intersections	Heterogeneous traffic condition

The previous studies demonstrate that the considered parameters have a significant influence in predicting queue lengths. Li et al., (2018) used vehicle arrival, discharge and turning movement while Ma et al., (2012) used stopping time, lagging time while Parmar et al., (2020) used lane width, flow, red time, and composition as the governing parameters for the study. Further, the studies have implemented various approaches for data collection to develop queue prediction models. Comret (2016) used mobile sensors, Li et al., (2017) used magnetic sensors while Gao et al., (2020) and Parmar et al., (2020) used video recordings to collect data. Li et al., (2018) and Anusha et al., (2013) have used 5 seconds and 10 seconds time sequences to extract the data.

However, from the literature survey it was clarified that only a small number of studies has been done previously based on un-signalized intersections. As per the authors' knowledge, only one study has been conducted for un-signalized intersections (Heidemann and Wegmann,1997). In that study, a mathematical model was developed with the aid of queueing theory to predict queue length. The rest of the studies were for queue length predictions at signalized intersections. Thereby the less amount of studies based on the queue prediction at un-signalized intersections was identified and further identified that there are no queue prediction models with respect to time which means no time series analysis has been done to predict the queue length. Thus, the study is focused on identifying the governing parameters and developing a time series analysis to estimate vehicle queue length at un-signalized intersections.

2 METHODOLOGY

The methodology of this study consisted of seven stages. Those are setting up the objectives, location selection, data collection, data extraction, data analysis, time series model development and validation of the model with the existing conditions.

2.1 Location selection

Locations were selected considering the developing queue and the availability of collecting data without any disturbances. Thereby the selected locations resided with optimum queue length and other governing parameters with heterogeneous traffic conditions. Figure 1 and Figure 2 show the selected location 1 which was the Peradeniya junction while Figure 3 and Figure 4 show the selected location 2 which was the Weliwita junction in Sri Lanka. Even though the selected road sections were single carriageways the observed width of the lanes were different. The type of the intersection was identified as a “T junction” with location 1 being an intersection of major- major approaches and location 2 being an intersection of major-minor approaches.

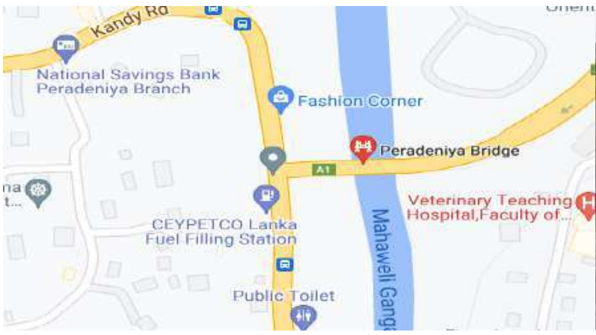

Figure 1. Trained image of selected Location 1

Figure 2. Generated queue sample from collected data Location 1

Figure 3. Trained image of selected Location 2

Figure 4. Generated queue sample from collected data Location 2

2.2 Data collection

From a field visit, it was observed that the development of the queue is varying from zero to 100m range for both locations. Thereby, the data collection was done with the aid of two cameras to cover the entire queue developing section. One camera was placed at downstream, and another camera was placed at upstream. Queue development at the selected approach at location 1 was recorded for two days. For location 1, a data collection was carried out on 16th April 2021 for a peak hour, starting from 12:30 p.m. till 1:30 p.m. and another data collection was carried out on 20th April 2021 for half an hour off-peak time, starting from 9:30 a.m. to 10:00 a.m. Similarly, another data collection was carried out on 30th July 2021 for location 2, starting from an off-peak hour 3:30 p.m. till a peak hour 5:30 p.m.

2.3 Data extraction

Data extraction was carried out manually by replaying the video multiple times. To measure the developed queue length a software called “TRACKER-4.11.0” was used (Tracker, 2021). Different vehicle categories were identified because of the heterogeneous traffic condition. Thereby, those were converted into one category using the Passenger Car Unit values (PCU). The PCU factors were obtained from Kumarage (1996) that study was done to find PCU standards for Highways in Sri Lanka . Those PCU factors are tabulated in Table 2.

Table 2. PCU factors (Kumarage, 1996)

Vehicle category	**PCU factor**
Motor Bike	0.5
Three-Wheeler	0.67
Car/Van/ Jeep	1
Medium Goods Vehicle (MGV)	1.75
Bus/Heavy Good Vehicle (HGV)	2.25

2.4 Model developing

Data were analyzed with respect to time. Therefore, a time series model was developed with the aid of the “EViews” student version software (Eviews 12 University Edition, 2021) to predict queue length at un-signalized intersections. The procedure of Box-Jenkins (1976) which has been used to predict the short-term traffic volume in Amman, Jordan’s capital by Hamed et al (1995) was followed for this study. The analysis was conducted in seven main phases. Those were stationarity checking, optimal lag selection, cointegration checking, granger causality checking, model developing, stability and model fitting checking.

Considered independent variables for this study were arrival flow rate (PCUs per 15 seconds), discharge flow rate (PCUs per 15 seconds) and the number of conflicts (PCUs per 15 seconds) and as the dependent variable, queue length (meters) at the end of each 15 seconds time sequences.

2.4.1 Stationary checking

According to Box and Jenkins (1976), the stationarity check was carried out in two perspectives ways. Those were visual inspections of the results through the correlogram test and the unit root test.

I. Visual inspection through correlogram

The stationary condition of the selected variables was visually inspected to identify any trend or seasonal pattern with the aid of the graphical representations of the autocorrelation function (ACF) and partial autocorrelation function (PACF) on the correlogram test.

II. Unit root check

The unit root test was done under the Augmented Dickey Fuller (ADF) test. The test was conducted in two phases, with the first phase focusing just on the intercept and the second phase focusing on both the intercept and the trend. The probability values were checked to be less than 0.05 while obtaining t-statics values less than 5% to be the condition of stationary for variables and it was identified that the probability values of selected variables for the study were less than 0.05. Thus, it was confirmed that variables were stationary.

2.4.2 Optimal lag selection

For both locations lag value was selected from Akaike Information Criteria (AIC), which gives minimum error value among other criteria while providing the best results (Akaike., 1974). It was observed that lag 1 (time lag by one-time sequence which is 15s-time sequence, AIC= 9.031) and lag 3 (time lag by three-time sequences which is 45s-time sequence, AIC= 10.438) as the minimum error values for location 1 and location 2 respectively.

2.4.3 Johannes-cointegration test

Johansen cointegration test was used to examine the cointegration between the group of non-stationary series. The test results manifest that all the probability values were less than 0.05 which means that there is cointegration between variables. The considered hypothesis of the test is shown below,

H_0 – No cointegration between variables
H_1 – There is cointegration between variables

2.4.4 Granger causality test

By following (Granger, 1969), the test was done to check whether the independent variables cause dependent variables. The considered hypothesis of the test is shown below,

H_0 – Independent variables does not granger cause to dependent variables
H_1 – Independent variables granger cause to dependent variable

2.4.5 Model developing

After identifying that the variables are stationary, cointegration between variables does not exist and the independent variables granger cause to dependent variable, Vector Autoregression (VAR) model was developed with the aid of the "EViews" software.

2.4.6 Stability and model fitting checking

I. Stability checking

To check the stability AR roots test was carried out for both models. The conditions of the test are as follows,

- If points lie inside the circle, the model satisfies the stability condition.
- If points lie outside the circle, the model un-satisfies the stability condition.

II. Check Model fitting

Forecasting graphs were observed to check the model fittings for the developed models. The Conditions of the test are as follows,

- If the Theil inequality coefficient is 0 or close to 0, the model is well fitted
- If the Theil inequality coefficient is 1 or close to 1, the model is not fitted

3 RESULTS AND DISCUSSION

To develop the model, 80% of data from the total set of data were used and the remaining 20% of the data were used to validate the models.

3.1 Developed VAR models

I. Developed VAR model for Peradeniya junction (Location 1)

Considering the queue length as the dependent variable and arrival flow rate, discharge flow rate and the number of conflicts as the independent variables a VAR model was developed. The selected lag for the model was lag 1 which was observed from the optimal lag selection test under AIC criteria.

Table 3 manifest the developed VAR model along with the individual significance of each selected variable for location 1. Thus, the queue length prediction model with coefficients that are related to each variable is shown below in Equation (1) and the observed probability values of the coefficients are less than 0.05 and significant.

$$\begin{aligned} Queue\ length\ =\ & (0.949357 \times Queue\ length_{t-1}) + (-34.1800 \times Arrival\ rate_{t-1}) \\ & + (31.77035 \times Discharge\ rate_{t-1}) \\ & + (-0.889981 \times Number\ of\ conflicts_{t-1}) + 9.412055 \end{aligned} \quad (1)$$

Where;

(t – 1) ; time lag by one time sequence. For this study 15s-time sequence.

Table 3. Developed VAR model for location 1 (Peradeniya model)

VAR model				
Related variable	**Coefficient number**	**Coefficient value**	**T - Statistic**	**Probability value**
Queue length	**C(1)**	0.949357	15.97094	0.0000
Arrival rate	**C(2)**	-34.18000	-8.668305	0.0000
Discharge rate	**C(3)**	31.77035	8.400800	0.0000
Number of conflicts	**C(4)**	-0.889981	-2.527398	0.0118
Model constant	**C(5)**	9.412055	2.935011	0.0035

$$Queue\ length\ = (C[1] \times Queue\ length_{t-1}) + (C[2] \times Arrival\ rate_{t-1}) + (C[3] \times Discharge\ rate_{t-1}) + (C[4] \times Number\ of\ conflicts_{t-1}) + C[5]$$

R-Squared	0.798569	**Durbin-Watson**	1.811990

II. Developed model for Weliwita junction (Location 2)

Considering the queue length as the dependent variable and arrival flow rate, discharge flow rate and the number of conflicts as the independent variables a VAR model was developed. The selected lag for the model was lag 3 (45 second lag) which was observed from the optimal lag selection test under AIC criteria.

Table 4. Developed VAR model for location 2 (Weliwita model)

VAR model				
Related variable	**Coefficient number**	**Coefficient value**	**T - Statistic**	**Probability value**
Queue length	**C(1)**	0.863241	16.08351	0.0000
Queue length	**C(2)**	0.101790	1.440552	0.1499
Queue length	**C(3)**	-0.043469	-0.819963	0.4124
Arrival rate	**C(4)**	-32.97608	-33.58264	0.0000
Arrival rate	**C(5)**	-2.982159	-1.485449	0.1376
Arrival rate	**C(6)**	0.539431	0.266165	0.7901
Discharge rate	**C(7)**	26.81571	38.18857	0.0000
Discharge rate	**C(8)**	1.843290	1.153714	0.2488
Discharge rate	**C(9)**	-0.815272	-0.510864	0.6095
Number of conflicts	**C(10)**	-1.817695	-8.132326	0.0000
Number of conflicts	**C(11)**	0.026664	0.110768	0.9118
Number of conflicts	**C(12)**	0.255436	1.062748	0.2881
Model constant	**C(13)**	10.93986	7.551259	0.0000

$$\begin{aligned} Queue\ length = {} & (C[1] \times Queue\ length_{t-1}) + (C[2] \times Queue\ length_{t-2}) \\ & + (C[3] \times Queue\ length_{t-3}) + (C[4] \times\ Arrival\ rate_{t-1}) \\ & + (C[5] \times Arrival\ rate_{t-2}) + (C[6] \times Arrival\ rate_{t-3}) \\ & + (C[7] \times Discharge\ rate_{t-1}) + (C[8] \times Discharge\ rate_{t-2}) \\ & + (C[9] \times Discharge\ rate_{t-3}) + (C[10] \times Number\ of\ conflicts_{t-1}) \\ & + (C[11] \times Number\ of\ conflicts_{t-2}) + (C[12] \times Number\ of\ conflicts_{t-3}) \\ & + C[13] \end{aligned}$$

R-Squared	0.945790	**Durbin-Watson**	2.000140

Table 4.2 manifest the developed VAR model along with the individual significance of each selected variable for location 2. Even though some of the coefficients were not significant (Probability values more than 0.05) by means the variables do not singly help to predict the dependent variable, but the coefficients were jointly helping to predict the queue length (Dependent variable) and it was identified from the Wald test under coefficient diagnostic test. The test was done by making a null

hypothesis, which is C (2) = C(3) = 0 (Davison and Mackinnon, 1993), and if the probability values are less than 0.05, we reject the null hypothesis. The observed probability values for this model were less than 0.05. Thereby the null hypothesis was rejected and the alternative hypothesis which is C(2) = C(3) ≠ 0 was accepted, thereby the coefficients are jointly helping to predict the dependent variable.

Thus, the queue length prediction model with coefficients that are related to each variable is shown below in Equation 2,

$$\begin{aligned} Queue\ length &= (0.863241 \times Queue\ length_{t-1}) \\ &+ (0.101790 \times Queue\ length_{t-2}) \\ &+ (-0.043469 \times Queue\ length_{t-3}) \\ &+ (-32.97608 \times Arrival\ rate_{t-1}) \\ &+ (-2.982159 \times Arrival\ rate_{t-2}) \\ &+ (0.539431 \times Arrival\ rate_{t-3}) \\ &+ (26.81571 \times Discharge\ rate_{t-1}) \\ &+ (1.843290 \times Discharge\ rate_{t-2}) \\ &+ (-0.815272 \times Discharge\ rate_{t-3}) \\ &+ (-1.817695 \times Number\ of\ conflicts_{t-1}) \\ &+ (0.026664 \times Number\ of\ conflicts_{t-2}) \\ &+ (0.255436 \times Number\ of\ conflicts_{t-3}) + 10.93986 \end{aligned} \tag{2}$$

where;

(t – 1) ; time lag by one-time sequence. For this study 15s-time sequence,
(t – 2) ; time lag by two-time sequence. For this study 30s-time sequence, and
(t – 3) ; time lag by three-time sequence. For this study 45s-time sequence.

3.2 Validation of developed two models

To validate the model, the stability of the developed model was obtained while checking the model fitting with the aid of the Theil inequality coefficients under forecasting graphs and a further residual correlation test was done.

I. Model Stability Check

Figure 5 and Figure 6 manifest the results AR Root test. Results indicate that no points lie outside of the circle for both models. Thus, both models are in stable condition.

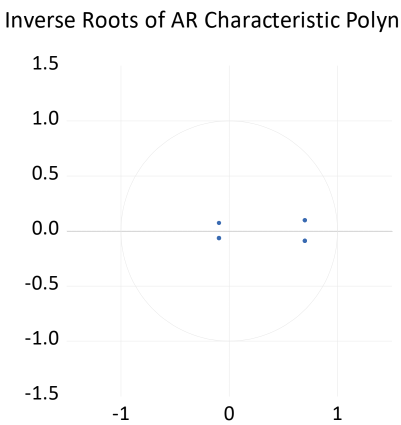

Figure 5. AR Roots test results for Peradeniya model

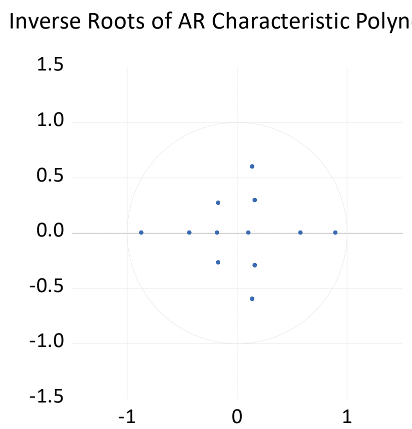

Figure 6. AR Roots test results for Weliwita model

II. Residual correlation test

Residual correlation test was done to check whether there is any correlation between variables under the selected lag. The considered hypothesis of the test is shown below,

H_0 – No correlation between variables
H_1 – There is a correlation between variables

Table 5 indicates the results of residual correlation test results to both models. Table 5 further manifest that there is no correlation between variables for the selected lag.

Table 5. Residual correlation test results

Model	Selected lag (AIC criteria)	Probability value
Peradeniya model	1	0.0000 ($p < 0.05$)
Weliwita model	3	0.0403 ($p < 0.05$)

III. Model fitting check

Model fitting was observed with the aid of Theil inequality coefficient under forecasting graphs. The observed coefficients are tabulated in Table 6.

Table 6. Theil inequality coefficients for both models

Model	Theil inequality coefficient
Peradeniya model	0.118
Weliwita model	0.278

Theil inequality coefficients of both models are close to 0. This means both models are well fitted to the trained data set.

3.3 Discussion on results

After the validation and the confirmation of the stability of the developed models, the comparison of the actual queue and the predicted queue was done to check the error percentages with the developed models for the same location and other locations. To evaluate the accuracy of the proposed model, the Mean Average Error (MAE), Mean Average Percentage Error (MAPE), and Root Mean Square Error (RMSE) values were calculated using the equations (3), (4), (5) respectively. (Li et al., 2018).

$$MAE = \frac{1}{m}\sum_{m}|Observation - Prediction| \tag{3}$$

$$MAPE = \frac{1}{m}\sum_{m}\left|\frac{Observation - Prediction}{Observation}\right| \times 100\% \tag{4}$$

$$RMSE = \frac{1}{m}\sqrt{m\sum_{m}(Observation - Prediction)^2} \tag{5}$$

Here m denotes the number of time sequences.

Equation 3, 4 and 5 was used to calculate the error values between the actual queue and the predicted queue for the selected locations. Here the developed models were used to predict the queue at the same location as well as the other selected location. Thereby, the most accurate model was selected as the queue prediction model. Figure 7 manifests the comparison results between actual peak queue at Peradeniya vs the predicted queue using the Peradeniya model and Weliwita model.

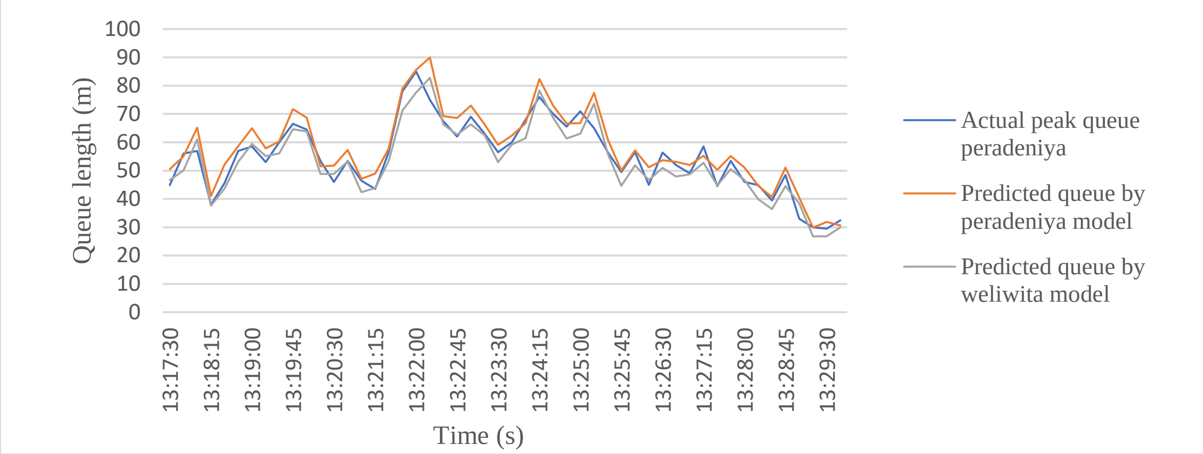

Figure 7. Actual peak queue at Peradeniya vs Predicted queue by both models

During the field data collection stage, it was observed that the Peradeniya junction has a continuous arrival rate while developing longer queues consistently. Thus, zero queues were not identified through the data collection period. Using the equations of 3, 4, 5 MAE, MAPE and RMSE values were calculated for the developed models and tabulated in Table 7.

Table 7. Calculated MAE, MAPE and RMSE values for both models

Actual queue at Peradeniya	**Predicted queue by Peradeniya model**	**Predicted queue by Weliwita model**
MAE	3.713	3.305
MAPE	6.699 %	6.070 %
RMSE	4.755	3.999

Hence the results of Table 7 revealed fewer error values, both models can be used to predict the peak queue at Peradeniya junction. But it was further identified that using the Weliwita model to predict the peak queue at Peradeniya gives lesser MAE, MAPE and RMSE values than the Peradeniya model.

Figure 8 manifest the comparison results between actual peak queue at the Peradeniya vs the predicted queue using the Peradeniya model and Weliwita model.

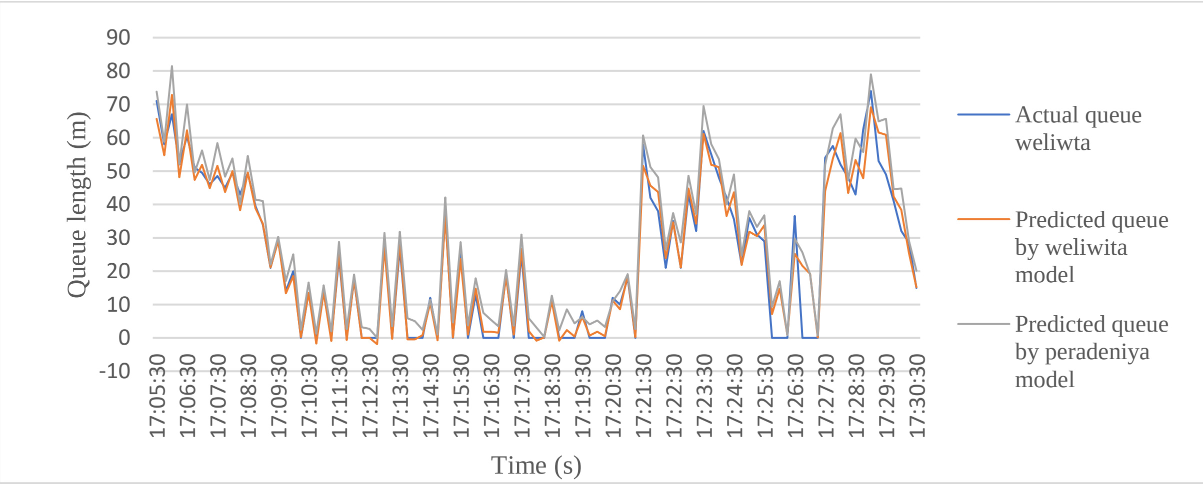

Figure 8. Actual peak queue at Weliwita vs Predicted queue by both models

During the field data collection stage, it was identified that the Weliwita junction condition was different from the Peradeniya junction. The observed arrival rate was not continuous. Thereby, zero queues were identified on that location. But from the graphical representations of Figure 8, it can be identified that both models predict the queue well. It was further identified that the accuracy of the zero-queue prediction of the Peradeniya model is lower than the Weliwita model. Thus, to obtain the accurate model equations 3, 4, 5 were used and the results are tabulated in Table 8.

Table 8. Calculated MAE, MAPE and RMSE values for both models

Actual queue at Weliwita	Predicted queue by Peradeniya model	Predicted queue by Weliwita model
MAE	5.043	3.042
MAPE	9.968%	5.665%
RMSE	6.800	5.042

Table 8 manifest that the obtained MAE, MAPE and RMSE values of the Peradeniya model are much higher than the Weliwita model when predicting the peak queue at the Weliwita junction. However, the results of all the comparisons indicate that the Weliwita model gives much accurate and good results. The only difference that identified was the less accuracy of zero queue prediction of the Peradeniya model.

Thus, for the confirmation of zero queue prediction, another comparison was done using the off-peak hour data of Location 1 (Peradeniya junction) and Weliwita model to predict the queue and the results are presented in Figure 9.

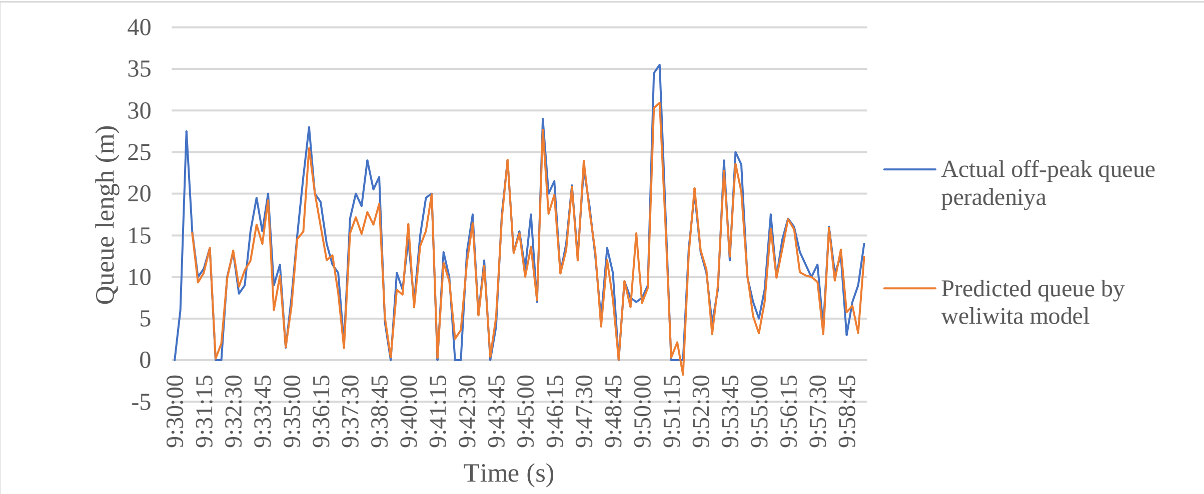

Figure 9. Actual off-peak queue vs Predicted queue by Weliwita model

The graphical representation shows that using the Weliwita model an accurately predicted queue can be obtained. It can be further observed that the accuracy of zero queue prediction is much higher in the Weliwita model.

Table 9. Calculated MAE, MAPE & RMSE values for Weliwita model

Actual off-peak queue (Peradeniya junction) vs predicted queue (By Weliwita model)	
MAE	1.457
MAPE	11.471%
RMSE	2.089

The results of each comparison revealed that the Weliwita model has lesser error values in queue length prediction for both locations while maintaining a higher R^2 value of 0.94%. Table 8 results manifest that the accuracy of zero-queue prediction using the Weliwita model was higher than the Peradeniya model. Thereby the queue prediction model which was developed for the Weliwita junction can be used to predict the queue length at any T type un-signalized intersection.

The MAE, MAPE and RMSE value comparison has been done between the developed model for Weliwita junction and the developed models for other locations in worldwide and tabulated in Table 10.

Table 10. Results comparison with developed queue prediction models

	Weliwita junction [Malabe, Sri Lanka]Developed model	**China(Li et al., 2018)**	**USA(Anusha et al., 2013)**
Intersection type (Signalized /Un-signalized)	**Un-signalized**	**Signalized**	**Signalized**
Method used	**Time series analysis**	**LWR shockwave theory**	**Queue polygon method**
MAE	3.042	1.83	-
MAPE	5.665%	11.28%	-
RMSE	5.042	2.42	1.3

MAE, RMSE and MAPE values equal to or lesser than 3, 3 and 20% which means the model is in the satisfactory range (Li et al., 2018). MAE, RMSE and MAPE values of the developed model are 3.042, 5.042 and 5.665%. Thus, the observed values for the Weliwita model are in the satisfactory range.

4 CONCLUSION

In this study, time series analysis with the aid of the Vector Auto Regression (VAR) model was used to develop a queue length prediction model in order to predict the developing queues at un-signalized intersections. The vehicle characteristics in a heterogeneous traffic condition, influencing the development of the vehicle queue length were identified and analyzed in this study. It was identified that the governing parameters which cause queue length development were arrival flow rate, discharge flow rate and the number of conflicts.

As full filling the secondary objective of this study, the study was adopted considering two highly congested locations in Sri Lanka. One model was developed for Peradeniya junction, Kandy and the other one was developed for Weliwita junction (located in front of SLIIT), Malabe. The assumptions made before developing the model, such as variables are stationary, the granger causality between variables, cointegration between variables was tested and confirmed using 80% data. After developing the model, validation and stability were checked using 20% data. The observed results manifest that the selected variables have a significance influence on developing queue length for both locations. Further, the observed MAE, MAPE and RMSE values for both models reveal that the Weliwita model has more prediction accuracy while maintaining a higher R^2 value and lesser error values for both locations. Thereby, the developed model for Weliwita junction can be implemented to predict the queue length at any T type un-signalized intersection with heterogeneous traffic conditions. This model can be used as an alternative way to predict the queue length when measuring queue length to signalize an un-signalized intersection.

This study was done only focusing on T type intersections where has single carriageways. Thereby, Further research can be done considering different type of intersections that has different geometrical parameters as well as considering more variables such as lane changing phenomena and pedestrian crossing.

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Performance Prediction Models for Flexible Pavements in Sri Lanka

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ABSTRACT

The pavement prediction model forecasts the future PCI ratings based on pavement category, thickness, traffic, pavement life period and existing PCI rating. Nevertheless, with time and inclusion of newer pavement types, there was a need to adjust the prevailing pavement performance models. In addition to, pavements management systems need to develop new models for newer pavement types as well. Some developed pavement performance models in the earlier for the Road Development Authority (RDA) Sri Lanka is used by the roadway segments to predict the future condition and rehabilitations of its network. The available data collections in the roadway agencies in Sri Lanka was used for the research study and the methodology and the analysis section depended on that data collection. Probably we were given the IRI data collections which were done in southern expressway section in Sri Lanka. Based on that data, the analysis part was done for determine the pavement roughness deterioration curves. With a comparison of the developed models, the most suitable model was taken at 95% confidence level with 0.8009 R^2 value. This study displays outcomes about of standardizing the present performance models, and creating unused models for the different asphalt forms within the roadway network in Sri Lanka. A comparison of IRI progression with pavement age and traffic volume is also conducted to see if there are major differences between such models developed in other countries. The anticipated expectations condition of the asphalts is utilized in assessing its outstanding benefit life to disappointment, which is of prompt utilize in prescribing future upkeep and recovery necessities for the arrange.

KEYWORDS: *International Roughness Index, performance model, flexible pavement, rehabilitation*

1 INTRODUCTION

During the studies of the pavement life under given structure there are some main goals can be determined in the pavement design and analysis, such as environmental, traffic conditions. Exact asphalt execution forecast speaks to a vital part in ordering upcoming support and recovery requirements, and anticipating upcoming asphalt condition in a pavement management framework. Roadway transportation area contribute a major character in accessing the development of any region or the country. Sri Lanka has very good road connectivity with approximately 13,000 km span of roadways (RDA, 2021). The pavement maintenance and rehabilitation side, there are two types of pavement failure methods identified. Such as structural failures and functional failures. The functional failure of flexible pavements and serviceability of the pavement accounts with the physical pavement characteristics; i.e., roughness, cracks, potholes etc. In past, there were many methods used for the evolution of the flexible pavement conditions, either visual inspections or very expensive equipment operated by well-trained engineers using various techniques. But that methods had some errors during the estimation of the roadway conditions, especially in visual inspection method (Kim, 2006).

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Also, other methods were not effective in economically. Because of that, engineers found some alternative methods for evaluating the flexible pavements conditions in more effective way. The functional conditions become as a most effective method for evaluating the flexible pavements conditions and several predictions models based on functional factors of flexible pavements were defined from many researchers. At the same time, 'performance models' were made a fundamental background in any pavement management system used by roadway authorities (Sandamal & Pasindu, 2020). The pavement performance model is a basic role of the pavement management system (PMS). Generally, this models are developed to understand the advancement of cracking, roughness, and potholes in flexible pavements. The objective of this research is to develop a pavement performance model to evaluate the variation of roughness for the relevant contributing factors such as traffic volume, pavement age and initial construction quality. It is important to decision making in the PMS during the rehabilitations and services in flexible pavement roads. Models involve the complex interaction between vehicles, environment, structures, maintenance, and construction as well (Chen et al, 2020).

2 LITERATURE REVIEW

2.1 Background

The pavement performance model is a basic part of the pavement management system (PMS). Normally, a strategic and data driven system is used by the pavement management system to optimize the budget provision to different type of maintenance and rehabilitations of the road pavement projects (Kargah-Ostadi, 2019). The main purpose of using the pavement performance model is to assesse the pavement rehabilitation and maintenance cost. Because it is not feasible to maintain and rehabilitation the pavement structures in same way under the financial situation of the roadway agencies and local government. If there are reliable pavement performance prediction model, it may be easy to enhance the rehabilitation and maintenance plan of the whole roadway network under the existing fund. Likewise, the pavement prediction models can be used correspondingly with other statistics, such as pavement rehabilitation budget model to govern the funding level required for the entire roadway system to attain at a predetermined stage of performance (Kim, 2006).

2.2 Roughness Evaluation

In the 1970s, the World Bank supported various enormous field experiments and research works, which were looked for more convenience maintenance substitute for roadway pavements. As a result, pavement roughness was defined as a most suitable primary indicator of the user cost related with flexible pavement conditions. In 1982, the World Bank suggested the IRI value as an ordinary static to calibrate the roughness measurements in road pavements (Sayers et al, 1986). There was a past study, which was conducted by Chandra et al. to evaluate the relationships between the pavement roughness and distress parameters like potholes, revealing, cracks and patches in India, demonstrates a nonlinear model with better R^2 value. In this study, researchers used an advance technology of Artificial Neural Network (ANN) for analyze the data which were obtained by surveying of four national expressways in India (Chandra, 2013). Elghriany et al. found, there is a significant effect from pavement roughness to the traffic safety of the road. That evaluation was done by a study of the different road surface conditions (change of IRI value) and accident rates of relevant road segment. Then it defined the significant relationship between the IRI value and crash rates. In this study, varies models were examined and finally quadric model formula was obtained as a most possible one. The final results of this study were more useful for the road agencies to improve the transportation system and decision making in road maintenance and rehabilitation stages (Elghriany et al, 2016).

Albuquerque and Núñez identified the roughness as a better predictor for assess the pavement condition. Therefore, their study based on the IRI and those models were developed for the asphalt pavement LVR network in northeast of Brazil. In this case, IRI was consider as the dependent variable and weather, structural number, EASL and AADT were takes as the independent variables. In this study, researchers collected data in Ceará State in northeast Brazil using a local virtual reality network. Age data, rainfall data, elevation data, temperature data, traffic data, layer material, and roughness data were comprised in the data base. Four models were established for the collected data, and the validity of each model was then analyzed. A scatter plot was utilized to compare the observed data was checked against values predicted by the model. Throughout that four type of models, HMA model demonstrated 0.87 values as the R^2 value and other models showed 0.15 and 0.09 R^2 respectively. However, HDM 4 model despite the highest R^2 values. The results of this analysis revealed that the model proposed in this study predicted roughness values in HMA pavements better than models proposed by Queiroz, Paterson, and the HDM-4 system due to regional variances (Albuquerque & Núñez, 2011).

3 METHODOLOGY

3.1 Study Methodology

In this study, it mainly focused to IRI data other relevant parameter's data which were mentioned in the introduction section. Usually, that data are obtained from the flexible pavement sections stored in an existing road management data base system. The proposed procedure was made a possible pavement performance model based on the availability data. Modeling performance prediction is greatly aided by collecting data. In the absence of any measured data from the site area, no calibration data were available for the model. Because of that, a critical road segment should be determined based on the review of available data. Data collection was supposed to be one of the most challenging tasks in this study, study required the continues and different kind of dependent and independent variable data. It is more convenience to select road segment, which roughness conditions and other relative parameters range varies with worst condition to best condition. That was better to analysis works as well. Furthermore, road segment is to be as straight segment as much as possible.

3.2 Data Collection and Process

The data required for creating pavement execution models incorporates execution estimations and variables influencing asphalt performance. These data comprise inalienable issues that got to be tended to utilizing preprocessing methods. For developing a model to predict IRI, the pavement distresses parameters and IRI data have been used for modeling and its validation. There was a huge challenge during the data collection stage in this study, because, currently Road Development Authority has proper data collection system regarding to the pavement distress data, like cracks potholes etc. but there some issues raised when borrowing that data, because some data can be only reviewed by the official computer system. But yearly IRI data collection was conducted by the RDA for both A, B class roads and the expressway. Because of that, southern expressway section (E01) data were taken for the analysis work in this study. Mainly, IRI, AADT and age data were collected based on section wise of the southern expressway. Table 1 shows that section names, relevant length and the lanes of each and every section of the study section.

Table 1. The road sections of southern expressway, Sri Lanka

Road Section	Length (Km)	Lanes
Kottawa – Kahathuduwa	6	4
Kahathuduwa – Geanigama	7	4
Gelanigama – Dodangoda	21	4
Dodangoda – Welipenna	11	4
Welipenna – Kurudugahahethekma	21	4
Kurudugahahethekma – Baddegama	12	4

Variable data like AADT, age, IRI and the weather data the IRI prediction models were obtained depending on the earlier mentioned independent variable data by using the SPSS software or appropriate software. That apparatus would be useful for the accurate scientific models in every data analysis work. But for the simplicity, excel software was used for the analysis. In this study an analysis of simple linier regression and multiple linear regression were conducted to do compute the correlation factor and correlation hypothesis, and to determine whether there is a statistically significant relationship between IRI and the other independent parameters. In order to that, statistical hypothesis tests display a p-value to determine whether distresses affect IRI values significantly or not. Also, fitted regression model was judged to be adequate when the coefficient of multiple determinations (R^2) was calculated. According to the R^2 statistic, the regression model makes up a significant portion of the variance of the response variable. General Regression equations take the form described in Equation 1 and 2 (Chandra, 2013).

- Simple linier regression model.

$$Y = ß_0 + ß_1X + \varepsilon \quad (1)$$

- Multiple linier regression model.

$$Y = ß_0 + ß_1X_1 + \ldots\ldots + ß_nX_n + \varepsilon \quad (2)$$

In this case, Y is taken as the dependent parameter (response), X is taken as the independent parameter, and $ß_0$ and $ß_1$, $ß_n$ are the intercept and the regression coefficients in order. For this data analysis a excel worksheet program was used. The data was examined and tabulated and graphs were drawn to describe the data collection trend, build models, and record correlations and relationships between pavement roughness (IRI) and types of distress and other parameters. A regression model linking IRI and distress values was constructed through the use of regression techniques. Based on the results of the statistical tests, a suitable model was then chosen. Several types of regression functions were used in constructing the regression model: linear, quadratic, and logarithmic nonlinear. But, as mentioned in earlier, the models were taken from the linier type.

4 DATA ANALYSIS AND RESULTS

4.1 Pavement age vs. IRI

In the initial stage IRI and the pavement age data were analyzed. Considering the data variation between the IRI and age of the pavement it seems that IRI value increasing with the pavement age. Considering that relationship, simple linier regression analysis method was chosen for develop the models between the IRI and the pavement age. Basically the IRI distribution variation with the age depends on the relevant pavement segments. Generally, most of the road segments demonstrates their IRI value gradually increases with the age and sometimes there may be little fluctuations. The overall data in the database was sorted at randomly and divided into several sets to eliminate any possible bias, referred to as every road segment between two interchanges data. All data groups composed most of the data, at around higher percentage, which was utilized to develop the simple linier regression models. The developed models would represent all sections' mean behavior in a particular pavement family.

Table 2. Output summary of IRI vs. age analysis in different segment of Southern Expressway, Sri Lanka

Road Segment		**Static values**				**Models**
	R^2	p value		t static value		
		Intercept	Age	Intercept	Age	
Kottawa - Kahathuduwa	0.2964	0.000	0.0043	73.74	3.18	1.551 + 0.014 Age
Kahathuduwa-Gelanigama	0.6541	0.000	0.000	158.60	6.745	1.484 + 0.013 Age
Gelanigama – Dodangoda	0.6404	0.000	0.000	70.51	6.54	1.208 + 0.024 Age
Dodangoda – Welipenna	0.3491	0.000	0.001	99.13	3.58	1.058 + 0.008 Age
Welipenna – Kurudugaha	0.8000	0.000	0.000	163.21	9.824	1.163 + 0.015 Age
Kurudugaha – Baddegama	0.0401	0.000	0.367	233.72	-0.918	1.152 - 0.009 Age

The correlation coefficient of IRI and age is lies in better range and the p-value is equal to within 0 – 0.008 range. As mentioned in Table 2, few section's data variations were out of the significant level and most of the results were in the significant level. An age-IRI relationship indicated by the positive sign of the correlation coefficient. In terms of the correlation factor, it was estimated about that the half of the IRI and age observations were distinguishable by a linear association. The best representation for the age data of all road segments was given by the formulas. According to Table 2 most suitable model was determined which indicated that the relationship between IRI and age was statistically significant at 5% significance level. Along that criterion, Welipenna – Kurudugahethekma road section was taken as the most critical model, which indicated the most critical static values as shown in Equation 3.

$$IRI = 1.1626 + 0.015\ AGE \tag{3}$$

4.2 Annual Average Daily Traffic (AADT) vs. IRI

IRI and the AADT data were analyzed through the simple linier regression analysis process. The variation of the AADT and the IRI values can be identified similar as the previous one. That clearly identify if the AADT values increase the IRI values also increase. Because, usually the AADT value is increasing with time. When considering the AADT values of each section there were two different values in both sides, then sum of that two values was used for he analysis, unless it will be complicated. The variation of both parameters indicates a positive relationship between the AADT and IRI values. The output results of the simple linear regression analysis between the IRI and AADT are presented in Table 3.

Table 3. Summary of IRI vs. AADT analysis in different segment of Southern Expressway, Sri Lanka

Road Segment		Static values				Models
	R^2	p value		t static value		
		Intercept	AADT	Intercept	AADT	
Kottawa - Kahathuduwa	0.362	0.000	0.004	73.74	3.18	1.545 + 0.000715 AADT
Kahathuduwa-Gelanigama	0.569	0.000	0.000	110.97	5.63	1.470 + 0.0000754 AADT
Gelanigama – Dodangoda	0.578	0.000	0.000	39.97	4.63	1.177 + 0.000178 AADT
Dodangoda – Welipenna	0.453	0.000	0.008	64.23	2.84	1.048 + 0.0000686 AADT
Welipenna – Kurudugaha	0.737	0.000	0.000	92.98	8.21	1.130 + 0.000134 AADT
Kurudugaha – Baddegama	0.047	0.000	0.279	199.22	-1.09	1.155 + 0.0000068 AADT

Based on the results, it can be concluded that there is a positive relationship between both parameters. It is evident, there is a trend in the linearity of the relation. Almost all cases shows the critical R^2 values which lie above the 0.5. Also the p-values indicate that almost all cases have the better significant relationships. Further it indicates that the relationship between the IRI and AADT is statically significant at 5% significance level. The best representation for the AADT data was given by simple linier regression formula which was obtained for the Welipenna – Kurudughahethekpma section which is shown on Equation 4:

$$IRI = 1.130 + 0.000134\ AADT \tag{4}$$

4.3 Weather versus IRI

The table 4 shows the one of the road segment's (Welipenna – Kurudugaha) main output of the simple linier regression analysis between the weather and the IRI progression. Actually, that values indicates a negative relationship between the precipitation, temperature and the IRI value. Also, there is no definite trend in the linearity of the relationship. The intercept coefficient of this relationships varies between 1.2-1.6 ranges. In other hand, considering the coefficient of the independent variable of the precipitation, that analysis shows it lies in negative range. That is why it mentioned in earlier this was a negative relationship.

Table 4. Weather data analysis output in analysis in different segment of Southern Expressway, Sri Lanka

Statics	Temperature	Precipitation
R^2 Value	0.05	0.004
p value	0.26167	0.7644
t value	-1.1495	-0.3037
Coefficient	-0.0135	-0.00001658

Further this output values shows that the p-values also in the out of the range. Generally p-value should be lower than the 0.05, it means the 95% significant level. In this case, p-values indicate that the models were not in the significant interval. Because of that, relationship between the precipitation and the IRI cannot be expressed as the linier one. In such a case, R^2 values are also in very lower range. Based on that reason, a non-linier relationship might be developed for it.

4.4 Residual Variations

The difference between the predicted and observed IRI values (residuals) are plotted against the predicted IRI values in Figures 1 and 2. The residuals vary mainly between −0.03 and 0.03 m/km and expand in a horizontal band around the zero line. No specific pattern is observed in the residuals' distribution, indicating a good fit for a linear model. Figures 1 & 2 indicate the residual variation of the IRI vs age and IRI vs AADT respectively of section Welipenna – Kurudugahaethekpma. Because, that section indicated the most significant model prediction section.

Figure 1. Residual variation in IRI vs. Age at Welipenna – Kurudugahahethekpma section

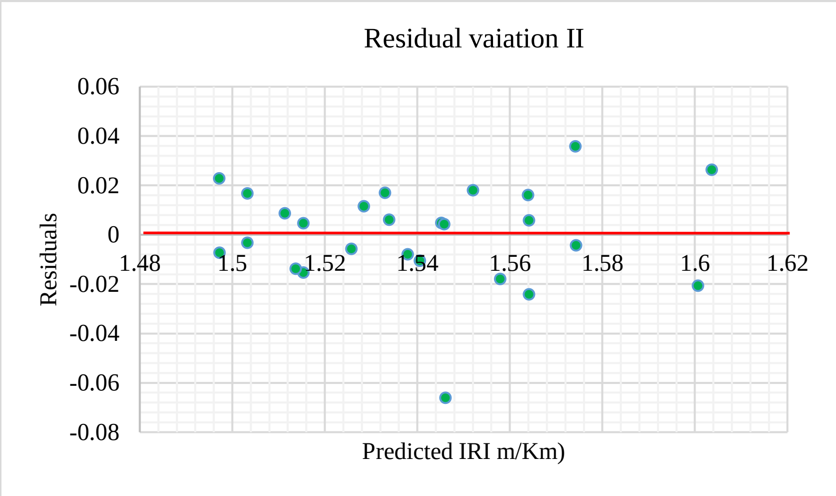

Figure 2. Residual variation in IRI vs. AADT at Welipenna – Kurudugahahethekpma section

4.5 Final models and Validation Process

Table 5 shows significant correlation between both independent variables (AADT & age) and IRI values. In ANOVA-test, the p-values are zero, indicating that the regression models show significant variation in the IRI response variables. The relationship between IRI and independent parameter’s values is sufficiently supported by the data. It is clear, that the segment of Welipenna – Kurudugahahethekpma demonstrates most significant static values throughout the all other modeling static values, like p-values, test static value, stranded error. As well as, the coefficient of multiple determinations (R^2) is equal to 80.1%, which means that 80.1 percent of the IRI values are represented and explained by the regression model. Because of that, the model which was obtained for the Welipenna – Kurudugahahethekpma road section is taken as the most significant model throughout this final multiple linier regression analysis.

Table 5. Final linier regression models

Road Segment	**Static values**							**Final Models**
	R^2	p value			t static value			
		Intercept	AADT	Age	Intercept	AADT	Age	
Kottawa - Kahathuduwa	0.319	0.000	0.3820	0.14	49.87	-0.899	1.5277	1.574 + 0.33 Age + 0.0000105 AADT
Kahathuduwa-Gelanigama	0.677	0.000	0.0211	0.0106	93.82	1.285	2.77	1.5 + 0.0243 Age + 0.000068 AADT
Gelanigama – Dodangoda	0.459	0.000	0.0021	0.000	40.74	-3.37	5.18	1.305 + 0.064 Age - 0.000036 AADT
Dodangoda – Welipenna	0.419	0.000	0.0172	0.017	49.23	-1.66	2.57	1.09 + 0.0216 Age - 0.000014 AADT
Welipenna – Kurudugaha	0.8009	0.000	0.0012	0.001	73.5	0.35	2.35	1.16 + 0.014 Age + 0.00005 AADT
Kurudugaha – Baddegama	0.0590	0.000	0.0256	0.0256	35.6	0.45	2.54	1.159 - 0.00002 Age + 0.0021 AADT

However, the all relationships are much strong enough for distress types to be used to predict pavement roughness condition and final linier regression model shown in Equation 5; which is based on Welipenna – Kurudugaha.

$$IRI = 1.16 + 0.014\ Age + 0.00005\ AADT \tag{5}$$

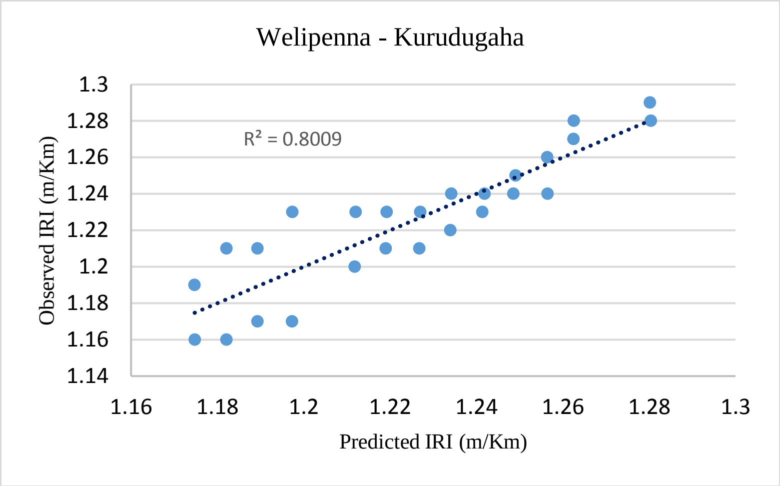

Figure 3. Relationship between observed and predicted IRI basedon proposed model

4.6 Comprehensive overview of developed models

A comprehensive overview was conducted between the model which evaluated in this study and the several other performance models evaluated by some different studies in different countries. Both of the proposed model and other existing roughness deterioration models in other countries are shown in the Table 6.

Table 6. Predicted models present study and past studies

Other Models		Predicted model in this study
Japan	IRI = 1.182 + 0.203 age + 0.123 YESAL	IRI = 1.16 + 0.014 Age + 0.00005 AADT
Sri Lanka (National Roads)	IRI = 6.86 – 4.66exp ^ (-0.0006Age^3.46) IRI = 2.15+ 0.0003Age^1.7343(1 + ADT^0.5075)	
France	IRI = 5.09 - 2.5*IRI + 1.7*Depth - 1.74*Duration + 0.706ESAL*Duration	
UK	Ln (ΔIRI +1) = Age(4.5FI +1.78CI +1.09FTC + 2.4PRECIP + 5.39log(ESAL)/ SN	

As shown in Table 6, some significant similarity and relative variations can be determined from both models. In this study intercept value is taken as 1.16. That is some average value of the IRI progression of the expressway in the initial stage. Considering that, relatively same intercept values can be observed from the other studies models. When looking the independent variables, several foreign performance models like in Japan, UK, took the ESAL parameter instead of AADT which was utilized in present study. But similar sense is made by both parameters to the performance model. All most all of prediction models which were developed in foreign countries, adopted the weather factors. Because, that type countries have most significant weather patterns (e.g.: summer, winter) and the most of pavement deteriorates under those scenarios. But, In Sri Lankan context that type of huge weather variation are not happened. Because of that, weather parameter is not really sensitive for the country context.

5 DISCUSSION

In this study, the effects of the flexible pavement deterioration parameters like IRI, pavement age, Annual average daily traffic (AADT) and the weather, which contributed in the selected expressway road segments was investigated. The results of the current study represented that the ride quality and the general parameters which could affected he flexible pavement. This research was carried out using flexible pavement sections located in the southern expressway section (E-001), with considering the pavement serviceability index (PSI) which better demonstrates the pavement deterioration progression based on the overall pavement deterioration parameters. Therefore, it was possible to determine hoe pavement structure, traffic, age and weather condition are involved on the selected flexible pavement segment's deterioration process throughout this study.

It was also found that as traffic demand, in this case AADT data was considered, increased pavement condition deteriorated and precipitation and temperature was analyzed as the most influence factors. Also, the pavement age value increased along that, pavement condition also deteriorate. But, in his study precipitation and temperature conditions data were analyzed based on segment wise. However, that data was not indicated the exact point condition, also indicates the overall area's condition. In terms of temperature, the annual average temperature and, the annual average temperature were little bit critical to influence the pavement deterioration especially in IRI progression in Sri Lanka country context. Also, considering the precipitation, the road section was divided in to two sections and that data were analyzed separately. That analysis output results showed that the road sections in the high precipitation zones experienced a faster deterioration process that on other area's sections. However, the final models did not indicate the higher significant static values from both precipitation and weather factors. Because, in Sri Lanka haven't the significant season cycles, like summer, winter. Because of that, annual data experienced very low variation.

In this study, mainly focused the simple and multiple linier regression model prediction process and it shows reasonable fitting for the gathered data samples. The computed p values for each and every road segment are below the 0.05 value and most of the intercepts are equal to zero and independent variable parameters are nearly equal to the zero. Throughout the final result, considering the static values Welipenna – Kurudugahahethakpma road segment's model was taken as the most significant model, which shows the most reasonable and significant static values. This indicates a significant multiple linier relationship between IRI and the independent parameters of AADT and age. The results of both simple linier and multiple regression coefficients illustrated 95% confidence that AADT and age are the most significant pavement deterioration parameters. However, it is realistic to conclude that IRI may completely reflect pavement deterioration conditions.

6 CONCLUSIONS

This study was carried out to obtain the most precise flexible pavement deterioration model using the existing data base. Six different pavement sections from southern expressway in Sri Lanka connecting Kottawa to Baddegama interchanges was selected in this study to evaluate the relationships of three types of pavement deterioration parameters of AADT, age and weather with the IRI values. The analysis was carried out to check the relationship between the above mentioned dependent and independent parameters. Based on the results, the final regression model was taken from the Welipenna – Kurudugahahethekpme section throughout all other predicted statistical models that relate IRI values to the independent parameter density values were established. The final model indicted the R^2 value of 0.8009 which was the highest value compared to others. The results indicate that while 95% statistically confidence level relationship exist between IRI and the deterioration parameters under the study. These relationships are normally strong enough for IRI to be used as a surrogate measure for pavement condition. It can be concluded that, it is possible this study will stimulate new modeling efforts in flexible pavement maintenance sector. Also provides valuable assistance in figuring out when to implement maintenance programs by defining a time frame for it and providing support to the authorities for setting-up the budget priority index and designing strategies for effective maintenance programs.

The future studies needs to be conduct to the wider range of the pavement distresses, like cracks, potholes, revels and the roughness. Especially, the additional predictor variables should be focused that impact on the pavement condition on the PSI. Other than that, it will be possible to do a data survey for the above mentioned distresses in local condition. For the future researchers, it is better to collect the relevant data, and based on that data prediction can be done, because the existing data is not easily accessible. The public accessible data bases are already available in other countries, like USA, Australia. But in Sri Lanka, those road data are not accessible. It is much needed to make a critical data base which can be accessible to the public. Otherwise before researchers will develop the models, they need to start to data collection several years before the model development.

7 ACKNOLEDGEMENT

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Impact of Variable Travel Time on the Solution of Vehicle Routing Problem: A Case Study of Bangkok

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ABSTRACT

In the logistics industry, it is essential to have optimized vehicle routes for cost-effectiveness and customer satisfaction. However, most conventional studies on vehicle routing problem (VRP) do not consider the variation in travel time, leading to nonoptimal routes. This study shows the importance of variation in travel time for different times of the day and different days of the week by comparing the optimization results of vehicle routes for constant travel time and variable travel time. Two different scenarios were considered for Bangkok city, Case-1, where customers are scattered across the city, while Case-2, where customers are concentrated on a small area. It was concluded that up to 27.59% error in travel time could be obtained with an average of 12% for Case-1. At the same time, a maximum 30.85% error in travel time can be obtained with an average of 7% for Case-2. Therefore, it is necessary to consider time-dependent travel time in urban logistics route planning in Bangkok. This study also put forward a method to collect travel time data of different origin-destination pairs for different times of the day and different days of the week that can be used by any logistics company.

KEYWORDS: *Time-Dependent VRP, Variable Travel Time, VRP Optimization*

1 INTRODUCTION

In the logistics industry, customers satisfaction and cost-effectiveness mainly depend on the optimization of vehicle routes. These optimized routes enable vehicles to full fill the customers' demands using the shortest path having minimum cost and time. This optimization of vehicle routes for a set of customers is known as the vehicle routing problem (VRP). It is essential for end-user satisfaction and the efficiency of the logistics industry as a whole.

Dantzig & Ramser (1959) were the first to introduce VRP for optimizing delivery problem for gasoline trucks. The VRP can be solved using exact methods (Adulyasak & Jaille, 2016). However, exact algorithms have very high computation time while solving large problems. Therefore, primarily heuristic algorithms are used to solve VRP. The VRP has different variants depending on the problem configuration, objectives, and constraints. Eksioglu et al (2009) performed extensive studies on the variants of VRP. One of these variants is the time-dependent VRP, also known as TDVRP, which considers "variable cost" in the objective function in tesrms of travel time instead of distance. In the real world, travel time is subjected to variations due to different times of the day and different days of the week, and many other factors. However, the data that capture the variation in travel time for different times of the day and different days of the week at the city level have not been available until recently. It is a challenging task to optimize VRP using these data.

Researchers have largely studied the TDVRP. Gendreau et al (2015) did a survey on the problem. They classified the problem in 3 categories depending on the quality and the evolution of the information related to travel times, namely: 1) Static and deterministic time-dependent VRP; 2) Static and stochastic time-dependent VRP, and 3) Dynamic time-dependent VRP. In this paper, we mainly focus on static and deterministic time-dependent VRP, in which the input is known beforehand.

Malandraki & Daskin (1992) were the first to introduce TDVRP. However, in their model of TDVRP "first in first out" (FIFO) principle was not considered when travel time was included. Step function was used by Horn (2000) with a piecewise linear continuous model to get the quadratic travel time model, which led to a more complicated problem framework and required some approximation and simplification of the problem. This problem was solved by Ichoua et al (2003) by using the travel speed step function to obtain the travel time function. This introduction of the travel time function helped the researchers to divide travel time into a few steps instead of considering it as a constant value. Fleischmann et al (2004) devised a framework to derive travel time data from the state-of-the-art traffic information system and used it in different algorithms for solving general VRP. An actual road network speed model was suggested by Kok et al (2012) to reflect traffic congestion. VRP instances were generated to test congestion avoidance strategies. It was concluded that the optimization would be more reliable if congestion was considered. Lecluyse et al (2013) used a method for considering time-dependent travel times that are both spatially and temporally correlated. The data were more realistic but challenging to obtain, and the VRP problem became more complicated to solve.

Xiao & Konak (2016) extended the time-dependent VRP by including a time window to further improve customer satisfaction. The time window was used to consider the available time of the customer as well as vehicle availability. Till now, the TDVRP was only considered for simple capacitated VRP; however, Sun et al (2018) and Atasagun & Karaoglan (2019) further extended TFVRP to pick-up and delivery problems. Carić &s Fosin (2020), for the first time, introduced a framework that used historical data for solving TDVRP by identifying congested areas and avoiding them using an efficient optimization algorithm. However, all these studies used a piecewise linear travel time function, in which travel time was divided only into a few intervals. Jie et al (2022) used a continuous travel time function for solving vehicle routing problem with a time window, considering variable travel time for different times of the day and different days of the week. Furthermore, their TDVRP model also included the weather effect of travel time and extended their TDVRP include time window as well.

The existing literature shows that the travel time data that reflect the actual congestion occurring in large cities and complex road networks are complicated to obtain. No previous studies were found to compare the impact of variable travel time with constant or average travel time to the solution of VRP, especially for a large city with a complex road network like Bangkok. Lombard et al (2018) modeled the TDVRP using open data, in which they have used Google Maps, distance API matrix. The authors used a time step of 2 hours, which did not provide any promising results. This work is very relevant to our work, and our finds will be compared to the finding of this work.

In order to illustrate the variation in travel time, travel time was collected between each pair of nodes of customers with a 15-minute interval for one week. Travel time data were collected for two generalized case studies in Bangkok. Both mentioned cases were solved using the Google OR Tool (Google, 2021), which is one of the standard optimization tools, to explore further the variation in optimization of routes using different times of the day and different days of the week.

The contributions of this study are as follows: first, the variation in travel time, which reflects congestion, throughout the day and week are explored, and peak periods are identified. Second, vehicle route optimization was done for a constant value of travel time as well as for different travel times of the day and different days of the week. The importance of consideration of variation in travel time is shown by calculating the difference in total travel time of optimized routes as compared to the result obtained by constant travel time.

2 STUDY AREA AND DATA COLLECTION

In this paper, the area within Bangkok outer ring road is considered the study area, as shown in Figure 1. The area is divided into two cases, one in which the customers are scattered across the city (Case-1). This area includes the whole Bangkok province and some parts of adjacent provinces near Bangkok like Pathum Thani, Nontaburi, etc. The outer ring road plays a significant role in connecting these provinces. Furthermore, this outer ring also includes the distribution centers of many logistics companies and supermarkets. This study area also provides the freedom to select trips ranging from only a few kilometers to almost 50 kilometers. Whereas the second case study, where customers are concentrated on a small area (Case-2). The trip size in Case-2 varies from 500 meters to 5km.

For data collection, Bing map distance matrix API (Bing, 2021) is used, which provides both the travel time and distance between a set of origins and destinations. Bing map distance matric API provides users with a template for both HTML and Microsoft Excel, which can be used for data collection. For this paper, Microsoft Excel was used for data collection. The Bing map distance matric

API needs the coordinates of origin and destination, time of the day, day of the week, and travel mode as input. And provide the user with distance or travel time between the provided origin and destination based on the routes calculated by Bing maps route API. This work is mainly focused on travel time; therefore, only travel time information was collected from Bing map distance matric API. Travel time calculation is based on the predictive traffic information, depending on the start time specified in the input.

It is worth noting that the travel time matrix obtained from the Bing map is not symmetrical due to the fact that some roads are one-way as well as the congestion at different times of the day affect the selection of specific route. The triangular inequality may not be satisfied due to different levels of traffic and different types of roads. Furthermore, those roads are selected which have the least travel time rather than the least travel distance. However, the travel time, which is the cost in the objective function, will satisfy the triangular inequality as the shortest travel time between two points is used.

The travel time matrix is generated in the following steps:

- Select the location of customers and depot on the map using their coordinates.
- Select the time horizon with a number of intervals (15 minutes) and days (Monday to Sunday).
- Use the coordinates of customers and depot, with the time stamp (date and time) as an input to Bing map distance API to obtain travel time.
- Combine the output travel time into a single travel time matrix.

A similar data collection methodology was used by Lombard et al (2018). However, the authors used Google map distance API and compared the optimization results using average/constant travel time with variable travel time.

In order to investigate the peak period over the city, the variation in travel time was obtained for different times of the day for 100 origin-destination pairs, as shown in Figure 2 (Case-1) and Figure 3 (Case-2). It can be concluded from the figure that the pattern of travel time variation is similar for the different locations, with the only difference in the value of travel time. Furthermore, it can also be seen from the figure that morning peak is around 8:00 AM and evening peak is around 6:00 PM. For the sake of this work, travel time around 12:00 PM is also considered. For the constant travel time, travel time at 8:00 AM, 12:00 PM, and 6:00 PM for all days of the week were computed. Twenty-one values of travel time were obtained for the whole week. The average of those values was calculated to find the constant travel time.

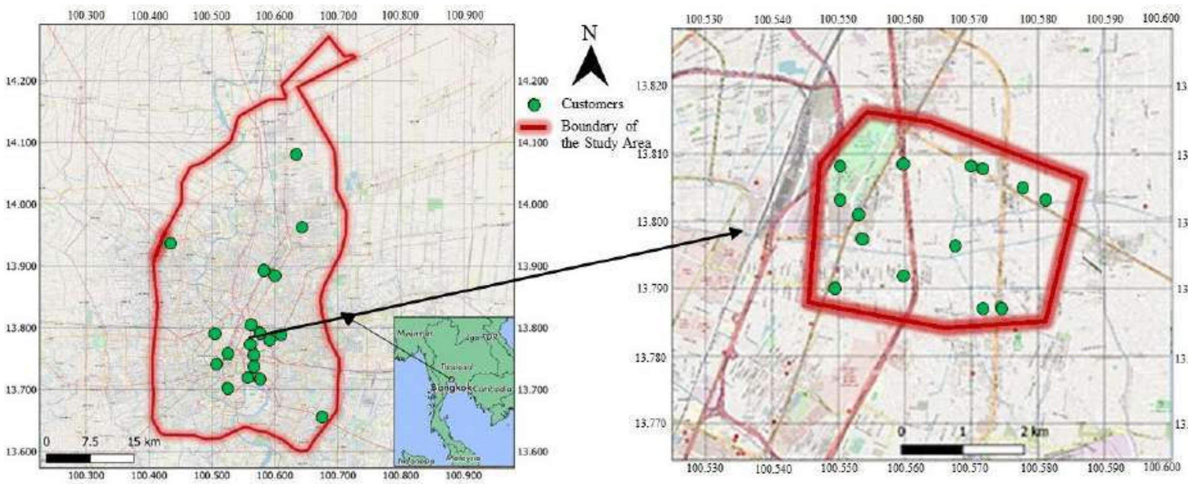


Figure 1. Study area and customers location for Case-1(left) and Case-2(right)

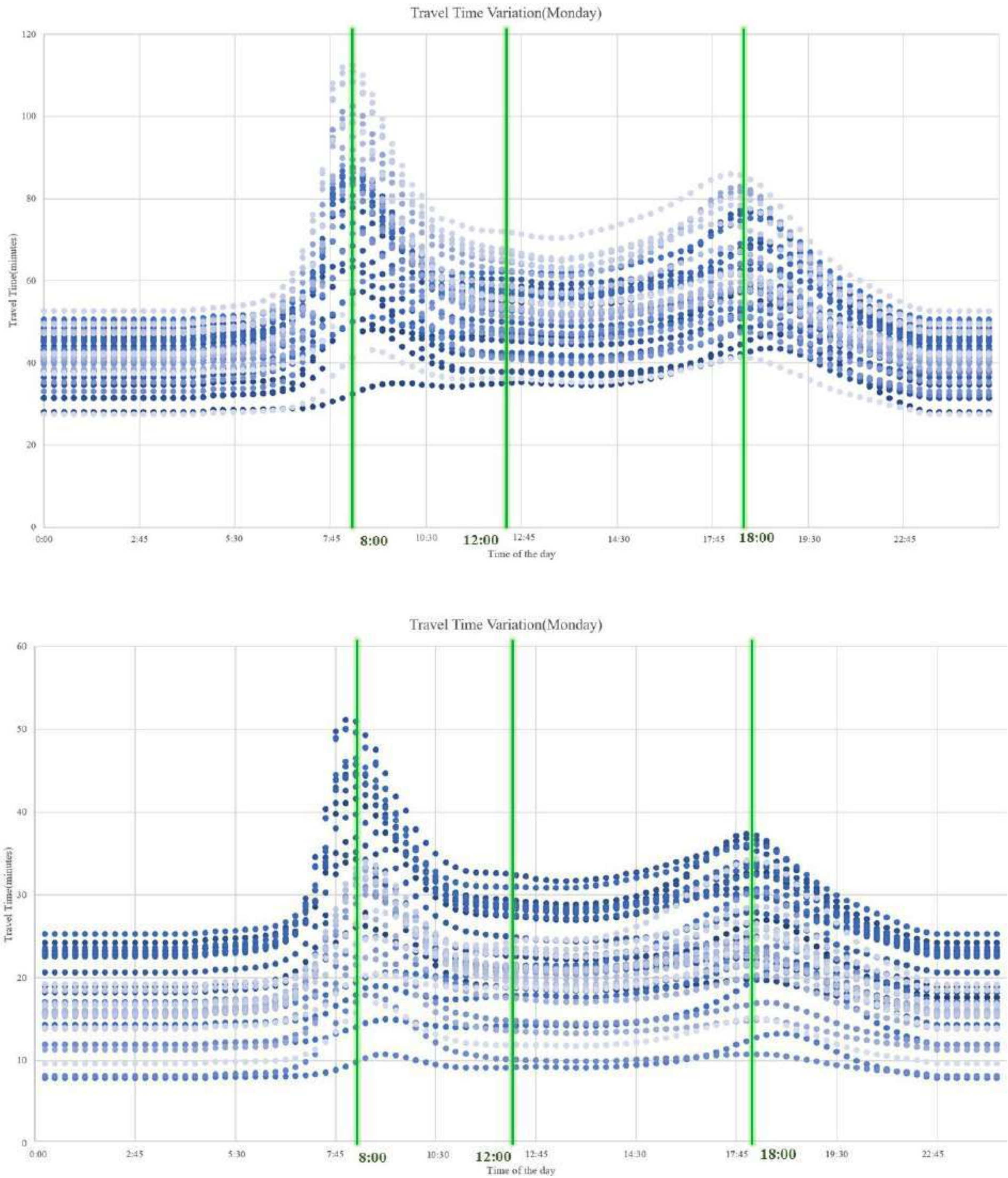


Figure 3. Travel time variation between different pairs of origin-destination (Case-2)

Similarly, Figure 4 shows the variation in travel time for different days of the week. It can be seen from this figure that the pattern of travel time variation from Monday to Friday is similar, with high intensity specifically for Friday. At the same time, the pattern on weekends is different as the peak occurs at different times. For this paper, travel time matrices for 8:00 AM, 12:00 PM, 6:00 PM, and an average of these three (constant/average travel time) were generated.

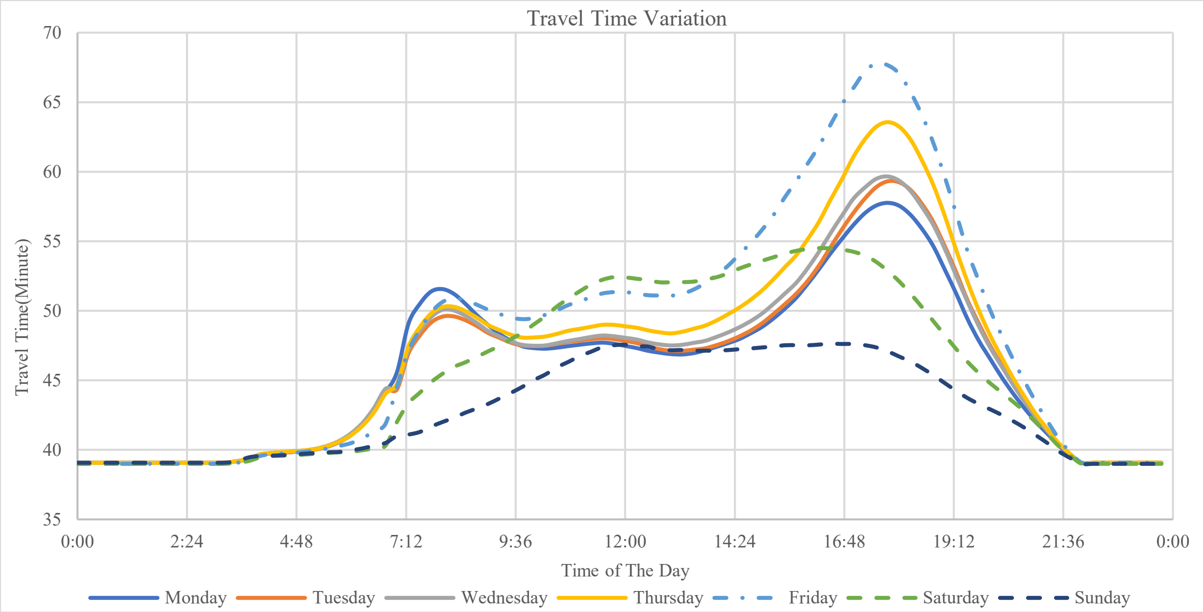


Figure 4. Travel time variation for different days of the week (Case-1)

3 VRP MODEL

VRP is a route optimization problem with some constraints. VRP model is a complete graph G = (V, E). The related sets, decision variables, and parameters are defined as follow:

Sets:

V = {0, 1, 2, …, n} represents customers, where 0 represents the origin(depot).

E = {(i,j) ϵ V, $i \neq j$} edges represents routes.

K = {0, 1, 2, …, k} set of the vehicles.

Decision Variables:

s_i: variable used for optimization priority

x_{ijk}: variable indicating the vehicle kth traveling from node i to j.

Parameters:

M: number of vehicles

R: Vehicle range (length of one shift).

v_{ij}: travel cost by vehicle k traveling across route (i,j) as x_{ijk}.

n: number of nodes, including depot.

As far as this paper is concerned, the main focus is on the effect of variation of travel time on vehicle route optimization. Therefore, to simplify the model demand of the customers as well as the capacity of the vehicles are neglected. Therefore, the optimization is done based on using the minimum number of vehicles to obtain the minimum overall travel time. The first objective of the VRP model is to minimize the number of vehicles, and the second objective is to minimize the travel cost. The objection function F(x) is shown as:

$$F(x) = s_1 M + s_2 \sum_{k=1}^{M} \sum_{i=0}^{n} \sum_{j=0}^{n} v_{ij} x_{ijk} \tag{1}$$

Where s1 >> s2 to ensure the priority in optimization is given to minimizing the number of vehicles. Equation (1) is subjected to:

$$\sum_{i=0}^{n} \sum_{k=1}^{M} x_{ijk} = 1, \forall j = 1,2, \dots, n \tag{2}$$

$$\sum_{j=0}^{n}\sum_{k=1}^{M} x_{ijk} = 1, \forall i = 1,2, \dots , n \tag{3}$$

$$\sum_{k=1}^{M}\sum_{i=1}^{n} x_{i0k} = \sum_{k=1}^{M}\sum_{j=1}^{n} x_{0jk} = M \tag{4}$$

$$\sum_{i\in K}\sum_{j\in K} x_{ijk} \geq 1 \tag{5}$$

Where M is the number of vehicles, n-1 is the number of customers. Constraints (2) and (3) ensure that each customer is served by one vehicle only once. Constraint (4) is for every vehicle to leave the depot and return to the depot. Constraint (5) eliminates secondary paths. Travel time variation will not make any changes to the model as the same model will be applied to the problem but at a different time of the day. Furthermore, R was used as vehicle range constraint selected as 210 minutes for Case-1 and 80 minutes for Case-2. In the standard VRP model shown above, it can be seen that objectives, vehicles, depots, customers, and roads are the main elements of the problem. Roads are the means of delivery, whereas customers are the nodes of the road network. The customers should be visited once and only once. Similarly, depots are the origin and destination for the vehicles which are responsible for picking up goods from depots and delivering goods to the customers. (Zheng, 2019)

4 PROBLEM-SOLVING METHOD

The problem considered in this work is a standard VRP problem. For the study area, twenty random points (one depot and 19 customers) were generated, and four vehicles were considered to fulfill the demands of those customers for Case-1. In comparison, fifteen random points (one depot and 14 customers) and four vehicles were considered for Case-2. For both cases, small four wheels trucks and delivery vehicles were considered as in Bangkok, more than four wheels trucks are not allowed during peak hours (Thailand, 2017). However, this ban is only limited to inner Bangkok, which includes Case-2 of the study area.

For solving the problem, Google OR Tool (Google, 2021) was used. Google OR Tool is one of the standard open-source combinatorial optimization tools. It consists of many libraries for different problems like bin packing, vehicle routing, scheduling, etc. The specialized library related to routing consists of many generalized VRP problems. It provides the user with the code based on some standard programming languages such as python, java, etc. The user must input their desired distance or travel time matrix and other inputs of the VRP problem. For metaheuristics, i.e., local search, OR Tool is set to automatic by default. This means the solver will select the best metaheuristic in terms of computation time to find the solution. However, the user has a choice of choosing the metaheuristic among greedy descent, guided local search, simulated annealing, tabu search, and objective tabu search.

In this study, the standard vehicle routing problem was considered with an asymmetric travel time matrix and with a default setting of OR Tool.

5 RESULTS

Before the optimization of the VRP problem a paired t-test was used to check whether the difference in the constant travel time and variable travel time is significant or not. The travel time of each pair of origin destination for each day of the week at 8:00, 12:00, and 18:00 o clock was compared with the constant travel time. The results of the t-test are summarized in Table 1 and Table 2 for Case-1 and Case-2 respectively. These tables show that for all of the case the difference is significant except for Case-1 on Sunday at 8:00 AM.

Table 1. Result of t-test (Case-1)

Day of the week	Time of the day	Mean	S.D.	t Stat	P-value
Constant	-	34.43	14.61	-	-
Monday	08:00	35.80	15.50	15.95	0
	12:00	38.79	16.43	25.40	0
	18:00	27.42	11.77	-42.65	0
Tuesday	08:00	37.37	15.98	23.67	0
	12:00	40.86	16.92	30.67	0
	18:00	27.42	11.77	-42.67	0
Wednesday	08:00	39.15	16.30	25.74	0
	12:00	41.26	16.98	32.24	0
	18:00	27.41	11.77	-42.70	0
Thursday	08:00	38.46	16.49	25.57	0
	12:00	41.33	17.07	33.43	0
	18:00	27.42	11.77	-42.63	0
Friday	08:00	42.76	19.08	28.18	0
	12:00	45.19	19.12	33.55	0
	18:00	27.34	11.80	-43.33	0
Saturday	08:00	39.91	18.17	23.79	0
	12:00	35.67	15.42	16.73	0
	18:00	27.36	11.79	-42.97	0
Sunday	08:00	34.47	15.95	0.27	0.79
	12:00	32.99	14.73	-13.02	0
	18:00	27.42	11.77	-42.71	0

Table 2. Result of t-test (Case-2)

Day of the week	Time of the day	Mean	S.D.	t Stat	P-value
Constant	-	47.63	12.50	-	-
Monday	08:00	47.88	13.01	2.60	0.01
	12:00	54.53	13.47	44.13	0
	18:00	38.75	11.29	-57.62	0
Tuesday	08:00	48.80	12.91	9.16	0
	12:00	56.11	13.40	44.21	0
	18:00	38.75	11.29	-57.60	0
Wednesday	08:00	49.61	13.03	13.44	0
	12:00	56.45	13.28	43.98	0
	18:00	38.75	11.29	-57.60	0
Thursday	08:00	49.58	12.93	11.17	0
	12:00	56.91	13.55	46.47	0
	18:00	38.75	11.29	-57.58	0
Friday	08:00	54.25	14.01	24.49	0
	12:00	63.07	14.87	63.07	0
	18:00	38.76	11.33	-57.60	0
Saturday	08:00	52.60	14.73	19.82	0
	12:00	49.32	13.53	12.56	0
	18:00	38.76	11.33	-57.69	0
Sunday	08:00	45.14	12.91	-19.12	0
	12:00	44.66	12.30	-35.10	0
	18:00	38.79	11.32	-57.41	0

The optimization was done using constant travel time and, for each day of the week at 8:00, 12:00, and 18:00 o clock. The results are summarized in Table 3 and Table 4. These tables show the travel time of the trips for vehicle 1 to vehicle four after optimization, as well as the total travel time of the trip. The total travel time of trip of constant travel time compared with variable travel time and the difference is calculated.

Table 3. Travel time for different vehicles after optimization (Case-1)

Day of the week	Time of the day	Vehicle 1 (minute)	Vehicle 2 (minute)	Vehicle 3 (minute)	Vehicle 4 (minute)	Total (minute)	Difference from constant travel time (%)
	Constant	173	172	167	155	667	-
Monday	08:00	160	158	157	147	622	-6.75
	12:00	141	136	133	125	535	-19.79
	18:00	206	203	200	182	791	18.59
Tuesday	08:00	177	162	156	125	620	-7.05
	12:00	139	138	133	130	540	-19.04
	18:00	188	187	182	172	729	9.29
Wednesday	08:00	166	166	160	158	650	-2.55
	12:00	138	139	133	130	540	-19.04
	18:00	195	194	193	149	731	9.60
Thursday	08:00	167	167	164	159	657	-1.50
	12:00	141	136	133	125	535	-19.79
	18:00	202	188	181	147	718	7.65
Friday	08:00	178	171	166	161	676	1.35
	12:00	142	142	135	133	552	-17.24
	18:00	190	189	186	180	745	11.69
Saturday	08:00	168	89	161	168	586	-12.14
	12:00	127	126	122	108	483	-27.59
	18:00	162	160	160	158	640	-4.05
Sunday	08:00	160	160	154	153	627	-6.00
	12:00	141	136	133	125	535	-19.79
	18:00	150	147	147	145	589	-11.69

Table 4. Travel time for different vehicles after optimization (Case-2)

Day of the week	Time of the day	Vehicle 1 (minute)	Vehicle 2 (minute)	Vehicle 3 (minute)	Vehicle 4 (minute)	Total (minute)	Difference from constant travel time (%)
	Constant	55	53	42	38	188	-
Monday	08:00	63	59	55	37	214	13.83
	12:00	51	48	40	34	173	-7.98
	18:00	78	74	65	-	217	15.43
Tuesday	08:00	65	58	52	45	220	17.02
	12:00	51	48	40	34	173	-7.98
	18:00	77	76	70	-	223	18.62
Wednesday	08:00	66	59	54	45	224	19.15
	12:00	51	48	40	34	173	-7.98
	18:00	75	70	51	43	239	27.13
Thursday	08:00	65	58	51	44	218	15.96
	12:00	51	48	45	30	174	-7.45
	18:00	75	75	68	-	218	15.96
Friday	08:00	67	67	66	46	246	30.85
	12:00	34	46	51	40	171	-9.04
	18:00	75	74	68	-	217	15.43
Saturday	08:00	60	57	53	33	203	7.98
	12:00	51	46	40	34	171	-9.04

	18:00	57	56	43	40	196	4.26
Sunday	08:00	57	56	43	40	196	4.26
	12:00	51	48	40	34	173	-7.98
	18:00	54	54	40	36	184	-2.13

It can be seen from the results that the difference in the travel time calculated using constant travel time and the variable time is considerable. In the case of overestimation, the constant travel time can lead to 27.59% error for Case-1 and 9.04% error for Case-2. Similarly, in the case of underestimation, the constant travel time can lead to an 18.59% error for Case-1 and a 30.85% error for Case-2. On average, the error can be up to 12.5%. This huge percentage of error is a clear indication of the importance of considering different travel times for different times of the day as well as the different days of the week. These results can be compared with the Lombard et al (2018) work; however, the authors used 2 hours' time step instead of 15 minutes as in our case. Their results show that if variable travel time is used instead of constant travel time can lead to 4.3% savings. This further favors our side that using variable travel time with small intervals can improve our ressults.

Furthermore, it is also worth noting that routing at a different time of the day and different days of the week can also lead to different route sequences, which is illustrated in the tables below. For illustration purposes, the route sequence for only one day is shown in figure 5 and figure 6.

Table 3. Vehicle Routing Sequence (Case-1)

	Monday (Case-1)		
	08:00	12:00	18:00
Veh1	0→3→6→12→13→7→8→9→0	0→6→12→13→7→3→2→0	0→6→12→13→7→3→1→0
Veh2	0→14→15→17→16→19→0	0→18→11→14→10→5→0	0→15→17→16→19→0
Veh3	0→18→4→2→0	0→15→17→16→19→0	0→5→10→14→11→18→0
Veh4	0→11→10→5→1→0	0→1→4→8→9→0	0→2→4→8→9→0

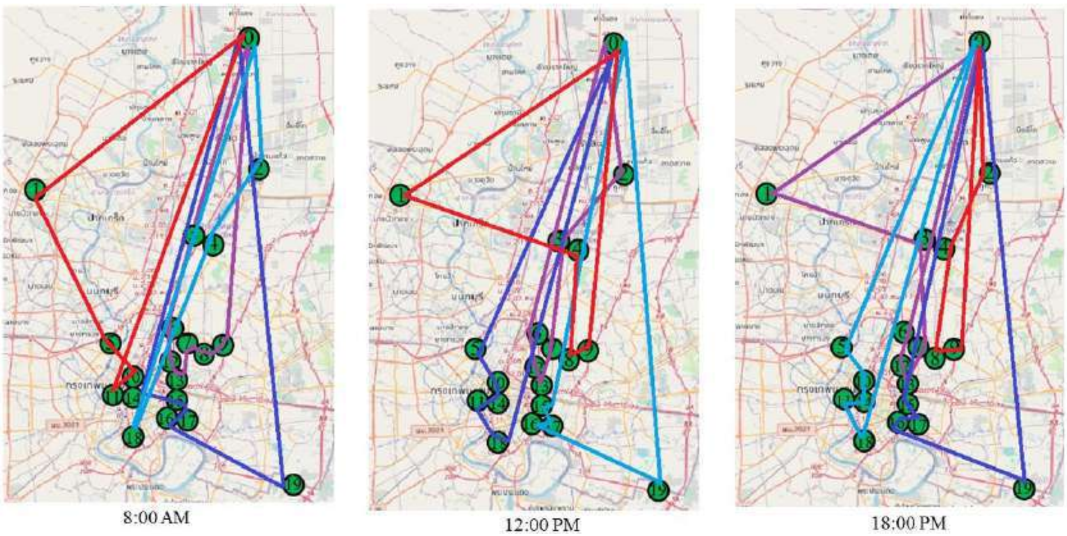
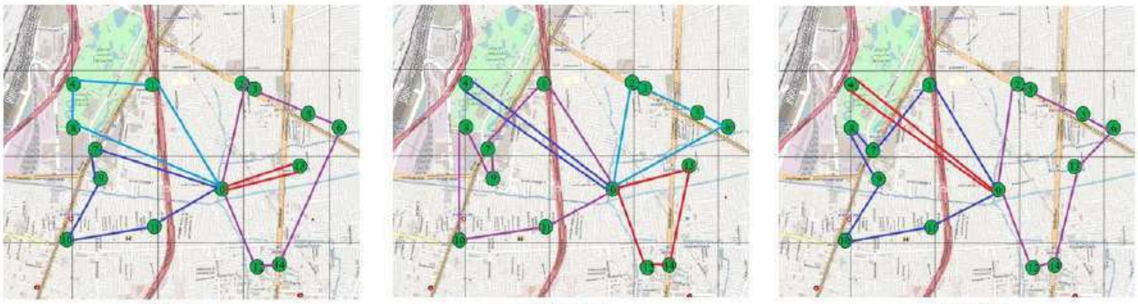


Figure 5 Vehicle route sequence (Case-1)

Table 4 Vehicle Routing Sequence (Case-2)

	Monday (Case-2)		
	08:00	12:00	18:00
Veh1	0→2→3→5→6→14→12→0	0→1→7→9→8→10→11→0	0→2→3→5→6→13→14→12→0
Veh2	0→1→4→8→0	0→4→0	0→1→7→8→9→10→11→0
Veh3	0→7→9→10→0	0→2→3→5→6→0	-
Veh4	0→13→0	0→12→14→13→0	0→4→0



8:00 AM 12:00 PM 18:00 PM

Figure 6 Vehicle route sequence (Case-2)

It can be seen from table 3, table 4, figure 5, and figure 6 above that for different times of the day, due to the variation in congestion, the vehicle routing sequence also changes. The main reason is that the algorithm will try to optimize in such a way by selecting the sequence of the customer to minimize the total travel time. In other words, we can say that the algorithm will take into effect the congestion and will try to avoid the congested routes during peak hours. The same is true for a different day of the week. This further clarifies the importance of considering the different travel times for the different times of the day and different days of the week. Consideration of this variation in travel time becomes more critical for other variants of VRP like VRP with time window. In which the delivery to the customer should be made in a specific time window.

6 CONCLUSION

This study shows the importance of considering different travel times for different times of the day and different days of the week. Bing Map API was used for travel time data collection over a period of one week and 15-minute intervals for 24 hours. Study periods were identified at 8:00 PM, 12:00 PM, and 6:00 PM, and average travel times were calculated, which is later on used as constant travel time. Optimization was done based on the constant travel time as well as variable travel time, and results were compared. It was found that a maximum of up to 30.85% error in the estimation of travel time can be observed if constant travel time is considered as compared to variable travel time. On average, a 12% error in travel time is observed. This study has also shown that it does not matter if the customers are scattered across the whole city or concentrated on a small area. In both, cases using constant travel time will lead to error in estimation and will give us nonoptimal routes. Furthermore, this study has also shown that the sequence of customers is also changed with the variable travel time, which further indicates its importance if the VRP with time window is considered.

7 RECOMMENDATION AND FUTURE WORK

In this study, the travel time is divided into three periods for illustration. However, the actual road network is more dynamic, and there is more uncertainty associated with travel time. Furthermore, the customers are usually requesting the delivery in a certain time window. However, this will further increase the complexity and size of the problem to the extent that it is beyond the capacity of existing algorithms.

In the future, state-of-the-art algorithms will be used to solve time-dependent VRP with a time window with at least 15-minute travel time intervals. One of the possible algorithms can be reinforcement learning with Monte Carlo Tree Search. Which is already used to solve alpha go zero, having state-space greater than 4.5*10^12 (Li, 2019).

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Estimation of Person-Kilometers of Travel in Sri Lanka

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ABSTRACT

Person Kilometers of Travel (PKT) provides all trip information of an individual including trips by motorized, non-motorized, public or informal public transport modes. Estimating PKT in developing countries seems much important as PKT is one of key parameters in transport planning and policy making. Since PKT focuses on an individual, it is influenced by socio demography of the person. However, timely PKT is not estimated by relevant agencies of Sri Lanka. The study focused on estimating PKT in Sri Lanka with travel mode distributions. A paper-based travel survey was conducted over all administrative districts in Sri Lanka for collecting trip information and socio demographic factors of people. 9,012 people participated in surveys resulting a 77.62% response rate. Respondents were asked to provide information of their trips in a typical week, in special holidays and seasons, information on travel modes and their socio demographic information. Data obtained from surveys were aggregated to annual level and weighted in order to obtain PKT/person/year under each socio demographic category. Weightages were estimated using census data in each administrative district. The study came up with important findings; weighted PKT estimations and travel mode distributions in each administrative district. Further, statistical comparisons of PKT estimates among different socio demographic groups and districts were conducted using One-Way Analysis of Variance (ANOVA) test. These findings were key contributions to the existing literature in the country.

KEYWORDS: *Personal Kilometers of Travel, travel mode distributions, transport planning, policy making, paper-based survey, socio demographic factors, statistical comparisons.*

1 INTRODUCTION

PKT is a measure of person travel. More generally, if one person travels one kilometer, it results one PKT. When several people participate for one trip, each passenger is making one - person trip and, it is accounted for estimating PKT. This differs from Vehicle-Kilometers of Travel (VKT) as it always refers to a vehicle. In PKT, focus is always on the person. PKT measures the amount of travel that a person makes by different transport modes as a driver or a passenger. PKT accounts for public transport, taxies and non-motorized transport modes other than private transport modes. In developing countries, most people do not own personal vehicles and, the main means for mobility are walking, intermediate means of transport and public transport services (Starkey & Hine, 2014). Therefore, PKT is more convenient than estimating VKT in developing countries like Sri Lanka. By 2009 in Sri Lanka, there was a demand for around 80 billion passenger km annually by all modes of motorized transport (Kumarage et al., 2009). For the majority in the country, public transport serves as the only means of transport. It accounted around 68% of the total motorized passenger transport by 2009. Bus transport is the most predominant mode of public transport where Sri Lanka railway accounts for only 5% of the passenger transport (Sri Lanka Country Report, 2012). Discussions on poor quality of public transport have been raised in policy making during past few decades; however, it is not in a satisfactory level for most users. Frequently addressed issues in the transport sector in the country are higher levels of congestion in urban areas, poor quality of public transport, increasing trend of vehicle fleet, accidents etc. In addressing such issues in Sri Lanka, the lack of professionalism is the most critical shortcoming (Kumarage et al., 2009). It results a critical gap of data and lack of research in the area. PKT and VKT are key parameters in transport planning and policy making; however, no responsible agencies are engaging with estimating timely VKT or PKT. Therefore, findings of this research study are a key contribution to the existing literature.

The objectives of the study were; to conduct a travel survey aiming to collect travel information of people during a year together with socio demographic information, to estimate weighted PKT under each socio demographic group, to obtain travel mode distribution of people in different administrative districts and, to compare PKT of different administrative districts statistically. This study was structured on data obtained from a paper-based survey. The survey was conducted over all 25 administrative districts in Sri Lanka. Information on trip distances, vehicle modes and socio demography of people were collected during surveys. The data on trip distances were aggregated to annual level and weighted under different socio demographic groups in order to obtain PKT/person/year. Vehicle mode-wise estimations were carried out under different socio demographic groups. Statistical analyses were conducted using One-Way ANOVA for comparing statistically significant differences of PKT among administrative districts under several socio-economic groups. The remainder of this paper is organized as follows. Second and third sections present literature review and methodology. Research findings and discussions are presented in the fourth section and, fifth section is allocated for conclusions.

2 LITERATURE REVIEW

Land passenger transport in Sri Lanka includes private vehicles, public transport, railway and non-motorized transport modes. Public transport has become the only means of transport for many people in Sri Lanka where public busses contribute for 55% of passenger kilometers of travel (Kumarage, 2012). Non-route busses, hired vans, three-wheelers and taxies contribute for another 11% of passenger kilometers of travel. The most common and visible mode of informal public transport in Sri Lanka is three-wheeler. However, knowledge on VKT, PKT and vehicle mode distribution is lacking in Sri Lanka as none of responsible agencies are engaging with timely estimations of such data. Only few researchers have attempted for estimating these data in some areas of the country (Weerasekara & Amarasingha, 2017; Amarasingha & Balasayanthan, 2018). Therefore, the lack of research and data is prominent in this area of study in Sri Lanka.

According to the United States' (US) department of transportation, Person-Miles of Travel (PMT) is the summation of all trip distances of a person in miles on the travel day or for a specific time period (U.S. Department of Transportation, 2016). Many demographic factors influence on daily passenger travel patterns. Elements of travel behavior such as PMT, VKT, mode split, route choice and trip frequencies can be influenced by factors of built environment, urban form and traveler's socioeconomic characteristics (Sardari et al., 2018). Another key factor is the influence from traffic congestion; however, it was rarely discussed. The influence of traffic congestion on individuals' PMT, VKT and trip frequencies in the US was examined with reference to VKT per driver. The study utilized National Household Travel Survey (NHTS) disaggregated data and traffic congestion data around households' and work locations. Research findings revealed that, due to the proximity of origins and destinations in denser areas with higher job-population balances, residents in compact development regions have lower daily VKT. As the NHTS was designed at national level, for most states or subdomains within states do not have sufficient samples to produce reliable estimates (Vaish et al., 2010). Therefore, a study was conducted aiming at small area estimates in all 50 states and district of Columbia. These state-level estimates were useful in identifying areas with higher daily PMT in the US. Out of 60,282 interviewed people in the NHTS data set, only 53,142 people reported any travel day trips. PMT of other 7,140 people was set to zero. State-level percentages with higher daily PMT were studied. Then PMT data were merged with personal and household data. The survey-weighted-hierarchical Bayes small area estimation method was employed in producing output. The study showed the efficiency of conducting small area estimates from large national surveys like the NHTS.

There are several methodologies for estimating VKT such as using traffic counts and roadway centerline length, fuel sale method, vehicle odometer surveys, travel diary surveys, paper-based household surveys etc. However, travel surveys seem flexible in collecting PKT and travel mode related data of people. All trips that are made by both motorized and non-motorized transport modes and socio demographic information of people can be collected using this travel survey method. This methodology was employed in Melbourne for assessing changes of VKT after implementing the travel behavior change program called *Travel Smart* (Seethaler & Rose, 2009). In the study, a before and after travel diary survey and, a household-odometer survey was conducted. Then, week-long odometer readings were aggregated to household level for calculating average daily household VKT. It reduced the variability of travel distance recordings among household members and weekday recordings in travel diaries. The relationship between vehicle fuel economy as a measure of energy efficiency and, VKT as a measure of consumption was examined in Columbia (Munyon et al., 2018). VKT data were extracted from the NHTS in 2009. The survey was conducted over 13 months in all 50 states and, the District of Columbia in the US. Several attributes related to households, drivers within the households, vehicles and travel data for each member of the household and, each vehicle were taken into account during the survey. Energy consumption related data such as mileage per gallon per any given vehicle type, gas price data etc. were collected through the Energy Information Administration and Oak Ridge National Labs. Miles driven by each vehicle per annum was estimated based on annualized odometer readings which were recorded using daily trips carried out by each vehicle in the household.

Another travel survey was conducted in Iskandar, Malaysia for investigating the impact of housing development designs on VKT (Majid et al., 2014). During the survey, travel diaries and questionnaire forms were distributed to households within a sample of housing developments. First, students from selected primary and secondary schools were asked to take travel diaries and questionnaires home. And they were also asked to return the completed documents in the following week. For additional respondents, travel diaries and questionnaires were distributed to a group of randomly selected households within the sample. Total of 325 forms were collected from households representing 24 housing developments for the study. VKT data were collected through a paper -based survey including information on impact factors such as purpose of travel, travel distance, transport type respectively for urban and inter-city travels, vehicle characteristics, odometer readings, respondent characteristics etc. in Beijing, China (Hou et al., 2013). The purpose was to examine daily VKT and its impact factors for designing of powertrain battery powered and plug-in hybrid electric vehicles. A total of 500 questionnaires were distributed among private passenger cars in Beijing. The daily VKT distribution was assessed with the help of software Minitab and, the statistical analysis was conducted using several tests such as ANOVA.

The knowledge on PKT and travel mode distribution is lacking in Sri Lanka. First, this study provides an understanding on PKT estimations of each district in Sri Lanka which is a major contribution to the existing literature. Second, this study aims at providing an understanding on travel mode distribution among different socio demographic groups of people. As very few studies can be found at this point of view in the current literature of the country, this would be a good contribution. Further, the study provides statistical comparisons of PKT under each socio demographic group in each area.

3 METHODOLOGY

3.1 Travel Survey

The data used in this study are derived from a paper-based survey conducted for the year 2019-2020 representing each administrative district in Sri Lanka. Sri Lanka is an island with a 65,610 km^2 land area and about 20 million of population. There are 25 administrative districts under 9 provinces in Sri Lanka. It is a lower-middle-income country with a GDP per capita of USD 3,852 (World Bank, 2019). The basic access to economic activities of people is provided by the road transport network (Asian Development Bank, 2017). It is consisted of 117,012 km of roads spread over the country. The aim of the travel survey was to collect information on trip distances, travel modes and socio demographic factors of people in Sri Lanka. Trip information for a typical week, holidays, new year season, school vacation and special yearly trips were taken into account separately. The selected socio demographic factors for the study were gender, employment status, residential area and age of the respondent. Initially, a questionnaire was developed. Then, prior to actual surveys, a pilot travel survey was performed in one administrative district, Colombo district. For the pilot survey, 100 respondents were participated. It was useful in developing a productive questionnaire form. Sample sizes for each administrative district were statistically derived with a 90% level of accuracy using following equation (Krebs, 2013).

$$Sample\ size = \frac{coefficient\ of\ variation^2 \times standard\ normal\ variant^2}{level\ of\ accuracy^2} \tag{1}$$

As the survey aimed at different population groups in gender, age, employment status, and residential area, stratified sampling method was used. It was useful to verify the participation of all selected groups of people for the surveys. The main purpose of this sampling method was to obtain a representative sample of selected socio demographic groups of the community in the country. For that, minimum number of samples that required to represent each socio demographic group were pre-defined in each district. Each percentage of population under different socio demographic groups in census data were represented in the actual survey sample. The number of required samples were satisfied during surveys in each district. The actual sample size for the country including all administrative districts was 6,995 samples. Totally, 9,012 number of questionnaires were distributed over the country for achieving the actual sample size, resulting an overall response rate 77.62%. The travel survey was conducted and completed over the country within four months of time period. Questionnaires were distributed at schools, government and private offices, shops, super-markets and, also, by visiting households in each district. As questionnaires distributed and collected at the same day, the survey was completed at the first call.

3.2 Weighted PKT Estimations and Travel Mode Distributions

Respondents within samples in each district were classified under selected socio demographic groups. There were two gender-groups, two employment status-groups, two residential area-groups and six age-groups. It resulted 48 possible categories of people that a person can be fallen based on socio-demography. Information on trip distances provided by respondents for a typical week, holidays and special seasons were aggregated to annual level. Then, PKT of each respondent were weighted under selected socio demographic factors. For estimating weightages, census data were used in each administrative district. Equations 2 -4 show the steps of calculating weighted PKT.

$$Weighting\ ratio = \frac{Average\ PKT\ in\ each\ category\ in\ sample}{Unweighted\ overall\ PKT} \tag{2}$$

$$Weighted\ overall\ PKT = \frac{\sum(Avearage\ PKT\ in\ each\ category \times Population\ in\ each\ category)}{Total\ population\ of\ all\ categories} \tag{3}$$

$$Weighted\ PKT\ in\ each\ category = Weighting\ ratio \times Weighted\ overall\ PKT \tag{4}$$

Category-wise weighted PKT estimations were used in calculating PKT of a random person under any socio demographic group. This weighting method provided more generalized values. Then, weighted PKT estimates under each vehicle mode was obtained and, predominant mode distributions among people in each administrative district were determined. Repeated attempts were made to estimate annual weighted PKT over 25 administrative districts.

3.3 Statistical Comparisons of PKT

ANOVA test was used for comparing PKT among districts under different socio demographic groups. Initially, one-way ANOVA was used and assumptions of the test were assessed. Assumptions of one-way ANOVA are; dependent variable should be measured at the ratio/interval level (continuous), independent variable should have two or more categorical, independent groups, independence of observations, dependent variable should be approximately normally distributed and homogeneity of variances. In the data set, dependent variable was not normally distributed for many groups, therefore, log-transformation of PKT was used in the ANOVA. Also, many categories violated the homogeneity of variance assumption. Levene's statistic was used in finding the homogeneity of variance. When this assumption is violated, the normal practice is to use the Welch's ANOVA test. Therefore, this study accommodated Welch's ANOVA test to identify statistically significant differences of groups under each socio-demographic category. Welch's statistic can be denoted as below (Mendes & Akkartal, 2010),

$$F_{welch} = \frac{\sum_{i=1}^{k} W_i \,(\overline{X_i} - X'_{..})/(k-1)}{[1 + \frac{2}{3}(k-2)\Lambda]} \quad (5)$$

Where, weight W_i to reduce the effect of heterogeneity of variance can be denoted as,

$$W_i = \frac{n_i}{S_i^2} \quad (6)$$

$$X'_{..} = \frac{\sum_{i=1}^{k} W_i \overline{X_i}}{\sum_{i=1}^{k} W_i} \quad (7)$$

Lambda, which is based on weights can be expressed as,

$$\Lambda = \frac{3\sum(1 - W_i/\sum_{i=1}^{k} W_i)^2/(n_i - 1)}{(i^2 - 1)} \quad (8)$$

Where, n_i = Sample size in the i[th] group, S_i = Observed Sample variance for the i[th] group, $\bar{X}_i$ = Sample mean for the i[th] group. Effect size of identified statistically significant differences from the Welch's ANOVA were measured using Eta-Squared estimates. They gave the size of effect as small, medium or large. This effect-size estimation improved the practical significance of results. Eta-squared value can be given as below where, SS_{effect} is the sum of squares of the effect and SS_{total} is total sum of squares (Lakens, 2013).

$$\eta^2 = \frac{SS_{effect}}{SS_{total}} \quad (9)$$

4 RESULTS AND DISCUSSIONS

4.1 Weighted PKT Estimates

Weighted PKT in kilometers/person/year under selected socio demographic groups are presented in Table 1. Colombo administrative district showed higher PKT values for several socio demographic and economic groups. For a male person, female person, unemployed person, urban person and, for a person within 15-24 years age group, 55-64 years age group and, more than 65 years group showed highest PKT in Colombo district compared to other districts. Colombo is the commercial capital in Sri Lanka. According to the Department of Census and Statistics (DCS) in Sri Lanka, Colombo district has the largest population; 11.4% from the total population of the country (Department of Census & Statistics, 2012). Areas coming under all municipal councils and urban councils are currently considered as the urban sector in Sri Lanka. In Colombo district, 77.6% people are living in urban areas. Also, Colombo municipal council accounts for 15% of the total population in urban areas. As the economic hub of Sri Lanka, Colombo is home to many of Sri Lankan corporate offices, trade centers, entertainment venues, hotels and restaurants, tourist destinations and for many famous landmarks. Therefore, the higher PKT values reported under different socio demographic groups may be indicators of above-mentioned features in the community of Colombo district.

For an employed person, the highest PKT was reported in Trincomalee district. A person within 45-54 age group also had the highest PKT in Trincomalee. A rural person in Vavuniya district travelled more compared to rural people in other districts. Also, a person within 35-44 years age group showed a higher PKT in Vavuniya district. These two districts were exposed to a civil war over three decades and, totally rescued in 2009 by the government armed forces. After, the infrastructure development is being undertaken by both state and private sectors in those areas. Higher PKT may reflect long trip distances for fulfilling daily needs and, thereby the need of further economic and infrastructure development in those areas. A person within 25-34 years age group showed higher PKT in Puttalam district. Also, in most of districts, PKT for a person within 25-34 years old seemed higher compared to people in other age groups. This may be because people within this age group are mostly engaged with the workforce of the country, involving for more economic activities. In 2015, about 82% of population in Sri Lanka lived in rural areas (World Bank, 2016). Also, about 80% of the rural road network remains unpaved or in fair to very poor condition. It does not provide people a proper connectivity to markets, employment, education, health and many opportunities. This may be resulted long trip distances/long distances between destinations, thereby higher PKT. As a result, in most of districts in Sri Lanka, PKT was higher for rural people more than urban people. In Colombo, Gampaha, Kandy, Puttalam, Kegalle, Galle, Ampara, and Jaffna districts, urban people have travelled more compared to rural people. There are four districts in Sri Lanka which are comprised only with rural areas. No urban areas are found in those districts according to the current definition introduced by the DCS, Sri Lanka. In most of districts, an employed person has travelled more compared to an unemployed person. It is obvious that, daily trips for their employments create higher PKT. Also, there is no noticeable difference in gender-wise PKT estimates over 25 districts in Sri Lanka.

Table 1. Weighted PKT Estimates in each Administrative District

Administrative District	PKT in kilometers/person/year											
	Gender		Employment status		Residential status		Age in years					
	Male	Female	Employed	Unemployed	Urban	Rural	15-24	25-34	35-44	45-54	55-64	>65
Colombo	8611	10950	8191	11370	10940	8622	9846	11634	7990	10760	10882	7572
Gampaha	5603	5569	5896	5276	5734	5437	6225	5593	4610	6813	5839	4433
Kalutara	5492	4001	5484	4009	4572	4921	6805	3974	4211	5676	3918	3894
Kandy	5803	4970	6288	4486	5748	5025	7575	3289	5240	5913	4762	5541
Matale	4212	5074	5090	4196	4051	5235	6762	2111	4120	3795	4024	7047
NuwaraEliya	4837	3921	5456	3301	3511	5246	6962	4191	3926	3508	3958	3727
Kurunegala	3936	5053	4081	4908	4066	4923	4739	4794	4504	3804	4359	4768
Puttalam	7093	5772	7496	5368	7104	5761	4628	13466	5597	5026	4283	5594
Kegalle	4480	7484	5863	6102	6501	5463	5821	4034	3000	12281	3667	7091
Ratnapura	5651	5237	4741	6148	4213	6675	4146	8070	7448	5993	4341	2665
Galle	5007	4554	4897	4665	5155	4406	6558	8201	4228	3854	3287	2556
Matara	3664	2403	4468	1599	2734	3332	4113	2940	2865	1953	4307	2022
Hambantota	3769	5721	4511	4979	4529	4961	5753	4165	6549	4631	3053	4320
Batticaloa	4093	4619	5559	3755	3918	4669	3754	4364	3498	4851	5160	5665
Ampara	3447	3734	3121	4059	3748	3431	3381	3281	3013	3686	5076	3393
Trincomalee	7633	8225	11895	6404	5854	8189	6506	2499	4242	12298	9933	5825
Monaragala	4837	6975	5923	5892	-	5906	7120	4884	5781	6036	5081	7162
Badulla	4654	5940	5484	5149	4511	6241	4545	4988	6008	4228	8213	3545
Jaffna	2903	3498	3611	2770	3309	2636	3581	4404	3567	3043	2066	270
Mannar	1542	3192	2660	1435	2039	6182	1975	1732	3636	3341	2856	367
Kilinochchi	2119	2241	2113	2372	-	2217	1730	2616	2038	2190	3978	652
Mullaitivu	4961	3876	4584	2859	-	4271	2434	6361	4457	4203	2873	1065
Vavuniya	6050	9318	8372	9616	6611	19301	7320	7910	12555	8977	6809	960
Anuradhapura	4342	3814	5503	2654	3125	5031	5457	3575	5281	4482	4330	1345
Polonnaruwa	2413	2771	2928	2256	-	5184	2552	2414	2607	1807	1979	4193

4.2 Vehicle Mode Distributions

Table 2 – Table 7 present vehicle mode distribution of people in each district. PKT values in PKT/person/year were converted to percentages under each socio demographic category. MB and TW

are denoted motor bicycles and three-wheelers respectively. Busses and motor bicycles were used as most predominant travel modes by males and females in many districts. A male person in Puttalam district has been travelled mostly by three-wheelers. In Ampara district, a male has travelled by cars more frequently. Van was the mostly used transport mode for a male person in Polonnaruwa district. For a female in Colombo and Galle districts, the most predominant transport mode was vans while it was three-wheelers for a female in Kegalle and Badulla districts. For employed people in most districts, motor bicycles and busses were the most used travel modes. Three-wheeler was the predominant travel mode for an employed person in Puttalam and Ampara districts. In Colombo and Galle districts, van was the mostly used travel mode by employed people. Regard to an unemployed person in Colombo, Kegalle, Badulla and Mullaitivu districts mostly used three-wheelers. Car was used as the most predominant travel mode by an unemployed person in Ampara and Trincomalee districts. In other districts, bus and motor bicycle were frequently used. An urban person in Colombo, Puttalam, Kegalle and Badulla districts frequently used three-wheelers for their travelling. In Ampara district, car was the predominant travel mode for an urban person. Busses and motor bicycles were frequently used by urban people in other districts. For a rural person in Matale and Badulla districts, the mostly used transport mode was three-wheeler. Van was the mainly used transport mode for a rural person in Colombo and Kegalle districts. Rural people in other districts commonly used busses and motor bicycles.

Table 2. Vehicle Mode Distribution as Percentages in each District by Gender

District	Male							Female						
	Car	Van	Jeep	MB	TW	Bus	Taxi	Car	Van	Jeep	MB	TW	Bus	Taxi
Colombo	4.02	16.33	0.48	14.48	12.26	51.41	1.01	1.68	42.27	0.90	6.68	36.26	11.48	0.73
Gampaha	4.28	6.02	3.58	21.22	14.59	48.04	2.26	0.96	8.16	0.34	19.58	9.94	59.22	1.80
Kalutara	3.49	11.32	0.02	32.23	13.90	38.16	0.87	2.64	10.38	0.81	30.27	6.88	46.99	2.03
Kandy	1.48	6.52	0.90	36.34	1.68	52.53	0.55	1.41	31.00	0.12	39.59	2.55	23.92	1.41
Matale	2.07	0.48	0.00	9.71	33.62	51.51	2.60	2.98	0.40	11.79	9.17	24.62	50.96	0.07
NuwaraEliya	10.40	5.91	0.22	9.66	3.11	70.40	0.30	1.99	1.30	0.00	19.58	8.78	65.48	2.88
Kurunegala	18.73	8.90	0.33	22.35	10.08	38.40	1.21	8.27	4.41	0.29	24.92	8.35	53.26	0.51
Puttalam	0.49	1.00	1.64	17.33	48.53	30.15	0.86	0.26	2.09	9.79	28.49	9.65	48.96	0.75
Kegalle	2.43	13.92	2.05	32.87	11.29	36.61	0.85	1.32	21.26	1.40	19.62	37.66	17.98	0.77
Ratnapura	0.88	9.05	0.00	37.11	3.69	48.84	0.44	0.62	6.97	0.64	25.00	11.73	51.67	3.38
Galle	4.51	6.27	0.69	26.67	20.26	41.12	0.49	1.23	37.40	0.26	14.10	10.68	35.47	0.86
Matara	13.61	2.54	0.57	42.28	5.74	34.79	0.46	8.61	6.57	2.69	28.04	6.98	40.49	6.61
Hambantota	1.21	15.22	1.26	31.87	15.33	34.00	1.10	1.22	4.10	2.17	36.37	10.04	45.46	0.64
Batticaloa	9.24	3.10	10.78	64.86	3.56	8.41	0.04	7.13	17.14	11.09	51.98	5.32	7.30	0.04
Ampara	44.84	8.16	8.68	15.94	12.14	9.99	0.26	16.27	11.77	0.86	31.41	25.67	13.81	0.20
Trincomalee	35.02	1.99	0.27	43.32	5.80	12.48	1.11	24.44	2.25	0.03	34.88	7.43	29.64	1.34
Monaragala	12.64	0.75	2.71	36.84	12.76	34.31	0.00	16.85	0.16	3.60	31.44	23.06	24.90	0.00
Badulla	22.14	1.34	0.02	35.77	31.41	9.33	0.00	3.57	1.72	0.00	33.41	48.17	13.14	0.00
Jaffna	7.57	0.34	0.20	37.66	0.44	53.80	0.00	13.76	1.39	0.00	45.35	0.00	39.49	0.00
Mannar	0.00	0.00	0.00	58.80	0.00	41.20	0.00	3.83	0.15	0.00	54.15	0.00	41.86	0.00
Kilinochchi	4.19	6.97	0.00	48.75	0.00	40.08	0.00	4.74	0.81	0.00	50.81	0.00	43.64	0.00
Mullaitivu	0.00	0.00	0.00	2.52	0.00	97.48	0.00	0.00	0.00	0.00	41.08	20.44	38.48	0.00
Vavuniya	0.00	0.00	0.00	73.70	0.27	26.02	0.00	2.71	0.00	0.00	83.54	0.04	13.71	0.00
Anuradhapura	6.61	3.37	0.74	66.22	5.97	16.87	0.22	19.71	8.36	0.14	27.38	14.47	29.69	0.25
Polonnaruwa	9.40	28.03	0.00	18.81	23.67	19.80	0.30	3.26	12.04	0.07	54.89	7.64	21.57	0.52

Table 3. Vehicle Mode Distribution as Percentages in each District by Employment

District	Employed							Unemployed						
	Car	Van	Jeep	MB	TW	Bus	Taxi	Car	Van	Jeep	MB	TW	Bus	Taxi
Colombo	3.30	42.56	1.89	14.65	11.42	24.81	1.36	1.96	27.79	0.05	6.02	38.53	25.17	0.48
Gampaha	2.53	9.94	3.62	24.16	16.44	40.77	2.54	2.64	4.23	0.19	16.51	7.88	67.06	1.49

Kalutara	3.33	5.43	0.05	43.54	3.42	43.33	0.90	2.86	18.64	0.77	14.31	21.55	39.86	2.01
Kandy	0.91	16.30	0.84	39.93	2.60	38.34	1.09	2.18	21.10	0.10	35.14	1.42	39.25	0.81
Matale	1.39	0.43	0.00	10.74	29.66	56.51	1.27	3.88	0.46	13.67	7.97	27.44	45.47	1.12
NuwaraEliya	9.65	5.66	0.00	13.98	4.45	64.86	1.39	1.66	0.85	0.33	14.10	7.53	73.98	1.54
Kurunegala	19.62	5.02	0.52	31.07	5.02	38.04	0.72	7.35	7.62	0.12	17.66	12.56	53.78	0.91
Puttalam	0.55	0.22	1.48	14.02	48.47	34.01	1.25	0.20	3.12	10.37	33.26	7.91	44.90	0.25
Kegalle	1.69	28.13	0.75	28.14	5.37	34.75	1.18	1.78	8.62	2.56	20.98	50.65	14.99	0.41
Ratnapura	1.58	7.20	0.72	22.06	5.86	58.69	3.88	0.16	8.69	0.00	38.15	8.70	43.97	0.34
Galle	4.14	31.45	0.86	17.16	19.40	26.08	0.92	1.31	10.18	0.00	24.25	10.60	53.29	0.38
Matara	13.26	4.74	0.40	45.45	5.12	29.64	1.39	7.09	2.51	4.22	12.35	9.23	57.46	7.15
Hambantota	1.58	11.65	0.31	29.05	13.03	43.34	1.04	0.87	5.79	3.17	39.58	11.37	38.61	0.63
Batticaloa	10.54	18.06	0.95	67.24	3.21	0.00	0.00	6.80	5.78	16.68	53.14	5.18	12.36	0.06
Ampara	14.29	9.29	10.84	24.61	25.53	15.23	0.19	44.98	10.18	0.84	21.76	12.88	9.10	0.25
Trincomalee	22.61	0.17	0.00	57.63	8.55	11.03	0.00	32.51	3.21	0.20	28.12	5.73	28.30	1.92
Monaragala	14.04	0.91	5.98	37.50	18.10	23.47	0.00	15.95	0.00	1.07	30.66	19.38	32.93	0.00
Badulla	15.61	3.22	0.02	38.44	27.86	14.85	0.00	7.72	0.05	0.00	30.78	52.92	8.53	0.00
Jaffna	12.05	0.92	0.14	41.68	0.17	45.04	0.00	9.80	1.00	0.00	42.77	0.22	46.21	0.00
Mannar	3.02	0.11	0.00	54.56	0.00	42.32	0.00	0.00	0.00	0.00	64.64	0.00	35.36	0.00
Kilinochchi	2.79	3.50	0.00	55.86	0.00	37.85	0.00	6.89	0.00	0.00	43.75	0.00	49.36	0.00
Mullaitivu	0.00	0.00	0.00	16.57	0.00	83.43	0.00	0.00	0.00	0.00	17.28	53.91	28.81	0.00
Vavuniya	2.78	0.00	0.00	80.74	0.11	16.37	0.00	0.00	0.00	0.00	86.98	0.00	13.02	0.00
Anuradhapura	6.73	5.84	0.53	62.77	7.07	16.95	0.11	25.85	4.70	0.37	16.89	15.91	35.79	0.49
Polonnaruwa	1.66	25.40	0.00	40.30	20.29	12.06	0.29	12.82	11.04	0.09	34.15	7.75	33.51	0.63

Table 4. Vehicle Mode Distribution as Percentages in each District by Residential Area

District	Urban							Rural						
	Car	Van	Jeep	MB	TW	Bus	Taxi	Car	Van	Jeep	MB	TW	Bus	Taxi
Colombo	2.63	27.74	0.34	8.81	41.31	18.34	0.83	2.25	42.07	1.39	10.12	8.26	35.10	0.80
Gampaha	2.78	7.72	1.30	14.84	13.72	58.42	1.22	2.38	6.47	2.57	26.33	10.59	48.78	2.88
Kalutara	1.49	10.72	0.53	37.11	11.94	37.15	1.07	4.70	11.11	0.18	26.05	10.01	46.31	1.64
Kandy	1.31	22.00	0.00	36.32	0.75	39.41	0.20	1.61	13.84	1.17	39.85	3.77	37.86	1.91
Matale	5.65	0.92	0.00	8.48	13.49	70.48	0.97	0.57	0.12	10.93	10.01	38.57	38.47	1.33
NuwaraEliya	13.93	7.40	0.00	9.90	5.73	61.65	1.40	1.69	1.44	0.21	16.88	5.50	72.79	1.48
Kurunegala	19.96	3.99	0.00	27.28	1.58	46.94	0.25	7.03	8.47	0.56	20.83	15.50	46.30	1.31
Puttalam	0.09	0.00	0.13	12.79	51.83	34.09	1.07	0.73	3.17	11.26	33.27	7.00	44.05	0.52
Kegalle	0.28	2.99	0.00	24.85	46.85	24.75	0.28	3.25	34.65	3.36	24.35	7.82	25.25	1.32
Ratnapura	0.66	11.73	0.76	23.23	3.36	57.07	3.19	0.81	5.80	0.03	36.34	10.04	45.97	1.02
Galle	2.04	28.76	0.00	21.57	5.00	42.13	0.49	3.81	14.15	1.01	18.95	27.28	33.94	0.86
Matara	18.47	3.69	3.00	39.12	4.81	29.46	1.45	5.92	4.55	0.12	34.48	7.42	43.36	4.16
Hambantota	0.00	0.65	0.00	48.06	13.73	36.81	0.74	2.27	15.58	3.41	22.62	10.78	44.44	0.90
Batticaloa	7.34	1.60	14.01	68.73	2.31	6.02	0.00	8.73	16.25	8.82	51.09	5.93	9.13	0.06
Ampara	45.25	7.82	0.61	21.75	15.12	9.15	0.30	14.01	12.44	11.12	24.63	22.52	15.15	0.14
Trincomalee	14.60	3.19	0.00	60.55	4.40	14.89	2.38	30.14	2.06	0.14	36.82	6.91	22.77	1.15
Monaragala	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.11	0.40	3.23	33.67	18.81	28.77	0.00
Badulla	4.15	0.80	0.02	36.50	44.47	14.06	0.00	17.46	2.17	0.00	32.70	38.22	9.44	0.00
Jaffna	12.49	1.06	0.09	38.33	0.21	47.81	0.00	0.00	0.00	0.00	73.72	0.00	26.28	0.00
Mannar	4.53	0.15	0.00	49.63	0.00	45.69	0.00	0.00	0.00	0.00	64.54	0.00	35.46	0.00
Kilinochchi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.61	1.92	0.00	50.46	0.00	43.01	0.00
Mullaitivu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.67	7.50	75.83	0.00
Vavuniya	3.64	0.00	0.00	76.47	0.14	19.75	0.00	0.00	0.00	0.00	90.80	0.00	9.20	0.00
Anuradhapura	18.77	2.19	0.93	49.10	6.38	22.51	0.12	7.98	7.64	0.19	49.96	11.68	22.24	0.31
Polonnaruwa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.17	19.60	0.04	37.82	15.21	20.74	0.42

Table 5. Vehicle Mode Distribution as Percentages in each District by Age

District	15-24 years							25-34 years						
	Car	Van	Jeep	MB	TW	Bus	Taxi	Car	Van	Jeep	MB	TW	Bus	Taxi
Colombo	1.78	64.3	0.16	4.43	14.54	14.45	0.29	2.45	12.57	1.56	8.29	53.43	20.90	0.80
Gampaha	2.51	6.94	1.35	11.37	19.55	54.22	4.06	0.61	4.34	0.54	29.28	9.55	53.45	2.23
Kalutara	2.36	18.7	0.27	19.70	26.20	31.28	1.46	4.09	16.98	0.00	27.57	12.00	39.14	0.22
Kandy	1.25	8.39	0.00	50.43	0.91	38.45	0.57	1.75	4.79	0.35	40.64	1.66	49.28	1.52
Matale	2.84	0.03	0.00	2.06	25.77	68.90	0.40	3.20	0.02	0.00	3.59	11.59	81.02	0.58
NuwaraEliya	0.55	0.43	0.48	15.41	10.31	70.90	1.91	0.73	1.64	0.00	10.09	4.48	82.70	0.36
Kurunegala	1.64	2.57	0.41	32.83	9.20	52.72	0.63	16.18	3.45	0.06	14.39	2.12	62.87	0.92
Puttalam	0.61	2.19	0.59	45.91	10.32	39.11	1.27	0.08	0.36	2.43	3.93	71.88	21.07	0.26
Kegalle	3.68	12.8	4.95	33.15	6.22	36.60	2.64	5.45	2.30	0.00	51.82	14.59	25.50	0.34
Ratnapura	0.46	1.78	0.02	17.21	16.26	63.45	0.83	0.12	14.11	0.00	42.93	10.71	27.22	4.90
Galle	0.20	1.18	0.00	30.21	37.22	30.99	0.19	2.08	46.62	0.05	15.38	3.52	31.82	0.53
Matara	10.78	1.23	0.24	38.15	7.18	39.19	3.24	14.55	11.56	0.07	14.17	6.88	52.05	0.71
Hambantota	3.08	8.32	0.69	59.03	2.17	24.88	1.82	3.05	3.30	0.00	35.86	3.52	53.78	0.49
Batticaloa	6.08	2.10	6.33	74.30	0.62	10.48	0.10	6.44	6.99	21.74	58.22	3.55	3.00	0.07
Ampara	45.36	9.20	0.00	16.83	28.58	0.00	0.04	21.24	1.57	20.27	17.77	17.52	21.31	0.31
Trincomalee	51.45	0.99	0.00	24.23	0.24	18.36	4.73	0.00	0.14	0.00	9.42	0.00	90.44	0.00
Monaragala	0.40	0.00	8.66	43.79	28.72	18.43	0.00	23.41	2.74	2.66	16.53	20.05	34.62	0.00
Badulla	16.50	1.69	0.00	33.57	29.82	18.41	0.00	7.23	3.02	0.04	44.90	30.88	13.93	0.00
Jaffna	13.90	0.82	0.00	34.81	0.14	50.34	0.00	5.93	0.00	0.00	34.39	0.00	59.67	0.00
Mannar	0.00	0.00	0.00	84.42	0.00	15.58	0.00	0.00	0.00	0.00	53.53	0.00	46.47	0.00
Kilinochchi	0.00	0.00	0.00	41.16	0.00	58.84	0.00	3.39	2.86	0.00	56.42	0.00	37.33	0.00
Mullaitivu	0.00	0.00	0.00	100.0	0.00	0.00	0.00	0.00	0.00	0.00	15.22	0.00	84.78	0.00
Vavuniya	100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	78.77	0.21	20.55	0.00
Anuradhapura	15.85	10.4	0.48	36.21	15.43	21.31	0.28	6.76	8.33	0.09	25.45	4.26	54.38	0.74
Polonnaruwa	3.41	5.41	0.00	47.10	12.12	31.55	0.42	2.35	31.49	0.00	42.10	3.62	20.29	0.15

Car was the main mean of transport for a person aged 15-24 years in Ampara, Trincomalee and Vavuniya districts. For a person aged 15-24 years in Galle district, mostly used transport mode was three-wheeler while a person in similar age group in Colombo district frequently used vans for travelling. In other districts, a 15-24 age person frequently travelled by motor bicycles and busses. Also, a person in 25-34 age range commonly travelled in motor bicycles and busses in many districts. In Colombo and Puttalam districts, three-wheeler was the most frequent transport mode of a such person. Van was the most predominant transport mode for a such person in Galle district. A person within 35-44 years age range in Nuwara-Eliya, Matara and Ampara districts frequently used cars for their travelling. A person in similar age group in other districts mostly used busses and motor bicycles. 45-54 years aged individual in Kegalle district used three-wheelers frequently. In Colombo and Kandy districts, the most predominant travel mode for a such person was vans. 45-54 years aged individual in Ampara and Monaragala districts mostly used cars for their travelling while the majority of people in similar age group in other districts used busses and motor bicycles. In Colombo and Badulla districts, a person within 55-64 years age range travelled by three-wheelers more frequently. A person in the similar age group in other districts commonly used motor bicycles and busses for their travelling. For a person aged greater than 65 years in Colombo, Kegalle, Galle, Batticaloa and Ampara districts mostly used vans. Three-wheeler was the most popular mode of transport for a person aged greater than 65 years in Matale, Monaragala and Polonnaruwa districts. An individual in the similar age group in other districts frequently used motor bicycles and busses for their travelling.

Table 6. Vehicle Mode Distribution as Percentages in each District by Age

District	35-44 years							45-54 years						
	Car	Van	Jeep	MB	TW	Bus	Taxi	Car	Van	Jeep	MB	TW	Bus	Taxi
Colombo	0.80	6.13	3.17	14.95	9.85	62.67	2.43	1.68	42.27	0.90	6.68	36.26	11.48	0.73

Gampaha	5.97	5.18	0.92	19.10	14.09	53.62	1.11	0.96	8.16	0.34	19.58	9.94	59.22	1.80
Kalutara	2.07	8.15	0.00	50.80	1.93	36.66	0.40	2.64	10.38	0.81	30.27	6.88	46.99	2.03
Kandy	0.54	17.34	1.93	57.06	3.51	18.10	1.51	1.41	31.00	0.12	39.59	2.55	23.92	1.41
Matale	0.48	1.96	0.00	10.92	5.38	77.93	3.34	2.98	0.40	11.79	9.17	24.62	50.96	0.07
NuwaraEliya	33.98	0.01	0.00	25.42	5.14	32.12	3.34	1.99	1.30	0.00	19.58	8.78	65.48	2.88
Kurunegala	36.70	3.77	0.95	10.82	3.92	42.42	1.41	8.27	4.41	0.29	24.92	8.35	53.26	0.51
Puttalam	1.59	0.07	0.00	17.50	11.20	69.55	0.07	0.26	2.09	9.79	28.49	9.65	48.96	0.75
Kegalle	3.66	9.45	6.16	51.18	3.88	25.21	0.46	1.32	21.26	1.40	19.62	37.66	17.98	0.77
Ratnapura	0.26	5.21	0.08	24.10	2.63	66.77	0.95	0.62	6.97	0.64	25.00	11.73	51.67	3.38
Galle	9.91	5.16	2.93	19.37	7.08	55.26	0.29	1.23	37.40	0.26	14.10	10.68	35.47	0.86
Matara	31.84	5.54	0.00	25.01	12.50	18.51	6.60	8.61	6.57	2.69	28.04	6.98	40.49	6.61
Hambantota	0.26	4.81	2.23	38.09	3.38	51.02	0.22	1.22	4.10	2.17	36.37	10.04	45.46	0.64
Batticaloa	5.35	11.52	0.00	42.80	15.92	24.41	0.00	7.13	17.14	11.09	51.98	5.32	7.30	0.04
Ampara	35.47	5.24	0.44	34.73	11.01	12.87	0.24	16.27	11.77	0.86	31.41	25.67	13.81	0.20
Trincomalee	8.49	0.40	0.00	49.73	24.14	15.97	1.28	24.44	2.25	0.03	34.88	7.43	29.64	1.34
Monaragala	15.29	0.00	0.21	49.56	11.23	23.71	0.00	16.85	0.16	3.60	31.44	23.06	24.90	0.00
Badulla	16.21	2.37	0.00	40.43	24.32	16.66	0.00	3.57	1.72	0.00	33.41	48.17	13.14	0.00
Jaffna	20.35	0.00	0.00	42.11	0.50	37.03	0.00	13.76	1.39	0.00	45.35	0.00	39.49	0.00
Mannar	0.99	0.27	0.00	82.06	0.00	16.68	0.00	3.83	0.15	0.00	54.15	0.00	41.86	0.00
Kilinochchi	21.42	7.14	0.00	45.44	0.00	26.00	0.00	4.74	0.81	0.00	50.81	0.00	43.64	0.00
Mullaitivu	0.00	0.00	0.00	39.95	0.00	60.05	0.00	0.00	0.00	0.00	41.08	20.44	38.48	0.00
Vavuniya	0.70	0.00	0.00	83.98	0.00	15.32	0.00	2.71	0.00	0.00	83.54	0.04	13.71	0.00
Anuradhapura	4.49	4.88	0.00	79.60	2.62	8.28	0.14	19.71	8.36	0.14	27.38	14.47	29.69	0.25
Polonnaruwa	5.48	31.08	0.00	36.09	5.87	20.97	0.51	3.26	12.04	0.07	54.89	7.64	21.57	0.52

Table 7. Vehicle Mode Distribution as Percentages in each District by Age

District	55-64 years							>65 years						
	Car	Van	Jeep	MB	TW	Bus	Taxi	Car	Van	Jeep	MB	TW	Bus	Taxi
Colombo	1.87	4.38	0.37	7.53	57.69	27.65	0.52	1.43	46.92	0.11	22.40	1.19	26.65	1.30
Gampaha	3.58	18.84	0.53	8.59	5.06	62.72	0.68	0.36	1.80	10.39	30.84	4.36	48.75	3.49
Kalutara	0.96	5.82	1.94	35.87	13.62	39.88	1.91	5.81	5.45	0.00	18.70	5.72	61.62	2.70
Kandy	0.31	19.52	0.02	39.75	1.34	38.01	1.05	0.21	7.24	0.97	23.97	0.92	66.51	0.18
Matale	0.00	1.43	0.00	32.47	22.03	40.88	3.20	0.08	0.00	20.58	7.13	53.71	18.49	0.00
NuwaraEliya	3.41	23.81	0.00	13.22	2.70	56.39	0.47	0.53	0.00	0.00	3.92	4.37	89.49	1.69
Kurunegala	2.58	2.72	0.34	20.81	1.52	71.11	0.92	10.17	13.11	0.00	45.95	16.02	14.11	0.65
Puttalam	0.39	7.03	0.00	12.16	22.74	56.47	1.21	0.05	0.08	26.67	27.62	0.86	44.63	0.09
Kegalle	0.56	8.12	0.70	34.99	4.79	50.10	0.73	0.28	66.05	0.00	4.34	9.65	19.18	0.49
Ratnapura	1.57	9.72	0.00	15.05	2.49	70.02	1.15	2.20	1.38	3.79	13.36	16.46	61.14	1.67
Galle	1.80	17.0	0.68	29.93	7.55	40.81	2.21	1.30	41.58	0.00	14.21	22.35	20.40	0.16
Matara	2.81	2.72	4.65	62.86	1.32	25.38	0.26	3.03	3.22	0.00	41.87	9.82	33.90	8.16
Hambantota	0.68	14.1	0.00	34.65	25.69	24.85	0.03	0.00	24.04	7.32	0.34	23.90	43.47	0.92
Batticaloa	17.44	5.47	32.46	44.63	0.00	0.00	0.00	9.73	43.60	1.87	42.82	1.97	0.00	0.00
Ampara	6.21	14.50	0.00	42.85	12.03	23.71	0.70	10.03	29.15	2.11	26.66	17.70	14.34	0.00
Trincomalee	25.99	2.47	0.00	61.75	1.95	6.63	1.21	33.29	7.16	0.75	38.04	0.00	19.69	1.07
Monaragala	8.37	0.00	0.00	36.84	3.64	51.15	0.00	0.00	0.00	4.76	29.70	53.02	12.52	0.00
Badulla	3.45	0.27	0.00	10.32	75.81	10.15	0.00	0.00	0.00	0.00	80.30	19.7	0.00	0.00
Jaffna	12.13	3.75	0.00	38.87	0.00	45.25	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
Mannar	0.00	0.00	0.00	0.00	0.00	100.0	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
Kilinochchi	0.00	0.00	0.00	34.90	0.00	65.10	0.00	0.00	0.00	0.00	86.21	0.00	13.79	0.00
Mullaitivu	0.00	0.00	0.00	51.82	0.00	48.18	0.00	0.00	0.00	0.00	0.00	0.00	100.0	0.00
Vavuniya	0.00	0.00	0.00	69.16	0.00	30.84	0.00	0.00	0.00	0.00	94.71	0.00	5.29	0.00
Anuradhapura	33.08	4.55	0.00	42.42	7.60	12.35	0.00	0.00	0.00	0.00	44.95	7.00	47.89	0.15
Polonnaruwa	25.39	14.39	0.00	44.33	6.15	9.31	0.43	4.28	16.56	0.00	16.92	39.0	22.63	0.60

4.3 Statistical Comparisons of PKT

Results from the statistical analysis are presented in the Table 8. All socio-demographic groups showed statistically significant differences among districts at 0.05 (α=0.05) level of significance ($p<\alpha$). Therefore, the null hypothesis H_o; all means are equal, was rejected for all the below cases. For age groups; 15-24,55-64 and >65, Welch ANOVA could not be performed due to low sample size of several groups. For 25-34 and 45-54 age groups, the effect size was in a medium range while all the other factors had a small effect size. These research findings; weighted PKT of people under each socio demographic group in each district, mode choice of people under each socio demographic group in each district and statistical comparisons of them can efficiently be used in transport planning and policy making in the country, in monitoring and enhancing public transportation, identifying travel pattern of individuals and many other purposes. PKT estimates would provide a representative measure of travel patterns/behavior of individuals in developing countries like Sri Lanka, where the only means of transportation for the majority is public or non-motorized transport modes.

Table 8. Statistically Significant Differences across Districts in Sri Lanka

Factor	Sub factor	*Welch statistic*	*p*	Significant difference among districts (Yes/No)	Eta-squared	Effect size
Gender	Male	4.484	0.000	Yes	0.020	Small
	Female	6.352	0.000	Yes	0.032	Small
Age (in years)	25-34	4.238	0.000	Yes	0.050	Medium
	35-44	2.405	0.000	Yes	0.036	Small
	45-54	2.536	0.000	Yes	0.058	Medium
Employment Status	Employed	6.979	0.000	Yes	0.027	Small
	Unemployed	4.412	0.000	Yes	0.032	Small
Residential Area	Urban	3.102	0.000	Yes	0.036	Small
	Rural	8.861	0.000	Yes	0.017	Small

5. CONCLUSIONS

Weighted PKT estimates were higher for many socio-demographic groups in Colombo district compared to other districts in Sri Lanka. Results revealed that, a rural person has travelled more compared to an urban person in many districts. Also, an employed person has travelled more compared to an unemployed person in many districts in Sri Lanka. In all administrative districts, motor bicycles and busses were the most frequently used travel modes by people in any socio demographic group. Then, three-wheelers, cars and vans were used and, taxies and jeeps have been rarely used. Mostly used travel modes in Colombo district were busses, three-wheelers and vans. Statistical comparisons revealed, PKT of districts were significantly different under any selected socio demographic group. This study showed the experience of a travel survey which was conducted all over the country for collecting travel information of people. Weighted PKT and travel mode distributions revealed travel patterns of the community in Sri Lanka. These district-wise data are useful in transport planning and infrastructure development in the country. It is beneficial to estimate such data in a timely manner.

Many studies that are related to travel surveys in other countries (Vaish et al., 2010) were conducted by state agencies. In Sri Lanka, there are ongoing-national-level surveys in every 10 years to collect census and population data of people. Therefore, this travel survey can be implemented parallel to the existing surveys. Also, many travel surveys conducted in other countries have considered small area estimates. In this study, administrative district-wise estimates have been obtained. However, this travel survey can be split into GN-Divisions, if this is implemented with the national census and population survey in the country. In some travel surveys conducted in other countries, people were given the travel-questionnaire and asked to fill the survey (Seethaler & Rose, 2009). However, it will be more beneficial to interview people rather than distributing questionnaires and collecting them back. Also, for obtaining more precise and clear understanding on travel patterns in each district or to compare them, it is recommended to include more influencing factors other than socio demography. More research work is needed and encouraged in this area of study to fulfill existing critical gap of data. However, this research effort would be a motivation for future research work, as the literature found to be very little in this area of study in Sri Lanka.

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Travel Issues of Sri Lankan Females

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ABSTRACT

This research looks into the mobility problems that female travelers undergo, with an emphasis on Sri Lankan women. Males and females have different social and economic roles and obligations in most civilizations, and as a result, there are major gender variations in travel and transportation demands. The aim of this research is to investigate the mobility issues of females while traveling. This research analyzes mobility problems of female travelers with special reference to the Western province of Sri Lanka. This research targets to identify the mobility barriers which affect the females' lifestyle, the problems, and threats females have faced, and the way they go through these problems. The socio-economic, perspective of people, and travel behavior data were collected from 450 females by using a paper-based questionnaire in August 2021. Ordinal logistic regression analysis and Chi-square test were used to analyze the data. According to the results, sexual harassment while traveling was a significant problem. Among the respondents, 17% of respondents stated that sexual harassment was the most concerning security risk when traveling and 46.8% of female respondents faced sexual harassment when traveling by buses. Based on the types of harassment 26% of females experienced physical harassment as the most frequent harassment type and 25% experienced verbal harassment in public places or public transportation. Majority 42% of the females were strongly stated that they faced sexual harassment problems after dark. Poor maintenance of open public spaces, overcrowded buses/trains, lack of effective/visible police or civil guards, and lack of regulation on transport safety such as men dealing with or taking alcohol/drugs were factors that contribute to sexual harassment by females in public places and transport. The results of this analysis provide valuable insights into the mobility problems of female travelers in day-to-day life due to various reasons.

KEYWORDS: *Females, Mobility, Ordinal logistic regression, Sexual harassment, Travel*

1 INTRODUCTION

It is commonly known that males and females have significantly specific variations of demand for transportation services and that transportation sector interventions typically do not adequately address female demands (Riverson, 2005). Progressively gender is being perceived to play a critical job in transport arranging, especially for tending to person versatility needs in rural and urban areas. It is becoming a huge problem when increasing the usage of vehicles. It is more challenging for females especially when considering the social believes, practices, behaviors, and habits. Females make transit decisions on a regular basis, and they want public transportation to be affordable, dependable, frequent, comfy, clean, and secure. Kapoor (2013) stated that both males and females rely on public transportation for their economic and social lives, and increased reliance on urban transportation systems puts a strain on both. Females rely on public transportation than males. Females do not even have a few other options for mobility. It is critical to have a safe, dependable, and comfortable form of public transportation. When traveling alone, women encounter higher obstacles and difficulties. Petty and violent crime, culture shock, inadequate sanitation, and sexual assault are just a few of the problems (Anon, 2013). Females can reduce risk and improve the chances of a secure and prosperous journey by planning ahead, using common sense, and respecting religious and social differences. Once in every three women (32%) in Canada-roughly 4.9 million females 15 years and older-experienced some sort of unwelcome sexual behavior while in a public location. Unwelcome sexual involvement, such as insults, signals, non-verbal, whistling, or shouts, are perhaps the most prevalent kind of undesirable behavior that women encountered in public places (Cotter et al., 2018). According to the United Nations Population Fund Sri

Lanka (2017) report, 90% of Sri Lankan female’s faced sexual harassment on public buses and trains. Women's involvement within the economy in Sri Lanka falls behind some other intermediate nations, and despite sustained economic development, the number of females in the labor has fallen to 36% in 2016 from 41% in 2010. Female's mobility, engagement in public life, and general wellness are all hampered by harassment using public transportation in Sri Lanka, according to the World Bank representative (UNPF, 2017).

Female mobility issues are a prevalent topic across the world, and it has been studied by many individuals, particularly in developing nations. It is critical to comprehend the mobility concerns that women experience when traveling, as well as to consider their needs and the security measures that need to be implemented in the country to address such issues. As an Asian country, it is highlighted the challenges for females are comparatively higher than males. Challenges for females mainly higher because of the cultural believes, tradition and the historical back ground. Therefore, it is appropriate to make a review on the mobility issues for females while traveling in Sri Lanka.

2 LITRETURE REVIEW

Kapoor (2013) studied women and their mobility in Bhopal, Gwalior & Jodhpur, India. The study's aim was to bring together a wide range of stakeholders in three Cities of India to improve female security in public locations. Safetipin software and standardized survey questionnaires were used to collect data from female participants in the cities of Bhopal, Gwalior, and Jodhpur. About 219 women were participated in this survey. Female's perceptions of security in public spaces and on public transit were the emphasis in the study. Focus Group Interviews with important urban transportation providers in every city were used to gather qualitative data. As phase of this research, women participants' personal experiences were recorded in order to better understand the effects of public transportation security risks on female's mobility. Several factors were cited by respondents as contributing to women's safety in public spaces and on public transportation. In Bhopal 96% of female respondents said major reason as they feel unsafe sales of drugs and alcohol in vicinity and being in a secluded or deserted location was cited by 97 percent of females in Gwalior and 78 percent of females in Jodhpur as one of the most common causes for feeling unsafe. Among 219 respondents 29% of them faced sexual harassment in the past year. In crowded places like bus stops and markets, a considerable percentage of women and girls encountered sexual harassment and abuse. The study found that the main reasons for not reporting crime were concerns about one's family reputation and a lack of trust in the police. The tolerance of harassment and abuse would be another reason for the poor reporting of such incidents. According to a UN Women-sponsored poll conducted in Delhi during 2012, 95% of females felt insecure in public places. According to research undertaken in cities, addressing the issue of female equality in public transportation will require a complete set of initiatives and policies.

The research by Malik et al. (2020) studied women's mobility via bus rapid transit in Pakistan. Pakistan is undergoing rapid urbanization and has a low global ranking for gender equality. Females in developing countries have more constraints when it comes to mass urban mobility. Furthermore, socio-cultural standards, a larger reliance on public transit, an absence of gender-responsive mass transit, and harassment experiences impede women's ability to explore potential career paths. The objectives of this research were to investigate the general mobility characteristics of females who utilize Pakistan's first Bus Rapid Transit (BRT) in Lahore, to learn about the obstacles they experience, and to suggest ways to improve the transportation system. To examine various quantitative, qualitative trip characteristics, data was gathered through face-to-face questioners-based survey along the BRT corridor. To generate accurate results, descriptive and cross-comparison statistical approaches were used. The responses to assault were recorded, analyzed, and presented graphically. Majority of participants in this study were low-income, comparatively younger or middle-aged, students, workers, and users with no or limited jobs. The main challenges were sexual harassment at railway stations and buses, poor amenities for the elders, Lack of facilities at the railway stations, limited dedicated space on buses, and ticket booths during rush hours. This article concentrates on common mobility trends among females and the challenges they face when taking the BRT in Lahore. Female education and employment achievements could be improved by addressing their concerns with mass urban mobility.

The study was done by Korn (2018) about sexual violence and women’s mobility on public transportation. This study aims to discover how women's widespread fear of sexual assault when traveling influences both their travel behaviors and their urban lives in general. This study looks at sexual violence on Santiago's mass public transportation systems and tries to figure out how the conditions of those process encourages the prevalence of sexual abuses in that area, limiting women's mobility in the region. For this research, the data was gathered by using survey of female colleges in Santiago, Chile. The universities selected for the survey were Universidad de Chile, Pontifia Universidad Catalica de Chile and Universidad Diego Portales. This survey was conducted to realize both of the sexual harassment in Santiago's local immigration network, as well as the unique association between the threats of abuses in this region and female transit. This survey included 407 women between the ages of 18 and 35. More than 3/4 of female use local transportation daily basis and 72% of respondents said they had been sexually harassed while using public transportation. Survivors of sexual assault were asked whether the events had affected how they used public transit. A most of the females indicated that they had been victim’s minimum once mentioned changing their public transit habits as a result of the incident (52%). Data show that violent events have an impact on mobility, emphasizing the connection between a harassment or attack incident and how a woman moves around the area. To appreciate the restrictions on women mobility imposed by the threats of sexual assault, it's essential to recognize that mobility encompasses not only the freedom to switch from a place to another place, but also the capability to feel safety and secure when they are doing so. The danger and spread of sexual harassment on Santiago's local transportation, according to survey findings, restricts women's mobility and perpetuates structures of exclusion, with serious consequences for equality in the region. The statistics also showed that after a sexual harassment event, the average female is unlikely to fully change her travel habits; thus, the priority should be on keeping the space of this public transport system as safe and confidential too. This study suggested policy strategies aimed not only at improving women's behavior and perceptions but also at improving the travel experiences of all passengers.

Upali (2010) conducted research about the access and mobility of rural women. This study is based on a study on changing gender connections as a result of a transportation intervention in a Sri Lankan rural community. For this research, primary data were collected through a field study. The field study was conducted in Malberigama, Hambanthota District in Sri Lanka. To provide a greater understanding, a sample size of 36 females was chosen. Specific individuals of the chosen respondents were interviewed separately. Each female's data were taken using a guideline that included both structured and open-ended questionnaires. The data were analyzed using an explanatory method. Females in this community confront a number of challenges, including access and travel. Isolated, or being cut off from critical services, is a big issue for these individuals. Because they were cut off from the conventional cultural development phase, the society, particularly women, faced several challenges in terms of access to resources and other necessities. In this community, females spend an average of 3 hours each day on transportation-related works. Most women stated that they have had to devote more time to typical female works such as water collection, fuelwood collection, and so on. In addition to this, the majority of the women reported collecting water, collecting fuelwood, traveling to medical centers, transporting kids to school, and traveling to adjacent cities to sell/buy items. The majority of the ladies stated that they must go to the neighboring city twice or once per week. They used to have to travel around 2-3 kilometers to get to the bus stop and the same distance back. They are now using alternative vehicles like three-wheelers and hand tractors to access the bus route, due to the upgraded roadway. These vehicles are sometimes used to get them to their destination, and the ladies saved around two and a half to five hours each week as a result of these changes. The major challenge of inaccessibility and transportation in rural areas is the development of relevant methods to decrease the transportation costs of community production and selling, rather than the provision of public carriage of passengers by the private or government sectors.

Multiple research studies have demonstrated that females face a variety of challenges while traveling. There are many mobility restrictions face by females in the world. Furthermore, female behavior and attitudes are different from one region to another region.

3 METHODOLGY

3.1 Problem Statement

With the developments and urbanization of the countries in the world, the demand of the transportation has increased. Males and females have different social and economic roles and obligations in most civilizations. Female have different travel habits, needs, and behaviors than males. The gender-based specialization inside the family and society is at the root of major disparities in female's and male's fundamental mobility requirements. Female mobility issues are a prevalent topic across the world, and it has been studied by many individuals, particularly in developing nations. It is critical to comprehend the mobility concerns that women experience when traveling, as well as to consider their needs and the security measures that need to be implemented in the country to address such issues. So, it is appropriate to make a review on the mobility issues for females while traveling in Sri Lanka.

3.2 Development of questionnaire and sample size

This research study investigates the mobility issues of females while traveling using the data collected through a questionnaire. Females mobility issues can be differed based on some factors such as age, home district, civil status, mode of travelling, purpose of travel etc. Therefore, those factors are included in the questionnaire to identify the variation of mobility issues of female travelers. Following are the mobility issues for female travelers which identified to include in the questioners in order to conduct the survey.

- Sexual assault or rape
- Sexual harassment
- Robbery or possessions stolen
- Murder or violent crime
- Traveling with children and babies
- Pregnant time: seating, density of travelers
- Distance of travel
- Pain while traveling

The questionnaire was consisting of three sections. Section 01- general information of the respondents, section 02- general information about mobility issues in transportation, and section 03- general information of harassment while traveling. The study's questionnaires employed five-point Likert scales. Cronbach's alpha test was used to determine the reliability of multiple-question Likert scale questionnaires. Reliability refers to the extent to which the data collection techniques or analysis procedure will yield consistent findings. The most frequently used technique to measure internal consistency is Cronbach’s Alpha technique. It is computed in terms of the average intercorrelations among the items measuring the concept.

The sample size calculation was done using below Equation (1) (Gunathilake et al, 2019).

$$N = \frac{\mathrm{z^2P[1-P]}}{\mathrm{d^2}} \tag{1}$$

Where; N – total sample size, Z – value corresponding to confidence limits, d – margin of error (total width of confined level), P – expected population proportion.

The minimal sample was computed assuming a 95 % confidence level (z=1.96), a female population of 51.31 % in Western Province, and a 5% acceptance amount of absolute error. It gave the minimum sample size of 385. Accordingly, a total number of 450 questionnaire forms were distributed and collected from the females in Western Province.

Among the 450 female respondents, 186 from Gampaha, 159 from Colombo and 105 from Kalutara. The majority of the female respondents represented the 31 – 40 age categories. 197 females belong to that age group category and the percentage was 43.8%. The rest of the respondents lies within the age group of below 20, 21 – 30, 41 – 50, above 51 and there were 40, 96, 59, 58 respondents. The percentage of them were 8.9%, 21.3%, 13.1%, 12.9%.

3.3 Study area

The three districts of Colombo, Gampaha and Kalutara in the Western Province were selected for the study. This province is Sri Lanka's most populated and developed in terms of socio-economic status. Overall, the Western Province inherits even more resources Provinces in the country.

The western province has a population of 6,165,000 people, according to the Census and Statistics Department (DCS) (2020). Males account for 3,002,000 (48.69%) of the population, while females account for 3,163,000 (51.31%). The female population in the three districts of the Western Province is shown in Table 1.

Table 1: Female population of Western Province in Sri Lanka

District	Number of female populations	Percentage of females out of total population
Colombo	1,250,000	39.52%
Gampaha	1,249,000	39.49%
Kalutara	664,000	20.99%

The working-age population is defined as anyone over the given age restriction (15 years and upwards) of either gender. This population is divided into two categories: economically active and economically inactive. And according to DCS from the year 2020, the distribution of economically active female population in the western province is shown in Table 2.

Table 2:Economically active population in Western Province, Sri Lanka

District	Economically active female population (%)
Colombo	32.6
Gampaha	33.4
Kalutara	35.1

3.4 Ordinal logistic regression

Ordinal logistic regression is a statistical analysis approach for modeling the relationship between one or more explanatory variables and an ordinal response variable. An ordinal variable is a categorical variable in which the category levels are clearly ordered. The explanatory variables can be categorical or continuous (Parry, 2020).

In this research study, A researcher wanted to understand whether the mobility issues that a female faced can be predicted from a factor that contribute more towards females' security experience. Factors that contribute more towards females' security experience were considered as the independent variables, and mobility problems were considered as the dependent variable.

Equation 2 represent the ordinal regression (UCLA,2021);

$$logit\left(P(Y \leq j)\right) = \beta j0 + \beta j1x1 + \cdots + \beta jpxp \tag{2}$$

Where;
Y – ordinal outcomes with j categories
P(Y<=j) – cumulative probability

3.5 Chi – squared test

The Chi-Square Analysis test of independence analyzes whether categorical variables are associated, whether the variables are independent or related (Yeager, 2021). It is a test that is not parametric. The data is analyzed using a cross-tabulation in this test. A cross-tabulation is a table that divides data into two categories based on two categorical factors. The one variable's classifications appear in rows when the other variable's classifications appear in columns. Each variable must have two or more categories. Each cell reflects the total count of cases for a specific pair of categories (Yeager, 2021).

A p-value less than or equivalent to the significance level for a Chi-square test shows that there is enough evidence to prove that the observed distribution is not the same as the expected distribution. A p-value greater than 0.05 (> 0.05) suggests strong evidence for the null hypothesis. This suggests that the null hypothesis should be kept and the alternative hypothesis should be rejected.

4 RESULTS

4.1 Preliminary results

Women's mobility problems are varied from each other. The survey included the most common problems women face when traveling. This Figure 1 shows the females mobility issues that they faced while traveling. According to the identified mobility issues for female travelers' sexual harassment (17%) was the highest rated issue. When robbery or possession stolen (15%) was the second highest rated issue.

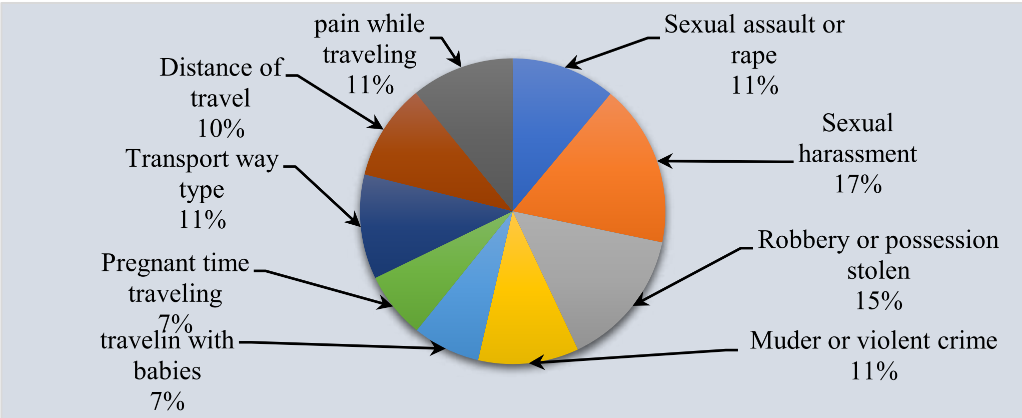

Figure 1: Types of mobility problems that women face while traveling

Public transport in Sri Lanka consists of buses and trains. Buses are the main mode of public transport. Among the 450 female responses, majority of female were sexually harassed when using Buses and trains respectively 211, 136. Based on the results 77% of the female faced sexual harassment while using public transport and they faced different types of harassment experience. Such as, verbal harassment, physical harassment, violent physical attack, visual harassment and flashing/blinking. Then below Figure 2 represent the types of sexual harassment they faced mostly in public transport or public places during the past year. Majority of the respondents were faced physical harassment such as, unnecessary touching, leaning, feeling up etc. There were 276 respondents and 26% percentage. Then the second highest respondents' verbal harassment (25%) such as, unwanted comments, whistling etc.

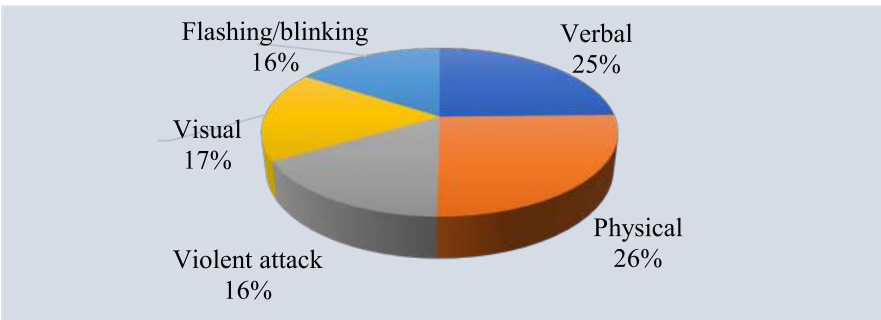

Figure 2: of sexual harassment faced by females while traveling

Females faced various kind of problems when using public transport. Sometimes they feel public transport services are not safer. Figure 3 represents that how they felt the safety of public transportation. According to the results, majority of female respondents said that SLTB buses (36%), Private buses (34.7%) and Trains (38.2%) were not safer than the hired three wheelers (8.9%) and hired taxis (13.1%).

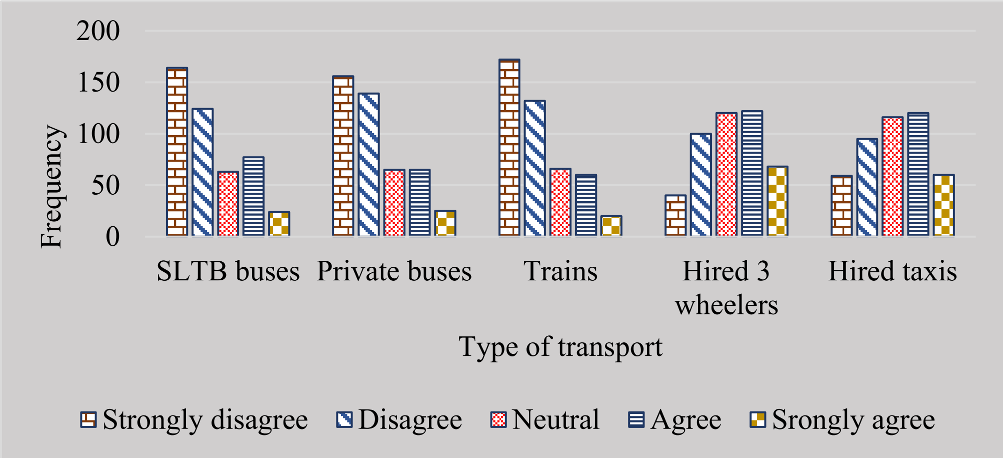

Figure 3: Women's perceptions about the safety of public transportation

As shown in Table 3, 40.9% the females do nothing when they were sexually harassed or assaulted while others were reported.

Table 3: Ways to seek help in case of sexual harassment

Methods	Frequency	Percent (%)
Nothing	184	40.9
Reported it to the police	31	6.9
Confronted the perpetrator	64	14.2
Reported to bus/train regulators	52	11.6
Asked bystanders for help	48	10.7
Asked for help from family/friends	71	15.8

Table 4 represents the safety measures taken to prevent problems when women travel. The most frequent safety measure was avoiding the going out after dark.

Table 4: Factors taken for female safety and secured environment when travelling

Factors	Frequency	Percent (%)
Avoid certain public spaces and public transport completely	153	10.6
Avoid going out along completely	159	11.1
Avoid going out alone after dark	303	21.1
Carry items to protect myself	219	15.2
Take alternative transport modes	236	16.4
The license plate number of a hired vehicle can be verified before entering a vehicle	196	13.6
Quite my job	85	5.9
Change my residing Location	87	6.1

4.2 Reliability test results

Table 5 shows Cronbach's alpha values of the independent variables and dependent variables of the questionnaire. Alpha score of 0.7 is generally acceptable. That means there are good consistency between questions which measures the independent and dependent variables.

Table 5: Reliability test results

Variable	No of item	Cronbach's alpha value
Mobility issues	09	.803
Safety of public transportation	05	.712
Security experience on transport	13	.815
Harassment experience on transport	06	.951
Types of sexual harassment	05	.761

4.3 Chi-squared test results

Table 8 represent the chi-squared test results of the sexual harassment. Most of the females in the Gampaha district were faced sexual harassment experiences than the other two districts.

Table 8: Chi -square results of the sexual harassment and districts

Independent variables			Sexual harassment				
			Strongly disagree	Disagree	Neutral	Agree	Strongly agree
District	Colombo	Count	25	12	34	35	53
		Expected Count	23.7	13.1	32.2	44.2	45.9
	Gampaha	Count	22	18	44	48	54
		Expected Count	27.7	15.3	37.6	51.7	53.7
	Kalutara	Count	20	7	13	42	23
		Expected Count	15.6	8.6	21.2	29.2	30.3

Many females between the ages of 31 to 40 experienced sexual harassment problems. Table 9 below shows the comparison between the reported and expected number of responses by age.

Table 9: Chi -square results of the sexual harassment and age

Independent variables			Sexual harassment				
			Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Age	Below 20	Count	5	3	9	15	8
		Expected Count	6.0	3.3	8.1	11.1	11.6
	21 - 30	Count	19	10	12	33	22
		Expected Count	14.3	7.9	19.4	26.7	27.7
	31 - 40	Count	26	11	53	38	69
		Expected Count	29.3	16.2	39.8	54.7	56.9
	41 - 50	Count	7	6	8	24	14
		Expected Count	8.8	4.9	11.9	16.4	17.0

	Above 51	Count	10	7	9	15	17
		Expected Count	8.6	4.8	11.7	16.1	16.8

Many females were sexually harassed while traveling on buses. According to Table 10, 58 out of 450 women strongly stated that they experienced sexual harassment while riding the bus. But the number of reported cases was less than the expected number.

Table 10: Chi -square results of the sexual harassment and mode of transport

Independent variables			**Sexual harassment**				
			Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Mode of transport	Bus	Count	31	23	45	54	58
		Expected Count	31.4	17.3	42.7	58.6	61.0
	Walking	Count	7	0	8	8	12
		Expected Count	5.2	2.9	7.1	9.7	10.1
	Train	Count	13	9	29	46	39
		Expected Count	20.2	11.2	27.5	37.8	39.3
	Hired 3 wheelers	Count	9	3	2	4	7
		Expected Count	3.7	2.1	5.1	6.9	7.2
	Hired taxi	Count	5	1	3	11	4
		Expected Count	3.6	2.0	4.9	6.7	6.9
	Other	Count	2	1	4	2	10
		Expected Count	2.8	1.6	3.8	5.3	5.5

Many females experience sexual harassment problems after dark. Table 11 According to the results of the Chi-Square test, 55 females responded to reports of sexual harassment after dark. But the expected number was lower than reported.

Table 11: Chi -square results of the sexual harassment and time of harassment happen

Independent variables			**Sexual harassment**				
			Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Time of harassment	Day time	Count	21	12	25	48	22
		Expected Count	19.1	10.5	25.9	35.6	37.0
	After dark	Count	23	18	33	37	55
		Expected Count	24.7	13.6	33.6	46.1	48.0
	Both	Count	23	7	33	40	53
		Expected Count	23.2	12.8	31.5	43.3	45.1

4.4 Ordinal logistic regression analysis

The model was used to analyze the factors that contribute more towards females' security experience. Model fitting information of the sexual harassment mobility problem from ordinal regression analysis gives the significant value is 0.003 ($p<0.05$) showing that developed model was better than null model.

The below Table 6 describes the parameter estimates of Ordinal logistic regression for sexual harassment of females while traveling.

Table 6: Paramter estimates of Ordinal logistic regression model for sexual harassment of females

Factors	Estimate	df	Sig.
Poor lighting in bus stops/terminals and other public places in the area	.024	1	.907
Poor Discipline of Driver/Conductor	-.006	1	.977
Poor discipline of other passengers	.014	1	.946
Poor maintenance of open public spaces*	.458	1	**.043**
Overcrowded Buses/Trains*	.438	1	**.044**
Crowded bus stops/Bus stations/Railway Stations	.348	1	.154
Lack of respect for women from men	-.165	1	.504
Lack of effective/visible police or civilian security guards*	.488	1	**.026**
Lack of regulation on transport safety Men dealing with or taking alcohol/drugs*	.428	1	**.047**
Lack of monitoring of the services Lack of published information on transport services	.065	1	.796
Poor transport service	-.037	1	.866
Lack of infrastructure such as CCTV at bus stops/stations	-.128	1	.559
Lack of infrastructure such as CCTV inside public transport	.250	1	.223
Significant Variables: Poor maintenance of open public spaces, Overcrowded Buses/Trains, Lack of effective/visible police or civilian security guards, Lack of regulation on transport safety Men dealing with or taking alcohol/drugs			
Dependent Variable: Sexual harassment			

Poor maintenance of open public spaces, overcrowded buses/trains, lack of effective/visible police or civilian security guards, and lack of regulation on transport safety men dealing with or taking alcohol/drugs factors were significantly affect for the sexual harassment issue that female faced while traveling as shown in Table 6.

The value of the overcrowded buses/trains coefficient is positive (0.438), which suggests that as overcrowded buses/trains increase the effect of the sexual harassment problem. Coefficient values of poor maintenance of open public spaces is 0.458, that suggests that if this factor increases the sexual harassment problem also increases.

5 CONCLUSION

This research is an in-depth study on the mobility issues faced by the females with special reference to Western Province in Sri Lanka. From this study factors that contribute to the females' mobility problems are investigated and results provided the security measures in order to avoid these mobility problems. For this study data collected done through paper-based questionnaire with 5 points Likert scale questions. Cronbach's alpha test is used to determine the reliability of multiple-question Likert scale questionnaires. In every variable, Cronbach's Alpha coefficient is greater than 0.7. This indicates that the questions used to measure the independent and dependent variables are consistent.

According to the main findings, the majority 17% of females are face sexual harassment while traveling. Females are faced different types of harassment experiences in their day-to-day life such as physical harassment, verbal harassment, visual harassment, violent physical attack, and flashing /blinking. The most frequent harassment type is physical harassment (26%) such as, unnecessary touching, leaning, feeling up, etc. and results show 25% of females faced verbal harassment such as, unwanted comments, whistling, etc. The chi-square test results values show that most of the females in

Gampaha (40%) and Colombo (35%) district than the Kalutara (25%) district are faced sexual harassment experience. Majority 42% of the females are strongly stated that they faced sexual harassment or assault problems after dark. Based on the respondents' past experience, most women (40.9%) did not try to do anything after they were sexually harassed or abused. This is because some of them have been intimidated or threatened by the perpetrator while others ignored such incidents as normal. According to the results, 15.8% of them were seek help from their family or friends after being assaulted or abused, 14.2% of them were faced the perpetrator and 6.9% of women were reported the incident to the police. Overall, according to the parameter estimate values from the ordinal logistic regression, poor maintenance of open public areas, overcrowded buses/trains, lack of effective/visible police or civilian security guards, and lack of regulation on transport safety (men dealing with or taking alcohol/drugs) are the factors that significantly affect for the female's mobility problems. Overall, to avoid female mobility problems can used varies safety methods. Majority 21.1% of respondents agreed that they avoid going out after dark for as one of their safety methods, and 16.4% stated that they use alternative transport modes to avoid mobility problems. To protect their self and for their security 15.2% stated that they carry some sharp tool when traveling and 11.1% stated that they avoid going out along for their safety.

Past studies also highlighted that sexual harassment or assault was the major mobility problem that females faced in their day to day life while traveling. There is a possibility of sexual harassment anywhere in the world specially in developing countries. Females in Sri Lanka have experienced the same situation and must be cautious and aware of sexual harassment while traveling. According to the several studies, In Canada 32% of females experienced some sort of unwelcome sexual behavior while in a public location (Cotter et al., 2018), In India crowded places like bus stops and markets, a 95% of women and girls were encountered sexual harassment and abuse (Kapoor, 2013), According to the UNFS (2017) report, 90% of females in Sri Lanka face sexual harassment on public buses and trains, the majority of females have been harassed once or twice per year. Abuse is much more common in long-distance travel than in short-distance trips (Rajaguru et al., 2018).

A comprehensive, female-friendly transportation system and infrastructure should really be developed in Sri Lanka to increase female's mobility. Female's transportation requirements should also be recognized by society. Women's walking accessibility may be aided by programs like Programs on Prevention of Gender Based Violence which expand their access to schooling, occupational, and other opportunities. These activities may also help to alleviate the mobility issues that females have when traveling. The following factors should be developed in order to improve the security experience of females using public transportation and public places. Poor lighting in bus stops/terminals and other public places, poor discipline of driver/conductor, poor maintenance of open public spaces, overcrowded buses/trains, crowded bus stops/bus stations/railway Stations, lack of regulation on transport safety, poor transport service, lack of infrastructure such as CCTV at bus stops/stations and inside the public transport. This study identified how mobility barriers affect lifestyle, what are the challenges and threats faced by women and how they overcome these challenges. In conclusion, with the advancement of the transport sector, women's mobility issues change over time.

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Modelling the Risk of Pedestrians in Walkways

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ABSTRACT

Pedestrians engaged crashes were increased day by day in the world. There is a high risk of accidents for pedestrians when crossing the road than walking on the road. To minimize the crash rate on pedestrians it is important to know about the risks faced by pedestrians on the road. This study aimed to report pedestrians' perceptions of risks while walking and crossing the road. A questionnaire survey was carried out to get the data about pedestrians' perceptions of risks while walking and crossing the road in Matara district. Data were collected with questions with a five-point scale during August and September 2021 from 225 females and 175 males. The collected data were validated by estimating the Cronbach Alpha values and analyzed using chi-square tests and multinomial logistic regression methods. The results of the study were shown the usage of that technical device while walking on the road is the most reported (66.2%) pedestrian risk in the walkways. Whereas crossing the road without using pedestrian crossings is the most reported risk (73%) during the time of crossing the road. The chi-square test results of the survey were indicated that some of the self-reported risks have a significant association with age and gender. Male pedestrians involved with risky behaviours than female pedestrians because male pedestrians have high observed values than the expected values in the reported risks. Age groups, less than 18 years and 18-30 pedestrians were mostly engaged with risky behaviours on the road. Their observed values in the pedestrian risks especially in using technical devices on the road are higher than the observed values compared to other age groups. When the average walking distance of pedestrians per day is increased, accidents happening on pedestrians is also increased. The results of this study would help infrastructure designers to make safer roads.

KEYWORDS: *crossing*, *pedestrians*, *self-reported risks, walking, age, gender*

1 INTRODUCTION

Pedestrian crashes were increased day by day in the world. The rapid increment of motor vehicles is one of the main reasons for motor crashes on pedestrians (Agarwal and Vikram, 2021). In the world, 23% of road injuries are caused by pedestrians. Pedestrian accident rates are at a higher value in low-income countries than in high-income countries (Yagil, 2020). In Australia, pedestrians represent 14% of road accidents (Williamson, 2015). Among the total deaths, 1.8% of deaths were resulting due to road accidents in the United States (US) (Costello, 2004). In European countries, the younger generation was involved with road accidents most of the time because of their high technical device usage on the road. The pedestrian fatality rate in Bangladesh is 32.7 per 10,000 vehicles (World Bank, 2020) and 25,858 pedestrian deaths happened in India in 2019 (Goswami, 2021).

Figure 1 shows the total deaths that happened for different road user categories due to road accidents in the world in 2015. Pedestrians have the third-highest value; 22% of the total road traffic deaths. According to Department of Motor Traffic, the total number of registered vehicles in Sri Lanka is 8,297,852 on the day of 2020.12.31 (DMT, 2021). In Sri Lanka, there were 23,415 road accidents happened during 2020 (Sri Lanka Police, 2020). Compared to 2018 and 2019 it was a lower value that may be due to Covid 19 pandemic travel restrictions in the year 2020. In 2020, 22% of deaths out of total road traffic deaths were reported for pedestrians (Sri Lanka Police, 2020). In 2020, 265 accidents were occurred due to the carelessness of pedestrians, out of that 32 were fatal accidents (Sri Lanka

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Police, 2020). About 3,165 pedestrian- motor crashes were happened because of failure to use marked pedestrian crossings to cross the road (Sri Lanka police, 2020).

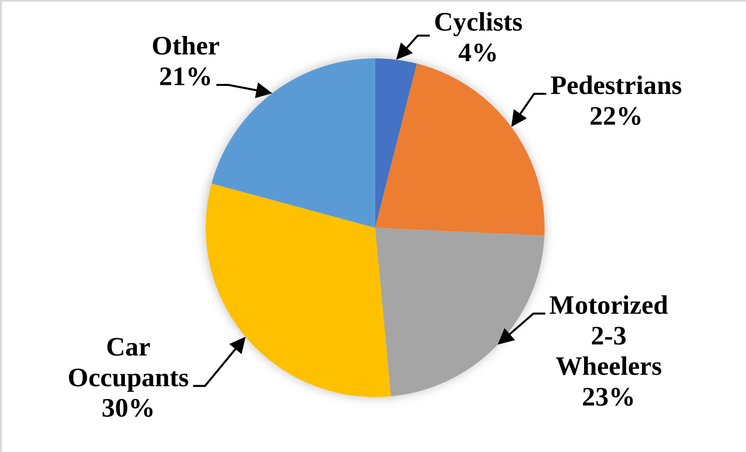

Figure 1. Road traffic deaths by type of the user in the world in 2015 *(Source – WHO, 2015)*

Figure 2 describes the total deaths that happened in different types of road user categories due to road accidents in 2018, 2019 and 2020 in Sri Lanka (Sri Lanka police, 2020). Accordingly, it pedestrians have the second-highest value. However, a proper studies on pedestrian safety in rural areas of Sri Lanka is not available. The objectives of this study are to identify the pedestrian risks from the self-reported data, find the reasons for those risks and propose suitable countermeasures to reduce the pedestrian risks.

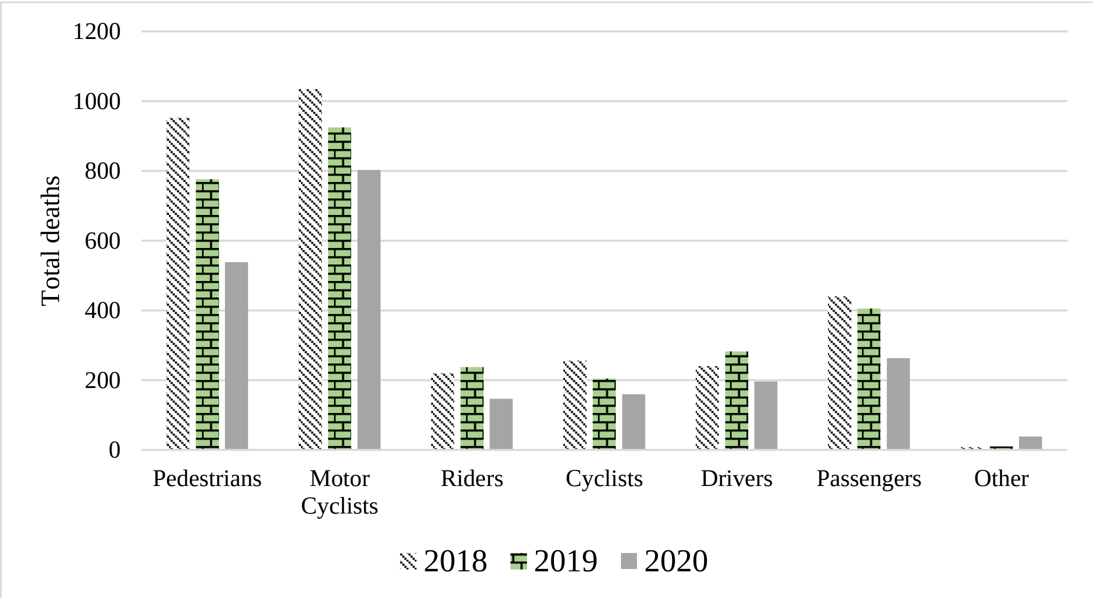

Figure 2. Total road fatalities in Sri Lanka in 2020 (Source- Sri Lanka Police, 2020)

Environmental factors, driver-related factors, pedestrian-related problems have a contribution to accidents on pedestrians (Hou et al., 2021). Crossing the road is riskier than walking on the road because when crossing the road pedestrians have a connection with vehicles. Mobile phones are now common among the young generation due to the increment of smart type. The usage of mobile phones while walking and crossing the road make people distracted. Purposes behind the interruptions of pedestrians who are utilizing cell phones are, cell phone clients walk more gradually, shift course more regularly, are more averse to recognizing others and are less inclined to take a gander at traffic before beginning goes across the street (Williamson and Lenon, 2015). Most crashes happened to pedestrians when crossing the road. Mobile phone usage can reduce situation awareness and increase the unsafe behaviour of pedestrians. Cognitive distraction, physical distraction, visual distraction and auditory distraction can be happened due to technology used on the road. The walking speed of mobile phones using pedestrians was lesser than normal pedestrians (Egodawatta and Amarasinghe, 2019). Pedestrians' careless road behaviours are another leading factor for pedestrian crashes. Pedestrian behaviour is affected by the age and gender of pedestrians. Unintentional mistakes by pedestrians, engagement with technology while walking, rude behaviours towards other pedestrians and road using groups and violating road rules are some of the behaviours that affect pedestrian crashes (O'Hern et al., 2020).

Driver's careless behaviour is another reason for pedestrian crashes as well as careless pedestrian's behaviour. These days' young drivers are more engaging in road accidents. Overestimate of their driving skills, multi-tasking with mobile phones, eating and talking with others while driving made young drivers distracted. The main reason for the crashes was high speed furthermore aggressive behaviour of young drivers was another reason for crashes because it reduced the attention of drivers (Amarasingha and Firdhaws, 2021). Most of the time risky road structures and vehicle density cause accidents on pedestrians. The number of vehicles on the road affected for crossing behaviours of pedestrians and the decision-making of pedestrians about walking and crossing while they are on the road (Agarwal and Vikram, 2021). When concerned about the time of high pedestrian crashes, in nighttime pedestrian crashes are high. Poor visibility in darkness is the main reason for pedestrian crashes during the nighttime. Pedestrian risks are between four- seven times greater in darkness than in light. Out of total pedestrian-involved crashes, 65.9% happened during darkness and according to the results of the study dark/light ratio for pedestrian crashes came as 4.14 (Sullivan and Flanngan, 2001). 20% of drivers were identified, pedestrians were presented after the crash occurred. Because of the headlight glare of the oncoming vehicles, drivers could not see the surroundings well. Headlight glare was a disturbance for drivers because of poor vision (Borzendowski et al., 2015). Because of the poor visibility drivers cannot see pedestrians. Size of the object, contrast with the background, ambient light levels and presence of glare were some of the properties that affected the detection ability of the object. Wearing reflective clothes had a contribution to accident rate reductions and adding reflective materials to the footwear, further decreased the accidents (Costello and Wogalter, 2004).

2 METHODOLOGY

2.1 Study Area

Matara district which is shown in Figure 3 was selected as the study area. Pedestrians who live in Matara District were taken as the respondents of the questionnaire survey. Matara district is one of the major districts in Sri Lanka among 25 districts. Matara district gives huge contribution to the Sri Lankan economy from multiple ways including agriculture, tourism, garments, fishery and production process.

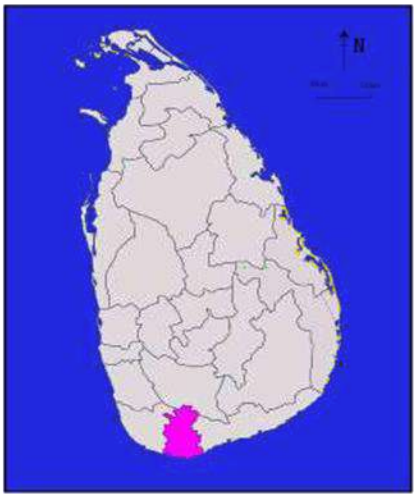

Figure 3 – Study Area (Matara District)

The total area of the Matara district is 1283Km^2 (Department of Census Statistics Sri Lanka, 2021). Akuressa, Deniyaya, Devinuara, Hakmana, Kamburupitiya, Matara, Weligama and Malimbada are polling divisions in Matara district. Sixteen Divisional Secretariats and 650 Grama Niladhari Divisions under Secretary Office Matara, 2020. Totally 196,397 vehicles were registered in Matara district (Department of Census Statistics Sri Lanka, 2021) and 784 accidents happened in Matara district in 2020 (Sri Lanka Police, 2020). According to all these reasons Matara district can be selected as a representative area for selecting the Sri Lankan pedestrian sample.

2.2 Sample Size Determination

Four Divisional Secretary divisions of Matara District were selected for data collection. Table 1 shows the population distribution of Matara, Malimbada, Weligama and Welipitiya polling divisions in Matara district.

Table 1 Population distribution at different polling divisions in Matara district

Divisional Secretary Division	Population (2020)
Matara	122 939
Malimbada	37 300
Weligama	77 330
Welipitiya	55 292
Total	292 570

Source: Department of Census Statistics Sri Lanka, 2021

The total population including all other polling divisions of Matara District is 866 000. Therefore the expected population proportion in the data collection polling division is ([292 570 / 866 000] * 100%) 33.78%. Equation 1 was used to calculate the same size (Bartlett et.al, 2001):

$$N = \frac{z^2 P(1-P)}{d^2} \tag{1}$$

where N = Sample size,
z = Value corresponding to confidence level = 1.96 (critical value for 95% confidence level),
d = Margin of error = 0.05 (acceptance amount of absolute error is considered as 5%), and
P = Expected population proportion.
The sample size calculated using the equation is 350.

2.3 Data Collection

Paper-based questionnaire survey was used to collect data for the study. Forty-eight questions were included in the questionnaire focusing the walking distance per day as a pedestrian, walking areas, risky behaviours of pedestrians while walking and crossing the road, information on risky environmental factors that cause risks for pedestrians on the road, information on factors that affect the risky walking and crossing behaviours of the pedestrians and suitable countermeasures to mitigate the pedestrian risks. Both males and females under five age categories of 18, 13-30, 31-44, 45-65 and above 65 years were eligible for the questionnaire survey. The reliability of the questionnaire paper was checked by the Cronbach alpha method. Cronbach alpha value for the questionnaire paper was found as 0.787 and it is fallen under the acceptable region. (O'Hern et. al, 2020; Yagil, 2000; Williamson and Lenon 2015).

2.4 Data Analyzing

Data were analyzed using SPSS software.

2.4.1 Chi-square test

Two main usages of Chi-square test are the Chi-square test for goodness of fit and Chi- square test for independence. Chi-square test for goodness of fit measures whether sample data match with population or not and the Chi-square test for independence measures the significant association between independent variables. In the study, Chi-square test for independence was used. Chi-square test can be used when independent and dependent variables belong to the categorical type. The significance level in the chi-square test was used as 0.05. If the given P-value by the Chi-square test is lower than the significance level, the null hypothesis will be rejected. Chi-square test is also comparing the deviation between observed and expected values of the variables (Statistical Discovery, 2021). In the study test null hypotheses were taken as age and pedestrian self-reported risk while walking and crossing the road are independent and gender and pedestrian self-reported risks while walking and crossing the road are independent. In this test age and gender are considered as independent variables and pedestrian self-reported risks were taken as dependent variables.

2.4.2 Binary logistic regression

The binary logistic regression model is a regression model that is used to measure the relationship between a categorical dependent variable with one or more independent variables. Equation 2 provides the model format of the binary logistic regression (Hua et.al, 2021);

$$P = \frac{\exp(a+b_1x_1+b_2x_2+b_3x_3+\cdots)}{1+\exp(a+b_1x_1+b_2x_2+b_3x_3+\cdots)} \quad (2)$$

where, P = Probability that a case is in a particular category,
a = the constant of the equation, and
b = the coefficient of the predictor variables.

The dependent variable in the model is binary, the observations are independent, no multicollinearity among the independent variables, there are no outliers, there is a linear relationship between independent variables and logit of the dependent variable and sample size sufficiently large are the assumptions of the binary logistic regression (Zach, 2021). In the study overall pedestrian risky behaviour associated with age, gender and mostly walking area were investigated by creating a binary logistic regression model.

3 RESULTS

The study was done with 400 pedestrian responses in Matara district. Out of the total sample, 56% were female pedestrians and 44% were male pedestrians. Data were collected under, five age categories. The large portion is from the 31-44 age category and that is 31% of the total sample size. About 28% of respondents were from the 18-30 age category and 26% of pedestrians were from the 45- 65 age category. Pedestrians who were below 18 years represented 8% of the sample. The least amount was in the age category of above 65 years which was 7% out of the total sample size. Out of the total sample, 54% of pedestrians were mostly walking in urban areas and 46% of pedestrians were mostly walking in rural areas. When considering the employment status of the respondents in the collected sample, out of the 400 responses, 39% of them were government employers. The other 17% of respondents were private-sector employers. Another 9% of the sample were running their own business. The collected sample was included the responses of 13% of undergraduates and 7% of students. Left 15% of responses were fallen under the other category.

Factors affecting the walking and crossing behaviours of the pedestrians were also reviewed through the questionnaire paper. Responses were taken under several factors. Their knowledge about road rules, obedience to the law, understanding the dangers of unsafe crossing and walking, traffic volume, bad weather conditions, pedestrian's mood, other pedestrian's behaviour and rush of the pedestrians. According to the responses of the sample, the most affecting factor for the behaviour of the pedestrians was their understanding of the dangers of unsafe crossing and walking. And knowledge about road rules, obedience to the law, pedestrian's mood, other pedestrian's behaviour and rush of the pedestrian were got 372, 371, 309, 299 and 301 responses out of 400 respectively. Traffic volume and bad weather conditions have the least contribution (287 responses) to the pedestrian's walking and crossing behaviours.

Table 2 presents the percentages of the different risky behaviours of pedestrians on the road.

Table 2 Percentages of pedestrian self-reported risks

Pedestrian risk	Never %	Occasionally %	Sometime %	Most of time %	Always %
Use of technical devices such as mobile phones, headphones, tablets while walking	33.8	36.8	22.3	5.3	2.0
Walk on the traffic lane, not on the walkways	38.5	37.0	18.3	5.3	1.0
Walking on the pedestrian paths as a group	46.3	32.0	16.0	4.3	1.5
Wear reflective clothing when walking on the road at night	53.3	22.5	15.3	7.5	1.5
Walking on the road after consumption of alcohol and drugs	81.3	8.3	8.3	2.0	0.3
Use of technical devices such as mobile phones, headphones, tablets while crossing the road	56.8	26.3	13.8	3.0	0.3
Cross the road without looking left and right	50	21.3	10.8	10.3	7.8
Cross the road without using pedestrian crossings	27.0	39.3	27.0	6.5	0.3
Crossing the road, when the red light is on for pedestrians	51.5	19.5	17.0	7.8	4.3
Cross the road between vehicles stopped on the roadway in traffic jams	33.0	36.5	24.5	5.8	0.3
Crossing the road after consumption of alcohol and drugs	82.0	10.8	5.5	1.8	0
Cross the road while talking with others	44.0	40.0	11.8	3.5	0.8

Solutions for mitigating pedestrian risks were raised in the study according to the agreement of respondents. Proposed solutions in this study were conducting traffic awareness programs for school children about traffic rules and new technologies in the transportation industry, establishing footpaths for pedestrians, countdown time installations in signalized intersections, installing pedestrian push buttons at pedestrian crossings, maintaining tidy road system, establishing a quick process for road and pedestrian path maintenances, encourage people to wear reflective clothing when walking at night, establish special footpaths for disabled people, limiting the registration of new vehicles and conducting enforcement of fines for pedestrians violating traffic rules. Responses for the proposed solutions were taken under a five-point scale of strongly agreed, agreed, neutral, disagreed and strongly disagreed. Most of the respondents strongly agreed to conduct traffic awareness programs for school children to reduce pedestrian risks. A high disagree percentage was reported for limiting the registration of new vehicles as a mitigation solution for pedestrian risks.

3.1 Chi-square test results

A chi-square test was done to identify the significant association between age, gender and pedestrian self-reported risks. Table 3 presents the cross tabulation with expected values and observed values of the pedestrian risks which have a significant association with gender. Observed and expected data show that males have high observed value than the expected value. When considering the data collection of males, a higher deviation between the observed value and the expected value was shown by walking on the road after consumption of alcohol. And females have lesser observed values than the expected values. In the female category also the highest deviation between the observed value and expected value was shown by walking on the road after consumption of alcohol. The results show that male pedestrians are highly engaged with risky walking and crossing behaviours on the road than female pedestrians' engagement with risky behaviours on the road. Therefore, males have a higher probability of engaging in motor crashes than females.

Table 3 Expected values and Observed values of pedestrian risks versus gender

Risk			**Never**	**Occasionally**	**Some time**	**Most of time**	**Always**	**Asymptotic Sig. (2 sided)**
Cross the road between vehicles stopped on the roadway in traffic	Male	Observed	37	80	45	12	1	0.000
		Expected	57.8	63.9	42.9	10.1	0.4	
	Female	Observed	95	66	53	11	0	
		Expected	74.3	82.1	55.1	12.9	0.6	
Cross the road after consumption of alcohol	Male	Observed	119	33	17	6	0	0.000
		Expected	143.5	18.8	9.6	3.1	0	
	Female	Observed	209	10	5	1	0	
		Expected	184.5	24.2	12.4	3.9	0	
Crossing the road while talking with others	Male	Observed	63	78	22	10	2	0.023
		Expected	77	70	20.6	6.1	1.3	
	Female	Observed	113	82	25	4	1	
		Expected	99	90	26.4	7.9	1.7	
Walk on traffic lanes not, on walkways	Male	Observed	56	72	29	15	3	0.009
		Expected	67.4	64.8	31.9	9.2	1.8	
	Female	Observed	98	76	44	6	1	
		Expected	86.6	83.3	41.1	11.8	2.3	
Walking on the road after consumption of alcohol	Male	Observed	117	26	26	6	0	0.000
		Expected	142.2	14.4	14.4	3.5	0.4	
	Female	Observed	208	7	7	2	1	
		Expected	182.8	18.6	18.6	4.5	0.6	
Cross the road without looking right and left	Male	Observed	70	42	21	28	14	0.001
		Expected	87.5	37.2	18.8	17.9	13.6	
	Female	Observed	130	43	22	13	17	
		Expected	112.5	47.8	24.2	23.1	17.4	

Table 4 presents the Observed Values and Expected Values of the Pedestrian Risks which have a significant association with age. When comparing all age groups 18-30 and 31-44 age categories have larger variances between expected counts and observed counts. Most of the time their observed values for the pedestrian risks are higher than the expected values. In particular, 18-30 age group have a high frequency of using technical devices such as mobile phones, headphones, tablets etc. while walking and crossing the road.

Table 4 Expected values and Observed values of pedestrian risks versus age

Risk			**Never**	**Occasionally**	**Some time**	**Most of time**	**Always**	**Asymptotic Sig. (2 sided)**
Use technical devices such as mobile phones, headphones and tablets while walking	<18	Observed	15	12	4	1	1	0.013
		Expected	11.1	12.1	7.3	1.7	0.7	
	18-30	Observed	26	40	31	10	4	
		Expected	37.5	40.8	24.7	5.8	2.2	
	31-44	Observed	43	52	23	4	0	
		Expected	41.2	44.8	27.1	6.4	2.4	
	45-65	Observed	33	38	27	4	3	
		Expected	35.4	38.6	23.4	5.5	2.1	
	>65	Observed	18	5	4	2	0	
		Expected	9.8	10.7	6.5	1.5	0.6	

Table 4 Expected values and Observed values of pedestrian risks versus age continue…

Risk			**Never**	**Occasionally**	**Some time**	**Most of time**	**Always**	**Asymptotic Sig. (2 sided)**
Walking on the traffic lane, not on the walkways	<18	Observed	11	12	7	3	0	0.003
		Expected	12.7	12.2	6	1.7	0.3	
	18-30	Observed	30	42	25	11	3	
		Expected	42.7	41.1	20.3	5.8	1.1	
	31-44	Observed	51	48	17	5	1	
		Expected	47	45.1	22.3	6.4	1.2	
	45-65	Observed	54	37	13	1	0	
		Expected	40.4	38.9	19.2	5.5	1.1	
	>65	Observed	8	9	11	1	0	
		Expected	11.2	10.7	5.3	1.5	0.3	
Walking on the pedestrian path as a group	<18	Observed	9	13	7	2	2	0.000
		Expected	15.3	10.6	5.3	1.4	0.5	
	18-30	Observed	36	40	24	9	2	
		Expected	51.3	35.5	17.8	4.7	1.7	
	31-44	Observed	56	41	21	4	0	
		Expected	56.4	39	19.5	5.2	1.8	
	45-65	Observed	65	28	11	0	1	
		Expected	48.6	33.6	16.8	4.5	1.6	
	>65	Observed	19	6	1	2	1	
		Expected	13.4	9.3	4.6	1.2	0.4	
Use of technical devices such as mobile phones, headphones and tablets while crossing the road	<18	Observed	19	7	5	2	0	0.009
		Expected	18.7	8.7	4.5	1	0.1	
	18-30	Observed	43	42	20	5	1	
		Expected	63	29.1	15.3	3.3	0.3	
	31-44	Observed	75	33	10	4	0	
		Expected	69.2	32	16.8	3.7	0.3	
	45-65	Observed	70	18	17	0	0	
		Expected	59.6	27.6	14.4	3.2	0.3	
	>65	Observed	20	5	3	1	0	
		Expected	16.5	7.6	4	0.9	0.1	
Cross the road without looking right and left	<18	Observed	21	1	5	2	3	0.003
		Expected	16.5	7	3.5	3.4	2.6	
	18-30	Observed	48	36	9	13	2.6	
		Expected	55.5	23.6	11.9	11.4	8.6	
	31-44	Observed	63	26	12	12	9	
		Expected	61	25.9	13.1	12.5	9.5	
	45-65	Observed	61	13	9	12	10	
		Expected	52.5	22.3	11.3	10.8	8.1	
	>65	Observed	7	8	8	2	4	
		Expected	14.5	6.2	3.1	3.0	2.2	
Crossing the road, when the red light is on for pedestrians	<18	Observed	12	4	9	5	3	0.003
		Expected	17	6.4	5.6	2.6	1.4	
	18-30	Observed	40	27	26	13	6	
		Expected	57.2	21.6	18.9	8.6	4.7	
	31-44	Observed	72	20	21	4	5	
		Expected	62.8	23.8	20.7	9.5	5.2	
	45-65	Observed	68	21	7	6	3	
		Expected	54.1	20.5	17.9	8.1	4.5	
	>65	Observed	14	6	5	3	1	
		Expected	14.9	5.7	4.9	2.2	1.2	

The above 65 age group also have higher observed values than the expected values up to some extent. The age group 45-65 has the least variations between observed and expected values. These results showed that 18-30 and 31-44 have high risky behaviours on the road than other age categories**.**

3.2 Binary logistic regression results

The relationship of overall risks for the pedestrians on the road with the age, gender, mostly walking area and the average daily walking distance of pedestrians was evaluated through the binary logistic regression model. In the model accidents that happened or not on pedestrians was taken as the dependent variable and age, gender, mostly walking area and average daily walking distance of pedestrians were taken as independent variables. Reference categories for gender, age, mostly walking area and average daily walking distance were taken as male, above 65 years, urban areas and more than 2Km respectively. The reference category for the dependent variable is taken as a number of accidents that happened to pedestrians.

The Model Summary of the test contains the Cox & Snell R Square and Nagelkerke R Square values illustrate the variations of the dependent variable. According to the test results, Cox & Snell R Square value is 0.067 and Nagelkerke R-value is 0.092, which illustrates that variations of the dependent variable range from 6.7% to 9.2%. Hosmer and Lemeshow test is a goodness of fit test for the logistic regression model. This test calculates how much, observed data is matching with the predicted data. The test P value was got as 0.058 and that is greater than 5%. That means the model is fitting good with the data sample.

Table 5 shows how the independent variables predict the dependent variable. Here, the variable, average walking distance per day as a pedestrian shows a significant association with the accidents happening on pedestrians and other independent variables are not significant with the dependent variable.

Table 5 –Binary Logistics Regression Model for Traffic Accident Occurrence in Matara District

Variable	**B**	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**
Gender(1)	-.406	.218	3.483	1	.062	.666
Age			14.825	4	.005	
Age(1)	-.361	.533	.458	1	.499	.697
Age(2)	.270	.430	.395	1	.530	1.310
Age(3)	-.759	.435	3.042	1	.081	.468
Age(4)	-.521	.437	1.424	1	.233	.594
Average walking distance per day as a pedestrian			10.202	2	.006	
Average walking distance per day as a pedestrian (1)	-.787	.253	9.701	1	.002	.455
Average walking distance per day as a pedestrian (2)	-.625	.289	4.686	1	.030	.535
Constant	.519	.426	1.484	1	.223	1.680
Dependent variable: Accident occurrence						

For independent variable *'average walking distance per day'*, the reference category is walking more than 2 km per day. The dependent variable '*accidents happening on pedestrians'* has the reference category is 'yes'. In step one, the average walking distance less than 1km and the walking distance between 1 km and 2 km have odds ratios of -0.797 and -0.628 respectively. It means that walking less than 1 km per day and walking between 1km and 2km have a lesser tendency for occurrence of pedestrian accidents compared to walking more than 2 km. In step two, average walking distance less than 1Km per day has a -0.787 odd ratio and walking and between 1km and 2km have per day has a -0.521 odd ratio. It shows that increasing walking distance increases the accidents happening probability on pedestrians.

4 CONCLUSIONS

Twenty-three percent of road accidents in the world are caused by pedestrians. The number of pedestrian accidents in low-income countries is higher than in developed countries due to the underdeveloped infrastructure and underdeveloped road networks in low-income countries. In 2020, 25% of pedestrian deaths were reported out of total deaths due to road accidents in Sri Lanka. The purpose of this study is to identify road accidents for pedestrians and to suggest appropriate measures to mitigate them. Self-reported risks of pedestrians, risky environmental factors, factors affecting the pedestrian's behaviour and proposed solutions to mitigate pedestrian risks were reviewed through the questionnaire paper. The pedestrian sample included 225 female pedestrians and 175 male pedestrians. The pedestrians were grouped into five age categories which were below 18 years, 18-30, 31-44, 45-65 and above 65 years. Walking area of pedestrians identified whether rural area or urban area. Average walking distance per day as a pedestrian were also accounted for the analyze. Pedestrian risks were reported under a five-point scale. The most reported risk at while walking on the road was using technical devices such as phones mobile (66.2%). The most reported risk while crossing the road was crossing the road without using pedestrian crossings (73%). The minimum reported risk both in crossing and walking the road was being a pedestrian after consumption of alcohol and drugs. The reported percentage for that is 18.7% and 18% respectively at walking on the road and crossing the road respectively.

Chi-square test and binary logistic regression test were used to statistically analyze the data. In the chi-square test significance association between the dependent variable and independent variables was evaluated. Age and gender were considered independent variables and pedestrian risks were taken as the dependent variables. Observed values and expected values of risks that have a significant association with age and gender were compared. Cross the road walking between stopped vehicles on the roadway in traffic jams, cross the road after consumption of alcohol, crossing the road while talking with others, walk on the traffic lanes not on the walkways, walking on the road after consumption of alcohol, and cross the road without looking right and left have a significant association with gender. When compared observed and expected data, it has been shown that males are involved with more risky behaviours than females. However, Yagil (2020) found that female pedestrians have high involvement with accidents. Use of technical devices while walking or crossing the road, walking on the traffic lane not on the walkways, walking on pedestrian path as a group, crossing the road without looking right and left and crossing the when the red light is on for pedestrians have a significant association with age. Here expected and observed data showed that below 18 years and 18-30 age categories have a high chance of engaging in risky behaviours than other age categories. Williamson and Lenon (2015) also discovered that the 18–30-year age category is the high-risk road user category compared to other age categories. Egodawatta and Amarasinge (2019) found similar results to these fundings that the younger generation has high involvement with the technical devices while on the road.Binary logistic regression model test results shows that, when walking distance is increasing, accidents happening probability on pedestrians is also increase.

The results of this study can be used to find mitigation methods for pedestrian risks and results of the study can be taken as a baseline for future studies. Recommendations of the study include to conduct traffic awareness programmes for school children, enforce the rules to minimize the technical devices used while on the road and encourage pedestrians to wear reflective clothing when walking at night. Objectives of the study were achieved through the data collection and data analysis parts of the study and identified research gaps were filled by the study.

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Investigating a method for rating Sri Lankan roads through identifying the factors affecting road safety

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ABSTRACT

Road safety assessment is imminent to reduce road accidents in Sri Lanka. The existing road safety assessments in other countries are inapplicable to Sri Lankan Road conditions as there are significant differences between the road conditions of Sri Lanka and other countries. This study aims to identify the governing roadside elements which are influential to the cause of accidents and can be used for road star rating. The study was conducted in three districts of Sri Lanka: Anuradhapura, Polonnaruwa and Kurunegala. The data for road characteristics were obtained through the Google Earth Web engine whereas accident data were collected from Sri Lanka Police. The variables such as road condition, road length, road width, delineation, shoulder condition, footpath, vehicle parking length, road divide status, roadside objects length, number of lanes, number of intersections, number of pedestrian crossings, and number of bus bays were analyzed to develop a Negative Binomial regression model considering the number of accidents as the dependent variable. The results reveal that six variables: number of lanes, road condition, number of intersections, road divide status, road section length and width of lane are significant towards the occurrence of accidents. Moreover, the results demonstrate the relationship between the road characteristics and the accident number which is crucial in road designing in order to reduce road accidents. The findings affirm the possibility in developing a road safety rating mechanism for Sri Lankan streets to standardize the road network with the international standards while enhancing the road conditions with reflecting to the required safety levels.

KEYWORDS: *Road safety, Road star rating, Sri Lankan roads, Negative binomial regression*

1 INTRODUCTION

Safety is a crucial component in road transportation due to the increase in road accidents as a result of the fast-growing infrastructure and the use of vehicles in Sri Lanka. Road safety assessment helps to analyze the potential causes for road accidents which leads to reduction of accidents through the effective adoption of the safety assessment methodology. Road safety assessment benefit in several perspectives such as produce designs that reduce the number and severity of crashes, reduce costs by identifying safety issues and correcting them before construction, promote awareness of safe road design practices, integrate multinomial road safety concerns, and identify key human factor considerations (Belcher et al. 2008).Therefore, this research study explores the potential of the implementation of a road safety assessment with considering the number of accidents and other governing road side elements to develop a generalized road safety assessment for Sri Lanka where heterogeneous traffic conditions are imminent.

2 LITERATURE REVIEW

2.1 Governing Factors in Road Safety Assessments

Belcher et al. (2008) assessed the road safety in Australia with respect to three core components which are road users at risk, scheme features and junction types. The road users at risk consisted of people with disabilities, pedestrians, pedal cyclists, and motorcyclists while scheme features consisted of road traffic signs, road markings, street lighting, road surfacing, surface water drainage, vehicle

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restraints and pedestrian guardrails. The junction types consisted of traffic signals, roundabouts, priority junctions and pedestrian or cycle openings. AUSTROADS (2009) provides a clear guideline in the risk assessment process and potential suggestions. Such that, the risk assessment is done in four main steps which are 1) estimate possible crash frequency (frequency is categorized as frequent, probable, occasional, and remote); 2) estimate the possible crash severity (severity is categorized as catastrophic, serious, minor and negligible); 3) determine the level of risk (risk level is categorized as low, medium, high and intolerable for frequency and severity), 4) determine a course of action (suggestion are provided for the four risk levels separately).

Demasi et al. 2018 analyzed the road safety while proposing a methodology to enhance risk management in urban roads and to promote better decision-making processes to design safer roads. The study developed risk factors for nine categories which are geometry, cross section, private access, pavement, lightning, road signs, intersection, urban furniture and stopping. The study further emphasized that these parameters contribute towards the Section Index Risk and the Branch Index Risk which are incorporated in evaluating the risk. Furthermore, the study acknowledged the correlations between the risk factors and the accident factors. Perera and Amarasingha (2021) did a similar analysis in Sri Lanka using risk metrics method and binomial negative regression for road risk assessment. Grasskopf (1998) developed a method to evaluate the existing road network safety performance. Such that, road safety index was calculated as a combination of accident index and the safety index. The accident index only had one element which is accidents. In this, the number of accidents and the accident severity were considered. The safety index was divided into four elements as operating conditions, land use, pedestrians and road elements. The operating elements was further divided into speed and weather conditions. Land use was divided into area characteristics and the road elements were divided into road hierarchy and characteristics, road lighting, access management, roadside hazard management, traffic control and geometry and pavement.

2.2 Road Safety and Accident Modelling

Road safety and accident prediction models have been developed since late 20th century where prediction models were mainly based on statistical models. Group et al. (1997) identified the road safety principles with predictive risk and accident consequence models. The study identified the factors influencing consequences such as traffic elements, accident type, speed, vehicle mass and age of injured. Ezra (2004) also modelled the road safety statistically with considering variables such as average annual daily traffic, percentage of trucks, speed limit, curvature, and gradient of the road.

Silva et al. (2020) developed a crash prediction model with using machine learning methods. The study identified three core models. Which are crash frequency, crash clarification by severity and crash frequency and severity. Bhasvar et al. (2021) modelled the safety of multi-lane rural highways in India as a statistical generalized linear model with having the accidents per km as the dependent variable and junction density, village settlement nearby, average daily traffic and average speed spots as independent variables. The authors identified accidents spots in the heterogeneous nature of accidents with assessing the severity of the accident as fatal and non-fatal.

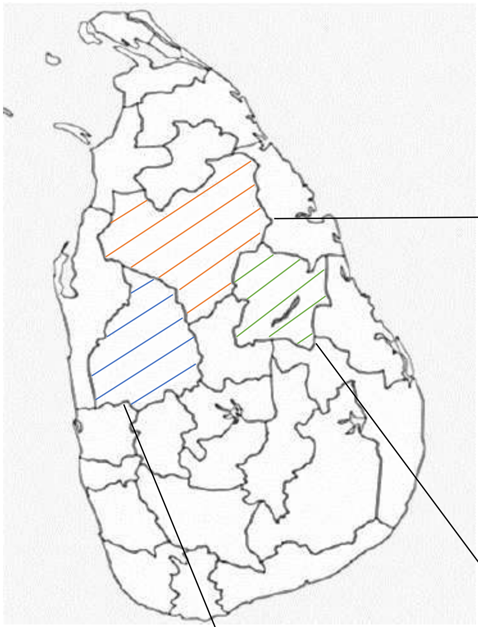
The methodologies of the regional Road Assessment Programs demonstrate the importance of a road star rating to a country to increase the safety performance of the roads and minimize the number of road accidents. Sri Lanka has been unable to develop such a road safety rating system thus making it more essential to implement such a system. However, there are various discrepancies among the regional methods in terms of the road demands, user desires, discipline, culture etc. Therefore, an expository analysis is required on developing such methodology for developing south Asian country like Sri Lanka to identify the governing parameters and to implement a complex road safety system.

3 METHODOLOGY

3.1 Study Area

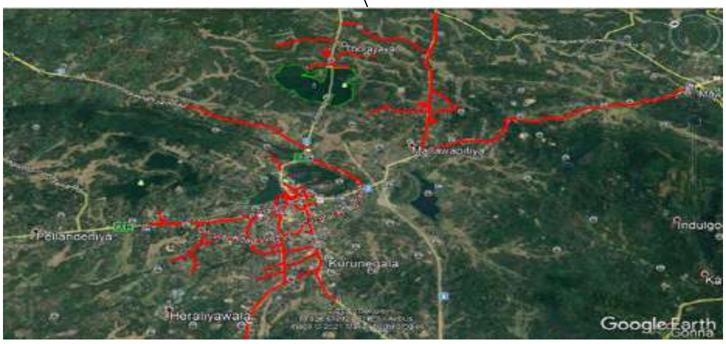
The location selection was the initial step in the research and was considered as one of the vital steps as the selected locations provides an insight of the safety features in that respective road. The overall locations were selected in the Anuradhapura, Polonnaruwa and Kurunegala districts of Sri Lanka. The study areas are further illustrated in Figure 1. According to the Road Development Authority

(RDA) of Sri Lanka, the road classess in this study area are A Class, AB Class, B Class. The research study was carried out with 380 considered road sections which is seen in red in Figure 1.



a) Anuradhapura District Road Sections

b) Polonnaruwa District Road Sections



c) Kurunegala District Road Sections

Figure 1. The Selected Road Segments in the Study Area

3.2 Data Collection

The data collection was done separately for each of the road sections with adhering to each of the governing roadside elements. The road sections were selected based on the physical identification of local people from one intersection to other. Fourteen variables were collected in this process. Which are road length, road width, number of lanes, delineation, road condition, shoulder condition, number of intersections, footpath, vehicle parking length, number of pedestrian crossings, road divide status, roadside objects length, number of bus bays and number of accidents. The considered variables, variable type and the respective unit of measurement are summarized in Table 2. Road condition and shoulder condition were categorized based on the visual observation. When taking the road condition and shoulder condition both ways of the road were considered. The data for road characteristics were obtained by visual observation through the Google Earth Web engine whereas accident data were collected from Sri Lanka Police in the same year. The accidents included both vehicle – pedestrian accidents and vehicle – vehicle accidents.

Table 2. Definition of the Variable in the Study

Variable	Variable type	Unit Measurement/Category
Road Length	Continuous	Kilometers
Road Width	Continuous	Meters
Number of Lanes	Nominal	1 – One lane 2 – Two lanes 3 – Three lanes 4 – Four lanes
Delineation	Categorical	0 = No Delineation 1 = Adequate Delineation
Road Condition	Categorical	0 = Weak Condition 1 = Intermediate Condition 2 = Good Condition
Shoulder Condition	Categorical	0 = Weak Condition 1 = Intermediate Condition 2 = Medium Sealed Condition
Number of Intersections	Nominal	0 = 0 to 10 Intersections 1 = 11 to 20 Intersections 2 = 21 to 30 Intersections 3 = 31 to 40 Intersections
Footpath	Continuous	Kilometers
Vehicle Parking Length	Continuous	Kilometers
Number of Pedestrian Crossings	Nominal	0 = 0 to 5 Crossings 1 = 6 to 10 Crossings 2 = 11 to 15 Crossings
Road Divide Status	Categorical	0 = Undivided 1 = Divided
Roadside Objects Length	Continuous	Kilometers
Number of Bus Bays	Nominal	0 = 0 to 5 Bus Bays 1 = 6 to 10 Crossings 2 = 11 to 15 Crossings 3 = 16 to 20 Crossings
Accident Number	Continuous	Accidents in Last 5 Years

3.3 Data Analysis

The data analysis was started in considering three modeling approaches, which are generalized linear model, Poisson regression and Negative Binomial regression. The Poisson regression was initially applied followed by the assumption check to fit the model. The assumption check was performed with the goodness of fit and this was measured using the residual deviance as shown in Equation 1.

$$D(y,\hat{\mu}) = 2\left(log\left(p\left(y/\widehat{\theta_s}\right)\right) - log\left(p\left(y/\widehat{\theta_o}\right)\right)\right) \quad (1)$$

where;
y =the outcome,
$\hat{\mu}$ = the estimate of the model,

$\widehat{\theta_s}$ = parameters of the fitted saturated.
$\widehat{\theta_o}$ = parameters of the fitted proposed models,
p(y|θ) is the likelihood of data given the model.

A saturated model is perfect fit that has as many parameters as it has training points, that is, p=n. The proposed model can be the any other model. The residual deviance was checked to be small as possible where for the Poisson/Negative binomial regression, the residual deviance is calculated as shown in Equation 2.

Residual deviance = number of observations – number of parameters (2)

The residual deviance was also considered as the residual degrees of freedom of the model. However, the higher residual deviance which is greater than the residual degrees of freedom is not considered as a good fit model where Poisson regression model is invalid and thereby, negative binomial regression is applied to overcome the less model fit (Shingleton, 2012). However, the Poisson regression analysis was disregarded due to the assumption violation. Thus, the Negative Binomial regression was performed to obtain the relationships with adhering to the statistical viability. The negative binomial distribution is closely related to the Poisson distribution in that the negative binomial is a measure of instances of an event until reaching a concluding event (Shingleton, 2012). The formula for the negative binomial distribution is shown in Equation 3.

$$f(y) = \frac{T\,(r+y)}{y!T(r)}(1-p)^r p^y \quad y = 0,1,2.. \tag{3}$$

where r>0 and, when it is an integer, r can be interpreted as the number of failures and y is the number of successes required to get exactly r failures and p is the probability of a success. The function T(x) is the gamma function and is a continuous version of the choose function (Shingleton, 2012).

The overall analysis was conducted with using the IBM SPSS 23 software. The input variables for the dependent and the independent variables were as follows.

- Dependent variable – Accident number; this is a measure of safety which could be used easily for this study other safety measures such number of conflicts, Level of Service, etc may need excessive data collections.
- Independent variables – Road length, Road width, Number of lanes, Delineation, Road condition, Shoulder conditions, Number of intersections, Footpath, Vehicle parking Length, Number of pedestrian crossing, Road divide status, Roadside objects length, Number of bus bays.

4 RESULTS AND DISCUSSION

4.1 Negative Binomial Regression

The categorical variable information is shown in Table 3. The table represents the total data amount and the percentage of each categorical variable. Eight categorical variables are shown along with the respective category of each variable. Even though number of lanes was defined by four categories, the sample comprise of road sections of three categories which consisting with 1,2 and 4 lanes. Where the most frequent number of lanes were 2 with accounting to 365 sections which is over 96% of the sample. The four-lane category comprise of 3.2% sections whilst the minimum of 0.8% accounting for single lanes. The category of delineation comprises of two as road sections without delineation and with delineation. Road sections without delineation are 280 data which is 73.7% and adequate delineation comprise of 100 data which is 26.3% of the dataset. Road Condition is categorized into three as the weak condition, intermediate condition, and good condition. The category of weak condition has 33 data which is 8.7% of the dataset, intermediate comprise of 156 data which is 41.1% of the dataset and good condition comprise of 191 data which is 50.3% of the dataset of the category.

Table 3. Sample Size Distribution of Categorical Variables

Parameter		**N**	**Percent**
Number of lanes	1	3	0.8%
	2	365	96.1%
	4	12	3.2%
	Total	380	100.0%
Delineation	No	280	73.7%
	Yes	100	26.3%
	Total	380	100.0%
Road condition	Weak	33	8.7%
	Intermediate	156	41.1%
	Good	191	50.3%
	Total	380	100.0%
Shoulder condition	Week	207	54.5%
	Intermediate	62	16.3%
	Good	111	29.2%
	Total	380	100.0%
No of Intersections	0 to 10	313	82.4%
	11 to 20	53	13.9%
	21 to 30	12	3.2%
	31 to 40	2	0.5%
	Total	380	100.0%
No of Pedestrian crossing	0 to 5	346	91.1%
	6 to 10	31	8.2%
	11 to 15	3	0.8%
	Total	380	100.0%
Divided / Undivided	No	373	98.2%
	Yes	7	1.8%
	Total	380	100.0%
No of bus bays	0 to 5	339	89.2%
	6 to 10	35	9.2%
	11 to 15	5	1.3%
	16 to 20	1	0.3%
	Total	380	100.0%

The variable ‘shoulder condition’ in category of weak condition has 207 sections which is 54.5% of the dataset, intermediate comprise of 62 data which is 16.3% of the dataset and good condition comprise of 111 data which is 29.2% of the dataset of the category. The number of intersections was categorized to four according to the number of intersections. Thus, the majority of the road sections encompass 0 – 10 intersections with accounting to 313 road sections. The second category has 53 road sections, representing that 13.9% of the sample has 11 – 20 intersections. There are 12 road sections with having 21 - 30 number of intersections and only 2 road sections with having 31 – 40 number of intersections. The number of pedestrian crossing constitute to three categories. Thus, the majority of the road sections in the sample have 0 – 5 pedestrian crossings with accounting to 91.1% of the sample. While 8.2% of the road sections comprise of 6 – 10 pedestrians crossing and only 0.8% comprise of 11 – 15 pedestrian crossings. The Road Divide dataset comprised of 373 data for undivided which is 98.2% of the dataset while only 1.8% of the roads were divided which is 7 roads. The number of bus bays were also categorized into four categories. The majority of the 89.2% of the road sections comprise of 0 – 5 bus bays whereas 9.2% account to 6 – 10 bus bays. However, 1.3% of the road section have 11 – 15 bus bays and only 0.3% have 16 – 20 bus bays. In some categorical variables, some groups show few observations which can also be combined with some other categories and similar analysis can be done. However, in this study the model developed with combined categorical variable did not improve the model therefore the model presented in this paper used the variable definitions shown in Tables 3 and 4. The dependent variable and the continuous variable information are demonstrated in Table 4.

Table 4. Continuous Variable Information

Variable		**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Dependent Variable	Number of accidents	380	0	241	9.83	24.519
Covariate	Road section length (km)	380	.08	6.85	1.2373	1.08488
	Width of the lane (m)	380	.00	3.00	1.7057	.57394
	Shoulder width (inches)	380	.0	4.0	1.780	1.9542
	Foot path (km)	380	.000	4.900	.60826	.695778
	Vehicle parking length (km)	380	.000	3.750	.36603	.547762
	Road side objects length (km)	380	.000	3.650	.65009	.534341

The results show the minimum, maximum mean and the standard deviation of the dependent variable, accident number and six covariates which are road section length, width of lane, shoulder width, footpath, vehicle parking length, and roadside objects length. The number of accidents in a road section is a count variable which range from zero to 241 with a mean of 9.83. The road section length ranges from 0.08 km to 6.85 km with a mean of 1.2373 km. The width of lane ranges from 1 m to 3 m with a mean of 1.7057 m while the shoulder width has a minimum of 0 m and a maximum of 4 m with the mean of 1.78 m. The footpath length is between 0 km to 4.9 km with an average of 0.60826 km. The vehicle parking length ranges from 0 km to 3.75 km with a mean of 0.36603 km. Whereas the roadside objects length ranges between 0 km and 3.65 km and have a mean of 0.65009 km.

When developing the negative binomial model, the descriptive analysis results reveal that the mean of the dependent variable is 9.83 and the variance is 601.175. If the variance is higher than the mean the distribution should be negative binomial (Shingleton, 2012). The results of the current study show that the variance is more than the mean. Therefore, the results ascertain that the data set comprise of a negative binomial distribution. Thereby, the descriptive statistics of the dependent variable, and the negative binomial distribution is applicable due to the adherence and fulfillment to the assumptions checks with the applicability requirements of the negative binomial distribution. The likelihood ratio chi-square value is 771.892 along with a high significance of 0.000 which is less than 0.05. The goodness of fit results further affirm that the fitness of the developed model is appreciable. According to the results of the test of models, there are five variables which are significant, and they are number of lanes, road condition, number of intersections, divide status, number of bus bays, road section length and width of lane.

The parameter estimates for each variable along with the coefficient, standard error, significance and the exponential coefficient are shown in Table 6. The intercept has a significance of 0.46 which is higher than 0.05. Thus, the intercept of the model is not statistically significant towards the accident number. As per the results, the variable, ‘one number of lanes’ is significant as the p value is 0.012 and the variable ‘two number of lanes’ is also significant with the lower p value of 0.005. The variable ‘one number of lanes’ has a positive coefficient of 1.825 which reveals that it is positively affecting to the ‘number of accidents’ compared to that of ‘four number of lanes’. However, the variable ‘two number of lanes has a negative coefficient of – 1.093 which is negatively affecting towards the number of accidents compared to that of ‘four number of lanes’. Furthermore, the coefficient of ‘four number of lanes’ is zero which signifies because it is the reference category. None of the levels of delineation variable were significant in the developed model. Even though the road condition encompasses of three levels, the results revealed that ‘weak road condition’ is insignificant. Whilst the intermediate road condition was statistically significant with a negative coefficient of -0.627, signifying that the intermediate level of road condition reduces the ‘number of accidents’ compared to ‘good road condition’. According to the obtained results, ‘shoulder condition’ is insignificant towards the number of accidents. The variable, number of intersections is highly significant towards the dependent variable as that has lower p value obtained for all levels. Therefore, ‘0 – 10 number of intersections’ affects the ‘ number of accidents’ positively due to the positive coefficient of 3.324 while the 11 – 20 intersections a coefficient of 3.162 and 21 – 30 intersections with a coefficient of 3.161. However, 31 - 40 'number of intersections' has a zero coefficient which signifies that if the 'number of intersections' are between 31 – 40, there is no potential effect towards the accident number.

Table 6. Parameter Estimates of Accident Frequency Model for Road Segments

Parameter	B	Std. Error	Sig.	Exp(B)
Intercept	-1.975	2.6747	.460	.139
One number of lanes	1.825	.7265	.012	6.204
Two number of lanes	-1.093	.3868	.005	.335
Four number of lanes	0[a]	.	.	1
No delineation	.242	.1890	.200	1.274
Adequate delineation	0[a]	.	.	1
Weak road condition	-.627	.3574	.079	.534
Intermediate road condition	-.670	.2010	.001	.512
Good road condition	0[a]	.	.	1
Week shoulders	-3.443	2.0827	.098	.032
Intermediate shoulders	.027	.2389	.911	1.027
Medium sealed shoulders	0[a]	.	.	1
0 – 10 number of Intersections	3.324	.9792	.001	27.759
11 – 20 number of Intersections	3.162	.9542	.001	23.628
21 – 30 number of Intersections	3.161	.9824	.001	23.605
31 – 40 number of Intersections	0[a]	.	.	1
0 – 5 number of Pedestrian crossing	.205	.8385	.807	1.228
6 – 10 number of Pedestrian crossing	.299	.8161	.714	1.348
11–15 number of Pedestrian crossing	0[a]	.	.	1
Undivided	-1.051	.4583	.022	.349
Divided	0[a]	.	.	1
0 – 5 number of bus bays	1.428	1.3644	.295	4.168
6 – 10 number of bus bays	2.194	1.3397	.101	8.974
11 – 15 number of bus bays	.909	1.4333	.526	2.482
16 – 20 number of bus bays	0[a]	.	.	1
Road section length (km)	.729	.1860	.000	2.074
Width of the lane (m)	1.652	.1665	.000	5.216
Shoulder width (inches)	-.887	.5238	.090	.412
Road side objects length (km)	-.062	.3288	.851	.940

The overall coefficients reveal that, with the increase in the number of coefficients, the 'number of accidents in a section' is reduced. Thus, the fascinating results of reduced impact on the 'number of accidents' with the increasing 'number of intersections' has a major influence from the rural road conditions of the selected sample. The results further reveal that there is no significance from 'the number of pedestrian crossings' towards the 'number of accidents' as it has higher p value of above 0.05. However, 11 - 15 number of pedestrian crossings comprise of a coefficient of zero, signifying that if the 'number of pedestrian crossings' is between 10 – 15, there is no potential effect towards the number of accidents. 'Undivided road' is statistically significant variable decreasing the 'number of accidents' compared to that of 'divided road'. The 'number of bus bays' has no potential impact towards the 'accident number' as it is statistically insignificance in the obtained model. The 'road section length' variable is significant with the significance less than 0.05, whilst the coefficient is 0.729 which shows that when the 'road section length' is increased by 0.729 units, then the 'accident number' is increased by $e^{0.729}$ units. Moreover, the width of the lane variable is significant as the significance obtained as 0.000. The coefficient for the width of the road section is 1.652 and it explicates that when the width of the road section is increased by 1.652 units, the 'accident number' that road section is increased by $e^{1.652}$ units. However, the 'shoulder width' and the 'roadside objects length' is insignificant as p value is more than 0.05.

The road accidents are influenced by multiple factors such as road, traffic, driver, environment and several others. The comprehensive study conducted by Ashraf et al. (2019) proposed that a variety of road factors such as allowable speed, road structure, junctions and sections lengths are extremely influential towards the accident number. As Eboli et al. (2020) alluded, the influential road characteristics such as location, street type, paving condition, intersection type, surface conditions have significance on the road accidents and can be statistically developed through a binary logistic analysis. Therefore, the present study was mainly oriented around the potential road characteristic that are influential towards the increase of the accident numbers in the form of a Poisson and negative binomial regression analysis. The considered variables of the current study assessed fourteen variables in total to identify the influence on the number of accidents in road sections. As per the results, only the variables such as number of lanes, road condition, number of intersections, divide status, road section length and width of lane shows statistical significance towards the number of accidents.

The road section length is a substantial variable which also critically analyzed by Ashraf et al. (2019). Thus, the authors stated that number of accidents is dependent on the road length. The findings of the present study further affirm these results as the considered road section length is positively related to the accident number. Thus, the shorter road lengths results in less accidents. The road surface condition is a critical factor governing towards the accident number. Haque et al. (2009) highlighted the importance of a good condition of the road to reduce number of accidents while Shaheed and Gkritza (2014) found that dry and good road surfaces reduce the accident severity. The present study results also revealed that road condition is significant towards the number of accidents where intermediate road conditions have less impact and good road conditions further reduce the number of accidents. Therefore, the findings of the present study further entangle with Shaheed et al. (2013) as they found that the roadway surface has a greater influence on the accident number.

The geometrical parameters such as delineation and shoulder were obtained as statistically insignificant in the present study. These parameters have mixed results in the previous findings where Manan et al. (2018) affirmed that the road shoulder type is statistically insignificant towards the crash frequency, yet certain road geometrical parameters show significance. Moreover, the results for divide status in the current study explicate that there is a negative correlation between undivided roads and the accident number while no potential impact from divided roads. According to the results of alluded Manan et al. (2018) the road dividing with the markings has a higher statistical significance where unmarked and undivided roads have a substantially high impact on the crash amount.

The selected road sections of the present study are of rural areas where the number of lanes is ranging from 1 to 4. Therefore, the road types of the present study have a broader range from single lane to two way two lanes. However, the number of lanes was significant where the single and dual lanes were obtained in the final model. According to the results, the positive coefficient of single lane proves that single lane road sections impact positively towards the number of accidents while the negative coefficient of the dual lanes impact negatively towards the number of accidents. On the contrary, Ashraf et al. (2019) proved in a study conducted in Korea that road types have the minimal effect towards the accident rates. Moreover, Eboli et al. (2020) also found that roadways with multiple lanes have high accident severity and crash probability.

The significance of the number of intersections was statistically proven by Eboli et al. (2020) and Haque (2009). The results of the present study further back these findings with having all the considered categories for number of intersections significant towards the number of accidents. The obtained results of the present study show that the roadside objects length is insignificant. Yet Shankar (1996) found that fixed object interaction has an extensive influence towards single vehicle motorcycle crashes while Maistros (2014) stated that the rigid roadside objects contributes heavily towards single vehicle motorcycles and car crashes and further increases the severity.

The road width study conducted by Chen et al. (2020) analyzed the lane width and the footpath width based on the crash analysis. Thus, the results proposed that increased lane width reduces the risk of crash and the severity. However, the increment in the footpath width has disparate effects on the pedestrian safety. Contrastingly, the results of the present study showed no statistical significance for the shoulder width, which signifies that there is no potential impact towards the number of accidents from the shoulder width. However, the lane width is statistically significant with a positive coefficient. Therefore, it reveals that increase in the lane width further enhances the number of accidents. Furthermore, the rural road condition is a core factor on this result where with higher lane widths the vehicle speed increases further increasing the crash risk (Davoudi-Kiakalayeh & Yousefzade-Chabok, 2014).

The increase in the number of pedestrian crossing enhances the risk of pedestrian crash due to the higher exposure of the pedestrians (Gobalarajah, 2016). However, the current study results exposed that the number of pedestrian crossings shows no statistical significance towards the number of accidents. Moreover, Porcu et al. (2020) found that the number of bus bays increase the accident risks due to the increased frequency and the severity of the bus accidents. Therefore, the increase in the bus bays has a significant influence in enhancing the number of accidents. On the contrary, the results of the present study revealed that number of bus bays shows no potential significance towards the number of accidents in the developed negative binomial regression.

Therefore, it is illuminated that, variables such as number of lanes, road condition, number of intersections, divide status, road section length and width of lane are only statistically significant in the negative binomial regression model where other variables are unacceptable due to the insignificance. Furthermore, the significant variables depend on the accident number of the road section where the road star rating can be developed. Therefore, lower accident numbers denoting a higher road star rating, whilst higher accident numbers denoting lower road star rating. These results can be used by the road agencies when developing and testing the road star rating system.

5 CONCLUSIONS

This study is important in identifying the variables for a road safety rating in Sri Lanka. thus, the study explored the relationship between the road accidents other influential road geometric aspects with specified to rural road sections of Kurunegala, Polonnaruwa and Anuradhapura districts of Sri Lanka. The road sections in these districts were selected as a pilot study and there may be minor differences on driver behavior, traffic composition, and road geometry in the other areas in Sri Lanka. This study shows that the number of lanes, road conditions, number of intersections, road divide status, road section length and width of lane are parameters which affect the number of accidents in a particular road section. These findings can be used to evaluate road safety in Sri Lanka and developing a star rating system for Sri Lankan roads. Therefore, the research objectives were achieved with the identification of the governing parameters for the implementation of the rad star rating system. Moreover, the developed negative binomial equation represents the relationship between the governing road parameters and the number of accidents in the road sections.

However, the data collections were limited to rural road sections where more applications of the developed methodology is required in urban road sections. Thus, a generic road safety rating can be developed through the comprehensive analysis of different road conditions with different road and traffic characteristics. It is recommended to conduct a similar study in other areas in Sri Lanka including the urban road sections and thereby to develop a general road star rating for the Sri Lankan roads.

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A Study on Curbside Overtaking in Sri Lankan Streets

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ABSTRACT

Overtaking slower moving vehicles on the curbside under mix traffic condition is very common in Sri Lanka. The overtaking should never be done from the curbside as a rule of thumb, also rules and regulations regarding the overtaking should be never broken by drivers. Traffic accidents statistics reveal that main cause for serious accidents in Sri Lanka are excessive speed and incorrect overtaking. However, to the best of authors' knowledge any research about curbside overtaking behavior has not been done so far. Objectives of this study are to investigate self-reported drivers' overtaking behavior, and to find out drivers' perspective about current rules and regulations on overtaking. A questionnaire form was developed, and a survey was conducted to collect data among 430 people in Colombo district. Chi–square tests and multinomial logistic regression analysis were done. Chi – square test results showed that among the selected variables, gender, age, occupation, driving license availability, charged a fine or accident due to curbside overtaking are the main factors that affect the curbside overtaking. The results of this study are facilitative to understand characteristics and some reasons behind curbside overtaking. Some methods such as educate public about dangerous overtaking and rules by organizing awareness programs, increasing fine for curbside overtaking, and imposing new laws are suggested to minimize the number of road accidents caused by overtaking slow moving vehicles on the curbside of the road.

KEYWORDS: *overtaking, drivers' misbehavior, traffic accidents, road safety, questionnaire survey.*

1 INTRODUCTION

Road accidents are defined as an unplanned injury, death, or property damage that occurs as a result of a series of circumstances. Accidents are becoming one of the most common causes of death (WHO, 2021). Road Traffic Accidents (RTA) are killing people at an alarming pace all over the world. Road traffic accidents take the most lives from all traffic accidents and it has become the most significant problem in the world. The number of persons killed in RTA each year is believed to be at 1.2 million, with an additional 50 million persons wounded. (Pathak et al., 2018).

Sri Lanka has a rate of annual road collision fatalities per capita (17.4) that is twice that of high-income nations and five times that of the world's top performing countries (Bandyopadhyay, 2020; Amarasingha, 2021). The stated death rate 17.4 is the highest in the South Asian area among Sri Lankas' nearest neighbors. According to the National Council for Road Safety (NCRS), over 38,000 incidents occur each year, resulting in over 3,000 fatalities and 8,000 serious injuries; the majority of these collisions occur between April and December, during the holiday season. Traffic accidents statistics Sri Lanka reveal that the most of accidents happening are due to overtaking and excessive speed, which leads to fatal injuries and severe damages to vehicle, properties as well as the passengers. Overtaking is one of the most difficult and significant maneuvers on undivided roads, where vehicles use the opposing lane to pass slower vehicles as oncoming vehicles approach from the opposite direction. Drivers must maintain road disciplines otherwise they risk endangering not only their self, passengers in vehicle, also other road users. Therefore, main aim of our study is to investigate the overtaking behavior of slow-moving vehicles from curbside. There are many studies focused on traffic accidents and overtaking but any study about overtaking from curbside could not be found in the literature.

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2 LITERATURE SURVEY

Iversen and Rundmo (2004) identified reasons of risk behaviors and involvement of accidents in traffic. The attitude of the drivers' risky behavior, reasons to break the rules and causes for the severe damages were investigated. This study was based on a questionnaire survey carried out among Norwegian drivers. The findings revealed that attitudes toward traffic safety issues, especially attitudes toward speeding, influenced participation in risky traffic behavior. Risky behavior had an effect on the number of near- misses and injuries, age and gender were found to influence attitudes and risk behavior. Wang et al. (2020) have conducted research about e – bike riders in China. A questionnaire survey was conducted to find out risky riding behaviors of electric bike riders in Nanning and Guiling cities. Tracking Survey and Random survey methods were used and collected total 573 valid samples. Results of this study showed the relationships between risky riding behavior, riding confidence with safety attitudes and risk perception.

Rezagholipour et al. (2016) conducted a research study on decreasing overtaking series accidents on two - lane curved roads in Iran. As the method of data collection two distinct driver behavior patterns were examined. Vehicle behavior in zigzag overtaking was the first model. The results show accurate accident modeling in provisioning and a reduction in accident rates also some ideas were provided to reduce overtaking accidents on two-lane curved roads. Richter et al (2017) revealed about reasons, results, and countermeasures of overtaking accidents on two-lane rural roads in Germany. The goal of this study was to identify the infrastructure and traffic- related factors that influence the occurrence and consequences of overtaking incidents, as well as drivers' overtaking behavior. As a result, they discovered that severe overtaking accidents can be avoided in Germany by incorporating road design groups and related overtaking rules into the supervision for the design of rural roads.

Asaithambi and Shravani (2017) has done a research study about lane Overtaking behavior of vehicles on undivided roads in non-lane based mixed traffic conditions in India. Overtaking data was obtained using a car and the registration plate method on a 1.2 km two-lane two-way an undivided road located in Mangalore city of India. According to the findings of the study, the average overtaking time for flying overtaking was 7.4 seconds and 9.2 seconds for accelerative overtaking. The mean overtaking time for heavy goods vehicles was bigger (10.3seconds) than for other vehicle classes. The mean overtaking time (7.5 seconds) was shorter for cars and two-wheelers, which may be attributed to their greater maneuverability. Heavy vehicles had a longer mean overtaking distance (145.0 meter), while two wheelers had a shorter distance (101.6 meter).

Mocsári (2009) conducted a study in Hungary about possible solutions to make overtaking maneuvers safer by using intelligent systems in the vehicle. Data was collected using video recordings and the instruments were installed in the car. As the conclusion they have mentioned that vehicle drivers should be made aware that speeding in the course of overtaking was also considered speeding, the primary features of accelerated, continuous, and numerous overtaking should be explained to drivers during their training. In another study by Kashani et al (2016) in Iran, identified significant variables influencing overtaking maneuvers on two-lane, two-way rural roads. The data was gathered, and the study was conducted using a field data gathering approach. On the remote roads of Zanjan and East Azerbaijan regions, an expert of transportation engineer was accompanied and recorded correspondent information of drivers performing overtaking maneuver. Pearson's chi-square test was used to select variables, which were then entered into a multivariate logistic regression mode. The model's findings revealed that for drivers aged 40 to 49, the likelihood of conducting a "lane sharing" move was around four times larger than that of doing a "cutting in" overtaking movement. The likelihood of executing a "cutting in" overtaking maneuver was lower among drivers who knew where police locate.

Llorca et al (2013) studied about the effect of age and gender on overtaking maneuver on two-lane, two-way roads in Spain. A passenger car was used settled with four cameras, laser rangefinders and a GPS tracker to collect data. This vehicle was driven at a significantly slower speed than the normal operating speed of different 4 road segments in Valencia (Spain) and observed 214 overtaking maneuvers. Multi factor ANOVA and multiple linear regression model were used for the analysis. Data analysis showed that there was a difference in behavior across age and gender categories, with young male overtaking drivers being more aggressive. Overtaking timings were roughly 1 second faster than other drivers, also showed 4 km/hr. higher difference in average speed.

Mehta et al. (2015) considered about evaluation of the passing behavior of motorized vehicles when overtaking bicycles on urban arterial roadways in India. A sensor array consisting of an ultrasonic sensor, a GPS receiver, and a video camera were mounted to a bicycle to collect data. On various sorts of urban arterials, a total of 5,227 passing incidents were observed in one month. It was revealed that when there is no bike lane, the proportion of passing autos moved laterally to the left and encroached into the next lane is higher. Drivers on arterial routes without on-street bike lanes tended to provide greater lateral clearance by changing lanes or infringing on the next lane.

According to the literature review, several studies on the overtaking maneuver have been conducted all over the world. Some experiments were preceded by questionnaire surveys, while others were carried out using on-the-spot video recordings. In most of the investigations, the data were analyzed using the chi square test and the multi nominal logistic regression test. There were several studies on right-side overtaking, but no studies were found on curbside overtaking.

3 METHODOLOGY

3.1 Study Area

Research study was conducted in the Colombo district of Sri Lanka as it is most populated district in Sri Lanka. According to the department of Census and Statistics, the current metro area population of Colombo in 2021 is 619,000**,** a 0.98% increase from 2020 (Department of census and statistics, 2021). Sri Lanka's motor vehicle population was increased by 7 to 7.2million in 2017 and most of the vehicles are registered in Colombo district as mentioned in the country's motor vehicle market published by the Ceylon Chamber of Commerce.

3.2 Development of Questionnaire and Data Collection

To achieve the study's goals, data were collected using a questionnaire survey to learn about drivers' ideas about overtaking behavior, current overtaking rules use in Sri Lanka and how it has affected in road accidents. By conducting the pilot study and examining prior research, the dangerous features and habitual behavior were discovered. A total of 430 survey forms was printed and distributed. This questionnaire consists of three parts; in the first part of the questionnaire include questions related to users' socio-economic characteristics like age, gender, profession, living district and etc. In the second part, respondents were asked some questions about driving and experience they had about overtaking and related rules like driving license class, vehicle type they use, accidents happened due to overtaking, awareness about current rules and regulations about overtaking. In the final part they had to give some ideas about how we can improve this drivers' misbehavior in the road.

Targeted respondents for the questionnaire survey are in the range of age from 18 to 60 which can be filled by anyone even who does not have license. "Have you overtaken from left side" is the dependent variable and there are several independent variables which was made to do the analysis easily. The sample size calculation was done according to the Equation 1 (Barlett et al,2001).

$$N = \frac{z^2 P(1-p)}{d^2} \qquad (1)$$

Where, N = sample size, z^2 = Value corresponding to confidence level, d = Margin of error, P = expected population proportion. The minimum sample was obtained by assuming a 95% confidence level (Z = 1.96) and a 5% margin of error (d =0.05). To obtain the minimum sample size expected population proportion of 50% was assumed. This resulted in a minimum sample size of 385.

3.3 Cronbach's Alpha Reliability Test

A 5-unit Likert scale from 1 to 5 was utilized to obtain this information from the respondents, where 1 = never, 2 = rarely, 3 = occasionally, 4 = sometimes, and 5 = always. This eliminates problematic survey questions such as open-ended and fill-in-the-blank questions. Cronbach's Alpha reliability test was used to determine the internal consistency between items on a scale in order to investigate the correlation between each item on the Likert scale. A number between 0 and 1 is used to represent this. The acceptable range for alpha is 0.70 to 0.95, with values less than 0.70 being regarded suspect (Garth, 2008).

3.4 Data Analysis

Aim of this study is to understand the reasons behind drivers' misbehavior on the road and to figure out ways to avoid or reduce curbside overtaking. The most common tool for studying a similar aim is a questionnaire. Mainly there is two categories, dependent and independent variables. Dependent variable is, "have you overtaken from left side". Categories of the vehicle type, age of the drivers, whether they have license or not, driving license classes they have, in which district they mostly drive or travel within and the occupation will be independent variables of the study. Data was entered and analyzed using SPSS statistical software.

3.4.1 Chi- square Statistics

When employing a crosstabulation, also known as a bivariate table, the Chi-Square statistic is the most typically employed to analyze tests of independence. Crosstabulation shows how is the distributions of two categorical variables at the same time, with the intersections of the variables' categories showing in the table's cells. One variable's classification appears in rows when the other variable's classification appears in columns. Each variable must have two or more categories and each cell reflect the total count of cases for a specific pair of categories. The researcher can examine if the observed cell counts are significantly different from the predicted cell counts by computing the Chi-Square statistic and comparing it to a critical value from the Chi-Square distribution. A chi-square test with a p-value less than or equal to the significance threshold indicates that there is sufficient evidence to substantiate that the observed distribution differs from the predicted distribution. A p-value greater than 0.05 indicates that the null hypothesis is strongly supported. It demonstrates that the null hypothesis should be retained, and the alternative hypothesis rejected. Equation 2 was used to determine the Chi-square statistics (Cheng Hua, 2021);

$$X^2 = \Sigma \frac{(Oi - Ei)2}{Ei} \quad (2)$$

where Oi is the observed number of counts and Ei is the expected number of counts.

3.4.2 Multinomial Logistic Regression

Multinomial Logistic Regression analysis is a predictive analysis and is used for explaining the relationship between a nominal or ordinal dependent variable and one or more independent variables. When the dependent variable is qualitative and if it has more than two possible answers or categories, then multinomial logistic regression could be used to estimate the probability of occurrences for each of the alternatives. A likelihood ratio test, chi-square test and a comparison of the complete model to a null model are included in the model fitting information of multinomial logistic regression. The full model will have all of the predictors, whereas the null model will not. The 5% significance level (p- value) is used to determine if an overall model is fit or not. The null hypothesis (intercept only model) is rejected if the significance value is less than 0.05. This indicates that the final model is more important than the null model, and that the final model considered as fit. Equations 3 and 4 are used to determine the results (Long, 1997).

$$\log(\text{odds})=\text{logit}(P)=\ln(P1-P) = a+b1x1+b2x2+b3x3+\dots \quad (3)$$

$$p = \left(\frac{\exp(a+b1X1+b2X2+b3X3+\cdots)}{1+\exp(a+b1X1+b2X2+b3X3+\cdots)}\right) \quad (4)$$

where: xi: the influencing independent variables for dependent variable "have you overtaken from the curbside", and bi: regression coefficients.

4 RESULT AND DISSCUSSION

A total of 430 survey forms were printed and distributed. Out of them, 291 (67%) were answered by male respondents and 139 (33%) were answered by female respondents. Despite the fact that there is some gender equality in the population of Sri Lanka, the number of females who hesitate to drive on the road is lower than expected. The majority of the people who answered the questionnaire was of the age group 19 to 28 which consisted of 42.32% of the total sample size. About 7% respondents were age below 18 years and the rest of 68% were age above 29 years. Also, most of the respondents are working in private sector, that is 37% and second highest value for the occupation was driving that is 22.5%. When distributing the questionnaires, special attention was paid to respondents who stated that driving is their primary source of income, as this allows for the collection of more precise information. Participants 302 (70%) had full license, 96 (23%) had just the learner's permit while 31 (7%) participants had not taken driving license, Nonetheless, from their experience, we were able to gather some information about curbside overtaking. From the total respondents 31% have met accident and 20% have stopped or charged a fine due to curbside overtaking respectively. Also, majority thinks that light motorcycles and three wheelers are the mostly overtaking vehicle types on the road.

4.1 Cronbach's alpha Reliability Test Results

All of the Likert scaled items were framed in negative order to apply Cronbach's Alpha reliability test to a set of items. The average correlation among the 10 items questioned is shown in the Table 1. Because the number is greater than 0.70, Cronbach's alpha value 0.899 indicates that the average correlation among the ten items in the questionnaire indicates satisfactory reliability

Table 1 - Reliability Statistics test results

Cronbach's Alpha	Cronbach's Alpha based on Standardized items	Number of items
0.899	0.861	10

4.2 Chi Square Test Results

Pearson's chi-square test was used to examine the impact of each independent variable on curb side overtaking maneuvers on roadways in this study. The findings revealed that the dependent variable "Have you overtaken from the curbside?" had a significance relationship with the majority of the variables. A significance level (α or alpha) of 0.05 was used to check association with the dependant variable. The variables gender, age, occupation, driving license status, vehicle type, accident involvement, awareness of rules, sufficiency of rules, charged a fine, and mostly overtaking vehicle type had a significant association between overtaken from the curbside.

Crosstabulation tables are used to evaluate which variable levels have the most influence on association, compare observed and predicted counts, or investigate the contribution to the chi-square statistic. Variables with the greatest differences can be identified by observing the discrepancies between observed and predicted cell counts. The observed count is the frequency that was observed in a certain cell of the crosstabs table. The expected count is the frequency that a cell is expected to have if the null hypothesis is correct. In below table it has shown the expected and observed values of our independent variable. The expected and observed values of our independent variable are displayed in Table 2.

According to Table 2 more females and less males have overtaken from curbside than expected. Age groups below 18 and 19-28 have overtaken from curbside than expected and at the same time age groups 29-38,39-48,49-58, and more than 50 observed values were less than expected. Respondents who work in the private sector and undergraduate students received greater values than predicted, while everyone else received lower values. Respondents with a learner's permit overtake from the curbside more than predicted, while those with a driver's license have a lower value than expected. Perhaps their lack of experience and carelessness led them to make this dangerous road move. Motorcycles and light vehicles overtook from the curbside more frequently than expected, but three-wheelers and heavier vehicles received lower values in the observation. Respondents who met accidents due to curbside overtaking are less than expected and respondents who charged a fine due to curbside overtaking are more than expected.

Table 2: Expected and Observed counts of the variables

Dependent variable: Overtaking slow moving vehicle from curbside			Never	Rarely	Occasionally	Sometimes	Always
1. Gender	Male	Observed	11	77	66	81	56
		Expected	16.2	67.7	55.5	79.9	71.7
	Female	Observed	13	23	16	37	50
		Expected	7.8	32.3	26.5	38.1	34.3
2. Age	<18	Observed	2	1	0	9	18
		Expected	1.7	7	5.7	8.2	7.4
	19-28	Observed	14	24	23	50	71
		Expected	10.2	42.3	34.7	49.9	44.9
	29-38	Observed	4	15	14	10	0
		Expected	2.4	10	8.2	11.8	10.6
	39-48	Observed	0	37	31	32	10
		Expected	6.1	25.6	21	30.2	27.1
	49-58	Observed	3	21	11	14	7
		Expected	3.1	13	10.7	15.4	13.8
	>59	Observed	1	2	3	3	0
		Expected	0.5	2.1	1.7	2.5	2.2
3. Occupation	Government employee	Observed	8	7	8	11	10
		Expected	2.5	10.2	8.4	12.1	10.8
	Private sector employee	Observed	8	19	21	49	62
		Expected	8.9	37	30.3	43.6	39.2
	own Business	Observed	0	15	13	9	0
		Expected	2.1	8.6	7.1	10.2	9.1
	Undergraduate	Observed	3	7	4	7	16
		Expected	2.1	8.6	7.1	10.2	9.1
	Driving	Observed	2	42	27	26	0
		Expected	5.4	22.6	18.5	26.6	23.9
	Other	Observed	3	10	9	16	18
		Expected	3.1	13	10.7	15.4	13.8
4. License Availability	Full license	Observed	15	93	75	75	44
		Expected	16.9	70.4	57.7	82.4	74.6
	Learners Permit	Observed	7	3	4	33	49
		Expected	5.4	22.4	18.3	26.2	23.7
	No license	Observed	2	4	3	9	13
		Expected	1.7	7.2	5.9	8.5	7.7
5. Mostly Drive/ Travel in Vehicle	Motorcycle	Observed	10	10	11	19	35
		Expected	4.7	19.8	16.2	23.3	21
	Light Vehicles	Observed	13	25	17	46	58
		Expected	8.9	37	30.3	43.6	39.2
	Heavy vehicles	Observed	0	18	19	16	1
		Expected	3	12.6	10.3	14.8	13.3
	Three wheelers	Observed	1	47	35	35	12
		Expected	7.3	30.2	24.8	35.7	32
	Others	Observed	0	0	0	2	0
		Expected	0.1	0.5	0.4	0.5	0.5
6. Accidents due to Overtaking	Yes	Observed	2	45	44	42	8
		Expected	7.9	32.8	26.9	38.7	34.8
	No	Observed	22	55	38	76	98
		Expected	16.1	67.2	55.1	79.3	71.2
7. Awareness of rules about Overtaking	Yes	Observed	23	81	65	102	86
		Expected	19.9	83	68.1	98	88
	No	Observed	0	13	5	11	11
		Expected	2.2	9.3	7.6	11	9.9
	unable to accessed	Observed	1	6	12	5	9
		Expected	1.8	7.7	6.3	9.1	8.1

Table 2: Expected and Observed counts of the variables continue..

Dependent variable: Overtaking slow moving vehicle from curbside			Never	Rarely	Occasionally	Sometimes	Always
8. Enough rules have been taken	Yes	Observed	20	57	45	77	94
		Expected	16.4	68.1	55.9	80.4	72.2
	No	Observed	4	38	21	33	10
		Expected	5.9	24.7	20.2	29.1	26.1
	unable to accessed	Observed	0	5	16	8	2
		Expected	1.7	7.2	5.9	8.5	7.6
9. Stopped or Charged by police	Yes	Observed	20	56	66	97	98
		Expected	18.8	78.4	64.3	92.5	83.1
	No	Observed	4	44	16	21	8
		Expected	5.2	21.6	17.7	25.5	22.9
10. Mostly Overtaking Vehicle Type	Light motorcycles	Observed	17	33	10	78	98
		Expected	13.2	54.9	45	64.8	58.2
	motorcycles	Observed	3	20	13	0	0
		Expected	2	8.4	6.9	9.9	8.9
	Motor tricycles	Observed	0	21	29	10	3
		Expected	3.5	14.7	12	17.3	15.5
	Light vehicles	Observed	2	2	11	21	3
		Expected	2.2	9.1	7.4	10.7	9.6
	Motor lorries	Observed	1	11	10	5	0
		Expected	1.5	6.3	5.1	7.4	6.7
	Multi axial	Observed	0	6	6	3	0
		Expected	0.8	3.5	2.9	4.1	3.7
	Others	Observed	1	7	3	1	2
		Expected	0.8	3.3	2.7	3.8	3.5

4.3 Multinomial Logistic Regression Test Results

A multivariate extension of a chi-square study of three or more dependent categorical outcomes is multinomial logistic regression. A reference category is chosen from the levels of the multilevel categorical outcome variable in multinomial logistic regression, and subsequent logistic regression models are run for each level of the outcome and compared to the reference category. In this study "Always" was taken as the reference category. Likert scale questions were analyzed using this method. The parameter estimates show how each choice on the Likert scale compares to the reference category option (always) of the dependent variable "Have you overtaken from the curbside?" As indicated in Table 3, there are 34 parameter estimates values, with 18 of them having significant values less than 0.05.

The first set of results from Table represents comparison between those who chose the option "Never" and those who opted "Always". From those set of results, ten parameters are statistically significant, having a significant value less than 0.05. One of above from category "Never" is use horn while overtaking (P = 0.027). β value of that variable is 0.585 and it is positive. This positive number indicates that participants who responded positively to the Likert scale item "Use horn during curbside overtaking" were more likely to choose Never rather than Always for the variable "Use horn while curbside overtaking". If I explain it in a more simplify manner, drivers who overtake slow drivers from the curbside are never use horn while overtaking. Also, they never check police locations before overtaking, never check the space between front vehicle before overtaking according to the results of this table. When β value of the variable is negative it means that respondents are more likely to choose always over never in following variables. Carelessness and less experience are always common reasons for curbside overtaking according to the respondents and drivers check the road type whether it is rural or urban before curbside overtaking, care about the weather condition and always indicate signals when changing lanes. From the category "Sometimes", Checking the road type before curbside overtaking has a significance value of 0.002 and it has a β value of -0.696 but negative. Negative β value indicates that participants who responded negatively to the Likert scale item " Checking the road type before curbside overtaking " were less likely to choose sometimes rather than Always for the variable " Checking the road type before curbside overtaking”. According to the parameter estimation table drivers sometimes use horn while overtaking and check the space between front vehicle before overtaking.

Table 3: Parameter estimates of Multinominal Logistics Regression

Variable		β	Sig.
Never	Reasons for wrong side overtaking according to you- CARELESS	-0.654	0.008
	Reasons for wrong side overtaking according to you - LESS EXPERIENCE	-0.832	0.000
	Use horn while overtaking?	0.585	0.027
	Check the road type before overtaking? (Urban/ Rural)	-0.621	0.007
	Check whether police locations before overtaking?	0.696	0.014
	Care about the weather condition before overtaking? (Heavy rain/ Mist)	-0.865	0.011
	Check the space between front vehicle before overtaking	0.541	0.018
	Overtake slow drivers from the left side?	-1.232	0.000
	Indicate signals when you are changing lanes	-0.641	0.017
	Care about the weather condition before overtaking? (Heavy rain/ Mist)	-1.362	0.000
Sometimes	Reasons for wrong side overtaking according to you - LESS EXPERIENCE	-0.482	0.019
	Use horn while overtaking?	0.595	0.020
	Check the road type before overtaking? (Urban/ Rural)	-0.696	0.002
	Wait till visible the road ahead vehicle?	-0.863	0.001
	Check the space between front vehicle before overtaking	0.489	0.015
	Overtake slow drivers from the left side?	-0.901	0.000
	Use horn while overtaking?	-0.437	0.075
	Care about the weather condition before overtaking? (Heavy rain/ Mist)	-1.088	0.001
Dependent variable: Overtake slow drivers from the curb side? Note: Only significant variables are tabulated.			

5 CONLUSIONS

Overtaking slower moving vehicles from curbside in Sri Lanka investigated in this study. Questionnaire forms with Likert scale questions were collected. From this study drivers’ curbside overtaking behavior was investigated also drivers’ perception about current rules and regulations regarding curbside overtaking was investigated. The developed questionnaire was validated using Cronbach’s alpha method that the value was 0.899 which is in acceptable level. This value is a good indication about the average correlation among the Likert scaled questions from the questionnaire. Chi-square test and multinomial logistic regression were used to analyze the data. From chi-square test some significance variables were found out such as gender, age, occupation, driving license availability, vehicle type, accidents happened before and charged a fine before due to curbside overtaking. Likelihood ratio test values from the multinomial logistic regression show that use horn while overtaking, check the road type while overtaking, check police locations before overtaking, wait till visible the road ahead vehicle, check weather condition, check space between front vehicle, indicate signals when changing lanes are the significant variables for the dependent value “have you overtaken from curbside”.

The findings of this study are consistent with prior research conducted in other countries. In many studies, wrong side overtaking has been identified as a risky riding behavior which cause traffic accidents. In this study it is revealed that young male drivers are more likely to do wrong side overtaking and same results have been found in a study done by Lorca et al. (2013) in Spain. Motorcycles are identified as mostly overtaking vehicle type in our study as well as a study done by Mehta et al (2015) in India. Research done by Kashani et al (2016) in Iran found that overtaking maneuver was lower among drivers who knew where police locations are and same results can be seen in our study too. However, curbside overtaking of slow vehicles was not clearly recognized to the authors' knowledge. The majority of overtaking study was carried out in nations with similar traffic conditions and driving behavior as Sri Lanka. Since there were no research about wrong side overtaking conducted in Sri Lanka this study helps to fill the research gap to some extent.

To overcome this curbside overtaking habit, several solutions can be suggested. According to several research, policymakers should implement driver-education and public-awareness campaigns. The suggested goals of these initiatives are to educate the public about the dangers of overtaking maneuvers and to reduce the number of dangerous drivers who engage in these activities on a regular basis, potentially leading to traffic accidents. According to several research, increasing the fine for curbside overtaking as well as imposing new laws for curbside overtaking will cause drivers to abandon the harmful practice. Finally, if these countermeasures will be successful in reducing curbside overtaking on the road. Also, it is suggested to investigate curbside overtaking behavior in rural areas of Sri Lanka.

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CRITERIA FOR SELECTION OF SUITABLE SITES FOR RAINWATER HARVESTING IN THE MIDDLE EAST FOR AGRICULTURE USE: A REVIEW STUDY

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ABSTRACT

In arid and semi-arid regions, rainwater harvesting represents an important alternate source of water supply around the globe. The middle east is an integrally dry zone and due to climate change, it has experienced a severe drought for the last decade that made the situation worse. Many countries are suffering from awful water crises due to increasing water demand for agriculture and rapid urbanization. Therefore, unconventional water supply resources practices such as using rainwater harvesting for agricultural purposes can be possibly used to tackle water scarcity. Numerous researchers have established different criteria and methods to identify suitable sites selection techniques for rainwater harvesting (RWH). The main objective of this study was to determine the most commonly effective methods and techniques that have been practiced in the middle-east region to summarize the best methods for rainwater harvesting site selection. These effective common methods of multi-criteria analysis (MCA) were discussed accordingly in this review paper and based on the previous studies the best applicable method was the integration between (MCA) method and the GIS technique. The study employed a method of gathering and recording the main criteria and techniques which were established in the last thirty years. It compared and categorized the main methodologies from previous studies and practices from international organizations and scientific research and identified the most common characteristics and sets of criteria suitable for use in arid and semi-arid regions. The techniques were diverse based on biophysical criteria to methods including socio-economic criteria, precisely in the last two decades. The most effective and significant criteria for suitable site selection of RWH in the arid and semi-arid regions found are: land use/land cover, slope, type of soil, rainfall intensity, streams distant and the cost. The success of RWH selection sites tended to increase when these criteria are measured and based on these criteria.

KEYWORDS: *RWH Selection Suitability, Arid and semi-arid zones, Middle East, Agriculture, GIS, Multi-criteria analysis.*

1 INTRODUCTION

The growing demand for water for urbanization, industrial, and agriculture use is increasing the pressure on water resources globally, especially under the current climate change conditions (Qi et al, 2019). Freshwater resources are currently under the risk and pressure of water scarcity in many parts of the world, specifically in aridity regions, including the Middle East region that is facing water shortages issues regarding both domestic and agricultural purposes (Alwan et al., 2020 & Sayal et al, 2017). The estimations mentioned that around two billion people will live under water stress by the year 2050, which will be a limiting factor for the continuity of development in many countries, especially the agriculture sector that depends on rain-fed and specifically in the developing countries according to the United Nations Environmental Program (Field at al, 2014).

Globally, the arid and semi-arid regions, are frequently facing water scarcity problems for domestic and agricultural use as the two regions represent about 35% of the land, about 50 million km² and a huge part of this land lies within the middle east zones (Zaidat et al, 2012). Water scarcity can be either a physical or economic issue. The economic water scarcity issue is a result of a poor investment or lack of ability to address the water demands, whereas the physical water sacristy problem is constrained the water availability in a country or a region. The rain-fed agriculture method is the major farming system in these regions and in the middle east as a whole, but climate change and aridity are the two main challenges confronted by farmers who depend on rain (Al- Muqdadi et al, 2016). To increase water availability for harvest irrigation demands and livestock production, the inhabitants of dry regions have developed several techniques for rainwater harvesting systems. Rainwater harvesting (RWH) is defined as the collection of rainwater through the management of the rainfall-runoff process to increase water accessibility for both domestic and agriculture use. It is considered one of the oldest techniques developed by man in history to tackle water shortage and climate change impacts (Mekdaschi & Liniger 2013; Sharafati et al, 2020a, b).

The most common types of RWH techniques in arid and semi-arid regions and the Middle East are dams, ponds and pans, terracing, separation tanks, and Nala (Oweis, Prinz & Hachum, 2012). The earliest indication shows the global use and techniques of rainwater harvesting (RWH), for instance in several countries and specifically in the middle-east region such as Syria, Jordan, Palestine, Sudan, Iraq, and Tunisia (Al-Adamat, 2008). There are many classifications for rainwater harvesting systems around the world, such as the collection and management of runoff water, or the collection and storage of the runoff water. However, Gupta and Sharma (1997), defined RWH as the method of collecting, conserving, and storing the surface run-off water for agricultural purposes, especially in the arid and semi-arid zones. The important purpose of rainwater harvesting is to increase water availability by seizing the rainwater in one place for domestic or irrigation use. Most rainwater harvesting systems contain the following mechanisms (Owies et al, 2012):

- A catchment area or known as a runoff area that can be small starting from a few square meters to several square kilometers as a large one and it can be a roof-top, a valley, or a road.
- A storing facility that represents the area that holds the runoff water in pounds, tanks above or underground cisterns to be used for irrigation or domestic purposes.
- The purpose of the water harvesting process, where the harvested water to be used for crops production or domestic use.

A successful RWH system depends mainly on the selection of suitable sites and the technical design of the system as many methods have been developed for site suitability selection (Ahmed, 2013). Some numerous historical studies and factors reported effective RWH suitable sites selection such as rainfall, topography, land cover and land use, soil texture, hydrology including the flow direction, flow accumulation, and socio-economic factors (Garget al, 2017).

Although there are many criteria and methods, that were considered for selecting and design of RWH globally, there are not enough focus studies and methods considered in the Middle Eastern region, therefore this research is conducted to fill that gap. In the present work, the comparison has been made for all criteria and methods that are utilizing GIS and Remote Sensing/RS for selecting and identifying the suitable RWH locations in arid and semi-arid regions in the middle-east.

2 CRITERIA AND TECHNIQUES USED FOR SUITABLE RWH SITE SELECTION

The suitable selection of RWH sites depends on many criteria (Mahmoud & Alazba, 2014). There are two main criteria for identifying and selecting a suitable site, these are biophysical and socio-economic criteria. Since the early nineties of the last century, many studies focused on biophysical criteria that include, rainfall, soil texture, slope, drainages, land use, and land cover while many studies after the year 2000 have tried to make an integration between both biophysical and socio-economic criteria (Yalew et al, 2016). The Food and Agriculture Organization of the United Nations (FAO) has itemized six key criteria for selecting RWH sites as cited by Khudhair, Sayal, and Darama (2020), these are hydrology, topography, climate, soils, agronomy, and socio-economic. Table 1. shows the most common techniques and criteria that have been used in the middle east and arid and semi-arid regions.

Table 1. The most common techniques and criteria that have been used in selection for RWH in the middle east

RWH techniques	Rainfall (mm)	Slope (%)	Type of Soil	Land Cover/Use	Catchment Area (ha)	References. Year and country
Check dams	<1000	<15	loam clay Sandy	Barren, shrub, and scrubland	N/A	Al-Daghastani (2010), Iraq Ziadat et al, (2012). Jordan Hameed (2013), Iraq
Ponds and pans	>200	<5	Clay loam sandy. and silty loam	Moderately cultivated, Shrub-land	< 2	Al- Adamat et al, (2008) Al-Adamat et al, (2010) Jordan
Percolation tanks	<1000	<10	Clay loam and silt	Barren or scrub-land	> 25	Al-Adamat et al, (2012) Jordan
Terracing	200-1000	5-30	Sandy clay, clay loam and sandy loam	Bushland with scattered trees and shrub-land	N/A	Weerasinghe et al, (2011) Egypt

3 TOOLS AND METHODS USED FOR SUITABLE SITES SELECTION FOR RWH

Multiple methods and criteria can be integrated with specific tools that can be used to identify suitable RWH sites. These tools can apply to arid and semi-arid regions including the middle - east, are categorized as the following:

- GIS integrated with RS tools.
- Multi-criteria analysis method integrated with hydrological modeling, GIS, and RS tools.
- Multi-criteria analysis method integrated with GIS.

3.1 GIS INTEGRATED WITH RS TOOLS

Recent advances in computing technology have contributed to numerous ways of identifying suitable sites for RWH. This included the use of GIS and RS tool packages that reduced cost and time effectively. Remote sensing (RS), can be used to develop precise information with a very high resolution. For instance, curve numbers (CNs) and land-cover, which are needed to calculate the runoff, can be easily obtained by using GIS applications. This is helpful and useful, especially, in places where very little information and data are available specifically in the developing countries (Mahmoud, 2014). GIS tool can also be used for collecting, storing, and analyzing spatial and non-spatial data in different layers applying the integration spatial analysis to identify suitable RWH sites (Mati et al, 2006). The integration use of GIS and RS tools for suitable sites selection for RWH can offer an effective reasonable spatial analysis that employs the integrated tool in a rapid easy to read/use and give a good opportunity to understand different patterns and produce information through maps. The accuracy of the GIS/RS tools depend on the resolution of the available data, therefore it can be very useful and applicable to identify the suitable sites for RWH in arid and semi-arid regions (Forzieri et al, 2008; Prinz et al, 1998; Ziadat, Mazahreh, Oweis, & Bruggeman, 2006). Table 2. summarizes the rainwater harvesting types and the studies and criteria applied in the Middle East countries when using GIS and RS tools.

Table 2. Summary of RWH types and criteria that have been applied by using GIS and RS tools

RWH types	Country and References
N/A	Syria, Oweis, Oberle,& Prinz (1998)
Cistern and pits contour	Jordan, Ziadat et al, (2006)
N/A	Syria, Bakir & Xingnan (2008)
Jessour and tabia	Tunisia, Ben Mechlia et al,(2009)
Dams and channels	Iraq, Al-Daghastani (2010)
N/A	Iraq, Kamel & Ahmed (2010)
Contour ridge and runoff strips	Jordan, Al-Shamiri & Ziadat (2012)
Reservoir	Iraq, Salih and Al-Tarif (2012)
Dams, ponds runoff and strips	Jordan, Ziadat et al, (2012)

3.2 MULTI-CRITERIA ANALYSIS METHOD INTEGRATED WITH HYDROLOGICAL MODELLING, GIS, AND RS TOOLS

Multi-criteria analysis (MCA) is a widely commonly used method for analyzing the combined data from different criteria. One of those methods is the analytical hierarchy process (AHP, which is an MCA method that has been applied extensively for identifying the potential RWH sites (Sekar & Randhir, 2007, Munyao, 2010, Krois & Schulte, 2014). One of the main procedures in the MCA method is the assessment of relative weight for each criterion, rather than assuming the same weight for all criteria and then comparing two or more alternatives. AHP is a multi-criteria decision-making method, providing a designed technique for organizing and analyzing composite decisions based on mathematics and expert knowledge (Saaty, 2008). The integration of the MCA method with GIS and hydrological modeling is a good and widely used method for detecting suitable sites for RWH in arid and semi-arid regions.

Numerous studies in the middle east region have been applied this integrated method, taking benefit of the MCA strengths together with those of hydrological modeling and GISs, as shown in Table 3. The table gives a summary of RWH types and criteria that have been applied using the integration of the MCA method with hydrological modeling and GIS/RS tools.

Table 3. Summary of RWH types and criteria that have been applied by using the integration of the MCA method with hydrological modeling and GIS/RS tools.

RWH types	Country and References
Reservoir	Lebanon, Jabr & El-Awar,(2005)
N/A	Egypt, Weerasinghe et al, (2011)
N/A	Egypt, Elewa et al, (2012)
Dams	Iraq, Hameed (2013)

3.3 MULTI-CRITERIA ANALYSIS METHOD INTEGRATED WITH GIS

Multi-criteria analysis (MCA) is a commonly wide used method of analysis that combines data from different criteria. One of those methods is the analytical hierarchy process (AHP, which is an MCA tool that has been applied extensively to identify potential RWH sites (Sekar & Randhir, 2007, Munyao, 2010, Krois & Schulte, 2014). One of the main procedures in MCA is the assessment of relative weight for each criterion, rather than assuming the same weight for all criteria and then comparing two or more alternatives. AHP is a multi-criteria decision-making method, providing a designed technique for organizing and analyzing composite decisions based on mathematics and expert knowledge (Saaty, 2008). MCA integrated with GIS is a good tool for detecting suitable sites for RWH and is widely used in arid and semi-arid regions. Numerous studies in the Middle East have applied this integrated approach, taking advantage of the strengths of MCA together with GIS techniques, as shown in Table 4. The table gives a summary of RWH types and criteria that have been applied using MCA integrated with GIS tools.

Table 4. Summary of the RWH types and criteria that have been applied to use the integration of MCA and GIS tools

RWH types	Country and References
Ponds	Jordan, Al-Adamat (2008)
Micro and Macro catchments	Syria, Pauw et al, (2008)
Ponds	Jordan, Al-Adamat et al, (2010)
N/A	Jordan, Al-Adamat et al, (2012)
Groundwater recharge	Saudi Arabia, Mahmoud (2014)
In-situ	Saudi Arabia, Mahmoud & Alazba (2014)
Groundwater recharge	Iraq, AL- Shammari et al, (2021)

4 CONCLUSION

The main objective of this study was to review the most effective and common methods that are used for selecting and identifying the suitable sites of RWH arid and semi-arid countries, specifically in the Middle East region that have been developed in the past years. The success of RWH depends mainly on both site identification and the technical design (Ammar et al, 2016). The study also discussed the development of criteria selection through the years specifically in the middle-east countries. The study reviewed the most numerous effective most common and widely used methods and techniques that were used in selecting the suitable sites of RWH sites in the arid and semi-arid zones and precisely in the middle-east region. This study focuses on the most common and effective methods that have been used to select the suitable sites of RWH in the middle east countries through reviewing the most recent studies that have been used different techniques and criteria to conduct the studies in that region and were represented in table 1. Based on the previous review studies that have been conducted in the middle-east countries, it is obvious that the integration between the MCA method that is supported by the GIS/RS techniques has been widely applied and used as shown in above table 2. While there were limited and fewer studies that have been used the combination of the MCA method with hydrological modelling by using and applying GIS/RIS techniques and tools in the middle-east region as shown in the above table 3. On the other hand, using the combination of the MCA method that is supported by the GIS techniques has been used and applied in many studies in the middle east region. It is a great challenge to determine the most useful and effective method for selecting suitable RWH sites, however, it is clear that there are limited studies in the middle east using the combination of the MCA method with GIS/RS and hydrological modelling compared with the two others methods that are using MCA supported by GIS/RS techniques. Therefore, the following table 5 summarizes and presents the comparison between the three methods and tools based on the features and requirements for arid and a semi-arid region, the limitations and accuracy of each method, specific data requirements for various countries. The three methods have been applied discretely. The analysis through this review study suggests that the integration of using MCA with GIS is the most innovative and applicable method that can provide a rational and unbiased technique for identifying suitable sites for RWH while there should be more investigations and studies in near future regarding using the combination between MCA with hydrological modelling that is supported by GIS/RS techniques. The following table 5. summarizes each method identification, advantages, and limitations that have been applied in the arid and semi-arid regions and specifically in the middle - east countries.

Table 5. Summary of each method identifications, advantages, and boundaries

Method and tools	Method identification	Advantages	Limitations
MCA with GIS/RS techniques	Use GIS/RS technique and properties to produce many thematic maps to select suitable RWH site	Accurate, good spatial resolution, saving time, cost-effective, easy to use, used in remote sensing places, and can identify RWH suitable sites.	The results accuracy is highly dependent on input data. Cannot provide a real image of a watershed and lacks between up and downstream relationship. Need a field survey for validation
MCA with hydrological model and GIS/RS techniques	Many criteria can be combined by applying MCA to assess a relative weight for each one. Applying the properties of the hydrological model and GIS/RS to select RWH suitable sites.	It is flexible and can be applied in different regions, MCA (AHP) can check reliability, providing validity to decide the suitability of RWH site selection	The weight of each criterion in MCA is highly affected by the proficiency of the author, therefore weights should be calculated carefully
MCA with GIS technique	Implementation of a GIS for combining groups of criteria to select suitable sites for RWH based on using decision rules to integrate with MCA.	Greatly flexible for applying MCA with GIS for various regions, can be applied in many regions, can identify suitable sites for RWH	The weight of each criterion in MCA is highly affected by the proficiency of the author, therefore weights should be calculated carefully, checking data quality and availability.

5 ACKNOWLEDGEMENTS

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Construction Project Risk Management for Performance Improvement (Polgahawela-Pothuhera-Alawwa Integrated Water Supplying Project)

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ABSTRACT

Construction risk management can be defined as the avoidance or the reduction of possible harmful incidents or actions in a construction project. It can be one of the most important factors in a construction project. Depending on the nature of the project, types of risks can be very wide in its range. Understanding the risk factors and the proper management of them, can lead a project to be completed on schedule, avoiding budget overruns whilst ensuring the safety and welfare of all the project participants. This research aims to identify the risks and their possible impacts on a specific construction project. The selected project is the construction of the Polgahawela-Pothuhera-Alawwa Integrated Water Supplying scheme located in the North-Western province of Sri Lanka. Risks categorized under the different sectors such as financial management, technical, quality, health, and safety, environment, social, legal and political were considered in the research but limited to the construction phase of the project. The methodology for this study is based on ISO 31000, which includes risk identification, risk analysis, risk evaluation and risk mitigation. To identify the relevant risks of the project, a structured interview using a questionnaire was conducted among selected project participants. In making the assessments founded on the responses received, weighted credits were assigned based on the academic and professional qualifications of the respondents. The responses were utilized in this manner to develop a listing of risk and its consequences. This highlighted the more severe risks enabling recommendations to be made to mitigate and manage such risks. The risk management process together with knowledge from previous literature was used in making recommendations to mitigate and manage risk towards project performance improvement. It should be noted that the findings could be of benefit to future contractors associated with similar projects.

KEYWORDS: *Risk, Water Supplying, Probability of occurrence, Consequence*

1 INTRODUCTION

Currently, in Sri Lanka, hundreds of construction projects are being carried out by both government and private sectors. Risk is one of the major factor that effects on each and every single project irrespective of their project value or scale. Any uncertain or unexpected incident that can be harmful or badly effect the performance of a project can be concerned as a risk. However there is a shortage of researches which have been conducted focusing a particular province in the country and especially no research have been conducted based on a project located in North-Western province of Sri Lanka. Moreover the risks of a water supplying project in Sri Lanka have not yet been researched. Since water projects are spread in a wide range unlike many other projects, risk warrants more attention.

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The technical aspects involves in all civil, structural, mechanical and electrical works, and also the working environment includes an extremely large perimeter when compared to many other projects.
ISO 31000 is the worldwide accepted standard for risk management (Sousa, et.al, 2012). Therefore methodology was prepared in accordance with this standard. From Impact and Probability in Risk (Assessment - apppm, 2021), it was revealed that the probability vs consequences matrix, which is used in this study, is one of the standard and common method for evaluation of risks. Certain researches evaluates risk factors which are faced especially by water and sewerage systems construction projects (Rybka, Bondar-Nowakowska and Polonski, 2016). Risk management techniques stands more as strategies than frameworks or systems. Hence it was followed when proposing the mitigation strategies (Dikmen I., Birgonul M.T. and Arikan A.E. 2004). The literature survey depicts that the effectiveness of mitigation the risks, depends on proper identification, analysis and evaluation. However there are numerous gaps in this field, especially in Sri Lanka risk management has not been properly researched yet. There is a blank of an efficient risk management framework that suits to the country.

Aim of this research was to develop risk identification and mitigation system for the performance improvement of Polgahawela-Pothuhera-Alawwa Integrated Water Supplying Project (PPAIWSP).
There were four major objectives;

- To identify the possible risks for a particular construction project
- To analyze the identified risks
- To evaluate the impact of each possible risk
- To propose mitigation methods for performance improvement

This research project is conducted to improve risk management of Polgahawela-Pothuhera-Alawwa Integrated Water Supplying Project (PPAWISP), located in North Western province of Sri Lanka. The project, which is budgeted for USD 108 million, consists of pipe laying of 320km total length, a weir across Ma Oya River, a water intake structure, and a water treatment plant with a capacity of 29000m 3 per day. The data collection of the research was done through a questionnaire and system boundary includes only the construction stage.

2 METHODOLOGY

The data which were collected, are mainly qualitative representations and they were primarily collected through rating based questionnaire system. The basic methodology was prepares in accordance with the ISO31000 standards.

Risk Identification

Risk factors that are possibly impacting on the project were revealed through interviews on live and online media participating experienced professionals representing both client and contractor.

Risk Analysis

The identified risk factors were then analyzed based on questionnaire type survey. A rating based questionnaire was prepared to assess each risk factor, with respect to consequence and the probability of occurrence. The consequence shall be the severity of the occurrence while the probability shall be the likelihood for a particular uncertainty to be occurred. Each risk section was responded by the specialists of the field and credits were offered based on the professional qualification of the respondent as in the Table 1

Table 1. Credits offered to each respondent category

Occupation (respondents)	Credits
Chief engineer, Deputy project manager, Site manager, Senior consultant engineer, HSE manager, QA/QC manager	2
Civil/site engineer, QA/QC engineer, Engineering assistant, Quantity surveyor, HSE officer	1
Junior site engineer, Technical officer Material technician, Trainee	0.5

Risk Evaluation

The collected data were then transferred to probability vs consequence matrix format to identify the risks which falls under most critical categories.

Risk Mitigation

The factors which were located in the red zone of the matrix (table 2) were considered as severe risks. The issues that might cause the particular risks were predicted and studied thoroughly. Then proposals were brought out to control those issues and to minimize the probability of occurrence of a risk by referring to the previous literature.

3 RESULTS AND DISCUSSION

3.1 Results of the risk evaluation

<u>Financial risks</u>
F1- Corruptions in payment chains
F2- Variations in material rates
F3- Delays in payments for subcontractors
F4- Delays in payments for contractors

<u>Health & safety risks</u>
H1- Electrocution
H2- Chemical hazards
H3- Injuries from machineries
H4- Collapses in pipe trenches
H5- Falling from heights
H6- Scaffolding failure
H7- Fire hazards

<u>Technical & quality risks</u>
T1- Insufficient quality assurance testing
T2- Insufficient supervision and inspection
T3- Damages to underground telecommunication line
T4- Faulty or incomplete drawings
T5- Poor material selection
T6- Errors in construction procedures
T7- Delays in design reviews

<u>Management risks</u>
M1- Contractual disputes
M2- Labor shortage
M3- Lack of skilled and unskilled staff
M4- Poor communication
M5- Bankrupt or leaving sub- contractors
M6- Material un-availability

<u>Legal, political and social risks</u>
L1- Political interruptions
L2- Public protests in land acquisition
L3- Public protests against pipe laying in road shoulders
L4- Legal obstructions in material transportation
L5- Changes of government policies interfering the project

<u>Environmental & climatic risks</u>
E1- Ground water level increases causing pipe laying difficulties
E2- Obstructions from environmental organizations
E3- River water pollution and threat to aquatic life
E4- Extreme weather conditions/ storms
E5- Flooding
E6- Increasing of river water level disturbing the weir construction

Table 2: Probability of occurrence Vs Consequence matrix

Probability → / **Consequence ↓**	Improbable	Remote	Occasional	Probable	Frequent
Negligible					
Minor		F1,H1,L1, L2	H2,H3	H4,H5,L3, E1	
Moderate		H6,M1,T1, L4, E2	F2,F3,M2, T2,L5,E3	M3,T3, E3	M4
Critical		M5,T4	M6,T5,T6, T7,E4	E5	
Catastrophic		H7	F4		

Low Risk
Medium Risk
High Risk

3.2 Discussion

Financial risks

Construction projects are highly exposed to the financial risks and changing nature of the economic aspects. In this study, four financial risk factors were identified as the most probable uncertainties. In summary, the evaluation results reveal that delays in payments for the contractor is the project's highest financial risk. The results illustrate that the variation in material rates is a medium risk as per the responses. Yet, the perspective of the respondents might have differed from the actual scenario here. Variation in material rates is the most critical and severe risk for a construction project, and it is linked to inflation, foreign currency exchange rates, etc. Therefore temporal rate variability is considered as a high risk in this study despite the responses. Main contractor is in control of delays in payment for sub-contractors, hence the risk is manageable. Corruptions in payment chains were identified to be the lowest risk. The recommendations are given to mitigate the high risks in finance identified in this study.

- Delays in payments for contractor:
  - An intelligent contract payment security system (SMTSEC) is proposed to be implemented in the project, decreasing the issues in payment for the project participants while converting the payment procedures more transparent. Here, both client and contractor initially agree on security payment conditions and those data are computerized through SMTSEC system. The system then provide the monthly payment amount by reviewing project cash flow and the updates of the project. Thereby, time efficiency of payment schedules can be improved (Ahmadisheykhsarmast and Sonmez, 2020)
- Variation in material rates:
  - It is more important to estimate the inflation that may prevail during the project and accommodate it at the tendering stage. And also the inflation and other economic rates should be monitored throughout the project. A model which can forecast the material price variation for previous similar projects would be the best solution to avoid project cost overrun (Musarat et al., 2020).

Health and safety risks

Health and safety risks are highly subjective, and many possible safety risks act on construction projects. Electrocution was identified as the lowest risk, which might have responded in such a way due to lesser weightage of mechanical and electrical work during the study's stage. According to the respondents, chemical hazards and injuries from equipment and machinery, even though has a considerable probability, will result in minor consequences. The collapses in pipe trenches were identified to have a higher probability and minor consequence. Yet it is considered as a severe risk because failures of channels are mostly fatal, and the possibility to survive is very low, and multiple workers may get trapped once (Chalupka, 2011). Similarly, falling from heights is one of the significant uncertainty which can cause fatal injuries or deaths of workers (Nadhim et al., 2016). The majority of the respondents have identified the impact of fire hazards as immensely high yet categorized in the medium-risk range due to its low probability. Scaffolding failure is evaluated as a medium risk; however, it is recommended to reduce the risk further since the upcoming stages of the project will need to engage in more high elevation constructions. Suggestions are provided for high risks; collapses of trenches, falling from heights, and scaffolding failures.

- Collapses of trenches
  - Providing training and refreshing courses on trench safety would be the best option because most trench accidents occur due to underestimating risk, overconfidence, time pressure, or economic pressure, which are preventable.
  - They are making the regulations on shoring stricter and clearly state the rules on specifications.
  - They encourage innovative techniques such as advanced trench box technologies, alternative methods to measure depths, etc.
    (Ruttenbur et al., 2019)
- Falling from heights
  - Taking proactive measures such as arranging short courses, seminars and training programs on-site is identified as the most effective solution.
  - Redesigning of construction procedures and site to reduce the complexity

- Ensuring the health condition of the employees through identification of hypertension, heart diseases, excessive fatigue, sleepiness, depression, etc. (Nadhim et al., 2016)

o Scaffolding failures
- Employ an external contractor for scaffold erecting who may pay extreme attention to scaffolding safety and ensure no structural flaws.
- Establish a rapid four-factor inspection method' which will ensure the safety of; planking, railing, access, and tying off to buildings.
(Halperin and McCann, 2004)

Technical and quality risks

Technical and quality risks can cause a severe impact on project schedules, standards of the project, etc. Insufficient quality assurance testing was revealed to be having a moderate possible consequence while the probability is relatively lower. The obvious specifications in quality assurance testing might have reduced the risk probability. The design and build type contract might have reduced the drawing issues (Ling and Chong, 2005). Insufficient supervision and inspection and damages to the underground telecommunication lines are rated as a medium risk. Poor quality material selection is one of the vital risks. The cost spent on materials in a construction project is approximately 60% of the total budget; therefore, extreme attention must be paid to selecting materials (Sitota, Quezon and Ararsa, 2021). Errors in construction procedures is another severe risk that may result in immense consequence on both cost and time of the project. The delays in design reviews in obtaining approvals for modifications or variations, is also a high risk. The recommendations are proposed to mitigate high risks; poor material selection, errors in construction procedures and delays in design reviews.

o Poor material selection
- Preparation or modification of the specification providing full details on each material referring to the standard codes and tightening the regulation ensuring the consistency with documents throughout the material selection procedure.
- Certification of the materials via independent third party institution which should be a recognized or approved body by a relevant authority
(Sitota, Quezon and Ararsa, 2021)

o Errors in construction procedures
- Documentation of the construction procedures by ISO: 9001 or relevant code while improving the quality management system of the project
- A probabilistic model of hazardous situation development is proposed to be implemented, which can reduce human errors as much as possible because human errors cause the majority of the constructions.
(Baiburin, 2017)

o Delays in design reviews
- Most delays are possible due to the high expectation of clients from the design and build contractor. Appoint expertise on the design management roles and maintain communication and cooperation with the client/consultant would minimize the delays in reviews and approvals.
(Ling and Chong, 2005)

o It is highly recommended to implement a high efficient quality management system to reduce all risks related to quality aspects.
For an example, check list can be identified as efficient and low cost QMS which can reduce most of the risks in construction (Mane, et al, 2015).

Management risks

Management risks are crucial in any construction project, which may lead the project to devastating failures. Contractual disputes may cause moderate impact, but the probability of occurrence has been identified to be relatively more minor. Since this is an international project, the disputes are comparatively less possible. Bankrupting a subcontracting company or leaving the subcontractors can have a critical impact; however, this risk also has a remote probability of occurrence. The labor shortage is another medium-range risk, while the lack of skilled and unskilled technical staff is illustrated as a high risk. The overall construction sector of Sri Lanka has a shortage of 400,000 workers (Sri Lanka's construction sector struggles with securing enough local talent, 2021), which affect each project more or less. Material scarcity and unavailability is another critical risk. Import restrictions, rapid depletion of resources, increase in demand, poor transportation networks, etc., cause shortages in construction materials such as; steel, lumber, cement, electrical appliances, copper, etc. Poor communication was identified as high risk with an excessive probability of occurrence. Mitigation proposals are brought forward for the high risks; material unavailability, lack of skilled and unskilled technical staff, and poor communication.

- Material unavailability
  - Most material un-availabilities are due to poor material management, incorrect or delayed orders, and logistic defects. Before finalizing the orders, it is recommended to allocate extra time or rounds for clarifying the quantities and type of materials and always compare the orders with construction drawings.
  - If rare, high demanded or scarce materials are needed, ensure that stocks are always available for a considerable period and constantly investigate the availability of those materials in the market through contacting the suppliers. (Netscher, 2021)
- Lack of skilled and unskilled technical staff
  - This risk's responsibility is mainly held at the national level, which should establish a standard educational system including training and certification in the construction industry.
  - At the project level, ensuring attractive and appropriate salaries and benefits for skilled workers, implementing strategies to motivate workers, and employing multi-skilled technical workers would considerably reduce the risk.
  - (Kumara, 2017)
- Poor communication
  - Arranging programs to improve the cooperation between laborers and officers/supervisors, take necessary actions to minimize on-site conflicts and bullies, reduce noise levels that can interrupt voice commands and introduce creative and attractive communication techniques and strategies would reduce the risk of poor communication (Olanrewaju, Tan and Kwan, 2017).

Legal, political and social risks

Construction projects, especially launched to provide an essential utility to the public in a particular area, are integrated with the local society. Hence, it is crucial to assess the possible uncertainties arising from the community and local political institutes and the legal system. Political interruptions in deciding distribution zones have been rated as a low risk. The project is foreign-funded and directly handled through the central government, therefore, forces of local political authorities are impossible (Seneviratne A., personal interview, 2021). Public protests against land acquisition and compensation processes were identified as less probable. However, protests against pipe laying in road shoulders has been rated as a risk with high probability. The low quality backfilling, barricading access roads for a long time, damages to newly built roads, etc., might have lead the public to protests. Legal obstructions in material transportation is another issue that is mainly related to soil, sand, and coarse aggregates. But as this construction is a government project, the legal interruption is relatively low. Changes in government policies also identified to be a medium risk. Considering the comparatively high probability of public protests against pipe laying in road shoulders, recommendations are given to mitigate this risk;

- Public protests against pipe laying in road shoulders
  - Accelerate the pipe laying process and repair the access road and entries as soon as possible. Using the 'Micro Tunneling' technology wherever possible would do least disturbance to the public.

Environmental and climatic risks

The project contains components such as weir across Ma Oya River, which can impact on the environment easily. Obstructions from environmental organizations is a risk that has a moderate consequence but may occur remotely. River pollution is an obvious possible risk during the construction of weir by adding cement materials, chemical compounds, and other hazardous or poisonous materials into water. Groundwater level increases is another medium-range risk that can disturb pipe laying in trenches. Extreme weather conditions or storms may decelerate the performance of the project; therefore it is rated as a high risk. Flooding and river water rise was identified as the most severe risks. Both can cause a critical impact on the project while river water increase has an even probability of occurrence. The high risks, flooding, river water increase and extreme weather conditions are considered in proposing risk mitigation methods.

- Flooding
  - Analyze and estimate the flood frequency and severity and predict the impending or possible floods using advanced technologies or software (example: HEC-HMS). Then it is possible to arrange the construction activities in an order which can reduce the potential risk.
- Increasing of river water level disturbing the weir construction
  - The construction of a strong cofferdam was identified as the best solution to mitigate this risk. Instead of the existing earthen cofferdam, it is recommended to construct a rock fill cofferdam that can endure higher velocity of the water.
- Extreme weather conditions/storms
  - High attention must be paid to this risk factor in the project planning stage. A risk management system integrated with extreme weather conditions predicts data, would reduce the risk. (Wedawatta, 2011)

4 CONLUSION

The improper risk management adversely impact on construction projects. Countries like Sri Lanka continually experience project failures due to unsuccessful risk management. Especially in large scale projects such as water treatment and supplying projects, the mitigation of risks becomes highly complicated. This study investigated the risks associated with Polgahawela-Pothuhera-Alawwa Integrated Water Supplying Project. A survey was carried out through a questionnaire with participation of project professionals, thereby severe risks were identified under six main categories as;

Financial – Delays in payments for sub-contractors and variation in material rates
Health & safety – Trench collapses, falling from heights and scaffolding failures
Technical & quality – Poor material selection, errors in construction procedures, and delays in design reviews
Management – Material unavailability, lack of skilled and unskilled technical staff, and poor communication
Legal, political & social – Public protests against pipe laying in road shoulders
Environmental & climatic – Flooding, increasing of river water level and extreme weather condition

It is emphasized that severity of risks should be determined with respect to both consequence and probability of occurrence. The most suitable risks mitigation strategies were proposed for each of those factors by referring the literature. In summary the paper reveals high risks of the acting on the selected water supplying projects along with recommendations to mitigate them. The results may be applicable to similar scale water projects which are located all over the country. It is recommended to conduct a risk analysis for any contractor before starting a similar project. And also continuous updating of the analysis would be significantly supportive. Future studies which can explore risks related to all stages of the project are suggested.

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Satellite Rainfall Products for analysis of Rainfall trends for Mahaweli River Basin

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ABSTRACT

The presence of accurate and spatiotemporal data is of utmost importance in hydrological studies for river basins. However, limited ground-measured rainfall data restrict the accuracy of these analyses. Data scarcities can often be seen not only in many developing countries but also in the developed world. Therefore, much attention is given to alternative techniques to accomplish the data requirement. Precipitation data extraction from satellite precipitation products is one of the frequently used techniques in the absence of ground-measured rainfall data. The Mahaweli River Basin (MRB) is the largest river basin in Sri Lanka and it covers 1/6th of the total land area of the country. Mahaweli River is the heart of the country and the water of it is being used for many activities, including hydropower development, water supply, irrigation, etc. Therefore, analyzing rainfall trends of MRB is interesting and worthwhile for many stakeholders of the river basin. Therefore, this research investigates the suitability of Satellite Rainfall Products (SRP's) as an alternative for Rain Gauge measured data in the MRB by performing trend analysis between the two datasets. Six precipitation products, namely PERSIANN, PERSIANN-CCS, PERSIANN-CDR, GPM IMERG V06, TRMM-3B42 V7, TRMM-3B42RT V7 were extracted for 10-35 years for 14 locations of the MRB spatially distributed in the three climatic zones of the catchment. Non-parametric tests, including the Mann-Kendall test and Sen's slope estimator tests, were used to detect the possible rainfall trends in precipitation products. Significant increasing trends were observed for both ground-measured and SRP's in the annual scale while mixed results were observed in monthly and seasonal scales. The trends from ground-measured rainfall and SRP's were compared and the suitability of SRP's as an alternative technique was stated.

KEYWORDS: *ground-measured rainfall data, Mahaweli River Basin, rainfall trends, satellite precipitation products, PERSIANN, IMERG, TRMM*

1 INTRODUCTION

Precipitation is of utmost importance when it comes to many hydrological studies. It plays an important role in climatic trends and the water availability on the earth. The natural water cycle is now heavily modified and had induced massive variability in the rainfall patterns throughout the country, thus the measurement of precipitation has become challenging and the importance of analyzing the rainfall trends has increased tremendously. The fields of hydrology, meteorology, geology, and ecology highly require and depend on proper rainfall data for future predictions and analysis to identify sudden changes in the environment and mitigate any damages to the ecosystem. Even though many global-scale trend analyses are present due to the scarcity of spatiotemporal rainfall data, researchers now have turned their focus onto carrying out trend analyses for more regional or local scales. But it is very clear that this is a difficult task if done with the use of ground gauge measurements due to several limitations it possesses. The main limitation is that ground gauge measurements are point measurements and the data cannot be applied for a wider area and therefore its coverage is very limited.

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For real-time application of rainfall data such as in flood and drought predictions, understanding global climate change, determining the water resources available to cater the human consumption, agriculture and industry, the data needs to be accurate. However, with the advancement of technology, the Satellite Rainfall Products (SRPs) had grabbed the attention of many researchers due to its ability to provide spaciotemporal rainfall data using the radar technology addressing to most of the shortcomings of the rain gauge measurements. But before using these SRPs it is of course necessary to assess the suitability of it to be used in hydrological analysis. Therefore, it is required to perform an intercomparison of these SRPs with ground gauge measurements and identify its degree of uncertainty before using them in real-time applications.

At present there are several SRPs and the methods they use to extract rainfall data differs from one to another and thus will be their accuracy. Tropical Rainfall Measurement Mission (TRMM) Multisatellite Precipitation Analysis (TMPA), Climate Prediction Center Morphing (CMORPH), Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN), Multi-Source Weighted Ensemble Precipitation (MSWEP) are some of the SRPs that are widely in use with research studies. Therefore, analyzing the trend of several SRPs and comparing them with the gauge measurements is essential to obtain a sound conclusion on their levels of uncertainty and determine its suitability to be used in real-time hydrological applications. Trend analysis is suitable in these applications because it is an accurate method to predict future movements of the particular measurement.

Researchers had already performed several studies with SRPs in relation to several hydrological applications. JIANG et al., (2010) performed an evaluation of SRPs with surface rain gauge observations from Laohahe Basin in northern China and concluded that SRPs can have some large errors when it comes to high altitude and complex-terrain regions. Teng et al., (2017) and Zhu et al., (2011) integrated data from SRPs to study rainfall and soil erosivity. Bitew and Gebremichael, (2009) and Anagnostou et al., (2010) concluded that there are certain errors in the SRP data and that it can sometimes underestimate the real scenario which might be crucial when it comes to flood control analysis. Also, Bitew and Gebremichael, (2009) concluded that PERSIANN - Cloud Classification System (PERSIANN-CCS) misses rainfall rates under 1.6mm/day and therefore has difficulty in detecting light rainfall events according to the results they obtained from their study in Ethiopia. When it comes to trend analysis researches done in Sri Lanka, Khaniya et al. (2019) analyzed the rainfall trend in the Uma Oya basin for the prediction of water scarcity problems due to multi-development projects in that area. Usage of rainfall trend analysis for future flood hazard mapping was also presented by (Alahacoon et al., 2018). He had used data covering most parts of the country and concluded on an increasing rainfall trend in that area. Also, he had validated his findings with satellite images for the area of concern. Several other research studies done to determine trends and predict future adverse effects on the climate include the analysis of rainfall trends (Thevakaran et al., 2021) and (Herath and Ratnayake, 2004).

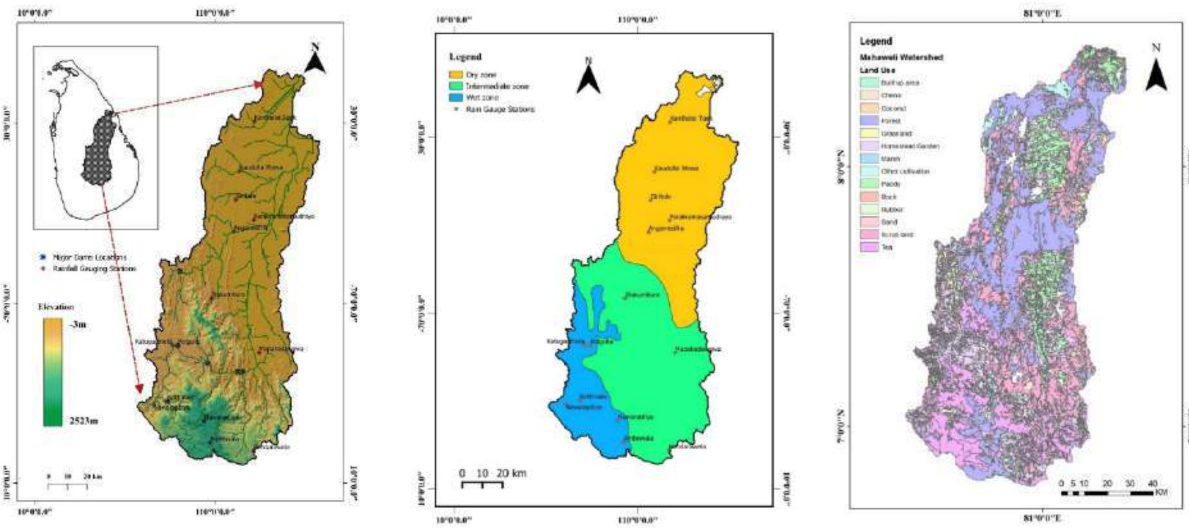
Trend analysis on SRPs and gauge measurements are being done in most of the countries and several research studies had been carried out in Sri Lanka as well as mentioned earlier. However, the researches that have been carried out in the Mahaweli River basin are mainly focused on areas such as water resource management in dry zonal paddy cultivation (Withanachchi et al., 2014), lain assessing the streamflow variability and rainfall trend of climatic zones (Shelton and Lin, 2019), drought occurrence and atmospheric circulation (Lin & Shelton, 2020) and it is clearly seen that researches which include the use of SRPs together with gauge measurements have not been done for the Mahaweli River basin which is the longest river in Sri Lanka spanning up to 335km. Being a river of utmost importance to our country due to its immense contribution to supply of water to various major activities in our country, it is definitely important to assess the availability of rain gauges in this area and find an alternative method to address any limiting rain gauge data so that future predictions can be performed accurately.

Therefore, in this research main focus is given to address this issue. Here, the Satellite Precipitation Products are compared with Gauge Measurements to analyze the trend and determine the accuracy of SRPs through non-parametric tests such as the Mann Kendal (MK) Test. Any uncertainties will be then quantified using Sens Slope Estimator for the Mahaweli River Basin, Sri Lanka. The results obtained will definitely be helpful to address the research gap that was identified in this area and be suitable for use in future hydrological studies.

2 STUDY AREA AND DATASETS

2.1 Study Area

The area of interest in this study is the Mahaweli River Basin (MRB), Sri Lanka. MRB is the longest river in Sri Lanka spanning to 335km. With Amban Ganga and Kotmale Oya inside the catchment, MRB flows from Horton Plains national park in Nuwara Eliya district to the sea from the southwestern side of the Trincomalee Bay. The MRB watershed is 10448km2 covering one sixth of the land mass in the country. Depending on the climatic and geographical distribution of annual rainfall amount, three climatic regions (wet, intermediate, and dry zones) are present in the Mahaweli catchment (Lin and Shelton, 2020). Also, the annual rainfall to the country is influenced by four monsoon seasons of Southwest Monsoon (SWM) in the months of May to September, Northeast Monsoon (NEM) from December to February, First-Inter Monsoon (FIM) during March and April and Second-Inter Monsoon (SIM) during October and November. Having the wet zone of the catchment in the southwest part of the country and dry zone in the northeast part of the country, the annual rainfall on the MRB is dependent on all these four seasons with the main ones being SWM and NEM (Malmgren et al., 2003). MRB is the main water supplier for agricultural activities in the eastern dry zone of the country irrigating more than 1000km2 of land. The hydroelectricity produced from six dams of the MRB supplies more than 40% of the country's electricity (Zubair et al., 2003). The elevation map, land use map and catchment distributed in the three climatic zones of MRB are shown in Figure 1.



(a) (b) (c)

Figure 1. (a) Rainfall Gauging Stations and Major Dam Locations of MRB, Sri Lanka, (b) Land Use Map, (c) Climatic Zone Map of MRB

2.2 Datasets

2.2.1 Ground Observed Rain Gauge Data

For the analysis, 25+ years of rainfall data were used. 14 rain gauge stations in the MRB covering all three wet, intermediate, and dry zones were obtained from the Department of Meteorology, Sri Lanka which is the official authority for the meteorological data collection of the country. The stations were selected considering the spatial resolution coverage of chosen satellite rainfall products as well. The spans of data were of different time scales. The 14 rain gauge stations that was selected with their location and time span are listed in Table 1 below.

Table 1: Details of Rain Gauge Stations

Rain Gauge Stations	Latitude	Longitude	Time Span
Ambewala	6° 52' 9.36"N	80° 47' 44.34"E	1983-2016
Angamedilla	7° 51' 18"N	80° 54' 25.19"E	1983-2018
Bandarawela	6° 49' 47.88"N	80° 59' 52.71"E	1983-2016
Giritale	8° 0' 16.10"N	80° 54' 58.58"E	1983-2017
Illukumbura	7° 32' 38.86"N	80° 48' 6.43"E	1983-2015
Kanthalai Tank	8° 22' 16.47"N	81° 0' 10.46"E	1987-2018
Katugasthota	7° 19' 26.78"N	80° 37' 13.96"E	1990-2019
Kaudulla Wewa	8° 8' 12.52"N	80° 56' 1.86"E	1983-2017
Kothmale	7° 3' 52.91"N	80° 35' 54.79"E	1985-2018
Mapakadawewa	7° 17' 21.55"N	81° 1' 32.78"E	1983-2016
Nawalapitiya	7° 2' 51"N	80° 32' 3.99"E	1989-2017
Nuwaraeliya	6° 58' 11.99"N	80° 46' 11.99"E	1990-2019
Parakramasamudraya	7° 54' 36.23"N	81° 0' 1.78"E	1983-2018
Polgolla	7° 19' 20.98"N	80° 38' 45.94"E	1988-2018

2.2.2 Satellite Rainfall Products

Similar to the gauge measurements, satellite rainfall products were also obtained for the 14 station locations mentioned in Table 1. The data range available varied with respect to when the satellite estimates began. However, the analysis was done for each satellite model data with each rain gauge station data depending on the data availability range of each of the datasets. 6 satellite data models were used in this analysis namely,

- Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)
- Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks – Cloud Classification System (PERSIANN – CCS)
- Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks – Climate Data Record (PERSIANN – CDR)
- Integrated Multi-Satellite Retrievals for GPM (IMERG) Version 6
- Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) Version 7 3B42
- Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) Version 7 3B42RT

The general details of the SRP’s that were used in the analysis are provided in Table 2 below.

Table 2: Details of SRPs

Product	Data Provider	Temporal coverage	Finest time resolution	Spatial resolution	Spatial coverage
PERSIANN	CHRS*	March 2000-present	1 hour	0.25°×0.25°	60°N-60°S
PERSIANN-CSS	CHRS	January 2003-present	1 hour	0.04°×0.04°	60°N-60°S
PERSIANN-CDR	CHRS	January 1983-present	1 day	0.25°×0.25°	60°N-60°S
TMPA-3B42	NASA*	January 1998-12/2019	3 hours	0.25°×0.25°	50°N-50°S
TMPA-RT	NASA	March 2000-12/2019	3 hours	0.25°×0.25°	60°N-560°S
IMERG	NASA	June 2000-present	30 minutes	0.10°×0.10°	90°N-90°S

*National Aeronautics and Space Administration, U.S.A. (NASA)
*Center for Hydrometeorology and Remote Sensing (CHRS)

2.3 Data Extraction

The six satellite products used in this study was extracted in different methods. PERSIANN group of products were directly obtained from CHRS data portal as CSV files. IMERG and TRMM products were obtained as NetCDF (Network Common Data Form) files from NASA GESDISC portal. Afterwards, IMERG was extracted through the process of merging the files in Climate Data Operator (CDO) followed by the extraction using R coding in RStudio. The TRMM products were merged using similar approach as in IMERG, but the extraction of the point rainfall data was done using MATLAB 9.6.

3 METHODOLOGY

Non-parametric tests were used to analyze the trend in the two datasets and to find the magnitude of the trends observed. Ultimately, the trend observed in both satellite data and rain gauge data were obtained through these tests.

To analyze the trends in the rain gauge and satellite data, the Mann Kendall (MK) Test was used. After obtaining the positive or negative trends from the MK Test, Theil's & Sens Slope Estimator was used to quantify the trends that were observed.

3.1 Mann Kendall Test

The MK Test (Mann, 1945 , Kendall, 1948) provides the significance of the trends that are observed in the rain gauge and satellite data. MK Test uses the hypothesis of H0 for no trend scenario and H1 when a trend is present in the datasets. The Mann Kendall Statistic, S is given by the following equation,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \tag{1}$$

$$sgn(x_j - x_i) = \begin{cases} +1, > (x_j - x_i) \\ 0, = (x_j - x_i) \\ -1, < (x_j - x_i) \end{cases} \tag{2}$$

An increasing trend will be the outcome if S is having a very high positive value and decreasing trend if S is having a very low negative value. To compute the probability associated with the calculated S and the sample size to obtain a significance of the trend, (Kendall, 1948) describes a normal – approximation test incorporating the Mann Kendall Statistic, S. A normalized test statistic, Z is computed along with the probability associated with the Z value, f(z).

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, S > 0 \\ 0, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, S < 0 \end{cases} \quad \text{where,} Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{t} t_i(i)(i-1)(2i+5)}{18} \tag{3}$$

Here, n = number of datasets, t = number of tied groups and t_i = number of datasets in the i^{th} group.

The probability density function, $f_{(z)}$ for a normal distribution with a mean of 0 and a standard deviation of 1 is given by,

$$f_{(z)} = \frac{1}{\sqrt{2\pi}} e^{\frac{z^2}{2}} \tag{4}$$

Taking a 95% significance level, trend will be determined to be decreasing if Z is negative and the probability is greater than 0.95. Similarly, the trend will be determined to be increasing if Z is positive and probability is greater than 0.95. If the probability is lesser than 0.95, then it was concluded that no trend is present in the datasets (Khambhammettu, P, 2005).

3.2 Theil-Sens Slope Estimator Test

To quantify and obtain a magnitude of the trends observed from the MK test, Sens Slope Estimator was used (Sridhar and Raviraj, 2017). Since the data sets used corresponds to the same time intervals and upon arranging the data sets in ascending order with time, the slope of each time series data pair was calculated using the following equation,

$$\mathrm{Q_k} = \frac{\mathrm{X_j - X_k}}{\mathrm{j-i}} \tag{5}$$

where j > k, X corresponds to a data value at a j/k time and k = 1,2,…N

Upon arranging the N values in ascending order, the median value of the Sens Slope, Qi will be calculated using the equation given below,

$$Q_i = \begin{cases} Q_{\frac{n+1}{2}}, if\ N\ is\ odd \\ \frac{1}{2}\left(Q_{\frac{n}{2}} + Q_{\frac{n+2}{2}}\right), if\ N\ is\ even \end{cases} \quad (6)$$

4 RESULTS AND DISCUSSION

Mann Kendall Trend test was used to identify any significant trends in the observed data and SRPs. Then in order to quantify the trends obtained, Sen's Slope Estimator was used on the datasets.

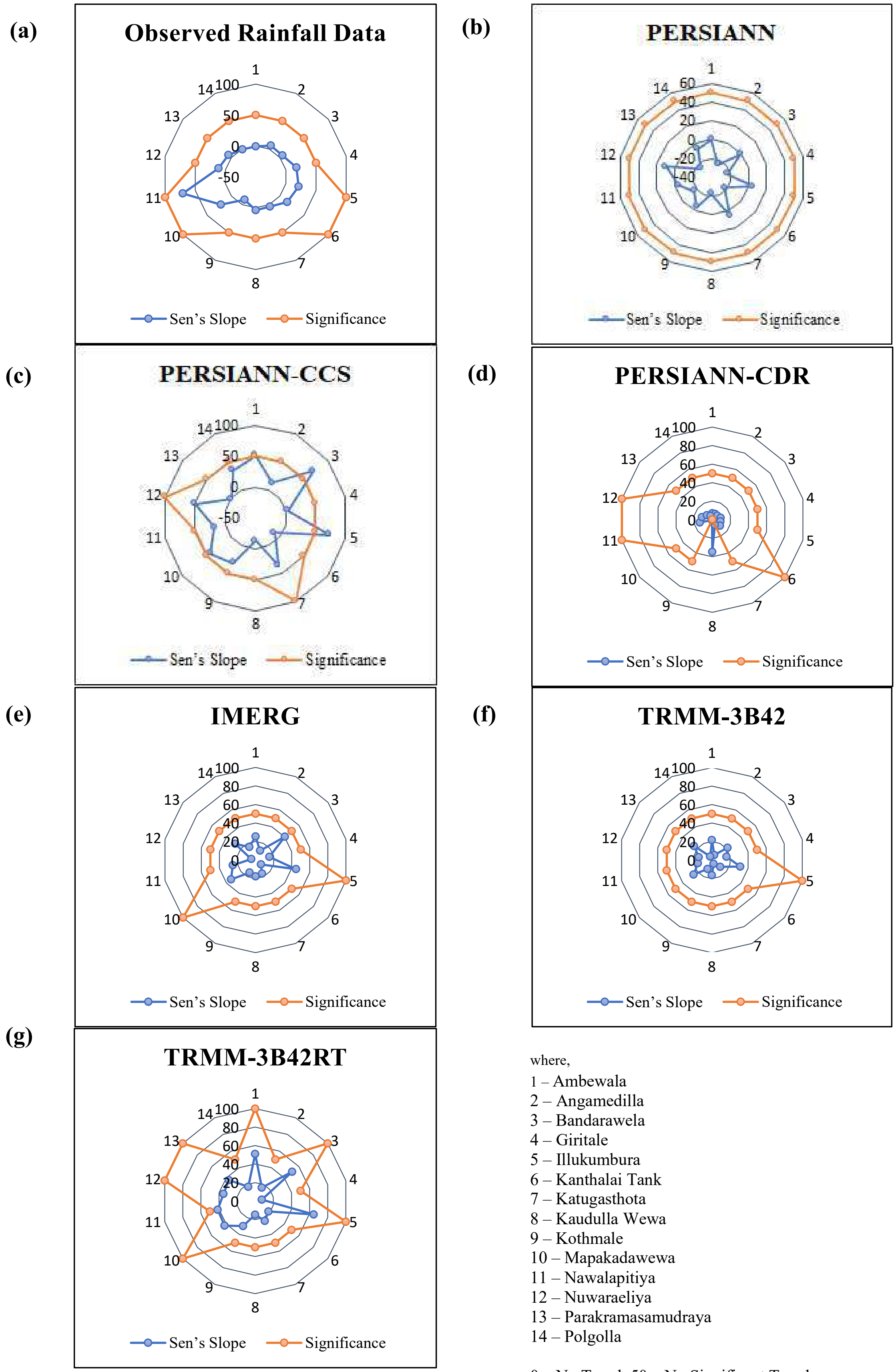
4.1 Mann Kendall Test

From the MK test that was performed for monthly, seasonal and annual time scales of the observed rainfall gauge data, showed significant increasing trends mostly in the intermediate zone of the catchment. Increasing trends in the seasonal analysis was mostly in the second inter-monsoon season. In the annual and monthly analysis, wet zone also showed significant increasing trends. IMERG product agreed more with the trends observed in the rainfall gauge data in the monthly and annual time scales. TRMM-3B42 showed significant increasing trends during the Second Inter monsoon in the intermediate zone. In TRMM-3B42 and PERSIANN-CDR, from the monthly analysis it was negative significant trends (dry zone) that were mostly observed. In all three time scales, PERSIANN-CCS showed increasing trends in the wet zone. However altogether, PERSIANN-CDR and TRMM-3B42RT showed mixed results while PERSIANN showed no significant trends in all three time scales.

4.2 Sens's Slope Estimator Test

The Sen's Slope (magnitude) of the trends obtained from MK test indicated a slope >1.5mm month-1 in the monthly analysis for the observed data. For the annual and seasonal analysis, the slopes were >20mm year-1 and >9mm month-1 respectively. In the monthly analysis IMERG indicated an increasing trend of >6mm month-1. High intensity increasing trend of >30mm year-1 in the annual time scale were observed in IMERG and both TRMM products. TRMM-3B42 showed increasing trends of >12mm month-1 during the second inter-monsoon season in the intermediate zone. The increasing trends shown by PERSIANN-CCS were >10mm year-1 in the annual analysis. The following Figure 12 highlights the MK and Sen's Slope Estimator results obtained for the annual time scale.

From this nonparametric analysis, the results concluded that IMERG product agrees more with observed rainfall data in monthly and annual time scales. This was further validated by Khalid et al., (2021) with his findings which concluded that IMERG product shows good agreement with rain gauge data when describing monthly trends in his study done in United Arab Emirates. Similarly, TRMM-3B42 appeared to agree more in the seasonal analysis and similar agreement in TRMM products has been observed in a study done in India which concluded that this product shows similar trend patterns to ground measured rainfall data in the annual and seasonal time scales (Mondal et al., 2018). So, depending on these results, careful choosing of products for the different zones in the catchment is required. It should be noted that the uncertainties observed in these products needs to be accounted for prior to using them in real-time applications (Mondal et al., 2018 and Feidas et al., 2006). This showed that even in the same catchment, products behave differently with trend patterns depending on the climatic seasons and zones of the catchment.



where,
1 – Ambewala
2 – Angamedilla
3 – Bandarawela
4 – Giritale
5 – Illukumbura
6 – Kanthalai Tank
7 – Katugasthota
8 – Kaudulla Wewa
9 – Kothmale
10 – Mapakadawewa
11 – Nawalapitiya
12 – Nuwaraeliya
13 – Parakramasamudraya
14 – Polgolla

0 – No Trend, 50 – No Significant Trend,
100 – Significant Trends

Figure 2. MK and Sen's Slope results for annual analysis (a) Observed Rainfall Data (b) PERSIANN, (c) PERSIANN-CCS, (d) PERSIANN-CDR, (e) IMERG, (f) TRMM-3B42, (g) TRMM-3B42RT

5 CONCLUSION

In this research study, six SRPs (PERSIANN, PERSIANN-CCS, PERSIANN-CDR, IMERG, TRMM-3B42, TRMM-3B42RT) were evaluated against observed rainfall gauge data. Observed data at 14 locations spatially distributed in the three climatic zones of the MRB, Sri Lanka were selected. The spatial resolution of the selected satellite products was also taken into consideration when selecting these station locations. From the non-parametric tests done on the two datasets (SRP and observed rainfall data) to identify any significant trends, it was concluded that IMERG product agrees more with observed rainfall data in monthly and annual time scales while TRMM-3B42 agrees more in the seasonal scale. In all three time scales, PERSIANN-CCS showed increasing trends in the wet zone. However altogether, PERSIANN-CDR and TRMM-3B42RT showed mixed results while PERSIANN showed no significant trends in all three time scales.

So, depending on these results, careful choosing of products for the different zones in the catchment is required. This showed that even in the same catchment, products behave differently with trend patterns depending on the climatic seasons and zones of the catchment. It was also clear that these products possess significant errors which cannot be ignored when using them in real-time hydrological applications. However, in places of scarce rainfall data in the MRB, IMERG product proved to be a better choice overall.

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Spatial Patterns and Temporal Trends of Rainfall Seasonality in Sri Lanka

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ABSTRACT

Understanding and knowledge of rainfall variability is necessitated for agricultural planning, flood mitigation activities, and water resources planning and management. Like other rainfall characteristics seasonality of rainfall is also spatio-temporally specific which has not been evaluated to Sri Lanka. In this study, seasonality in rainfall over Sri Lanka was analyzed using the seasonality index (SI) proposed by Walsh and Lawler. Rainfall data at 39 raingauge stations for the period 1988-2017 were collected to obtain the annual monthly rainfall cycles. The SI, a measure of annual rainfall distribution, was used to identify different rainfall regimes. Southwest and central highlands covering the stations Baddegama, Pelawatte, Kudawa, Deniyaya, Mawarella, Mapalana and Beausejour (lower) were identified as "equable with a definite wetter season". Skirting to the definite wetter season was the "rather seasonal with a short drier season" regime surrounding the Colombo, Ratmalana, Nuwara Eliya, and Bandarawela. The region centered on Mannar received the most rain in three months or less. Markedly seasonal with a long drier season is in the eastern extending from Pottuvil to Trincomalee and in the northern part of the country above Puttalam and Maha Illuppallama except the surrounding of Mannar. Intermediate region to SI classes "rather seasonal with a short drier season" and "markedly seasonal with a long drier season" was designated as "seasonal". However, the seasonal rainfall contribution, i.e., in NEM (Dec.-Feb.), IM1 (March-April), SWM (May-Sep.), and IM2 (Oct.-Nov.), and the annual monthly rainfall profiles confirmed the presence of sub-regimes within the identified rainfall regimes. Non-parametric Mann-Kendall test and Sen's slope were applied to identify the temporal changes in SI. Approximately, half of the country showed strong trends in the SI. Sixty one percent of the area including the northern part of the country surrounding Jaffna and the definite wetter region in the southern corresponds to the decreasing trend in seasonality.

KEYWORDS: *Intra-annual variation, rainfall regimes, rainfall variability, seasonality index, Sri Lanka, trend analysis.*

1 INTRODUCTION

Rainfall is the major component of the hydrological cycle. Many activities including agricultural, domestic, industrial, and hydropower generation rely on rainfall. Its variation depends on the topographical and geographical characteristics and is characterized by the seasonal distribution, intensity, duration, frequency, precipitation extremes, annual total rainfall, etc.

There have been many attempts to analyze the rainfall variability around the world. Among those attempts, empirical orthogonal function analysis (Sun, et al., 2012; Lyons, 1982), harmonic analysis (Horn & Bryson, 1960) and index-based methods (Walsh & Lawler, 1981; Oliver, 1980) are the most widely applied methods in the literature. Each of these methods has its own specific basis to identify the variations in rainfall. Out of these methods, index-based methods provide a value to identify and compare the characteristic features. An index is easier to interpret and enables better communication

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with the relevant sectors. There are many different indices such as climate change indices (Deniz, et al., 2011), Environmental indices (Dobbie & Dail, 2014), Water quality indices (Abbasi & Abbasi, 2012; Wickramagamage, 2010). Precipitation indices include Seasonality Index (SI) (Walsh & Lawler, 1981), Precipitation Concentration Index (PCI) (Oliver, 1980), Standard Precipitation Index (SPI) (WMO, 2012), and Gini index (GI) (Monjo & Martin-Vide, 2016), to name a few, developed for specific purposes. Both the SI and the PCI can be used to identify the rainfall regimes based on the intra-annual variations in rainfall considering the monthly rainfall distribution. The SI is more specific and has wider range providing a descriptive output on the intra-annual rainfall variation. It has been applied to countries such as Africa (Dunning, et al., 2016), India (Rai & Dimri, 2019) and China (Zeng, et al., 2003).

Sri Lanka has been generalized into three climate zones: wet zone, dry zone, and intermediate zone (Meteorology Department, 2021).This climate zone classification is based on the average annual rainfall distribution in Sri Lanka. The intra-annual variation of rainfall is not interpreted through this approach. There is not much research work to identify the variations of intra-annual rainfall seasonality in Sri Lanka. Further, many studies have been carried out to identify the trends in rainfall data, however those are limited to the trends in annual total rainfall, seasonal rainfall, rainfall extremes, monthly rainfall (Alahacoon & Edirisinghe, 2021; Naveendrakumar et al., 2018; Karunathilaka et al., 2017; Jayawardene et al., 2005;). This research study aims to apply the SI to identify the rainfall regimes with intra-annual rainfall variations in Sri Lanka and to evaluate its temporal changes.

2 METHODOLOGY

2.1 Study Area and Data

Sri Lanka is an island in the South Asia located between latitudes 5°-10° N and longitudes 79°-82° E. It has a tropical climate due to the moderating effect of the ocean winds. The mean annual rainfall of the country varies from less than 900 mm in southeastern and northwestern to more than 5000 mm in the western slope of the central highlands (Meteorology Department, 2021). Sri Lanka experiences four climatic seasons: SWM-SouthWest Monsoon (May to September), NEM-NorthEast Monsoon (December to February), IM1-first Inter-Monsoon (March to April), and IM2-second Inter-Monsoon (October to November) (Meteorology Department, 2021).

In this study, monthly rainfall data at 39 stations located over the country, representing the climate zones, were obtained from the Department of Meteorology, Sri Lanka (Figure 1). The most recent 10 years' period 2008 to 2017 was considered in analyzing the SI variability in Sri Lanka, while data from 1988-2017 was utilized for trend analysis in SI in some locations depending on the availability of data.

2.2 Seasonality Index

The SI was applied for the monthly rainfall data of the selected stations. It was developed by Walsh and Lawler in 1981. It measures the degree of seasonal variation in monthly rainfall. The intra-annual variation of the rainfall can be clarified clearly by considering the monthly rainfall distribution. This index method can also be used to demarcate the boundaries of the rainfall regimes (Walsh & Lawler, 1981). The SI is defined as;

$$SI = \frac{1}{\overline{R}_{annual}} \sum_{n=1}^{n=12} | \overline{R}_m - \overline{R}_{annual}/12| \qquad (1)$$

Where $\overline{R}_m$ is the mean monthly rainfall and $\overline{R}_{annual}$ is the mean annual rainfall.

This index varies from 0 to 1.83. The value 0 indicates equal rainfall in all months while a value of 1.83 refers to all rainfall in one month. Table 1 shows the classification of SI classes (Walsh & Lawler, 1981).

The SI calculated using mean monthly rainfall data is referred to as $\overline{SI}$ and the averaged SI value calculated for individual years is denoted as $\overline{SI_i}$.

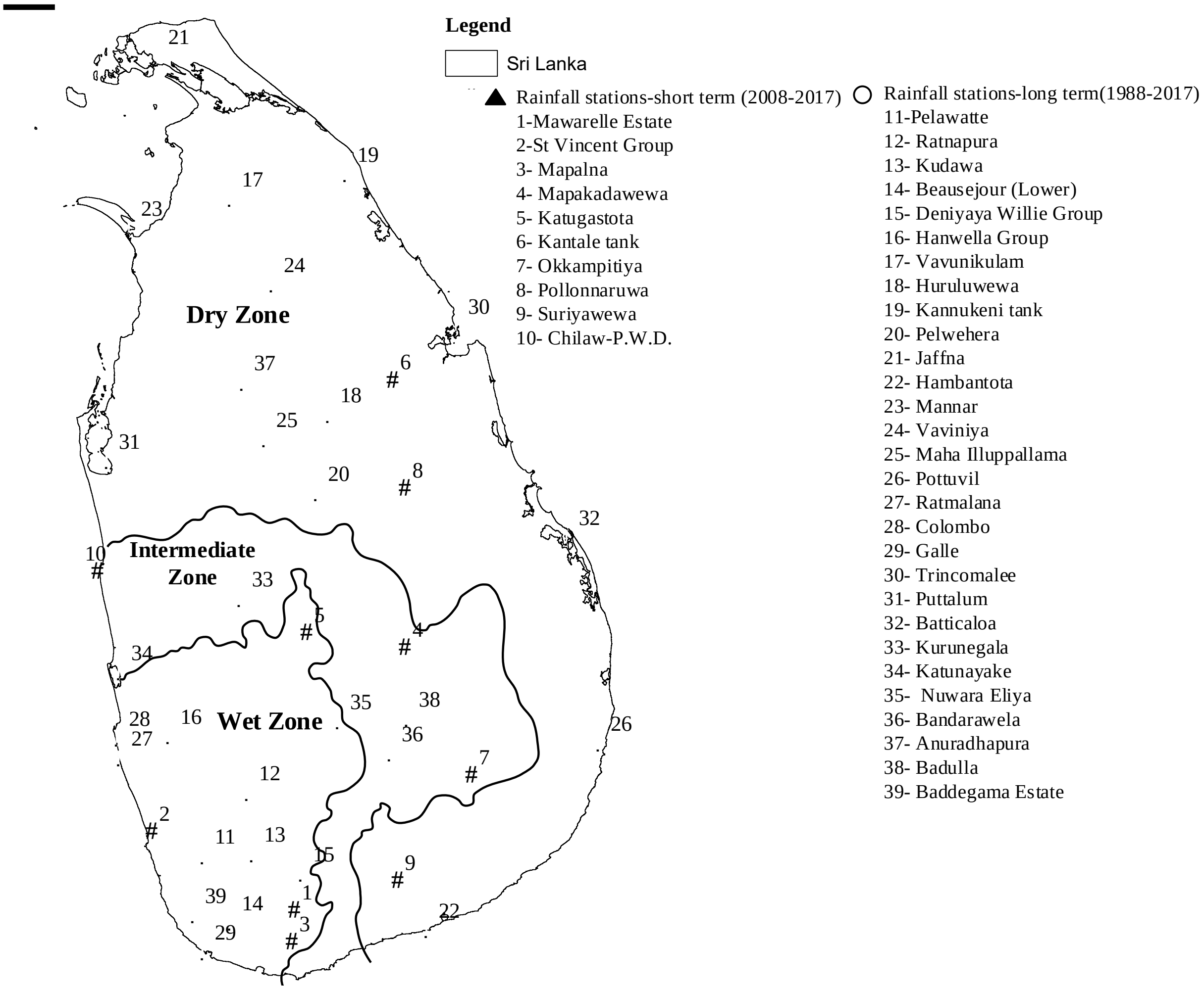

Figure 1. Location of the raingauge stations

Table 1. Seasonality index classes (Walsh & Lawler, 1981)

Rainfall regime	SI class limits
Very equable	≤0.19
Equable but with a definite wetter season	0.20-0.39
Rather seasonal with a short drier season	0.40-0.59
Seasonal	0.60-0.79
Markedly seasonal with a long drier season	0.80-0.99
Most rain in 3 months or less	1.00-1.19
Extreme, almost all rain in 1-2 months	≥1.20

2.3 Trend Analysis

Trend analysis is used to identify the significant changes in the temporal patterns in the $\overline{SI}_i$. This research study applied widely accepted non-parametric Mann Kendall test and Sen's slope estimator in identifying the trends in SI.

Static S is obtained from the Eq.(2).

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(SI_j - SI_k) \quad (2)$$

Where $sgn(SI_j - SI_k) = \begin{cases} +1, if\ (SI_j - SI_k) > 0 \\ 0, if\ (SI_j - SI_k) = 0 \\ -1, if\ (SI_j - SI_k) < 0 \end{cases}$, n is the number of years, SI_k and SI_j are from $k = 1,2,..,n-1$ and $j = k+1, \dots, n$.

The test statistic Z is given by

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, if\ S > 0 \\ 0, if\ S = 0 \\ \frac{S+1}{\sqrt{var(S)}}, if\ S < 0 \end{cases} \quad (3)$$

Where $var(S) = \frac{n(n-1)(2n+5)}{18}$

Positive values of Z indicate an increasing trend, and vice versa. In this study, 0.05 confidence level was used and the categories of trends are as in Table 2.

Table 2: Significance of the rainfall trends and the range of Z statistics

Categories	Scales
Very weak	0.1
Weak	0.1-0.19
Moderate	0.19-0.29
Strong	Above 0.29

The magnitude of the trend in SI was evaluated using the Sen's slope estimator(β).

$$\beta = median\left(\frac{SI_j - SI_i}{j - i}\right)$$

$\beta > 0$ indicates upward trend and vice versa.

3 RESULTS AND DISCUSSION

3.1 Seasonality Index Variation

Mean±std of the ratio $\frac{\overline{SI}}{\overline{SI}_i}$ was 0.90±0.21 indicating that no much degree of variation in the occurrence of the rainfall peaks and the troughs through time. The $\overline{SI}_i$ obtained for the selected stations for the period of 10 years were interpolated using the Inverse Distance Weighting (IDW) method. Figure 2 presents the SI map for Sri Lanka.

The obtained $\overline{SI}_i$ values vary from 0.26 in Pelawatte, close to the central highland to 1.04 in Mannar, in the southwest of the country. Mainly, four classes of rainfall regimes were present in the country based on the SI: Equable but with a definite wetter season, Seasonal, Rather seasonal with a short drier season, and markedly seasonal with a long drier season.

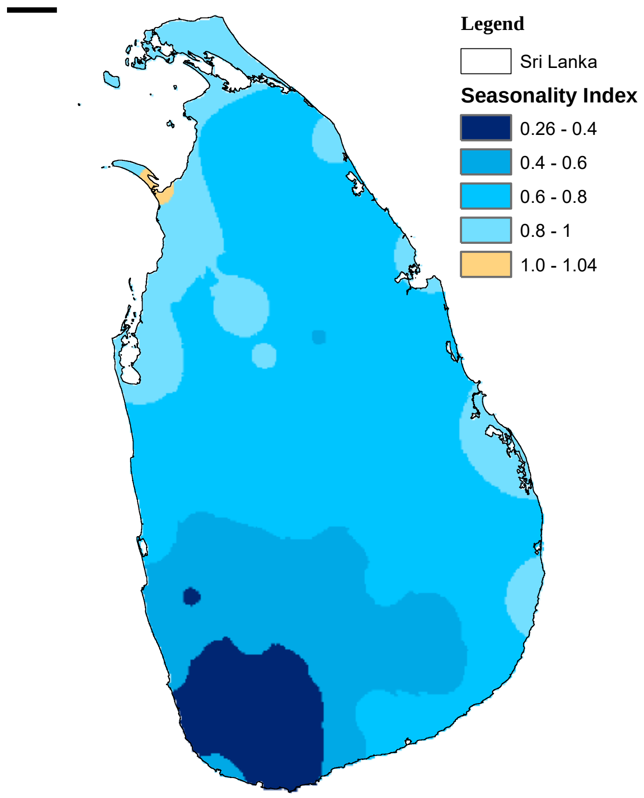

Figure 2. Seasonality index map of Sri Lanka

Southwestern region showed the lowest variation in monthly rainfall from the mean monthly rainfall providing the SI from 0.2 to 0.4 marking a definite wetter season. All stations shared a similar profile in monthly rainfall distribution receiving the lowest rainfall in the NEM. Stations closer to central highlands get quite high rainfall and decreases towards the stations in the lowland. Northwest to southeast coastal region extending from Puttalum to Pottuvil region shows markedly seasonal characteristics with a long drier season. Monthly rainfall profiles show disparity in shape due to the fall of rain in different seasons. Trincomalee, Pottuvil, and Batticaloa stations in the eastern part of the country receive substantial rainfall in the NEM and IM1, and experience dry season from March to September. Compared to eastern coast stations, Northern stations, i.e, Kannukeni tank, Jaffna, and Mannar receive rain only at the start of the NEM extending the dry season further. On the other hand, nearby stations Puttalum, Anuradhapura, and Maha Illupallama located in between northeast and west get rain mainly in the IM2, IM1, and at the start of the NEM. Skirting to the coastal belt rainfall regime extending up and around to the west and southeast is the region exhibiting seasonal characteristics. This ‘seasonal’ rainfall regime shows significant dissimilarities in the monthly rainfall profile. For example, rainfall stations, Chilaw, Suriyawewa, and Hambantota receives the lowest rainfall with mean monthly rainfall less than 100 mm. IM1, IM2, and NEM bring high rainfall to the stations just above the central highlands whereas northern stations, Vavunikulam, Vavuniya get comparatively less rain in IM1 and SWM. Mapakadawewa, Pollonnaruwa, and Kantale stations have similar profiles as eastern coast stations. Intermediate rainfall regime lies between the ‘seasonal’ and ‘markedly seasonal with a long drier season’ regimes with a shorter drier season. However, Okkampitiya, Huruluwewa, and Nuwara Eliya stations monthly rainfall profiles mismatched with that of other stations.

3.2 Trend Analysis

Z statistic varies from 1.96 to -1.88. Figure 3 shows Z statistic variation over the country and Figure 4 presents the change in SI per year. Out of the total area, 55%, 16%, 13%, and 16% of the area display strong, moderate, weak, and very weak trends in SI, respectively. Further, 35% of the area shows strong decreasing trend in SI while 20% of the area corresponds to the strong increasing trend. Mainly, southern and northern parts of the country show strong decreasing trend in the seasonality. Northeastern and southwestern areas exhibit strong increasing trend in seasonality.

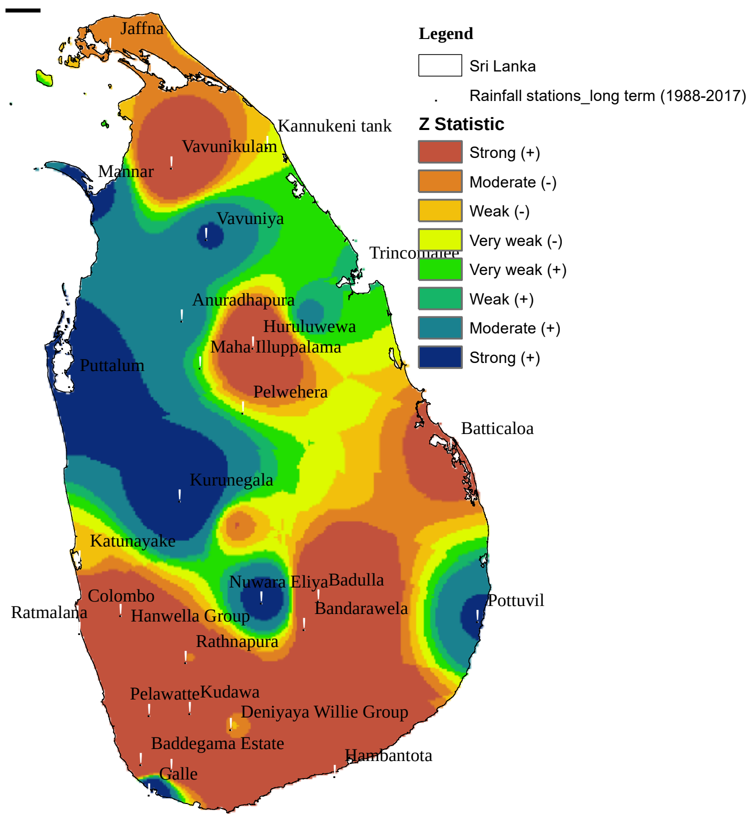

Figure 3. Z statistic variation over Sri Lanka

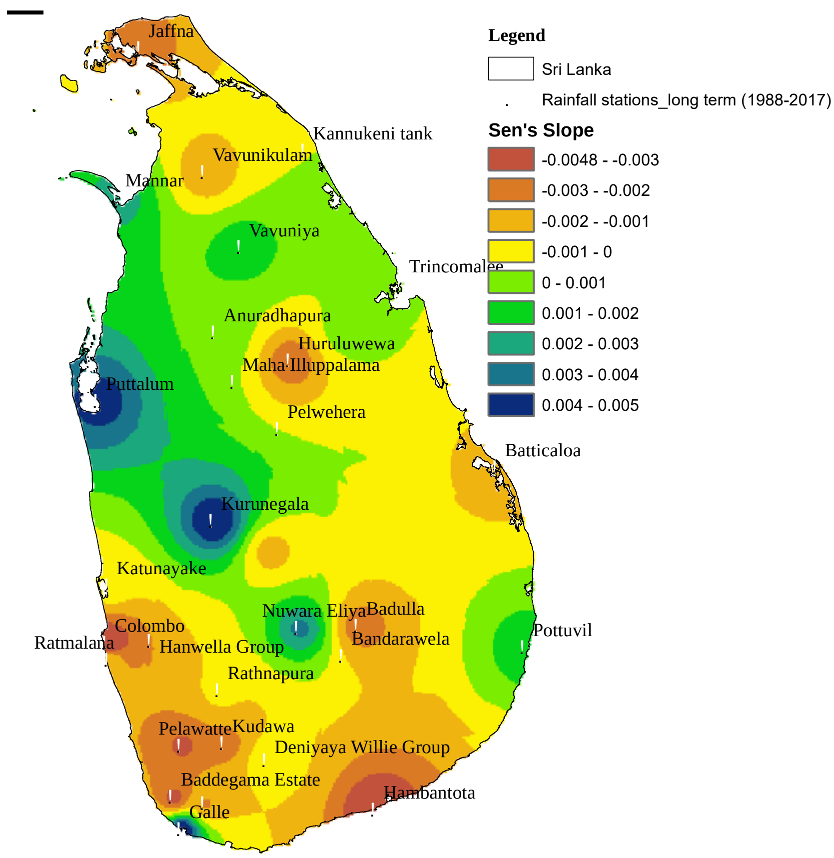

Figure 4. Sen’s Slope variation over Sri Lanka

4 CONLUSIONS

This study evaluates the seasonality index variation over Sri Lanka and its temporal trends for the period 1988-2017. Analysis of results showed the presence of four regimes: Equable but with a definite wetter season, Seasonal, Rather seasonal with a short drier season, and markedly seasonal with a long drier season. The SI is a measure of degree of variability of monthly rainfall distribution and not an indicator for intra-seasonal variation in rainfall pattern. Therefore, attempts should be made to revise the index to include the intra-seasonal variation leading to homogeneous rainfall regimes. Trend analysis results indicated that the 55% of the area has undergone a significant change in the SI over the 30-year period from 1988 to 2017. Rainfall regimes with a definite wetter season and short drier season and the northern part of the country showed a strong decreasing trend while long drier season areas, Mannar, Potuvil and Puttalum exhibited strong increasing trends in the seasonality. The findings of this research will provide possible avenues for introducing management and adaptation procedures.

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Affordable and Reliable Video Laryngoscope with Wireless Connectivity

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ABSTRACT

Along with the pandemic situation across the world, the resilience of using ordinary medical devices is limited. Also the demand for medical devices which are used to diagnose COVID-related diseases rapidly increased. Taking all these facts into consideration, a new laryngoscope device was developed with exciting functionalities. The proposed device is affordable and comes with remote monitoring capabilities. An ordinary video laryngoscope uses an expensive camera module to capture video streams, and the proposed device uses ordinary USB camera modules which are cheap and affordable. Therefore, it is even possible to replace/discard camera modules each time after investigating COVID-related patients. The proposed USB camera and Laryngoscopic blades can be easily replaced for a very affordable cost. In the proposed system, a real-time video stream can be remotely monitored in multiple displays, including personal mobile devices. Since the live video footage can be streamed across the world, expertise in the field can monitor and consult promptly. This device broadcasts video wirelessly through LAN (local area) and WAN (wide area) networks in real-time. So far, the device transmits live video streams wirelessly with less than 250ms latency on LAN networks, and 500ms to 1000ms latency in WAN networks. An inbuilt rechargeable power supply will power up the device for ~ 45min in continuous use.

KEYWORDS: *laryngoscope, wireless, anesthesia, covid, telemedicine, disposable, cost-effective, real-time.*

1 INTRODUCTION

Coronavirus (COVID-19) is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). It is spread through direct contact with respiratory droplets produced by coughing and sneezing from an infected person. Therefore, maintaining a social gap between one another was a top priority.

Laryngoscopy is a visual examination below the back of the throat, where the voice box (larynx) containing the vocal cords is located. Coronavirus symptoms are beginning from the upper part of the throat (M Sorbello, 2020). Video laryngoscopy reduces ambiguity and improves first-attempt intubation success. Also, they are used to inspect the damages and diseases of the upper parts of the throat. Due to the higher cost of ordinary laryngoscopes and their lack of reusability, it is even harder to discard after investigating COVID-related patients. Therefore, there are two main issues with this ordinary laryngoscope, safety issues arising with COVID-related patients and affordability issues with higher demand for the existing video laryngoscopes. Ordinary laryngoscopes are capable of replacing the

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Laryngoscopic blade after being used for one patient but when it comes to COVID-19 related patients, this replacement is not enough.

The proposed design uses ordinary USB camera modules which are cheaper and affordable. Therefore, the whole part that is contaminated to the COVID-related patient can be discarded or replaced completely. Other than this benefit, real-time video streams inside the throat can be remotely monitored in multiple displays, including personal mobile devices. Since the live video footage can be streamed across the world, expertise in the field can monitor and consult promptly.

1.1 Literature Review

One of the main requirements of the design is that there should not be any transmission delay between the transceiver and the display. This can be done easily by using high-performance hardware components, which results in increasing the design cost exponentially. Many countries have allocated funds for improving the reliability of medical devices during this period. Air ventilators, laryngoscopes are some of the popular medical devices that have attracted the attention of many organizations.

Most of the laryngoscopes that are designed to use in the pandemic situation have wireless video transmission capability with smart mobile phones (Gautham Sonal, 2019). The main drawback of this design is the transmission delay due to interference with another electronic device's wireless connection. Table 1 shows some devices that use inbuilt Wi-fi modules.

Table 1: Existing devices with their transmitters

Device Name	Transmitter
Wireless Ear Endoscope Otoscope	ESP8266
W-LAN MRI scanner	Realtek RTL8710
LYCEUM Ear probe	EMW165
Novel Video-Laryngoscope	Realtek RTL8710

As mentioned in table 1, each device used several types of wireless transmitters. For example, Raspberry Pi 3+ integrates BCM2837, IEEE 802.11 b/g/n and Orange PI zero uses ER819, IEEE 802.11 b/g/n. There are common characteristics to be considered when selecting the Wi-Fi module on the microcontroller for transmission. Table 2 indicate those characteristics and their background.

Table 2: Characteristics of Wi-Fi modules

Name of the Characteristic	Description
Protocol/ Standard/support	The modern wireless LAN standards that are included: 802.11 a/b/g/j/n/p/ac/ad. Each standard has different specifications and designers have to choose best according to the application.
Operating frequency	2.4GHz (2.4 – 2.483 GHz) – 802.11b/g/n 5 GHz (5.15 – 5.725 GHz) – 802.11a/h/j/n/ac 2.4GHz (5.85 – 5.9 GHz) – 802.11p
Transit Range	The range of Wi-fi networks depends on the number type of access points being used. The network range depends on the protocol employed, the overall power of the transmitter and the nature of obstructions and interference in the surrounding area.
Data rate (Max Throughput)	The theoretical maximum data rate of a Wi-Fi module could be from 1 Mbps (802.11 b) to 6.75Gb/s (802.11 ac). The best data rate should be selected by considering the thread-off and the application.

Whether the laryngoscope is wired or wireless, the camera that is used by the system has the same characteristics. A list of cameras along with specifications, which are uses for some common endoscopes are given in Table 2.

Table 3: Camera used by common endoscopes

Endoscope Model	Diameter	Sensor	Resolution	Frame rate (FPS)
KARLSTORZ Endoscope	5.5mm	CMOS	320 x 240 640 x 480	30
King vison Laryngoscope	8.0mm	CMOS	720 x 480 1280 x 720	30/60
Cold light endoscope	3.2mm	M.CMOS	320 x 240	15/30
TL-601 Laryngoscope	5.5mm	M.CMOS	640 x 480	60

Almost every camera has a CMOS sensor, and the average resolution is 640 x 480. The ideal frame rate is 30 and the diameter of the camera is between 3.2mm to 8.0mm. NVL - Wireless Image transmitting laryngoscope designed by the Anesthesiology Department of Central Hospital, New Mexico (TL-601 Laryngoscope, 2014) used ESP32 camera module for the laryngoscope design. The main drawback of this design is that the quality of the video is poor. ESP32 has a camera module that is connected through an SPI connection. King Vision Laryngoscope (king systems, 2017) uses a 5MP macro camera with an anti-fogging treatment for clear vision.

Wireless communication is the most popular communication method in medical electronic devices. (Rube, 2019). It enables healthcare professionals to be more watchful and connect with the patients proactively. Modern devices contain lots of electronic devices such as sensors, microcontrollers to communicate and track the device status and process.

A group of researchers (Rube, 2019) in the institute of medical science and technology in Scotland built a wireless MRI scanner that can communicate with the magnetic room while maintaining a sterile environment. Wireless ultrasound scanners are started to replace conventional scanners due to their reliability, portability, and affordability. As Clarius health care states (Checn, 2020), a wireless ultrasound and tablet is the most appropriate type of ultrasound equipment to evaluate individuals with the coronavirus and can be covered in single-use plastic for fewer contaminations.

2 METHODOLOGY AND RESULTS

2.1 Methodology

As the proposed design contains three main parts, laryngoscope module, receiver with display, and GUI/cloud network, each part needs to be discussed separately. Overview diagram of this system is mentioned in Figure 1 below,

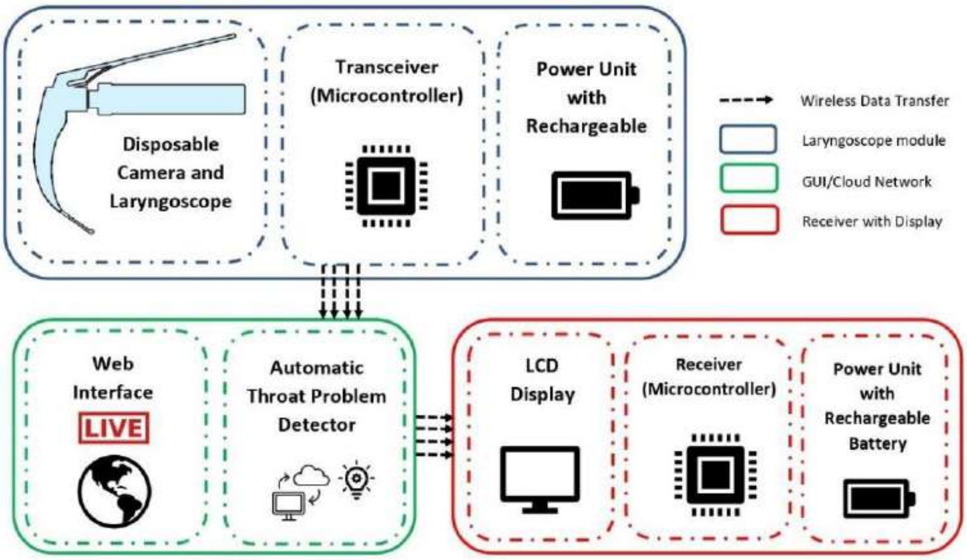

Figure 1. Laryngoscope Module

1. Laryngoscope module (as Transceiver)

As mentioned in the overview diagram above, this module consists of three subsections, a disposable camera with a laryngoscope blade, transceiver module, and power supply unit. The goal of this module is to capture clear video footage of the throat by using the endoscopic camera and transmit them to the display wirelessly.
A detailed view of this module is given in Figure 2 below,

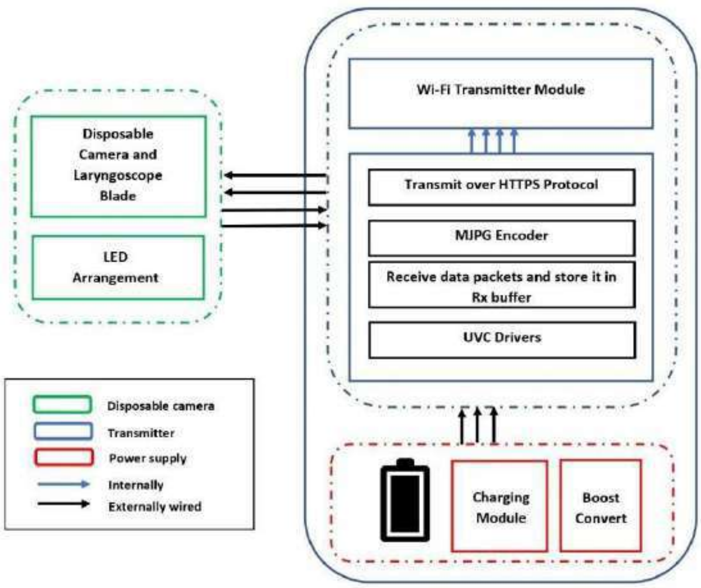

Figure 2. Detailed view of Laryngoscope module

Live video will be captured by the camera and sent to the transmitter through an external wired connection. Here, the Orange Pi Zero acts as the transmitter microcontroller. Once the video is received from the transceiver, it will be streamed over HTTP protocol. UVC (Universal Video Camera) directly produces JPEG data which allows fast and performant M-JPEG streams. This algorithm copies JPEG frames from the camera to an IP-based network. As shown in Figure 2, the power unit consists of a rechargeable battery, a charging module, and a boost converter supply power to the entire laryngoscope module. Also, this whole part can be categorized into two subparts,

- Disposable part - Camera with the laryngoscope
- In disposable part - Transmitter module with the power supply unit

Camera with laryngoscope

The main task of this part is the same as an ordinary laryngoscope but with a safer mechanism and accurate outcome for an affordable cost. Macintosh blade type is used for this proposed device. Adjustable LED set arranged inbuilt on the camera to increase the visibility inside the throat. It can be adjusted manually from the laryngoscope blade. This whole part is disposable, and it can be replaced for an affordable cost. The camera with laryngoscope is given in Figure 3 below,

Figure 3. Camera with laryngoscope

Transmitter

The main task of the transmitter is to get the video from the camera module and transmit it to the cloud network. This should be executed within a short amount of time. Both the power unit and the transmitter are implemented inside the same enclosure. The power unit powers up the transmitter module and all the other components will be powered by using this transmitter. Power unit and transmitter module cannot be disposed of after single use. The camera module and the blade can be replaced or discarded completely after a single-use. Since the transmitter has a USB interface to connect the camera, almost all the aftermarket USB cameras can be connected without the aid of an external interface. This unlocks the capability to connect most of the medical-grade cameras to the device. The portability of this device is much higher due to rechargeable capabilities. Devices can be changed easily by using standard 5V/2A mobile phone chargers. Inside of the transmitter is given in Figure 4 below,

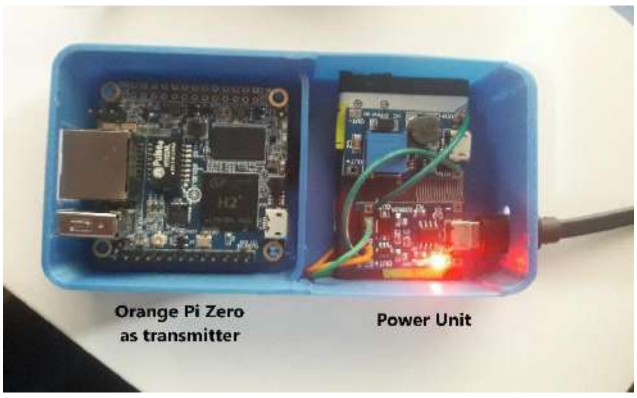

Figure 4. Inside of the transmitter module

The prototype of the final laryngoscope module is mentioned in Figure 5 below,

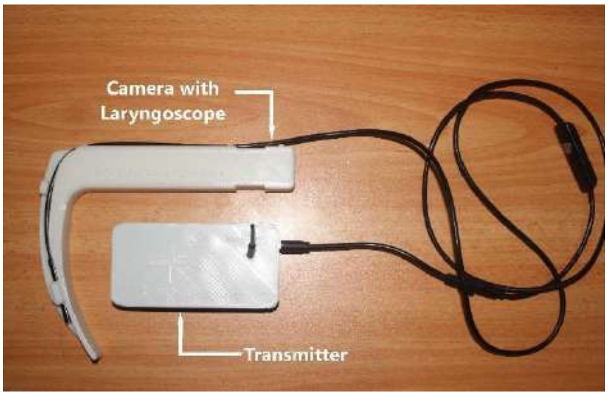

Figure 5. Final prototype of the laryngoscope Module

2. GUI/Cloud Network

This cloud network transmits the video feed to additional monitors. Also, it allows any device with wireless connectivity to stream the video from the laryngoscope wirelessly. The received video from the transceiver is broadcast by a web application over a wide area network where any number of users can log in to the session and watch the video at the same time.

The system's input plugin is a Linux-UVC compatible USB camera in the transceiver section. The Video4Linux (V4L2) driver package is used to connect the camera to the OS. The camera's JPG frames will be captured and streamed as M-JPEG to web browsers through HTTP. To connect to the camera, a HTTP URL can be used as a token. The same streaming port should be port forwarded to the cloud services to stream the video. In the web application, a section called 'LIVE' was developed with immediate access to the receiving video. In this project, static IP was utilized to ensure that the IP address did not change frequently. A snapshot of the graphical user interface (GUI) is mentioned in Figure 6 below,

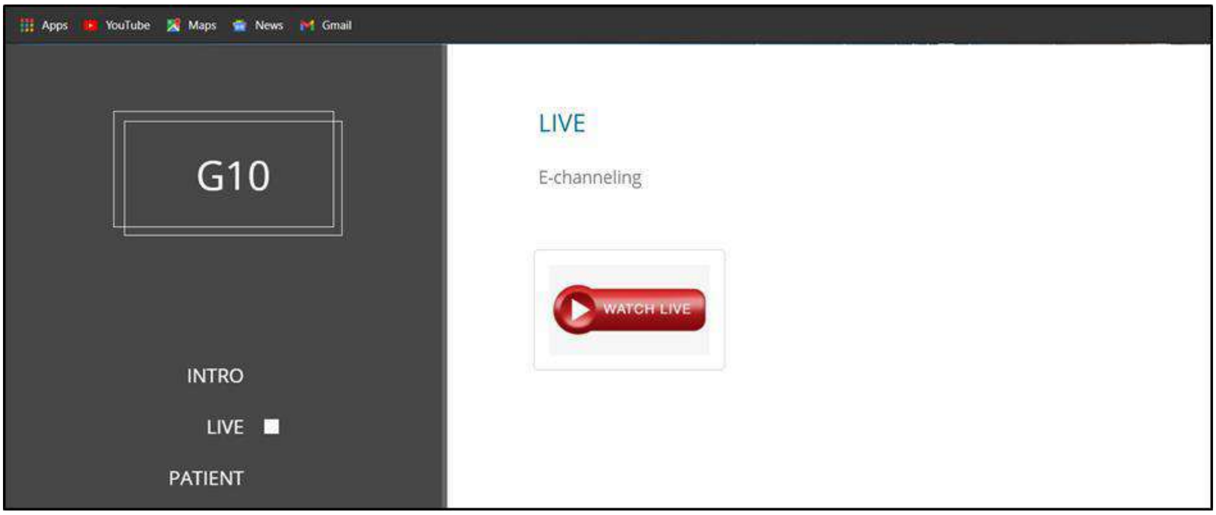

Figure 6. Photo of the GUI

As future improvements, this part can be further extended into several other features. This includes,

- Image processing solution to detect throat problems automatically.

Some of the throat/vocal cord diseases require confirmation through a microscope, while others can be detected by monitoring just the video feedback from the laryngoscope. In the absence of medical personnel, gastroesophageal reflux disease, ulcers, cancer links, inflammation or swelling, blockages, and precancerous abnormalities such as Barrett's esophagus can be detected using a trained AI model. This model can predict the condition of the patient using input data received from the transmitter. The model may be trained and obtain real-time predictions using a Raspberry Pi model 3b or a Jetson nano development kit.

- Can be synced with the hospital database.
- Cloud storage to save patient details along with the video

3. Receiver with Display

This part also consists of three main parts which are LCD, receiver module, and power supply unit. This is the screen that medical officers use to stream live video. It is portable and wirelessly connected to the laryngoscope through WAN or LAN. This can be either used separately with the laryngoscope or can be mounted into the laryngoscope if necessary. Unlike normal LED screens, this device can stream the video from a laryngoscope wirelessly. Raspberry Pi 3b acts as the receiver inside this device. A similar type of power supply that uses for the laryngoscope module is used to power up the receiver. Some of the major factors that are considered on this part are the weight and video receiving latency. Latency should be minimized to watch the video in real-time. At the same time, the size should be minimized, because medical offers use this from a single hand, and this will affect the total weight of the blade too. Photo of the device inside and the display of the device is given in figure 7 and figure 8 respectively.

Figure 7. Inside viewer of the receiver module

Figure 8. Receiver with Display

2.2 Results

Final testing was done under 2 phases, the initial test on 1st phase and the final optimized test on the 2nd phase. Table 4 shows the latency of the initial test done on PC via local area network was almost real-time.

Table 4. Latency with Resolutions

Resolution	**Phase 1**	Host OS: Windows 10 Browser: Microsoft Edge 11 Network: Wi-Fi Object: Kodak camera	**Phase 2**	Host OS: Windows 10 Browser: Microsoft Edge 11 Network: Wi-Fi Object: Calculator
	Latency(seconds)		**Latency(seconds)**	
320 × 240	Less than 0.5		Less than 0.5	
640 × 480	Less than 0.5		Less than 0.5	

The following Table 5 shows the latency of the initial test done on mobile via the local area network.

Table 5. Latency with Resolutions (Mobile)

Resolution	**Phase 1**	Host OS: Android 9.1 Browser: Google chrome Network: Wi-Fi Object: Kodak camera	**Phase 2**	Host OS: Android 9.1 Browser: Google chrome Network: Wi-Fi Object: Calculator
	Latency(seconds)		**Latency(seconds)**	
320 × 240	Less than 0.5 and 1.0		Less than 0.5	
640 × 480	Less than 0.5 and 1.0		Less than 0.5	

The following Table 6 shows cloud network latency.

Table 6. Cloud network latency

Resolution	**Latency (seconds)**	**Framerate per second (FPS)**
320 × 240	Less than 0.5	30/15
640 × 480	Less than 0.5	30/15

Photos of the completed transmitter module, disposable camera, and blade are given in Figure 9,

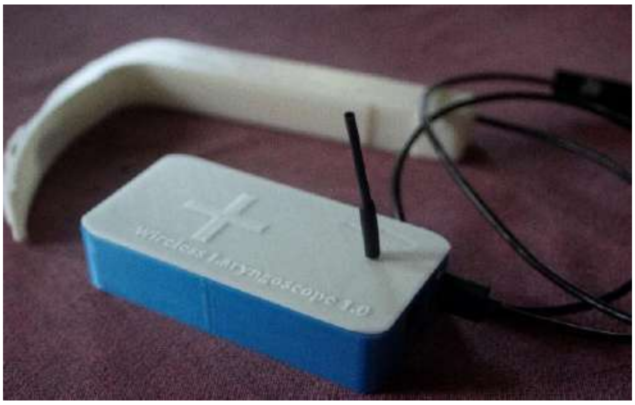

Figure 9. Complete prototype

Figure 10 and Figure 11 are the sample photos taken from the final product.

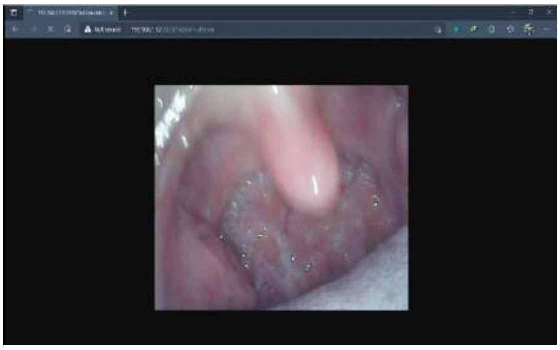

Figure 10. Sample photo 1 taken from the prototype

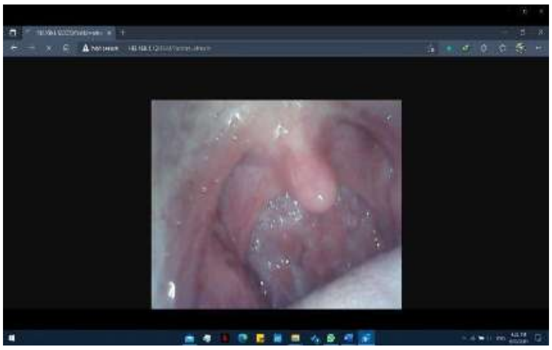

Figure 11. Sample photo 2 taken from the prototype

In Sri Lanka, a typical laryngoscope costs between 200,000 and 600,000 LKR. The entire design was accomplished while keeping the overall cost to a minimum. The cost of the complete product is 10 340 LKR in total. An ordinary video laryngoscope costs roughly Rs.400 000 on average. The proposed solutions' cost is 2.6% of the ordinary laryngoscope. Furthermore, a traditional laryngoscope had to germicide the Laryngoscopic camera and the blade each time it was used, while our device includes a low-cost disposable camera that can be discarded after one usage.

3 CONCLUSION

In comparison to existing laryngoscopes on the market, we have developed this device to address the safety difficulties that standard video laryngoscopes confront in a pandemic situation and are far less expensive, making them more accessible to developing countries. Upgrading the ordinary laryngoscope with wireless connectivity is the proposed solution for safety risks. It minimizes medical officials' safety concerns, but the video stream's reliability is reduced as a result of the transmission lag in wireless latency. This latency was minimized to less than 0.5 seconds after multiple tests and optimization approaches, which is practically real-time and adequate for laryngoscopy. The developed wireless laryngoscope is 2.6% of the average cost of the ordinary laryngoscope. Mounting a portable wireless screen on the blade that will guide the medical officers to get the maximum visibility of the throat, using of transparent cover on the camera to overcome health issues that can be occurred due to the use of a consumer-grade camera, developing AI model to automatic detection, and implementing a battery level indicator to increase the user-friendliness are some future improvements that can be carried out by this device.

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Semi-Automated Spice Packaging Machine for Middle Scale Business in Sri Lanka

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ABSTRACT

In Sri Lanka, small scale spice packaging businesses use traditional methods while middle scale spice packaging businesses use separate machineries for each individual tasks such as weighing, filling, and sealing processes. Comparatively, considering the higher demand for large-scale spice products in the market, they use highly expensive, technically improved, automated machinery. According to the researches and the site visits, it is observed that currently, there is no affordable packaging machine available in the local market for middle scale businessmen, which includes all weighing, filling and sealing processes in a single system. Therefore, it limits their profits and production. The current used methods in middle scale businesses cause high wastage of raw materials, less accuracy, less hygienic, higher labor costs, and low efficiency. This project proposes a semi-automated, Arduino based machinery for middle scale spice packaging business where a packet is fed manually to the system, while weighing, filling, and sealing processes are automated and sequentially completed. The operation of this machine can be carried out with an involvement of a single laborer. The designed product is pneumatic based and uses some sensors for position, weighing and level detection, heating element, stepper motors, pneumatic system components for smooth operation and Arduino as the micro controller to make it cost effective. With this innovative structure, three packets can be filled and sealed within fifteen seconds while the current used method takes fifteen seconds to complete this process for a single packet. Cost and time effectiveness, reducing ingredient wastage and labor cost are the main advantages of this project. Due to the COVID-19 health restrictions, the hardware implementation is partially completed but to illustrate the working principle and the design plan, a 3D animated model was implemented using SolidWorks, incorporated with electrical stimulation in the Proteus software package.

KEYWORDS: *Packaging-machine, Middle-scale, Pneumatics, Weighing, Sealing, Semi-Automated.*

1 INTRODUCTION

Spices are widely consumed in culinary and other food products which increases its demand day by day. Depending on the per capita income, most of Sri Lankans attract towards medium quality products. The ease in initiation and operation, less legal barriers also affect in people to choose small and medium scale businesses as their source of income.

Most of the middle scale and small-scale businesses do the spice packaging process by using time consuming and laborious conventional methods, since the fully autonomated machines used in large scale businesses are not at all affordable for the middle scale spice packaging businessmen.

The issues identified in the local middle scale chili powder packaging business are gathered through a local middle scale spice packaging business owner and the design is also manufactured considering his requirements. The identified issues are, ingredient wastage, inability and uncomfortable to attend in this process for long hours due to the burning nature of the chilli powder, inaccurate weight measurements etc. These reasons result in less productivity of the business.

According to the research carried out, it is identified that in most of the middle scale businesses the packet doesn't come in a printed roll instead it is purchased separately with the middle and the bottom borders sealed where only the top border is not sealed. The reason for this is that middle scale businesses don't have high profits. Therefore, it is difficult for them to invest in expensive machinery and if they go for a machine where a packet roll is fed, they have to change their entire system and also have to invest and bear expenses related to packet material, printing cost etc. at once. Furthermore, since middle scale spice products don't have a high demand in the market a high output is not required, therefore, a fully automated machine doesn't match their requirements.

Low-cost automation is a safe strategy to cope up with the market competition. The originality of this product is that currently, there's no machine available in the market for middle scale spice packaging business in the local market (in Sri Lanka) where separate packets are fed to the machine instead of a packet roll. The designed machine is a semi-automated machine, and it can be operated by either skilled or non-skilled single laborer.

The automated processes are,

- weighing the powder quantity
- filling the packet with powder
- sealing the packet
- moving the packet to each packet filling, sealing and packet feeding stations.

Arduino based automation is used to reduce the overall cost of the machine since PLC based automation is costlier. In-order to obtain a smooth operation and make the machine more efficient pneumatic systems, stepper motors are used.

This research is an attempt and an innovative approach to design and manufacture a packaging machine for middle scale businesses as an affordable and efficient alternative solution to currently used packaging machinery.

2 OBJECTIVE

The major Objectives of this project are,

- To make a machine which is time efficient compared to the current used solutions.
- To reduce the production of ingredient waste.
- To design a spice packaging machine which is cost effective to the middle scale businessmen, compared to the current used methods.
- To manufacture a machine requiring less space.
- To make the machine easy in handling, user-friendly.
- To measure the weight measurements of the powder accurately.

3 BACKGROUND READING

3.1 Packet feeding, holding, opening and moving mechanisms

In 2018, A rotary pouch packing machine is designed by Viking Masek (Leonhard, 2021) to move the packets along with the filling, sealing processes, using a vacuum suction cup mechanism moved by a robotic arm which would pass the bags to the grippers that are controlled by pneumatic systems or motors. The grippers hold the packet once the proximity sensor detects a packet. The speed of it is up to 200 bags per minute. The bag is also inflated by an air blower. These opening jaws (figure 1) moves separately outward in order to open the packet. The packet is filled only if a packet is detected, opened and placed correctly. Two rectangular suction cups are used in order to open the packet at the either side of the packet.

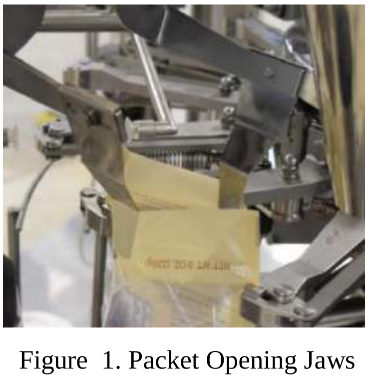

Figure 1. Packet Opening Jaws

3.2 Research on Load Cell

According (Schwartz, 2008), the load cell which is a force transducer converts an input mechanical force such as load, weight, tension, compression or pressure into an electrical output signal. Strain gauges are applied onto a mechanical spring that deform when a weight force is applied, and this deformation is detected by the strain gauges and converted into an electrical resistance change

The setup is in figure 2; The opposite force to the applied load is produced by the elastic deformation of the mechanical spring "1" which contains four strain gauges. Two strain gauges "2,3" are compressed (resistance lowering) and two "4,5" are stretched (resistance rising). The change of the total load-dependent resistance is detected as a voltage signal in the Wheatstone bridge circuit and electronically processed. The following figure is what was explained above on strain gauge load cell.

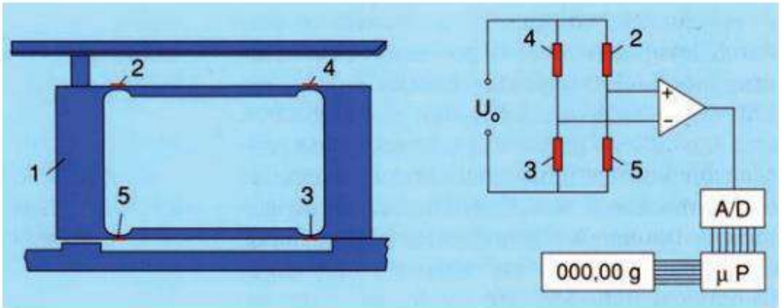

Figure 2. The set-up of a weighing instrument with a strain gauge load cell

HX711 module

The strain gauge in a load cell generates an electrical signal which has a few millivolts amplitude Therefore, it should be amplified by an amplifier. The most used amplifier is the HX711 weighing sensor module which is 24-bit analog to digital converter (ADC) and a simple digital pin-driven controlled system, so no programming is needed for the internal registers. The following features can be identified in the HX711 module.

- Two selectable differential input channels; gain of 128/64 for channel A and 32 for channel B, corresponding to a full-scale differential input voltage of ±20mV or ±40mV respectively.
- In built power supply regulator for load-cell and ADC analog power supply
- There is an on-chip oscillator, so an external clock source is not needed.

3.3 Different methods of sealing for food packaging.

- **Ultrasonic sealing**

Ultrasonic welding is an established and well-known method for joining polymers. This method of welding plastic parts has comparatively short welding times. During ultrasonic welding, the polymer parts or films get compressed and oscillated by longitudinal vibrations of the tool, the horn. A high frequency electrical field is converted into a mechanical oscillation within the so-called converter, typically made up of piezoelectric transducers (Sealing Technology, 2003).

- **Heat sealing**

Generally, heat seal technology is used in packaging made of thermoplastic material as this technology can easily produce bags used in packaging (Sealing Technology, 2020). Basis of heat sealing relies on the foundation of adhesion where a combination of heat, time and pressure create a seal with a set of crimp seal heating bars. When the jaws come together, this melts a layer of plastic and bonds the two layers of film together. Some mechanisms used in heat sealing include chain bonding, wedge bonding, vacuum bonding, intermolecular bonding, and static electric bonding.

Factors affecting heat seal quality:

- **Temperature effect**

The commonest shape of packaging materials utilizing laminate films is the bag or pouch. These are manufactured with different types of sealing technologies, such as chemical adhesives, ultrasonic welding, heat sealing, impulse heat sealing, hot air welding, etc. Heat seals are made by fusing the polymers to one another through the application of heat and pressure. The initial pressure enables intimate contact between the films. Adhesion is promoted by application of heat from the outside.

- **Wear resistance**

Electrical heating elements should have a high resistivity in order that the dimensions may be consistent with a compact design and mechanical strength while keeping the current to acceptable values; Heat sealing tapes consist of a substrate, which is the surface that comes into contact with the plastic, and an adhesive, which firmly bonds the substrate to the sealing machine. Fundamentally, heat sealing tapes must transfer thermal energy from the hot platen to the plastic without allowing the plastic to adhere to the tape.

- **Seal pressure**

Many studies indicate that any increase above the required level of sealing pressure, which is adequate to supply full contact between layers does not affect the sealing temperature and sealing strength significantly. Also, according to Najarzadeh and Ajji, increasing the seal pressure from at a very low level such as from 0.1 to 0.5 N/mm2 will decrease the seal initiation temperature. In that range, increased pressure provides better contact between two film layers. However, above that level, seal initiation temperature does not show any chance.

- **Cooling rate**

Controlling the cooling rate that influences crystal growth may help to enhance seal strength. Films showing a faster crystallization behavior had higher hot tack strength at temperatures lower than the temperature that supplies total melt of the crystals. This means that at the low temperatures, the seal strength will be enhanced by solidification due to quickly starting recrystallization.

3.4 Key attributes of the packing machines currently used in the spice packaging industry.

Table 1 Currently used machines for spice packaging

Company	Figure	Comment
Alibaba	 Figure 3. Chili powder packing machine	All the weighing, filling, sealing processes are included. Polythene rolls are used to form the packets. Rs.1, 375, 304.08

Dunuwila Traders	 Figure 4. Automatic powder filling machine	Filling process only Voltage 220V 50HZ Power 100w Filling Speed: 05 – 10bags per min (50g& 100g) Semi-Automatic
Dunuwila Traders	 Figure 5. Automatic powder packing machine	All the weighing, filling, sealing processes are included Voltage 220V 50HZ Power 500w Fully Automatic Filling Speed: 10 – 15bags per min (50g / 100g)

Most of the packaging machines used in the industry, uses the packing rollers to make the packets as shown in the above table and these machines are used for packaging businesses which carry out a bulk production. But since middle scale businesses do not require a bulk production, they always purchase separate equipment for each weighing, filling and sealing processes when doing packaging. Such machines which were observed during the site visits are listed below.

Table 2. Machines identified through site visit

Company	Figure	Comment
Sarupa Rasa Piyasa, Athurugiriya	 Figure 6- Intelligent Weighing Scale & Filling Machine	Filling process only Rs.110,000.00

Sarupa Rasa Piyasa, Athurugiriya	 Figure 7. Stainless Steel Band Sealer (Horizontal)	Sealing process only Rs.68,500.00

4 METHODOLGY

The project consists of two main parts, called hardware and software. The hardware part of the machine focused on three main sub-mechanisms, namely the packet moving mechanism, the powder filling mechanism, and the packet sealing mechanism. In all these mechanisms, pneumatics is the main controlling system used, since it has more reliable components and a long operating life, and is cheaper than hydraulics, especially since the required maintenance is less.

Moreover, most of the current autonomated machines use PLC as the programming board. In this project, the chosen programming board is the Arduino. More memory, as well as a large number of input and output pins, are required to process a large code. Considering the flesh memory, SRAM, and the number of input/output pins, the Arduino Mega is used to program the machine.

4.1 Overview of the project

The process flow of the designed machine is as below (figure 8).

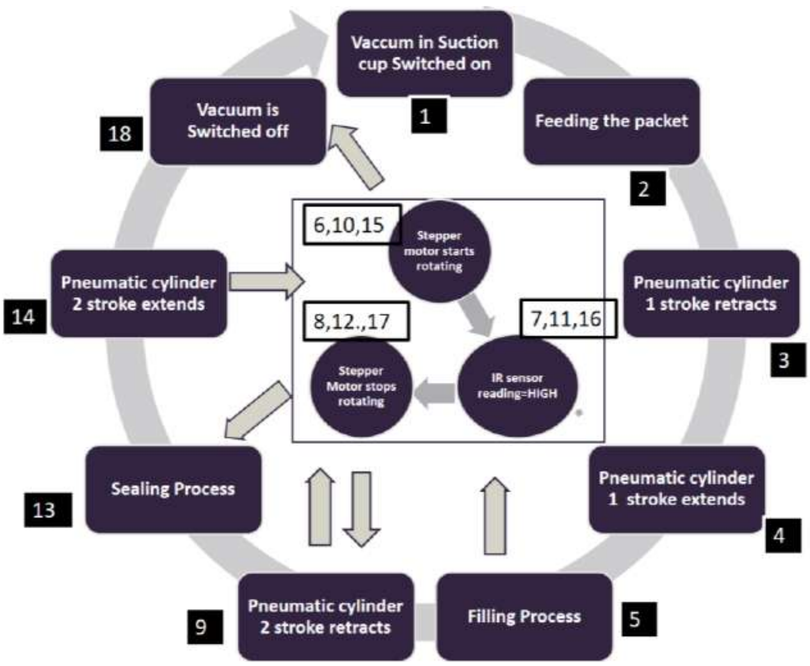

Figure 8. Complete process flow of the designed machine

Process happens as per the sequence - 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18, and the same sequence repeats.

Initially, the vacuum is switched ON when the power is switched on and the suction is turned on as well. Then the process starts with an empty printed polythene packet being fed to the two stationary suction cups. The stroke of the pneumatic cylinder at the packet feeding station retracts, moving the vertical bar where the suction cup is attached forward to hold the packet. Next, the stroke of the pneumatic cylinder extends, and the packet is opened due to the force generated by the tension of the spring draws back the vertical bar. Then the packet is moved to the filling section.

The storage tank, gutter, and vessel are the three basic parts of the powder filling structure. The storage tank is used to store the spices for the filling process, and the gutter is placed next to it to control the flow of the spices. Next to the gutter section is the vessel, which is the part that connects to the packet and fills it with powder. Side view of the powder filling section is shown in below figure 9 and figure 10.

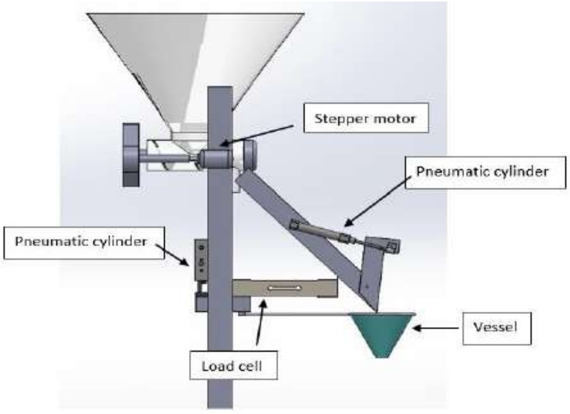

Figure 9. Solid works design for the powder weighing and filling processes

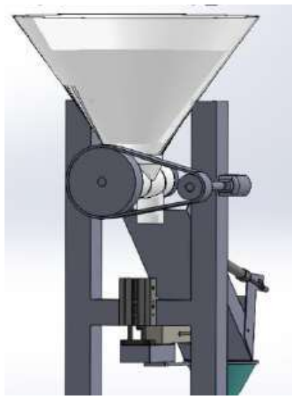

Figure 10. Gear system to connect screw to the stepper motor

The powder is first stored in the storage tank, and then when the machine is turned on, the screw rotates, moving the powder towards the gutter. The powder is then dumped into the gutter until the load cell reading reaches 100 grams (a pre-defined value). When that value is set, the IR sensor reading should be used to determine whether the packet has arrived at the filling region. As a result, if the packet has arrived, the twin-rod pneumatic cylinder should extend its stroke to the gutter. Because the entire gutter part is connected to the pneumatic cylinder, this is possible. Then the other pneumatic cylinder, which is the CDJ2D10-30 mini round cylinder, should extrude its stroke since the lid of the gutter is connected to it. As a result, when the packet is opened, the powder is loaded into the packet. Finally, when the load cell signal indicates that the load has been reset, the mini round cylinder extends the stroke to close the lid, and the TN 25X50 Twin rod cylinder extrudes the stroke to raise the entire gutter section. The process flow of the designed machine is as below figure 11.

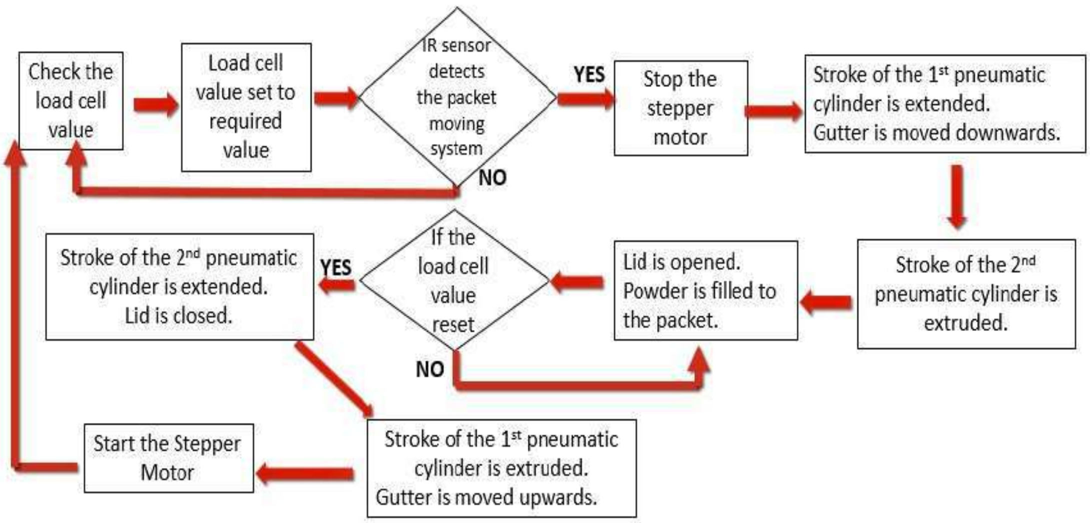

Figure 11. Process flow of the filling section

When the powder filling process done packet moves to the sealing station with stepper motor rotation. When the package arrives at the sealing station, the pneumatic cylinder mounted on the table retracts and ready to start sealing process.

Two pneumatic cylinders played the most important parts in the sealing process. Each pneumatic piston is connected with two separate metal plates. As shown in the below figure 12, the heating element is joined to the bottom pneumatic cylinder, and the other plate has silicon rubber connected to compress the packet. Finally, Teflon tape was covered both the silicon rubber and the element. Then the always packet should only be in contact with Teflon tape; as a result, the seal should be very smooth.

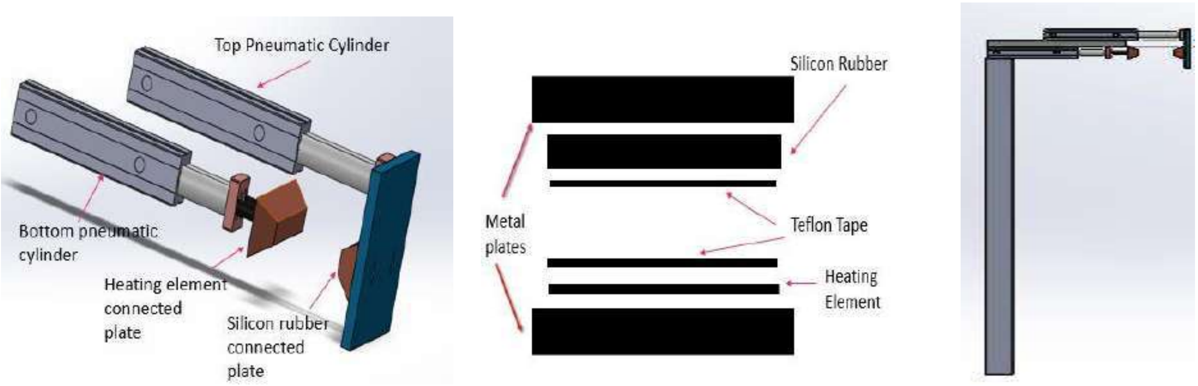

Figure 12. Cross sections of the sealing plate arrangements and the sealing station

The top piston is in the maximum stroke position at the start of the sealing process, while the bottom piston is in the minimum stroke position. The Arduino sends a signal to pneumatic valves when the packet arrives between two plates. The top pneumatic cylinder's piston moves backward, while the bottom pneumatic cylinder's piston goes forward, according to that signal. The element is then passed through a current, which heats up the heating element. As a result, the polythene layers softly melt, and the sealing process is completed once the packet is sealed. After the packet is sealed, the circuit from the relay is disconnected, and the pneumatics are allowed to cool for 1 second. Both pneumatics then returned to their original positions.

The vacuum is turned off once the packet is sealed. When the vacuum is turned off, the stationary pneumatic cylinder at the base extends its stroke, and the packet is discharged to the gutter slope, where it falls into the box that collects the completed packets

When the hardware implementation was decided, it was decided to remove the outer ring from the hardware element in order to reduce production costs. Solid work design for the proposed machine shown in below figure 13.

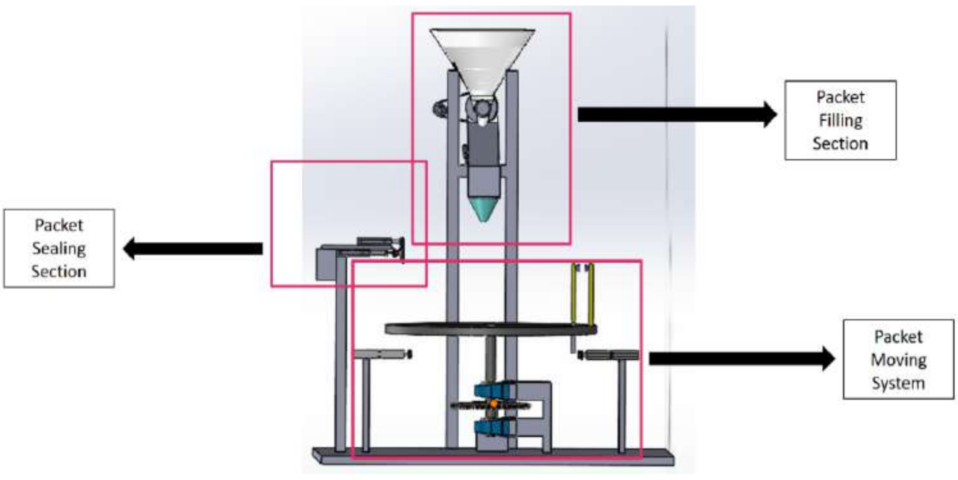

Figure 13. Finalized Solid work design of the machine

The method of powering up the sealing element is shown below figure 14.

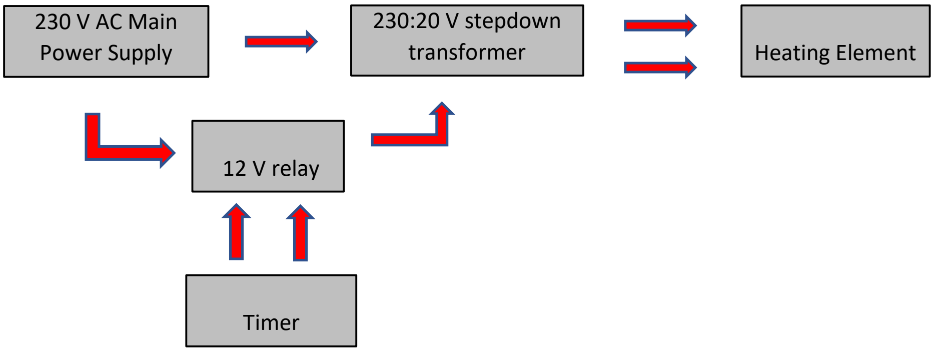

Figure 14. Sealing element power-up mechanism machine

Parameters of the selected heating element are as follows.

- Material of the element: Nichrome
- Element dimentions:15 cm* 1.5 cm
- Power requirement:133.33 W
- sealing time: 12 seconds

5 RESULTS AND DISCUSSION

An innovative design based on the requirements of a local middle scale spice packaging business could be designed which can be operated by only an involvement of a single laborer. The complete mechanical hardware part could be completed in a cost-effective manner where all the packet moving, filling and sealing parts are included in a single machine. The components were selected based on calculations and the requirements of the customer.

As a whole machine all the three individual parts were successfully completed by the three members, but the trial-and-error process has to be carried out with the actual machine and should check whether these simulation processes work align to the actual procedure and have to do the trouble shooting with the programming parts with the actual machine since this is a real product that we manufacture as per a customer requirement. The complete mechanical structure of the machine is shown in figure 15.

Figure 15. Complete mechanical packaging

5.1 Packet Moving System

The Mechanical Hardware of the Packet moving system shown in below figure 16.

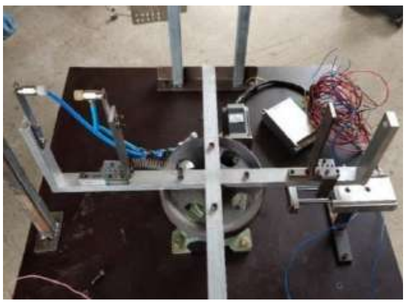

Figure 16. Mechanical structure of the packet moving system

The Solid work design for the system designed to discharge the packet is as below figure 17.

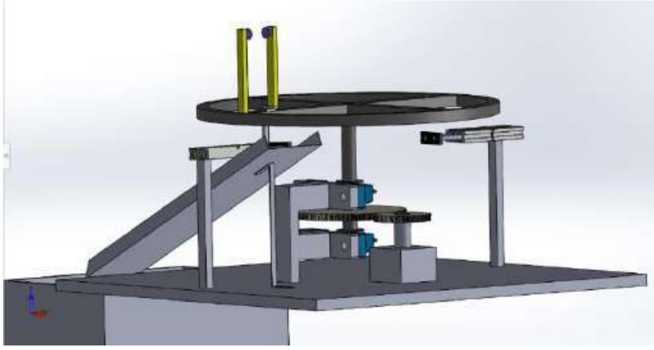

Figure 17. Designed system for packet discharging

5.2 Filling Section

The completed Mechanical Hardware of the filling section shown in below figure 18.

Figure 18. Mechanical structure of the filling section

5.3 Sealing Section

The completed mechanical hardware of the sealing section is shown in figure 19.

Once the filled packet reaches the heating element, packet is sealed finishing the packing cycle. When sealing the packet, the element passes a higher current load, and it should pass when the packet is at the proper orientation. Otherwise, the packet melts and cause damages to the machine. A timer circuit has been designed, to keep a constant time taken to seal a bag at the required temperature. To determine this pre-defined time a potentiometer was used and to make the machine user-friendly, a nob was used so that the operator is given the opportunity to adjust the sealing time depending on the type of polythene and the temperature of the system. Timer circuit was introduced to this system by considering all above factors.

Figure 19. Mechanical structure of the sealing section

Normally one RCCB and several MCB are used in machines. When using MCB, one main MCB and several other MCBs are used section wise. Since the target customer group is small and medium scale businesses and they usually operate in domestic entities we assumed they already have MCB and RCCB protection.

Very expensive and complicated mechanisms and methods have been used in local and global large-scale businesses such as grippers, robotic arms, actuators, conveyor belts. Because of high cost and more space middle scale businesses are not interest with above mechanisms. So, in this innovative design, following are the highlighted components used in all three processes which are packet moving mechanism, filling section, and sealing section. Pneumatic cylinders, vacuum suction cups, linear bearings, stepper motors, solenoids, venturi meters are used.

Pneumatics is used as the main implementation technology since it is cheaper than hydraulics, smooth operation, ease to obtain and store, components are reliable, has a long operating life and the required maintenance is less. In all of these 3 main sections pneumatic components such as twin rod and single rod pneumatic cylinders have been used. So, when selecting the pneumatic components specifically the pneumatic cylinders in the application, following factors should be considered.

- Stroke length
- Stroke moving distance
- Size and other physical characteristic
- Pressure that can be applied
- User friendliness

As an example, at the sealing point the two sides of the polythene bag should come closer to each other to create a seal. So TN10*25 double acting cylinder was used to move the sealing plates where the heating element and silicon rubber is attached, in order to close the opening of the bag.

5.4 Results analysis: -

Highlighted key points of the machine shown in below table 3.

Table 3: Specifications of the manufactured packaging machine

Current requirement	8.46 A
Power requirement	203.04W
Total height	1.2m
Total length	1m
Total width	1m
Cost estimation	Rs.110,000 (approx..)

Mainly, our packaging machine is more cost effective as it consists of all the weighing, filling, and sealing processes in itself and worth Rs.110,000.00 approximately while all other packaging machines which consists of all the three processes worth above Rs.1,000,000.00. If the equipment for each process is bought separately, that can cost about Rs.170,000.00) which will also increase the labor force needed.

As well as this project needs three type of power requirements and the selected SMPS power ratings shown in below table 4.

- To operate sealing process -230 V AC
- To operate compressor- 230 V AC
- To operate other DC components – Used switch mode power supply

Table 4. Total power requirement of the SMPS

Output DC current values	24 V	7.4 A
	12 V	1.06 A
Total output current	24 V +12 V	8.46 A

When comparing the power requirement, most of the machines which consists of all the three processes have about 500W consumption, but this machine require 200W amount approximately. Moreover, the special feature of this machine is the portability as it is made as a desktop version.

Comparing all of these aspects, this manufactured machine is more suitable for middle scale spice packaging businesses

6 CONCLUSION

The designed machine is constructed according to the requirements of a local middle scale spice production business. The design is an innovative approach which is not currently available in the market. This machine can be operated using domestic single phase AC power and doesn't need three phase AC power. The labor involvement of the designed machine is less since it is a semi-automated machine. The components used can be easily found in the market, therefore, the maintenance and repairs are easy and high skilled laborers are not required for the operation. The design is carried out considering the safety of the operators by not including sharp attachments such as sharp edges or blades to cut packets etc. Middle scale spice production business owners can purchase this product considering the affordability, efficiency, reduced ingredient wastage compared to the current available packaging machines in the market. This can be made available for different weight ranges.

Further research on this product can lead to many more developments such as making it available for several packets to be filled at the same time and improve it to pack a range of weights and testing the code with the actual mechanical hardware structure.

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Real-Time Embedded System for Inattentive Driver Monitoring.

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ABSTRACT

One of the causes of motor vehicle accidents in Sri Lanka is driver inattention or drowsiness. In the field of intelligent transportation systems, continuous research and development are conducted to address this contemporary issue. Many approaches, such as driver assistance and drowsiness detection systems, have been proposed to overcome this fatality. The purpose of this research was to implement a product that can maximise road safety while improving the transport sector's efficiency and reliability of the logistics chain to reinforce the country's economic growth. In this paper, the correlation between the preprocessed vehicular parameters and visual features are used to analyse the driver state and make predictions of the driver's perfomance.

The proposed system uses computer vision and fuzzy logic inference implemented on the single-board computer Raspberry Pi to detect facial features and to determine the driver's drowsiness state, an ELM327 is used to read the vehicle parameters from the Electronic Control Unit (ECU) and motion sensors were used to obtain the steering angle. The data acquired is stored in a cloud platform using REST API. The database also contains driver details. The system uses a fingerprint scanner to identify the driver. An actuator was installed in the vehicle to alert the driver when the system detects inattentiveness. Overall the proposed project provided satisfying experimental results. It can be used as a solution to improve road safety and a supporting tool for the logistics sector to monitor vehicles and driver performance.

KEYWORDS: *Driver monitoring system, computer vision, fuzzy logic, vehicle telematics, steering angle, Rest API, cloud computing, RTOS.*

1 INTRODUCTION

The vehicle industry has seen a significant boost in the manufacturing of "intelligent" vehicles with active and passive safety systems. Grandjean (Grandjean, 1979) defines drowsiness as a "gradual and cumulative process associated with a loss of efficacy and disinclination for any kind of effort". According to Hossain et al (J. Hossain, 2003), drowsiness is "a state in which one's capacity or efficacy for work is reduced following physical and mental effort; it does not necessarily imply the irresistible desire for or tendency to fall asleep.

The rapid growth in the increase of motor vehicle use has raised many concerns across the country and the globe. According to the article released by the World Health Organization (WHO), in June 2021, approximately 1.3 million deaths are caused due to road accidents each year. The report also highlights that distracted driving is one of the leading causes among many reasons for road accidents. (World Health Organization, 2021)

The scope of this project is to create a non-intrusive device to analyse driver driving patterns across a fleet of vehicles and display precomputed information to the customer on a dashboard accessed through the world wide web. This research is divided into sub-parts, each of which contributes to monitoring driver inattentiveness and driver performance. Driver fatigue and driver inattentiveness are detected using computer vision technology, driving style and performance is monitored by obtaining data from the OBD port of the vehicle and the active steering engagement. This data is entered into a relational database via an API, and fingerprint data is used for the identification of drivers to create a driver driving profile.

This research can be considered unique as it proposes a hybrid approach in driver behaviour monitoring systems by using both the facial features and vehicular information as opposed to using only one type of information to make the system more robust and suppress false positives, thereby providing the user with the frictionless experience.

2 RELATED WORK

According to the literature review of related works, multiple methods have been used in detecting driver behaviour. The forms can be considered invasive and noninvasive. A noninvasive approach uses behavioural measures to evaluate the state of the driver, whereas, in an invasive, a wearable device is used. The noninvasive method is more feasible to implement and cost-effective. All the below-cited work has taken different approaches towards detecting driver attentiveness. It is evident that in most of the research conducted based on non-invasive methods uses facial features or vehicular parameters to determine driver attentiveness.

In the researches (Warwick, 2015) (Li, 2015) (Jung, 2014), a wearable device is used to obtain physiological parameters like EEG, ECG and EoG signals. Jung et al (Jung, 2014) modified the steering wheel and attached a sensor to obtain the ECG signal of the driver to evaluate the drowsiness. This approach has many drawbacks. The cost and the approach demand the driver to wear devices while driving, and some techniques require modifications to the vehicle. Due to these reasons, this approach is not universally applicable.

In the noninvasive approach by Zhang and Hua (Zhang, 2015) local binary pattern features, and support vector machines are used to evaluate the state of the driver using facial information. Picot et al (Picot, 2012) proposed an approach that uses the blinking feature for drowsiness detection. In the research by Hariri et al (Abtahi, 2011), they presented a method for detection of driver drowsiness based on yawning behaviours. The modified Viola-Jones object detection algorithm is used for face and mouth detection. This method is based on several algorithms, which are insensitive to the changes in the lighting conditions, skin types and geometrical facial features.

In the research by Eyosiyas et al (Tadesse, 2014) a Hidden Markov Model based dynamic modelling of the facial emotions and the behavioral changes in addition to the detection of eye closures for drowsiness detection of the driver. The research concludes that instead of using frame-based approach to detect the drowsiness of the driver, temporal analysis of facial expressions maximized the accuracy and speed of detection.

Shaout et al (Shaout, 2018) presented a standalone embedded system to listen to CAN frames from the CAN bus and to predict possible future failure that may occur in the vehicle. Samson et al (Samson, 2019) presented a system that continuously monitors driver behaviour parameters such as ECG, speed, eye blinking, steering angle, turn signal usage to observe driver distractions. Castignani et al (Castignani, 2013) presented a fuzzy inference system that runs on a smartphone that uses the sensors of the phone to produce a score for driving behaviour.

Another method used in detecting driver attentiveness was the detection of the steering angle to analyse the driver engagement and thereby to monitor attentiveness. In the research (Zacharia, 2017), a system has been developed to detect driver engagement. The system was efficient but was complex in implementation. Here, the principle of giant magnetic resistance was used along with the MPC5567 microcontroller and CAN module.

3 METHODOLOGY

The overall overview diagram of the development conducted via this research is shown in Figure 1 below. The aim of the project is to monitor driving style and observe driver attentiveness. The facial features were detected using computer vision, the vehicular parameters were obtained from the Electronic Control Unit (ECU) via the OBDII port, the steering angle of the vehicle was determined by building a hardware system using a Micro Electro-Mechanical System (MEMS), an alarm was used to alert the driver in case of inattentiveness, a Rest API was implemented to store and retrieve data sent to the database from the ECU, the driver details obtained from the fingerprint authentication and the facial details and vehicular parameters were stored in a centralised database incorporated to a cloud server.

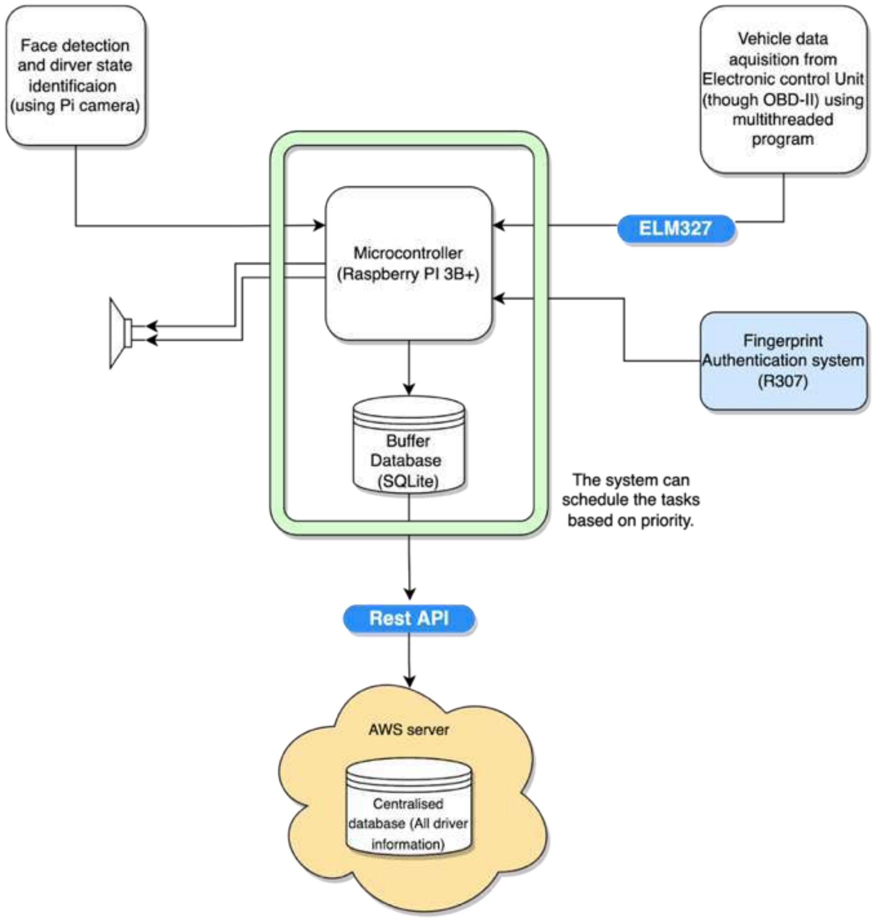


Figure 1. Overview Diagram

3.1 Attentiveness detection using facial features.

The proposed Driver Inattentiveness Monitoring System should be able to prevent the threats posed by the inattentiveness of drivers. The proposed solution should address the inattentiveness of the driver in real-time, prevent accidents, and it should be noninvasive.

In this proposed system, computer vision is used in capturing the facial features, which are accurate indicators of the driver's state and fuzzy logic is used in determining the state of the driver. This approach proves that this monitoring system is able to predict the state of the driver accurately compared to other existing solutions, and it can be implemented with minimal resources at an affordable cost. The driver state detection system consists of 3 stages. First is the facial features extraction stage: a CNN is used to detect the driver's face and compute the facial landmark points. The next stage is the computation of the drowsiness level indicators using the face landmark point information. The parameters used in determining the state of the driver are Head pose (HP), Blink frequency (BF), PERCLOS, Eye Closure Duration (ECD) and Mouth Opening Duration (MOD). The final stage is the driver state prediction; the calculated parameters are mapped to the driver's state using a fuzzy inference system.

Facial features extraction stage

In the proposed driver state detection system, CNN has been used to predict the face landmark points and the bounding box coordinates of the driver's face.

The CNN architecture consists of 28 convolutional layers, one Global average pooling layer and an output layer consisting of 3 different output units: one for predicting the confidence score, another 4 perceptrons for predicting the bounding box coordinates of the face and 68 perceptrons for predicting the (x, y) coordinates of the face landmark points. The depthwise separable convolution for feature extractions using kernels was used. A bounded ReLU activation function is used for applying non-linearity to the output of the feature maps. Binary cross-entropy function and mean squared error functions are used to compute the error values of the CNN predictions. A sochastic gradient descent algorithm is used to train the CNN.

Computation of the drowsiness level indicators stage

The parameters used to detect drowsiness is computed using the facial feature information obtained from the CNN. Parameters used for the evaluation are:

1. Head pose (HP) - The head pose of the person is a prevalent indicator of drowsiness in behavioural-measures-based systems. If the head pose of the person is identified as down or at different sides rather than looking forward to a reasonable amount of time for a given temporal window, then the system will identify the person as drowsy and not focusing on the driving.

2. PERCLOS - is the proportion of closed eye frames to the total number of frames in a one-minute time window.

3. Average Eye Closure Duration (AECD) - This metric is the mean duration of intervals in which eyes are closed in the defined temporal window. According to (Kaplan, 2015) (Satzoda, 2014), when the driver is awake, the proportion of closed-eye frames is less than 30%. The eye closure time for the driver is less when they are awake than the eye closure time when the driver is in a drowsy state. So if the eye closure time exceeds a certain threshold value, the system can determine the driver as drowsy.

4. Frequency of Blinking - is the number of times the driver blinks in a minute. When people are awake, they blink 8 to 15 times a minute. But when the driver is in a low vigilant state and in a mild drowsiness state, the frequency of blinking will increase. But when they are extremely tired or drowsy, the frequency of blinking will drastically decrease.

5. Average Mouth Opening Duration (AMOD) - is defined as the mean duration of time intervals for which the driver kept their mouth open during a defined temporal window. According to (Barbizet, 1958), it is known that the whole yawning process lasts for 7 seconds.

These metrics are complementary to each other. Therefore, if one or more indicators gives false-positive results, the other indicators will act as the proper validators of the driver's state. From the trials performed using these features, it was found that the last metric, which is the AMOD, is the metric that gives the most false-positive results. Because the mouth of the person is kept open while the person is talking. So, it can be mistakenly taken for yawning, which is an obvious indicator of drowsiness. So by combining multiple feature values, this problem can be solved.

Driver state prediction stage

The mapping of the drowsiness indicators to the state of the driver is performed by the fuzzy inference system (Mamdani, 1975). This provides a non-linear, interpretable glass box like algorithm for this task. It maps the HP, PERCLOS, AECD, blink frequency and AMOD to the state of the driver output, which are awake, low vigilant and severe drowsy state.

In this proposed driver state detection system, the driver state identification process is done by the Mamdani FIS, which uses triangular and trapezoidal membership functions while the output consists of singleton membership functions. The reason for the choice of singleton membership functions for the output is because this FIS has been modelled like a multinomial classification system. So the singleton MFs are the suitable choice because each output MFs consists of only one element with membership degree equal to one and zero for others.

The details of the fuzzy operators used in this FIS are as given below; Figure 2 shows the membership function of the system:

- OR operator(T-conorm) is used as the connecting operator for the rules in the rule-base
- Mamdani Implication operator is minimum
- Aggregation operator is maximum
- Largest of the maximum is used as the defuzzification method.

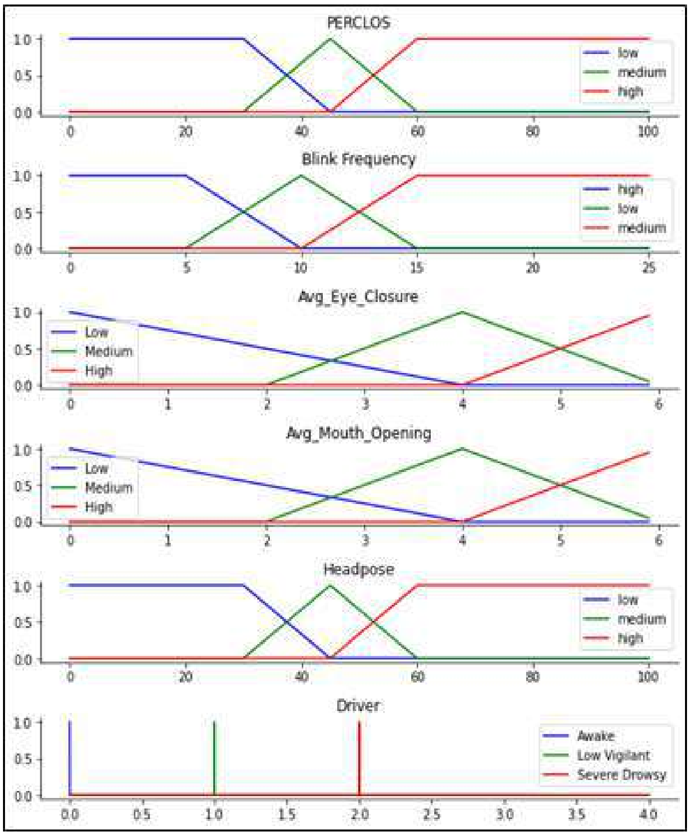


Figure 2 Input and Output membership functions of the Mamdani FIS

Dataset

The CNN was trained using a wild dataset (Huang, 2008) to detect the face landmark points. The dataset consists of 13,000 images collected from different sources. To obtain data for drowsy state indicators, the dataset "Real-life Drowsiness Dataset" (Ghoddoosian, 2019) was used. The dataset was used in detecting multi-stage drowsiness. The main goal of this dataset is to detect the early symptoms of drowsiness in addition to detecting visible cues of drowsiness. This dataset consists of videos of 60 participants under the awake, low vigilant and severe drowsy state.

3.2 Vehicle Data

ECU Data Acquisition

The vehicle data acquisition was made using an ELM327 microcontroller through the DLC. The program for data extraction was created using Python3 on a Linux environment. Vehicle data would be extracted from the ECU in real-time and uploaded to a local "buffer" database before being uploaded to the cloud at the end of the trip. The system is equipped with an actuator (alarm) to sound when a driving anomaly is detected. The fingerprint scanner is used to identify the driver of the vehicle in a fleet of vehicles, so the driving details would be saved under the particular driver's profile.

The flow diagram for the interconnection of all the systems is shown in Figure 3 below. Extracting vehicle parameters from the running vehicle is done using two threads in Python3. The operation of the threads is shown in the diagram below.

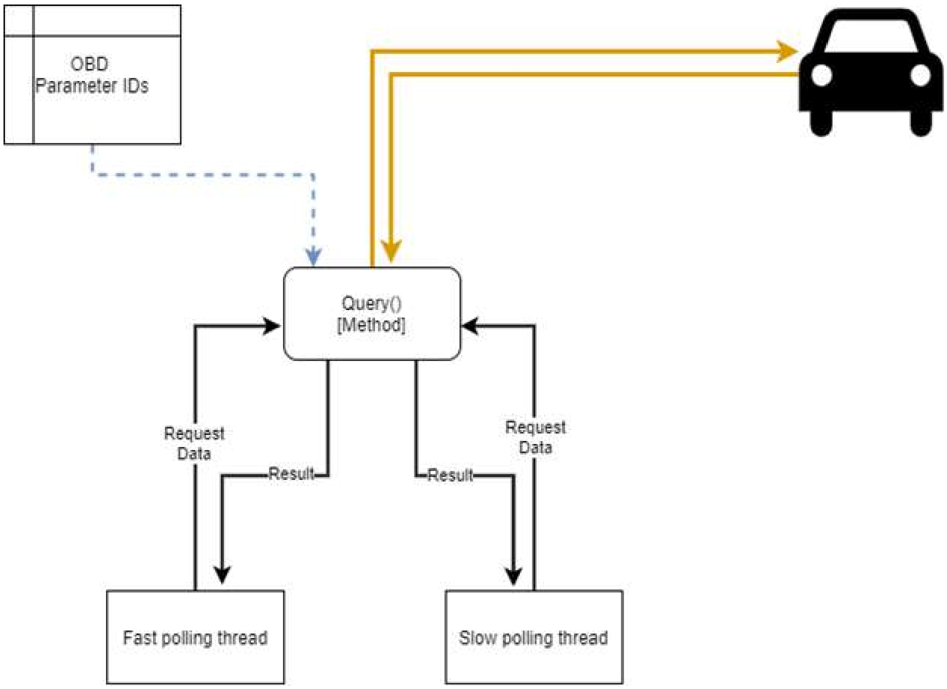


Figure 3. Flow diagram for data acquisition

The python program uses serial communication to communicate with the ECU of the vehicle. After serial communication is set up in the operating system, the python script uses the *Query*() method to send and receive data serially.

The vehicle uses multiple sensors which collect many different types of data and constantly feed this data to the vehicle ECU, which uses this information to control critical actuators in the vehicle. This data can be obtained by using Parameter IDs (PIDs). When a certain vehicle parameter is required, the respective parameter ID must be passed into the ECU through the Data Link Connector (DLC). The response will be sent containing the required parameter.

Figure 4 below displays the structure of the Python program. The block diagram is described below:

1. Thread 1 (Main thread) - This thread is responsible for initiating the rest of the threads and is also responsible for exception handling and terminating the program if any keyboard interrupt is detected.

2. Thread 2 (Fast thread) - This thread is responsible for polling the frequently varying parameters. This thread polls' Engine load', 'RPM', 'Speed', and 'Throttle position' every second, and the contents will be stored in lists created for each parameter. Thirty data samples will be collected through a while loop and stored in individual buffers. The data was collected through the OBD-II port of the vehicle using the *Query*() method, which is shared between the fast and the slow threads.

Shared memory is used to temporarily save the contents of the fast and slow threads while preventing race conditions (SQLite, n.d.) by deploying access control methods. The notify_all command is used to prevent deadlocks.

3. Thread 3 (Slow thread) - This thread is similar to the fast-polling thread, but fewer vehicle parameters are acquired in the thirty-second window. This thread will poll 'Engine coolant temperature' and 'Intake air temperature' every 15 seconds taking a total of 30 seconds, similar to the fast-polling thread.

4. Thread 4 (Upload thread) - This thread is set as a daemon thread as it must run in the background, collecting data sent by the fast and the slow threads and uploading it to the database at set time intervals. The upload thread will upload the contents of the *buffer* into the database after the upload flags of fast and slow polling threads have been set. The upload thread uses the sqlite3 database API to upload the contents to the database.

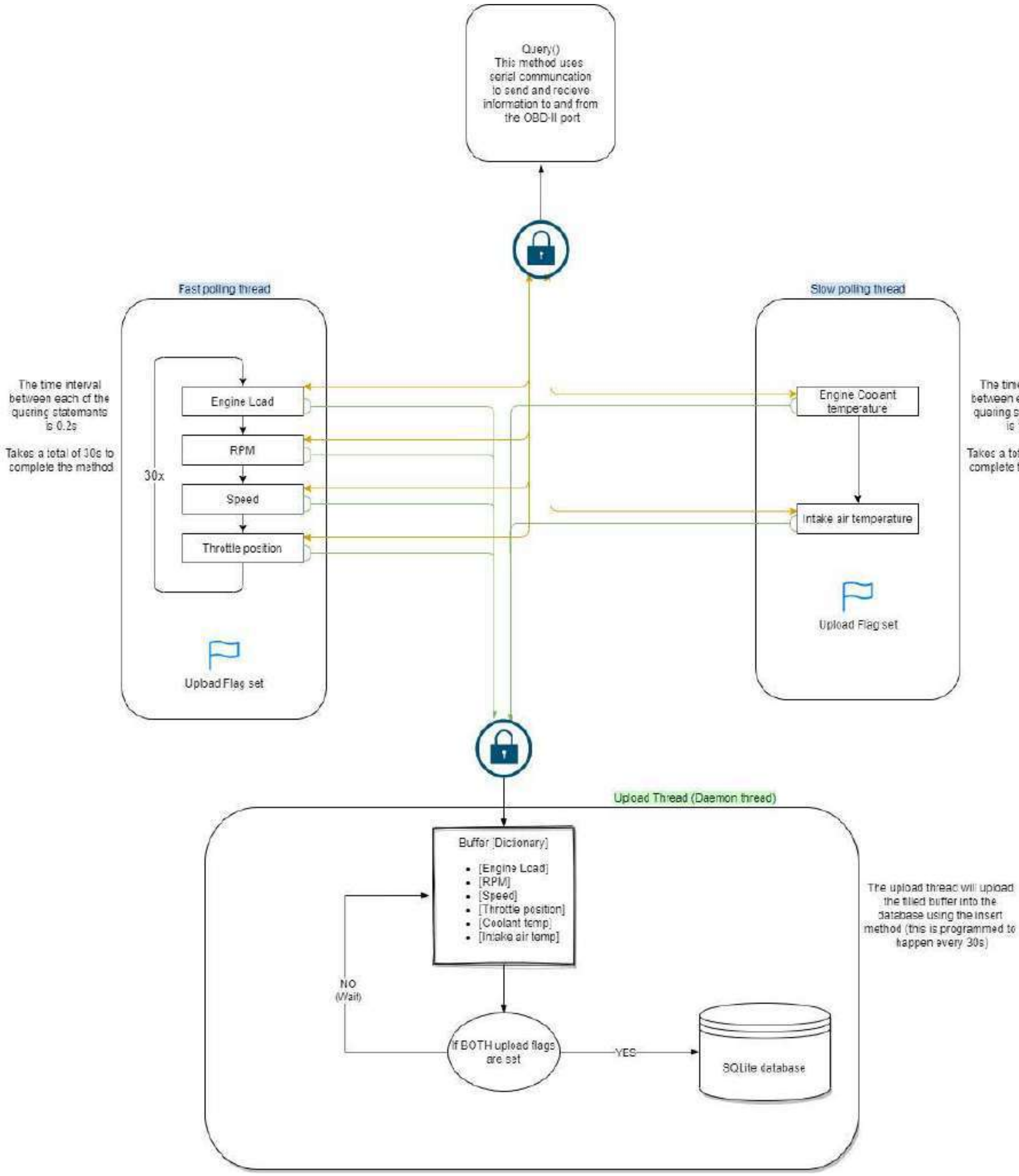


Figure 4 Structure of the multithreaded program

Implementation of steering angle detection mechanism.

The inattentiveness of drivers can be measured by their engagement with the steering wheel. Apart from the computer vision used to analyse the facial feature in detecting the driver attentiveness, the steering angle and vehicle parameters were used to detect the driver engagement.

The system to detect the steering angle was designed using the ESP3266, MPU6050 and HC-05 Bluetooth module. The prototype was built using Arduino, as shown in Figure 5. The circuit was planned to be placed at the back of the steering wheel, as shown below in Figure 6.

The data obtained from the sensor was processed, and the driver state was detected as active, moderately active and inactive. SPI communication was used in obtaining the data, and fuzzy logic was used in predicting the driver state. The driver state data combined with the vehicle data was used for driver profiling and driver inattentiveness measures.

Figure 5 Components used and prototype

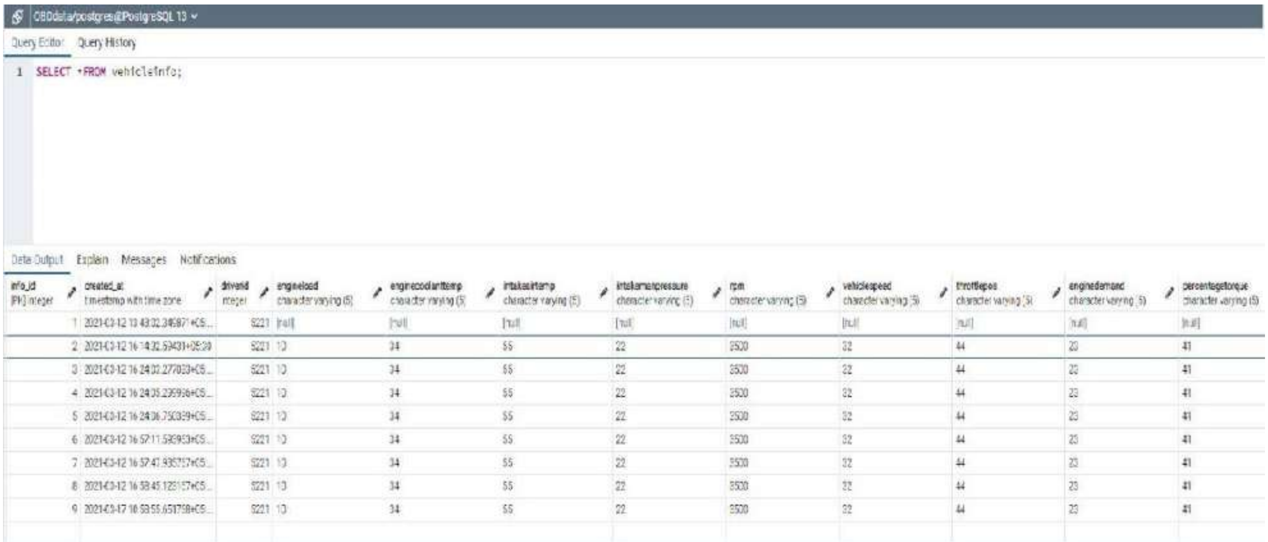
Figure 6 Placement of the device

Database

Local Database

The local database was implemented in raspberry pi to save the data collected from the vehicle in a structured and organised manner. The advantage provided by introducing a local database buffer is that a constant connection with the cloud is not required.

Figure 7 is an image of the local database with the vehicular parameters collected with the timestamp information.



OBDdata/postgres@PostgreSQL 13

Query Editor Query History

```
1 SELECT *FROM vehicleinfo;
```

Data Output Explain Messages Notifications

info_id [PK] integer	created_at timestamp with time zone	driverid integer	engineload character varying (5)	enginecoolanttemp character varying (5)	intakeairtemp character varying (5)	intakemanpressure character varying (5)	rpm character varying (5)	vehiclespeed character varying (5)	throttlepos character varying (5)	enginedemand character varying (5)	percentagetorque character varying (5)
1	2021-03-12 13:43:02.346871+05...	5221	[null]	[null]	[null]	[null]	[null]	[null]	[null]	[null]	[null]
2	2021-03-12 16:14:32.59431+05:30	5221	10	34	55	22	2500	32	44	23	41
3	2021-03-12 16:24:02.277033+05...	5221	10	34	55	22	2500	32	44	23	41
4	2021-03-12 16:24:05.295956+05...	5221	10	34	55	22	2500	32	44	23	41
5	2021-03-12 16:24:06.750339+05...	5221	10	34	55	22	2500	32	44	23	41
6	2021-03-12 16:57:11.593953+05...	5221	10	34	55	22	2500	32	44	23	41
7	2021-03-12 16:57:47.935757+05...	5221	10	34	55	22	2500	32	44	23	41
8	2021-03-12 16:58:45.123157+05...	5221	10	34	55	22	2500	32	44	23	41
9	2021-03-17 10:58:55.651758+05...	5221	10	34	55	22	2500	32	44	23	41

Figure 7 Local Database

The vehicular parameters from *Figure 7* are used to analyse patterns in driving styles and thereby determine the attentiveness of the driver using data in conjunction with visual parameters to increase the accuracy of prediction.

Authenticate

The authentication table of the database consists of the driver information and the fingerprint authentication. The table comprises a RowID; this is the first field in the table. This field also contains the PRIMARY KEY and is set to AUTOINCREMENT. This field is mainly to monitor the number of entries to the Authenticate table, a DriverID: this field stores the identification number of the driver and is of INTEGER datatype, the Name: The name of the driver is stored and the FingerTemplate: this is the most important column and it is used to store the fingerprint template of the drivers. This column is of BLOB datatype (Binary Large Object). The fingerprint features of the drivers are converted into a hexadecimal format in a process called serialisation and stored in this field. This value is used by the fingerprint scanner module to authenticate the user (driver).

3.3 REST API

To develop the Rest API the spring framework and Java programming language was used. There are several factors to be considered when developing a Rest API, and its implementation is done in several—identifying the model objects, creating model URLs, determining the representation type and assigning methods.

According to the first step, the objects that need to be represented as resources are configured. The resources are the endpoint of the API, and the URL models connect the resources with the sub-resources. The common representation is of two types: XML and JSON. In this application, a JSON representation was used. Assigning the HTTP methods is a crucial part. These methods are used to create, retrieve, update and delete (CRUD) data to the API.

Table *1* below shows the HTTP and CRUD representation. Initially, the API was built using an array list. Thereafter it was modified to apache derby and finally implemented in the PostgreSQL database.

This API was further developed to implement multiple-table databases. The database comprises three tables. One to store the collected vehicle data and another to store the driver information. The main table for mapping data the many to many mappings approach was used in the implementation.

Table 1 REST API Methods

Method	**Description**
GET	Retrieve information about the REST API resource
POST	Create a REST API resource
PUT	Update a REST API resource
DELETE	Delete a REST API resource or related component

4 RESULTS AND DISCUSSION

The implemented system consists of facial feature detection, vehicular parameter analysis and an implemented DBMS to record and interpret data. Table 2 below shows the facial feature data used. Table 3 below shows the vehicle parameters obtained from the ECU at the same instance as the data obtained for the facial feature.

Table 2 Performance Evaluation Data

HP	**PERCLOS**	**BF**	**ECD**	**MCD**	**Subject State**
15	20	10	1.1	0.9	0
70	89	4	3.9	3.5	2
65	80	3	3.4	2.7	2
40	52	23	2	2	1
40	48	20	2.3	1.8	1
15	45	17	1.7	1.2	0
10	30	12	1.9	1.5	0
10	35	14	1.5	1.7	0
50	90	2	3.9	3.6	1
64	90	3	4	3.7	1

Table 3 Shows the vehicle parameters recorded at the same instance as Table 2

info_id	created_at	driverID	Engine Load	Engine Coolant Temp	Intake Air Temp	RPM	Vehicle Speed	Throttle Position
455	09-07-21 8:50	5221	58	82	50	1506	23	22
456	09-07-21 8:51	5221	68	82	50	1190	27	18
457	09-07-21 8:51	5221	22	83	50	942	25	17
458	09-07-21 8:51	5221	25	83	50	773	11	18
459	09-07-21 8:51	5221	39	83	50	882	6	17
460	09-07-21 8:51	5221	44	84	50	839	4	18
461	09-07-21 8:51	5221	62	84	50	1640	8	23
462	09-07-21 8:51	5221	69	83	50	1621	20	23
463	09-07-21 8:51	5221	69	83	50	1537	27	22
464	09-07-21 8:51	5221	74	83	50	1734	24	23

The CNN model was trained for 20 epochs and achieved 97% accuracy on the training set and 95.7% accuracy on the validation data set. The overall loss of the CNN was 1.6341 at the end of the 20 epochs and stopped decreasing. So the training was stopped at that point. Figure 8 shows the accuracy of the CNN after 20 epochs and the loss of the CNN after 20 epochs.

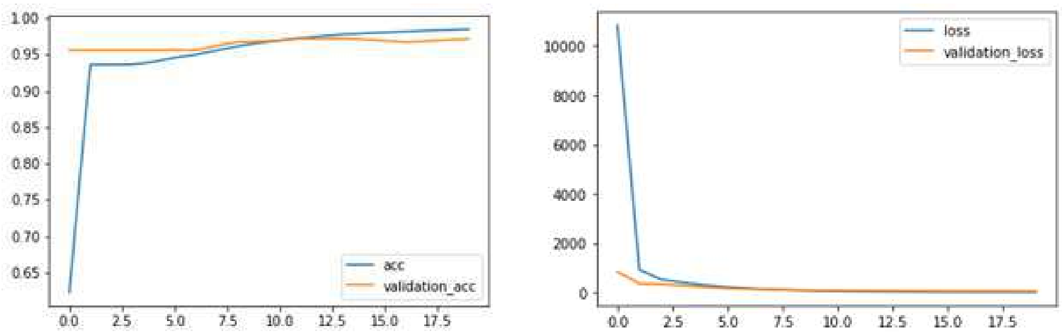


Figure 8 Training and validation accuracy and loss of CNN

The use of depth wise convolution reduces the amount of computation and the number of learnable parameters needed to implement the same CNN topology using the standard convolution. For the convolutional layer with the input size of 14x14x512, kernel size of 3x3x512x512, Table 4 shows the amount of Mult-Adds and parameters needed for those implementations.

Table 4 Memory and Computation resource usage for standard convolution and depth wise convolution

Layer/Modification	Million Mult-Adds	Million Parameters
Convolution	462	2.36
Depthwise Seperable Conv	52.3	0.27

Evaluation results of Mamdani FIS

The Mamdani fuzzy inference system is able to capture the non-linear relationship between the drowsiness indicators and the state of the driver in a very interpretable way. Its decision-making process is more transparent compared to the other computational learning algorithms. But the performance of the Mamdani FIS is subjected to varying parameters: the choice of input and output membership functions, the shape of the membership functions, the number of rules in the rule base, the antecedents and consequents used in the rule base. These are the hyperparameters that need to be adjusted in order to get the optimal algorithm for this proposed driver state detection system.

There are many tradeoffs in changing these parameters

- Increasing the number of rules in the rule base will increase the performance of the FIS but it will increase the amount of computation needed to evaluate the output.
- The knowledge base can be optimised by the subject experts related to the problem, but there are difficulties in finding the right people for the task.
- Changing the membership functions to be more non-linear will increase the accuracy but will increase the amount of computation and time needed to make predictions in the defuzzification unit.
- Table 5 shows the performance evaluation metrics of the Mamdani fuzzy inference system.

Table 5 Performance evaluation results

Algorithm	Precision	Recall	F1-Score
Mamdani fuzzy inference system	0.9333	1.0	0.9655

REST API

The REST API developed was tested using the postman software to ensure the functioning of the methods. The multi-table database was created and generated using the API. The implementation of the HTTPS methods was successful, and data from the local database was sent to the centralised database via the API.

5 CONCLUSION

Over time support technologies have proven themselves to be effective in preventing motor vehicle accidents caused by the inattentiveness of the driver. However, most systems either use the vehicular parameters or facial features whereas, this research proposes a hybrid system which improves the accuracy and reliability. The proposed system consists of a non-intrusive computer vision and fuzzy logic-based system to detect the early drowsiness symptoms of the drivers and warn them beforehand to avoid accidents and loss of lives. The proposed approach uses the facial feature information obtained from a camera to evaluate the state of the driver, their ability to drive and alert them if necessary.

Rather than using the in-car sensor's information and vehicle technical condition solely for assessing the state and the driver's ability to drive, using facial information that reflects the person's true state and reduces false positives. The use of fuzzy logic makes the proposed system well equipped to handle the uncertainties and subjectiveness present in the conditions for evaluating the drowsiness condition of a person. Further studies are needed to find more facial behavioral indicators of drowsiness robust to false positives and provide clinical validations to support those findings.

A real-time driver state detection system has been implemented successfully using a low-cost System on Chip Raspberry Pi 3B+, Pi camera, some additional electronics components, deep learning frameworks and fuzzy logic to detect the state of the driver and evaluate their ability to drive. The Mamdani fuzzy inference system used for the detection of driver state using facial features had a precision of 0.9333, a recall of 1.0 and F1-score of 0.9655 which proves the system to be reliable. The more important vehicle parameters and steering angle were obtained every 30 seconds to obtain accurate details of the parameters.

The use of multiple parameters and the hybrid approach makes the system more reliable. Also, this system is low cost, portable and can be used in any vehicle as there are no technical constraints in implementation. Another main advantage of this system is it is noninvasive. Thereby, it can be concluded that the proposed system can fulfill the objective of inattentive driver monitoring.

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Special Event Item Prediction System for Retails – Using Neural Network Approach.

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ABSTRACT

Selling and buying is the general process marketing field follows. Nowadays marketing field bonded with the modern technology, and it highly effected to field expandability. Marketing become fruitful when it achieves its key points which are called sales and profit. Mostly people are move to the retails because all the essentials and other things can buy from one place. There are many technological concepts involve with marketing field as an enhancement. Prediction processes, data analysis, item designing and profit calculation are some representatives for those concepts. This study is a prediction process, developed for retails using machine learning approaches. Item sales data analyzed and generated prediction results on set of items which are given maximum or expected profit margins and which items satisfy the customer most. Item suppliers are key stakeholder type a retail can have, there is a recommender system in this approach for suppliers and the recommendation is based on past sales data. There are certain types of machine learning approaches used in sales item prediction, sales item feature prediction, sales price prediction and etc. Novelty of this research is, it focused only special event items such as items in Christmas season, items specialized for Mother’s Day, Valentine Day, Sinhala, and Tamil new year and etc. This research process had completely followed the machine learning neural network concept. Recurrent Neural Network is subpart of neural networks and this research study followed up through this RNN method. Neural network had applied using a form of machine learning called deep learning. This model had worked on sequential data therefor LSTM (Long Short-Term Memory) layers were used and to avoid overfitting issue several dropout layers were used. The results prove neural network method has highest accuracy.

Key words: Sales prediction, Special Event Items, Machine Learning, Neural Network, Deep Learning, Retail.

1 INTRODUCTION

Artificial Neural Networks(ANN) are basically an inspiration of human brain. Mostly it comes under supervised learning approaches in machine learning and Recurrent Neural Networks(RNN) are subdivision of ANN. There for RNN can discuss as a machine learning approach. Machine learning is a specialized technical discipline that may be used to perform a variety of tasks, including data prediction, data mining, data optimization, data categorization, clustering, and dimensionality reduction. It is a rapidly emerging subject of computer science, with applications that are extremely complicated when combined with other technology (Dey, 2016).. Data Prediction is one of them, and machine learning approaches have a big influence on it. Machine learning technology is used in several areas of data prediction, including sales item prediction, item design prediction, sales profit predictions, medical diagnosis prediction using symptoms (Cancer, Virus, and so on), bankrupt's predictions, personality prediction using textual data, item popularity prediction (Ex; Car popularity prediction), and so on. This

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method of prediction calls for the use of previously examined data. The main goal of this study is to estimate retail sales for things that are sold during special events, days, or seasons. Today, sales items have become a critical component of the corporate world, and sales item data is rapidly increasing. Clothing retails, vegetable and fruit retails, retails with all needs, cosmetic retails, and so on are all examples of retails. Two categories of retails are investigated in this study: retails that solely sell gift items and retails that sell both essential and gift items. Retailers or retailers earn on sales items.

Predicting sales items is a critical procedure nowadays. It helps to meet customer expectations by increasing sales profit, reducing cost overruns, and increasing customer satisfaction. Customer expectations are constantly being updated with new features. In stores, there is an item management team that is responsible for identifying and analyzing customer expectations. People tend to buy everything in one spot due to their hectic lifestyles. "Arpico Super Center" and gift shops like "Vondy Party City" are two of Sri Lanka's most well-known merchants. Items that fall within the categories of exceptional events, seasonal festivals, and calendric days are considered in this study. For each of the dates listed above, there are a variety of specific gift items available, such as cakes, chocolates, flowers, ornaments, teddy bears with varying colors, shapes, tastes, amount of flowers in the bouquet, band, and so on. Calendar days, seasonal festivals, and special functions are the three types of special events that are relevant to retailers.

Originality of this research study is, it is considered special event sales items. There are three types of special events in the retail industry. Calendric day: These are events that occur on a specific date or month, such as Mother's Day, Father's Day, Children's Day, Lovers' Day, and so on. Most likely, it is an international holiday, although it can also be limited to a single country, as in Sri Lanka's May Day and Independence Day. The majority of individuals observe these event days as a personal preference, tradition, or habit. They used to exchange gifts or special mementos during such gatherings. Retailers will be able to enhance their sales and profit margins during that time period by offering things related to a specific event. Retailers can also gain extra benefits by preparing for upcoming events utilizing item prediction processes based on previous year's data. For such process, the proposed "Special Event Item Prediction System" will be quite valuable. Seasonal festivals: Seasonal festivals can be classified as a different form of calendar event because they occur on a specific date or month throughout the year. Seasonal festivities include "Christmas," "Vesak," "Ester," "Ramazan," and "Sinhala and Tamil New Year," to name a few. During this occasion season, people are extremely motivated to purchase gift items, decorations, and meals. Then these particular event types will provide an opportunity to take advantage of the benefits indicated above(in the calendric day paragraph). Seasonal festivals, in particular, are a form of shopping occasion. Retailers should have prepared their specific stocks by then. Special functions do not have a unique or specified date or month in the calendar year. The most common instances of special functions are birthdays and wedding anniversaries. The "retail event management team" should pay greater attention to such events because they can have deals on certain things every day. As previously stated, by arriving early to these types of events, retailers may meet customer expectations while maintaining predicted profit margins.

In the proposed work, we present a machine learning subdivision called RNN-based special event item prediction system for retailers. RNNs are used to perform item recommendation and prediction tasks. This approach will aid in increasing predicted profit margins and meeting consumer expectations in certain events. By researching existing systems, we were able to determine the system's critical importance and requirements. As a consequence, the appropriate algorithms and machine learning techniques were identified. The suggested system's additional goals are to prepare the dataset, design the systems, implement the system, train the model, and assess the outcomes.

2 RELATED WORKS

Predicting future customer purchases is very important and support to planning the inventory of retail, shop, or warehouse (ndr«es Mart«õnez, Claudia Schmuck, Sergiy PereverzyevJr., Clemens Pirker, Clemens Pirker, Markus Haltmeier, 2018). In paper “A Machine Learning Framework for Customer Purchase Prediction in the Non-Contractual Setting” proposed an advanced analytics tools to perform above mentioned task. Their proposed application implemented through various machine learning algorithms for binary classification. They had used three types of classification methods called: logistic

Lasso regression, extreme learning machine and gradient tree boosting. These methods are totally different one from another, reason to use such methods is to increase accuracy with reasonable computational effort. From the results they had proved gradient tree boosting has highest accuracy. This prediction done for before one month to get the inventory for next month.

Sales time series forecasting has been taken by a system using Stacking approach for machine learning models (Pavlyshenko, 2018). Stacking approach provide ability to use the results of multiple model prediction on the validation set as input regression for next level model and also this approach caused to improve accuracy validation and out of sample data sets. The proposed solution is a three-level model and as the first level used single models, mostly XGBoost machine learning algorithm. As the second stacking level used three models called Extra Tree and Neural Network models. Then summed the results of second level with weights of third level.

There are large number of sales forecasting researchers adopted by neural network models. As the paper (A.L.D. Loureiro, V.L. Miguéis, Lucas F.M. da Silva, 2018) includes, Decision Tree, Random Forest, Support Vector Regression, Artificial Neural Network and Linear Regression are the machine learning techniques they used. For achieve better performance they had used deep learning approach. From evaluation matrices proved Random Forest method has accurate results and better performance than other techniques. This proposed model developed with 10 variables, there for products were characterized by considering those variables. Product price is the only numerical variable this approach contained.

In paper “Application of Long Short-Term Memory Neural Network to Sales Forecasting in Retail" described a case study on sales forecasting in using historical data. The methodology had followed up deep learning based method called Long Short-Term Memory(LSTM). LSTM is a sort of Recurrent Neural Network (RNN) (Yu Q., Wang K., Strandhagen J.O., Wang Y., 2018). In this research study forecasting had done using sales data of 66 products sold in 45 weeks. Most important fact is forecast had done in week level, there for sales dates of first 30 weeks used as training data, the second 15 weeks used as test data. As common way sales values are scaled between [0,1].

Kui Zhao and Can Wang had presented a sales forecasting approach using Convolutional Neural Network(CNN) This study presented for overcome the limitations of existing sales forecasting methods. There for this approach learn effective features automatically form structured raw log data using CNN. In this paper CNN model architecture consists with data frame, convolutional feature maps, activation function, pooling, multiple feature map and fully convention. Finally applied the Linear Regression to obtain the final results of specified feature vector. Then can conclude in neural network activation function used to overcome the linearity issue by achieving non-linearity (Kui Zhao, Can Wang, 2017) and also, this presented research work transferred the knowledge obtained from one problem to another using transfer learning and as the optimization function it used the Stochastic Gradient Descent(SGD) algorithm. This approach was compared with other several approaches called ARIMA, FE+GBRTA and DNN. But CNN model had achieved highest accuracy.

Mostly Sales forecasting approaches follows the neural network methods. It is possible to use small dataset with a neural network for sales prediction approaches (Rosa María Cantón Croda, Damián Emilio Gibaja Romero, Santiago Omar Caballero Morales, 2018). Neural network implementation done respectively training, validation and prediction. Sales forecasting can do considering small time slots, in (Rosa María Cantón Croda, Damián Emilio Gibaja Romero, Santiago Omar Caballero Morales, 2018) had considered the month by month. The models used for this is Simple Moving Average(SMA) and Artificial Neural Network(ANN). SMA can calculate approximation error for each time period. But in ANN cannot replicate entire time series behavior, database size is the main reason for this. There for ANN done prediction for a time period which is larger than SMA consider time period. According to (Rosa María Cantón Croda, Damián Emilio Gibaja Romero, Santiago Omar Caballero Morales, 2018) ANN considered three months. When search through results ANN error is less than SMA. Then ANN has best performance.

Yuto and Katsutoshi were presented a deep learning approach for sales prediction and provide deep learning is effective for analyzing the point of sales data of retail stores (Y. Kaneko and K. Yada,, 2016). Prediction had done for particular day by considering past three years’ worth point of sales data. Deep Learning L1 regularization and Logistic Regression models were used build up the prediction model and deep learning model achieve more accuracy than other. Most important thing is used attributes were divided into three categories and highest accuracy achieved by category 1 data. Number of attributes vary form 62 in category 1 to 3312 in category 3. There for number of attributes caused to prediction accuracy.

Artificial Neural Network(ANN) provides an approximation for all non-linear continuous functions and it is applicable for sales forecasting (M. Garetti, and M. Taisch,, 1999). There are not any unique types of approaches for sales forecasting there for ANN consists with different structures and those structures different from problem to problem. There is a research study for electricity demand forecasting used hybrid structure and data presented in seasonal effects (N. An, W. Zhao, J. Wang, D. Shang, and E. Zhao, 2013). This approach architecture consists with two steps. First step used to reduce the seasonal effects using empirical mode decomposition and second step obtained the demand forecast for specified following time periods considering previous time periods. Multi output feed forward ANN technique used for second step. There is another study of ANN used with stochastic connections for noisy data prevail in water consumptions (H. Rodriguez, V. Puig, J. J. Flores, and R. Lopez,, 2016). Both research studies above mentioned are constructed with ANN architecture used for a long time series.

In paper “House Price Prediction Using Machine Learning and Neural Networks”: Author has done extensive study on Predicting housing prices with real factors (Ayush Varma, Abhijit Sarma, Sagar Doshi, Rohini Nair, 2020).The results of research proved that this approach provides minimum error and maximum accuracy than individual algorithms applied It considered parameters are 'square feet area', 'no. of Bedrooms', 'No of Bathrooms', 'Type of Flooring', 'Lift availability' ,'Parking availability' and 'Furnishing condition'. As a unique approach to increase accuracy, used that the actual real estate value also depends on nearby local amenities such as railway station, supermarket, school, hospital, temple, parks etc. Author has done this study using number of algorithms such as Linear Regression, Forest Regression, Bootstrap Regression and Neural Network.

3 METHODOLOGY

As initial data set, past sales data were used. CSV file consisted with several rows and for prediction process used few of them. This proposed application has two types of users called. Special event item suppliers and system admin. There for system functional requirements can divide considering system users and prediction processes,

1. Retail Special Event Item Management Team or Manager (Admin)
    - Predict the items with higher number of sales (User expected items).
    - Predict the items which give maximum profit in specific event.
2. Item Suppliers
    - Recommend items or item categories, which can give maximum profit to suppliers by supplying the items to the retail.

There for there are two prediction processes, item prediction for higher number of sales, it based on Sold Quantity attribute of dataset and item prediction for find which items give maximum profit in specific event based on Unit Profit attribute of dataset. Item Recommendation process is same as item prediction for higher number of sales processes.

Methodology of built RNN model has several steps, finalize the data set, finalize the dataset attributes used to prediction processes, RNN model build from Spyder and test the build models accuracies.

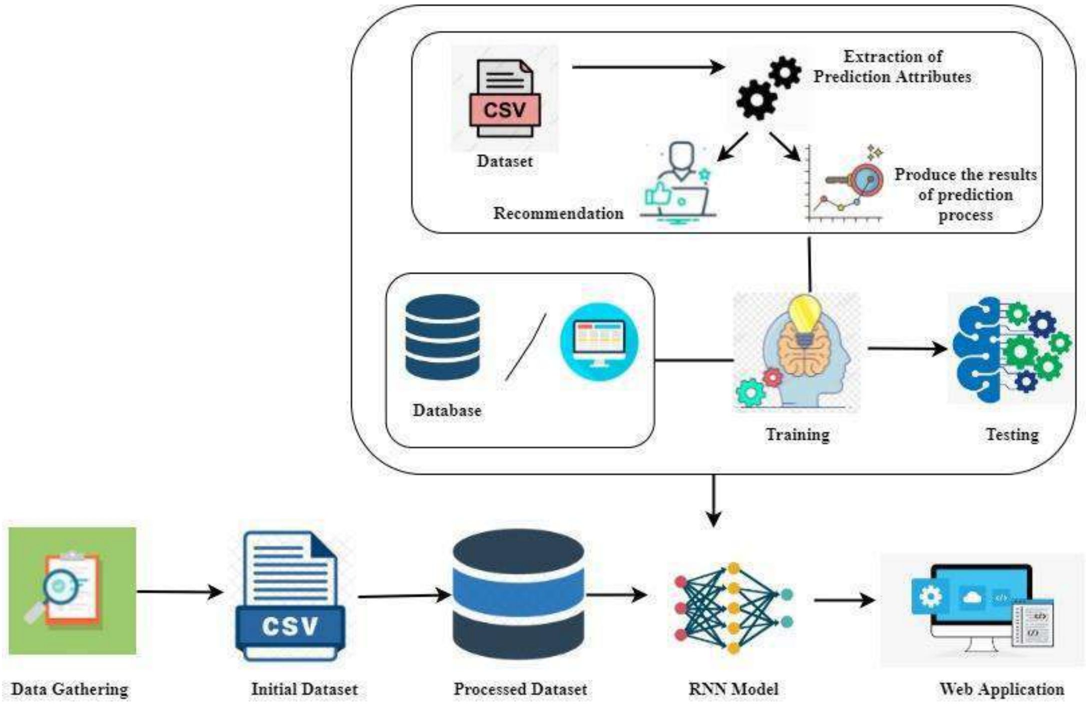

Figure 1 RNN Model Implementation Process.

3.1 Dataset

Table 1 Dataset Attributes

Event Name	Event Id	Item Name	Item Id	Sold Quantity	Unit Price	Unit Profit

Above table columns represented the attributes of referred dataset. Event Id and Item Id used to match the each and every item with the specific event. Sold Quantity, Unit Price and Unit Profit attributes are used for item prediction and item recommendation processes. Dataset is found from Kaggle website and edited with real time sales dataset.

- Unit Price : Used for price forecasting, it would be useful for select the number items which can change the prices in specific time period.
- Unit Profit : Used to predict the profit of items which are selected from price forecasting process.
- Sold Quantity : Used for Predict the items with higher number of sales (User expected items) and Recommend items or item categories, which can give maximum profit to suppliers by supplying the items to the retail.

3.2 Recurrent Neural Networks.

In neural network approaches, RNN is the most prevalent type. RNNs basically take the output from the previous step/layer and feed it into the next step/layer as input. In most neural networks, all of the inputs and outputs are independent of one another, while RNN notions are the polar opposite. If this research study is correct, while predicting products based on prior sales data, the model must remember the past sales data, and to tackle this problem, the model must contain hidden layers. Hidden states are used in the RNN process to remember important information about the sequence (Yu, Y., Si, X., Hu, C. and Zhang, J., , A review of recurrent neural networks: LSTM cells and network architectures). Because

RNN memory can retain all information about completed computations, it prefers parameters for each input to execute the same task on all inputs/hidden layers in order to create the output. As a result, the complexity of parameters was reduced. This is one of the fundamental distinctions between RNNs and other artificial neural networks.

3.3 Model Built from Spyder.

For the sequential model, the Keras deep learning package was employed and this is a python-based deep learning library that is open-source software. Other deep learning libraries can be used as the frontend with this library type. Keras is a high-level API model, thus it's simple to grasp and use (Gulli, A. and Pal, S., , 2017). The advancement of RNN model implementation was heavily influenced by tensor flow and keras. Each layer of the model has its own activation function, as well as the possibility to add layers to the model. Both of Spyder's prediction models go through a training phase. All of the layers in the network were altered after the training process was done. When it comes to the ultimate accuracy rates obtained during the training, validation, and testing phases. LSTM layers were used extensively in both prediction model layers because it is capable with memorize important information in the dataset and feed data back to the neural network. Relu was employed as the activation function for all LSTM layers in both prediction processors. Both prediction models used the Dense layer as the final layer, with the SoftMax activation function as the Dense layer activation function.

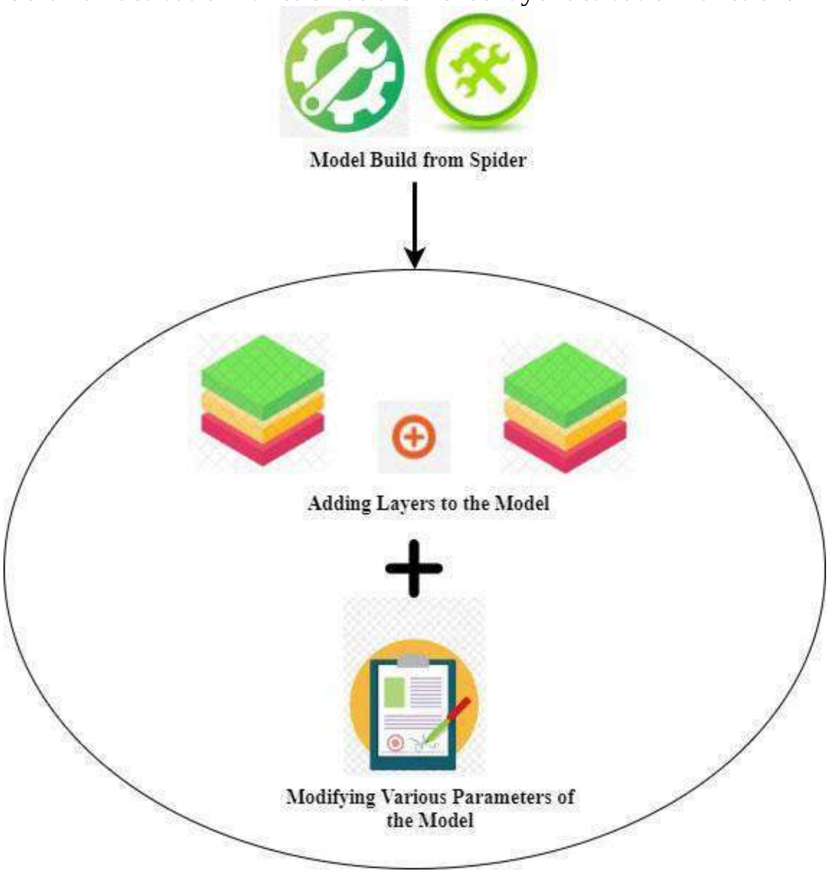

Figure 2 Design the model built from Spyder

Python is the core programming language of this approach and it is the choice for developing prediction and classification models. This is the core programming language for machine learning problems and is classified as a general-purpose computer language. Python is a fairly simple language to learn and use. Python has a number of advanced machine learning libraries (Srinath, K.R., , 2017. ,).

3.4 Changing Layers.

Layers changing process can explain with following scenarios.

1. Considering the inputs shapes changing 50 LSTM layers in Return Sequence.
2. Changing the 50 LSTM layers in Return Sequence consists with 0.2 Dropout and constant 32 batch size.
3. Changing the 50 LSTM layer s without Return Sequence consists with 0.2 Dropout and constant 32 batch size.
4. Finally go through Dense layer and it is the final output layer.

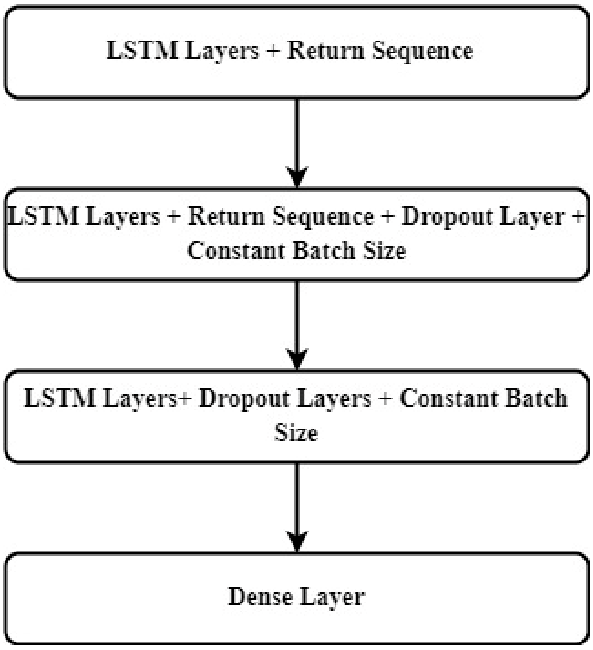

Figure 3 Network architecture of the model developed from Spyder.

3.5 Simulation Setup

Dropout Regulization

The Dropout regulization was set to a constant value of 0.2 over all 50 LSTM layers. It resulted in the creation of an accurate model by preventing the issue of model overfitting.

Number of Epochs

The number of epochs was also a fixed value, there for 25 epochs were used to train the network.

Batch Size Parameter

Batch size also considered with a fixed value; it is 32.

4 RESULTS.

The RNN model was tested under three approaches.

Checking the Accuracy and Loss of RNN model using training dataset.

When the model is being trained, a training accuracy is kept understanding the accuracy acquired by the model during its training phase. This value normally rises with the number of epochs as the model sees more of the training sales dataset.

Checking the Accuracy and Loss of RNN model using validation dataset.

The model examines the sales data in the validation dataset after each epoch to see how accurate the model's weights are for that epoch. After all of the sales data in the validation dataset is input into the model to determine a validation accuracy, the model modifies its weights accordingly, and then repeats the process of having the training dataset stream through all of its layers and the validation dataset do the same at the end of the epoch. This method will be repeated until the training and validation datasets have passed through the model layers a specified number of times (epochs) (Pawar, K., Jalem, R.S. and Tiwari, V., , 2019).
The outcomes of the training technique are used to create two graphs for each model. One of these was the Accuracy graph, which compares the training and validation accuracy plots. The Loss graph, on the other hand, displayed the training loss plot vs the model's validation loss plot.

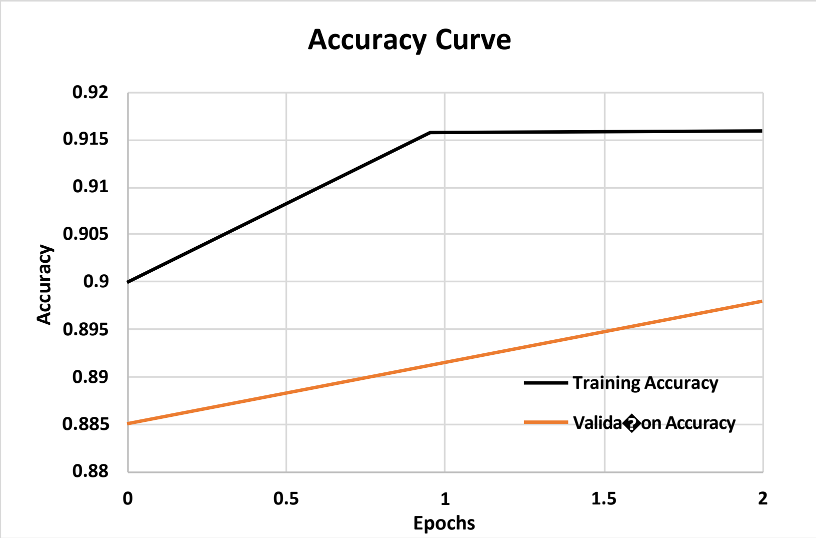

Figure 4 Training and Validation Accuracy Graphs for Model Trained using Spyder.

Figure 5 Training and Validation Loss Graph for Model Training using Spyder

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Checking the Accuracy and Loss of RNN model using testing dataset.

At the end of the training operation, the testing dataset is utilized to determine an unbiased accuracy, which is known as the testing accuracy. A collection of sales data that has never been viewed by the RNN model is employed to achieve unbiased accuracy. The phase of implementation and training is the most important aspect of the entire study process. RNN may be used to create two sorts of prediction models. One prediction is based on the things' profit, while the other is based on the items' sold quantity. Both prediction processes employed item sales data as a data set. These prediction models were created with the Flask Python framework and trained with Spyder.

While the training process is in progress, training accuracy/loss begins to increase/decrease at a faster pace than validation accuracy, and the training process must be terminated.

5 CONCLUSION

During special occasions such as calendar days and seasonal festivals, most retailers are unable to accomplish their profit margins and meet customer expectations due to unfitted present items or décor. This study used a machine learning methodology to propose a retail special event item prediction strategy. This is one of the most crucial learning outcomes in the study process. If the training process cannot be stopped, the model begins to overfit, resulting in erroneous outputs. The testing phase was used to understand and gain some knowledge about the accuracy of the results provided by the RNN models individually, and one flaw was discovered: when a large number of past sales items are present, the event prediction process takes approximately 4 seconds to produce final results.

This proposed approach can enhance with several requirements as future works. Services, users, and events can all be expanded to make this application more useful. This developed system can only be used by retail members and special event item suppliers, and it can be improved as an e-commerce website by giving services to customers. Furthermore, this application can be improved by providing customers with item customization services for a unique special occasion.

This built RNN model generates prediction results based on prior sales data such as sold quantity and profit, as well as item characteristic parameters such as design, color, and size for the prediction process. It will be more feasible than the currently available model.

In the future, our approach could provide location-based retail recommendations to help retailers find the closest suppliers for specific events. This can be accomplished by offering maps to suppliers during the registration process and to administrators on their home page.

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Low Cost – Remote Passive Sensory Based Weather Prediction System with Internet of Things

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ABSTRACT

Climate effects many major daily aspects of the society, from the food sources and transport infrastructure to the choice of fashion and certain daily routines. Due to these reasons, the demand for means to accurately foresee climatic changes have increased. Weather forecasting, especially in Sri Lanka, has been hampered due to numerous reasons and this has resulted in erroneous predictions that has adversely affected many areas of development ranging from agriculture, irrigation, and the tourism industry to certain branches of engineering. Many researchers have analyzed and proposed solutions to these problems. However, the need for accurate predictions prevails due to the hardship of accurate data acquisition, processing, and transmission. To address these problems, in this paper, a system that adheres to the rules and regulations set forth by the World Meteorological Organization (WMO) to carry out well informed and reliably accurate weather predictions based on the data attained from a wireless passive remote sensory medium has been implemented. This task was carried out by means of feeding the relevant climatic parameter readings measured via multiple wireless passive remote sensory nodes placed within the proximity of a considered area to a selected computational model, which in turn was implemented to yield considerably accurate predictions compared to the weather prediction systems currently available in the market. The paper comprises of the implementation of the category, Low-Cost Automatic Weather Station (LC-AWS) specified by the WMO and Internet of Things (IoT), one of the latest technologies, for the transmission of attained data even in the absence of Wi-Fi. The research was further conducted to perform an analytical comparison between highly accurate weather stations and the implemented low-cost weather station when compromising accuracy due to low cost. The hardware and related software implementation yielded an acceptable success rate and was concluded successfully.

KEYWORDS: *Low-Cost Automatic Weather Station, World Meteorological Organization (WMO), Wireless passive remote sensory medium, Internet of Things (IoT)*

1 INTRODUCTION

Abrupt changes of weather patterns may hinder many day-to-day activities of humankind. It not only affects the daily lifestyle of people, but it also adversely affects many daily revenues of development in countries such as transportation, agriculture, irrigation etc. Hence, the importance of accurate weather prediction systems has been identified and implemented. When considering Sri Lanka, accuracy in weather prediction has been hampered due to numerous reasons and has also adversely affected the development of many industries and revenues.

Weather Forecasting has been identified as one of the most important aspects of the society as it plays an important role in any village, city, or country. Since the 19th century, humans have attempted to predict weather informally. However, the accuracy in data acquisition, processing, and transmission and the choice of reliable and accurate sensors plays a major role in this implementation. This research and design focuses on high accuracy and cost efficiency compared to other Automatic Weather Station's (AWS) available in the current market of Sri Lanka.

Inaccurate weather prediction results in many downfalls of development in many revenues and engineering branches of a country. Therefore, it is highly necessary to adhere to suitable World

Meteorological Organization (WMO) guidelines and conquer this situation. Addressing this problem, a stand-alone AWS with facility of remote communication to capture and then transmit meteorological parameters with high accuracy was developed. SDG friendly means of disposal, Minimum possible Power Consumption, Simple User Interface, Durability, and Maintainability were focused on.

1.1 WMO Guidelines

The WMO guidelines were followed thoroughly throughout the design and construction of the AWS for the choice of sensors and placement of nodes. The sensors recommended for AWS by the WMO are the ones most commonly used at traditional manual observation stations that are currently active. Since AWS controls long distance measurements, it is necessary that the sensors used in the design and implementation must be robust, maintenance free, high accuracy, high range, and long-lasting life. Therefore, overall sensors with an electrical output are preferred for this purpose. Furthermore, research also states that the new development is of which sensors are to be considered such as the enhancements in existing sensors and new physical principles. Furthermore, the research also specified that the three types of sensors were also categorized depending on their outputs as follows,

- Analogue - Output in the form of Current, Voltage, Charge, Capacitance or Resistance.
- Digital - Output contains information in a bit or in a group of bits. Also includes sensors with pulse or frequency output.
- Intelligent - Sensors with a microprocessor that performs basic data collecting and processing and provides a serial digital or parallel output.

These factors were considered extremely important to adhere to when deciding on the appropriate sensors to be chosen for the construction and final implementation of the model. Along with these, the necessary factor to be considered while choosing sensors for various measurements were also included as follows,

Considering the objective of the project cost efficient high accuracy sensors were of high preference. The currently existing sensors in the market were known to be of extremely high cost whereas the predictions were not of high accuracy. Multiple sensors met the cause for each dedicated scenario causing multiple comparisons between sensors to be made. The cost efficiency, the accuracy, the range the availability and feasibility of the sensors were discussed in these comparisons. After a considerable amount of research, the sensors for the design were chosen mainly due to their cost efficiency, high accuracy, and availability.

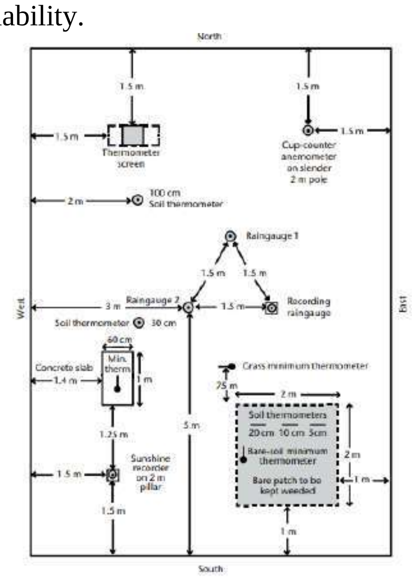


Figure 1.1. Layout of Site for AWS Installation

Outdoor instruments must be put on a flat piece of ground, ideally no smaller than 25m × 25m when there are numerous installations, but in circumstances where there are few installations (as in Figure *1.1*), the space can be much smaller, for example 10m x 7m (the enclosure), according to the

WMO rules. It was also noted that the location must be free of trees, buildings, walls, and other impediments. Sensors inside a screen should be installed at a height set by the meteorological service (between 1.25m to 2m, as per the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8)). The node was put on a rooftop surface away from impediments at a height of 10 meters above ground level, following all standards.

2 CURRENTLY EXISTING AWS

It was necessary that the system consists of separate modules for data acquisition, storage and communication. These modules communicate with each other serially and are controlled by microcontrollers. Data storage and communication are as important as the other sections of the research. As per previous projects and research done on AWS's, there are two options to serve this purpose. The measured (by sensors) and recorded meteorological parameters can be stored in built-in data loggers or it could also be transmitted to a remote location via a communication link. However, it has been considered a failure as with the built-in data logging option, data must be physically downloaded onto a computer for further processing. This is highly inconvenient since the AWS is located in a remote location. Thus, it is understood that a communication system plays a major role in Automatic Weather Systems (AWS).

Previous systems focused solely on collecting temperature data or transmitting it through ZigBee, GSM, Wi-Fi, or some other distant means. Despite these systems measuring the same parameters, they have one flaw: accuracy. And the major goal of this project is to create a freestanding modular weather station with a remote communication facility that can effectively and accurately gather and transmit meteorological information. Many implementations performed without proper observations or patterns tend to be erroneous. There have been multiple implementations of communication with communication devices or through serial and parallel ports to obtain hard copies of weather data. The University of Colombo implemented the built-in data logging facility using a USB communication facility. ("I", 2021). This used a wired communication method for the transmission of data. It transmitted data to the monitoring station through the computer's built-in USB interface.

However, this is not a feasible option as in real situations since this requires physical cables as links between the AWS and the monitoring station. The proposed system will use a communication module will accept incoming serial data and transmit through GSM. An interactive android mobile application interface was implemented to provide the user with the real time data to suite his needs. The lesser known 'ngrok' service, a cross-platform program that allows developers to conviniently expose a local development server to the internet was used to access attained weather parameters from anywhere across the globe.

3 HARDWARE OF PROJECT

3.1 Microcontroller

The ESP32 was chosen to be the microcontroller of this design. The primary reason being that it possesses the ability to transmit data even in the absence of Wi-Fi by utilizing a SIM card with an active data connection for the purpose. The ESP32 is a feature rich MCU with integrated Wi-Fi and Bluetooth connectivity for a wide range of applications. ("I", 2021). It is robust and functions extremely reliably on all industrial environments. It can operate at temperatures ranging from –40 to +125 degrees Celsius. ESP32 can dynamically erase exterior circuit defects and respond to changes in the external environment thanks to improved calibration circuitry. Power consumption is extremely important for an AWS as it needs to operate from remote areas and constantly be up and running to provide real time data. Because the ESP32 is designed for mobile devices, wearable electronics, and IoT applications, it uses a mix of proprietary technology to achieve highly low power consumption. It also incorporates cutting-edge technologies like fine-grained clock gating, several power modes, and dynamic power scaling, all of which contribute to the goal of low power usage.

3.2 Sensor Compliance with the WMO

It was mandatory that the sensors used in the construction of the AWS was in comply with the requirements and specifications of the WMO standard. The following comparison was performed between the WMO specifications and high level sensors to prove accuracy of selected sensors:

Temperature Sensors

① DS18B20 Temperature Sensor Module KY-001
② NTC Temperature Sensor Module (MD0410)
③ LM35 Temperature Sensor (IC0140)
④ DHT22

Table 1. Comparison of Temperature Sensors

	WMO Requirement	①	②	③	④
Measurement Range	-20°C to +60°C	-10°C to +85°C	-20°C to +105°C	-55°C to +150°C	-40°C to +80°C
Resolution	0.1°C	0.5°C, 0.25°C, 0.125°C	0.125°C	0.01°C	0.1°C
Accuracy	±0.1°C	±0.5°C	±0.5°C	±0.5°C	±0.5°C

Humidity Sensors

Table 2. Comparison of Humidity Sensors

	WMO Requirement	HR202L Humidity Sensor Module	DHT22 Humidity Sensor
Measurement Range	0-100% RH	20-95% RH	20-95% RH
Accuracy	+1% RH	+5% RH	+4% RH
Operating Temp. Range	-40°C to +60°C	0°C to +60°C	0°C to +50°C

Pressure Sensors

① Digital Barometric Pressure Sensor Module 0-40KPa 3.3-5V Liquid/Air (MD0535)
② GY-65 BMP085 6-pin 3.3V Digital Barometric Pressure Sensor (MD0616)
③ MS554 MS5540-CM 10-1100mbar Digital Pressure Sensor Module 16bit DC
④ BMP/E 280

Table 3. Comparison of Pressure Sensors

	WMO Requirement	①	②	③	④
Measurement Range	500-1100hPa	0-40KPa	300-1100hPa	10-1100hPa	300-1100hPa
Operating Temp. Range	-40°C to +60°C		-40°C to +85°C	-40°C to +85°C	-40°C to +85°C
Total Accuracy	±0.25hPa		±1.0hPa	±0.5hPa	±0.12hPa
Resolution	0.10hPa		0.01hPa	0.01hPa	0.18hPa
Long Term Stability	±0.10hPa		±1.0hPa	±1.0hPa	±1.0hPa

According to the above comparisons, it was evident that with all the available sensors in the market, the chosen sensors were the best choice for the construction of the AWS of Node 1. The following are the chosen sensors in brief:
Temperature/Humidity Sensor - DHT22
Pressure/Altitude Sensor - BMP/E280
Furthermore, research papers were found to further prove the fact that the sensors chosen complied with the WMO standards and hence, is appropriate for the construction of the AWS. According to (Ioannou et al., 2021), after extensive research of WMO requirements, it was evident that The World Meteorological Organization (WMO) publishes papers that detail how to set up, install, and use various AWS stations. There are four (4) types of AWS, according to the WMO:

- AWS for a limited number of variables (air temperature and/or precipitation).
- Basic AWS for the collection of basic meteorological data (air temperature, precipitation, relative humidity, atmospheric pressure, wind speed and direction).
- AWS with extra solar radiation, sunshine duration, soil temperature, and evaporation measurements.
- AWS with visual observation automation (present weather and cloud base height)

All of the categories allow for the logging of data using a proprietary data logger as well as the transmission of data via a number of means. WMO also acknowledges another kind of weather station, dubbed Automatic Weather Station—Low Cost, in addition to the AWS classifications (AWS-LC). This sort of station is distinguished by its inexpensive cost of operation and procurement, as well as its low power consumption, real-time data transmission capabilities (with or without logging), and ultimately, its miniature and compact size. This was the type of weather station that was chosen to be implemented. Other than traditional stations, the AWS-LC offers a range of benefits. These benefits include the capacity to monitor data in sparse and rural regions, cost savings, reduced random mistakes, greater dependability, and measurement precision, among others.
The research also determined the most efficient sensor with the most accurate measurements), MCP9808 and BMP180, MCP9808 and DHT22, and BMP180 and DHT22 were separated into pairs, and the correlation between their measured levels and the regression between measured data were computed. Additionally, two-sided t-tests were used to see if there was a distinction between the 2 populations' means. Finally, the sensors' responses to maximum and lowest values, and the average measurement each day, were studied. In order to determine whether the measurements acquired from the BMP180, MCP9808, and DHT22 are quantitatively equal to the distribution of real values, it was determined whether the sensor readings were normally distributed (Oneway ANOVA); otherwise, a Kruskal–Wallis H-test was performed whenever the sensor values were not normally distributed. In addition, regression analysis was performed on each sensor to assess the association with the mercury thermometer. The results obtained depicted that the BMP180 and DHT22 sensor measures as compared to the values supplied by the MCP9808 sensor, values whose distribution more closely resembles the distribution of the real values (Ioannou et al., 2021). Therefore, it was concluded that the choice of BMP280 and DHT22 sensors were appropriate for the construction of the Node. The prototype was constructed using the selected sensors to test accuracies as follows:

Figure 3.1. Prototype Testing

3.3 Construction of Anemometer and Wind Vane

Due to the Anemometers and Wind Vanes available in the market being of extremely high cost, it was necessary that this was DIY constructed and tested to troubleshoot. Extensive research was carried out to implement the best Anemometer and Wind Vane as there is a wide range of types to choose from. The following is the research carried out:

The WMO does not specify any strict parameters and requirements for the construction of the Wind speed and direction sensors and further mentions that it may be able to supply some extremely low-cost, simple equipment that assist the observer in taking measurements at locations where traditional anemometers cannot be installed. Therefore, parameters were chosen using research that has already been done for reliable measurements. However, some guidelines mentioned in the WMO requirements,

- Arm connecting the cup to the rotation axis must not be longer than the diameter of the cup.
  This is due to the reason that near the starting threshold, for wind speeds of less than 4ms^{-1}, the calibration of cup anemometers can deviate substantially from linearity and therefore, it was necessary to avoid this occurrence.
- Multiple vane fins should preferably be parallel to the vane axis.
  This is because a vane with two fins at angles > 10° - This is to maintain an equilibrium position to obtain a satisfactory measurement.
- Height – 10m above ground level
  To avoid obstacles and, especially over rugged terrain (rough patch of land), wind speed increases dramatically with height.

3.3.1 Wind Vanes

According to the research performed, there were three types of Wind Vanes identified. Namely,

I. Vanes with a Potentiometer
II. Vanes with a Selsyn Motor System
III. Vanes with an Optical Pulse Encoder

Vanes with potentiometers offer disadvantages such as Sliding contactors wear quite rapidly, Torque of the receiver to move the indicator pointer is miniature, the distance between the vane and the indicating device greatly affects the electrical resistance of the cables between the potentiometer and the receiver, and in case the connection of the three cable leads is not tight, large wind-direction errors may appear.

If the position of the transmitter's rotor does not correspond to that of the receiver, the voltage induced in each of the transmitter's three windings does not correspond to that in each of the receiver's three windings. Consequently, a current flow’s, producing torque, causing the receiver's angle to match the transmitter's spin. The transmitter is also subjected to the same torque, but it is restricted by wind pressure. As a result, the receiver's axis, which has a very light pointer, spins until it matches the angle of the transmitter. According to all the above, it was concluded that the Vane with an Optical Pulse Encoder was the best choice for the implementation due to the following advantages it offers:

- Zero contacting parts and therefore, Free of mechanical friction
- It is possible to attain superior reaction characteristics by making the unit tiny and light.
  Because the output may be handled as digital signals, it's better for data processing using a computer.

the Wind Vane was designed using the 3D AUTOCAD software and the following design was used:

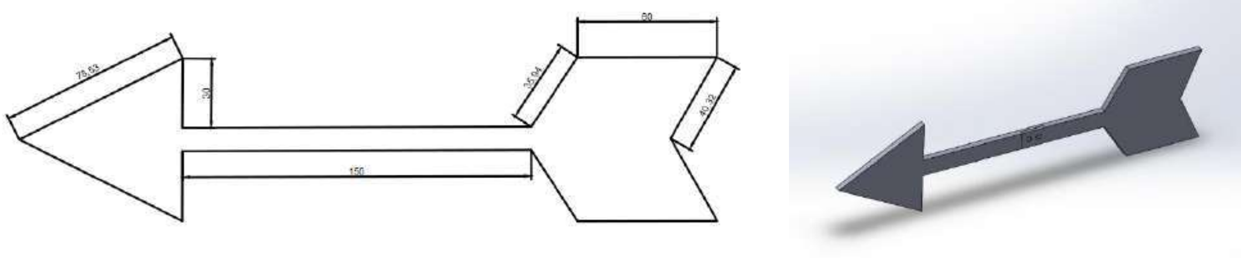


Figure 3.2. 3D Design of Implemented Wind Vane

The Wind Vane was printed in 2 parts so that mounting and locating the center of gravity would be much easier. The 3D printed Wind Vane is as follows,

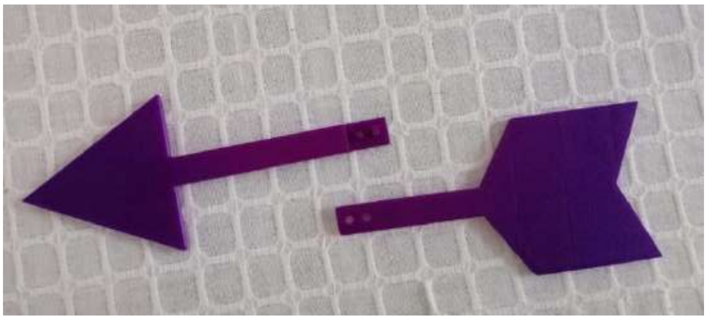


Figure 3.3. Implemented Wind Vane

3.3.2 Anemometers

Just as Wind Vanes, there exists two types of Anemometers namely the 3-Cup Anemometer and the Propeller Anemometer. However, the 3-Cup Anemometer is the better choice for the construction of the AWS for the following reasons:

- Propeller anemometers are unable to respond to rapid changes in wind direction.
- Such delayed response to these changes significantly makes wind speed observation erroneous.
- The propeller axis faced the airflow directly faster as the wind speed increased. The response will be delayed, and wind speed cannot be measured accurately if the wind direction changes within the time the propeller axis takes to face the wind direction directly. (This can be avoided by reducing the amplitude and having a short oscillation period).

The 3-cup Anemometer works on the concept that the cup's revolution speed is proportionate to the wind speed. Three cups are symmetrically positioned around a freewheeling vertical axis in the cup anemometer. The cup turns in the direction of the concave side to the concave side of the following cup due to the difference in wind pressure between the concave and convex sides. Regardless of wind direction, the revolution speed is always proportional to the wind speed. According to the principles used, the types of 3-Cup Anemometers are as follows:

- Generator Type Cup Anemometer
- Pulse Generator Type Cup Anemometer
- Mechanical Type Cup Anemometer

Counting the number of cup rotations is a much simpler way for measuring wind speed using a cup anemometer utilizing the Mechanical Type cup. Through gears attached to the sensor axis, a mechanical-type cup anemometer indicates the number of cup revolutions. This kind has the advantages of not requiring a power source, having a simple design and construction, and not requiring a power supply. The necessity to travel outdoors to acquire readings can be removed, as opposed to alternative choices with a reed-relay immediately attached to the counter. Therefore, considering all the above conditions and requirements the parameters and design of the Anemometer was decided to be of type 3-Cup Anemometer and the dimensions according to the analysis and requirements with a Diameter of 8cm, Radius 4cm, and Axis length of 10cm.

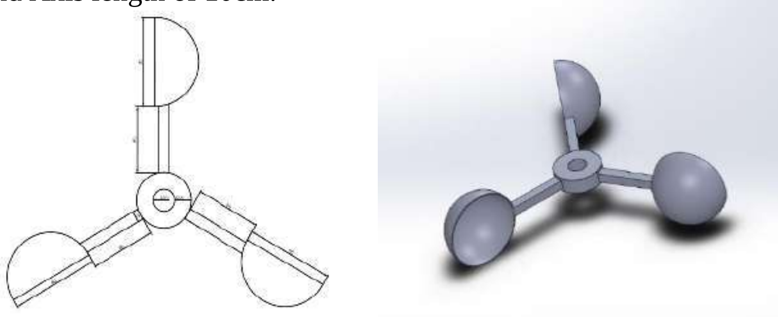


Figure 3.4. 3D designed Anemometer

Therefore, the following 3-Cup Anemometer was printed as 3D as follows:

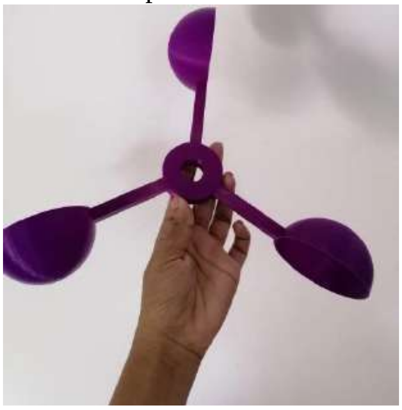


Figure 3.5. Implemented Anemometer

3.3.3 Construction of Node

The body of the node was designed to be made of Aluminum due to it being an extremely versatile material with numerous advantages such as,

- Light in weight and highly robust therefore, installation, inspection and replacing will be easy and convenient.
- Strong therefore, ability to endure rough weathers.
- Corrosion Resistant to avoid corrosion during adverse weather conditions and during constant exposure to air and rain.
- Durability and longevity.
- Infinitely Recyclability and therefore, eco-friendly.
- Lower Energy costs and carbon emissions also eco-friendly.
- Reflects up to 95% of sunlight which protects the hardware, sensors and does not cause erroneous predictions.

With having considered all the above-mentioned advantages, an Aluminum body was designed consisting of a tripod at the bottom to hold up and balance the node. Furthermore, an Aluminum plate was used to keep the body straight and a Damping mat composite to make the surface even when fixing the Wind Vane and Anemometer to the horizontal plane of the body.

The following is the body of the node designed (Apart from the radiation box),

Figure 3.6. Implemented Body of Node 1

The implementation of the Final Hardware was decided to consist of the body of the node along with an enclosed project box to contain the sensors and microcontroller to protect them from radiation and rainwater. All sections of the electronic and data processing unit must be encased in a sealed sturdy container with simple access to all components and mounting options at least to a mast or a wall, according to WMO regulations. The following items must be included in the enclosure:

- All connections must be through waterproof connectors, one connector for each sensor or device.
- All connectors must be clearly labelled as to their function.
- To decrease the chance of water or humidity penetration, the connections must be positioned on the enclosure's bottom side.
- The enclosure should be thoroughly ventilated using a system that prevents dampness from entering.

4 DATA TRANSMISSION

The Web server was able to be viewed through the web server by simply copying the IP address displayed on the serial monitor onto the URL of any web browser. However, the issue with this implementation was that clients around the world did not have the ability to access the web server other than a client accessing it through the local network (Wi-Fi) having the same IP address as the host. Therefore, this issue needed to be resolved as well.

However, it was vital to be able to connect to the web server from anywhere on the planet. The web server may be accessed using a third-party service that will transport the ESP32 IP address from the local area network to the internet. This way, anybody from any location will have the ability to access the sensor readings obtained. To serve this purpose, ‘ngrok’ service was used. ngrok is a cross-platform program that allows developers to conveniently expose a local development server to the Internet. The program lets the locally hosted web server seem to be hosted on a ngrok.com subdomain, removing the need for a public IP address or domain name on the local system ("ngrok and Cross-Platform Development", 2022). It allows to expose a web server running on one’s local machine, to the internet. ngrok provides a real-time web UI where one can introspect all HTTP traffic running over tunnels. However, ngrok only works using any port number other than port 80. Due to this reason, port number 8888 was used in the code. Next, it was necessary to create a ngrok account and obtain an ‘Authtoken’ to access the tunnel.

The following Authtoken was obtained after the registration to the service, *1wnpCCNUNBemSGaRZ2VWTN7CYD2_48eFgzGwkukxKvz1EE9Lv*

This tunnel authtoken was necessary for the next step of the procedure. The downloaded ngrok software was run on windows and the following command was necessary to be entered, (This included the IP Address of the local network and the authtoken)

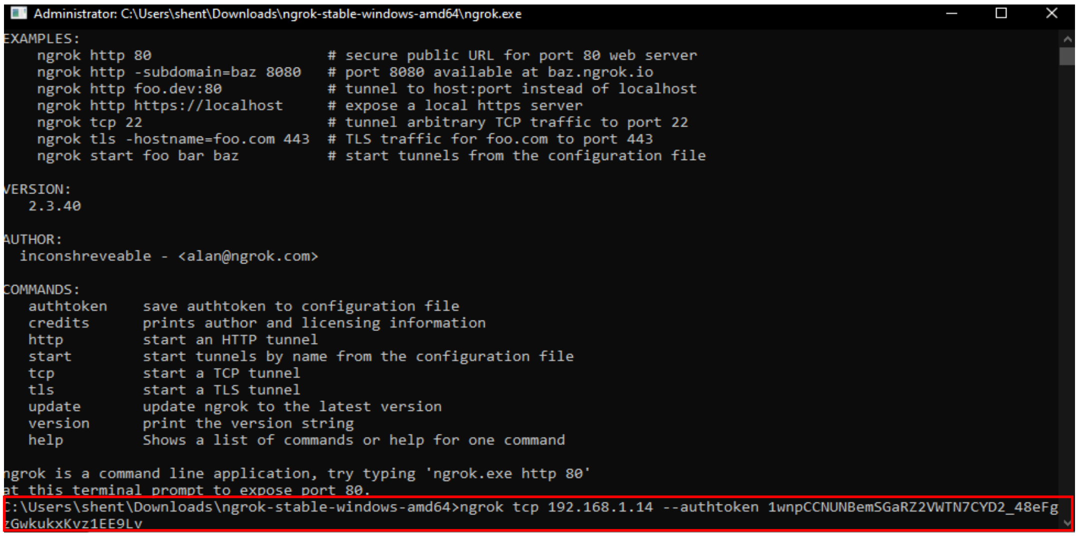
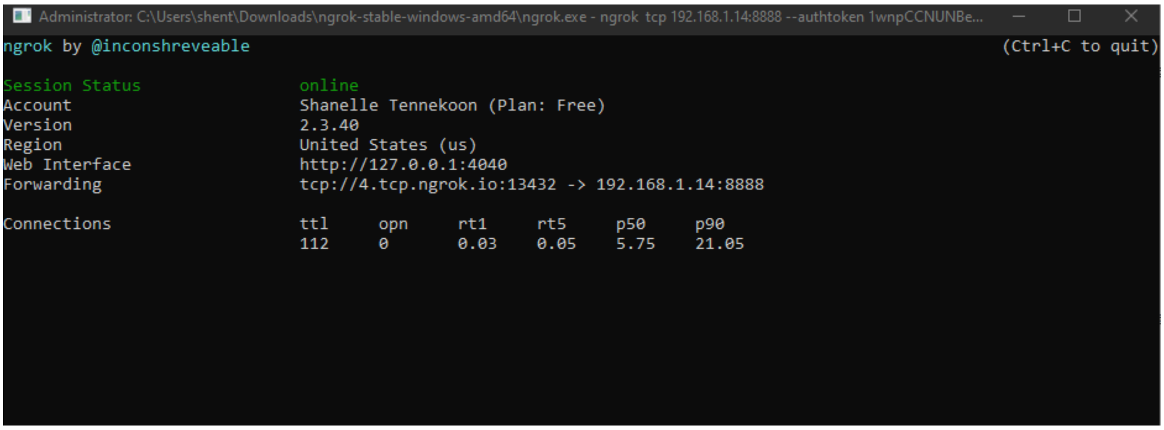


Figure 4.1. Accessing ngrok Service

Next the preceding step, the following window displays the tunnel URL, as seen in the image. Instead of using an IP address, this URL was utilized to reach the web server. The URL obtained in the next window had to be taken note of to access the web server. Anyone could access the web server from anywhere in the world using this URL. If the URL is of TCP type tcp://0.tcp.ngrok.io:**** the tcp can be replaced with HTTP and enter the URL in any web browser and be able to access the web server



from anywhere across the globe. The following was the URL obtained at a certain instance,

Figure 4.2: Obtaining URL from ngrok

The URL was of type TCP. Therefore, the following URL was used to access the web server from any location without using the IP Address directly, http://4.tcp.ngrok.io.13432

However, it was necessary that the ESP32 was active, up and running during the time of obtaining the URL. And it was necessary that this procedure was followed every time the microcontroller was turned off and restarted. Thereafter, a few changes to the code were made in order to change the structure and design of the web server and the following web server was observed from different locations of the country using the URL obtained via ngrok. The following are a few instances as such,

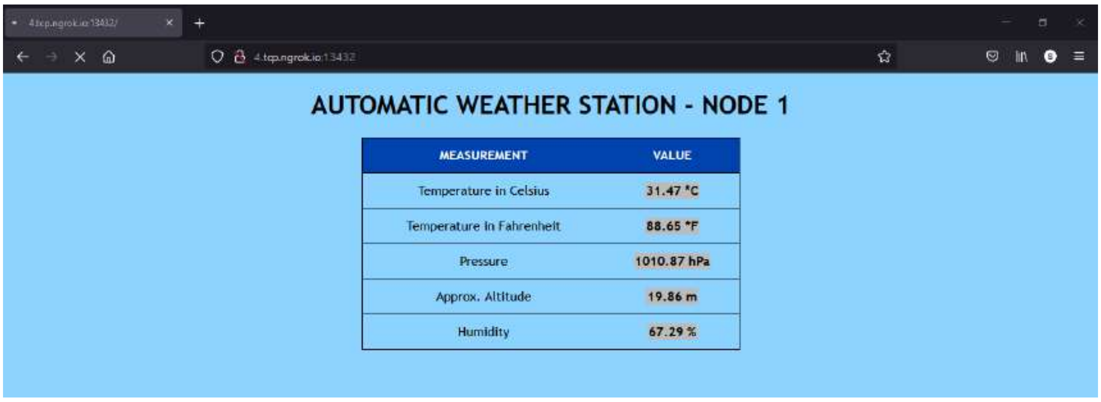


Figure 4.3. Web Server Desktop View

The above figure depicts the web server that was observed when accessing through the desktop. In both instances, the URL used to access the web server was now not just the IP address of the local network but of type, http://4.tcp.ngrok.io.13432

In the setup(), a serial communication must be started at a baud rate of 115200 for debugging purposes. (Any other baud rate would not satisfy the purpose). The Wi-Fi connection was established with WiFi.begin(ssid, password) with the SSID and the Password of the local network provided. It was necessary to wait for a successful connection and print the ESP IP address in the Serial Monitor.

In addition to this a mobile app was developed to showcase the data obtained from the sensors. The 'Blynk' app on the app store and the Blynk Library is an add-on that runs on top of the hardware application that has been installed. This is where the data exchange and connection routines between the implemented hardware, Blynk Cloud, and the developed app project are handled. An authtoken was obtained to connect to the Blynk cloud. The Blynk software is an extremely simple software that allows app designing extremely convenient. The ESP32 was connected to the PC via USB cable. The code implemented was uploaded and thereafter, was connected to the Blynk software.

Figure 4.4. Weather App on Phone using Blynk

5 DISCUSSION

It was identified that the design was implemented successfully adhering to the WMO guidelines and accuracies of sensors. The prototype results proved accuracies of sensors and the extensive research performed prior to the construction of the Anemometer and Wind Vane were of success. Another primary objective of the design was adhering to a low cost. To achieve this, the Budget was planned accordingly from initial stages and the budget of the design is as follows:

Table 4. Budget of Design

COMPONENT		**NO OF UNITS**	**COST (LKR)**
Sensors	Temperature – DHT11	1	375.00
	Pressure – BMP/E280	1	180.00
	Raindrop Module – YL-83 FC-37	1	160.00
	Light Intensity – BH1750	1	325.00
16*2 LCD Screen		1	440.00
Wind Anemometer		1	2100.00
Wind Vane		1	550.00
ESP32 Microcontroller		1	3250.00
Wires & Others		-	1000.00
Station Body		1	12,000.00
		TOTAL	**20,380.00**

A total of Rs. 20,380/= has been spent for the construction of node 1 of the AWS. The design has suited the category of weather stations specified by the WMO as an AWS-LC which is a Low-Cost weather station. The goal of this is to spend a lesser amount than the currently available weather stations in the market and achieve a higher accuracy of predictions. A high accuracy weather station available in the market would approximately cost around LKR 150,000.00/= which is an extremely costly price. However, with the Low-cost AWS, compromising only ±0.5 accuracy of sensors, it was able to achieve a better market value of just Rs. 20,380.00/= proving that it is possible to perform accurate predictions with low-cost weather stations deployed.

6 CONCLUSION

The primary constraint and requirement of this design is high accuracy and cost efficiency. Furthermore, adhering strictly to WMO guidelines to design an accepted product with the ability to be put up for the market was also looked into comprehensively. The WMO mentioned that the construction of the AWS had several types and therefore, according to the scope and Budget of this project the Automatic Weather Station Low-Cost type (AWS-LC) was chosen and implemented successfully.

Another important aspect was that since Sri Lanka is still a developing country, the need for data transmission using wireless means in the absence of wi-fi was necessary and therefore, was proposed to achieve by utilizing an active SIM card with an active data plan so that this design project would be a product that can be used extensively in all areas of Sri Lanka. The mobile app to be developed is also designed to be accessed by anyone with any level of technology knowledge and therefore, can be used by farmers, fishermen, etc. The ESP32 was used to successfully achieve this task as well. Furthermore, ngrok service was used to tunnel network traffic, thereby allowing anyone from around the world to access the data read from the sensors and depicted on the web server. Furthermore, the android app 'Blynk' was utilized to implement a Mobile Interface to access real time data read from the sensors. The results were observed and compared with already existing weather apps such as AcuWeather. It was observed that the weather parameters measured were in accordance with the weather platform readings.

Next, the implementation of the completed AWS (The Body), mobile app, research on pushing and thereafter accessing data from the cloud, central processing device and the predictions were completed. It was tested using equipment if the sensors depicted accurate data. For example, when a hairdryer was held onto the sensors with known temperature, the Web Server depicted a high temperature value that was in accordance with the temperature value set on the hairdryer. Furthermore, known values were used to compare with the obtained values form the sensors used in the Node.

In conclusion it can be stated that the project was of success and every objective that was planned at the initial stage of the project was completed and therefore, is a success. When considering the implemented AWS in terms of accuracy and cost efficiency, it can be stated that the product is extremely reliable, cost efficient in comparison to the already existing products in the market and was successfully completed adhering to all requirements and specifications set forth by the WMO and the MET Department.

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Support Vector Machine Based an Efficient and Accurate Seasonal Weather Forecasting Approach with Minimal Data Quantities

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ABSTRACT

Climate change makes a big impact in our daily activities. Therefore, forecasting climate changes prior to its actual occurrences is important. Even though highly accurate weather prediction systems throughout the world are available, they require mass amounts of data exceeding thousands of data points to obtain a significant accuracy. This study was aimed at proposing a Support Vector Machine based approach to carryout seasonal weather predictions up to thirty-minute intervals, the results of which would be considerably effective with respect to predictions carried out with models trained with annual datasets. The model was trained utilizing a dataset corresponding to the district of Kandy which consisted of 136 samples, 20 features, and 5 labels. By means of carrying out numerous data preprocessing steps, the model was trained, and the relevant hyperparameters were optimized considering the grid search algorithm to yield a maximum accuracy of 86%, once tested via the k-fold cross validation. The performance of the Support Vector Machine was also then compared for the same dataset with that of the K-Nearest Neighbor algorithm which consumed relatively fewer computing resources. An optimal accuracy of 61% was observed for this model for a K-value of 27. This approach supported the concept of a Support Vector Machine's ability to perceive time series forecasts to a relatively higher degree and its ability to perform effectively in higher dimensional datasets with smaller number of samples. As per the future work, the Receiver Operating Characteristic analysis is proposed to be carried out to evaluate the performance of the model and the dataset size is proposed to be further enhanced to a maximum of a thousand samples to yield the best performance results.

KEYWORDS: Support Vector Machines, Principal Component Analysis, Receiver Operating Characteristic, Machine Learning, Weather Forecast, Hyperparameter Optimization

1 INTRODUCTION

It is not uncommon to need over thousands of data samples to train a weather prediction model to achieve an acceptable accuracy. To obtain a sufficiently large amount of data dating back to perhaps multiple decades to appropriately train a suitable model would be a highly taxing procedure. There are many sources available on the internet where one would be able to obtain a large enough dataset, however, at the expense of a considerable large sum of money. Upon carrying out a local survey, to carry out sufficiently accurate enough weather predictions, one would need to implement numerous weather nodes, each having a considerably large budget of around LKR 50 000. To obtain a sufficiently large dataset, these nodes would also have to be maintained throughout a sufficiently long enough time, which in turn will demand further financial liabilities. Either a better suited model or a better suited approach to solving the problem of optimal weather prediction accuracies can prove as a solution which would account for hence said liabilities.

In general, prediction models can yield inadequate results due to reasons ranging from inadequately taken measurements, insufficient understanding of the atmospheric phenomena, and the use of non-standard data acquisition equipment. One major factor which was also contribute to the overall performance is the selection of the most appropriate model. If these steps are not carried out with care, the results would most likely be unfavorable. Two statistical models namely the Bayesian and the Frequentist's statistics and the eligibility of each statistical model were introduced. Various steps that were to be considered to minimize the uncertainty in the predictions made and how the uncertainties

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present were to be effectively communed to the end users utilizing probabilities and more precise scales of likelihood via words such as highly likely, likely, unlikely, and highly unlikely were thoroughly elaborated.

According to (Isabel, 2021) and (Andrew, 2011), Support Vector Machines (SVM) perform considerably well when exposed to time series-based forecasting methods. When considering the finding from (Isabel, 2021), it can be noted how SVMs performs considerably well in the presence of higher dimensional datasets with limited number of samples. As most recognized and as observed from the results of the Principal Component Analysis (PCA) as illustrated in results, weather prediction is highly dependent of the time of year and the time of the date under consideration. The dataset which was available was not of great length either. Hence, a SVM was the algorithm expected to give the highest accuracies when considering the restrictions at hand.

According to a comparison carried out between the performance of a novel lightweight data-driven weather forecasting model by exploring temporal modelling approaches of LSTM and temporal CNNs with existing classical machine learning approaches by (Hewage, Trovati, Pereira, and Behera, 2020), deep learning-based models such as temporal convolutional neural networks which can take a sequence of any length and map it to an output sequence of the same length outperformed the WRF up to twelve hours for ten surface parameters. Though deep learning-based approaches yielded considerably accurate results, this was not considered a viable approach to result considerably promising results. The main reason behind this was the absence of a significant enough amount data that would be required to train the neural network. Like (Hewage, 2020), (Behera, Kumari, and Kumar, 2020) also proposes a deep learning model which was utilized to obtain high prediction accuracies. Due to the high data requirements of the deep learning models, and since the main purpose of this application was to carry out optimal predictions with minimal data quantities, this approach was neglected in this specific application for weather prediction.

1.1 Computational Model Selection and Implementation

Two models were considered and implemented to carry out the weather predictions. Then the performance of these two algorithms were then compared to observed which yielded the better accuracy for the dataset of consideration.

Due to the K-Nearest Neighbor (KNN) algorithm’s simplistic nature in terms of comprehension, implementation, and parameter optimization, it was initially selected for the task of carrying out predictions. The whole algorithm was based around performing a lightweight calculation of Euclidean distances between the training data samples and the testing data sample which resulted in the processing capabilities required to deploy the algorithm in an embedded device highly viable.

SVMs are known to perform in higher dimensional spaces of datasets with considerably lower number of features. The initial dataset which yielded considerably lower accuracies consisted of 62 dimensions and only 19 samples. This nature of SVMs was expected to prevail when carrying out the predictions. Above all, it was the SVMs history of performing exceptionally well when exposed to time series forecasts that won its place in the selection process.

1.2 Diagnosing and Optimizing the Model

If a machine learning algorithm makes unacceptably large errors, one of four steps can be considered to improve its performance according to (Andrew, 2011). Getting more training samples, trying a smaller set of features, trying additional features, and varying the contributing parameters.

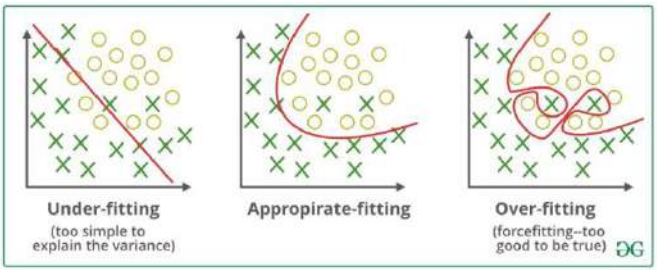

Figure 1. Illustration of three common faults in a model
Adapted from: (Nautiyal, 2021)

Figure 1 above illustrates the three types of behaviors most observed in unoptimized machine learning algorithms. If a certain machine learning model is performing considerably well on the training set but performing noticeably bad on the test set, it can be concluded that the model is overfitting on the training dataset. To fix such a scenario, reducing the number of features available in the dataset may increase the overall performance of the model. If a certain model is neither performing exceptionally well on the training nor the test dataset, the reason maybe high bias. This may be overcome by collecting more samples for the data frame. Using additional features can also help solve this issue.

The approach most used to train a suitable weather prediction model consists of gathering an annual dataset and training a single model to carry out predictions for the span of the whole year. This prompts the need for a larger dataset to yield better generalized results, the generation of which can be both time and resource consuming. Hence it was planned to carry out the weather predictions considering a shorter time span to reduce the number of data points needed for a better generalized prediction. The approach to train the model using a dataset consisting of samples from the two months June and July is proposed to train a model to make predictions for the exact same two months. SVM in addition to these factors will have more parameters which contribute to the overall performance. By varying these the trends can be observed and hence the errors can be rectified. For this purpose of evaluating hypothesis, the dataset can be divided into the most basic form, two parts known as the training set and the test set. This convention requires that around 70% of the dataset be allocated for the training set and the remaining 30% for the test set. However due to the smaller dataset that was considered for this implementation, for the model to be properly trained, the training set was allocated 90% of the data and the test set around10% of the data.

2 METHODOLOGIES

Weather data collected was observed to have considerable number of anomalies and deviations. Due to this fact the following data preprocessing steps were carried out.

2.1. Cleaning, and Preprocessing the Dataset

Since legal means of web scrapping from any of the relevant online resources were not available, the dataset was collected manually and, due to this fact, it consisted of a considerable number of deficiencies. To ensure that none of these missing values were processed as features, certain variables were dropped from the dataset.

2.2. Dimensionality Reduction

Due to the high variance observed for the higher number of features used, it was required to reduce the number of features of the dataset. For this Principal Component Analysis was considered. By calculating the percentage of variation each principal component accounts for, the relevant scree plot was generated as illustrated in Figure 6.

By considering the Kaiser-Guttman Criterion, the maximum number of feasible linear combinations to be extracted from the dataset was considered. According to the Kaiser-Guttman Criterion, any principal with variance less than one, contains less information than one of the original variables and hence is considered not worth retaining. It was noted that the first three components were in accordance with the nature of the variance required according to (Steiger, 2015).

2.3. Accounting for Missing Data Values

To observe the presence of any missing data values, the unique samples available for each feature available were observed utilizing the *unique()* function available in the python environment. By observing the output, the missing data values were located and accounted for considering one of two suitable methods elaborated below.

a) Dropping the samples consisting of missing data values

The entire row features which contain a missing value would be dropped from the dataset. As a result, a smaller dataset would be resulted.

b) Imputing the missing values

The data values which are missing would be replaced considering a suitable value. This value derived however may not entirely be the best estimate to that missing data sample and hence may affect the accuracy of the predictions carried out.

Usually, weather predictions are made considering over thousands of data samples. Since this level of accessibility was not available for the optimization process, dropping samples and hence reducing the size of the dataset was not considered. Hence, imputation was performed to account for the missing data values.

2.4. One Hot-Encoding

Majority of the machine learning models are incapable of working with categorical data directly. It was required to encode each of the available categorical data type in each categorical data feature into a binary number format.

Wind direction was the only categorical data required to be encoded in the new dataset generated. For each state observed in the wind direction feature, a new column feature is created. Then the presence of each state is considered and assigned a one in the new feature for samples in which the specific state is observed to be present. A zero is assigned to the newly created feature in all other samples where this specific state is not observed. After the creation of these new columns, the single column which accounted for the wind direction is dropped.

2.5. Feature Normalization

To shift the scale of values of the data given in a data column to a range in between 0 and 1, feature normalization was performed considering Eq. (1).

$$x(normalized) = \left(\frac{x - min(x)}{max(x) - \min(x)}\right) \tag{1}$$

2.6. Detecting and Eliminating the Outliers Utilizing box plots

After the one hot-encoding and normalization procedures were performed, boxplots were utilized to observe the presence of anomalies among the samples in a feature of focus. Once the anomalies were visually detected utilizing box plots, it is made possible to account for this anomaly and hence prevent them from effecting the overall performance of the model by expanding the ability of the model to generalize to a more satisfactory degree. There were two methods which were considered for handling outliers according to (Vidhya, 2021). Removing the outliers and replacing outliers with a suitable value Out of these two solutions, the later method was considered for implementation.

2.7. Andrew's plots

Variations in the hence processed data frame was observed by means of utilizing various plots such as Andrew's plots. In 1972, Andrew's suggested the idea of representing multivariate data by means of coding. Each multivariate observation can be transformed to a curve such that the coefficients of the Fourier Series is represented by the observations. The outliers appear as single Andrew's curves which are different from the rest. By utilizing these plots, it was hence made possible to visualize the degree to which the rectification of the outliers in the data set were carried out as illustrated by (Jaadi, 2021).

3 EXPERIMENTAL EVALUATIONS

3.1. Rectification of Outliers

Detection and the rectification of outliers is considered one of the most crucial steps in the procedure of data preprocessing. If the outliers in the dataset were not accounted for, the ability of the model to yield well generalized results to highly variant readings may not be feasible. The final data frame considered consisted of twenty dimensions. For each of these dimensions, box plots were generated to gauge the presence or the absence of outliers. (Dawson, 2011)

Outliers could have been accounted for by means of either removing the samples specific outliers, or by means of replacing the outliers with the closest quantile. By considering the later means, outlier values will be rounded up to or down to the nearest quantile value as observed from the box plots.

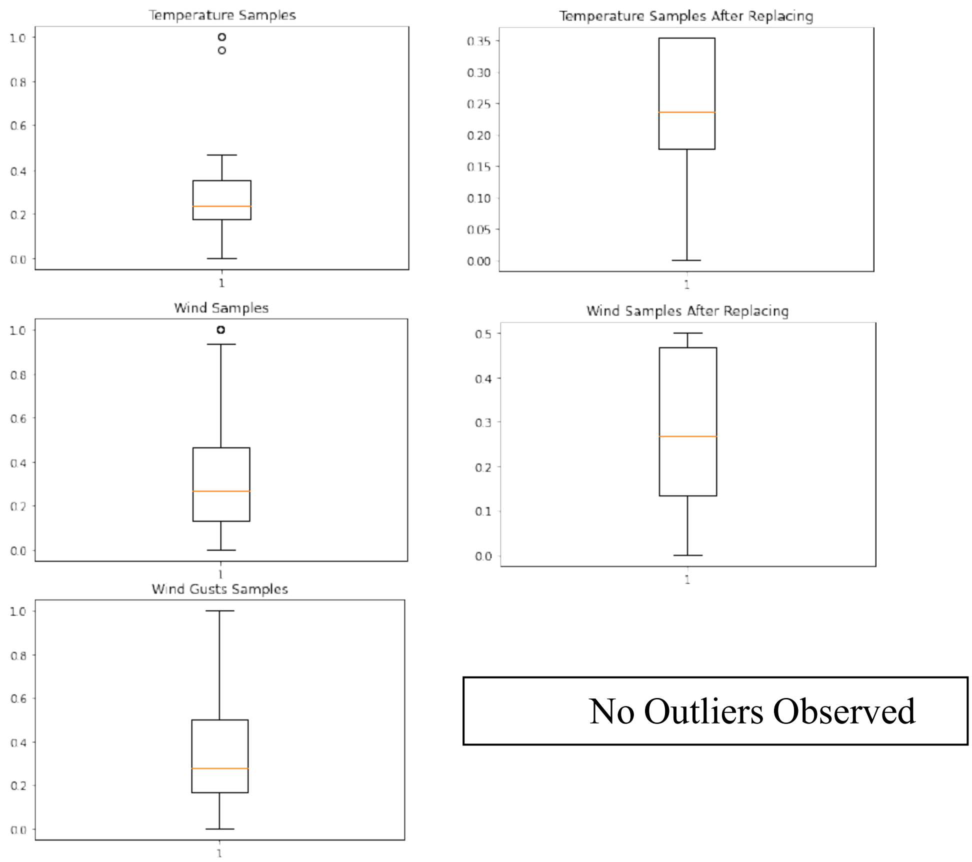

Figure 2. Box plots generated to visualize the presence of outliers in the dataset generated for Kandy

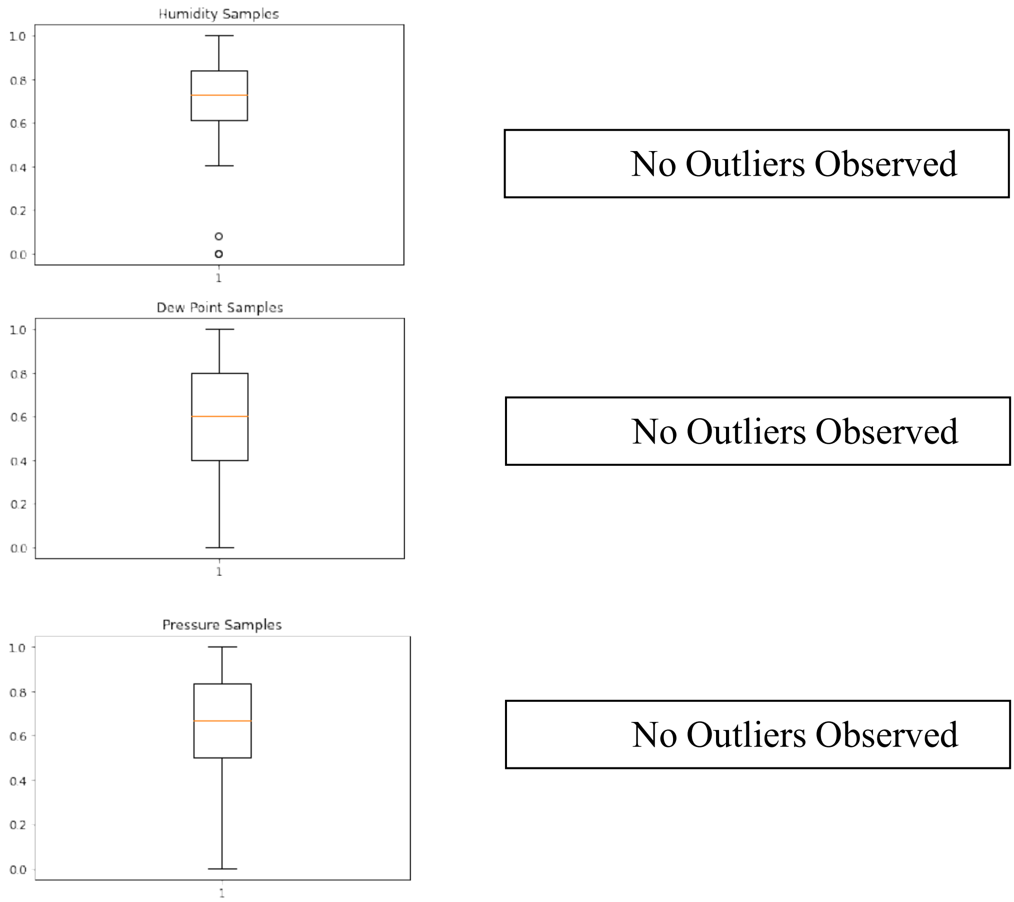

Figure 3. Box plots generated to visualize the presence of outliers in the dataset generated for Kandy

3.2. Identifying Variations in the Data Frame

Due to the considerably higher number of dimensions, it proved difficult to visualize the position of data points in all the dimensions. Scatter plots can only help in the visualization of data up to three dimensions and hence were not considered an efficient solution. For this purpose, Andrew's plots were used.

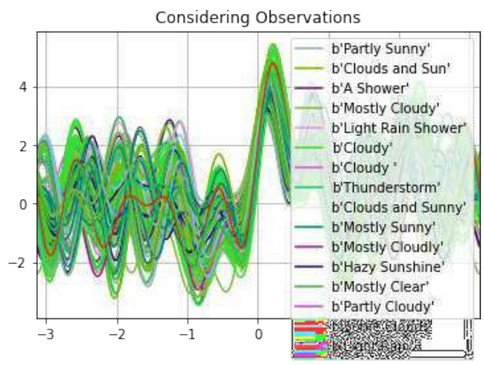

Figure 5. Andrew's plot for the labels in the Kandy dataset

Though there were considerable number of variations among the plot corresponding to each of the available output labels, it did not illustrate any curves which deviated from the rest to a considerable degree. All the curves were clustered together. Hence the outlier rectification procedure was therefore verified to be successful. A downside observed in the plot were the considerably bad signal-to-ink-ratio observed due to the number of curves being overlaid exceeding the recommended amount. Nonetheless, the main purpose of verifying the absence of outliers was confirmed.

3.3. Diagnosing the Model

Initially, it was noted that the algorithm suffered from considerably high bias as it failed to perform well in neither the training nor the testing datasets. This was accounted for by increasing the sample size of the dataset.

Table 1. Results After Accounting for High Bias

	Kernel	C	Degree	Coef0	Gamma	Accuracy
Training Set	poly	10	1	0.01	auto	0.46
Testing Set	poly	10	1	0.01	auto	0.15

It was noted that both the overall accuracies when using either training or testing dataset decreased, but it was noted that the performance of the model for the training dataset was considerably higher compared to that of the testing dataset. The overall decrease in the performance was concluded to be due to the dataset undergoing significant changes and hence resulting in a different optimal parameter vector. This could have also been due to the considerably larger testing dataset resulted. The manual Grid Search and Random Search optimization methods were yet again carried out to yield the optimal results indicated in Table 2.

Table 2. Results After Optimizing for the Second Time

	Kernel	C	Coef0	Degree	Gamma	Accuracy
Training Set	poly	8	144	3	auto	0.86
Testing Set	poly	8	144	3	auto	0.26

The performance on the training set was considerably higher compared to that of the training set. According to the machine learning model diagnosis findings from (Andrew, 2011), it was concluded that the model was overfitting. One effective action recommended to be taken to account for overfitting was to reduce the number of features of the dataset. The dimensional size was then reduced to a size of twenty such that only the real time readings obtained from the sensors were used instead of also considering past values. The hence resulted dataset was utilized to retrain the model and obtain the optimal hyperparameters.

Table 3. Results After Optimizing for the Third Time

	Kernel	C	Coef0	Degree	Gamma	Accuracy
Training Set	poly	8	144	3	auto	0.92
Testing Set	poly	8	144	3	auto	0.57

Upon carrying out this downsizing of the label states, it was noted that the training accuracy yielded increased.

Table 4. Results After Reducing the Resolution of the Labels

Parameter	kernel	C	Coef0	Degree	gamma	Accuracy
Training Set	poly	8	144	3	auto	0.92
Testing Set	poly	8	144	3	auto	0.64

To maintain the time series nature of the dataset, the order of the samples was not randomized prior to using to train the model. Hence upon reobserving the data frame, it was noted that the label 'Clear' present in the training set was not observed in the training set. Hence, when the SVM saw this variable for the first time, it had considerable difficulty in identifying it as it was not initially trained to identify such a label. Hence, some samples which consisted of the label 'Clear' were randomly shifted to the training dataset. This was done due to the lack of data that was available to carry out the training procedure effectively.

Table 5. Results After Randomizing the Order of the Samples to a Certain Degree

Parameter	Kernel	C	Degree	Coef0	Gamma	Accuracy
Training Set	poly	3	3	144	auto	0.92
Testing Set	Poly	3	3	144	auto	0.86

3.4. Principal Component Analysis

The Principal Component Analysis was performed for both the Kandy and Badulla datasets generated. The results can be interpreted as follows.

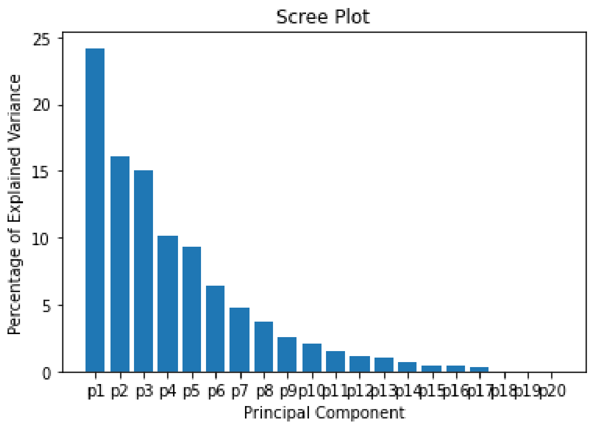

Figure 6. Scree Plot Resulted for the Kandy dataset

Each principal component contributed some level of information of the data and by leaving out principal components, data can be lost. If the first few PCs have caught majority of the information, the rest is negligible. An ideal plot should bend at an 'elbow' and then flattens out. However, as observed from Figure 6, the plot is far from ideal.

If there existed more than 3 principal components, as is the case with both plots above, according to (Ngo, 2018), PCA is not recommended. Therefore, the results of the PCA were not considered when carrying out the feature reduction process and the features were selected considering the physical implementations of the weather nodes. The inadequacy of taking the results of the principal component analysis into account is better highlighted when observing the results of the PCA biplots for the data frame.

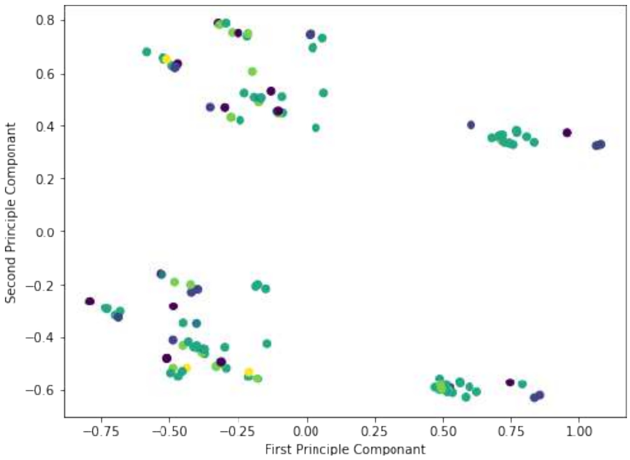

Figure 7. Biplot resulted for the Kandy dataset

Instead of discarding any samples, PCA reduces the number of dimensions by constructing principal components, which in turn describe variation and accounts for the varied influences of original characteristics. These influences are then backtracked from the plot to find what produces the differences among clusters. As observed above, the different components are not effectively clustered. PCA was not considered a viable candidate for model optimization for this specific instance.

3.5. Performance Evaluation

Confusion Matrix of the SVM

```
array([[14,  0,  0,  0,  0,  0],
       [ 0, 16,  0,  1,  0,  0],
       [ 0,  0,  3,  0,  0,  0],
       [ 1,  0,  0, 59,  1,  0],
       [ 1,  1,  0,  5, 17,  0],
       [ 0,  0,  0,  0,  0,  3]], dtype=int64)
```

Confusion Matrix of the KNN Implementation

```
array([[ 9,  1,  0,  1,  0,  0],
       [ 1, 11,  0,  1,  2,  0],
       [ 2,  0,  0,  0,  0,  0],
       [ 5,  4,  0, 35,  2,  0],
       [ 2,  2,  0,  3, 11,  0],
       [ 2,  0,  0,  1,  0,  0]], dtype=int64)
```

Upon glance, it is evident that the true positive and the true negative rate of the confusion matrix corresponding to the SVM is considerably higher than that of the confusion matrix corresponding to the KNN implementation.

4 CONCLUSIONS

The SVM performed better due to it being able to perceive time series forecasts to a considerably higher degree. In addition to this, the SVM had a considerably higher number of parameters which were adjustable, which indicated that the SVM was more flexible to optimization procedures.

Table 6. Final Optimal Performance Comparison

Model	**KNN**	**SVM**			
Optimal Parameters	K = 27	Kernel: Poly	C = 3	Degree = 3	Coef0 = 144
Accuracy	61%	86%			

The accuracy reached by the SVM, for the time span of consideration, exceeded the general accuracy observed in weather prediction models in the local industry. It should be noted that deep learning models would have a considerably higher level of accuracy, however due to the lack of data that was available, this implementation was not considered a viable candidate.

It can also be noted that the use of considerably smaller dataset and how the dataset was divided as 10% for the testing set and 90% for the training set may not have allowed the model to generalize to a satisfactory degree. This short come can be accounted for by means of utilizing a bigger dataset to train the model. Hence, as future work, the concept of making seasonal weather predictions based on a model trained using a seasonal dataset consisting of data corresponding to the same season spanning back numerous years and having a different model for each season can be further proved to be effective over the use of a model trained with an annual wise dataset.

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Domestic Energy Saver

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ABSTRACT

Most of the activities in the modern world are heavy power consumers. Therefore, wasting of power is identified as a critical factor which is badly impacted the environmental and economic growth. Using electrical appliances such as ceiling fans and bulbs in the commercial and domestic environment unnecessarily is identified as a main way of wasting power. As a solution, this paper proposes the designing and producing of a power saving device for ceiling fans and bulbs. Variables such as room temperature, light intensity and the number of people present in the location were considered as parameters to control ceiling fans and bulb automatically, so as to save power by changing the speed and turning off when not necessary. This device is consisting of six main units namely a main control unit using Arduino Nano microcontroller, bidirectional visitor counter unit using two Passive Infrared motion sensors, temperature and light intensity measuring unit using a LM35 temperature sensor and a light dependent resistor sensor, an output display unit using 1604 LCD display, ceiling fan controller unit using a fan regulator that was constructed using two RC circuits, a relay module and a bulb controller unit. Ceiling fan speed and the delay time to switch off the appliances is controlled using a fuzzy logic controller. Inputs of the fuzzy logic controller are temperature difference with the set temperature, rate of change of temperature difference within a five-minute interval, difference of the number of people inside the location with the set number of people and the rate of change of number of people within a five-minute interval. It was observed that, for the test cases, an average of 318Wh per day could be saved from a single bulb and a ceiling fan while avoiding unnecessary usage of appliances.

KEYWORDS: *Energy saving, fuzzy logic controller, Passive Infrared motion sensor, bidirectional visitor counter, fan regulator, room temperature and light intensity.*

1 INTRODUCTION

As a result of the globalization and industrialization in modern era, electricity is the indispensable and high consume resource in the world. But wasting of electricity is the point to pay more attention to avoid the bad impact on environment and economic growth. Because, most of the generated electricity is wasted by the humans in many ways. This proposed method is a solution for the electricity wastage from the bulbs and ceiling fans in domestic and industrial applications that occurs due to human carelessness. Most of the people do not control the bulbs and ceiling fans as the necessity while considering the temperature, light intensity and number of occupants. As well as, at some times the users do not turn off these two appliances when leave the location due to their carelessness. In modern world there are some home or industrial automated systems to control the ceiling fans and bulbs.

In (K.T. Ahmmed, 2014) a device is designed and implemented to control the ceiling fan and bulb according to the room temperature, light intensity and number of persons inside the room. In this device used two IR sensors to count the number of people inside the room. If the number of people is greater than one, the fan turn on if the temperature is higher than the set value and the bulb turn on when the light intensity is lower than the set intensity value. LM35 temperature sensor and LDR sensor is used to measure the temperature and light intensity. As an additional facility a smoke sensor is used to detect the smoke inside the room and a safety alarm is controlled to inform about the occurred smoke inside the room.

A home automation system is mentioned in (Sharma, 2019) to control two devices using IOT method. Ceiling fan and bulb are used as the two appliances and Wi-FiESP8266 (NodeMCU) module is used as the embedded controller and programmed through Arduino. DHT11 temperature and relative humidity sensor is used to measure the temperature and humidity level of the location. LDR sensor is used to measure the light intensity. The received data can be transmitted over the internet and the devices are controlled according to the commands through web. Arduino program is created to communicate.

(S. Piyush, 2014) This journal article mentioned a temperature controller to control the temperature using a fuzzy logic controller. The fuzzy logic controller has the feedback loop to get the desired response of the output. Fuzzifier, rules, inference engine and defuzzifier are used as the steps to implement the Mamdani type fuzzy controller.

The proposed domestic power saving device is more efficient than modern home automation systems due to the specifications of the device. This device is designed and implemented according to the temperature and number of occupants data collected from the six locations of five member family house. The device used three main factors to control the ceiling fans and bulbs according to the necessity while reducing the power wastage. Those are number of occupants, temperature and light intensity of the location. There are six units in the device. Two PIR motion sensors are used to detect the human motion and to get the bidirectional count of occupants in the location. LM35 temperature sensor is used to measure the temperature and LDR sensor is used to measure the light intensity. Arduino Nano is used as the microcontroller and the algorithm is developed using a Mamdami fuzzy logic controller which is implemented using the gathered data during three weeks. Fuzzy logic controller has four inputs and two outputs. This fuzzy logic controller controls the ceiling fan speed according to the room temperature. The bulb is control using the light intensity. Sometimes person can be go outside from the location for a few time period. So the appliance have to waste power again to turn on when that person come inside again. Therefore, a delay time to switch off the device is controlling according to the number of people present in previous and current status to avoid the power wastage that occurs when power consume to turn on the appliances unnecessarily.

2 DESIGNE OVERVIEW

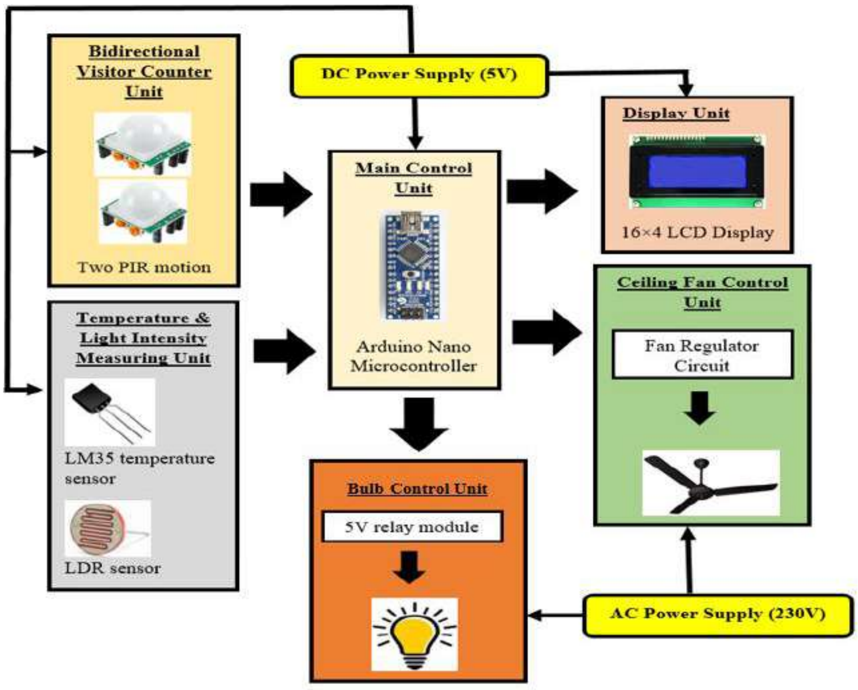

Figure 1. Design overview of domestic energy saving device

The domestic power saving device is consisting with six main units as in the overview diagram which is showing in figure 1 to control the ceiling fans and bulbs to reduce the power wastage while considering three main factors as number of occupants, temperature and light intensity of the relevant location. Six units of the device are main controller unit, bidirectional visitor counter unit, room temperature and light intensity measuring unit, display unit, ceiling fan control unit and blub control unit.

2.1 Main Control Unit

Arduino Nano microcontroller and fuzzy logic controller are the two parts of main controller unit. This unit process the input data and control output data signals according to the conditions of fuzzy logic controller. Main inputs to the microcontroller are digital signals of two PIR sensor modules and analog signals of the LM35 temperature sensor and the LDR sensor. As the outputs, the microcontroller controls the display unit, ceiling fan control unit and the bulb control unit according to these sensor values when the sensor values are adhering to the conditions of fuzzy logic controller.

2.2 Bidirectional Visitor Counter Unit

Bidirectional visitor counter unit is one of the input signal generating units of the proposed project to count the number of person present of the relevant location. Two PIR motion sensors are used to detect the motion of people who entering and exiting from the room. One PIR sensor module is connected inside of the room and the other PIR sensor module is connected outside of the room to count the number of people in bidirectional. PIR motion sensors are constructed mainly using BISS0001 PIR controller and 200BP sensor according to the HC-SR501 PIR sensor datasheet (HC-SR501 DETECTOR. Datasheet , n.d.).

2.3 Room Temperature and Light Intensity Measuring Unit

The main objective of this unit is to measure the temperature and the light intensity of the location. LM35 temperature sensor is used to measure the temperature. LDR sensor is used to measure the light intensity.

2.4 Display Unit

16×4 LCD display is used to display the current and previous status of number of occupants in the relevant location, the current and previous states of the temperature values and the output controller values of fuzzy logic controller.

2.5 Ceiling Fan Control Unit

This device consisting of a fan regulator circuit as one of the output units to control the ceiling fan speed according to the output signals of the microcontroller. This fan regulator circuit is constructed using two safety capacitors and three 5V relay modules which are connected to the digital pins of the microcontroller.

2.6 Bulb Control Unit

The bulb control unit is the other output unit of the device. This unit is connected to the microcontroller through a 5V relay module. Relay module control the electric current to open and close the contacts of the switch according to the output signals of the microcontroller.

3 HARDWARE AND SOFTWARE IMPLEMENTATION OF THE PROPOSED ENERGY SAVING DEVICE

3.1 Proposed Power Saving Device

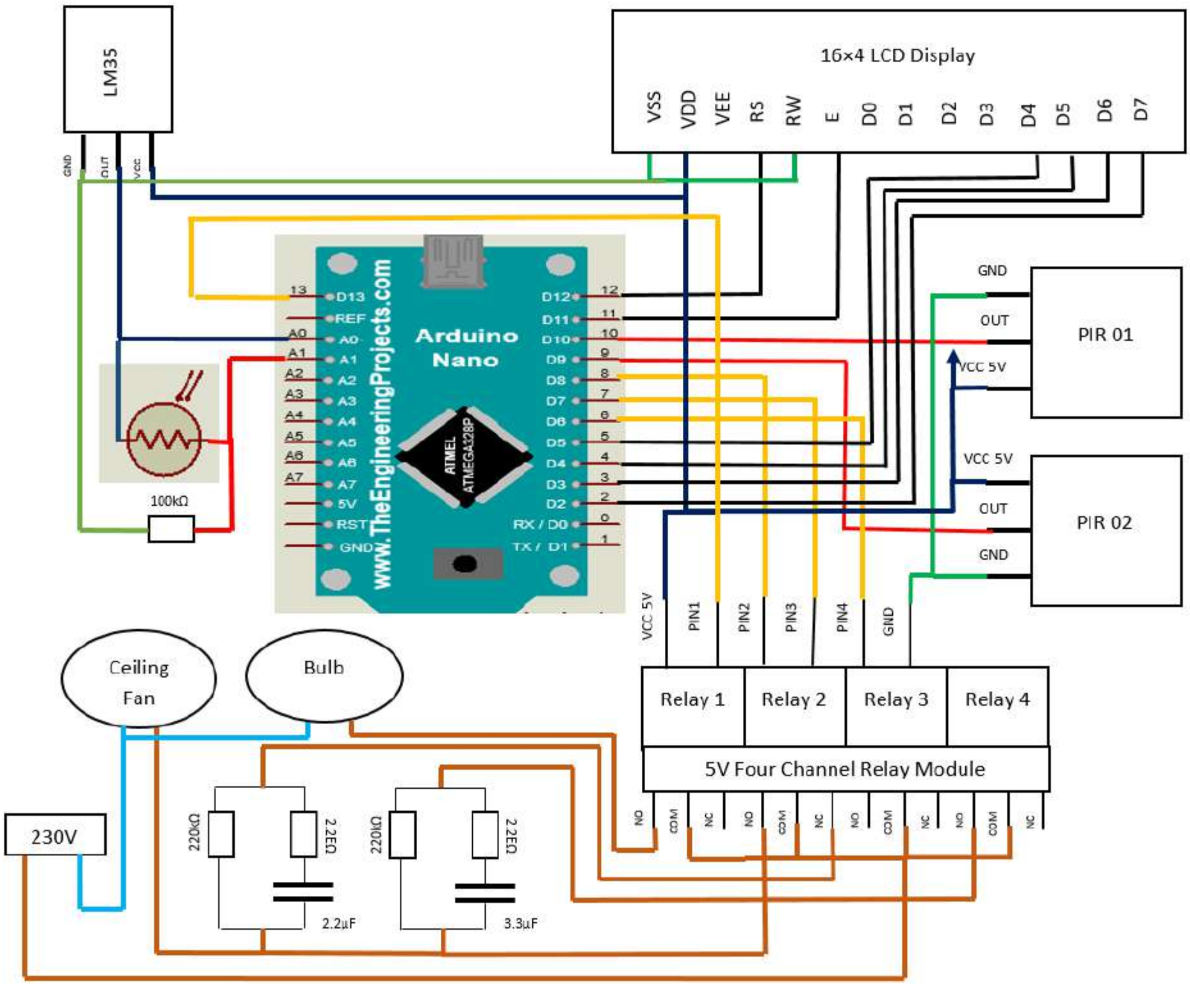

Figure 2. Circuit diagram of proposed power saving device

In figure 2 shows the circuit diagram of the proposed power saving device. Arduino Nano is used as the microcontroller of the device. Pin connection of Arduino Nano microcontroller of the circuit diagram is showing in the table 1.

Table 1. Pin connection of Arduino Nano microcontroller of the circuit diagram

Pin Number	Pin Connection Description
D2	D7 pin of 16×4 Display
D3	D6 pin of 16×4 Display
D4	D5 pin of 16×4 Display
D5	D4 pin of 16×4 Display
D11	E pin of 16×4 Display
D12	RS pin of 16×4 Display
D6, D7, D8	Fan control three 5V relay Modules
D9, D10	Two PIR sensor module
D13	Bulb control 5V relay module
A0	LM35 temperature sensor
A1	LDR sensor

3.2 PIR Sensor Module

Main components used to construct the PIR sensor module are BISS0001 PIR controller and 200BP sensor. BISS001 PIR Controller is the main control IC of the PIR motion sensor circuit. This IC has 16 pins with special noise immunity technique. Supply voltage can be vary in between 3.3V to 5V. Input voltages VSS is approximately (-0.3) V and VDD is 0.3V. The operating temperature range of the IC is -20℃ to 70℃. The storage temperature range is -20℃ to 125℃. 200BP is the pyroelectric passive infrared sensor that used as the sensor of the PIR sensor module.

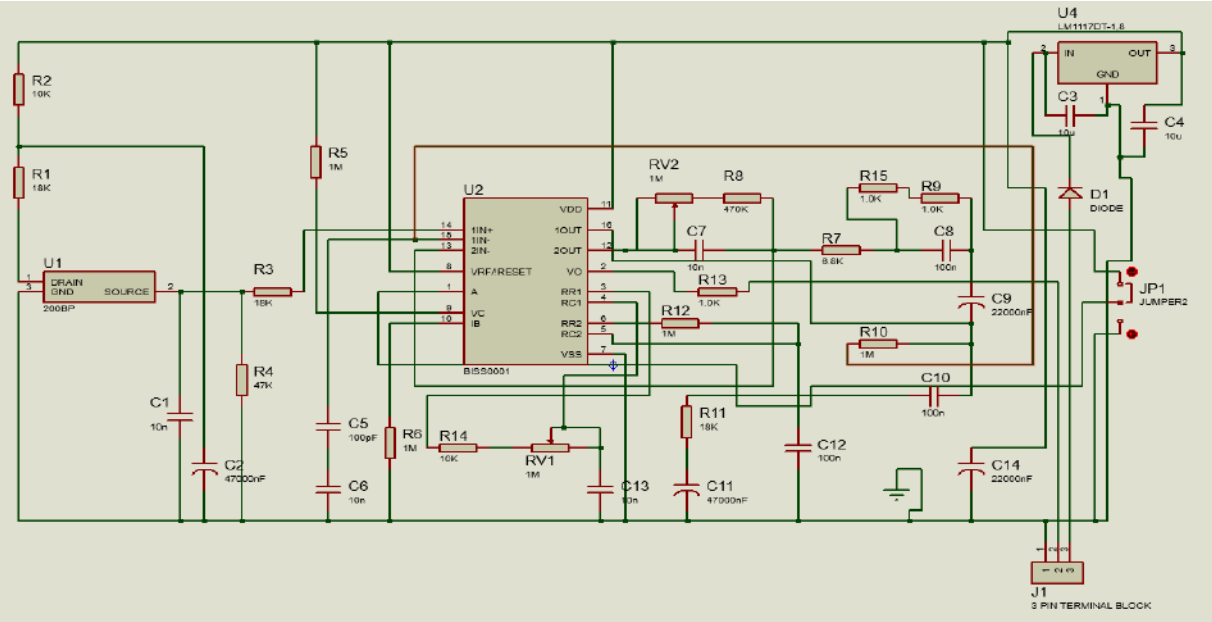

Figure 3. PIR sensor module circuit diagram

Figure 3 shows the PIR sensor module circuit diagram. The circuit diagram is designed by referring to the given specifications of the HC-SR501 PIR sensor module datasheet (HC-SR501 DETECTOR. Datasheet , n.d.) while making some differences to the circuit given in the datasheet.

The output signal of the 200BP PIR sensor is sending to the pin 14 of the BISS001 PIR controller. The PIR controller IC has two operational amplifier units in between the pin 14, 15, 16 and the pin 13, 12 to amplify the small signals from the PIR sensor. A potentiometer is connected to the feedback of the second operational amplifier to control the sensitivity range of the PIR sensor module. PIR controller has a comparator to compare the output voltage of the second operational amplifier with the two internal threshold voltage values. Then output of the comparator goes internally to the pin 9 and the output of the pin 9 is connected with 3.3V through a resister. Pin 1 can use to select the triggered behavior of the circuit. Finally the output of the PIR controller is transmitting via pin 2 as the output of the PIR sensor module.

3.3 Fan Regulator Circuit

Fan regulator circuit is designed to control the fan speed according to the output signals of the microcontroller. A small research based on the reverse engineering method was carried out to identify the pin connections using a four speed level ceiling fan regulator. First of all, the zero to four speed level fan regulator is dismantled and check and identified all the connection using a multimeter. Then designed and constructed the fan regulator circuit.

Required components for fan regulator circuit are two 220kΩ (1/4W) resistors two 2.2Ω (1/2W) resistors, 2.2µF (250VAC) safety Capacitor, 3.3µF (250VAC) safety Capacitor and three channel 5V relay module.

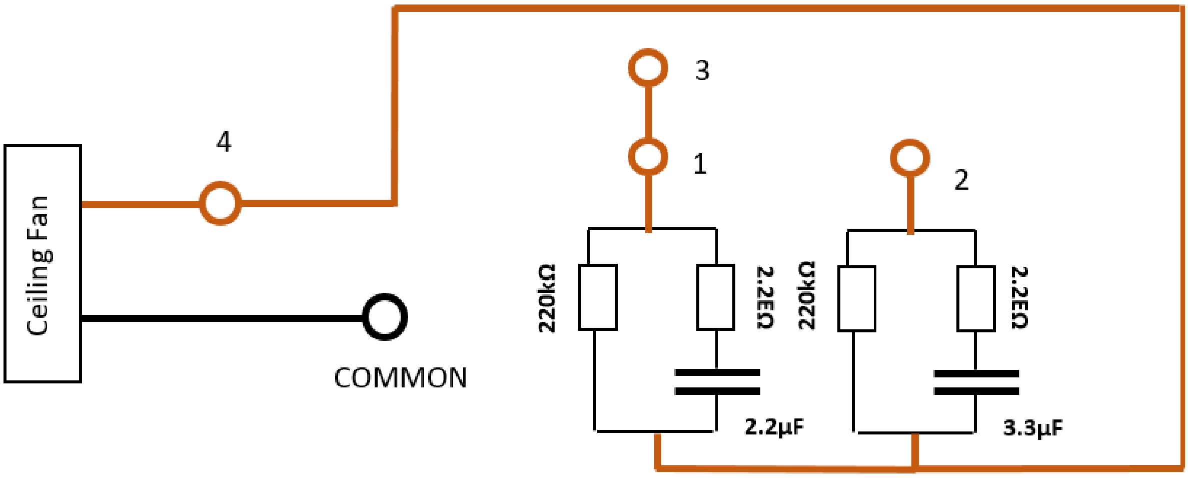

Figure 4. Fan regulator circuit diagram

The circuit diagram of figure 4 shows the designed fan regulator circuit to control the ceiling fan speed from zero to four speed levels. R1 and R3 are the 220kΩ (1/4W) resistors, R2 and R4 are the 2.2Ω (1/2W) resistors. C1 is the 2.2µF (250VAC) capacitor and the C2 is the 3.3µF (250VAC) capacitor. 1, 2, 3 and 4 points connect with the common terminal while limiting the current flowing through the circuit to change the speed levels. Three 5V relays are used to connect the common terminal with the relevant point of the circuit to control the fan speed within speed level zero, one, two and four according to the output signals of the microcontroller.

Speed level zero can be obtained when the common terminal is not connected with any point of the circuit. Therefore, the current flowing through two RC circuit is zero. Point one is connected with the common terminal and the current flowing through the R1, R2 resisters and C1 capacitor of the RC circuit of figure 4 to obtain the speed level 1. The current flowing through the circuit is approximately 153mA. Speed level two can be obtain when the common terminal is connected to the point two and the current flowing through R3, R4 resistors and C2 Capacitor in the circuit of figure 4. The current is approximately 229mA. To control the speed level three the common terminal is connected with the point three in the figure 4 and that point internally connected with the point one and point two. Therefore, the current flowing through both RC circuits and that is about 382mA. If the speed level is four, the common terminal is connected with the point four and the current directly flowing to the fan without flowing through the RC circuits with a maximum current than other speed levels.

3.4 Fuzzy Logic Controller

An algorithm is implemented with a fuzzy logic controller to control the ceiling fan and bulb according to the necessity. Mamdani fuzzy inference system is designed and simulated using MATLAB software based on the collected data of temperature and human presence of six locations of the house during three weeks. The fuzzy inference system has four inputs and two outputs which obtained using if-then rules. Figure 5 shows the Mamdani fuzzy inference system that designed using MATLAB software.

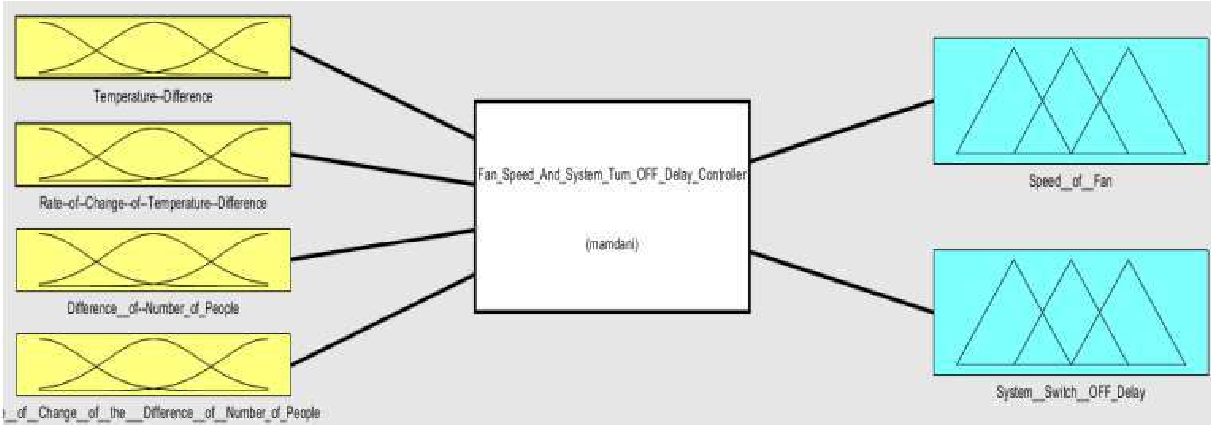

Figure 5. Mamdani fuzzy inference system

Mamdani fuzzy inference system has four input. Those are temperature difference (Diff_Current), Rate of change of temperature difference (D_T), Difference of number of people (Diff_C_Previous) and Rate of change of difference of number of people (D_C).

The temperature difference is obtained from the difference between the temperature (T_k) and a set temperature value. This set temperature value is 27℃. Membership functions are very hot, hot, optimal, cold and very cold.

$$Diff_{Current} = 27℃ - T_k ℃ \tag{1}$$

The rate of change of temperature difference is obtained from the difference between the current temperature differences (Diff_Current) and the previous temperature difference (Diff_Previous) within 5 minutes. Membership functions are negative, zero and positive.

$$D_T = \frac{(Diff_{Current} - Diff_{Previous})\ ℃}{5min} \tag{2}$$

The difference of number of people is obtained from the difference between the previous person count (N_{k-1}) and a set count of people. This set count of people is 3. Membership functions are very high number, high number, optimal, low number, very low number and zero

$$Diff_{C_{Privious}} = 3 - N_{k-1} \tag{3}$$

The rate of change of difference of number of people is obtained from the difference between the previous person count differences (Diff_C_Previous) and count before previous count difference (Diff_B_C_Previous) within 5 minutes. Membership functions are negative, zero and positive.

$$D_T = \frac{(Diff_{C_{Privious}} - Diff_{B_{C_{privious}}})}{5\ min} \tag{4}$$

Outputs of the Fuzzy Control System are speed of the fan and system switch off delay. Speed of Fan – the speed levels are varied with zero level to speed level 4. Membership functions are very high speed, high speed, medium speed, low speed and zero speed

System switch off delay – the delay periods are vary in between 5 minutes to 15 minutes to switch off the power saving device of the ceiling fan ad bulb. Membership functions are very high delay, high delay, medium delay, low delay, very low delay and zero delay.

1. If (Temperature--Difference is Very__Hot) and (Rate--of--Change--of--Temperature--Difference is Negative) then (Speed__of__Fan is Very__High__Speed) (1)
2. If (Temperature--Difference is Very__Hot) and (Rate--of--Change--of--Temperature--Difference is Zero) then (Speed__of__Fan is Very__High__Speed) (1)
3. If (Temperature--Difference is Very__Hot) and (Rate--of--Change--of--Temperature--Difference is Positive) then (Speed__of__Fan is Very__High__Speed) (1)
4. If (Temperature--Difference is Hot) and (Rate--of--Change--of--Temperature--Difference is Negative) then (Speed__of__Fan is High__Speed) (1)
5. If (Temperature--Difference is Hot) and (Rate--of--Change--of--Temperature--Difference is Zero) then (Speed__of__Fan is High__Speed) (1)
6. If (Temperature--Difference is Hot) and (Rate--of--Change--of--Temperature--Difference is Positive) then (Speed__of__Fan is Very__High__Speed) (1)
7. If (Temperature--Difference is Optimal) and (Rate--of--Change--of--Temperature--Difference is Negative) then (Speed__of__Fan is Medium__Speed) (1)
8. If (Temperature--Difference is Optimal) and (Rate--of--Change--of--Temperature--Difference is Zero) then (Speed__of__Fan is Medium__Speed) (1)
9. If (Temperature--Difference is Optimal) and (Rate--of--Change--of--Temperature--Difference is Positive) then (Speed__of__Fan is High__Speed) (1)
10. If (Temperature--Difference is Cold) and (Rate--of--Change--of--Temperature--Difference is Negative) then (Speed__of__Fan is Low__Speed) (1)
11. If (Temperature--Difference is Cold) and (Rate--of--Change--of--Temperature--Difference is Zero) then (Speed__of__Fan is Low__Speed) (1)
12. If (Temperature--Difference is Cold) and (Rate--of--Change--of--Temperature--Difference is Positive) then (Speed__of__Fan is Medium__Speed) (1)
13. If (Temperature--Difference is Very__Cold) and (Rate--of--Change--of--Temperature--Difference is Negative) then (Speed__of__Fan is Zero__Speed) (1)
14. If (Temperature--Difference is Very__Cold) and (Rate--of--Change--of--Temperature--Difference is Zero) then (Speed__of__Fan is Zero__Speed) (1)
15. If (Temperature--Difference is Very__Cold) and (Rate--of--Change--of--Temperature--Difference is Positive) then (Speed__of__Fan is Low__Speed) (1)
16. If (Difference__of--Number_of_People is Very__High__Number) and (rate__of__Change__of__the__Difference__of__Number_of_People is Negative) then (System__Switch__OFF_Delay is Low__Delay) (1)
17. If (Difference__of--Number_of_People is Very__High__Number) and (rate__of__Change__of__the__Difference__of__Number_of_People is Zero) then (System__Switch__OFF_Delay is Very__Low__Delay) (1)
18. If (Difference__of--Number_of_People is High__Number) and (rate__of__Change__of__the__Difference__of__Number_of_People is Negative) then (System__Switch__OFF_Delay is Medium__Delay) (1)
19. If (Difference__of--Number_of_People is High__Number) and (rate__of__Change__of__the__Difference__of__Number_of_People is Zero) then (System__Switch__OFF_Delay is Low__Delay) (1)
20. If (Difference__of--Number_of_People is High__Number) and (rate__of__Change__of__the__Difference__of__Number_of_People is Positive) then (System__Switch__OFF_Delay is Very__Low__Delay) (1)
21. If (Difference__of--Number_of_People is Optimal) and (rate__of__Change__of__the__Difference__of__Number_of_People is Negative) then (System__Switch__OFF_Delay is Low__Delay) (1)
22. If (Difference__of--Number_of_People is Optimal) and (rate__of__Change__of__the__Difference__of__Number_of_People is Zero) then (System__Switch__OFF_Delay is Medium__Delay) (1)
23. If (Difference__of--Number_of_People is Optimal) and (rate__of__Change__of__the__Difference__of__Number_of_People is Positive) then (System__Switch__OFF_Delay is Low__Delay) (1)
24. If (Difference__of--Number_of_People is Low__Number) and (rate__of__Change__of__the__Difference__of__Number_of_People is Negative) then (System__Switch__OFF_Delay is High__Speed) (1)
25. If (Difference__of--Number_of_People is Low__Number) and (rate__of__Change__of__the__Difference__of__Number_of_People is Zero) then (System__Switch__OFF_Delay is Medium__Delay) (1)
26. If (Difference__of--Number_of_People is Low__Number) and (rate__of__Change__of__the__Difference__of__Number_of_People is Positive) then (System__Switch__OFF_Delay is High__Speed) (1)
27. If (Difference__of--Number_of_People is Very__Low__Number) and (rate__of__Change__of__the__Difference__of__Number_of_People is Negative) then (System__Switch__OFF_Delay is Very__High) (1)
28. If (Difference__of--Number_of_People is Very__Low__Number) and (rate__of__Change__of__the__Difference__of__Number_of_People is Zero) then (System__Switch__OFF_Delay is Very__High) (1)
29. If (Difference__of--Number_of_People is Very__Low__Number) and (rate__of__Change__of__the__Difference__of__Number_of_People is Positive) then (System__Switch__OFF_Delay is High__Speed) (1)
30. If (Difference__of--Number_of_People is Zero) and (rate__of__Change__of__the__Difference__of__Number_of_People is Zero) then (System__Switch__OFF_Delay is Zero__Delay) (1)
31. If (Difference__of--Number_of_People is Zero) and (rate__of__Change__of__the__Difference__of__Number_of_People is Positive) then (System__Switch__OFF_Delay is Zero__Delay) (1)

Figure 6. Mamdani fuzzy inference system rules

The figure 6 shows the rules that implemented using AND condition to control the outputs. Fifteen rules are implemented for fan speed controller output and sixteen rules are implemented to system switch off delay output. The output controller calculations are mention below.

Final_Output - the output controller of the fan speed control output.

$$\mathrm{Final}_{\mathrm{output}} = \frac{\mathrm{Output}}{\mathrm{Output\_Divide\_}} \tag{5}$$

C_final_Output – the output controller of the system switch off delay

$$C\_Final_{Output} = \frac{C\_Output}{C\_Output\_Divide} \tag{6}$$

4 RESULTS

This proposed device and the algorithm is developed using temperature and number of people within the six locations of five member family house during three weeks. This device control the ceiling fan speed according to the fuzzy logic controller output that based on the temperature deference and rate of change of temperature difference. As well as, control the delay time to switch off the system based on the fuzzy logic controller outputs created using difference of number of people and rate of change of difference of number of people. This proposed power saving device results a saving about 318Wh per day as an average value. The constructed PIR sensor is showing in the figure 7.

Figure 7. Constructed PIR sensor module

The proposed domestic power saving device is showing in the figure 8.

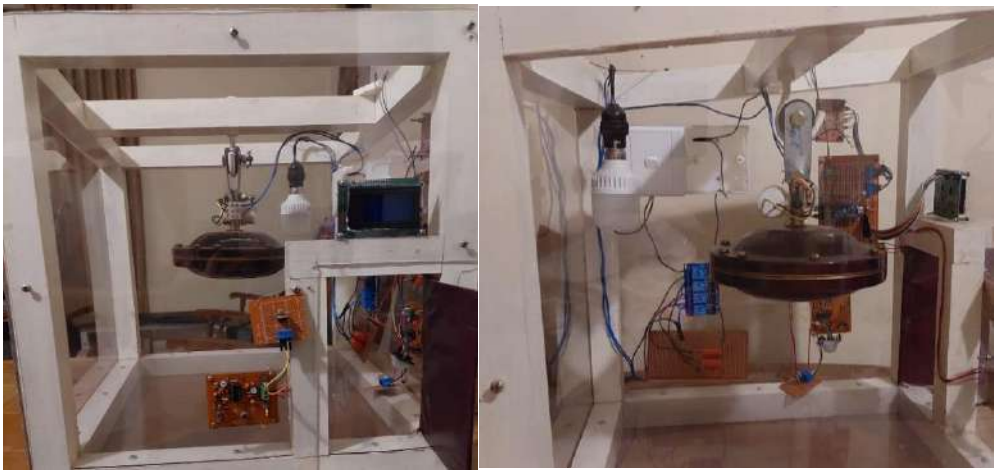

Figure 8. Domestic power saving device

Figure 9 shows the rule viewer of fan speed and system turn off delay controller.

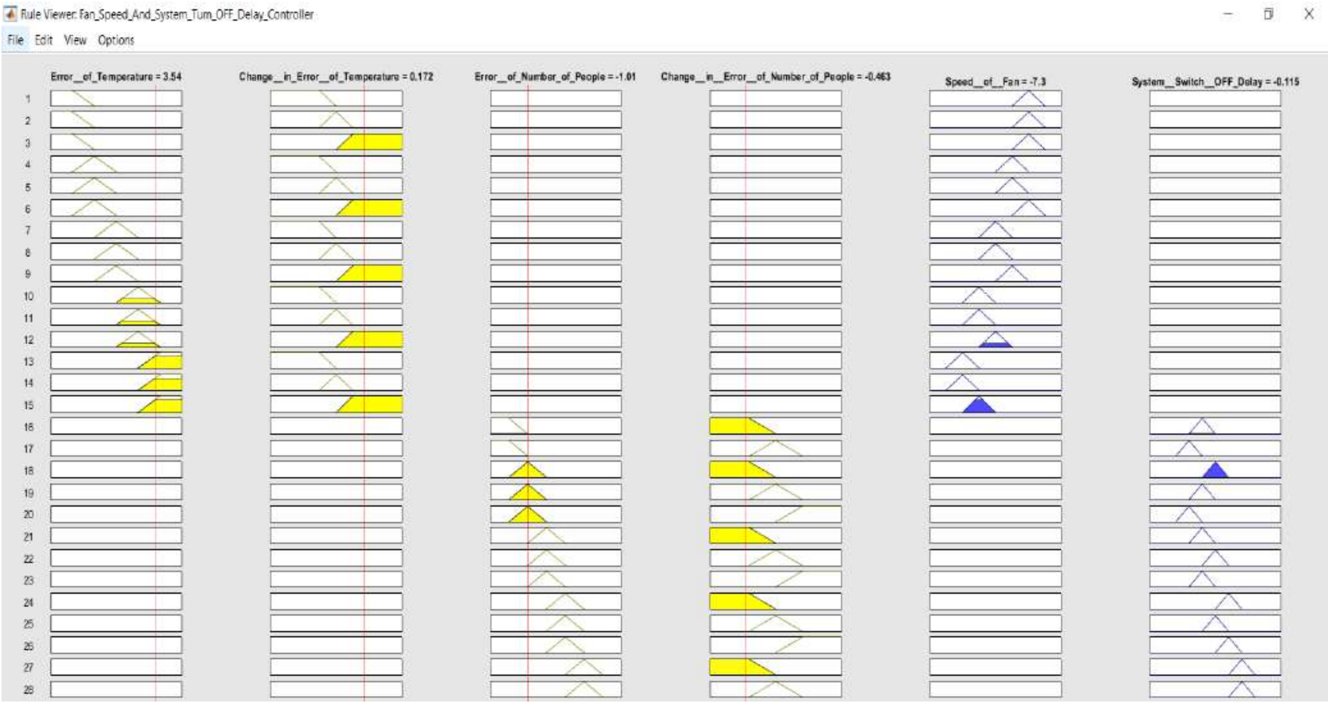

Figure 9. Rule viewer of fan speed and system switch off delay controller

Table 2. Calculated data using designed Fuzzy logic controller for Monday and Tuesday.

Time	Monday	ΔT (° C)	(d ΔT)/5 ° C/min	Speed Level	Watt per hour	Tuseday	ΔT (° C)	(d ΔT)/5 ° C/min	Speed Level	Watt per hour
12.00 a.m - 01.00 a.m	24° C	27-24 = 3 ° C	0 .6	2	27	26° C	1° C	0	1	16
01.00 a.m - 02.00 a.m	24° C	3 ° C	0	0	0	26° C	1° C	0	1	16
02.00 a.m - 03.00 a.m	24.5° C	2.5 ° C	(-0.1)	1	16	25° C	2° C	0.2	2	27
03.00 a.m - 04.00 a.m	24.8° C	2.2° C	(-0.06)	1	16	25° C	2° C	0	1	16
04.00 a.m - 05.00 a.m	25° C	2 ° C	(-0.04)	1	16	25° C	2° C	0	1	16
05.00 a.m - 06.00 a.m	25° C	2 ° C	0	1	16	26.2° C	0.8° C	(-0.24)	1	16
06.00 a.m - 07.00 a.m	25.6° C	1.4° C	(- 0.12)	1	16	26.8° C	0.2° C	(-0.12)	2	27
07.00 a.m - 08.00 a.m	26° C	1° C	(-0.08)	1	16	26.5° C	0.5° C	0.06	2	27
08.00 a.m - 09.00 a.m	27° C	0° C	(-0.2)	2	27	26.9° C	0.1° C	(-0.08)	2	27
09.00 a.m - 10.00 a.m	27° C	0° C	0	2	27	26.5° C	0.5° C	0.08	2	27
10.00 a.m - 11.00 a.m	27.3° C	(-0.3 C)	(-0.06)	2	27	27° C	0° C	(- 0.1)	2	27
11.00 a.m - 12.00 p.m	27.3° C	(-0.3 C)	0	2	27	27° C	0° C	0	2	27
12.00 p.m - 01.00 p.m	28° C	(-1C)	(-0.14)	2	27	27.5° C	(-0.5° C)	(- 0.1)	2	27
01.00 p.m - 02.00 p.m	29° C	(-2 C)	(-0.2)	3	45	28° C	(-1° C)	(- 0.1)	2	27
02.00 p.m - 03.00 p.m	29° C	(-2 C)	0	3	45	28° C	(-1° C)	0	2	27
03.00 p.m - 04.00 p.m	29° C	(-2 C)	0	3	45	30° C	(-3° C)	(-0.4)	3	45
04.00 p.m - 05.00 p.m	27° C	0° C	0.4	3	45	30° C	(-3° C)	0	3	45
05.00 p.m - 06.00 p.m	27° C	0° C	0	2	27	30° C	(-3° C)	0	3	45
06.00 p.m - 07.00 p.m	27° C	0° C	0	2	27	29° C	(-2° C)	0.2	4	55
07.00 p.m - 08.00 p.m	27° C	0° C	0	2	27	29° C	(-2° C)	0	3	45
08.00 p.m - 09.00 p.m	26° C	1° C	0.2	1	16	29° C	(-2° C)	0	3	45
09.00 p.m - 10.00 p.m	26° C	1° C	0	1	16	28° C	(-1° C)	0.2	3	45
10.00 p.m - 11.00 p.m	26.3° C	0.7° C	(-0.06)	1	16	28° C	(-1° C)	0	2	27
11.00 p.m - 12.00 a.m	26° C	1° C	(-0.06)	1	16	26° C	1° C	0.4	2	27
					Total = 583					Total = 729

Table 3. Calculated data using designed Fuzzy logic controller for Wednesday and Thursday.

Wednesday	ΔT (° C)	(d ΔT)/5 ° C/min	Speed Level	Watt per hour	Thursday	ΔT (° C)	(d ΔT)/5 ° C/min	Speed Level	Watt per hour
26° C	1° C	(-0.2)	1	16	26° C	1° C	0	1	16
26° C	1° C	0	1	16	26° C	1° C	0	1	16
26° C	1° C	0	1	16	25° C	2° C	0.2	2	27
26° C	1° C	0	1	16	25° C	2° C	0	1	16
26.6° C	0.4° C	(-0.12)	2	27	25° C	2° C	0	1	16
27° C	0° C	(-0.08)	3	45	26.2° C	0.8° C	(-0.24)	1	16
26.2° C	0.8° C	0.16	2	27	26.8° C	0.2° C	(-0.12)	2	27
26.5° C	0.5° C	(-0.06)	2	27	26.5° C	0.5° C	0.04	2	27
26.9° C	0.1° C	(-0.08)	2	27	26.9° C	0.1° C	(-0.08)	2	27
26.5° C	0.5° C	0.08	2	27	27° C	0° C	(-0.02)	2	27
27° C	0° C	(- 0.1)	2	27	27° C	0° C	0	2	27
27° C	0° C	0	2	27	27° C	0° C	0	2	27
27.9° C	(-0.9° C)	(-0.18)	2	27	28° C	(-1° C)	(-0.2)	2	27
28.3° C	(-1.3 ° C)	(-0.08)	2	27	28° C	(-1° C)	0	2	27
28.3° C	(-1.3 ° C)	0	2	27	28° C	(-1° C)	0	2	27
28.5° C	(-1.5° C)	(-0.04)	3	45	29° C	(-2° C)	(-0.2)	3	45
28.7° C	(-1.7° C)	(-0.04)	3	45	30° C	(-3° C)	(-0.2)	3	45
28.5° C	(-1.5° C)	0.04	3	45	29.7° C	(-2.7° C)	0.06	3	45
29° C	(-2° C)	(- 0.1)	3	45	29.7° C	(-2.7° C)	0	4	55
29.1° C	(-2.1° C)	(-0.02)	3	45	28° C	(-1° C)	0.34	3	45
29° C	(-2° C)	0.02	3	45	28.5° C	(-1.5° C)	(- 0.1)	3	45
29° C	(-2° C)	0	3	45	27° C	0° C	0.3	2	27
28° C	(-1° C)	0.2	3	45	27° C	0° C	0	2	27
26° C	1° C	0	1	16	27° C	0° C	0	2	27
				Total = 755					Total = 711

Table 4. Calculated data using designed Fuzzy logic controller for Friday and Saturday

Friday	ΔT (° C)	(d ΔT)/5 ° C/min	Speed Level	Watt per hour	Saturday	ΔT (° C)	(d ΔT)/5 ° C/min	Speed Level	Watt per hour
26° C	1° C	0.2	1	16	26° C	1° C	0.2	1	16
26° C	1° C	0	1	16	26° C	1° C	0	1	16
27° C	0° C	(-0.2)	1	16	26° C	1° C	0	1	16
26.8° C	0.2° C	0.04	2	27	26° C	1° C	0	1	16
27° C	0° C	(-0.04)	2	27	26.6° C	0.4° C	(-0.12)	2	27
27° C	0° C	0	2	27	27° C	0° C	(-0.08)	2	27
28° C	(-1° C)	(-0.2)	2	27	27.8° C	(-0.8° C)	(-0.16)	2	27
29° C	(-2° C)	(-0.2)	3	45	27.5° C	(-0.5° C)	0.06	3	45
28.5° C	(-1.5° C)	0.1	3	45	26.9° C	0.1° C	0.12	3	45
29° C	(-2° C)	(- 0.1)	4	55	27° C	0° C	(-0.02)	2	27
30° C	(-3° C)	(-0.2)	3	45	27° C	0° C	0	2	27
30.5° C	(-3.5° C)	(- 0.1)	4	55	27° C	0° C	0	2	27
31° C	(-4° C)	(- 0.1)	4	55	27.9° C	(-0.9° C)	(-0.18)	3	45
31° C	(-4° C)	0	4	55	28.3° C	(-1.3° C)	0.12	3	45
30.8° C	(-3.8° C)	0.04	4	55	28.3° C	(-1.3° C)	0	2	27
30.8° C	(-3.8° C)	0	4	55	28.5° C	(-1.5° C)	(-0.04)	3	45
30.6° C	(-3.6° C)	0.04	4	55	29° C	(-2 ° C)	(- 0.1)	3	45
30.6° C	(-3.6° C)	0	4	55	28° C	(-1° C)	0.2	3	45
30.6° C	(-3.6° C)	0	4	55	29° C	(-2° C)	(-0.2)	3	45
30° C	(-3° C)	0.12	4	55	29° C	(-2° C)	0	3	45
30° C	(-3° C)	0	3	45	29° C	(-2° C)	0	3	45
30° C	(-3° C)	0	3	45	29° C	(-2° C)	0	3	45
30° C	(-3° C)	0	3	45	28° C	(-1° C)	0.2	3	45
30° C	(-3° C)	0	3	45	26° C	1° C	0.4	2	27
				Total = 1021					Total = 820

Table 5. Calculated data using designed fuzzy logic controller for Friday to Sunday.

Sunday	ΔT (° C)	(d ΔT)/5 ° C/min	Speed Level	Watt per hour
26° C	1° C	(-0.2)	1	16
26° C	1° C	0	1	16
25° C	2° C	0.2	2	27
25° C	2° C	0	1	16
25° C	2° C	0	1	16
26.2° C	0.8° C	(-0.24)	1	16
26.8° C	0.2° C	(-0.12)	2	27
26.9° C	0.1° C	(-0.02)	2	27
26.9° C	0.1° C	0	2	27
26.9° C	0.1° C	0	2	27
27° C	0° C	(-0.4)	2	27
27° C	0° C	0	2	27
27° C	0° C	0	2	27
28° C	(-1° C)	(-0.2)	2	27
28° C	(-1° C)	0	2	27
30° C	(-3° C)	(-0.4)	3	45
30° C	(-3° C)	0	3	45
30° C	(-3° C)	0	3	45
29° C	(-2° C)	0.2	4	55
29° C	(-2° C)	0	3	45
29° C	(-2° C)	0	3	45
28° C	(-1° C)	0.2	3	45
28° C	(-1° C)	0	2	27
26° C	1° C	0.4	1	16
				Total = 718

The table 2 to 5 show the collected average temperature values for a week. As well as the inputs of temperature difference (Diff_Current) is showing (ΔT) and Rate of change of temperature difference (D_T) is showing (d (ΔT). As well as the calculated consumption of watts per hour of the fuzzy controlled fan speed is showing.

Indian fan was used for the experiment. According to the details given in the (Atomberg, 2017) the ordinary fan consumed 16 watts per hour at speed 1, 27 watts per hour for speed 2, 45 watts per hour for speed 3 and speed 4 consumed 55 watts per hour. Therefore, 1080Wh consumed if the fan use for 24 hours at speed level 3. But according to the calculated data mentioned in table 2 to table 5, the proposed fuzzy controlled ceiling fan consumed 762Wh during the whole day as an average value while changing the speed of the fan according to the temperature of the location. Though, the ceiling fan is in ON mode continuously during 24 hours of a day this proposed device can save about 318Wh (1144.8 kJ). Since the developed algorithm controls the speed of the ceiling fan according to the temperature, the above mentioned efficient power saving occurs. As well as due to the cancellation of unnecessary usage of these appliances results more amount of energy saving. This proposed system can avoid useless switch ON and OFF modes due to the switch off delay of appliances in fuzzy logic control system. This will help to save the lifetime of the appliances while working efficiently.

5 CONCLUSION

Domestic power saving device is proposed in this paper to save the power wastage from the ceiling fans and bulbs which are in active mode unnecessarily. This device control ceiling fan and bulb based on the three factors as number of person presence, room temperature and the light intensity. Manually collected temperature and number of people presence data during three weeks in six locations of five member family house to implement the Mamdani fuzzy inference system membership functions and rules. Six main units consist of this device as main control unit to control the inputs and outputs by using the microcontroller, bidirectional visitor counter unit to detect the motion of people entering and leaving from the location to get the count of people presence, temperature and light intensity measuring unit to measure the room temperature and light intensity, LCD display unit to display the output values of the fuzzy logic controller, ceiling fan controller unit to control the ceiling fan ON/OFF status, fan speed based on the fuzzy logic controller output values and bulb control unit to control the bulb ON/ OFF status based on the fuzzy logic controller output values. As the tested results this device helps to save about 1144.8 kJ per day from a single ceiling fan and bulb while controlling the fan, bulb ON/OFF status and fan speed according to the temperature, number of people presence and light intensity. This is a 5V battery charging device and for the efficient service the installation location of the device should be a covered space within the sensing range (7m 120 degree cone) of PIR motion detectors. The life time of the device about five years. When the comparison in between the proposed device and the existing devices in the industry some modifications and significances can be identified. According to the existing devices, those systems bring the appliances to the ON and OFF modes directly rather than that, this proposed device controls the ceiling fan and bulb towards the OFF mode with a delay time to eliminate the power consumption during the power on stage of the device while enhancing the life time of appliances by reducing the unnecessary OFF modes of appliances. As well as the developed fuzzy logic algorithm to control the ceiling fan and bulb according to the three factors as room temperature, number of people in the specified space and the light intensity of the environment. When comparing with the other devices existing, this proposed device used high quality PIR motion sensors instead of IR sensors to detect the motions. As further developments the algorithm is proposed to build with a new feature to compete with different and various databases in the industrial and domestic systems.

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Assessment of Nationally Determined Contributions of Sri Lankan Power Sector

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ABSTRACT

The nationally determined contributions (NDCs) aim to attend long-term temperature goals, which have been imposed by the Paris agreement to strengthen climate change efforts. Fossil fuel is the major energy source in power generation in Sri Lanka, contributing 67% of total input energies. Sri Lanka is intended to achieve 70% renewable energy in the power sector by 2030 and achieve carbon neutrality in the power sector by 2050 through its NDCs. This study analysed the NDCs in the Sri Lankan power sector. The study was carried out through Asia-Pacific Integrated Assessment Model (AIM/End-use), a recursive dynamic least-cost optimisation framework based on bottom-up modelling principles. The Sri Lankan Power sector has been categorised into a few sectors based on the fuels used in power generation. It mainly considers thermal coal, thermal oil, and hydro. It will also consider all the existing power generation technologies, committed technologies and technologies identified as candidates. A business-as-usual scenario (BAU) and three alternatives NDC were considered in this study. These NDCs include enhancing renewable energy by adding 3867 MW, converting existing fuel oil-based combined cycle power plants to natural gas and establishing new natural gas plants, and improving the efficiency of transmission and distribution network (lost reduction 0.5% compared with BAU by 2030). The study analysed the output data and confirmed the feasibility of meeting GHG emission reduction targets through consideration of selected NDCs in the time span of 2020-2030. The GHG emissions from the BAU scenario and three countermeasure scenarios were analysed in 2015-2050. The input primary energy supply was determined to compare the variation in energy with the effect of NDCs.

KEYWORDS: *Power Sector, Nationally Determined Contributions, Sri Lanka, AIM/Enduse, CO_2 Mitigation.*

1.0 INTRODUCTION

Sri Lanka is a middle-income country located near the equator and experiences tropical climate throughout the year. Since ancient times Sri Lanka has had an agriculture-based economy. The country's economy gradually transformed into an agricultural and industrial-based economy. Modern technology heavily impacted society and lifestyles. Sri Lankan GDP has significantly risen after the civil war in 2009 until the Covid-19 global pandemic. Major development projects and the vast improvement of tourism have resulted in economic growth in the recent past. Continuous and uninterrupted electricity supply is a must for a developing country to achieve its economic goals. To satisfy the rising electricity demands in the country, expansion in the power generation sector is essential. With the rise of demand, a large amount of energy is required to fulfil the demand. In the past, most of the electricity demand was supplied using hydropower, and a small percentage was supplied using fossil fuel-based thermal power plants. However, with the demand rising, the country had to consider other generating options. At that time, the significant factor was cost efficiency and rapid installation. As a result, many fossil fuel-based thermal powers were commissioned during the past few decades. Because of that, today, 51.65% of electricity is generated by using fossil fuel-based

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thermal power plants(The Generation Planning Unit Transmission and Generation Planning Branch Ceylon Electricity Board Sri Lanka, 2019)

The Parsi agreement was established in 2015 in response to global climate change concerns. The agreement aims to keep global warming well below two degrees of Celsius (preferably 1.5°C) compared to pre-industrial levels. The Paris accord empowers countries to determine their own long-term Nationally Determined Contributions (NDCs). Nationally Determined Contributions can be thought of as the heart of the Paris Agreements, as they detail each country's specific greenhouse gas (GHG) mitigation efforts over a specified time period.(UNFCCC, 2015).

Sri Lanka submitted the first NDCs to the UNFCCC secretariat in 2015, and an updated version was submitted in July 2021. Sri Lanka's updated NDCs cover a range of different sectors. However, for the purposes of this study, consideration is limited to NDCs in the Sri Lankan power sector. Given that the power sector accounts for a sizable portion of the country's GHG emissions, assessing the power sector's NDCs enables decision-makers to gain a better understanding of future energy and emission patterns. Additionally, assessing NDCs is critical for achieving the global and local energy-environmental targets defined.

According to the Ministry of Environment Sri Lanka, the updated NDCs are based on more recent analysis and include strategies for mitigating and adapting to climate change over the period considered (2021 -2030). For the power sector, a total of five NDCs have been submitted. The county expects to reduce GHG emissions by 25% (5% unconditionally and 20% conditionally) between 2021 and 2030 by implementing the five NDCs. Identifying future GHG emission scenarios' possible challenges and predictions are essential when reaching the determined GHG emission targets in the power sector. Modelling is a powerful tool for analysing the power sector and assisting decision-makers in achieving future sustainable targets in the power sector(Ministry of Environment, 2021)
There were no recent studies that analysed the effects of NDCs on the Sri Lankan power sector.

However, several similar studies have been carried out for the Sri Lankan and regional contexts in the recent past. Emissions in the different sectors like transport, industrial, agricultural and power have been modelled in previous studies. Different types of energy modelling scenarios have been considered in each study. Country and regionally based scenarios must use the forecasting technique most appropriate for the country or the region. Most of the studies used modelling techniques to predict GHG emissions, but their analysing aims were different.

Sugathapala, 2020 is a recent study that carried out in the Sri Lankan context to assess multi-criteria energy sector mitigation action. This study analysed the 52 nationally appropriate mitigation actions (NAMAs) to identify their pros and cons. The studies state that NAMAs submitted by Sri Lank has mainly focused on marginal abatement cost and are not very much concerned with other factors, such as co-benefits, enablers and barriers. However (Sugathapala, 2020) has a different objective; it did not specially focus on the power sector, but all the energy sectors generally.

(Selvakkumaran & Limmeechokchai, 2017) is a study that was carried out to assess Sri Lankan and Thailand Power sectors. The study aimed to assess how Low Carbon Scenario (LSC) affects both countries' power sectors in the case of mitigating CO2, techno-economic results, energy security, and marginal abatement cost. The AIM Enduse model had been used to model the power sectors. However, this study did not focus on analysing the NDCs, and it mainly focused on various aspects of the LSC scenario. Since this study used the older version of the Sri Lankan Long Term Generation Plan, some of the data could be changed with the new plan. Unavailability of NDCs at that time and latest government policies were adapted according to the NDCs, and lack of consideration of economic factors can be identified as the major drawbacks.

2.0 METHODOLOGY, SCENARIOS AND DATA

2.1 Modelling Framework

The modelling was performed by using the AIM/Enduse model, which was developed in the late 90s by the National Institute for Environmental Studies in collaboration with Kyoto University, Mizuho Information & Research Institute and several research institutes in the Asia-Pacific region

(AIM Project Team, n.d.). The AIM/Enduse model is a recursive dynamic bottom-up optimisation model capable of selecting detailed technologies inside a country's energy economic environment system. The technology selection is based on the least cost optimisation framework. The power sector of Sri Lanka was modelled considering all existing and potential future expansion technologies. Modelling considers the BAU scenario with three countermeasure scenarios. The three countermeasures' scenarios are based on selected NDCs for the study.

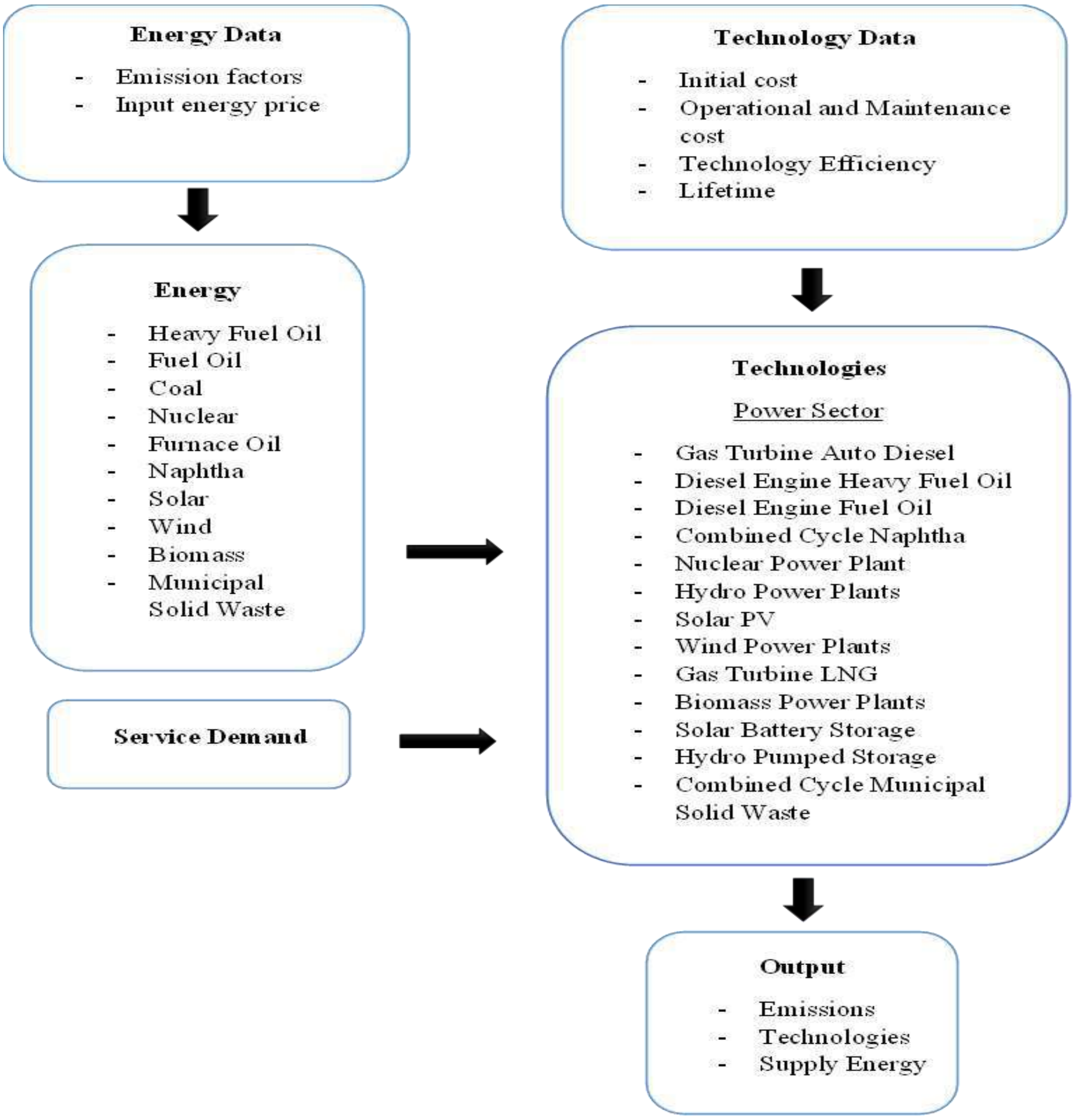

Figure 1 Schematic Diagram of Modelling Framework

2.2 Scenario Development

Three countermeasure scenarios were developed using the AIM/Enduse model in addition to the business as usual scenario. The first step in modelling was to define and model the BAU scenario. The business as a scenario was developed in accordance with CEB's current expansion strategy. There is a total of five NDCs under the power sector of Sri Lanka. Among them, three countermeasure scenarios were selected for analysis in the study. The NDCs are selected based on the possibility of the model using the AIM/Enduse model. The NDC 01, NDC 03, and NDC 04 were used to model countermeasure scenarios (CMs)(Ministry of Environment, 2021). Each countermeasure was described in accordance with the applicable NDC/NDCs.

Table 1 Scenario Description

Scenario	Relevant NDC/ NDCs	Description
CM01	NDC 01	The scenario focuses on enhancing renewable energy contribution (RE) by adding 3867 MW. Solar PV, wind, hydro and sustainable biomass share was increased.
CM02	NDC 01 & NDC 03	The scenario focuses on employing the effect of CM01 + conversion of existing Fuel Oil-based power plants to natural gas (NG) and the establishment of new NG plants*. (Cumulative effect of NDC 01 & 03)
CM03	NDC 01, NDC 03 & NDC 04	The scenario focuses on employing of CM01 + CM02 + 0.5% transmission and distribution loss reduction*. (Cumulative effect of NDC 01, 03 & 04)

Each countermeasure scenario evaluates the effect of NDCs on the Sri Lankan power sector in terms of reducing GHG emissions, supplying primary energy, and distributing end-use energy. The effect was calculated by combining NDC 01 and NDC 03 in CM02, as the NDCs are intended to be applied concurrently in the actual scenario. By examining the cumulative effect of NDCs in two countermeasure scenarios, it is possible to compare the effect of each NDC to the cumulative effects of NDCs.

CM01 and CM02 were directly modelled using AIM/Enduse. The respective technologies' share was varied to achieve the NDCs' in the selected time frame. CM01 was achieved by increasing the share of renewable technologies (devices) respective to BAU.

Countermeasures can be implemented in the model utilising a variety of different ways. Three viable methods to define countermeasure scenarios in the model are managing the renewable share, stock quantity, and recruited quantity. Additionally, the combination of three methods can be utilised to create scenarios with the desired service share. Between 2021 and 2030, Countermeasure scenario CM01 focuses on boosting existing renewable energy. According to the data, the expansion of renewable capacity in NDC 01 nearly doubles the existing share of renewable energy. That is, the NDC 01 can be met by approximately doubling the existing renewable capacity. The existing renewable share was doubled in the model in order to achieve the aims of NDC 01. In Countermeasure scenario CM02, the additional LNG share was added to Countermeasure scenario CM01. The cumulative addition of renewable share and LNG share was incorporated into the CM02. The countermeasure 03 was manually calculated using the CM02 enduse energy results. From 2021 onwards, the effect of the 0.5% efficiency improvement in transmission and distribution network was evenly distributed across all generation options in the CM02. When modelling the CM03, it was assumed that the reduction in net electricity generated by efficiency improvement was distributed evenly across all generation technologies in the CM02.

2.3 Data Collection

This study relies heavily on historical data. This model required data on the Sri Lankan power sector in a wide range of input energies to output emissions. Numerous studies conducted by various institutions served as a significant source of data.

The primary data required to construct the model were device/technology-related data. Technology data consisted of installation costs (initial cost), operational and maintenance costs of technologies, emission factors, lifetime and efficiencies. Additionally, the model relied heavily on primary input energy data and end-user electricity demand data. The data obtained from the sources were converted to the appropriate units before being entered into the model. Technology data inputs are most of the times input as per device unit. The primary data collection sources for the model are listed in table 2.

Table 2 Data Sources

Source	Author	Year
Long Term Generation Expansion Plan (2020 – 2039)	Ceylon Electricity Board	2019
Updated Nationally determined contributions, Sri Lanka	Ministry of Environment	2021
Sri Lanka Energy Balance - Sri Lanka	Sustainable Energy Authority	2018
Development of a small scale IGCC power plant using solid waste at Hambantota, Sri Lanka	Charith Liyanage	2013
Emission of greenhouse gases from waste incineration in Korea	Kum-Lok Hwang, Sang-Min Choi, Moon-Kyung Kim, Jong-Bae Heo, Kyung-Duk Zoh	2017
Study Report on Use of Battery Energy Storage Systems	Public Utilities Commission of Sri Lanka	2015

3.0 RESULTS AND DISCUSSION

3.1 Energy and Emissions in BAU Scenario

The main primary energies, which are inputs to the Sri Lankan power sector, are classified into five groups and are represented in figure 17. Energies are represented for 2015-2050 respective to the BAU scenario. Annual energy consumptions based on primary energy sources are represented in figure 2. Diesel oil, fuel oil, heavy fuel oil, and naphtha are all types of petroleum oil. Other renewable energy sources include solar, wind, and biomass. The classification system is intended to facilitate the process of representing and studying.

Coal was the most consumed primary energy source in Sri Lanka's power sector in 2015 (modelling start year), accounting for 54.72 GJ. In comparison to other energy sources, it accounts for 50.18 %. Petroleum oil was the second most consumed energy source in 2015, accounting for 28.68 % of consumption (3098 TJ). Hydropower accounts for 18.18% of total energy consumption (1967 TJ). In 2015, no municipal solid waste incineration power plants were operational, and the consumption of other renewable energy sources was 2.33 %. According to the model predicted primary energy consumption in future years, the coal energy supply tends to increase rapidly. The main reason for the increase in the amount of coal power plants can be identified as broadly available, and it is cheaper than petroleum oils. Moreover, the BAU scenario does not consider any technology changes; therefore, the model prioritises the least cost technology to fulfil the rapidly increasing energy demand. However, a significant reduction in petroleum oil consumption can be seen after 2030. The primary reason for the decline could be the retirement of several large petroleum oil-fired power plants in 2020-2030.

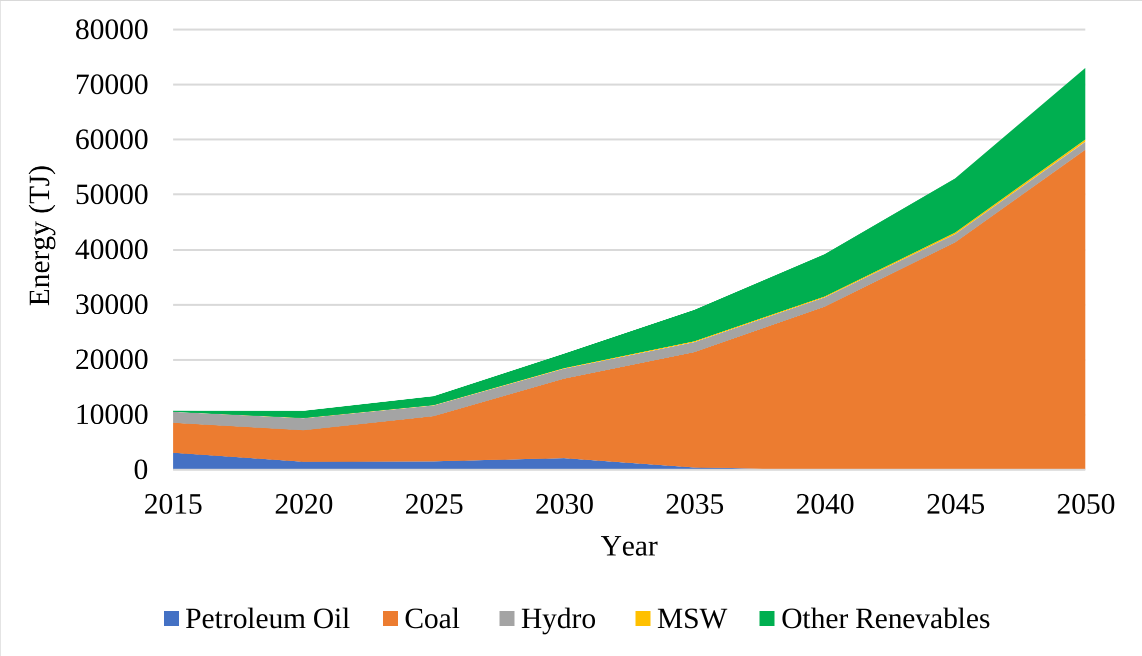

Figure 2 Primary Energy Consumption in BAU scenario 2015-2050

The area chart in figure 3 depicts the power sector's GHG emissions in the BAU scenario by energy type. The charts demonstrate unequivocally that coal power plants will contribute significantly to GHG emissions. The percentage increase in emissions from coal power in 2050 relative to 2015 is 962 %, and coal power will account for more than 98 % of emissions in 2050. Since country's expansion strategies prioritise reducing reliance on petroleum oil-based electricity production, petroleum oil-based generation emissions cannot be expected to increase significantly after 2030. Even though the mid-2030s will phase out petroleum-based energy generation, coal-fired power plants will continue to meet growing electricity demand. The country's primary challenge would be to reduce coal generation in the future in order to meet global climate goals.

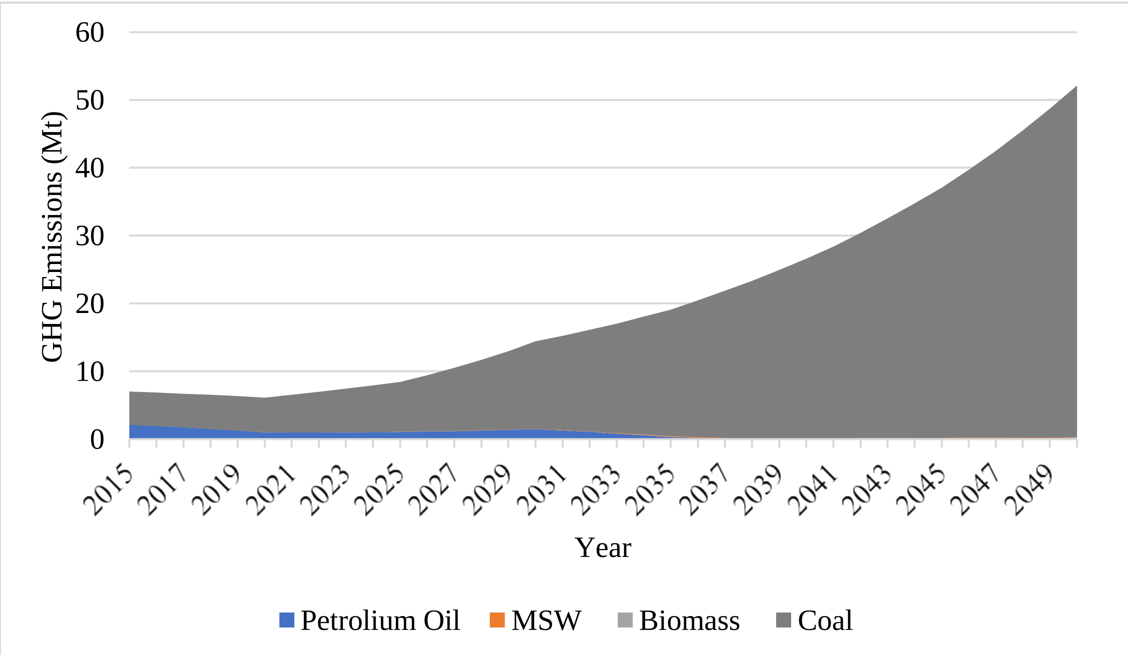

Figure 3 Emissions in BAU scenario 2015-2050

3.2 Countermeasure Scenarios

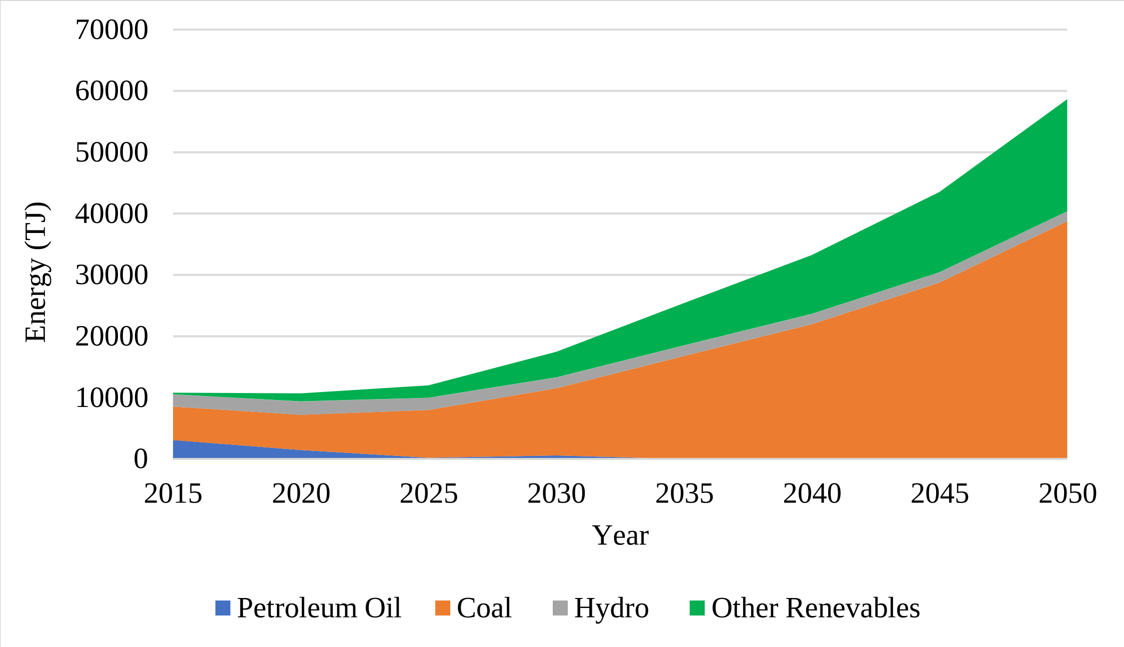

Figure 4 Primary Energy Consumption CM01 scenario 2015-2050

The Countermeasure scenario CM01 aims to enhance the renewable energy contribution to the national generation mix by adding a renewable capacity of 3867 MW. The effect of NDC 01 is completely taken into account in countermeasure 01. The renewable addition is expected to implement by establishing rooftop, small-scale and large-scale solar PV and wind power generations.

By increasing solar and wind energy, CM01 increases the renewable energy share. It has a significant impact on the significant increase in the share of other renewable energy sources. Renewable energy generation was 2.33 % in 2015, and with the implementation of NDC 01, it will increase to 31.11 % in 2050. Most significantly, coal consumption can be reduced by 17165.88 TJ by 2050; this represents a 33 % reduction compared to BAU. Respectively in 2030 and 2040, the coal consumption reduction will be 24% and 26%. The increase in hydro share is only 13% compared to BAU in 2050. Since the major hydro has the higher initial cost model attempts to minimise the selection of major hydropower in future expansions. Moreover, the model does not select the municipal solid waste (MSW) power plants for the expansion under the effect of NDC 01. The high initial and high O&M costs can affect the elimination of MSW in CM01.

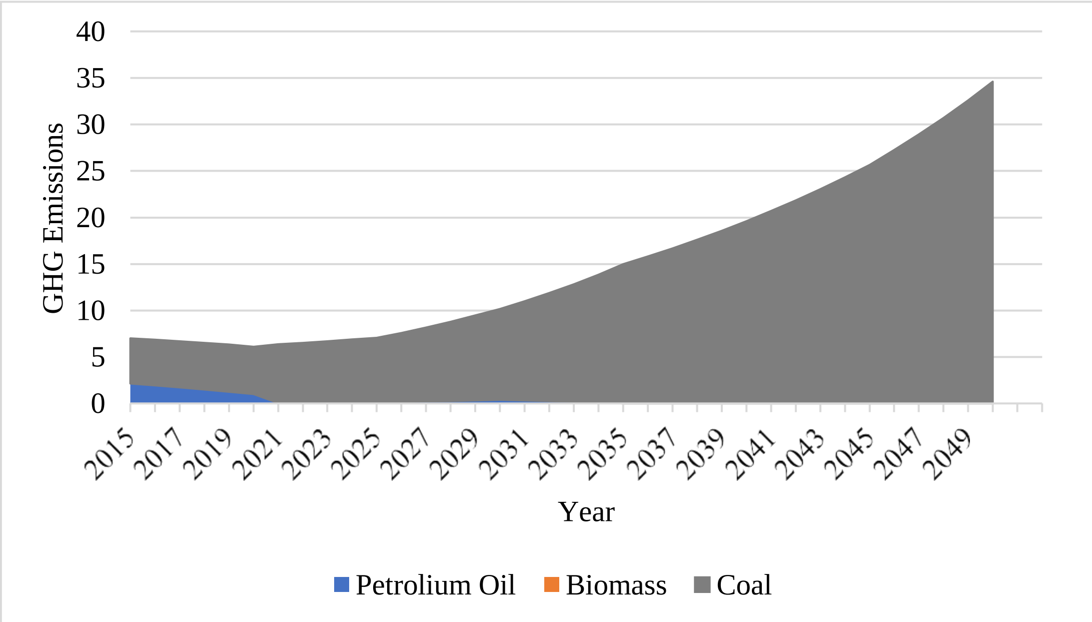

Figure 5 GHG Emissions in CM01 for 2015-2050

The addition of renewable energy to CM01 significantly reduces total emissions. Coal-fired power generation emissions will increase by 608% by 2050 compared to 2015. In 2050, CM01 would have reduced emissions from coal power generation by 355% compared to the BAU scenario. The CM01 results indicate that the NDC 01 significantly reduces emissions from coal power generation by meeting a significant portion of growing electricity demand and limiting coal power expansion. Given that many thermal power plants are scheduled to retire between 2020 and 2030, the additional renewable energy capacity added during that time period assists in meeting the power supply reduction caused by the absence of petroleum-based power plants

The Countermeasure scenario CM02 absorbs the effect of NDC 03 along with the NDC 01. NDC 03 aims to convert existing petroleum oil-based combined cycle power plants to Natural Gas and establish new natural gas plants. Conversation of 600MW fuel oil-based power plants to NG and 700 MW new combined cycle power plants in place of anticipated coal power capacity addition in the BAU.

In comparison to the BAU scenario, the CM02 scenario emphasises the inclusion of LNG power plants. LNG could provide 12% of the country's annual energy requirements in 2050. LNG additions may be beneficial in order to maximise GHG reductions. According to CM02, coal consumption will be reduced by 29056 TJ or 27.48 % by 2050. When CM01 is compared to CM02, the individual effect of NDC 03 can be determined. When COM02 is compared to CM01, CM02 reduces coal consumption by an additional 13.96% and increases other renewable energy consumption by 1.61% in 2050. Even though other renewables consume the same amount of energy in 2050 as CM02, their share has increased. The primary reason for this could be the addition of LNG to CM02, as higher LNG efficiencies can result in an increase in the share of other renewables in CM02, even if consumption remains constant. Higher efficiencies of LNG can reduce the total requirement of primary energy; due to that, a minor increase in other renewable shares can occur.

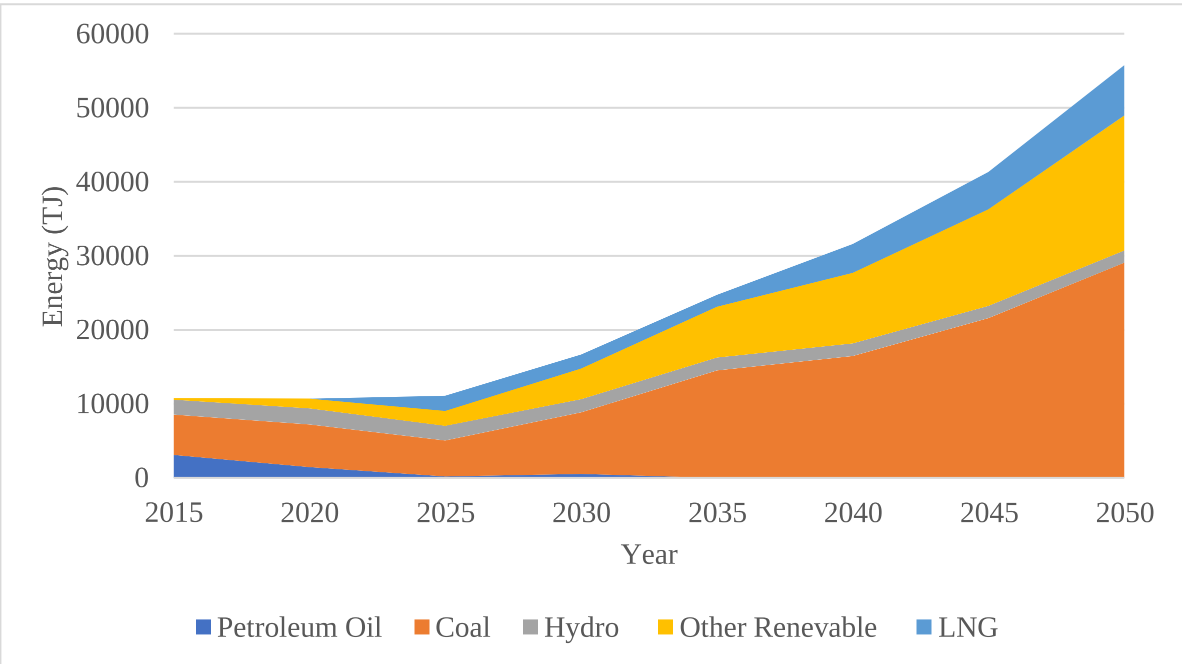

Figure 6 Primary Energy Supply in CM02 2015-2050

The countermeasure scenario absorbs the effect of NDC 03 along with the NDC 01. NDC 03 aims to convert existing petroleum oil-based combined cycle power plants to Natural Gas and establish new natural gas plants. Conversation of 600MW fuel oil-based power plants to NG and 700 MW new combined cycle power plants in place of anticipated coal power capacity addition in the BAU.

In comparison to the BAU scenario, the CM02 scenario emphasises the inclusion of LNG power plants. LNG could provide 12% of the country's annual energy requirements in 2050. LNG additions may be beneficial in order to maximise GHG reductions. According to CM02, coal

consumption will be reduced by 2956 TJ or 27.48 % by 2050. When CM01 is compared to CM02, the individual effect of NDC 03 can be determined. When COM02 is compared to CM01, CM02 reduces coal consumption by an additional 13.96% and increases other renewable energy consumption by 1.61% in 2050. Even though other renewables consume the same amount of energy in 2050 as CM02, their share has increased. The primary reason for this could be the addition of LNG to CM02, as higher LNG efficiencies can result in an increase in the share of other renewables in CM02, even if consumption remains constant. Higher efficiencies of LNG can reduce the total requirement of primary energy; due to that, a minor increase in other renewable shares can occur.

LNG additions and conversions of existing combined cycle power plants to LNG demonstrate a considerable reduction in GHG emissions from coal. Coal emissions will be reduced by 43% relative to BAU and 24% compared to CM01 in 2030. However, LNG produces additional emissions. CM02 has reduced GHG emissions by 15% when LNG and coal emissions are combined, compared to coal emissions in CM01. Even though the inclusion of LNG increases GHG emissions slightly, it has the effect of reducing GHG emissions when compared to CM01, which did not include LNG additions. The decrease percentage does not substantially increase beyond 2030, remaining between 12 and 16 per cent, while the amount reduced increases from 1.45 Mtonne in 2030 to 5.17 Mtonne in 2050. However, LNG addition enables a considerable reduction in GHG emissions in Sri Lanka's power sector.

The conversion of existing combined cycle plants causes the reduction in petroleum oil-based generation emissions significantly from 2021. The cumulative emissions from petroleum oil-based generations from 2021 -2030 will reduce from 2.04 Mtonne to 1.88 Mtonne, accounting 16.4% reduction. The emissions from biomasses are not significant compared to coal and LNG emissions. The focus of renewable addition highly based on solar and wind technologies results in low biomass emissions.

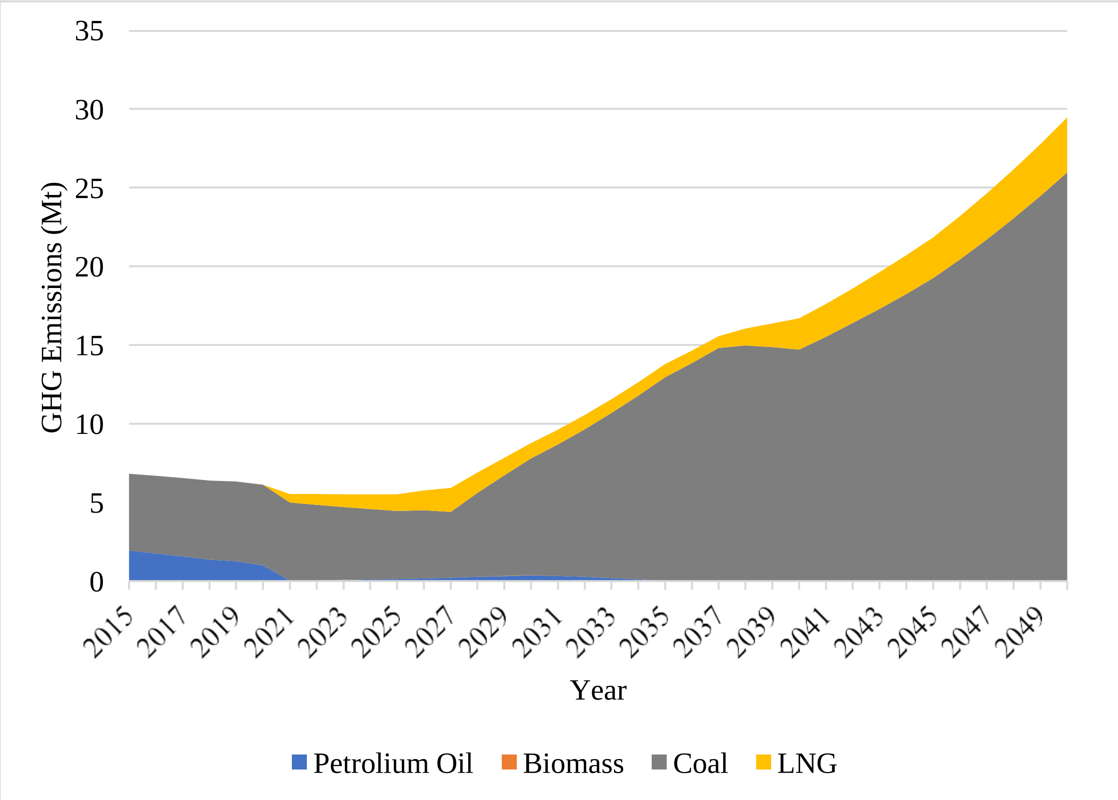

Figure 7 Emissions in CM02 scenario 2015-2050

Countermeasure 03 combines the effects of NDC 04 and CM02. CM03 was used to account for the cumulative effect of the three NDCs evaluated in the study. NDC 04 is an additional NDC that is taken into account in the CM03. The primary energy consumption and GHG emission graphs for CM03 are similar to the graphs of CM02. The slight reduction in GHG emission and primary energy supply does not show any visible changes compared to the graph of CM02. Therefore, the graphs for the CM03 are not presented in the paper. In NDC 04, the country aims to increase the efficiency of its transmission and distribution networks by reducing losses by 0.5 % compared to BAU in 2030. Between 2021 and 2030, the NDC is expected to save approximately 6652.8 TJ of energy.

The primary energy consumptions result of CM03 and CM02 does not show a significant difference. Since the efficiency improvement is slight, the difference between CM03 and CM02 is not visible in yearly primary energy consumption.

The GHG reduction in CM03 compared to CM02 is not significant. However, when the total generation rises, the amount of GHG emitted will be increased gradually. In 2030 the reduction of GHG compared to CM02 is 167 TJ, and in 2050 the reduction amount will rise to 615 TJ (257% increase). The effect of NDC 04 affects the GHG reduction in the long term due to the increase of the service demand.

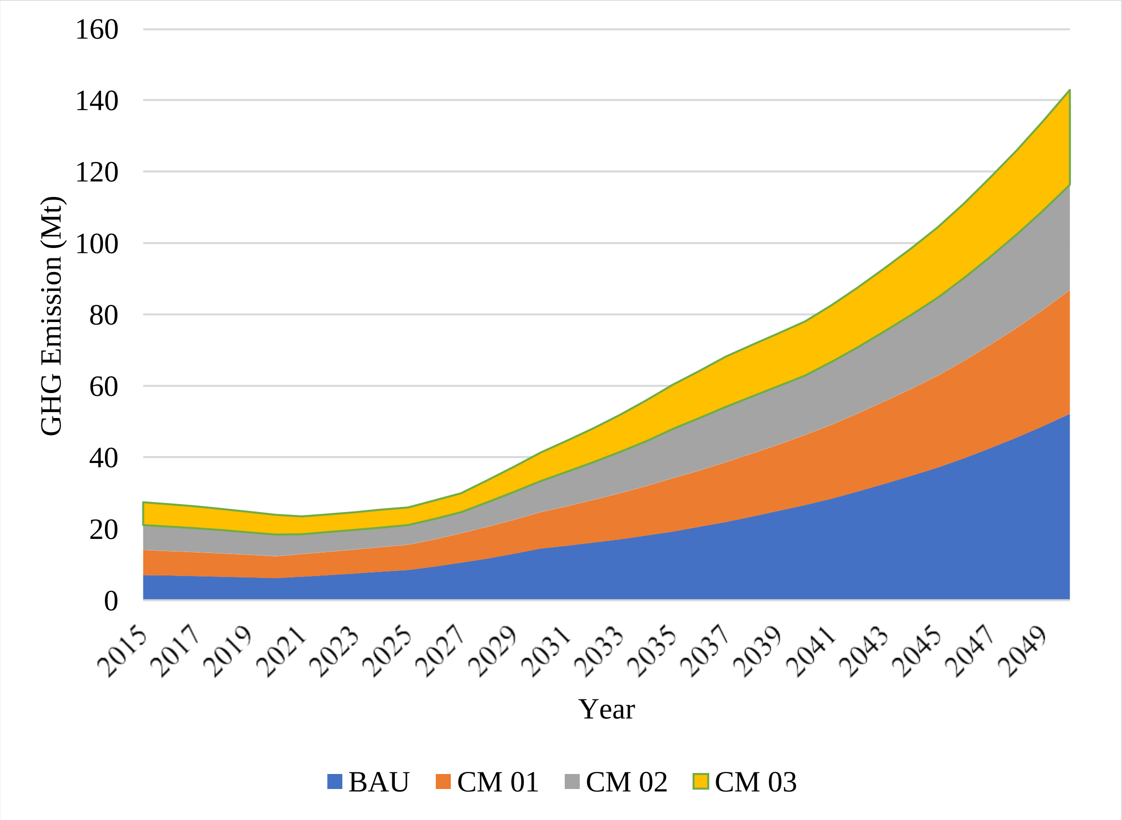

Figure 8 GHG Emissions from all scenarios 2015-2050

The power sector's GHG emissions increase primarily in lockstep with demand growth. As the country's GDP increases, its energy demand increases proportionately, increasing the requirement of rapid power generation capacity expansion. Incorporating high carbon primary energies and technologies cause high GHG emissions due to the rapid expansion. In the BAU scenario, the GHG emissions increase rapidly with the rise of the power supply. Many GHG emitting technologies would have been implemented in future in the BAU scenario. In the BAU scenario, predicted GHG emissions were increased from 41.16 Mtonne compared to 2025 in 2050. In the years 2025, 2030, 2035, 2040, and 2050, NDC 01 alone will be able to reduce GHG emissions by 16.46%, 29.37%, 21.7%, 26.3%, 30.8%, and 33.67 %, respectively. As demonstrated in figure 5, the CM01 is able to minimise GHG emissions with the rise of electricity generation capacity. Since the model is based on least-cost optimisation methods, the selected technology mix is optimised for economic benefit. The CM01 is controlled by incorporating renewable technologies such as solar PV and wind for the generation mix. The model output GHG emission results shown above illustrate the effect of the addition of renewable generation technologies, which contributes to reducing the emission in CM01 compared to BAU.

CM02 includes LNG additions as well as LNG conversions of existing fuel oil plants along with the effects of CM01. To examine the impact of NDC 03 on its own, the impact of CM02 must be subtracted from the impact of CM01. CM02 line in figure 8 shows the obvious reduction of GHG emissions with respect to CM01. Predicted GHG emission reductions compared to CM01 are 18.37%, 9.89%, 6.29%,10.96%,10.30% and 9.87% respectively in years 2025, 2030, 2035, 2040, 2045, and 2050. Since the LNG replaces the coal additions in future expansion, LNG has 40%-50% lesser CO2 emissions compared to coal power plants. Compared to BAU, CM02 is able to minimise the GHG emissions by 34.83%, 28.0%, 37.31%, 41.10% and 43.54% in five years gaps from 2025 to 2050. The GHG reduction percentage was decreased from 34.83% to 28.0% from 2025 to 2030. The primary cause of the decrease can be attributed to the model parameter limitations used in CM02 to model NDCs. NDC 04 in reducing GHG emissions is minimised because the NDC only aim to incorporate minor efficiency improvement to the transmission and distribution grid. Therefore the 0.5% efficiency gain directly applies to the GHG reduction due to reduction in total energy before transmission. The calculations assume that the effect of 0.5% efficiency gain equally affects all generation technologies.

4.0 CONCLUSION

The study has assessed the Sri Lankan power sector by considering the effect of Nationally Determined Contributions for the period of 2015 -2050. Selected three NDCs from the latest NDCs of Sri Lanka were used to develop countermeasure scenarios in the study. The AIM/Enduse model was selected as the modelling tool for the study. The CO_2 equivalent GHG emissions were considered when analysing the emissions from the power sector.

In the business-as-usual scenario, GHG emissions will increase by 643% in 2050 compared to 2015. The increase in the power sector emissions is drastically caused by coal power expansion options and fossil fuel-based generation options. The significant growth in coal power generation after 2030 can be identified as a major challenge the country must overcome when meeting the global energy and environmental targets.

The countermeasure scenarios based on the NDCs have a significant impact on reducing GHG emissions and share of coal power generation. According to CM03, the coal supply will be reduced from 27.63%, and the total GHG emissions will be reduced from 43.8% by 2050. The addition of LNG in CM02 also has a significant effect. The major share of coal power expansion will be occupied by the LNG, which has a lower percentage of GHG emissions than coal power plants.

The effect of the NDC04 (0.5% efficiency improvement of transmission and distribution network) is not much significant when compared with the other two NDCs, but it is also capable of saving a greater amount of energy with the growth of demand.

The study's findings comprehensively highlight the impact of NDCs on Sri Lanka's electricity sector between 2021 and 2030 and beyond. The selected NDCs 01 and 03 provide significant support for reducing GHG emissions and coal use. However, consideration of additional mitigation options beyond 2030 is necessary to meet the nationally and globally established sustainable development targets.

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Nitrogen, Phosphorus and Potassium Concentrations in the Grains of Selected Rice Varieties in Sri Lanka

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ABSTRACT (HEADING 1)

Rice (*Oryza sativa* L.) is the staple food for Sri Lankans, and it serves as a key source of essential mineral elements. The variation of grain nutrient concentrations as affected by genetic factors (variety, grain color and age group) are not known, and those were tested in the current study. Total of 200 rice grain samples were collected using a stratified random sampling approach, representing all agro-climatic zones in Sri Lanka. Grain nitrogen (N), phosphorus (P) and potassium (K) concentrations were measured using Kjeldahl, Colorimetric, and General methods, respectively. Grain N P and K concentrations were significantly different among rice varieties (P<0.1). Grain N concentration varied between 4-19 mg g^{-1}. The highest grain N concentration was recorded in Bg 307 (14 mg g^{-1}) while the lowest (*i.e.,* < 10 mg g^{-1}) in Bg 367, Bg 374, Bg 358, Bg 310 and Bg 379-2. Grain P concentration varied in the range 0.6-1.7 mg g^{-1}. Grain P concentration in At 406 was the highest (1.6 mg g^{-1}), followed by Bg 307, Bg 94-1, Bg 367 *i.e.,* >1.3 mg g^{-1} and the lowest in Bg 403, Ld 365 and Bg 310 *i.e.*, < 1 mg g^{-1}. Bg 357, Ld 365, Bg 406, Ld 368 and Bg 310 rice varieties showed significantly lower P concentration than other varieties (P<0.1) Grain N, P and K concentrations were similar among different age classes of rice varieties (P>0.05). Moreover, grain N and P concentrations between the red and white grain varieties were similar (P>0.05). However, varieties with white color grains had higher K concentration than in red rice varieties. There was a significant correlation between grain P and K concentrations (r =0.496, P<0.001). This information would be useful when selecting rice varieties with high and low nutritional qualities and implementing sustainable nutrient management practices in rice-based cropping systems in Sri Lanka.

KEYWORDS: *Age class, Nitrogen, Phosphorus, Potassium, Rice*

1 INTRODUCTION

It is expected that authors will submit carefully written and proofread material. Careful checking for Rice (*Oryza sativa* L.) is one of the principal food crops belongs to the family Poaceae and has an edible starchy cereal grain (Abeysekara *et al*., 2017). It is widely cultivated throughout the world including Sri Lanka. Therefore, rice records as the most important cereal crop for Sri Lankans (Hettiarachchi *et al*., 2016). According to the Department of Agriculture in Sri Lanka, more than 1.8 million farm families rely on rice cultivation for their livelihood. As one of the most important tropical cereal, rice provides almost 21 percent of the total caloric intake of the human population and contains higher amount of nutrients such as protein, lipids, minerals, vitamins and especially dietary carbohydrates which provides most of the daily energy for the mankind mainly in developing countries. In addition to the traditional rice varieties, Department of Agriculture in Sri Lanka has developed high yielding, improved rice varieties which are currently being cultivated island wide (Samaranayake *et al*., 2017). It is also known that physiochemical and nutritional properties of rice vary significantly among varieties (Abeysekara *et al*., 2017).

Demand for rice increases with the rapid population increment. Hence, nutrient application plays a vital role in increasing productivity in order to achieve this demand (Gunaratne *et al.,* 2011). Application of fertilizers has been identified as a key factor affecting the yield and quality of rice grain

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(Gunaratne *et al.,* 2011). At present, nitrogen (N), phosphorus (P) and potassium (K) have become the major nutrients recommended to increase the productivity of rice and the quality of rice grain (Moe *et al*., 2019). Rice is the major source of energy, protein, minerals and vitamins for Sri Lankans (Abeysekera *et al*., 2017; Kumari *et al*., 2017). Hence, both physiochemical properties and nutritional properties of rice grains are important to the rice consumers (Samaranayake *et al*., 2017). However, these properties show a significant difference among rice varieties (Abeysekera *et al*., 2017).

According to Ning *et al*. (2010) N effects on AA composition, protein accumulation and their distribution in rice grains. Subsequently, it enhances the eating and cooking qualities of rice grains (Ning *et al*., 2010). Murthy *et al*. (2015) also elaborated that the grain quality increases with the increment of N and P nutrition. Because, N and P are the main components of protein synthesis and protein content and this directly affects the grain quality in terms of grain strength and head rice recovery (Murthy *et al*., 2015). Both soluble and storage proteins of rice grains and their distribution vary with N content of grains (Leesawatwong *et al*., 2005). Nitrogen also contributes to yield by facilitating many physiological processes including photosynthesis. However, N is the most crucial and limiting nutrient that affects grain yield (Wang *et al*., 2017).

Potassium plays a vital role in unloading sugars from chloroplasts to grain storage cells through phloem cells. Therefore, K deficiency would result in low grain yield of rice (Ranamukhaarachchi *et al*., 2006). In addition, K is important in regulating stomatal movements, photosynthesis and N metabolism (Hou *et al*., 2019). About 60 – 85% soil P is stored in grains and therefore, considerable amount of P is removed at harvest through grains (Wang *et al*., 2016; Yamaji *et al*., 2017). Moreover, most of the grain P is non-accessible to humans as the major fraction of grain P is present in the chemical form called phytate which cannot be easily digested. Therefore, understanding P concentration in rice grains is important to manage P removal from agricultural lands and avoid eutrophication (Yamaji *et al*., 2017).

As an agricultural country, Sri Lanka possesses large number of traditional rice varieties with high medicinal and nutritional properties. However, as a result of population growth and technology development improved rice varieties were introduced (Hafeel *et al*., 2020). At present, improved rice varieties are widely cultivated in the country due to their high yield, disease resistance and drought tolerance (Diyabalanage *et al*., 2016). It has been reported that out of the total paddy cultivating lands, 98.8% is acquired by improved rice varieties (Liyanaarachchi *et al*., 2020). Bg360, Bg352, Bg367, Bg366, Bg358, At306, At405 are commonly used improved rice varieties by Sri Lankan farmers (Hettiarachchi *et al*., 2016). Accumulation of N, P and K in rice grain may vary with rice varieties, grain color and their age group. However, this variability has not been explored before. Hence this study was designed to provide necessary information on the accumulation of N, P and K in rice grains. Using these data; N: P: K ratios of different rice varieties can be generated and subsequently it can be used to balance the fertilizer application plans. Information from this study can be used to reduce nutrient losses through harvesting and minimize environmental pollution through fertilizer application.

2 MATERIALS AND METHODS

2.1 Grain sample collection

Total of 200 grain samples were collected representing 25 administrative districts, different irrigation methods and agro-climatic zones (ACZ). Twenty-five panicles were collected from a selected paddy track (*Yaya*) representing the mainly cultivated rice variety of that *Yaya*. Grain samples collection was done using a stratified random sampling approach as described in Kadupitiya *et al*. (2021).

2.2 Grain potassium and phosphorus measurements

One gram of de-husked rice grain sample was taken to the crucible. It was kept inside the muffle furnace for two hours until getting the ash. Temperature was set as 200 °C in the 1st hr and 450 °C in the 2nd hr. After cooling the sample, five mL of 6 M nitric acid was added in to the crucible by using 5 mL pipette. Then grain ash was mixed with nitric acid properly by using a glass rod. It was put in to the 100 mL beaker and crucible and glass rod were washed out with 1% nitric acid in to the beaker. Then beaker was boiled about 15 minutes and 5 mL of 3 M nitric acid was added during boiling. Then solutions were kept outside for cooling. Beaker solution was filtered into the 50 mL volumetric flask.

Beaker was washed and filtered in to the volumetric flask. Then it was volume up until 50 mL by using distilled water.

For P concentration measurements, 2 mL of solution were pipetted out from the volumetric flask and added in to the test tube by using 2 mL pipette. Then 6 mL of distilled water was added in to the test tube. 2 mL of nitro-vando molybdate was added in to the test tube. After that, the test tube was shaken properly. Then P concentration was measured by using spectrophotometer.

Potassium concentration in 50 mL volumetric flask was measured by using the flame photometer. When determining both P and K concentrations in rice grain samples, laboratory standards and blanks were used for quality control (Givens *et al*., 2004).

2.3 Grain nitrogen measurements

De-husked rice grain samples were ground by using mortar and pestle. Then one gram of grain sample was measured by using electronic balance and added it in to the Kjeldahl tube. Then 7 mL of sulfosalicylic acid was added in to the tube and it was kept for 30 minutes in fume hood. Then 0.5 g of sodium thiosulfate was added in to the tube and again it was kept for 15 minutes. Then 0.2 g of catalyst mixture was added in to the tube. Then 3 mL of conc. sulfuric acid and 3 mL of hydrogen peroxide were added in to the tube. Then Kjeldahl tube was kept about one and fifteen hours in digestion unit under 380 °C temperature. After the digestion, it was kept about 30 minutes for cooling. Then 30 mL of distilled water was added in to the tube. Then it was distilled by using distillation unit. Twenty mL of methyl bromide solution was placed in to the conical flask, and it was kept inside the distillation unit. After the conical flask was filled to 100 mL and the solvent turns green, it was titrated until the solvent color was getting light pink color by using 0.1 M of HCL. When determining N concentration in rice grain samples, laboratory standards and blanks were used for quality control.

2.4 Statistical analysis

The mean, minimum and maximum of N, P and K concentrations were determined using descriptive statistics. Strengths of the relationships between elements (paired comparisons) were determined using Pearson's linear correlation coefficient (r). Concentration of elements among rice varieties was compared using analysis of variance (ANOVA), and mean separation was done through Duncan's Multiple Range Test (DMRT). All the interpretations are made at α=0.05.

3 RESULTS

3.1 Grain N, P and K concentration of selected rice grains in Sri Lanka

Nitrogen concentration in rice grains was relatively higher than P and K concentrations (Fig. 1). Nitrogen concentration of rice grains varied between 3.95 mg g^{-1} to 19.36 mg g^{-1} with a mean value of 10.80 mg g^{-1}. Mean grain P concentration was 1.17 mg g^{-1} and it ranged between 0.10 mg g^{-1} to 1.76 mg g^{-1} (Fig. 1). Grain K concentration was in the range of 1.61 mg g^{-1} to 4.65 mg g^{-1} with a mean value of 2.81 mg g^{-1} (Fig. 1).

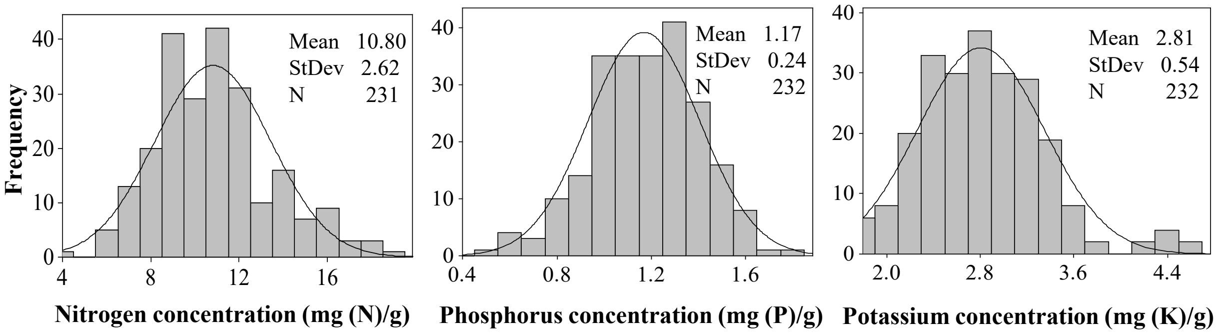

Figure 1. Distribution of N, P and K concentrations of selected paddy grains in Sri Lanka

3.2 N, P and K concentration of selected rice varieties

Grain N, P and K concentrations were significantly differed among selected rice varieties ($P<0.1$). The highest grain N concentration was recorded in Bg 307 (14 mg g^{-1}) while the lowest in Bg 367, Bg 374, Bg 358, Bg 310, Bg 379-2 *i.e.,* < 10 mg g^{-1} (Fig. 2). Traditional rice varieties recorded 11.42 mg N g^{-1} concentration.

At 406 and Bg 307 rice varieties showed the highest grain P concentration *i.e.,* > 1.50 mg g^{-1} while Bg 403, Ld 365 and Bg 310 varieties recorded lowest P concentration i.e., less than 1 mg g^{-1} (Fig. 2). Bg 357, Ld 365, Bg 406, Ld 368 and Bg 310 rice varieties showed significantly lower P concentration than other varieties ($P<0.1$). 68% of the farmers have cultivated rice varieties bred at Batalagoda followed by Ambalantota (19%), bombuwala (7%), Labuduwa (2.6%) and traditional rice (2.6%) varieties.

Grain N, P and K concentrations were similar among the age categories of selected rice varieties *i.e.,* 3, 3.5, 4, 4.5 age categories. Most of the cultivated rice varieties belonged to 3.5 months age category (85%) while the second highest was in the age group less than three months (11%). Moreover, grain N and P concentrations between the red and white grain varieties were similar ($P>0.05$). However, varieties with white color grains had higher K concentration than in red rice varieties. At 406, Bg 307 rice varieties recorded relatively higher N, P and K concentrations.

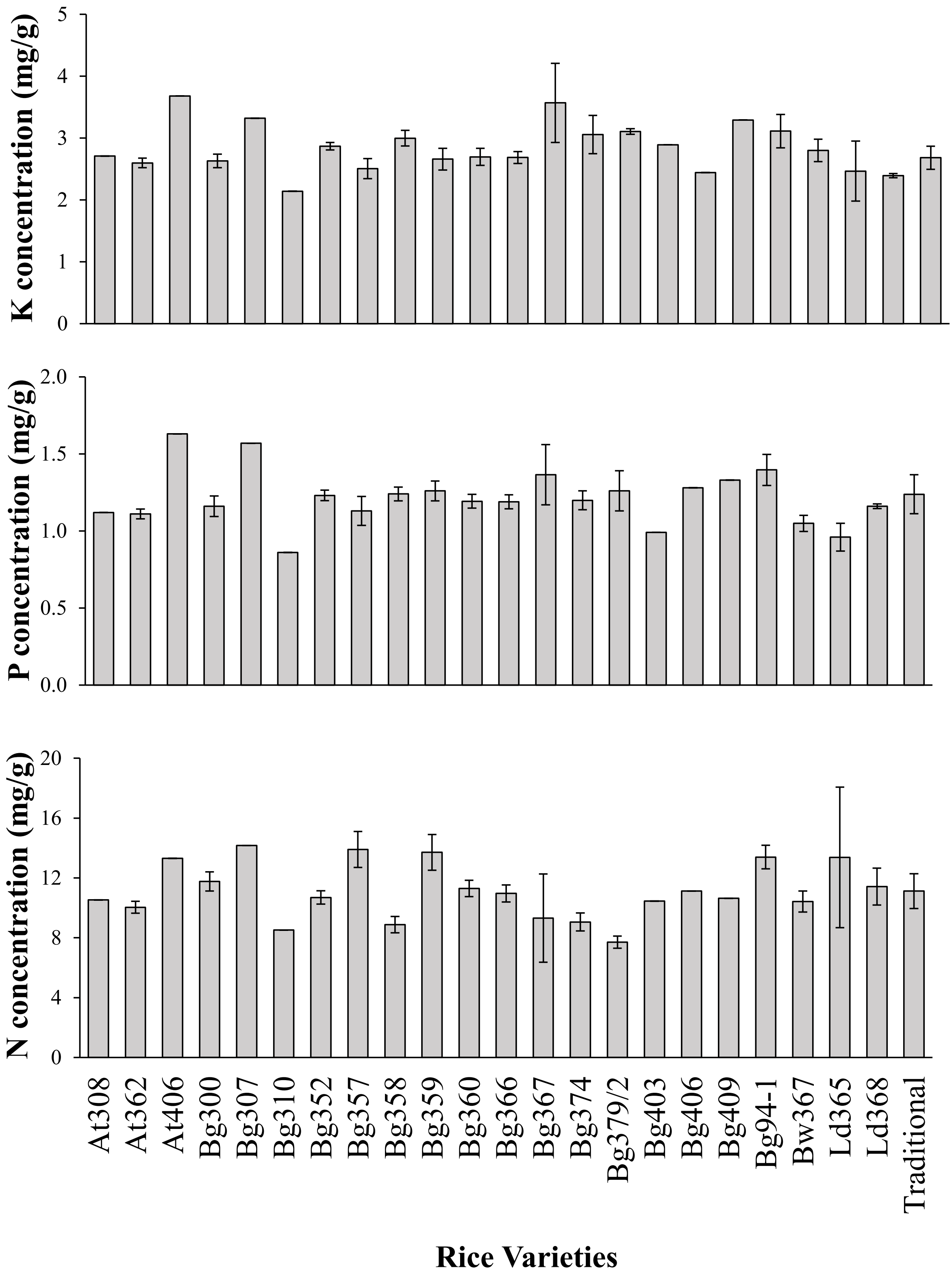

Figure 2. Nitrogen, phosphorus and potassium concentrations of selected rice varieties

3.3 Relationships between N, P and K concentrations of rice grains

There was a significant correlation between grain P and K concentrations (r =0.496, P<0.001) (Fig. 3). However, correlation between N and P concentrations, and N and K concentrations were not significant (P>0.05) (Fig. 3).

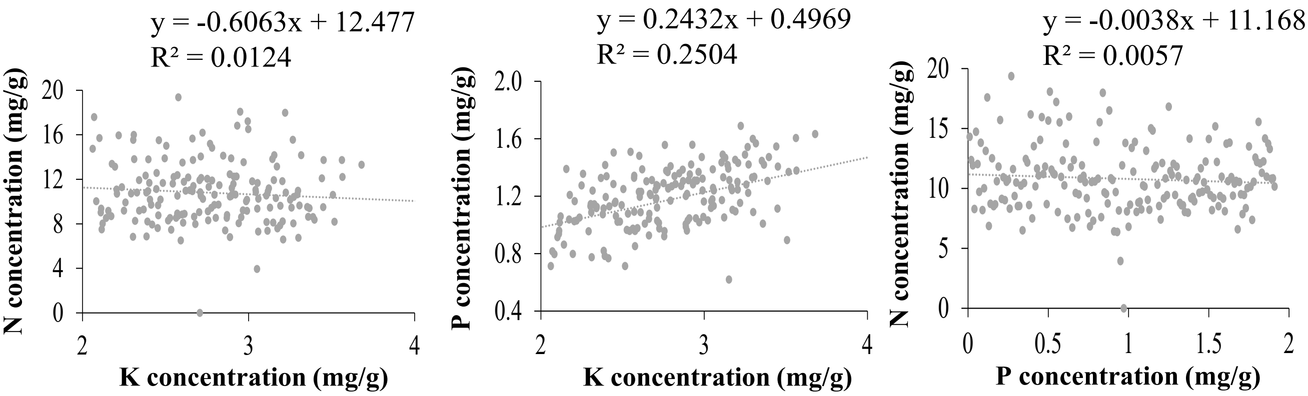

Figure 3. Linear relationships between grain N, P and K concentrations

4 DISCUSSION

Nitrogen, P and K are the essential nutrients which are responsible for high productivity (Lan *et al*., 2012). According to Li *et al*. (2014) there was a difference in N, P and K accumulation among varieties in China. In our study grain N, P and K concentrations exhibited a significant difference among varieties (Fig. 3.2). When comparing three graphs of N, P and K concentrations (Fig. 3.2), N concentration was considerably high in all selected rice varieties. Urea is the main source of N used in paddy cultivation. Almost all farmers (100% farmers of the study) applied urea as the main source of N fertilizer (data not shown). Murthy *et al*. (2015) reported that N uptake and accumulation in rice plant and grain significantly increased when increase the N fertilizer dose. High N concentration creates favorable conditions for foliage growth to enhance the accumulation of photosynthates and eventually it increases the growth and the yield (Murthy *et al*., 2015). In this study all rice varieties recorded high N concentration indicating high uptake due to the high availability of N in soil. According to Fig. 3.2, K and P concentrations in grains were relatively low. However, the concentrations of P and K do not reflect deficiency for rice. All farmers except few have applied TSP (98%) and MOP (99%) as P and K sources in to the soil. Overall results reveal that the observed grain N, P and K concentrations were reached due to the application of N, P and K through supplementary fertilizers and it would be needed to maintain the same practice to ensure similar grain N, P and K concentrations.

In Sri Lanka, all the rice varieties belong to genotype of *Indica*. Yulong *et al*. (2021) reported that *Indica* rice has higher nitrate absorption activity than *Japonica*. However, in their study the average grain N concentration reported was 11.8 mg g^{-1} (Yulong *et al*. 2021). In this study, the average grain N concentration reported was 10.8 mg g^{-1} which is similar as Yulong *et al*. (2021). Hafeel *et al*. (2020) analyzed the crude protein (CP) content of improved and traditional rice varieties of Sri Lanka and reported that N concentration of improved rice varieties varied from 8.3 to 15.25 mg g^{-1} in cooked rice (Hafeel *et al*., 2020). When considering the findings of Abeysekara *et al*. (2017) the maximum N accumulation by rice grains could not be occurred under Sri Lankan condition. Other than the varietal effect, N, P, and K concentrations may vary with soil type, environmental factors and the rates of fertilizer application especially, urea and muriate of potash (Lie *et al*., 2014; Pinson *et al*., 2014). Recent study revealed that grain N concentration also affect by the climatic change (Yulong *et al*., 2021). Yulong *et al*. (2021) elaborated that climate warming could increase N concentration in crop while lowering the Nitrogen use efficiency (NUE). Therefore, proper N application and management would result maximum utilization and accumulation of N in rice grains (Li *et al*., 2014). Pinson *et al*. (2014) reported grain K concentration in between 1.5 – 4.3 mg g^{-1} and P concentration in between 2.19 – 4.78

mg g^{-1} (Pinson *et al*., 2014). Potassium concentrations reported in the present study (1.6 – 4.7 mg g^{-1}) are in agreement with Pinson *et al*. (2014). However, P concentration reported in this study is less than that reported by Pinson *et al*. (2014). Cassman *et al*. (2002) defined that 10 – 12 mg g^{-1} is the ideal N concentration for grain which is given optimal cooking and eating quality. Interestingly, our findings are agree with that by given N concentration in 10 mg g^{-1}. Moreover, Huang *et al*. (2020) reported that the daily requirement of P and K concentration of human 800-1000mg and 2000-2500mg respectively.

Many studies reported that N accumulation is positively related to K accumulation (Lie *et al*., 2014; Hou *et al*., 2019). According to Lie *et al*. (2014), a positive correlation between N, P and K accumulation was present in high yielding rice varieties. Recent study showed that both grain N and K are critical elements to enhance yield. Nitrogen directly affects grain yield and yield components. Moreover, N accumulation of rice grains is influenced by K application. Maximum N utilization and accumulation by rice grains could be achieved by proper management of both N and K (Hou *et al*., 2019). However, present study did not show a correlation between N and K concentrations of rice grains. In comparison to N concentration, K and P concentrations reported were at low levels. Stone and Homberger (2016) described that, farmers especially in the Asian countries apply more N fertilizer (urea) exceeding the recommended level, as it is cheap without considering its effective utilization. According to Hou *et al*. (2019) adding more N without considering K application is wastage. High N concentration in grains reflects that more N is available in soil to be taken up by rice grains. However, it does not reach to the maximum level. Because, effective N accumulation was prevented by low K concentration. However, there was a correlation between K and P concentrations (Fig. 3.3). According to Pinson *et al*. (2014) the strongest and most consistent correlations are occurred among P, K and Mg. This P and K correlation is not considered in terms of chemical analogs or uptake mechanism. However, P and K correlations are highly associated with grain accumulation which means that P is available in the grain as a mixed form of K-Mg salt in phytic acid. Therefore, a high correlation could be seen among P, K and Mg (Pinson *et al*., 2014).

According to the present study, N and P concentrations were similar among both red and white rice varieties. But, varieties with white color grains had higher K concentration than in red rice varieties. However, Priya *et al*. (2019) reported that red rice varieties contain more N and P than white rice varieties due to the presence of rice bran (Priya *et al*., 2019). Nitrogen concentration in Sri Lankan red rice was reported as 15.41 mg g^{-1} whereas Priya *et al*. (2019) reported it as 10.56 mg g^{-1}. The study conducted by the Jiang *et al*. (2008) found that K concentration of milled rice from white brown rice were higher than those from red and b lack brown rice. Moreover, the variation in nutrient composition in different rice varieties also differ with the environmental condition, nature of soil and fertilizer application (Jiang *et al.,* 2008). Soil variation and fertilizer application by farmers which were not analyzed in this study may be the reason for this nutrient concentration variation among red rice varieties.

5 CONCLUSION

Present study revealed that the varietal effect of rice grains has a significant impact to the grain nutrient concentrations. Grain N concentration was considerably higher than P and K concentration in all selected rice varieties. Grain nutrient concentrations were similar among the age categories of selected varieties. A positive correlation could be observed between grain P and K concentrations. This information would be crucial when selecting rice varieties with high and low nutritional qualities, and implementing sustainable nutrient management practices in rice-based cropping systems in Sri Lanka.

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Preparation of a Low Cost Nutrient Bar Incorporated with Underutilized Seeds as a Convenient and Functional Meal Replacement Alternative

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ABSTRACT

People with busy lifestyles routinely consume fast food as an easy alternative for main meal. Consequently, they prone to suffer from non-communicable diseases such as diabetics. The purpose of this research was to develop a nutritious bar as a meal replacement under the Recommended Dietary Allowances (RDA) using underutilized seeds such as pumpkin, winged beans, watermelon, corn, mung beans, and rice flakes. The proximate analysis, physicochemical properties, sensory attributes and microbiological parameters were evaluated using the Association of Official Agricultural Chemist standards (AOAC), Human Research Ethics Committee standards (Brazil), and Sri Lanka Standards Institution (SLS 516: 1991) respectively. Developed mung based (321), rice flake based (123) and commercial nutrient bar (801) revealed a significant difference ($p \leq 0.05$) in attributes except mouthfeel in the sensory evaluation. A mold and a package was designed with an effective packaging material. The shelf-life was evaluated after adding the permitted preservative (E211-Sodium benzoate) to developed mung based (321), rice flake based (123) bars which had a self-life of one-month. The mung based nutrient bar revealed an average of 1.7±0.1 % moisture, 0.9±0.7% fat, 9.7±0.1% ash, 21.8±2.5% crude fibre, 36.6±0.0 % protein, 29.2±8.3% carbohydrates, and the rice flake bar contained an average of 2.2±0.3% moisture, 2.7±0.2% fat, 7.9±0.2 % ash, 11.4±1.4 % crude fibre, 31.9±0.0 % protein, 43.8±0.0 carbohydrates. The commercial nutrient bar had 1.5±0.1% moisture, 1.5±0.0% fat, 7.8±0.0% ash, 0.5±0.5% crude fibre, 32.5±0.0 % protein, and 56.3±3.9% carbohydrates on average. The energy content (kcal) in rice flakes based, mung based and commercial bars were 327.1, 271.3, and 360 respectively. The finding ascertained that the developed nutrient bars (123, 321) directly fulfill the recommended dietary allowance as a meal replacement concerning European Union Commission Regulations and substantiate that the same nutrient profiles in the commercial nutrition bars could be obtained from the developed samples with a lesser processing cost.

KEYWORDS: *Commercial nutrient bar, meal replacement, recommended dietary allowance, underutilized seeds*

1 INTRODUCTION

The human body digests and absorbs nutrients in food and with metabolism releases energy for mechanical work, and those nutrients are essential to the growth, development and wellbeing. Many people consume fast food instead of a balanced diet and later suffer from non-communicable diseases such as hyperglycemia and hyperlipidemia. Food bars produced under the recommended dietary allowances could offer a healthy alternative to replace popular yet unhealthy fast food (Kelly *et al*, 1997). Nutrient bars are considered as the most functional and convenient food in the market for people with busy lifestyles who often tend to skip their main meals and yet looking for alternatives to boost their energy requirements. Nutrient bars are designed to offer great nutritional profile with all three macro nutrients (proteins, carbohydrates, and fats), dietary fibre, and antioxidants included in them.

In view of producing nutrient bars relatively cheap and with recommended levels of dietary fibres and other essential nutrients, selected grains with proven nutritional values are incorporated. The popular choice of grains for nutrient bars included cereals such as rice, corn, wheat, and barley. However, incorporation of underutilized seeds such as winged beans (*Phaseoius aureus*), pumpkin seeds (*Cucurbita maxima*), Mung beans (*Phaseoius aureus*), and watermelon seeds (*Citrullus lanatus*) could bring in some important plant based proteins and dietary fibre to increase the nutritional profile of nutrients bars. Moreover, watermelon seeds and pumpkin seeds are often discarded as waste, yet they are a good source of nutrients.

Pumpkin seed meal is high in crude protein, vitamin B complexes, pectin, dietary fibres, and essential antioxidants such as carotenoids, lutein, zeaxanthins, and other polyphenolic compounds (Yadav et al, 2010). Watermelon seeds are a rich source of protein, lipids, carbs and minerals such as magnesium, potassium, phosphorus, sodium, iron, zinc, manganese, and copper (Collins et al, 2007). Watermelon seeds contain chemical compounds such as alkaloids, and phenolic compounds such as lactones, tannins, and flavonoids which are proven to be cancer preventing.

This study aims at developing a ready- to- eat nutrient bar using two formulations: flaked rice-based and mung bean based, incorporated with a multitude of grains and underutilized seeds to improve the nutritional profile and health benefits. Use of underutilized seeds like pumpkin and watermelon seeds would bring down the production cost of the nutrient bar in the competitive market and would be a good way of popularizing the consumption of these often wasted seeds. The study also deals with determining the nutritional value, shelf-life, and the sensory profile of the final product.

2 METHODS AND MATERIALS

2.1 Materials

Table 1. Materials of the Nutrient Bars (123,321)

Types of ingredients	Developed rice flakes based Nutrient bar (123)		Developed mung based Nutrient bar (321)	
	Quantity (g)	**Percentage** (%)	**Quantity (g)**	**Percentage (%)**
Rice flakes	30	26.08 %	-	-
Mung bean	-	-	30	26.08%
Pumpkin seeds	10	8.69 %	10	8.69%
Watermelon seeds	5	4.34 %	5	4.34%
Corn flour	15	13.04 %	-	-
Pop corn	-	-	15	13.04%
Winged bean	15	13.04 %	15	13.04%
Desiccated coconut	40	34.77 %	40	34.77%
Salt	0.03	0.02 %	0.03	0.02%

The desiccated coconut and binding agent were produced and, the collected seeds were precooked, and ground into fine particles. The commercial nutrient bar was purchased from the market and it contained rice, soya, glucose, vegetable oil, mung beans, soy lecithin, salt, citric acid, and plant extraction (Rosemary) as the ingredients according to information in the label.

2.2 Preparation of food binder

A significant amount of proximal sugar caramel and glucose syrup were combined to create a food binder. Then the mixture was heated in a food-grade stainless steel container where the binder was homogenized at a Total Soluble Solid (TSS) content of 71± 1 after methods described by Carla et al, 2020.

2.3 Preparation of desiccated coconut

Mature and good quality coconuts were selected and cracked into halves. The coconut halves were then placed in an oven at 65 °C for 10-15 minutes to separate the meat from the shell and the soft brown skin was peeled off. Next, the coconut meat was chopped into small pieces and blended until a fine consistency was obtained. After that it was dried in an oven at 180 °C for 10-15minutes

2.4 Preparation of Nutrient bar

Two formulations were developed: flaked rice-based nutrient bar (123) and mung-based nutrient bar (321). The Commercial nutrient bar (801) served as the control.

As the First step, all of the seeds (Flaked rice/mung beans, winged beans, pumpkin seeds, and watermelon seeds) were cooked at low heat of 65 °C. Then, corn flour, desiccated coconut, and salt were added and thoroughly mixed. After that, vanilla flavor and artificial preservatives were added and remixed well. Sugar caramel and liquid glucose binder were put into the mixer in I 1:3 ratio. Finally, mixture was compressed in a mold to produce nutrient bars with dimensions of 2.5 cm × 2.5 cm × 5.6 cm and weight of 35 g and kept for 30 minutes to set. Then all nutrient bars were placed in an aluminum metalized bag and stored at 25 ± 2 °C temperature for further analysis.

3 ANALYSIS OF NUTRIENT BARS

3.1 Microbial evaluation

The microbial count was recorded (SLS 516: 1991) just after preparation and time intervals of 3,7,14 and 30 days from preparation. The nutrient bars were kept sealed in an aluminum metalized bag at 25 ± 2°C room temperature until the evaluation of the microbial count. The evaluated microbiological parameters included the total viable plate count in Nutrient Agar medium, yeasts and molds development in Potato Dextrose Agar.

3.2 Proximate composition

The Association of Official Analytical Chemists (AOAC) procedures were used to determine the proximate composition of the nutrient bars. Total carbohydrates quantification was performed according to the Phenol-sulfuric acid method in AOAC 923.09, ash according to the AOAC 1942, and moisture were quantified according to methods AOAC 2002, crude fibre content according to the AOAC 978.10, fat content according to the AOAC 2003.05 respectively. The sum of all the components; total carbohydrates, moisture, ash, crude fibre and crude fat were summed and subtracted from 100 to calculate the crude protein content.

3.3 Phytochemical Composition

The pH of the nutrient bar was determined using the SLS 280 (2009) method, and the color of the nutrient bar was measured using the Royal Horticultural Society Color Charts Edition V. The Association of Official Analytical Chemists (AOAC) procedures were used to determine the water activity, Brix range, total phenolic content, and antioxidant activity. The total phenolic content of nutrient bars was determined using Folin-Ciocalteu reagent (Singleton & Rossi, 1965).

3.4 Stability during storage

The freshly prepared nutrient bars were placed in metalized bags at room temperature (25± 2 °C). The color, moisture, and microbiological attributes (Yeast and molds, and total plate count at 25± 2 °C) were analyzed after 3, 7, 14, and 30 days of storage.

3.5 Analysis of sensory properties

The sensory attributes were evaluated for the purpose of monitoring stability, and for market acceptance. The sensory evaluation was conducted with the participation of a consumer-type panel that included 30 untrained panelists (university students and staff) ranging in age from 20 to 40 years old. The 9-point hedonic scale was used for the sensory evaluation.

3.6 Cost analysis

The production cost of the two nutrient bars that were developed included cost of ingredients, cost of packaging material, and cost of treatment and miscellaneous costs.

3.7 Statistical analysis

All results in the paper were reported as mean and Standard Deviation (SD) from three replicates (n = 3). A one-way analysis of variance (ANOVA) with post-hoc Tukey HSD test was used to compare mean values between groups, and all tests were evaluated for statistical significance at $p \leq 0.05$ using MINITAB 17 software. (Montgomery, 2009)

4 RESULTS AND DISCUSSION

4.1 Proximate composition of prepared nutrient bars and commercially available nutrient bar

The moisture level of 321, 123, and 801 nutritional bars were measured according to the FDA standard for cereal flours and related products (Food and Drug Administration, 2017). The moisture content of the 123,321 and 801 type nutrient bars were 2.23±0.3%, 1.66±0.1%, and 1.45±0.1% respectively. 123,321 and 801 samples have a significant difference in moisture ($P < 0.05$). The desirable texture of dried snack food items and crispness are sensitive to moisture uptake by the food from the atmosphere. The P-value related to the moisture parameter versus storage is 0.028, and there was a significant difference ($P < 0.05$) in moisture against the storage.

The P-value in the analysis of the variance in ash content is 0.004, and there was a significant difference ($P < 0.05$) between 123,321 and 801 Samples. 321 and 801 nutrition bars belong to the same group when result was grouped using the tukey technique at 95% confidence. Samples with high ash content may have a high concentration of various mineral elements able to speed up metabolic processes and promote growth and development. As a result, it is possible to aggregate a 321 nutrition bar with various mineral elements. (Zamora-Gasga *et al*, 2014)

The crude fibre content of the 123, 321, and 801 bars were 11.4 ±1.4%, 21.8 ± 2.5%, and 0.5±0.5%, respectively where the P-value is 0.007, and there was a significant difference ($P < 0.05$) between 123,321 and 801. The 321 (Mung based nutrient bar) nutrient bar has a higher fibre content as compared to the fibre content of commercial available nutrient bar. While fibre-rich foods are known to expand the inside walls of the colon, allowing waste to move effortlessly and reducing the risk of various cancers, they also lower cholesterol levels in the blood and reduce the risk of numerous cancers (Bello et al, 2008). However, the importance of keeping low fibre intake in the feeding of infants and weaning children has been emphasized, as high fibre levels in the weaning diet can irritate the mucosa of the intestine. (Bello et al, 2008).

Fats are essential because they provide a larger portion of energy (9 kcal/g) to the body. The crude fat content of the 123, 321, and 801 nutrient bars were 2.7±0.2%, 0.9±0.7% and 1.5±0.0% respectively where the P-value is 0.166 and there were no any statistically significant difference ($P > 0.05$) between 123,321 and 801 samples.

The 123 type nutrient bar provides 43.8±0% useable carbohydrates, whereas the 321 type nutrient bar has 29.2± 8.3% and the 801 type nutrient bar has 56.3± 3.9%.Since the P-value is 0.080, there was no any significant difference in carbohydrate content which nearly gives half of the energy content by fats (4 kcal/g) among 123,321 and 801 samples.

The 123, 321, and 801 bars had a protein content of 31.9%, 36.6%, and 30.33%, respectively. The P-value for analyzing protein content variance is 0.808, and there were no statistically significant differences ($P > 0.05$) between 123,321 and 801. Mung beans are a rich source of proteins. Consequently sample 321, which is the mung bean based nutrient bar, had the highest protein content.

Table 2. Proximate Content of the Nutrient Bars (123,321,801)

Component analyze	321 Sample	123 Sample	801 Sample
Protein %	36.6±0.0	31.9±0.0	30.3±0.0
Carbohydrates %	29.2±8.3	43.8±0.0	56.3±3.9
Fat %	0.9±0.7	2.7± 0.2	1.5± 0.0
Ash %	9.7±0.1	7.9± 0.2	7.8± 0.0
Fibre %	21.8±2.5	11.4±1.4	0.5± 0.5
Moisture %	1.7±0.1	2.2±0.3	1.5±0.1

Values are mean ± Standard deviation of 3 replicates (n=3). Treatment means having significant difference between samples ($P \leq 0.05$)

Figure 1. Mung based nutrient bar (321), Flake rice based nutrient bar (123) and Commercial nutrient bar(801).

The 123,321 and 801 nutrition bars have a calorific value of 327.1, 271.3, 360 kcal per 100g. (calorific value of food by employing the 4-9-4 method). According to the European Union Commission Regulation, meal replacement' products (shakes, bars) are considered to have calorific value 200-250 kcal energy, protein of 25-50% of total energy content, and fat of ≤ 30% of total available energy content. The prepared energy bars (123,321) were in the standard range of calorific value.

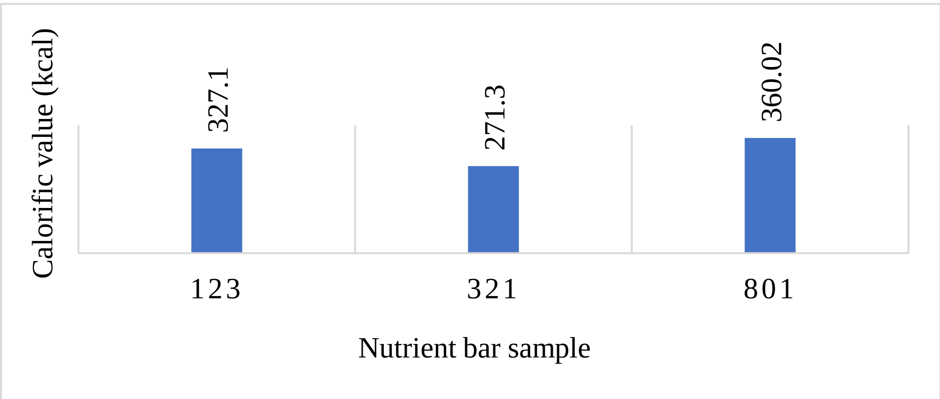

Figure 2. Calorie (kcal) content in 123,321,801 Nutrient bars

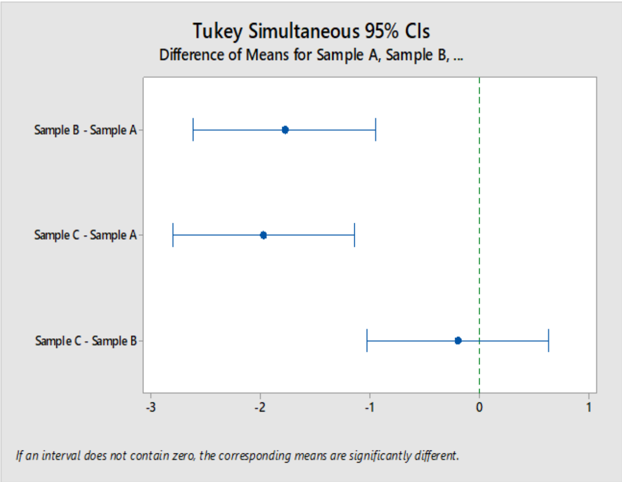

Figure 3. Comparative difference of mean Ash content in Nutrient bar (123,321, 801sample) using Tukey simultaneous 95%.

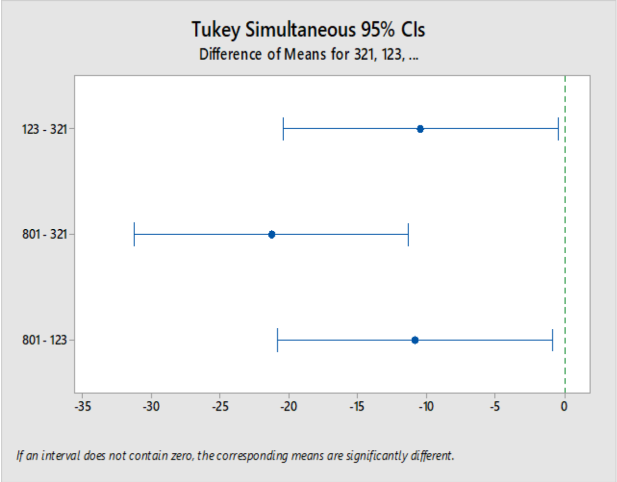

Figure 4. Comparative difference of mean crude fibre content in Nutrient bar (123, 321, 801 sample) using Tukey simultaneous 95%

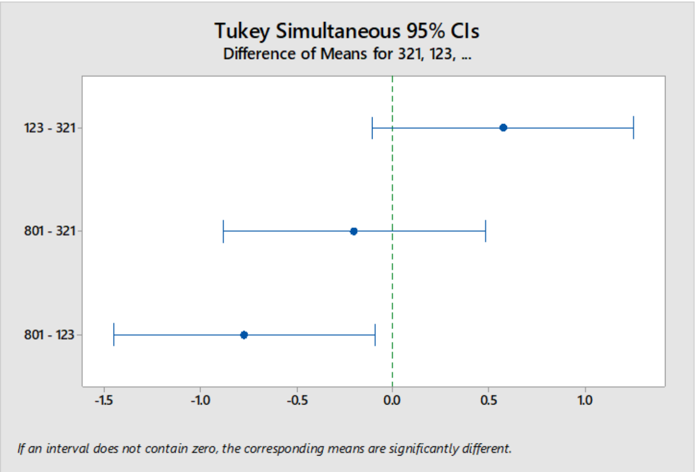

Figure 5. Comparative difference of mean moisture content in Nutrient bar (123,321, 801 sample) using Tukey simultaneous 95%

4.2 Microbial characteristics of prepared nutrient bars and commercially available nutrient bar

The limited total viable plate count in food was (CFU 10^{-1}) 100-10000 due to the SLS normative standards limits. In analyzing the variance in total plate count, the P-value is 0.040 and they have significant differences ($P < 0.05$) between 123,321 and 801 when grouping data using the tukey method at 95% confidence, samples 123, 321, 801 nutrition bars belong to the same group. Sample 801 nutritious bar had the higher Total viable plate count.

According to the Sri Lankan Institute of standardization, the food items categorized under the instant meal replacements must have their yeast and mold count under the stipulated limits of 10-1000 (CFU 10^{-1}). For yeast and mold, the P-value is 0.219 and, they have no significant difference ($P>0.05$) between 123,321 and 801. Sample 801 nutrient bar had higher yeast and mold count. There were no any statistically significant differences ($P > 0.05$) among the three different nutrient bars after 30 days of shelf life when the yeast and mold count were analyzed.

4.3 Sensory evaluation of prepared nutrient bars and commercially available nutrient bar

Table 3. Results of sensory evaluation

Parameter	P value	123	321	801	Highest sum of rank
Aroma	0.00	7.08	6.91	5.75	49.0
Color	0.00	7.50	7.25	5.25	49.0
Texture	0.01	6.50	7.91	6.08	53.5
Taste	0.01	7.00	8.00	6.00	52.0
Mouth feel	0.45	7.50	7.50	7.25	44.0
Overall acceptability	0.00	7.33	8.50	6.66	56.50

The results were statistically analyzed using Friedman test by Minitab 17 version.

In Hypothesis determination,

Null Hypothesis (H_0): There is no any significant difference within each ingredient combination of nutrient bar samples.

Alternative Hypothesis (H_1): There is a significant difference within each ingredient combination of nutrient bar samples.

Reject H_0 if,

Statically tested "P" value < Critical α value (0.05).

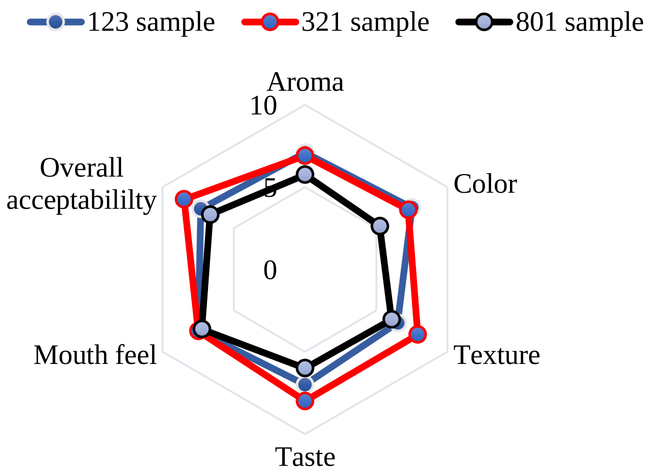

Figure 6. Mung based nutrient bar (321), Flake rice based nutrient bar (123) and Commercial nutrient bar(801).

4.4 Physiochemical characteristics of prepared nutrient bars and commercially available nutrient bar

The pH value of a food items are used to determine the acidity of the particular food items. Any pH value below pH 7 is considered acidic, whereas values above pH 7 are considered basic. The more acidic food is in lower pH reading. They must achieve pH equilibrium in a reasonable amount of time (Rushing, 1999). The mean pH value of the 123, 321, and 801 nutrient bars were 6.2 ± 0.0%, 6.3 ± 0.0% and 6.9 ± 0.0% respectively. The P-value in the pH parameter during the shelf life analysis is 0. 073. There was no any significant difference ($P > 0.05$) in the pH value with respect to shelf life.

Water activity (aw) is the amount of water in a food product and is usually related to its moisture. That amount of water is used (free water) for microorganisms to grow. The water activity of food such as honey, bread, and cookies are 0.9 or less and can be considered as shelf-stable without refrigeration

(Pittia *et al*, 2016). In the nutrient bar samples of 123, 321 and 801, the water activity was 0.6±0.0%, 0.6±0.0%, and 0.6±0.0% respectively. When it comes to the evaluation of water activity against shelf life, the P-value is 0. 434 suggesting that there was no any statistically significant difference (P > 0.05) in water activity with shelf life. (P > 0.05)

The salinity of the 123, 321 and 801 nutrient samples were 1.7 ± 0.0%, 1.4±0.0%, and 1.4 ±0.0%, respectively. In the salinity parameter versus shelf life, the P-value is 0. 008. Therefore, a statistically significant difference (P < 0.05) is present for salinity with respect to shelf life and with the time salinity increased in all three samples.

The 123, 321, and 801 have mean Brix value of 45.4±0.3%, 46.9±0.3%, and 55.3±0.2%, respectively. The P-value for Brix value versus shelf life is 0.461. As a result, there was no statistically significant difference (P > 0.05) in Brix value within the shelf life among the three samples.

Antioxidant Value in Nutrient Bars

The IC_{50} values, which correspond to the concentration of nutrient bar samples that can scavenge 50% of the free radicals present with in the human body once they ingest the food with antioxidants. High IC_{50} values imply low antioxidant activity. The IC_{50} values for samples 123, 321, and 801 were 113.54 μg/ml (0.01%), 261.12 μg/ml (0.01%) and 138.23 μg/ml (0.01%) respectively.

In analyzing the variance in phenolic content, the P-value is 0.345. Due to that, there was no significant difference (P< 0.05) among 123,321 and 801.When data were grouprd using the tukey method at 95% confidence, samples of 123,321 and 801 nutrition bars belonged to the same group. However, sample 123 comparatively recorded a lower IC50 value which indicates that rice-based nutrient bar had a higher antioxidant activity than 321 and 801.

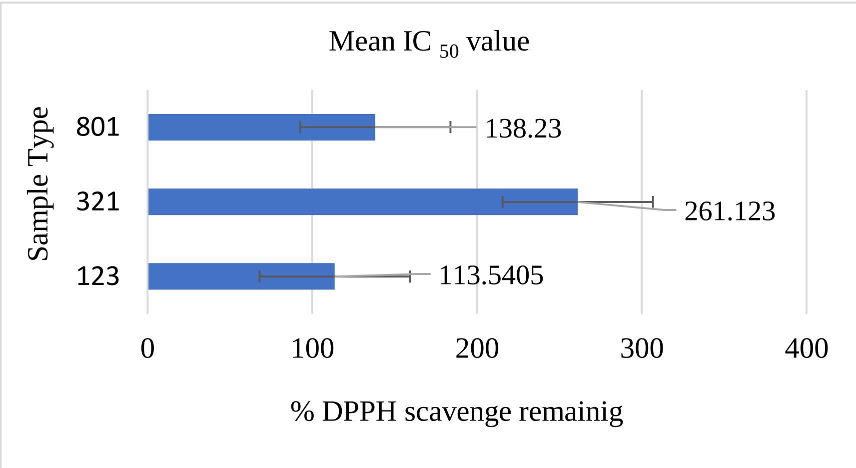

Figure 7. Radical DPPH scavenging activity of the 123, 321, and 801 nutrient bars.

Total Phenolic Content

The plant based food items are rich in phenolic compounds and as a result they are associated with high profile of sensory characteristics (Chi-Tang, 1992). The phenolic values in the 123, 321, and 801 samples were 0.006%, 0.003 % and 0.005% respectively.

P-value for the total phenolic content, is 0.012. Due to that, they have significant differences (P< 0.05) between 123,321 and 801.

The results showed that the samples had reduced total phenolic compound levels. It has been reported that total phenolic components could be get destroyed significantly during food preparation (Perret & Yu, 2002). Folin-Ciocalteu method is widely used to determine the total phenolic levels in botanical and biological samples although it has its own limitations. Other reducing agents, such as L-ascorbic acid and sulfur dioxide, might react with the Folin-Ciocalteu agent and add to total absorbance, causing total phenolic levels to be overstated (Singleton & Rossi, 1965).

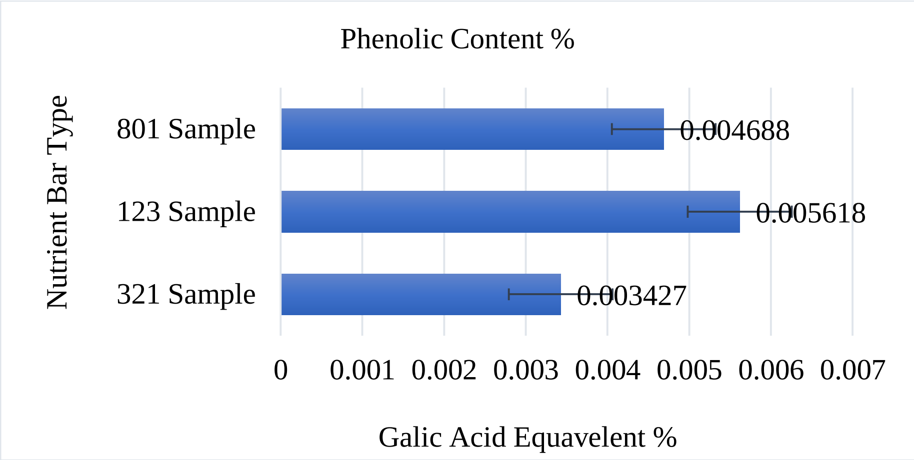

Figure 8. Total phenolic contents of the Nutrient Bars 123,321,801.

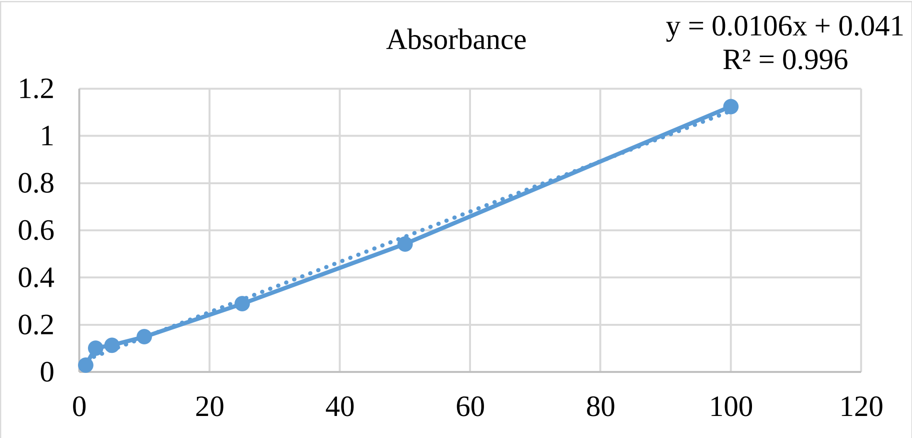

Figure 9. Standard Gallic Acid Curve (Genwali et al, 2013)

4.5 Cost Analysis of prepared nutrient bar and commercially available nutrient bar

Total cost analyses contained material cost and other expenses (labor, energy, and equipment cost).

Table 4. The cost of 1 nutrient bar (35g)

	Developed rice flakes based Nutrient bar (123)	**Developed mung based Nutrient bar (321)**
Material cost	Rs.16.28	Rs.16.32.
Other Expenses (Energy Cost, Equipment cost, Labour cost)	Rs. 12.76	Rs. 12.76
Total Cost	Rs.29.04.	Rs.29.08.

The commercially nutrient bar of 10 g costs LKR 10. Accordingly, production of a 35 g commercial nutrient bar would cost LKR 35.00. Production cost of 35g of 123 and 321 nutrient bars was LKR 12.76 and 12.76 respectively and could be available for a market value of LKR 30.00.

5 CONCLUSION

Proximate analyses have revealed that the developed nutrient bars 123 and 321 meet the Recommended Dietary Allowances. Since foods categorized under the compositional criteria for "meal replacement" products (shakes, bars) energy content should be in the range of 200-250 kcal, energy from protein should be at 25-50%, and energy from fat ≤ 30% of total available energy content. Except for the attribute 'mouthfeel', all other sensory attributes have shown significant differences among samples 123,321 and 801. In the physicochemical analysis, only the water activity remains constant among the three nutrient bars. There was no any significant difference in phenolic content or antioxidant activity between samples. In shelf-life evaluation revealed that the developed bars (123,321) can be kept for 30 days at 25 ± 2 °C with aluminum metalized packaging material. According to the European Union Commission Regulations (EUCR), a meal replacement product should have 200-250 kcal energy composition. Accordingly, the prepared 123, 321 type bars could be considered to fulfill the calorie requirements set forth by EUCR with less effort and at a lower cost than commercially available nutritional bars (801). The lowest cost of nutrient bar on the Sri Lankan market costs Rs.10.00 (0.050 USD) for 10g. The 123,321 nutrient bars could be processed at 10g for around LKR 8.50 (0.042 USD). As 123 and 321 nutrient bars are made entirely of plant-based ingredients, vegans and vegetarians could use it as a meal replacement due to its rich nutritional profile.

6 ACKNOWLEDGEMENTS

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Variation of Microwave Leakage Exposure Levels Close to a Microwave Oven with Load, Container Type and Time.

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ABSTRACT

Nowadays people are living in a rush world and most people seek efficient methods to complete their day to day work with less time. Microwave ovens are the best option to cook foods as well as for reheating precooked foods. Microwave ovens use radio frequency (RF) electromagnetic waves around the frequency 2.4 GHz for cooking and reheating food by dielectric heating or high frequency heating. Many scientific reports have been confirmed that eating microwave food is not a risk, because radio waves cannot ionize foods. But the problem is exposing to the leakage microwave radiation when operating the oven. Authorized bodies such as International Commission on Non-Ionizing Radiation Protection (ICNIRP) as well as Federal Communications Commission (FCC) have been published limitations for exposure to these RF waves. The limited plane wave power density for a microwave oven is 50 W/m^2 at any point 5 cm away from the oven. Over exposure to these RF waves with high plane wave power densities may lead to health effects such as cataracts in the eyes, infertility, and brain tumors. In this study, leakage microwave plane wave power densities were evaluated by using spectran HF6065 spectrum analyzer under three situations with newly brought microwave oven. In the first study variation of RF levels at 40 cm from the front glass of the microwave oven with the load (water) were evaluated, In the second study RF levels around the microwave oven for same load kept in plastic and ceramic containers were evaluated separately and, in the third study, time variation of the power density at a distance 40 cm in front of the microwave oven for a duration of 180 s was evaluated. Results in the first study show that negative correlation (r=-0.6136) between the load and leakage microwave emission around the oven as well as maximum average plane wave power density of (512.78 $\pm$ 0.01) mW/m^2 with no load inside the oven and maximum average plane wave power density with the load is 195.06 $\pm$ 0.01 mW/m^2 with 100 $\pm$ 1 g of load kept in a plastic container with mass 68 g. For the second study considerably low RF levels were recorded when using the ceramic container than plastic container. Results for the third study show that microwave emission around the oven is fluctuating rapidly with time and it can be varied between 0.01 mW/m^2 and 108.48 mW/m^2. Evaluated maximum RF plane wave power density among all three studies was (677.84 $\pm$ 0.01 mW/m^2) and this value is 1.35 % of maximum permissible leakage level for a microwave oven as well as it is found that frequency of the microwave radiation is also varying when it is operating. However, authors would like to request not to stay close to a microwave oven when it is operating, especially children and pregnant women because they are more sensitive for non-ionizing RF radiations.

KEYWORDS: *microwave ovens, radio waves, leakage microwave exposure, health effects*

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1 INTRODUCTION

1.1 Microwaves and Radiofrequencies

In the electromagnetic spectrum 100 kHz to 300 GHz region is considered as radio frequency region and according to most of the text books 1 GHz to 300 GHz region is considered as the microwave region and there are enormous applications of these radio waves. Wireless communication systems such as mobile communication, radar systems, television and radio broadcasting as well as special frequency band is allocated for industrial, science and medical applications (ISM band). Microwave Ovens use this frequency band to operate (Sorrentino, R., & Bianchi, G.,2010).

1.2 Operation of a microwave oven

A microwave oven converts electrical energy into radiofrequency electromagnetic waves produced within the microwave cavity to warm up and cook foods and this method is known as dielectric heating or high frequency heating (Liu, S., Ogiwara, Y., Fukuoka, M., & Sakai, N.,2014). Most of the domestic microwave ovens use frequencies around 2.45 GHz because high-power efficiency is possible around this frequency. Inside a microwave oven, these high frequency radio waves are produced by using a device called magnetron and the produced microwaves are transferred to the cooking area through a metal tube known as a wave guide. Continuous supply of these radio waves will produce a standing wave inside the cavity of the oven and foods which are exposed to this high intensity microwaves will heat up rapidly (Luan, D., Wang, Y., Tang, J., & Jain, D.,2017).

1.3 Risk of Microwaves

Leakage microwaves to the surrounding is the main risk of microwave ovens. Operating a microwave oven with damaged door or door seals will increase the risk of exposure to high intensity microwaves. According to international bodies such as International commission on Non-Ionizing Radiation Protection (ICNIRP) and Federal Communications Commission (FCC) there are some limitations for these leakage microwaves, 50 W/m^2 at any location 5 cm away from the oven is the maximum permissible level for any domestic microwave Oven (ICNIRP,2020; Matthes, R.,1992).

1.4 Health Effects of microwave exposure

Heath effects of microwaves are cause mainly due to thermal effects induced in the body tissues. Areas such as the eyes and testes are more vulnerable for this RF heating because of less heat dissipation due to relatively low blood flow. Exposure to very high intensity microwaves may cause painful skin burns and cataracts in the eyes. Non thermal effects also possible due to exposure for these microwaves, especially neuropsychiatric effects such as depression (Dean, A. L., Rea, W. J., Smith, C. W., & Barrier, A. L. ,2012; Pall, M. L.,2016).

1.5 Propagation of microwaves and plane wave power density

Since the microwaves are a type of electromagnetic waves, they carry the energy with the help of perpendicularly oscillating electric and magnetic fields. The electromagnetic energy per unit area passing through a surface perpendicular to the wave per unit time is defined as the energy flux (S) or plane wave power density and the expression for the pointing vector $\vec{S}$ to the direction of propagation is given by the expression,

$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{H}$ Here μ_0 is the permeability of free space. (1)

At very high frequencies, energy flux variation is extremely rapid therefore most of the measuring devices measure only an average. Time average (S_{AVG}) of the energy flux of an EM wave is given by the following expressions,

$$S_{AVG} = \frac{1}{2} c\, \varepsilon_0 E_0^2 = \frac{1}{2\mu_0} c\, H_0^2 = \frac{E_0 B_0}{2\mu_0} \tag{2}$$

Here ε_0 is the permittivity of of free space, E_0-Amplitude of the electric field, B_0-Amplitude of the magnetic field and c is the speed of light in free space (Pozar, D.,2005).

1.6 Literature on microwave leakage levels.

A group of researchers in the Centre for Electromagnetic Compatibility at the University Tun Hussein Onn Malaysia were conducted a study about the microwave leakage levels from microwave ovens by using six ovens and they found that all the ovens emit a certain amount of microwave leakage levels and one microwave oven exceed the international standard level (Muhammad Zin, N., Mohamed Jenu, M. Z., & Ahmad Po'ad, F.,2011). Another study conducted by two scientists at Shiraz University, Iran conducted a study to find the relationships with microwave leakage levels emitted by a microwave oven with the body weight, thyroid hormones, and cortisol levels in adult female mice. The results in the study shows decrease in the body weight, increase T4 (Thyroxine) and cortisol levels (Jelodar, G., & Nazifi, S.,2010). A group of researchers at the Public University of Navarra and Carlos III Health Institute in Spain conducted a study about the microwave power leakage levels around a domestic microwave oven and exposure levels. As well as they have developed a model to estimate received electric field for the entire volume of an indoor environment. The results of the study revealed a strong dependence of the microwave exposure levels on the location, topology and morphology as well as some interference to the wireless communication systems (Lopez et al.,2015). An interesting research was carried out by a group of researchers in The University of Tokyo and Georgia Institute of Technology revealed a method to harness power from leakage microwaves by microwave ovens and they were able to harvest 9.98 mJ of electrical energy by operating a microwave oven for a duration of 120 seconds and that energy was enough to operate a digital timer for a duration of 180 s and beep for 2.5 s (Kawahara et al., 2013).

2. METHODOLOGY

A newly brought microwave oven (Model No: ABOVAMS25LGR) of a famous brand in Sri Lanka is used for the study. Table 1 shows the manufactures data for the microwave oven.

Table 1. Specifications of the microwave oven used for the study.

Specification	Details
Microwave Power	900 W
Power level	9
Cavity	White Painted Cavity Dimension:220mm(H)×340mm(W)×344mm(D)
Product Dimension	281mm(H)×483mm(W)×404mm(D)
Glass Tray diameter	270mm
Rotational Speed of the Tray	6 rpm

The oven is placed away from wi-fi sources and mobile phones to make sure no radio interferences as well as the experiment was carried out in a place having very poor ambient RF exposure levels within the frequency range 2200 MHz to 2800 MHz. Microwave power of the selected oven is 900 W and it is a kind of lowest power microwave oven. Figure 1 shows the instrumental setup used for the study.

Figure 1. Spectran HF6065 spectrum analyzer with the microwave oven used for the study.

2.1 Evaluation of microwave leakage levels with load in front of the microwave oven with 40 cm from the front door.

In this study a plastic container (Type 5 polypropylene) is used, and water is used as the load. Added mass of water is varied by 50 g steps and at each instance peak plane wave power density of the leakage microwaves and frequency of the strongest signal were detected by using the spectrum analyzer while allowing the oven to operate for a duration of 3 minutes. A digital balance with accuracy $\pm$ 1 g is used to measure the mass.

2.2 Evaluation of microwave leakage levels around the microwave oven for porcelain and plastic containers having same load.

In this study plastic (Type 5 polypropylene) container and porcelain cup is used and equal mases (250 g) of water was added to the containers and RF levels were recorded with a distance 50 cm from the centre of the oven and eight readings were obtained in 45 degree steps after placing the containers with the load separately. Peak microwave leakage level for one sweep of the spectrum analyzer within the frequency range 2200 MHz to 2800 MHz was measured. Reason for selecting 45 degree steps is the antenna used in the study has a beam width around 45 degrees. Figure 2 shows the measurement procedure for this situation.

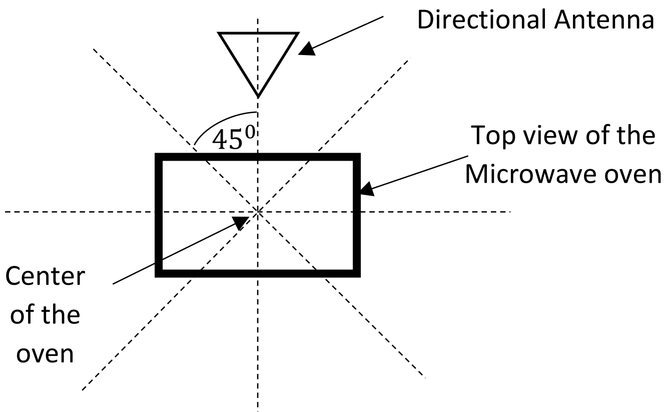

Figure 2. Measurement technique used to observe microwave leakage levels around the microwave oven.

2.3 Time variation of microwave leakage levels Infront of the microwave oven

In this study 250 g of water is poured into the plastic container used in the previous studies and the antenna is placed with a distance 40 cm from the front glass of the oven since a normal person stands approximately with this distance close to the oven so that he or she can open the door of the oven easily. The oven was operated for a duration of 180 s and microwave leakage levels were measured in each second.

3 RESULTS AND DISCUSSION

3.1 Study 01: Variation of microwave leakage levels Infront of the microwave oven with load.

Microwave oven is allowed to operate for 180 s period and the spectrum analyzer is used to collect the peak plain wave power density Infront of the oven for the above time period. Following are the readings obtained from the spectrum analyzer for each load when the system is loading and unloading with 50 g steps. Table 2 and Table 3 shows the variation of peak plane wave power density levels of leakage microwaves when the system is loading and unloading.

Table 2. Variation of Microwave leakage levels and frequency of the strongest signal when the mass of water (load) is increasing (Loading).

Load ± 1(g)	Frequency (MHz)	Peak plain wave power density ± 0.01(mW/m^2)
No Load	2469	677.84
50	2464	145.41
100	2466	82.99
150	2214	77.73
200	2368	169.21
250	2472	175.11
300	2478	102.15
350	2466	131.33
400	2469	181.34
450	2469	166.23
500	2466	95.99

Table 3. Variation of Microwave leakage levels and frequency of the strongest signal when the mass of water (load) is decreasing (Unloading).

Load ± 1(g)	Frequency (MHz)	Peak plain wave power density ± 0.01(mW/m^2)
500 g	2461	131.28
450 g	2466	85.39
400 g	2466	89.02
350 g	2469	120.11
300 g	2461	79.04
250 g	2602	81.59
200 g	2383	177.47
150 g	2334	80.73
100 g	2466	307.14
50 g	2281	241.67
No Load	2532	347.72

Variation of microwave plane wave power density with the load, when loading and unloading can be graphically represented as follows. Figure 3 shows the variation of plane wave microwave power density levels for the above two instances.

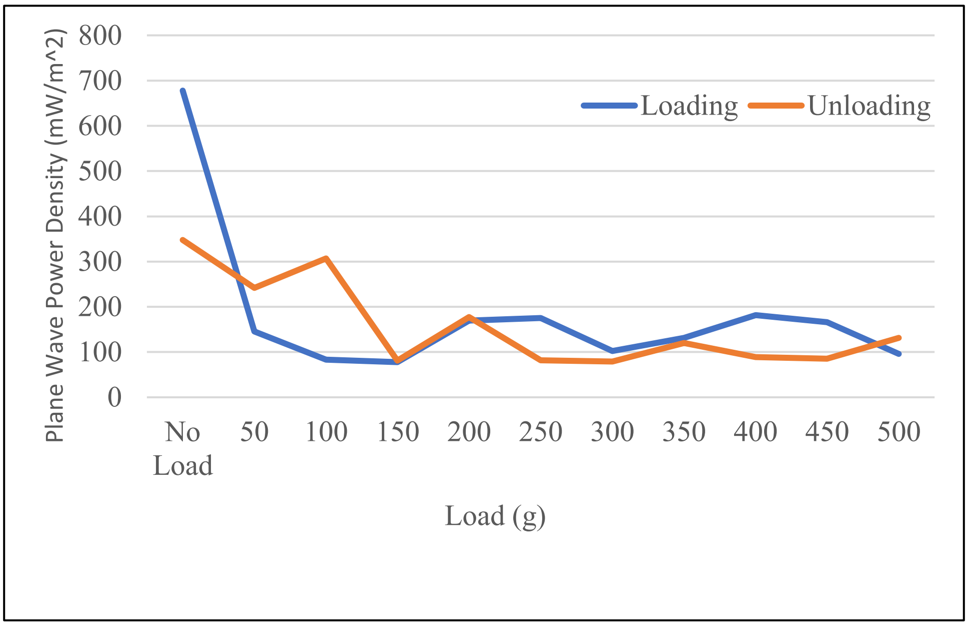

Figure 3. Variation of Microwave leakage levels with the load kept inside the oven.

According to the figure 3 microwave leakage levels are decreasing considerably when a load is inserted to the oven. Based on the results in Table 2 and Table 3, average microwave leakage levels were calculated to analyze the above situation conveniently. Table 4 shows the calculated average plane wave power densities with the corresponding load.

Table 4. Variation of the average microwave leakage levels

Load $\pm$ 1(g)	Average of peak plain wave power densities $\pm$ 0.01(mW/m^2)
No Load	512.78
50	193.54
100	195.06
150	79.23
200	173.34
250	128.35
300	90.60
350	125.72
400	135.18
450	125.81
500	113.66

Figure 4 shows the scatter plot of the average of peak power densities corresponding to each mass based on the values in Table 2 and Table 3 and the polynomial trendline which fits to the points.

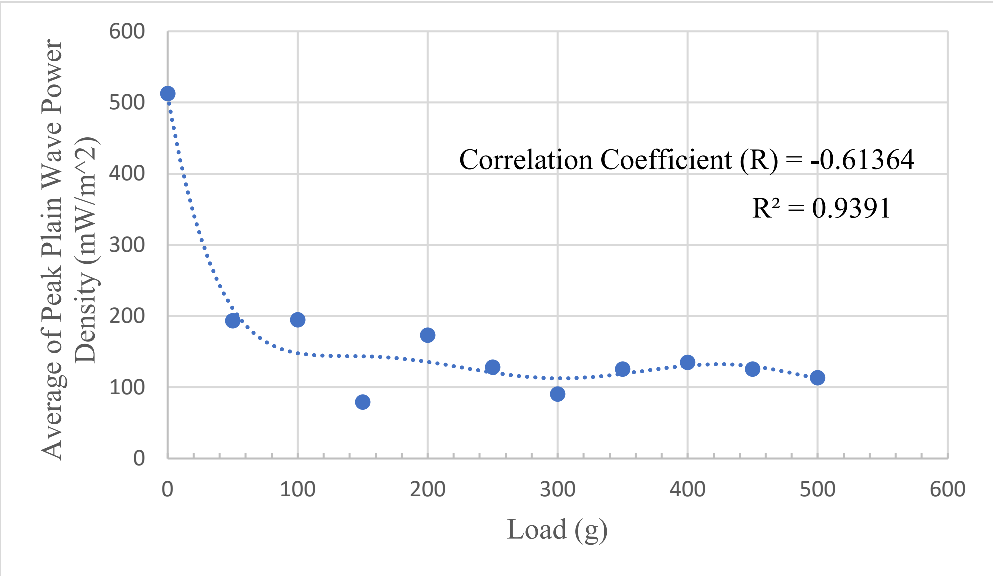

Figure 4. Scatter plot of the variation of the average of peak plain wave power densities with load and 6th order polynomial trendline fits to the data.

According to the Figure 4 it can be observed that the microwave leakage levels show a polynomial variation with the load inserted to the oven as well as a negative correlation with the load. A 6th order polynomial was the best fit with the highest value of R square according to trendline tool in Microsoft Excel. As well as the calculated correlation is -0.61364 and the reason for negative correlation may be due to absorption of microwaves by the load and thereby leakage microwave levels becoming lower. Figure 5 shows the variation of frequency corresponding to the strongest signal with the load for both situations shown in Table 2 and Table 3.

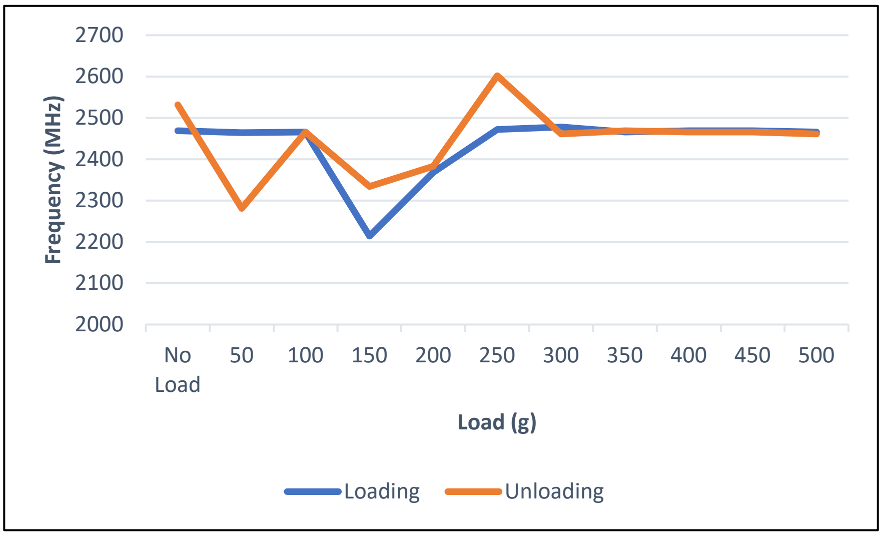

Figure 5. Variation of the frequency corresponding to the strongest signal when loading and unloading

According to Figure 5 rapid variation of frequencies can be observed for the strongest signal up to 300 g and then the variation limited to the range 2460 MHz to 2470MHz.

3.2 Study 02: Evaluation of microwave leakage levels around the microwave oven for porcelain and plastic containers having same load.

Table 5 shows the measurements obtained for microwave leakage levels for porcelain and plastic containers seperately according to the mesurement procedure given in Figure 2 . Mass of porcelain container and plastic container were 310 ± 1 g and 68 ± 1 g respectively.

Table 5. Measured peak microwave leakage levels around the microwave oven with 45-degree steps for one sweep within the frequency range 2200 MHz to 2800 MHz with distance 50 cm from the oven for a load of 250 g kept in a porcelain container and a plastic container.

Counter clockwise angle from the top view	Peak microwave leakage levels for porcelain container ± 0.01(mW/m^2)	Peak microwave leakage levels for plastic container ± 0.01(mW/m^2)
0°	75.89	52.1
45°	2.83	29.16
90°	2.52	23.78
135°	2.16	6.83
180°	15.77	19.51
225°	4.62	14.63
270°	7.52	10.54
315°	2.77	79.61

Figure 6 shows the radar chart for the for the microwave leakage levels for porcelain and plastic containers.

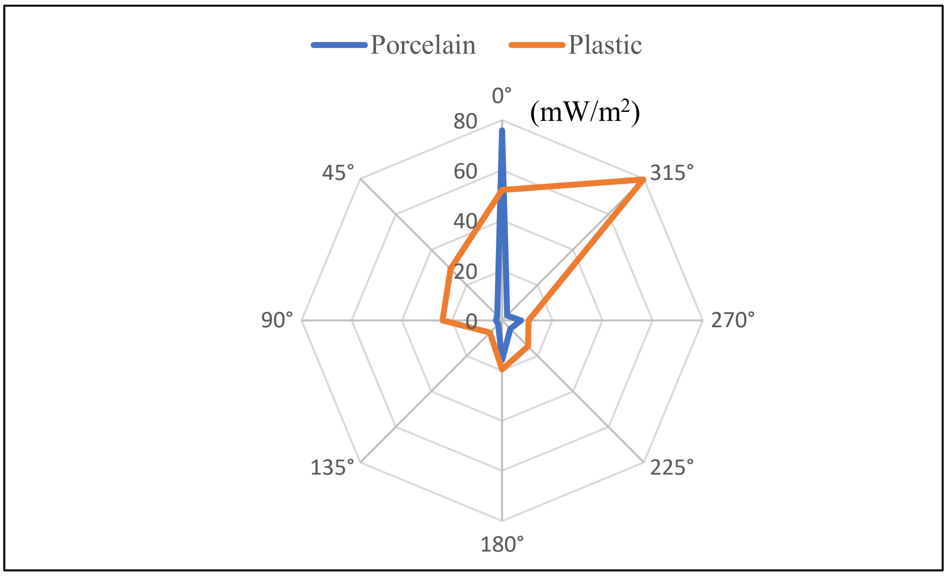

Figure 6. Variation of microwave leakage plain wave power density around the microwave oven for two instances (from the top view) for the same load (250 g) inserted into porcelain and plastic containers.

According to Figure 6, a considerable increase of microwave lekage levels can be observed around the oven when using the plastic container than the porcelain container. However, measured microwave leakage level infront of the oven is greater for the situation where the porcelain container is used.

3.3 Study 03: Time variation of microwave leakage levels Infront of the microwave oven

Table 5 shows time variation of microwave leakage levels infront of the microwave oven. The antenna of the spectrum analyser is located 40 cm from the centre of the front glass of the oven.

Table 6. Variation of Microwave leakage levels infront of the microwave oven with 40 cm from the front glass. T Represent time measured in seconds and P_D represent microwave leakage levels in mW/m^2 measured with an accuracy ± 0.01 mW/m^2.

T	P_D	T	P_D	T	P_D	T	P_D	T	P_D	T	P_D
0	0.43	30	0.14	60	3.03	90	32.5	120	2.13	150	39.89
1	3.70	31	0.10	61	2.7	91	1.13	121	4.77	151	0.06
2	0.04	32	2.40	62	4.59	92	3.6	122	0.11	152	0.79
3	0.05	33	4.53	63	3.01	93	108.48	123	5.32	153	3.72
4	5.76	34	0.10	64	2.05	94	0.03	124	3.17	154	2.75
5	22.39	35	5.80	65	1.57	95	3.63	125	4.04	155	0.11
6	0.28	36	2.37	66	4.59	96	0.08	126	8.05	156	0.02
7	88.60	37	3.02	67	0.01	97	4.88	127	6.09	157	0.07
8	1.07	38	3.55	68	3.66	98	7.47	128	57.78	158	0.46
9	2.94	39	5.10	69	5.58	99	2.47	129	4.47	159	2.49
10	0.07	40	3.66	70	0.36	100	0.23	130	0.31	160	0.01
11	1.03	41	2.79	71	0.19	101	0.04	131	0.02	161	5.4
12	0.13	42	0.09	72	3.38	102	2.64	132	0.19	162	2.76
13	3.72	43	0.38	73	0.05	103	95.59	133	2.45	163	19.02
14	4.67	44	4.31	74	0.09	104	4.73	134	0.06	164	7.64
15	0.06	45	2.12	75	0.15	105	0.27	135	0.51	165	0.12
16	0.38	46	5.59	76	0.09	106	0.01	136	4.87	166	0.01
17	5.00	47	0.03	77	2.8	107	0.04	137	0.62	167	28.64
18	1.52	48	0.03	78	2.25	108	2.23	138	4.79	168	0.01
19	6.39	49	8.46	79	7.01	109	0.37	139	0.51	169	2.9
20	4.22	50	2.90	80	0.05	110	65.01	140	0.03	170	4.29
21	0.08	51	0.53	81	14.34	111	0.69	141	6.32	171	1.93
22	5.80	52	5.84	82	2.95	112	3.39	142	0.2	172	1.73
23	0.12	53	2.22	83	37.65	113	0.05	143	2.23	173	0.04
24	0.40	54	4.55	84	0.01	114	20.91	144	3.58	174	4.07
25	0.07	55	0.24	85	2.07	115	3.64	145	33.75	175	3.78
26	0.03	56	0.11	86	3.81	116	0.32	146	3.11	176	0.01
27	0.23	57	5.34	87	0.03	117	3.21	147	6.11	177	0.06
28	0.03	58	1.49	88	0.07	118	2.44	148	3.39	178	8.75
29	0.35	59	4.28	89	0.4	119	4.06	149	105.04	179	2.36
										180	0.33

Figure 7 shows the variation of microwave leakage levels with time infront of the oven based on the data obtained in Table 6.

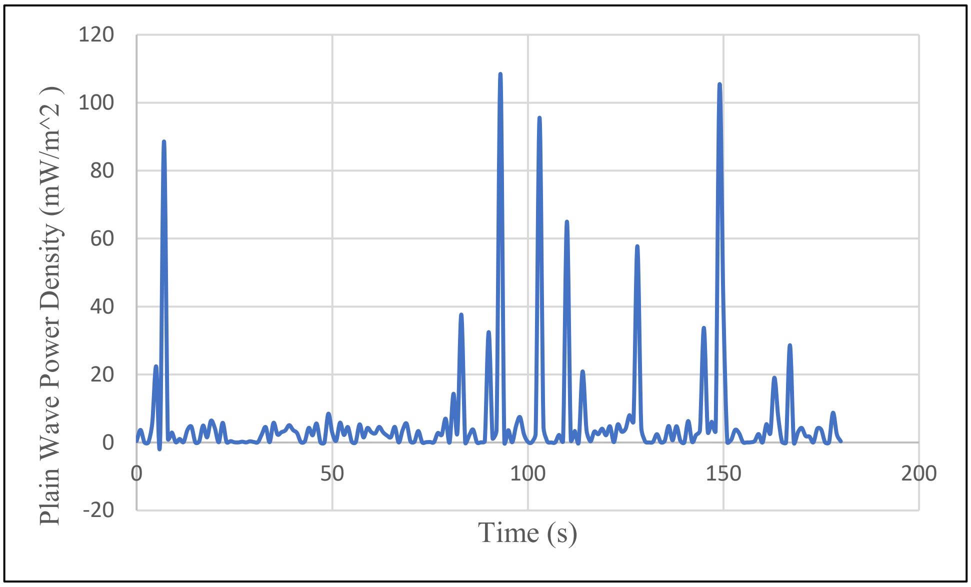

Figure 7. Variation of the plain wave power density of microwave leakage levels with time for a duration of 180 s.

According to Figure 7, It can be seen that microwave leakage levels are not continuous with time and the rate of having high plain wave power density spikes is increasing with time.

3.4 Ambient plain wave power density

The average value of the ambient plain wave power density of microwaves within the frequency range 2200MHz to 2800MHz was 360.46 nW/m^2 at the place where all the above studies were carriedout.

4 CONCLUSIONS

From the 1st study it can be concluded that the microwave leakage levels are highly depend on the load (mass of food) kept inside the oven and having a negative covariance (-0.61364) implies that these radiation levels decrease with the increase of the load. Based on the results of the 2nd study it can be concluded that using a porcelain container is more suitable to reduce average microwave leakage levels around the oven but further studies needed to investigate rate of heat generation in the food. Results of the 3rd study reveal that microwave legake levels are not persistant with time and they are varying rapidly with time. As well as leakage levels of slightly high intensity microwave levels are getting more frequent with time.

When considering all of the above three studies it can be concluded that considerable increase of microwave radiation is possible around a microwave oven when it is operating. Authors would like to request not no stay close to the microwave oven when it is operating since the effects of low power microwaves are still under research. Since pregnant women and infants are more sensitive for these radiation, it is advisable not to stay close to the microwave ovens when these devices are operating.

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Development of Silica-Copper Nanocomposite for Water Purification

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ABSTRACT

Water pollution is one of the serious concerns across the world at the moment. Industrial wastewater significantly contributes to the negative impacts caused by water pollution. Textile industries discharge large amounts of effluents into water streams with little or no treatment of the discharge because wastewater treatment is an expensive process. Thus, there exists a need for a cheap and effective way to treat textile effluent that contains dyes before being discharged. A high purity silica-based Nano-adsorbent was synthesized by using rice husk as the commercially available main cheap precursor. Copper-loaded silica nanoparticles were successfully functionalized with 3-aminopropyl triethoxysilane (APTES) via the sol-gel pathway to enhance the adsorption performance of organic dyes from textile effluent. The performance of produced Nano-adsorbent was evaluated by using methylene blue as waste adsorbate. As synthesized nanomaterial was characterized by X-Ray Diffraction (XRD) and Fourier Transform Infrared (FTIR) spectroscopy, the XRD results confirmed the presence of silicon dioxide (SiO_2) and paramelaconite (Cu_4O_3) as predicted. The FTIR confirmed the presence of Si–O stretching, N-H bending, C–H stretching, Cu–O stretching and O–H bending vibrations thereby suggesting the presence of SiO_2, NH_2 groups, CH_2, Cu_4O_3 and physisorbed H_2O. The optimum conditions for pH and adsorbent dosage were successfully evaluated for the adsorption process. The optimum pH at which the nanomaterial performed best was at pH 4. The optimum mass of the adsorbent that gave maximum adsorption performance was 20 mg. Kinetic studies revealed that the experimented data was in better correlation with pseudo-second-order kinetics. The outcome of this project would be of interest to textile industries looking for a cheap and effective way to treat textile wastewater.

KEYWORDS: *Adsorption, APTES, Methylene Blue, Nano adsorbent, Rice Husk, Silica, Sol-gel,*

1 INTRODUCTION

Pollution has become the inevitable by-product of the rapid spike in the industrial revolution. Out of many types of pollution that impact the environment, water pollution has become a serious concern in recent times (Owa, 2013). Water pollution is where the source of water is contaminated with undesirable inclusions and is left untreated to the extent that the water can no longer be used for general purposes (Halder & Islam, 2015). The main sources of water pollution are domestic wastewater, industrial wastewater, agricultural run-off, rainwater and sewage (Nag, 2018). In parts of Sri Lanka, urban areas have been polluted heavily with domestic sewage and industrial effluents. Rural areas suffer due to agricultural run-off (Berg, 2017). In certain parts of the dry zone, high fluoride and iron content have been reported. Overcrowded cities and areas encounter water-borne diseases due to poor drainage and sewage systems (Bandara, 2003). Industrial wastewater is one of the critical sources of water contamination. Wastewater from industrial outputs can severely affect the natural ecosystem by increasing salt and mineral content, changing the pH, increasing the ambient temperatures, depleting oxygen, etc (Maulin P, 2017). After agriculture, the textile dyeing industry is the most chemically intensive industry at the moment and has a major role to play in water pollution across the world. After agriculture, the textile dyeing industry is one of the most chemically intensive industries (Carmen & Daniela, 2012). Around 90-94% of water consumed by the textile industry is used as processing water. The common processes conducted include de-sizing, scouring, bleaching, mercerizing and dyeing processes. Effluents from these processes have become of alarming concern since they heavily contribute to the water pollution issues across the world. Around 2-20 % of textile dyes are discharged as effluents into different ecosystems (Carmen & Daniela, 2012).

The effluent from the textile industry negatively impacts the environment in many aspects irrespective of its model and area of disposal. Matter present in dyes causes issues such as bad appearance, prevention of sunlight penetration and oxygen into water, clogging pores in fields, corroding sewage pipes and providing a breeding ground for many types of bacteria and viruses.

There are various wastewater treatment methods established such as Granular Activated Carbon (GAC), Electro-Coagulation (EC), ultrasonic-treatment, Advanced Oxidation Process (AOP), Ozonation, Membrane Biological Reactor (MBR) and Sequencing Batch Reactor (SBR) (Bashir, 2016). However, most of these processes are quite expensive to set up and operate on an industrial scale (Carmen & Daniela, 2012). Adsorption is one of the widely explored types of purification processes. It is an efficient, effective and economical method for water purification (Gunathilaka et al., 2021). Many materials such as activated carbon, clay minerals, sawdust, zeolites, metal oxides, agriculture waste, and polymeric materials have been experimented with for adsorption of textile dyes from the effluent.

Activated carbon is commonly preferred due to its attractive features such as high surface area, porous structure, special surface reactivity, inertness, thermal stability and ability to be utilized over a range of pH. However, it has its limitations such as high cost, difficulty in removal of the exhausted carbon and inefficient performance of regenerated activated carbon (Zhuang et al., 2009).

Silica nanoparticles are another appealing option for the adsorption process due to their characteristics such as high surface area, ease of preparation, low-cost precursors, high compatibility for various surface modifications and acute toxicity. Moreover, silica nanoparticles can be obtained from rice husk which is a cheap precursor compared to other precursors to synthesize silica nanoparticles. Studies say that interaction with metals can help enhance the adsorption process in the removal of dye pollutants. Cu is a low-cost option that can be used to functionalize the surface of the silica nanoparticles (Makhlouf et al., 2008). Cu is well known for its ability to degrade organic pollutants such as dyes in a process known as the Fenton process (Fathima et al., 2008). Cu supported on mesoporous silica has shown excellent dye degradation performance (Sun et al., 2018). This research looks at synthesizing copper embedded surface-functionalized silica nanoparticles using rice husk as the precursor and the optimum condition for maximum performance of the nanomaterial.

2 METHODOLOGY

2.1 Materials

Sulfuric acid (98%, H_2SO_4), hydrochloric acid (37% HCl), sodium hydroxide, 2-propanol, 3-aminopropyl triethoxysilane (APTES), toluene, dichloromethane, and diethyl ether were purchased from Sigma-Aldrich (USA). Methylene Blue and copper (II) chloride dihydrate were purchased from Sisco Research Laboratories Pvt. Ltd. Maharastra (India). Rice husk was obtained from a paddy field in the Gampaha district.

2.2 Synthesis of silica nanoparticles

First, the rice husk was washed thoroughly. It was acid leached using 2M H_2SO_4 and 2M HCl and then calcined. Afterward, it was washed thoroughly and it was burnt in the muffle furnace. It was cooled down overnight and powdered nano-silica particles were obtained. Then 3M NaOH was added to the nano-silica particles. The solution was then heated and was stirred. Finally, it was filtered and the supernatant was obtained.

2.3 Integration of Copper onto silica nanoparticles

Initially, an APTES-Copper solution was prepared. APTES was added to a mixture of deionized water and propan-2-ol. Then Copper Chloride ($CuCl_2$) was added to deionized water. The $CuCl_2$ solution was added dropwise to the APTES solution while stirring. The amino group in APTES attaches to the Si-OH group of the nanomaterial thus acting as a linkage to functionalize Cu onto the nanomaterial. The supernatant was added dropwise to the APTES- Cu solution while stirring and a jelly-like solid residue was obtained. It was washed several times till neutral pH was obtained. The solid residue was allowed to dry. It was then crushed and ground into a fine powder. The fine powder was oven-dried and copper functionalized silica nanoparticles were obtained.

2.4 Performance of nanomaterial on anionic and cationic dyes

At first, the nanomaterial was tested to see which type of dye it adsorbs efficiently. Thus, Methylene Blue (MB), a cationic dye, and Methyl Orange (MO), an anionic dye, were chosen for the adsorption process. At first, 50 ml of 10 ppm of each dye solution were prepared. Then the nanomaterial was added to each solution. They were shaken using an orbital shaker. After diluting with deionized water, the absorbance values of each of the dye solutions were recorded every 5 minutes for 60 minutes.

2.5 Determination of optimum conditions

50 mg of the nanomaterial was added to a solution of 25 ml of 0.5 ppm MB. After shaking, it was diluted and the absorbance values were recorded. The steps were repeated in batch wise for concentrations, C (ppm) = 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5. A calibration graph was plot and the molar absorbance coefficient was determined.

50 mg of nanomaterial was added to 50 ml of 10 ppm MB solution. The absorbance values were recorded by altering the pH batch wise by 2 for the range 2 to 12. The absorption uptake, q_t for a given pH was plotted against the time and the absorption uptake at equilibrium, q_e was determined.

50 ml of 10 ppm MB solution was transferred to a beaker, and its pH was altered to pH 4. The absorbance values were recorded by altering the mass of adsorbent dosage batch wise by 20 mg for the range 20 to 100. The q_t for a given mass was plotted against the time and the q_e was determined.

50 ml of 5 ppm MB solution was transferred to a beaker and its pH was altered to pH 4 and 20 mg of nanomaterial was added to the solution. The absorbance values were recorded every 5 minutes for 60 minutes. The steps were repeated for concentrations 10ppm and 15ppm batch wise. The q_t was plotted against the time and the q_e was determined.

2.6 Characterization of nanocomposite

The crystal structures present were determined via X-Ray Diffraction (XRD) using a Rigaku Ultima IV X-Ray Diffractometer (Cu Kα radiation, λ = 1.54060 Å) at the University of Sri Jayewardenepura. Chemical functional groups present in the sample were determined using ABB MB 3000 FT-IR spectrophotometer available at the Institute of Chemistry Ceylon.

3 RESULTS AND DISCUSSION

3.1 Characterization of nanomaterial

An FTIR was performed to determine the chemical functional groups and bonding present in the synthesized nanomaterial. Figure 1 illustrates the FTIR spectrum obtained for the sample. The values 800 cm^{-1} and 1042 cm^{-1} correspond to bending vibrations of Si - O - Si, Si - O symmetrical stretching and Si - O - Si asymmetrical stretching respectively (Biricik & Sarier, 2014). The presence of Cu-O stretching (600 cm^{-1}), Amino bending / in-plane bending of —O-H from residual H_2O (1645 cm^{-1}) and C—H stretching (2362 cm^{-1})) was also confirmed from the respective peaks from the spectrum (Singh et al., 2011).

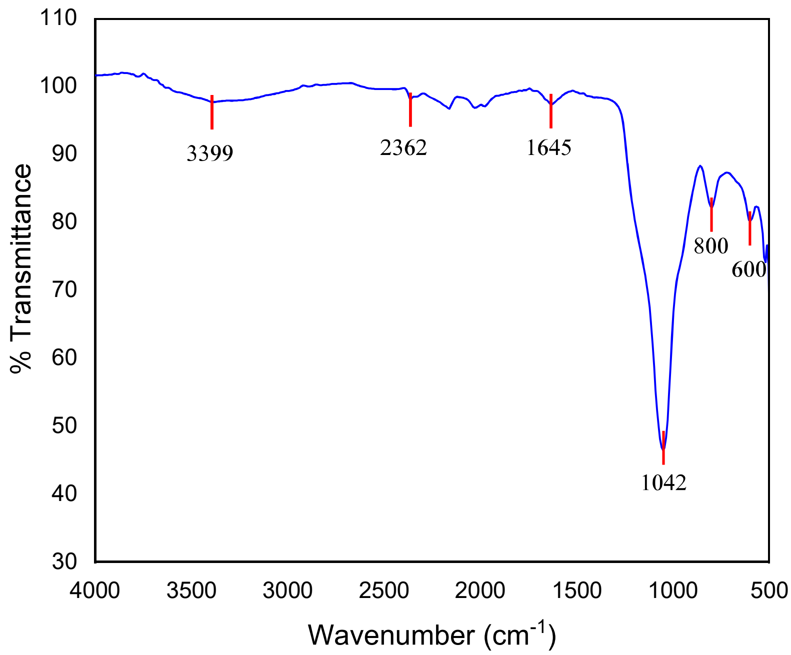

Figure 1. FTIR spectrum of Cu functionalized silica nanomaterial sample

Figure 2 shows the X-Ray Diffraction (XRD) pattern for the synthesized nanomaterial in the range of $2\theta = 5 - 80^{o}$ at a scan rate of 2. Distinct peaks were observed at $2\theta = 22.66^{o}$ and 35.57^{o} where they confirm the presence of Silicon Dioxide (SiO_2) and Copper Oxide (Cu_4O_3) respectively.

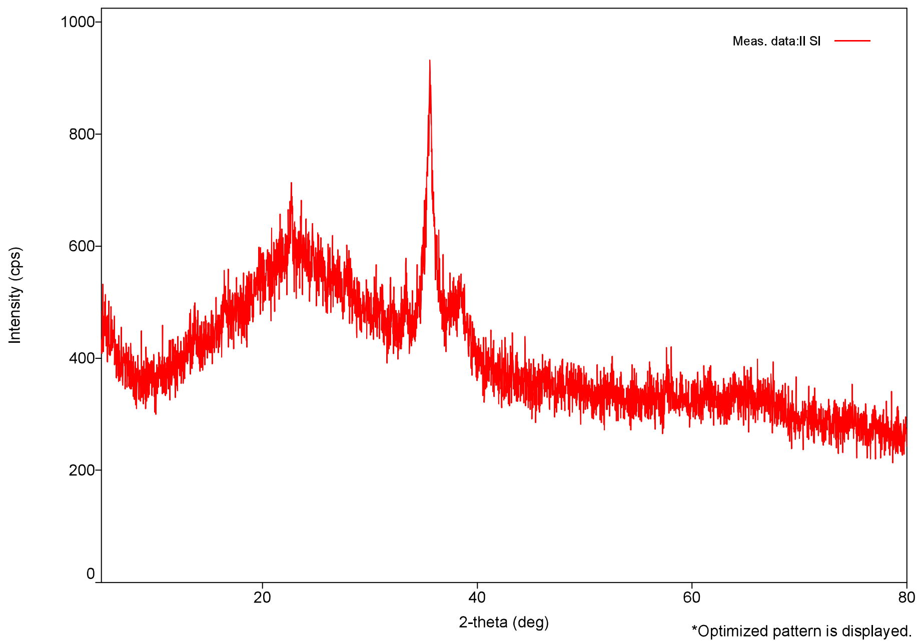

Figure 2. XRD pattern of Cu functionalized silica nanomaterial sample

3.2 Adsorption studies

At first, the nanomaterial was evaluated to see which type of dye it adsorbs efficiently. The nanomaterial was added to separate solutions containing MB and MO. The amount of dye removed from each solution was recorded and calculated to find the performance of the nanomaterial in both solutions. The performance of the nanomaterial on the type of dye was determined using the percentage removal method.

The percentage of dye removed was calculated using Equation (1):

$$\text{Percentage removal}(\%) = \frac{(A_0 - A_{60}) x\ 100}{A_0} \quad (1)$$

Where:

A_0 – initial absorbance

A_{60} – absorbance after 60 minutes

The amount of MB and MO removed was 62.15% and 2.20% respectively. Thus the nanomaterial was very good at adsorbing cationic dyes such as MB therefore the performance of the nanomaterial was evaluated using MB solution in the subsequent processes.

To evaluate the performance of the nanomaterial, the exact variations in concentration had to be recorded. The molar absorbent co-efficient of a given material is required to find the varying concentrations. Thus the molar absorbent co-efficient was determined using the help of a calibration plot shown in Figure 3, based on Beer-Lambert's Law. Beer-Lambert's law states there is a direct relationship between the concentration and absorbance of a given solution. Thus, the concentration of a solution can be determined if the absorbance can be measured. A procedure was conducted with varying concentrations of MB solutions (0.5 – 3.5 ppm) and the corresponding absorbance values were recorded.

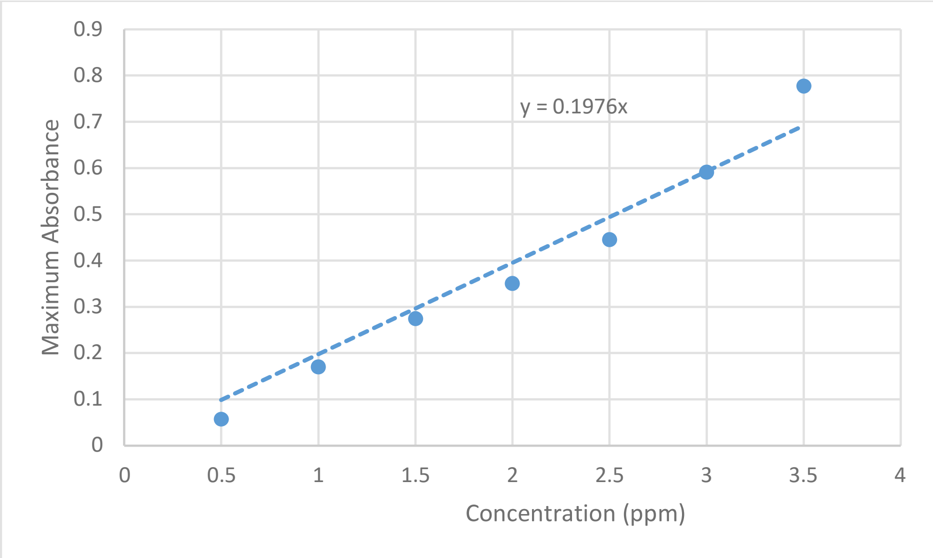

Figure 3. Calibration Plot of Methylene Blue solution

The molar absorption coefficient was determined as 0.1976 M^{-1} cm^{-1} from the gradient of the graph (Optical length was a constant value of 1 cm). The optimized conditions such as desirable pH, the mass of adsorbent were determined for the synthesized nanomaterial. The procedure was followed as mentioned in 2.5.

When taking absorbance reading, the MB solution was diluted with deionized water in a ratio of 1: 2. This was accounted for while calculating the concentration.
Thus, the concentration of the solution was calculated using Equation (2).

$$\text{Concentration, C} = \frac{3 \text{ x Max. Absorbance}}{\text{Molar Absorption co-efficient}} \qquad (2)$$

The concentration values were used to calculate adsorption uptake, q_t (mg g^{-1}), using Equation (3).

$$q_t = \frac{(C_0 - C_t)V}{m} \qquad (3)$$

Where:

C_0 – initial concentration (ppm)

C_t – concentration at a given time, t (ppm)

V – the volume of adsorbate (MB) (dm^3)

m – the mass of adsorbent (mg)

The adsorption uptake at equilibrium, q_e (mg g^{-1}) tells us about the maximum adsorption uptake when the nanomaterial reaches saturation i.e. the material has reached its maximum capacity of adsorption. Higher the q_e value, the greater the adsorption of the substance. Figure 4 shows the effect of pH varying from 2- 12, on the adsorption uptake of MB solution by the nanomaterial. As the graph suggests, an increase in pH has increased the adsorption uptake until pH 4. The graph shows that the highest q_e has been recorded at pH 4 which is 7.84 mg g^{-1}. Further increase in pH did not influence the adsorption uptake thus resulting in lower q_e values (Karim et al., 2012).

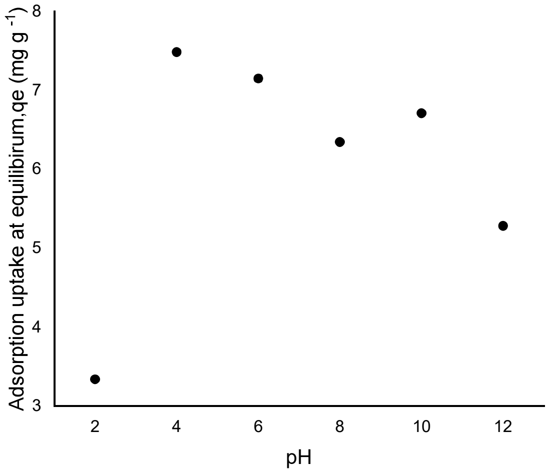

Figure 4. Effect of pH on adsorption uptake at equilibrium q_e

Figure 5 shows the effect of the mass of the adsorbent on the adsorption uptake at equilibrium. The effect was studied in the mass range of 20 - 100 mg and MB concentration of 10 ppm. The mass of the adsorbent determines the amount of surface area available for the adsorption process. As the graph depicts, the increase in the mass of the adsorbent has decreased the adsorption uptake. The highest adsorption uptake at equilibrium was 9.982 mg g^{-1} and was recorded at the lowest amount of adsorbent which is 20 mg. This is because a small amount of adsorbent means, a larger overall surface area is exposed to the MB solution for adsorption to take place, compared to the other masses. Thus, more MB cations would have been adsorbed resulting in the highest q_e value at 20 mg (Karim et al., 2012).

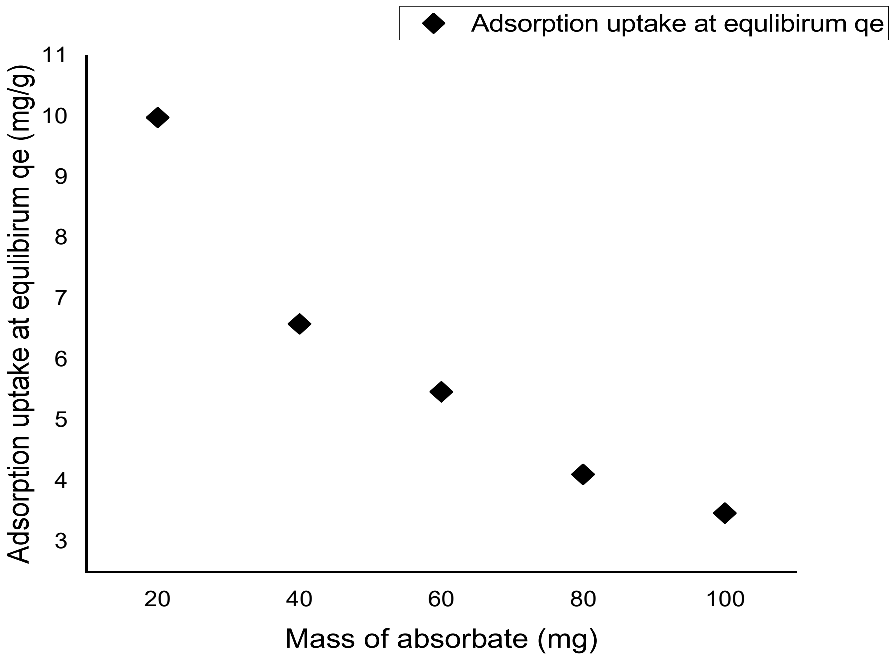

Figure 5. Effect of the mass of adsorbent on adsorption uptake at equilibrium, q_e

Once the optimum pH and the mass of the adsorbent were determined, the performance of the nanomaterial was tested. MB solutions of varying concentrations from 5 – 15 ppm have experimented with 20 mg of the nanomaterial at pH 4.

Figure 6 shows the effect of initial concentration on the performance of the nanomaterial. The adsorption uptake increases quickly until 20 minutes. From 20 minutes onwards, in both 5 and 10 ppm, the qt values gradually decreased to reach equilibrium. However, in 15 ppm, the adsorption activity did not seem to reach equilibrium significantly. It is visible that when the initial concentration of MB is increased, the adsorption uptake has also increased. This is because of the larger concentration gradient created by the higher concentration that serves as a driving force for the adsorption process. 15 ppm seems to show the highest adsorption with a qe value of 11.01 mg g^{-1}. The short time taken to reach close to equilibrium indicates the affinity of the dye molecules towards the nanomaterial resulting in effective adsorption (Karim et al., 2012).

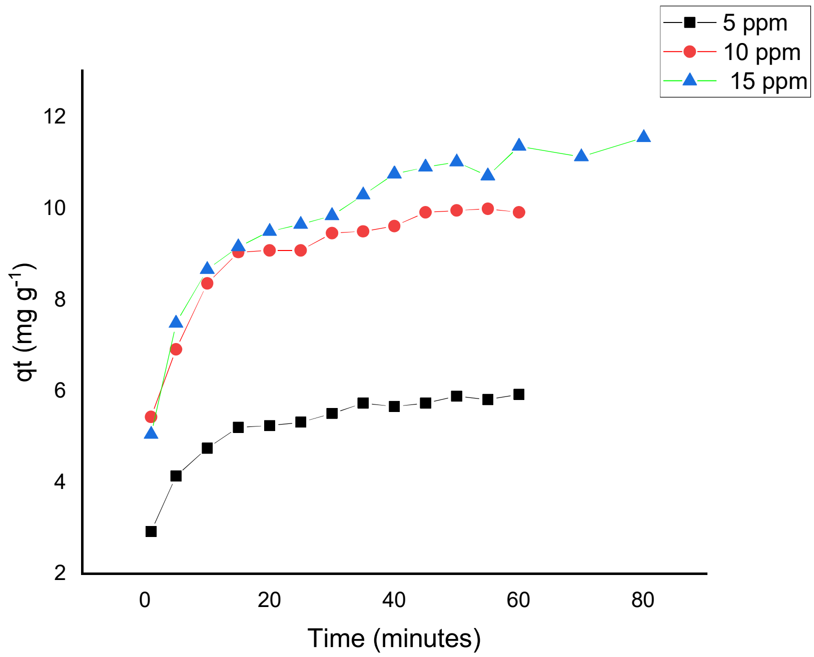

Figure 6. Performance of nanomaterial on different initial MB concentrations

3.3 Kinetics Model

Adsorption kinetics is an important concept to study the adsorption uptake rate and understand the nature of the adsorption process. To evaluate the performance of the nanomaterial on the adsorption process, the experimental data were fit into 2 conventional kinetic models and were interpreted.

These kinetic models are;

Lagergren Pseudo First Order: $$\ln(q_e - q_t) = lnq_e - k_1 t \quad (4)$$

Ho Pseudo Second Order: $$\frac{t}{q_t} = \frac{1}{k_2 {q_e}^2} + \frac{t}{q_e} \quad (5)$$

Where;

q_e – adsorption uptake at equilibrium (mg g^{-1})

q_t – adsorption uptake at time,t (mg g^{-1})

k_1 – rate constant for pseudo first order (min $^{-1}$)

k_2 – rate constant for pseudo second order (g mg^{-1} min^{-1})

t – Time (min)

Since the equations are linear expressions, k_1 can be determined from the gradient of a pseudo-first-order graph and k_2 can be calculated using the gradient and intercept of a pseudo-second-order graph (Dashamiri et al., 2017). The validity of a certain model towards the experimental study is determined by the correlation coefficient and how close the theoretical and experimental adsorption uptake match. This is indicated by the R^2 value. The adsorption experimented were fitted into both pseudo-first-order and pseudo-second-order models. Table 1 summarizes the kinetic information obtained for both Pseudo first and second order.

Table 1. Co-efficient of pseudo-first- and second-order adsorption kinetic models

Initial Concentration (ppm)	Pseudo First Order			Pseudo Second Order		
	qe (mg g^{-1})	k_1 (min^{-1})	R^2	qe (mg g-1)	k_2(g mg^{-1} min^{-1})	R^2
5	3.0446	0.0721	0.9203	6.0919	0.0640	0.9986
10	5.6277	0.0877	0.8701	10.2774	0.0432	0.9988
15	7.3472	0.0794	0.9166	11.8259	0.0209	0.9965

The graphs obtained for pseudo-first order and pseudo-second-order are illustrated in Figure 7.

a) b)

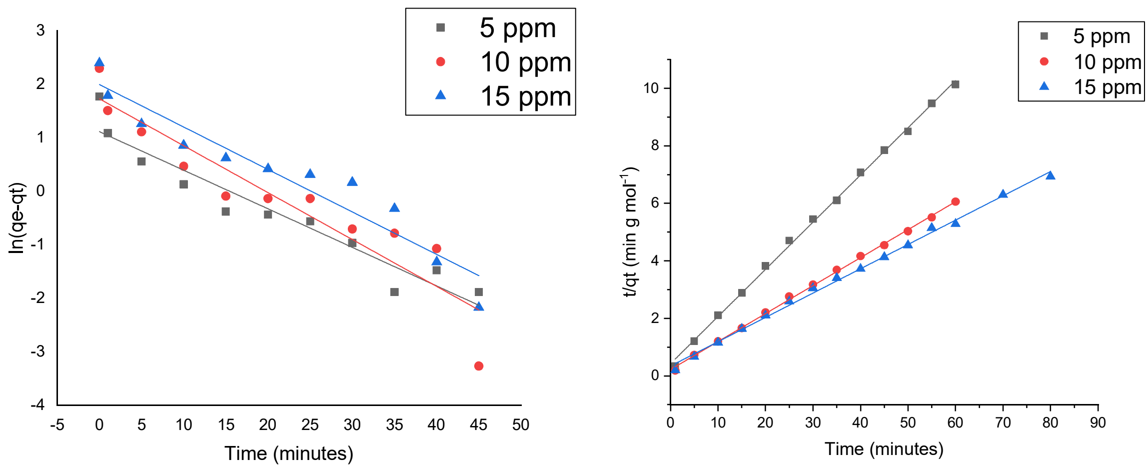

Figure 7. a) Pseudo-first order and b) pseudo-second-order kinetics model for MB adsorption onto nanomaterial

It is clear from the data in Table 2 and Figure 7 that pseudo-second-order has R^2 values much closer to 1 than pseudo-first-order. This indicates that the experimental data closely adhered to pseudo-second-order kinetics (Hu et al., 2014) (Dahri et al., 2015).

4 CONCLUSION

This research aimed at synthesizing silica nanoparticles from rice husk which is a relatively cheap precursor in the Sri Lankan context. The silica was surface-functionalized using Cu, another cheap element, to enhance its adsorption performance to remove organic dyes from textile effluent. The dye used in this research was methylene blue. The XRD results confirmed the presence of major compounds such as silicon dioxide and copper oxide as predicted. The FTIR confirmed the presence of expected chemical bonds such as Si–O stretching, C–H stretching, Cu–O stretching and O–H bending. The optimum conditions for the best performance of the nanomaterial have been experimented with. The optimum pH at which the nanomaterial performed best was at pH 4. The optimum mass of the adsorbent that gave maximum adsorption performance was 20 mg. Once the optimum parameters were determined, the nanomaterial was exposed to varying methylene blue concentrations of 5ppm, 10ppm and 15ppm. Kinetic studies revealed that the experimented data was in better correlation with pseudo-second-order kinetics.

5 ACKNOWLEDGEMENT

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Aeroacoustic Noise Produced from Novel Wind Turbine Rotor Design for Small-scale Applications in Sri Lanka

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ABSTRACT

Growing concerns regarding non-renewable energy sources have driven academic and industrial scholars as well as global superpowers to seek sustainable, greener power generation alternatives. One such prominent renewable substitute is wind power which was initially utilized in harnessing electricity towards the late nineteenth century though archaeological evidence has proved that wind power had been employed for various purposes since predynastic Egypt. Extensive research and development has enabled the efficient operation of multi megawatt wind farms at present though inherent drawbacks still persist, of which aerodynamic noise, also referred to as aeroacoustic noise, is of major concern. This paper details the simulative investigation of the aeroacoustic sound levels produced by an optimized novel wind turbine design intended for the use in small scale applications with medium wind speed conditions in Sri Lanka, using ANSYS Fluent. A transient analysis using the Shear Stress Transport turbulence model was used to obtain the converged pressure fluctuations which subsequently revealed the sound pressure levels via Fast Fourier Transforms at six predetermined locations of interest. The results revealed the presence of acoustic vibrations within the Infrasonic and Low Frequency Noise range with sound pressure levels exceeding one hundred decibels, particularly up to a frequency of twenty five Hertz. Prolonged exposure to elevated levels of low frequency noise has been identified to cause severe discomfort to humans though further conclusive research is required. Finer mesh controls which incorporate minute boundary layer variations during motion and precisely encapsulate the turbine geometry could further improve the accuracy of the results, however this would require adequate computational capacity. The results of this research primarily serve as a basis for identifying possible improvements for the novel rotor design in addition to providing a comparative study for future research, both simulative and empirical, on the aerodynamic noise emissions associated with wind turbines.

KEYWORDS: *Aerodynamic Noise, Wind Turbine, Infrasonic and Low Frequency Noise, ANSYS Simulation*

1 INTRODUCTION

The concept of generating electricity from wind power was successfully implemented only during the 19th century, though wind power had been utilized by mankind from as far back as the predynastic era of Egypt (U.S. Energy Information Administration, 2021). Grain milling - which coined the term windmill, water pumping - as seen mainly in The Netherlands and America among others and sailing were the three most prominent applications of wind power prior to the 19th century, after which however, the term wind turbine quickly replaced and far exceeded the use of the term windmill. As with all mechanical applications, the use of wind power also has its inherent limitations and drawbacks. one of the most prominent of which is the noise concerns. Wind turbine noise can be attributed to two main contributors: Mechanical and Aerodynamic noise.

Mechanical noise commonly refers to the undesired acoustic vibrations generated through the interactions of numerous mechanical components, as the name suggests, such like gears, shafts and other fixtures present within the nacelle of the turbine. The noise produced thus has been further identified to be amplified within the tower (Stauber, Marmo, & Black, 2017). However, through

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extensive research and development over the years, mechanical noise of wind turbines has been almost completely mitigated via damping mechanisms and active noise control methods (Lee, et al., 2021). Aerodynamic noise though, is still persistent and the intrinsic complexities of the sources of aerodynamic noise create difficulties in modeling and assessing it. Ongoing research, particularly on Computer Aided Aeroacoustics (CAA), aim to provide a better understanding of the occurrence and propagation of aerodynamic noise which in turn will allow novel mitigation techniques and more efficient control measures to be developed (Jianu, Rosen, & Naterer, 2012). In addition to devising noise controlling mechanisms there is also heightened focus on improving performance characteristics and developing application specific wind turbine models.

One such novel development is a simplified optimized rotor designed for small-scale applications in Sri Lanka which was the brainchild of Sugathapala, et al. (2020). The current study expands on the said study by simulative analysis of the aeroacoustic noise levels produced by the novel three bladed rotor design, intended for an upwind application in medium wind speed conditions. The blades of the said rotor design used a National Advisory Committee for Aeronautics (NACA) 4412 airfoil and consisted of a constant chord length and pitch angle with a design tip speed ratio of five. Proportionate dimensions have been used for the hub within the context of this study and Table 1 summarizes the details and dimensions while Figure 1 shows a depiction of the rotor used for this study.

Table 1: Details and Dimensions of Optimized Novel Rotor Design Used

PARAMETER	VALUE
Airfoil used	NACA 4412
Chord length	0.13 m (constant)
Pitch Angle	7^{o} (constant)
Radius	1.326 m
Number of Blades	3
Tip Speed Ratio	5
Hub Diameter	0.432 m
Hub Length	0.360 m
Wind Speed (average medium condition)	5 m/s
Wind Turbine Orientation	Upwind

This study therefore, mainly aims to assess the aerodynamic noise based Sound Pressure Levels (SPLs) produced by the novel wind turbine rotor design of Sugathapala, et al. (2020) and to identify whether significant levels of infrasonic and low frequency noise levels are produced. Furthermore the results of this study could serve as a basis for refined expansion on the topic of aerodynamic noise generated from small-scale application type wind turbines. In addition, this study contributes to improving the extant deficiency of scientific ventures particularly in Sri Lanka, that are based on wind turbines and associated aerodynamic noise.

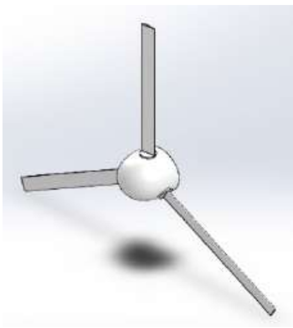

Figure 1: Depiction of novel rotor design used in simulating aerodynamic noise levels

2 BACKGROUND

The first known wind turbine was invented by Professor James Blyth, a Scottish academic who used a large vertical axis wind turbine design that had four hemispherical cups mounted on extended metal arms (Price 2005). This wind turbine relied on the wind drag to operate, similar to the drag based Panemone windmills of ancient Persia (Shepherd 1990). The American entrepreneur Charles Francis Brush is credited with the invention of the first lift based horizontal axis wind turbine with working principles much like that of modern wind turbines. He built an enormous wooden wind turbine with a rotor diameter of more than fifty feet, that successfully powered his home for an estimated twenty years (Righter, 1996; Allerhand, 2021).

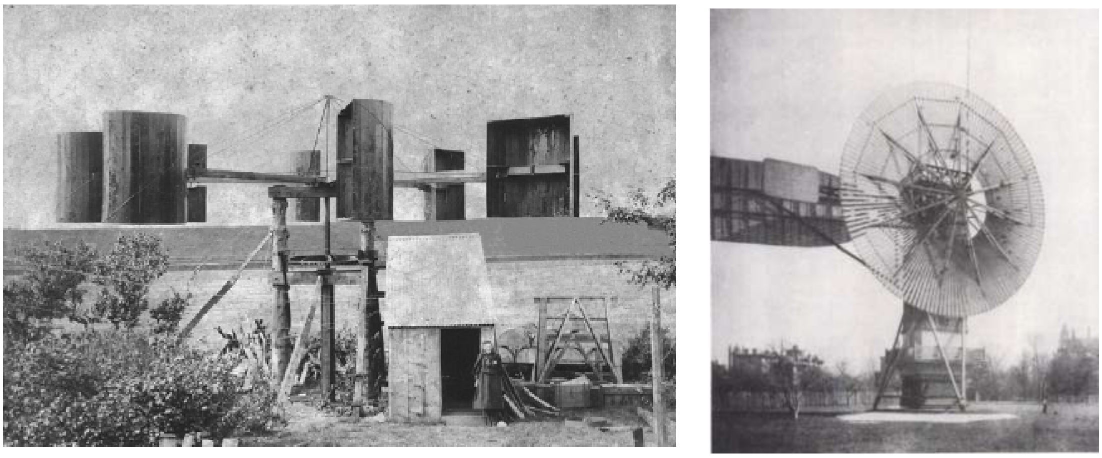

Figure 2: Professor Blyth's wind turbine (*left*) (Price, 2005) and Brush's wind turbine (*right*) (Righter, 1996). Note the human figures standing in the foreground of each picture for a size comparison.

Though these initial wind turbines were successful in generating electricity, the respective efficiencies were low with the Brush turbine identified to have generated only a meagre 12 kilowatts of energy (Tong, 2010). Extensive research, which also included some of the first ever wind tunnel tests, conducted by the Danish Poul La Cour led to a revolutionary refinement of wind turbine designs. He suggested that a large number of blades were unnecessary for optimal performance which subsequently led to the classic three bladed rotor designs for horizontal axis wind turbines, which is still the accepted norm. La Cour further invented the *kratostat*, a device which regulated the erratic changes in the rotational speed of the turbine drive shaft so that a steady output can be obtained (Pedersen, 2010; Powell, 1910), which was fundamental to the success of the initial wind turbine designs and published his findings in the form of a book named "*Forsøgsmøllen*” which is the Danish translation of "The Test Turbine” in 1900.

The initiation by La Cour followed by the period of extensive research and development during and after the Second World War by notable scientists like Albert Betz – who theorized that the maximum efficiency of a lift based wind turbine cannot exceed 59.3%, popularly known as Betz’s Limit (Hau, 2006) – in addition to growing concerns over usage of fossil fuels and environmental harm, established the sustainable concept of wind powered electricity generation in most parts of the world. Within a relatively short time span wind turbines had evolved from meagre kilowatt generating dwarfs to megawatt generating giants that can be erected both onshore and offshore. At present, a significant proportion of the electricity demand of many countries like Denmark is supplied by windfarms capable of generating multi-megawatts of power (Lee and Zhao 2021), though aerodynamic noise impacts still persist.

Due to the inherent complexities of aerodynamic noise sources, purely analytical models prove difficult, if not impossible to build. Therefore, semi-empirical, semi-analytical models and derived results are used when modelling aerodynamic noise, particularly from wind turbines (Brooks, et al. 1989).

2.1 Aerodynamic Noise Sources

The sources of aerodynamic noise with reference to a wind turbine can be mainly categorized into two: 1) self-noise that arises due to the geometry and characteristics of the airfoil utilized and 2) turbulence inflow which is caused due to atmospheric turbulence present in the oncoming wind (Sørensen 2012). There are several sources of self-noise of a wind turbine namely: 1) turbulent boundary layer trailing edge noise, 2) separation-stall noise, 3) laminar boundary layer vortex shedding noise, 4) tip vortex formation noise and 5) trailing edge bluntness vortex shedding noise (Brooks, Pope, & Marcolini, 1989).

2.2 Infrasonic and Low Frequency Noise (ILFN)

Wind turbines are notorious producers of low frequency acoustic vibrations, however there is a deficiency in the number of academic ventures that aim to assess the exact levels of low frequency noise produced thus (Hansen & Hansen, 2020). The frequency range sensitive to humans with unimpaired hearing averages between 20 to 20,000 Hertz and is known as the auditory or sonic region. Frequencies exceeding 20,000 Hertz are categorized as the Ultrasonic region whereas the region below 20 Hertz is defined as the infrasonic region (Bies, Hansen, & Howard, 2018). There is no absolute upper boundary to the range of low frequency vibrations, however frequencies below 100 Hertz are usually considered as low frequency though some research have used frequencies below 200 Hertz as well. With respect to the context of the current study, frequencies below 100 Hertz have been considered as low frequency.

Several researches have been conducted on the effects of low frequency and infrasonic vibrations on humans and the respective findings have revealed that prolonged exposure to ILFN resulted in severe to acute discomfort in humans and that physical manifestations could also occur in the form of nausea, sleep disorders and Vibroacoustic Disease (VAD) according to the individual sensitivities of the effected (Leventhall 2009). However, the results are yet to be confirmed as entirely conclusive.

2.3 k-omega Shear Stress Transport Viscous Model

The k-omega SST turbulence model belongs to the class of hybrid Reynolds Averaged Navier Stokes (RANS) turbulence models that govern fluid flow with all the turbulent effects included (SIMSCALE 2021), (AutoDesk 2019). This model was developed by Florian Menter in order to minimize the errors present in the k-epsilon and k-omega models (Menter 1994). It is referred to as a hybrid model since it combines two other turbulence models namely; the Wilcox k-omega and k-epsilon models. This makes the k-omega SST model better suited for modeling flows around airfoils (ANSYS, Inc. 2021).

In addition to the conservation equations, the k-omega SST model contains two partial differential equations that govern the transport of two variables namely; the turbulent kinetic energy (k) and the specific turbulent dissipation rate (omega) (SIMSCALE 2021). Further modifications have been done which make it a reliable model to predict the behavior of viscous flows with low Reynolds numbers in particular, although inherent limitations exist (Versteeg and Malalasekera 2007).

2.4 Ffowcs-Williams and Hawkings (FW-H) Acoustic Model

As the name of the model indicates, it was developed by John "Shôn" Eirwyn Ffowcs Williams, an Emeritus Professor at the University of Cambridge and one of his fellow students David Hawkings (Ffowcs Williams and Hawkings 1969). This acoustic model is an inhomogeneous wave equation derived by a combination of the continuity and Navier-Stokes equations and can be used to accurately predict mid-field to far-field acoustics (ANSYS, Inc. 2021).

3 PROCEDURE

3.1 Simulation

The aeroacoustic noise levels produced by the novel turbine design were simulated using ANSYS Fluent software. A transient analysis with 1500 time steps and time step size of 0.01 was conducted using the k-omega SST viscous model to simulate the flow characteristics while the acoustic pressure fluctuations at the six receiver locations of interest were obtained using the FW-H model. The pressure fluctuations thus obtained were used to derive the Sound Pressure Levels (SPLs) at the respective receiver locations using Fast Fourier Transforms.

The geometries of the rotating domain which include the turbine, modeled to actual size, were created using Solidworks while the stationary domain which was used to model the envelope of air flow across the turbine was created using ANSYS SpaceClaim so that the contact surfaces between the two domains were generated automatically. A velocity inlet of 5 m/s and a pressure outlet of zero gauge pressure were assigned to the stationary domain as shown in Figure 3 while the turbine and all other surfaces excluding the contact surfaces - which were assigned as interfaces - were considered as stationary walls.

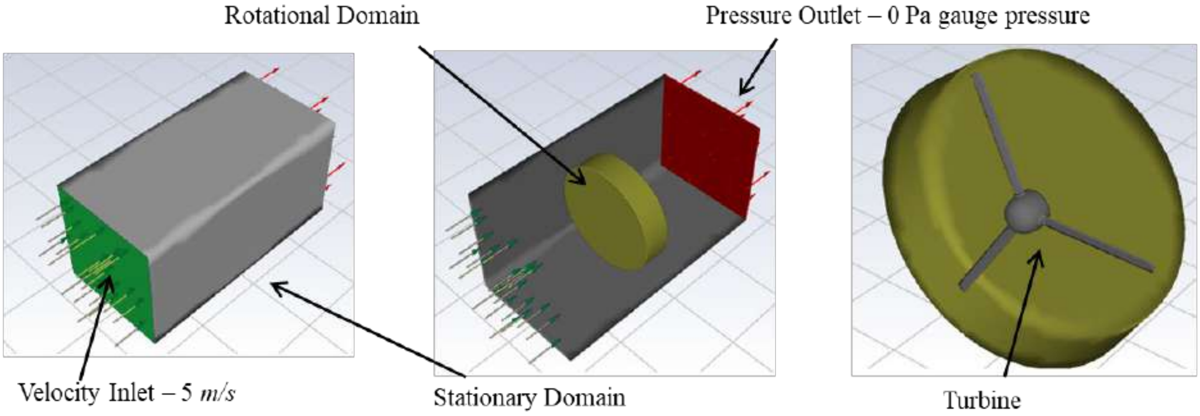

Figure 3: Rotational and Stationary Domain and Boundary Conditions Used in the Simulation

The overall mesh of the actual sized rotor of the wind turbine contained 184,347 nodes and a total of 949,865 tetrahedral elements, all of which followed a linear order. The wind turbine geometry was meshed with a general sizing of 30mm while the maximum element size was set to 500mm without enabling the adaptive sizing function. All mesh components less than 0.15mm in size were set to be defeatured. Patch conforming tetrahedron elements were used for the rotational geometry of the model. An inflation setting containing four layers at a smooth transition and a growth rate of 1.2 was applied to the wind turbine geometry only.

Nine faces of the peripheral geometry – bounding cuboid and cylindrical periphery – were meshed using an element size of 360mm and a defeatured limit of 0.24mm. This was done to minimize the number of elements and reduce the overall complexity of the mesh. A default growth rate of 1.2 was used with the Influence Volume function set to No. The peripheral mesh was further customized to capture the proximity of both faces and edges with a minimum size setting of 0.6mm and the default value of 3 cells across a gap. However, the capture curvature function was set to No in order to stay within the boundaries of the available computational capacity.

3.2 Receiver Locations

The Sound Pressure Levels from six receiver positions were obtained in order to identify the aeroacoustic noise produced from this wind turbine model. Two of the receiver locations were positioned 0.5m in front and to the rear of the rotor while the other four were positioned on the vertical plane passing through the center of the airfoil chord. These four receivers were located on the top, bottom, left and right extremities of an imaginary circle which was concentric to the rotor, having radius equal to half the blade length.

4 RESULTS AND DISCUSSION

Convergence of the simulation was established by using residual monitoring as well as from a user defined parameter which monitored the moment generated by the turbine. The simulation results revealed that aeroacoustic noise below 50 Hertz was present with tonal peaks corresponding to the harmonics of the blade pass frequency of the wind turbine. These peaks indicated high SPLs with several exceeding 100 decibels. This is indicative of high levels of acoustic vibrations that fall into the category of infrasonic and low frequency noise. The four receiver locations on the rotating plane of the rotor, displayed frequency spectra with notable similarities observed amongst the four receivers but indicated clear differences with the spectra corresponding to the other two locations as seen in Figure 4. A marked reduction in the SPLs of the receivers before and beyond the rotor can be identified with a greater reduction seen in the SPL of the receiver location in front of the rotor. Even though the SPL trends downwards however, tonal effects might persist as seen by the spike in amplitudes corresponding to the blade pass frequency harmonics.

In addition to the continuous frequency spectra, sound pressure levels according to octave bands of the receiver location on the right of the rotating plane of the rotor as shown in Figure 5, further indicate that the novel turbine design produced significantly high levels of infrasonic and low frequency acoustic vibrations due to aerodynamic interactions. Only the receiver on the right has been considered since it corresponds to the highest peaks in the SPL as seen in Figure 4. It is evident from the octave band frequency spectrum that a larger SPL is present towards the lower end of the spectrum. This can be interpreted as an indication of the presence of high levels of infrasonic and low frequency noise which are produced by the blade interactions with the wind which is at a steady speed of 5 m/s.

Since the receiver locations that are 0.5m away from the rotor indicate reductions in the respective SPLs as the distance from the rotor to the receiver increases, the ambient noise present might mask the noise produced by the rotor. However due to the presence of tonality, the subsequent characteristic effects could still persist at varied distances from the rotor. This could cause disturbance, varying from mild to severe in nature, to the residents in the vicinity who are subjected to prolonged continuous exposure in addition to distressing the fauna present.

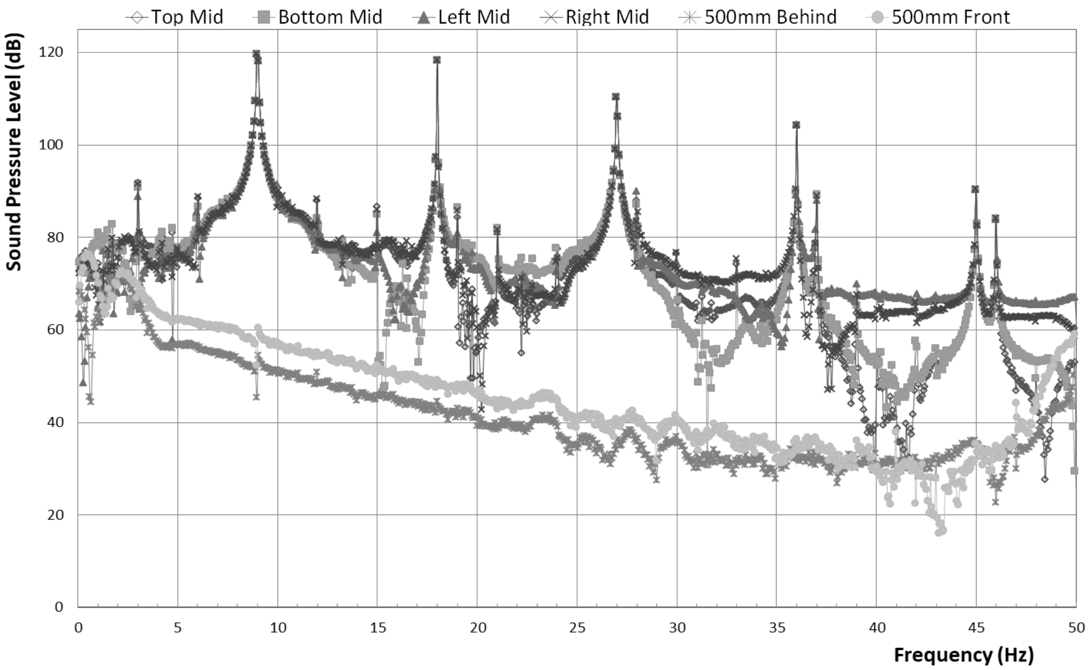

Figure 4: Spectra of Sound Pressure Levels of the Six Receiver Locations of the

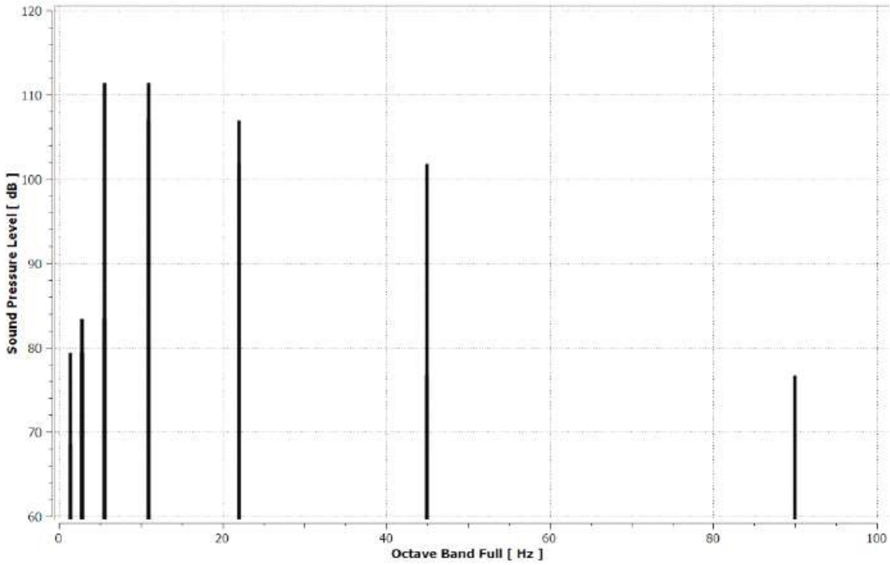

Figure 5: Octave Band Sound Pressure Levels of the receiver location on the right of the rotating plane

In light of this it can be surmised that the novel rotor design might not be ideally suited for use in densely populated areas due to the high levels of tonal ILFN produced. Though the SPL tends to decrease within a short radius from the rotor, tonal effects present, could still cause discomforts to individuals in the vicinity. Particularly sensitive individuals might even display severely adverse effects in the form of nausea or VAD.

5 CONCLUSIONS

The aeroacoustic noise emissions of a novel horizontal axis wind turbine design for small scale applications in Sri Lanka were investigated for the medium wind speed condition of 5 m/s using a simulation in ANSYS Fluent. Aeroacoustic noise up to a frequency of 50 Hertz was identified to be produced along with tonal peaks exceeding sound pressure levels of 100 decibels corresponding to harmonics of the blade pass frequency. Therefore, it is advisable to refrain from operating the novel wind turbine design in densely populated areas due to potential discomforts which may arise upon prolonged exposure to the infrasonic and low frequency noise emitted from this wind turbine design. Further research using mesh refinements and precise parameters can be used to derive a more realistic simulation though this would require machines with considerable computational capacity. Additionally performance enhancements as well as noise reduction and mitigation methods for the novel rotor design utilized within this study could be designed and developed and the subsequent effectiveness could be gauged by comparison with the current results.

6 ACKNOWLEDGEMENT

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Design and Fabrication of a Novel Hybrid Solar Dryer

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ABSTRACT

A hybrid solar dryer was designed and tested for commercial dissemination of active and passive drying methods over traditional sun drying methods. The proposed dryer employs novel features such as user controllability of the drying parameters and includes sensors and controllers for active monitoring of drying parameters. The functionality of the dryer is broadened by using logic control whereby intermittent drying patterns are introduced to the system for more efficient operation. This paper documents the design calculations and fabrication process of the dryer as well as the results of drying obtained under a controlled environment.

10 experiments have been carried out to assess the limits and potential improvements to the system which yielded satisfactory conditions with a temperature fluctuation of $\pm 1℃$ and change in %RH of $\pm 2\%$ at any given temperature within the specified limits. The developed system has been used for drying apples which yielded dried products from an initial weight of 346 grams to a final weight of 55 grams in 5 hours in pure convection and the same initial weight was reduced to 52 grams in 3 hours when operating in solar hybrid mode. The average energy consumption of the dryer was obtained at 300 Watts at uninterrupted solar insolation operation and 224 Watts during pure convective operation, portraying the efficient operation of the system to be eligible to be powered by a solar-powered energy storage

KEYWORDS: *Solar-Hybrid Drying, Convective Drying, Design, Fabrication.*

1 INTRODUCTION

Drying is a method of preserving hygroscopic foods for prolonged periods by dehydration. The drying process is an energy-intensive process accounting for 15-20% of energy consumption in the food industry. And when commercial drying systems decline in efficiency, the mentioned usage percentage can reach as high as 30-33%. Due to the declining availability of non-renewable energies, there has been a major requirement to find alternative energies to drive this process. Solar energy is the most abundant energy source that is also the most easily obtainable source of energy to fulfill the energy requirement.

The main disadvantage however is the inconsistency of supply, mainly during nighttime. Due to this reason, traditional greenhouse dryers are not self-sustained for long operating periods. Hence the requirement arises to implement an alternative energy source for the dryer to be operable regardless of solar irregularities and time of day. This paper proposes a novel hybrid solar dryer that utilizes direct solar irradiation and electrical energy stored through a photovoltaic panel to be utilized in the process of drying and be robust to climatic changes.

Hybrid dryers that utilize two or more energy sources have existed since past times. Designs have originated from passive dryers which use the greenhouse effect to increase the temperature inside the drying chamber, and buoyant flow for evacuating humid air volumes outside the drying chamber. (Sharma et al., 1986) designed their natural convection dryer for rural areas which consisted of solar-powered drying, and buoyance-assisted flow (natural flow). They started by laying the mathematical foundation required for the parametric design of the dryer and fabrication. They have concluded their

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results stating that a span of 3 days was required to dry 10kg of green peas (Estimated energy requirement – 18.4MJ). The passive drying technique evolved to an active drying technique where forced draft is used to evacuate humid volumes outside of the system without depending on the buoyant flow. Authors who attempted to compare the three techniques have yielded exponentially improved results when using active drying. (Pochont et al., 2020) have carried out a comparative study in drying red chilli by methods of greenhouse drying (Active and Passive mode) and open sun drying. They have achieved a reduced time of drying by 50% in passive drying and 54.1% in active drying. They also reached a lower moisture content in active mode (18.67% wet basis) and passive mode (18.7%) compared to open sun drying method (24.24%). By view of this, it is observed that the process is capable of being hybrid powered especially being a country closer to the equator the annual GHI of Sri Lanka is evaluated at $2000kWh/m^2$.

When implementing an efficient system for drying it is important to understand the drying kinetics. Understanding the kinetics allows an individual to identify times at which the drying rate can be increased by increasing temperature, without causing damage to the products and times which the system can run at a low energy intensive mode while yielding the same results as continuous drying. Drying of hygroscopic material is divided into two main phases of operation based on the surface moisture content and the product properties at a cellular scale, such as diffusivity, thermal conductivity etc.

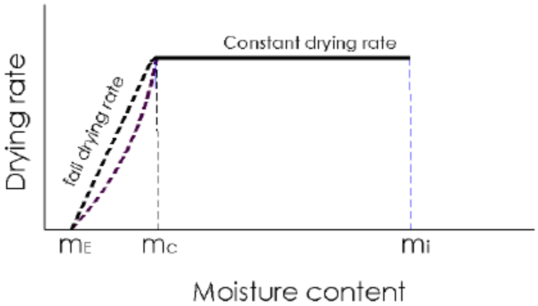

Figure 1 Phases of drying

The drying rate of a hygroscopic product usually adheres to this behavior which is confirmed by numerous studies relating to this area. Initially, the constant rate drying period where the product contains surface moisture which allows free evaporation. At this stage, the drying rate is governed by the properties of the inflow (Temperature, Humidity, etc.), where the temperature can be increased to achieve high drying rates while the products are stabilized at the wet-bulb temperature. Once this free moisture layer is depleted, further drying requires the product to transport internal moisture to the surface of the product which is governed by the thermal and physical characteristics (Moisture diffusivity and thermal conductivity) of the cellular structure. At this stage of drying, internal heating of the product is crucial to maintain moisture transportation from within the product. Simply increasing the drying temperature as previously, would result in case hardening of the products (Gulati and Datta 2015). As per studies investigated, solar irradiation is an excellent source for providing the required internal heating compared to convective heat transfer which can only heat the products to drying temperature. Hence, theoretically by using direct solar irradiation, the process should be faster compared to pure convective drying.

Most designs incorporate manual control of the flow and temperature but do not possess the feature to control humidity. As explained in the drying curves, it is beneficial to adjust the drying conditions at different stages of drying to obtain several major advantages. The process of actively adjusting the conditions is defined as 'intermittency'. Several authors have investigated the effect of intermittent drying on various products (Foods, Clay, Ceramic), where they have made a common conclusion that intermittent drying not only expedites the process but also majorly reduces the energy demand (Kowalski and Pawłowski 2011; Kumar, Karim, and Joardder 2014; da Silva et al. 2015).

This research aims to develop a solar hybrid dryer capable of continuous operation, robust to the changes in climatic conditions, incorporating renewable energy sources for driving the drying process. The novel design offers features such as temperature, airflow, and humidity control. The suggested design incorporates a microcontroller operating as the brains of the system. This allows active control of the parameters of drying, either to be set as a constant value or a variable value dictated by the algorithm. This yields advantages such as the autonomous operation of the dryer without human interaction, robustness to changing weather conditions, and intermittent patterns of drying to adjust the quality of the output product (da Silva et al. 2015).

2 DESIGN AND FABRICATION

2.1 Dryer design

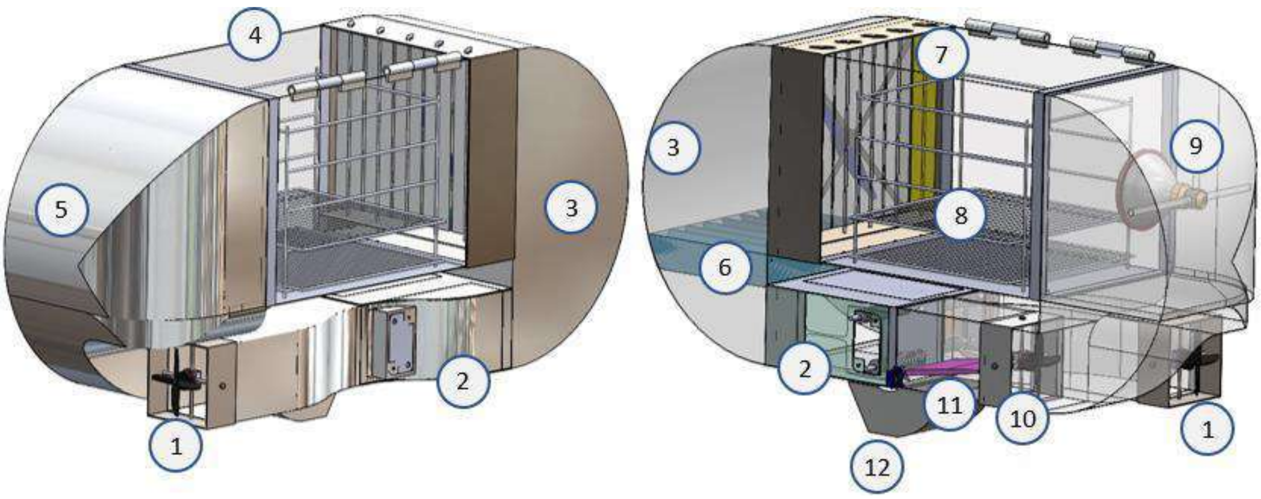

Figure 2 Dryer design (Visual representation - Left, Internal representation – Right)

Table 1. Description

Index	Description
1	Ambient air intake (tertiary propeller)
2	Heating port
3	Circulation duct
4	Drying chamber
5	Funnel duct
6	Mixer vent
7	Infrared screens and the primary propeller
8	Drying Shelves
9	Infrared source (Conceptual)
10	Secondary propeller
11	Recycling gate
12	Exhaust

The design is mainly focused on minimizing the thermal and aerodynamic losses of the system. The unusual shape of the system originates from the tangent curves of the ducts which provide the smooth translation of the flow vector by 180 degrees. The combination of two ducts provides the full 360 degrees of circulation of the drying air which allows to partially recycle the flow back into the system for preserving thermal energy. In addition to recirculation, external surfaces exposed to ambient conditions have also been insulated using thermal foil to further improve the thermal efficiency of the system.

Many solar dryer designs incorporate a flatbed drying surface (>1 m in width) for high solar absorption (Amer, Hossain, and Gottschalk 2010; Pochont et al. 2020a), but the new design is expected to operate at night time, hence to reduce the adverse heat loss to the ambient at nighttime, the drying chamber is designed to be narrow which allows sufficient insolation into the drying chamber (0.3 m). Compared to designs that incorporate induced draft (Laminar flow) in the drying chamber (Reyes et al. 2013), the new design uses forced draft to generate turbulent airflow which aids in heat and mass transfer from the products.

When the dry air passes the drying chamber, it gathers moisture and proceeds to the funnel duct. The funnel shape along with the secondary propeller directs the air into the recycling gate. A humidity probe placed before the gate detects the humidity of the exhaust flow and opens the gate at a precise angle to facilitate partial exhaust of drying air. This helps to maintain a set humidity in the drying chamber by equating the vapor extracted from the drying chamber to vapor exhausted at the gate. Similarly, Temperature control is achieved by sensors placed in the path of flow which triggers the activation of the heater coils based on the value read by the sensors (A tolerance is introduced to bypass sensor errors). Through autonomy, the heating system can operate for pulses of variable widths dictated by the standard logic algorithms that control the system.

The design constitutes 3 propellers of different sizing to facilitate airflow across the system at required flow rates. A 10-inch propeller is used in the drying chamber to match the $11.8 \times 11.8\ in^2$ cross section of the chamber. The propeller initiates turbulent rectilinear flow within the drying chamber, which aids efficient heat transfer to the products and vapor mass transfer from the products. Similarly, the secondary propeller and tertiary propellers are sized to match the cross section of the respective ducts to achieve rectilinear flow. The speed of the brushless motors is adjusted through 3 phase speed controllers using a PMW signal generated by the microcontroller.

The heating of the flow is achieved through coiled Nichrome wires of 20 AWG installed in the heating duct. The power required for heating is supplied through a custom 50 VAC transformer capable of providing 15 Amps at 45 VAC, which leads to $\approx 650\ Watts$ of power dissipation at the heater coils. Asbestos and Mica have been used selectively for electrical resistance and high heat application of the heating duct. Current flow to the heater coils is controlled through a bta41600b Triac (40 A capacity) and an optocoupler arrangement. This allows for the current to be easily controlled by adjusting the ‘gate’ current of the transistor. The optocoupler isolates the microcontroller from the high voltage paths which ensures component safety.

It should be noted that the system was originally designed to operate at 12 V DC since high current sources (12 V) were readily available in the market for low prices. However, to produce high heat (2.3 KW) at 12 V would require a nichrome wire of 4.8 mm Diameter (5 AWG), which is not commercially available. Additionally, the lowest gauge of wire available at the time of fabrication was 20 AWG which required moderately high voltage to produce ample heat as calculated above.

2.2 Fabrication

Fabrication of the flow ducts has been mainly done by using Galvanized aluminum sheets of 0.5mm gauge. The selected gauge is easily formable and can be fabricated to required shapes using common household tools. Additionally, the galvanized property prevents corrosion under high humidity and temperatures. Once the 3D model was constructed, the surfaces were converted into 2D geometries using the CAD software (‘SOLIDWORKS’) and individual surfaces were fabricated using the sheet metal and joined together using rivets, epoxies, and silicone. Galvanized iron sheets of 1mm gauge were used to construct the skeleton structure for holding the individually fabricated ducts in place. Gauge was selected based on the weight of the structure to ensure no deformation in the structure would occur. The deformation could lead to moving parts (Propellers, Gates) colliding with the enclosed surfaces.

Material selection of the system based on prior assessment of the application has led to the inexpensive and fast fabrication of the system. Additionally, utilizing the CAD model to aid the fabrication process has led to the precise fabrication of the parts which were joined together to obtain the rigid structure without the need for any fasteners (Fasteners were used for additional safety). Direct insolation provisions in the drying chamber are provided using Polycarbonate sheets of 3mm gauge and silicone is used for airtight sealing of air ducts and the drying chamber.

Drying shelves are constructed using steel rods of 2mm spaced by 20mm to facilitate uninterrupted radiation to the bottom shelves and maintain airflow through the chamber.

Figure 3 Fully fabricated system

2.3 Cost

The build of the system for operation based on grid electricity requires an estimated cost of 75 000 LKR. The cost has been heavily impacted by the recent increase in the price of material and other equipment. Based on experiments, when the system is running at its highest settings ($50℃, 20\% RH, Hybrid\ mode$), the average power consumption was valued at $\approx 300W.$ Whereas, when solar power is unavailable, the system could operate at a temperature of $45℃$ with an average power consumption of $\approx 230\ W$. Based on the following data, for 24 hour operation of the system, an electrical storage of 300 Ah and a Solar panel with a rated output of $\approx 700\ Watts$ along with the charge controlling equipment would be required to power the system at its standard operating conditions ($45℃$).

It should be noted that the required components (Nichrome wire of required gauge, Thermocouples, Heat insulation etc.) could not be obtained at the time of fabrication due to unavailability of stock. Hence 40% of the cost (30000LKR) has been spent on implementing a 50 VAC transformer to power the nichrome wires of 22 AWG, to produce the heating requirement of $650\ Watts$. The cost would reduce to 50000 LKR if a lower gauge nichrome wire coupled with a high current source at 12 V could be used.

2.4 Controlling parameters

- Temperature control

As mentioned previously, temperature control of the system is achieved through a sensor and feedback system which activates the heater coil circuitry as required.

$$(\dot{Q}_{Loss} + \dot{Q}_{Drying})t_{cycle} = mC_p\Delta T_{air} = \dot{Q}_{Heater} \times t_{active} \tag{1}$$

Where,

$\dot{Q}_{Loss} + \dot{Q}_{Drying}$	Heat requirement for isothermal operation
t_{cycle}	Cycle time at standard circulation speed
m	Mass of air
C_p	Specific energy of air at constant pressure
ΔT_{air}	Temperature change per cycle
$\dot{Q}_{Heater}$	Heat input to the system/ Heat output from heater coils
t_{active}	Time of activation

Temperature is continuously decreased due to heat loss and heat absorbed by the products. Temperature is maintained by assessing this heat loss by terms of temperature difference (ΔT_{air}) in subsequent cycles of circulation, the required duration of activation (t_{active}) can be calculated from the equation above where the coil output can be calculated by measuring the current and the voltage of the source ($\dot{Q}_{Heater} = VI$).

- Humidity control

Humidity control is achieved through the following governing equation of vapor balance

$$\omega_{Drying} = R\left(\omega_{Initial} + \frac{\dot{m}_{Vapor}}{\dot{m}_{Air}}\right) + (1 - R)\omega_{atmos} \tag{2}$$

ω_{Drying}	Absolute humidity in drying chamber (User specified)
R	Recycling rate (Algorithm dictated)
$\omega_{Initial}$	Absolute humidity after absorbing vapor from the chamber
$\dot{m}_{Vapor}$	Rate of vapor extraction
$\dot{m}_{Air}$	Rate of airflow from the ambient
ω_{atmos}	Atmospheric absolute humidity

The chamber absolute humidity 'ω_{Drying}' is a function of the Recycling rate 'R' used at the recycling gate. 'ω_{Drying}' can be controlled regardless of the rate of vapor absorption in the chamber '$\dot{m}_{Vapor}$' by controlling the value of 'R' but would require high energy input as heat recovery from the exhaust will be low at low recycling rates.

Absolute humidity is considered in calculations which indicates the mass of water vapor in the atmosphere, independent of the temperature. Since the drying chamber and the atmosphere function at different temperatures, absolute humidity provides common grounds for performing humidity calculations and reference to psychrometry.

Experiments have been conducted to assess the stability of the humidity and temperature of the system explained through the equations in the previous section. The parameters are controlled by a standard logic code (C++) that reads sensor feedback and compares it with the user specified values of temperature and humidity and performs actions accordingly. During experimentation, Temperature stability has been obtained at the set value, oscillating between the high and low bounds set by the algorithm. Stability of humidity has also been achieved in the drying chamber at a satisfactory deviation of $\pm 2\%\ RH$.

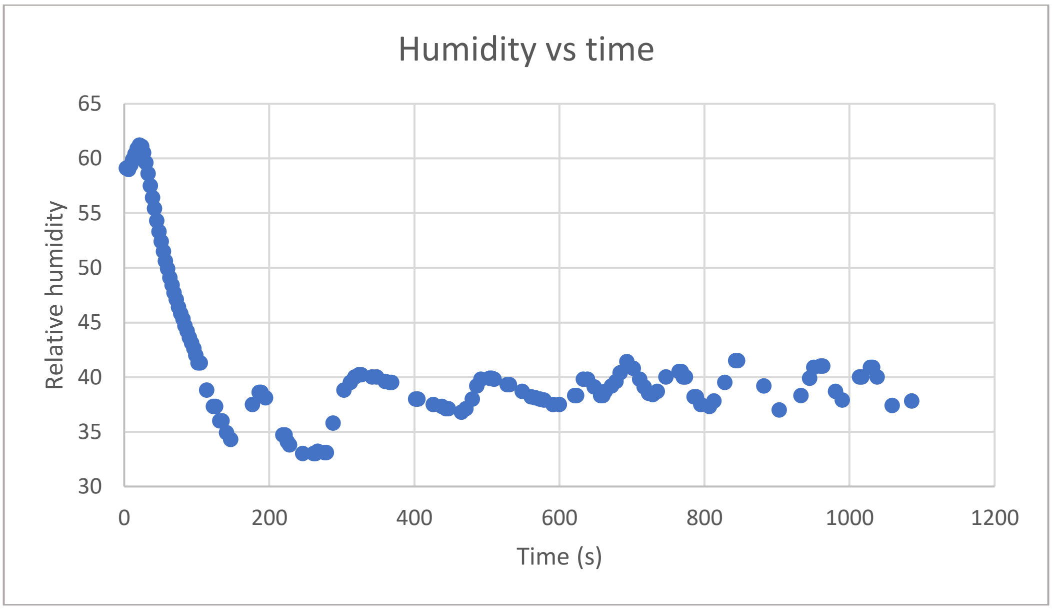

Figure 4 Humidity behavior when stabilized at 40%RH

3 EXPERIMENTS AND RESULTS

Experiments were conducted based on the two operating modes of the dryer. Pure convective mode which utilizes generated heat at the coils to drive the process, and Hybrid mode which utilizes both generated and solar heat to drive the process. Following steps have been followed in both experiments to establish uniformity of the process.

<u>Methodology:</u>

- Fresh green apples at ambient conditions have been sliced to $\approx 3mm$ thick slices and obtained at 346 g of mass.
- Slices are evenly distributed on the 5 trays for drying and dried at conditions of $45°C$ in pure convective drying and $50°C$ in hybrid mode.
- Subjects are taken out of the chamber at equal periods of elapsed time (30 minutes) and measured using a scale of $\pm\ 1g$ accuracy
- The weight reading is recorded with the respective time of measurement
- The procedure is carried out until a weight reduction of $\Delta W \leq \pm\ 2g$ was achieved.

3.1 Sequential experiments

Pure convective mode

Table 2 Control parameters for convective drying

Chamber Temperature	$45 \pm 1\ ℃\ (\max capacity)$
Chamber humidity	$40 \pm 3\%\ RH$
Flow velocity	$1.2\ ms^{-1}$

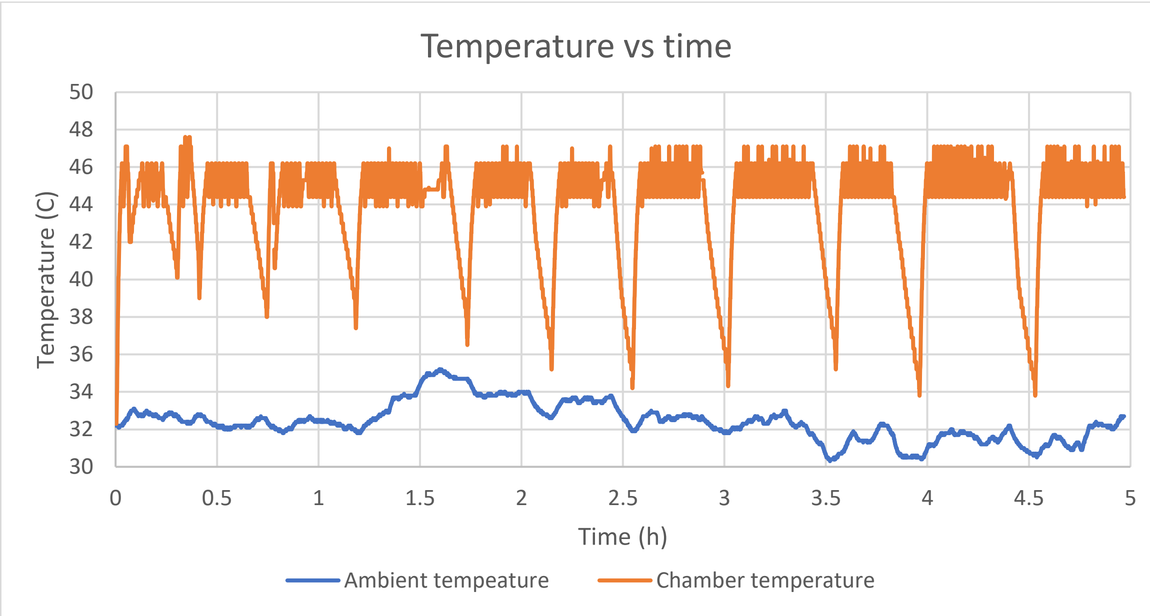

Figure 5 Temperature vs time behavior of convective drying

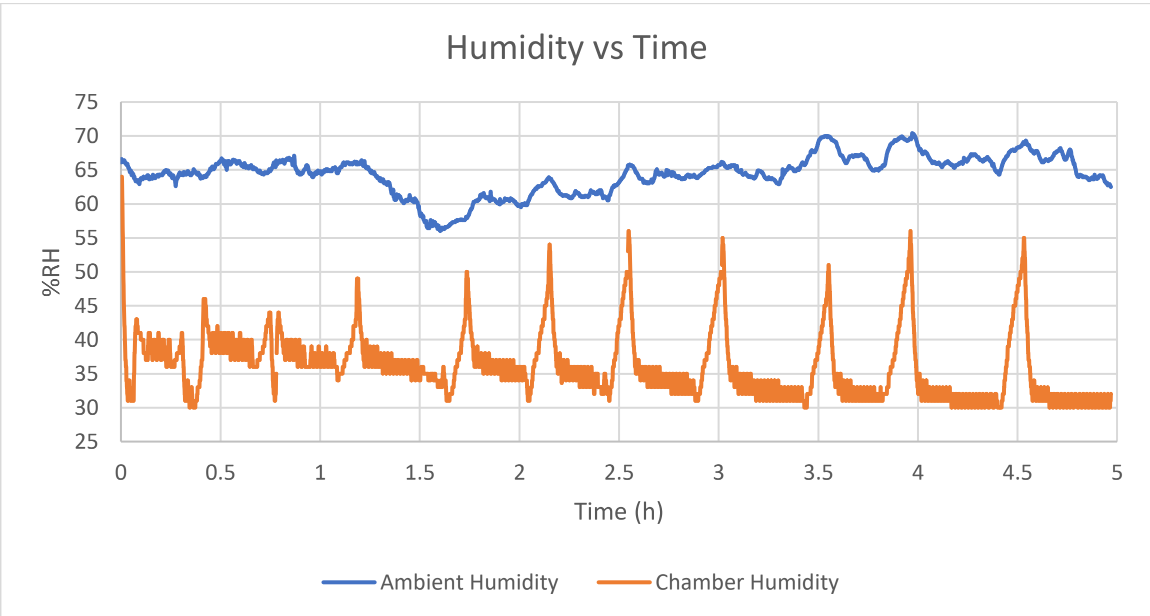

Figure 6 Humidity vs time behavior of Convective drying

- The spikes in the charts correspond to the unloading and loading of the subjects when obtaining weight readings.

Hybrid mode

Table 3 Control parameters for Hybrid drying

Chamber Temperature	$50 \pm 1\ ^\circ\mathrm{C}$ (max $capacity$)
Chamber humidity	$20 \pm 3\%\ RH$
Flow velocity	$1.2\ ms^{-1}$

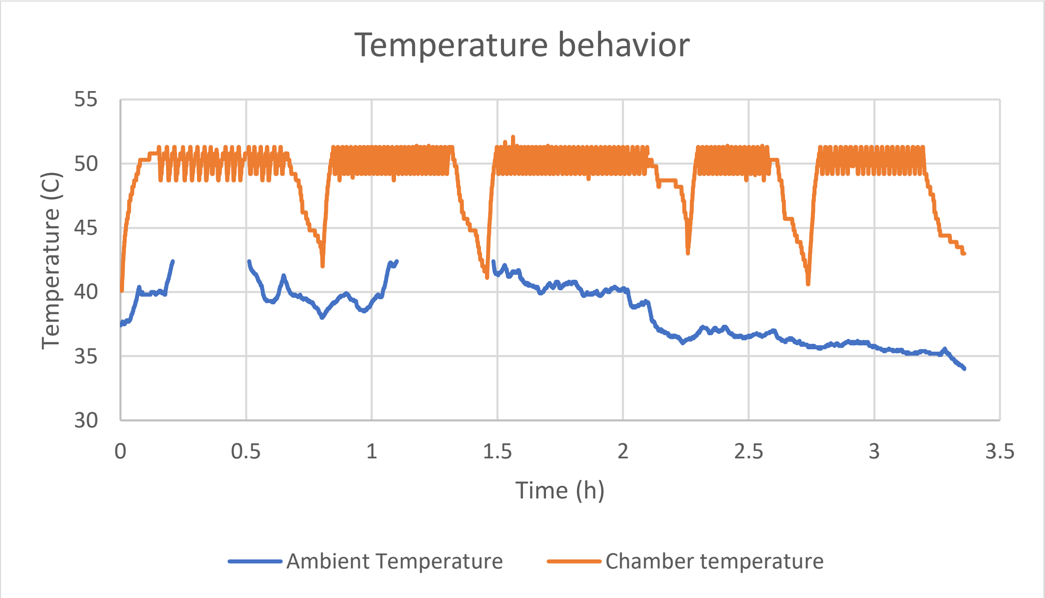

Figure 7 Temperature vs time behavior of hybrid drying

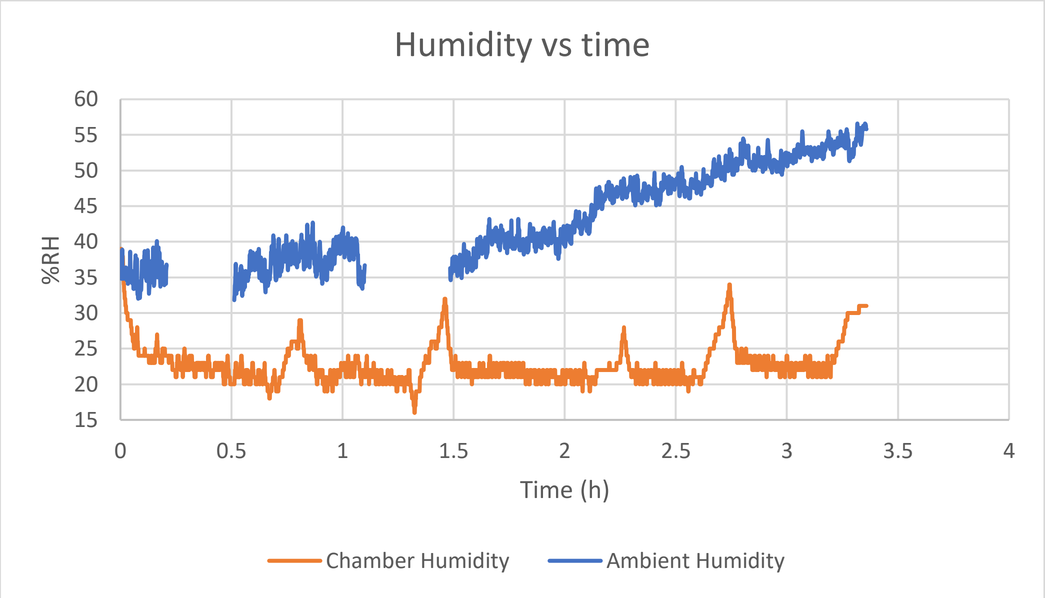

Figure 8 Humidity vs time behavior of hybrid drying

The main disadvantage of designs proposed by previous designs is the dependency of drying conditions on atmospheric conditions. Although the temperature is well controlled by using various techniques, most designs do not propose a method for humidity control. By the figures represented above, it can be acknowledged that the system is robust to changes in the atmospheric temperature and humidity, by using the microcontroller to process the feedback from the sensors and manage the properties accordingly (Section 2.4).

3.2 Results comparison

Figure 9 Visual comparison of the subjects dried under different modes (Before drying, Convective drying and solar hybrid drying)

By visual comparison of the subjects, it can be observed that the convective drying process has led to more browning of the subjects. Sundried samples at 50 C temperature seemed to be visually more appealing compared to convective drying at 45 C. At low temperatures, moisture remains for a longer duration on the surface which spans the chemical process of browning for a longer time, whereas at 50 C, the moisture is rapidly removed from the surface stalling the process of browning. As mentioned in section 1, high drying rates cause the moisture routes to shrink and impair the product of being further dried, hence the samples dried at 50 C further reduce the browning effect by trapping the moisture within the product.

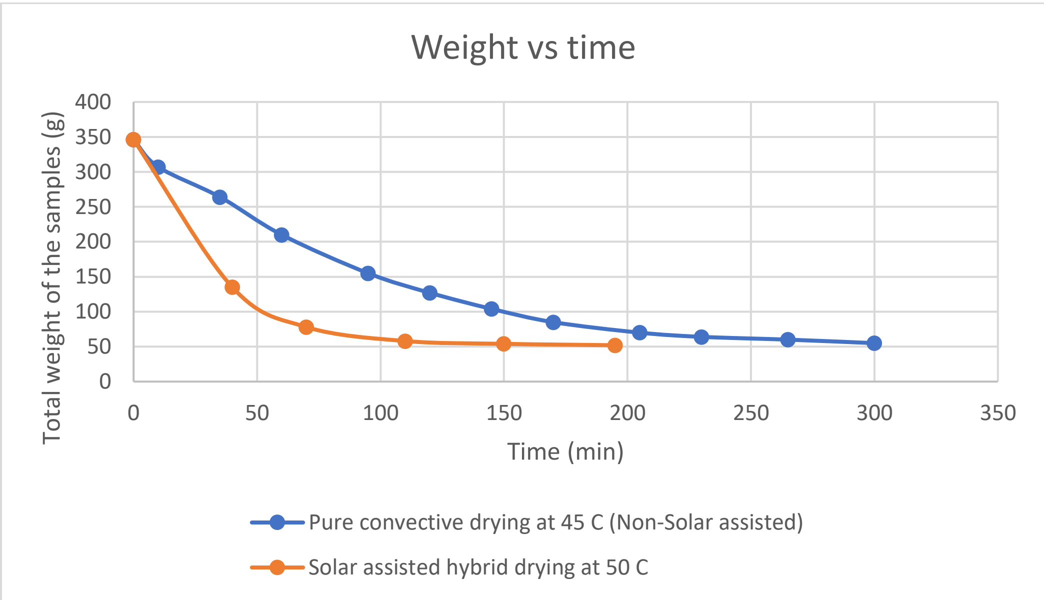

Figure 10 Rate of weight reduction in two modes of drying

It can be observed that the convective mode at 45 ℃ concluded the drying process (from 346g initial weight to 55g final) in 300 minutes whereas the hybrid mode performed the process (from 346g initial weight to 52g final) in 195 minutes. This experiment indicates substantial improvement in drying time when using high temperatures assisted by solar radiation. Hence, it can be stated that a solar incorporated hybrid dryer would enhance the performance of the system when drying is performed at intermediate temperatures (45<T<60) (Jeevarathinam et al. 2021). As mentioned in section 1, the curved shape of moisture reduction is due to the conversion of the hygroscopic subject from saturated surface moisture to transporting moisture from the inner cellular structure.

Drying at this stage requires high internal heating of the product, which can be supplied by increasing the convective temperature to $60-70$°C or exposure to high intensity infrared waves/ Solar insolation. The convective temperature is limited by the heat output at the coils and solar insolation cannot be controlled, hence an infrared source is proposed (Section 2.1) to increase the functionality of the system.

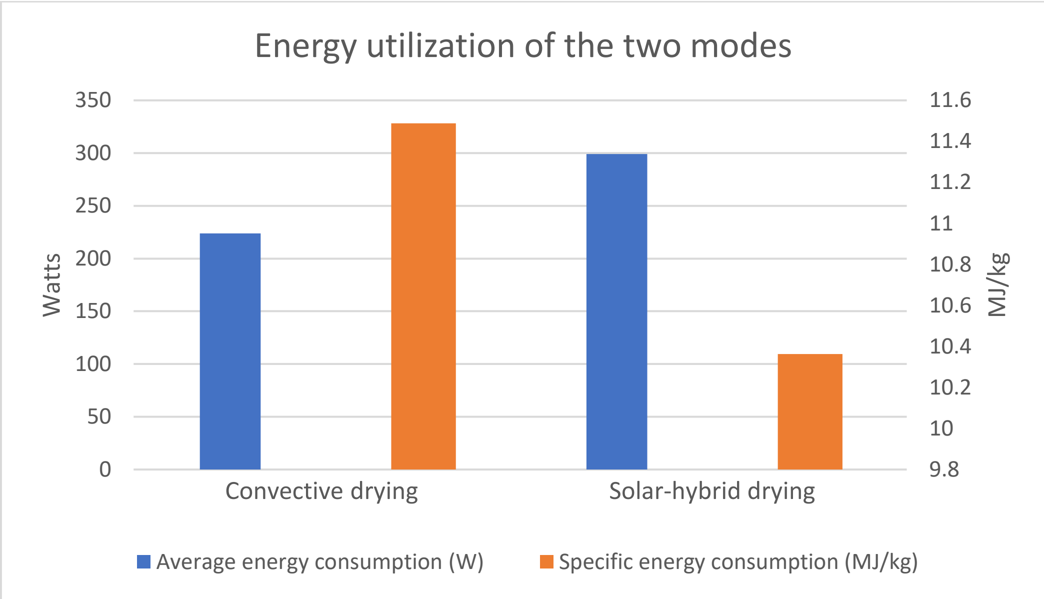

Figure 11 Energy utilization when drying from two methods

Studies of (EL-Mesery et al., 2021), have concluded the importance of direct radiation in drying apple slices as it could significantly increase the rate of heat transfer to the internal body of the product compared to convective heat transfer. As observed in the following figure, the specific energy consumption when operating in hybrid mode resulted in a significantly less magnitude when compared to pure convective drying. Inducing high heat conduction rates to the inside of the product can aid the rapid transportation of moisture from inside of the product, thereby reducing drying times and energy requirement to dry a kilogram of the product (Specific energy). When comparing the obtained results, they have observed an SEC of 12.72 MJ/kg when drying apple slices at 30°C at an infrared intensity of $0.15\ Wcm^{-2}$, whereas the author conducted the experiment at 50 °C at a similar infrared intensity (Solar) and observed an SEC of 10.4 MJ/kg. SEC has been improved due to increased moisture absorption at high temperatures due to low %RH. Additionally, increasing the density of drying material in the drying chamber also helps to increase the efficiency of the dryer as the rate of heat transfer to the products is increased.

4 CONCLUSION

A solar hybrid dryer was designed and built to determine the effect of incorporating solar irradiation in the convective drying process. The dryer was able to reach higher temperatures, 50°C in hybrid mode compared to 45°C in convective mode. As a result, a 10% saving in specific energy consumption was achieved when drying in hybrid mode compared to convective mode. As previously explained, direct irradiation to the products yielded a significantly less time of processing compared to convective mode and also led to a lower moisture content (-3 g) at the end of the experiment. The average energy consumption when drying in Hybrid mode was 300W at 50°C, which proves the eligibility of the system to be powered by photovoltaic electrical energy storage.

5 ACKNOWLEDGEMENTS

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Experimental investigation of concrete-filled and bare 6082-T6 aluminium alloy tubes under in-plane bending

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ABSTRACT

The application of aluminium alloys in construction sector is increasing owing to their excellent corrosion resistance, light weight and attractive appearance. However, one of the main disadvantages of aluminium alloys is the low elastic modulus, which may cause a stability issue in aluminium structural members. The performance of aluminium tubes can be improved by filling concrete within them. Research on the flexural behaviour of concrete-filled aluminium alloy tubes is limited. This paper presents an experimental study on the behaviour of square and rectangular concrete-filled and bare aluminium tubular sections subjected to in-plane bending. Total 20 beams were tested, including 10 concrete-filled aluminium tubes (CFAT) and 10 bare aluminium tubes (BAT). The hollow aluminium tubes were fabricated using 6082-T6 alloy and filled with 25 MPa cylinder compressive strength concrete. The material properties of aluminium were measured by tensile test of coupons. It is shown that the flexural strength, stiffness and ductility of square and rectangular BAT flexural members was remarkably improved by the infilled concrete and the improvement is more pronounced for the thinner aluminium sections. Due to absence of design standards for CFAT beams, in this study the design rules available for concrete-filled steel tubular flexural members in the Eurocode 4 are considered by substituting the mechanical properties of steel with those of aluminium alloy. It is demonstrated that the proposed design rules provide good predictions of the flexural capacity of CFAT.

KEYWORDS: *6082-T6 Aluminium alloy, Concrete-filled sections, Bare sections, Four-point bending, Flexural behaviour.*

1 INTRODUCTION

The application of aluminium alloys in construction sector is increasing owing to their superior properties including excellent corrosion resistance, light weight, ease of production, high recyclability and attractive appearance (Mazzolani, 2004; Georgantzia, Gkantou, & Kamaris, 2021). However, one of the main disadvantages of aluminium alloys is the low elastic modulus, which may cause a stability issue of aluminium structural members (Mazzolani, 1995; Zhu & Young, 2008). Hence, concrete-filled aluminium alloy tubular (CFAT) structural members are introduced to improve the performance of bare aluminium alloy tubular (BAT) ones. Concrete-filled steel tubular (CFST) structural members are increasingly applied in modern construction because of their several advantages such as, high bearing capacity, ductility, fire resistance etc. The weight of the CFST members can be reduced significantly by replacing the steel tube with aluminium tube (Patel, Liang & Hadi 2020).

A considerable number of research was performed to study the flexural response of CFST beams. Lu and Kennedy (1994) conducted an experimental investigation on the behaviour of CFST beams and demonstrated that the flexural strength of CFST members significantly increased due to the concrete infill. Han (2004) carried out research on structural response of CFST beams and suggested a method to determine the flexural capacity of CFST members. Montuori and Piluso (2015) performed tests on CFST beams under non-uniform bending and suggested a fibre model to predict the bending strength of CFST members. A test programme was conducted by Hou et al (2016) to investigate the influence of chloride corrosion on the flexural behaviour of CFST beams. They found that the chloride corrosion noticeably affected the bending capacity and ductility of the members. Chen et al (2017a, 2017b) experimentally determined the bending stiffness of concrete-filled stainless-steel tubular beams and compared it with the design stiffness calculated using the British, European, American and Japanese standards. They showed that the existing design standards are conservative in calculating the design stiffness of CFST sections made with stainless steel. Zhang et al (2021) investigated the flexural response of elliptical CFST beams and suggested equations to calculate the bending strength and stiffness of the members.

Numerous research studies were conducted to investigate the flexural behaviour of BAT flexural members. Moen et al (1999a, 1999b) studied the flexural strength and rotational capacity of 6082 and 7108 aluminium alloy beams with welded stiffeners. They demonstrated that due to welding the aluminium alloy flexural members experienced premature tensile failure, which resulted in reduction of rotation capacity. Zhu and Young (2009) investigated the behaviour of 6061-T6 aluminium alloy beams under in-plane bending and suggested design equations to predict design capacity. Su, Young and Gardner (2014) conducted research on the bending response of 6061-T6 and 6063-T5 aluminium alloy hollow sections. They compared the experimental flexural strength with the design strength determined by the European, American and Australian standards and concluded that the design specifications are conservative. Feng et al (2017) studied the structural response of perforated BAT beams made with 6061-T6 and 6063-T5 grade alloys and demonstrated that the North American specifications are appropriate for designing perforated aluminium alloy beams.

Previous research has focused on the behaviour of CFST beams, whereas research on the structural behaviour of CFAT flexural members is limited. Moreover, minimal number of research studies exist on the flexural response of BAT beams made with 6082-T6 alloy. Nowadays, the 6082 grade aluminium alloy has gained more popularity in modern construction (Kissell and Ferry, 2002) because of its high bearing capacity, corrosion resistance and weldability. This paper presents an experimental study on the performance of CFAT and BAT beams subjected to in-plane bending. The square and rectangular hollow aluminium sections were made of 6082-T6 alloy. The structural response of the specimens is presented by failure mode, flexural strength, flexural stiffness, and ductility. Due to absence of design standards for CFAT beams, in this study the design equations available for concrete-filled steel tubular flexural members in Eurocode 4 (2004) are considered by substituting the mechanical properties of steel with those of aluminium alloy.

2 EXPERIMENTAL INVESTIGATION

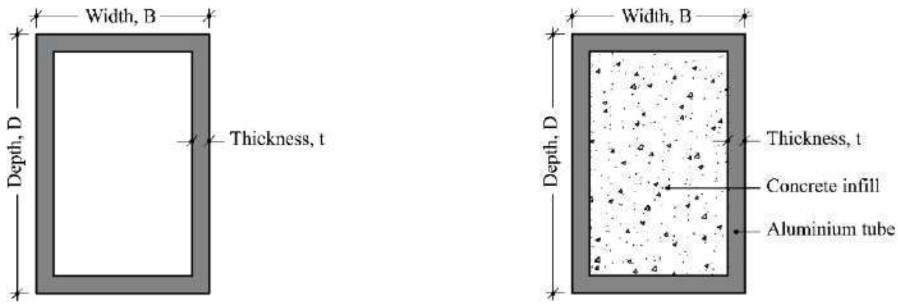
2.1 Test Specimens

Total 20 square and rectangular beams were tested subjected to in-plane bending, whereas 10 were concrete filled and 10 were bare specimens. The aluminium tubes were fabricated by 6082-T6 alloy. The specimens' length was 1000 mm. The dimensions of all specimens measured before the tests are presented in Table 1. The label of a specimens was given based on its cross-sectional measurements. For example, the label '101.6×25.4×3.3-C' refers to a specimen with depth (*D*) of 101.6 mm, width (*B*) of 25.4 mm and thickness (*t*) of 3.3 mm and the notation '-C' refers to the existence of concrete infill. Figure 1 presents the geometric properties of typical BAT and CFAT sections.

For CFAT specimen, a wooden plate was attached by tape at the bottom end of each hollow tube to avoid any leakage of concrete. During casting, the concrete was filled in layers and compacted by a vibrating table. All specimens were enclosed by plastic sheet and kept 28 days for self-curing.

Table 1. Measured cross-sectional dimensions of all specimens.

Specimen	*D* (mm)	*B* (mm)	*t* (mm)	Specimen	*D* (mm)	*B* (mm)	*t* (mm)
76.2×76.2×1.6	76.3	76.2	1.54	76.2×76.2×1.6-C	76.3	76.2	1.54
76.2×76.2×3.3	76.2	76.2	3.21	76.2×76.2×3.3-C	76.2	76.2	3.21
76.2×76.2×4.8	76.2	76.1	4.71	76.2×76.2×4.8-C	76.2	76.1	4.71
76.2×76.2×6.4	76.2	76.2	6.21	76.2×76.2×6.4-C	76.2	76.2	6.21
76.2×25.4×3.3	76.3	25.5	3.33	76.2×25.4×3.3-C	76.3	25.5	3.32
76.2×38.1×3.3	76.2	38.3	3.26	76.2×38.1×3.3-C	76.2	38.3	3.26
76.2×50.8×3.3	76.1	50.7	3.15	76.2×50.8×3.3-C	76.1	50.7	3.15
101.6×25.4×3.3	101.6	25.4	3.21	101.6×25.4×3.3-C	101.6	25.4	3.20
101.6×50.8×3.3	101.9	51.4	3.44	101.6×50.8×3.3-C	101.9	51.4	3.41
101.6×76.2×3.3	101.5	76.3	3.14	101.6×76.2×3.3-C	101.5	76.3	3.14



(a) (b)

Figure 1. Cross-sections of a typical (a) BAT beam, (b) CFAT beam.

2.2 Material properties

The mechanical properties of aluminium alloy sections were determined by tensile test of coupons. The coupons with gauge length and width of 100 mm and 12 mm, respectively were collected from each specimen based on the recommendation of BS EN ISO 6892-1 (2009). The tests were conducted using a 50 kN capacity machine and displacement-control load of 0.2 mm/min was applied during the tests. The longitudinal strains of the coupons were measured by an extensometer. The mechanical properties found from the coupon tests are listed in Table 2, where *E* debote modulus of elasticity, $\sigma_{0.1}$ is 0.1% proof stress, $\sigma_{0.2}$ is 0.2% proof stress, σ_{u} is ultimate stress, ε_{u} is the ultimate strain and ε_{f} is the strain at rupture.

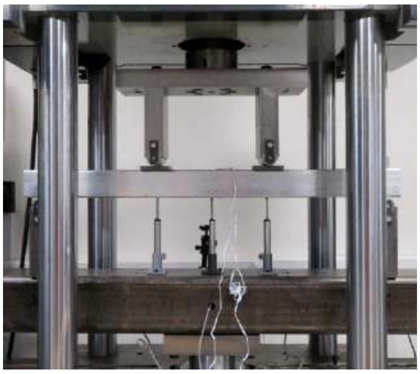
Table 2. Mechanical properties of aluminium alloy tubes.

Specimen	*E* (GPa)	$\sigma_{0.1}$ (MPa)	$\sigma_{0.2}$ (MPa)	σ_u (MPa)	ε_u (%) (mm/mm)	ε_f (%) (mm/mm)
76.2×76.2×1.6	67.9	288.4	292.9	316	6.9	8.4
76.2×76.2×3.3	66.2	295.2	299.1	321	7.5	10.5
76.2×76.2×4.8	64.7	303.7	306.1	316	6.3	9.7
76.2×76.2×6.4	69.3	290.4	295.3	326	8.8	15.3
76.2×25.4×3.3	68.9	271.8	277.9	316	8.8	14.3
76.2×38.1×3.3	68.5	270.4	276.8	315	7.8	9.3
76.2×50.8×3.3	67.5	285.9	289.5	312	7.1	9.1
101.6×25.4×3.3	63.9	234.7	242.5	290	7.6	13.2
101.6×50.8×3.3	71.6	166.9	175.1	204	7.4	12.1
101.6×76.2×3.3	72.8	303.5	306.7	320	5.6	6.9

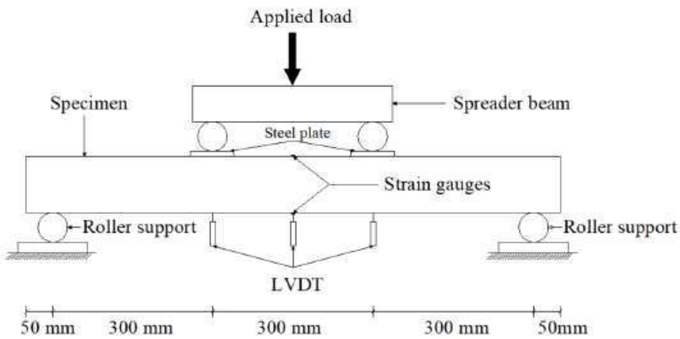
For concrete mix, Portland cement, sand, stone chips (≤10 mm) and water were used with a ratio of 1:1.49:2.51:0.5 by weight. The nominal strength of concrete cylinder was considered 25 MPa during the mix design. During concrete casting, three concrete cylinders were made from same concrete mixture. The nominal height and diameter of a cylinder was 300 mm and 150 mm. The concrete cylinders were cured in a water container for 28 days. The compressive tests of the cylinders were conducted according to the guideline of BS EN 12390-3 (2009) and the average strength value obtained is 26.1 MPa.

2.3 Test set-up and procedure

The four-point bending tests were performed to study the flexural response of CFAT and BAT beams. The gap between two end supports was 900 mm, while the gap between two loading points and shear span was 300 mm. A 600 kN capacity hydraulic machine was utilized for the tests. A displacement control load of 1.5 mm/min was applied during the tests. Roller supports were used to allow movement along longitudinal direction and rotation around bending axis of the specimens. Underneath the loading points steel plates were used to prevent concentration of stresses on the specimens. Furthermore, inside BAT beams wooden blocks were located at supports and loading points for distributing the loads. During the tests, three LVDTs were positioned at loading points and mid-span of the bottom flange of the specimens to measure the vertical displacement. To record longitudinal strain, two strain gauges were installed at upper and lower faces of the specimens. A data logger was used to record all data during the tests. Figure 2 presents a snapshot and a schematic drawing of the test set-up.



(a) Photograph



(b) Schematic diagram

Figure 2. Test set-up and instrumentation.

3 TEST RESULTS

3.1 Failure modes

Figure 3 presents the typical modes of failure of the bare and concrete-filled specimens obtained from the tests. It is observed that all specimens failed by yielding (Figure 3(a)). Besides yielding, inward and outward local buckling were spotted between the loading points on the top flange and upper side of the web of most of the BAT specimens (Figure 3(b)). However, in CFAT specimens inward buckling was absent and outward buckling was comparatively smaller than the corresponding BAT specimens. This is related to the fact that the concrete infill prevented the forming of inward buckling and delayed the development of outward buckling. Moreover, some specimens (i.e., 101.6×50.8×3.3, 76.2×76.2×1.6-C, 76.2×76.2×3.3-C, 101.6×50.8×3.3-C and 101.6×76.2×3.3-C) experienced fracture at the tension side of the tube after reaching ultimate bending moment (Figure 3(c)). Table 3 summarises the failure modes of all specimens observed during the tests.

(a) 76.2×76.2×4.8-C (b) 76.2×76.2×4.8 (c) 6.2×76.2×3.3-C

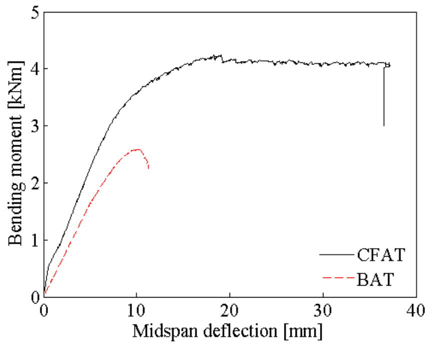
Figure 3. Typical failure modes, (a) Yielding, (b) Local buckling, (c) Fracture in tension zone of tube.

Table 3. Modes of Failure of specimens.

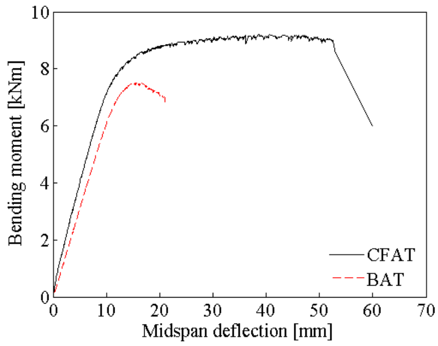
Specimen	Failure mode	Specimen	Failure mode
76.2×76.2×1.6	LB	76.2×76.2×1.6-C	Y+LB+TF
76.2×76.2×3.3	LB	76.2×76.2×3.3-C	Y+LB+TF
76.2×76.2×4.8	Y+LB	76.2×76.2×4.8-C	Y+LB
76.2×76.2×6.4	Y+LB	76.2×76.2×6.4-C	Y
76.2×25.4×3.3	Y	76.2×25.4×3.3-C	Y
76.2×38.1×3.3	Y	76.2×38.1×3.3-C	Y
76.2×50.8×3.3	Y+LB	76.2×50.8×3.3-C	Y+LB
101.6×25.4×3.3	Y+LB	101.6×25.4×3.3-C	Y+ LB
101.6×50.8×3.3	Y+LB+TF	101.6×50.8×3.3-C	Y+LB+TF
101.6×76.2×3.3	LB	101.6×76.2×3.3-C	Y+LB+TF
Note: Y = Yielding, LB = Local buckling, TF = Tensile fracture			

3.2 Flexural strength

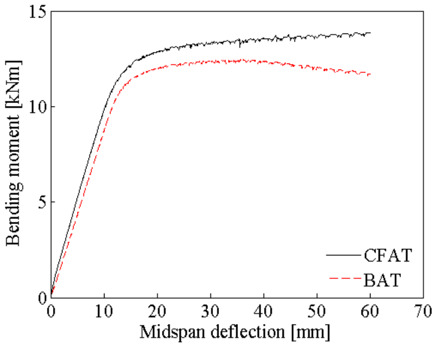
Using the experimental data, the bending moment versus mid-span deflection graphs of CFAT and BAT beams are plotted in Figure 4. The maximum bending moment obtained from the curve is considered as the flexural strength of the corresponding specimen and the values of all specimens are listed in Table 4. It can be observed from the figure and table that due to existence of concrete in the CFAT specimens, the flexural strength is significantly enhanced compared to the counterpart bare specimens. In Table 4, the percentage increase of flexural strength of CFAT specimens compared to BAT specimens is also presented. It is found that percentage increase is highest for 76.2×76.2×1.6-C which is 64.17% and for specimen 76.2×76.2×6.4-C the value is lowest which is 4.48%. This indicates that when the width and depth of a cross-section are constant, the strength improvement decreases with the increase of wall thickness. This is attributed to the inner concrete that slows down the formation of local buckling of slender cross-sections, thereby resulting in gaining additional strength. Moreover, it is also observed that when the thickness is constant, the percentage increase is higher for specimens with larger cross-sections. This is attributed to the larger cross-section which offers more confinement to the inner concrete, resulting in addition of extra strength.



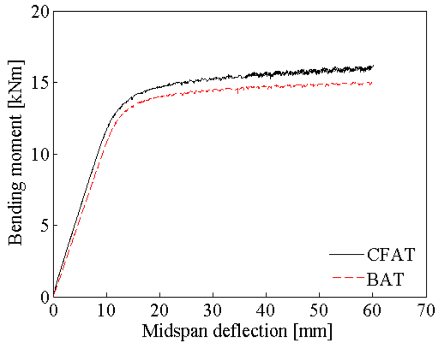
(a) 76.2×76.2×1.6 (-C)



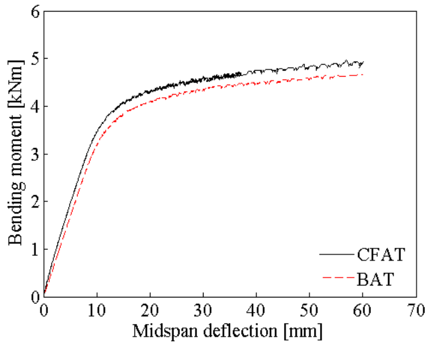
(b) 76.2×76.2×3.3 (-C)



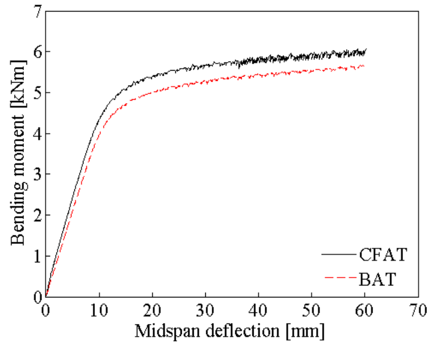
(c) 76.2×76.2×4.8 (-C)



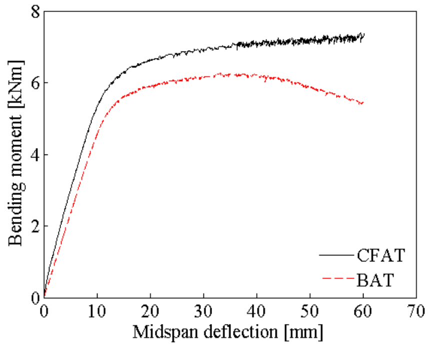
(d) 76.2×76.2×6.4 (-C)



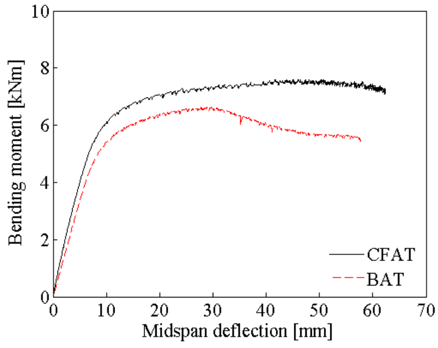
(e) 76.2×25.4×3.3 (-C)



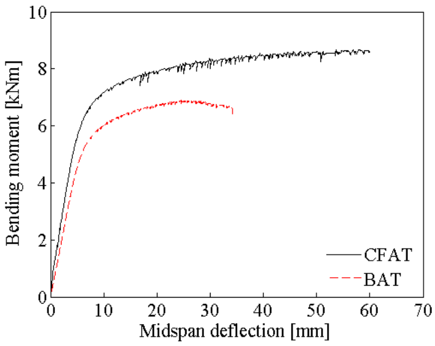
(f) 76.2×38.1×3.3 (-C)



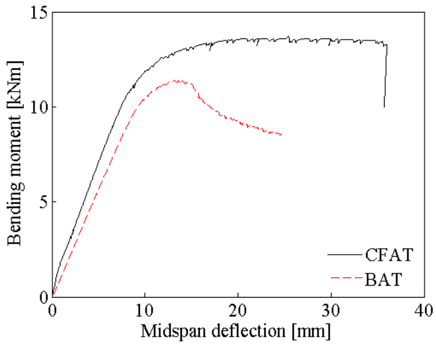
(g) 76.2×50.8×3.3 (-C)



(h) 101.6×25.4×3.3 (-C)



(i) 101.6×50.8×3.3 (-C)



(j) 101.6×76.2×3.3 (-C)

Figure 4: Bending moment versus mid-span deflection graphs of specimens.

Table 4. Flexural strength of specimens.

Specimen	M_{BAT} **(kNm)**	**Specimen**	M_{CFAT} **(kNm)**	$(M_{CFAT} - M_{BAT})$ / M_{BAT} **(%)**
76.2×76.2×1.6	2.59	76.2×76.2×1.6-C	4.25	64.17
76.2×76.2×3.3	7.52	76.2×76.2×3.3-C	9.01	19.84
76.2×76.2×4.8	12.47	76.2×76.2×4.8-C	13.39	7.37
76.2×76.2×6.4	14.54	76.2×76.2×6.4-C	15.33	5.43
76.2×25.4×3.3	4.46	76.2×25.4×3.3-C	4.60	3.14
76.2×38.1×3.3	5.38	76.2×38.1×3.3-C	5.66	5.20
76.2×50.8×3.3	6.27	76.2×50.8×3.3-C	6.93	10.56
101.6×25.4×3.3	6.64	101.6×25.4×3.3-C	7.25	9.18
101.6×50.8×3.3	6.84	101.6×50.8×3.3-C	8.31	21.52
101.6×76.2×3.3	11.39	101.6×76.2×3.3-C	13.73	20.54

3.3 Flexural stiffness and ductility

Based on the experimental data, the flexural stiffness and ductility of BAT and CFAT flexural members are calculated by Eq. (1) and (2), respectively and presented in Table 5.

$$K = \frac{0.2 M_u L^2}{\pi^2 \delta} \tag{1}$$

$$\mu = \frac{\delta_u}{\delta_y} \tag{2}$$

where K is the flexural stiffness, μ is the ductility, M_u is flexural strength, δ is the mid-span vertical displacement at $0.2M_u$, δ_y is the mid-span vertical displacement at yield moment and δ_u is the mid-span vertical displacement at flexural strength.

It is observed from Table 5 that the flexural stiffness and the ductility of CFAT specimens are higher than that of BAT specimens. The improvement of stiffness is more pronounced for specimens with thinner sections.

4 DESIGN EQUATIONS FOR CFAT BEAMS

Due to absence of design standards for CFAT flexural members, in this study the design equations available for concrete-filled steel flexural members in Eurocode 4 (2004) are considered by substituting the mechanical properties of steel with those of aluminium alloy. Based on Eurocode 4, the flexural capacity of CFAT beams can be determined by Eqs. (3).

$$M_{u,prop} = M_{pl} = \left(W_{pla} - W_{pla,n}\right) f_{0.2} + 0.5\left(W_{plc} - W_{plc,n}\right) f_c \tag{3}$$

In this equation, W_{pla} and W_{plc} are the plastic moduli of a hollow and concrete section, respectively, calculated by Eq. (4) and (5). $W_{pla,n}$ and $W_{pla,n}$ are the plastic moduli of a hollow and concrete section at $2h_n$, determined by Eq. (6) and (7). h_n is the distance between the centreline and the centroid of the composite section which is calculated by Eq. (8). In this equation, A_c and f_c are area and compressive strength of concrete, respectively.

$$W_{pla} = \frac{BH^2}{4} - \frac{2}{3}(t)^3 - (t)^2(4-\pi)\left(\frac{H}{2} - t\right) - W_{plc} \tag{4}$$

$$W_{plc} = \frac{(B-2t)(H-2t)^2}{4} \tag{5}$$

$$W_{pla,n} = Bh_n^{\ 2} - W_{plc,n} \tag{6}$$

$$W_{plc,n} = (B-2t)h_n^{\ 2} \tag{7}$$

$$h_n = \frac{A_c f_c}{2Bf_c + 4t\left(2f_{0.2} - f_c\right)} \tag{8}$$

Table 5. Flexural stiffness and ductility of the specimens.

Specimen	**K (kNm^2)**	**(K_{CFAT} - K_{BAT}) / K_{BAT} (%)**	**δ_y (mm)**	**δ_u (mm)**	**μ**	**(μ_{CFAT}-μ_{BAT}) / μ_{BAT} (%)**
76.2×76.2×1.6	29.95	55.63	4.72	10.10	2.14	48.66
76.2×76.2×1.6-C	46.61		5.80	18.45	3.18	
76.2×76.2×3.3	51.85	40.60	7.32	15.92	2.17	205.44
76.2×76.2×3.3-C	72.90		6.89	45.77	6.64	
76.2×76.2×4.8	72.50	23.79	8.60	37.53	4.36	64.39
76.2×76.2×4.8-C	89.75		8.37	60.02	7.17	
76.2×76.2×6.4	90.02	16.25	8.36	59.98	7.17	3.04
76.2×76.2×6.4-C	104.65		8.12	60.03	7.39	
76.2×25.4×3.3	28.23	22.14	8.47	60.01	7.09	4.30
76.2×25.4×3.3-C	34.48		8.13	60.08	7.39	
76.2×38.1×3.3	34.21	23.71	8.29	60.01	7.24	4.95
76.2×38.1×3.3-C	42.32		7.90	60.02	7.60	
76.2×50.8×3.3	36.87	45.49	8.14	41.67	5.12	57.25
76.2×50.8×3.3-C	53.64		7.48	60.24	8.05	
101.6×25.4×3.3	55.17	35.94	6.07	30.22	4.98	57.83
101.6×25.4×3.3-C	75.00		5.90	46.36	7.86	
101.6×50.8×3.3	77.61	47.39	4.49	27.30	6.08	120.31
101.6×50.8×3.3-C	114.39		4.48	60.01	13.40	
101.6×76.2×3.3	91.21	44.56	6.05	13.63	2.25	163.40
101.6×76.2×3.3-C	131.85		5.91	35.07	5.93	

The design flexural strengths of all CFAT specimens predicted using Eq. (3) are listed in Table 6 and compared with flexural strengths obtained from the experiments. The mean value of the tset over the proposed moment ratio ($M_u/M_{u,prop}$) is 1.04, indicating that the proposed design equations provide good prediction of the flexural capacity of CFAT beams.

Table 6. Comparison of experimental flexural strength with design flexural strength.

Specimen	M_u	$M_{u,prop}$	$M_u/M_{u,prop}$
76.2×76.2×1.6-C	4.49	4.25	0.95
76.2×76.2×3.3-C	8.84	9.01	1.02
76.2×76.2×4.8-C	12.49	13.87	1.11
76.2×76.2×6.4-C	14.88	16.18	1.09
76.2×25.4×3.3-C	4.69	4.97	1.06
76.2×38.1×3.3-C	5.72	6.07	1.06
76.2×50.8×3.3-C	6.59	7.38	1.12
101.6×25.4×3.3-C	7.49	7.60	1.01
101.6×50.8×3.3-C	9.21	8.68	0.94
101.6×76.2×3.3-C	13.38	13.73	1.03
		Mean	1.04
		COV	0.06

5 CONLUSIONS

This paper presented an experimental study on the behaviour of square and rectangular CFAT and BAT beams under in-plane bending. Total 20 beams were tested, including 10 CFAT and 10 BAT specimens. Based on the observed results the following points can be concluded:

1) The flexural strength, flexural stiffness and ductility of CFAT specimens are significantly enhanced up to 64.17%, 55.63% and 205.44%, respectively compared to the counterpart BAT specimens. This indicates that the concrete infill effectively reduced the formation and extentension of local buckling of BAT specimens.
2) It is demonstrated that the increase of flexural strength due to concrete infill was prominent for thinner sections. This is attributed to the inner concrete that slows down the formation of local buckling of slender cross-sections, thereby resulting in gaining additional strength.
3) Due to the absence of design standards for CFAT beams, in this study the design equations available for concrete-filled steel tubular flexural members in the Eurocode 4 are considered by substituting the mechanical properties of steel with those of aluminium alloy. The mean and COV values of the ratio of experimental and design flexural strength are found 1.04 and 0.06, respectively. It is indicated that the proposed design equations provide good predictions of flexural capacity of CFAT beams.

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Challenging Arbitral Awards in the Construction Industry

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ABSTRACT

One of the most common alternative dispute resolution methods used in the Sri Lankan construction industry is arbitration. However, challenging arbitration awards based on legal grounds at the courts has been a current trend by the disagreeing party. If this situation occurs continuously, the purpose of having arbitration as an alternative dispute resolution method can be abandoned. Therefore, the study aims to identify the causes where arbitration is challenged in multi-story building construction projects in Sri Lanka through a case study. The methodological choice was qualitative and used semi-structured interviews from six arbitrators and 2 case studies that referred to courts to challenge arbitration awards as research strategies. The study found the poor attitude of parties, lack of technical knowledge, reliability, and capability of the arbitrator to act according to the arbitrary acts imposed by the government as the main causes. Further. The study recommends arbitrators consider the reasons to act well enough and reject the cases if the arbitration is likely to be challenged in courts, train arbitrators to be reliable and on technical knowledge, and improve parties' attitudes by educating on the arbitration procedure and its benefits.

KEYWORDS: *Arbitration, Challenge, Award, Dispute, Sri Lanka*

1. INTRODUCTION

The study is aimed at identifying the causes where arbitration is challenged in multi-story building construction projects in Sri Lanka. The aim was fulfilled under 3 objectives. Firstly, a thorough identification of the arbitration procedure in construction projects in Sri Lanka is completed. Secondly, the reasons for Arbitral challenges were identified and lastly, mitigatory solutions were formulated to overcome the challenges in Arbitral awarding.

The construction industry is complex. (Harmon, 2003 and Cheung, et al., 2002). With the use of many documents and different professionals working together, conflicts are inevitable. (HADI , 2015) to resolve such, the conventional legal system offers a range of paths supported by both public and private institutions with trained, skilled, and qualified professionals (Tanielian, 2013). (HANSEN, 2019). With that, it is clear not only human nature but also other special circumstances lead to creating disputes in the construction industry (Turner & Turner, 1999 & Cheung, 1999 and Ashworth, et al., 2002).

Practices such as negotiation, conciliation, mediation and arbitration have been conjoined now as Alternative Dispute Resolution (ADR) methods (Zavadskas, et al., 2010). However, litigation and negotiation come under the wide bracket of traditional dispute resolution methods but brought about the concepts of arbitration and mediation under the specific spectrum of ADR (Chinyere, 2011). As an alternative perspective, Colvin refers that ADR comprises a variety, inclusive of meditation, arbitration, ombudsmen and peer review (Colvin , et al., 2006). However, the court proceeding is costly and time-consuming. Therefore, parties go for these ADR methods (Hadi , 2015). It is identified as a ‘damage limiting exercise’ (Hadi , 2015). There are different methods to approach the resolution of disputes

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outside the court system. (Zavadskas, et al.,2010 and Abeynayake, 2017). There are two groups of ADR methods in the construction industry - binding methods and - non-binding methods. The former is predominantly arbitration and to some extent Adjudication. Latter includes negotiation and mediation (De Zylva, 2006).

2. LITERATURE REVIEW

2.1 Dispute resolution methods in Sri Lanka

Drawbacks of litigation have opened up (ADR) methods identified as negotiation, mediation, conciliation, adjudication and arbitration (Abeynayake , 2017) that the statistics show that ADR forums within the Construction arena have received much popularity in Sri Lanka (Gunasena, 2010). In this study, I take ADR as negotiation, mediation, conciliation, adjudication and arbitration. The main reasons are that parties' autonomy to choose their desired ADR method and ADR sessions are held confidentially. Also, the procedure is faster and avoids animosity to a great extent (Hadi , 2015).

However, it is essential to note that ADR in the manner of Conciliation Boards; commonly referred to as Samagi Mandalaya was formulated in the year 1958 in Sri Lanka, initiated to encourage settling civil disputes beyond the spectrum of traditional court proceedings (Hadi , 2015). Parliament has implemented several ADR statutory laws (Ekanayake, 1992)'i.e., Arbitration Act No.11 of 1995, Mediation Board Act No. 72 of 1988, Commercial Mediation Center of Sri Lanka Act No. 44 of 2000 and Mediation Boards (special kind of disputes) Act No. 21 of 2003. Additionally, it is important to note that The Institute for Construction Training and Development (ICTAD)- in their first revised edition of Standard Bidding Document (SBD) in 2006, brought up the practice of Adjudication. It spoke about how adjudication and arbitration practices are the very first step towards remedying disputes in Sri Lanka's Construction Industry. (Abeynayake, 2017). From ADR, the researcher selected negotiation, mediation, conciliation, adjudication and arbitration. From that, Arbitration is the most frequent ADR method. Most construction agreements include an Arbitration clause (Cheung, 1999).

2.1.1 Arbitration

Arbitration could easily be referred to as the most often used ADR system in Sri Lanka; mainly in the local construction industry (Abeynayake , 2017). It is an extremely confidential process in which parties to the claim nominate one or more individuals, formally known as 'Arbitrators'- where they make a legally binding decision to the dispute (Ganesaratnam, 2013). They can be either 'institutional' or 'ad hoc' (center, 2004). The freedom in having to nominate an arbitrator to the parties' liking is held to be an important characteristic of the Arbitration mechanism. The parties have the flexibility in nominating an Arbitrator who may have sufficient experience and knowledge in the specific area of the dispute, i.e., the Construction industry (Harmon, 2003) The practice of Arbitration has now grown at tremendous levels (Abwunza, 2020 and Hansen, 2019). It has been commonly agreed that there are two elements to Arbitration, namely ad hoc arbitration and institutional arbitration (Greenberg, et al., 2011) Institutional arbitration can be identified as a system governed by its own separate set of rules and regulations as laid down by a specialist arbitral institution (blackby et al, supra note 4). Whereas, ad hoc arbitration can be described as a separate spectrum inclusive of all arbitration ways that are in no way institutional (Sanders, n.d.) It is flexible and independent of all or any attachment to an institution. Furthermore, it is independent to the extent that the process of such is continued without any appointed administrative authority (Schroeter, n.d.).It has also been noted that parties to the claim prefer an adversarial process of arbitration over others. This is fundamentally due to its high enforceability in its arbitral award (Hemantha, 2016). Moreover, even in disputes about International Trade Law, the preference mainly lies in International Commercial Arbitration over the conventional litigation process due to lack of efficient legal recognition and enforcement of judicial decisions outside the scope of its jurisdiction in which the course of action took place (Hon. Justice Saleem Marsoof, 2013 and Greenberg, et al. 2011). The parties may resort to court to appeal an arbitral award to have it set it aside but unfortunately in the majority of countries, under their national arbitral laws and regulations, grounds for setting aside such an award are made limited (Organization, n.d.).

(Hemantha,2016) discussed the most common grounds on which local arbitral awards become unenforceable in Sri Lanka. ((Hansen,2019) researched to identify the circumstances for challenging arbitral awards in the Indonesian construction industry regarding infrastructure disputes. In the absence of thorough research in Sri Lanka's construction industry, this research will be conducted on challenging arbitral awards in Sri Lanka, particularly to find out the most common grounds on why there is a challenge in enforcing local arbitration Awards in multi-story construction.

The purpose of this research is, to find why the challenging grounds are generated. Parties spent money to settle the dispute through Arbitration. Then, why they cannot come to a settlement from the final award? Or didn't they consider the above legal grounds at the beginning of this procedure? If that decision also becomes again a problem, it will be a messy situation. Therefore, it is important to understand the procedure.

2.1.2 Arbitration in the construction industry

Disputes about the construction industry can take place within the course of a construction project with two or more parties involved (Hansen, 2019). Whereas, mainly due to many construction disputes, Arbitration has now become the most commonly resorted commercial ADR method (Hinchey, 2012 and Mistelis,2004 and Shontz, et al., 2011 and Abuwanza,2020 and Hansen, 2019 and Wijeratne, 2011). The growth of International Arbitration has also risen especially during the last 40- 50 years. It has easily become the most preferred dispute resolution method in global commercial conflicts in both Asia – Pacific and all over the world (Greenberg, et al., 2011). The parties mutually agree to execute an Arbitrator's judgment who they freely nominate and allow that judgment to be legally binding. Such judgment is final and the award has the legal force of a Commercial High Court (Hansen, 2019 and sims, et al., 2003 and Reynolds, 1993).

2.2 Arbitration history

It is under English Law; modern arbitration is developed. While arbitration in England dates back to the 15th century, it was formally recognized under the Arbitration Act of 1697. With the growth of international commerce, it is referred to as the International Commercial Arbitration (Wijeratne, 2011).

The foundation of English standards of arbitration in Sri Lanka was sanctioned in a resolution structured by the Arbitration Ordinance No.15 of 1856 (Wijeratne, 2011). Dr. A. R. B. Amerasinghe and K. Kanag – Isvaran additionally outlined the arbitration history as like the S.S Wijeratne. After the British conquering of Sri Lanka certain legitimate changes were presented which implied an intense change in the Sri Lankan legal system. The remainder of the change identifying with the agreeable settlement of disputes presented by the British was the Arbitration Ordinance No. 15 of 1866 and Civil Procedure Code of 1899. The system under these extremely old statutes was not fit for managing the assortment of issues associated with the advanced commercial disputes and with the sensible requests of the business community. (Amerasinghe, 2011 and Kanag - Isvaran, 2011)

2.3 Advantages and disadvantage

Sri Lankan Arbitration Act became law on 1 August 1995. (Amerasinghe, 2011 and Wimalchandra, 2007). This enables the arbitration process to become more thorough efficient and reliable (Weddikkara & Abeynayake, 2012). The main advantage of arbitration is that it is consensual and private in nature (Tannen, 2016). Parties allow them to choose their arbitrators, the arbitration seal and the rules of procedure of the arbitrators to be followed under the arbitration-related principle of "party autonomy" (commission,1985 and Weddikkara & Abeynayake, 2012 and Amerasinghe,2011). Arbitrators are not constrained by the same legal proceeding as courts and it avoids considerable costs and delays which are more likely in litigation. (Tannen, 2016). Lord Denning once famously complained: "One of the greatest threats to cash flow is the incidence of disputes. Resolving them by litigation is frequently lengthy and expensive. Arbitration in the construction context is often as bad or worse." (Skene & Shaban, 2002 and Tanielian, May 2013). This arbitration growth was due to its perceived positive qualities such as flexibility, expertise, perceived time performance (Naimark & Keer, 2002 and Stipanowich & Lamare, 2014). For various industries, including construction, banking, mining, manufacturing, healthcare, electricity, communication, retail and wholesale, the above features have attempted to arbitrate (Stipanowich & Lamare, 2014). It seems that the claims on the construction industry are of the most technical sort and the cases are far more connected to the technical nature of the disputes. Therefore, parties are willing to give the case to a person who has the technical knowledge to decide according to the normal procedure (Weddikkara & Abeynayake, 2012). Arbitration is economical compared to court action. Parties do not have to wait for the court's free dates either (Weddikkara & Abeynayake, 2012). The whole procedure is simple too.

In the Sri Lankan arbitration process, researchers have shown some disadvantages such as delaying the process, high arbitrators' fees, less concentration on technical issues, unawareness of the procedure, various solutions offered by different arbitrators, difficulty in challenging the award, inability to conduct multi-party disputes using arbitration. Also, the inability to preserve the relationship between the parties (Abeynayake, 2017 and Cabral, 2018).

2.4 Arbitral awards in the construction industry Sri Lanka

One main role of the arbitrator is to grant the award. It could also be held as the 'make your time up' time (Hartwell, 2001). Arbitral Awards are both final and binding in law. There are only a few rare exceptions to such (Burch, 2010). An Arbitral Award, equivalent to an award granted by the traditional court system- is a written aid that is fully legal. There are held to be six requirements, whereas four out of the six are natural requirements such as the awards must be cogent, complete, certain and final (Hartwell, 2001). Moreover, the arbitrator has full discretionary powers over the arbitral awards. (Burch, 2010). There could be circumstances where the arbitral award may not have enforceability in every jurisdiction if it is inconsistent with local laws or with the arbitration seat rules. Therefore, the arbitration clause in the agreement must be precise and must not have any anonymity (Tanielian, 2013). The enforceability in awards showcases the balance that lies between the autonomy of the arbitral proceedings and the traditional powers of the local courts (Greenberg, et al., 2011). Thereby, if a party isn't satisfied with the arbitral award, they may contest in a court of law to have the award ruled void. But in many countries, this is made limited (Organization, n.d.). When a party needs to enforce an arbitral award, they may apply to the High Court within one year for 14 days of granting the said award (LANKA, 1995). If there is no contention, the court shall give the order favoring the award (Amerasinghe, 2011). Section 32 of the Arbitration Act No. 11 of 1995 encompasses the grounds for contesting an arbitral award. These include formal procedural mistakes or errors- which consists of cases of invalid arbitration agreements, non-arbitral subject matters of awards that conflict with public policy. (Amerasinghe, 2011). Statistics show that around 3.3% of arbitral awards in Sri Lanka have eventually become unenforceable within the cases that were filed in High Court during the years between 2009-2012. Within all such cases that were filed in the aforementioned years, 11.76% of arbitral awards given for construction matters have been made unenforceable because of being set aside or being refused to enforce by the court. This 11.76% is considerably high in comparison to cases in the financial and insurance industries (Hemantha , 2016).

Moreover, the implementation of the Convention of the Recognition and Enforcement of Foreign Arbitral Awards (New York Convention,1958) has been shown to create adverse effects on the efficiency of arbitration. This issue revolves around a few parties from the Middle East countries who have been affiliated with Sri Lankan contractors- not being a part of the aforementioned New York Convention. Thereby, this requires all parties to the agreement to adhere to other various regional arrangements i.e., National Convention on Commercial Arbitration. This, for instance, requires the arbitration process to be held in Arabic (Abeynayake , 2017) Thereby, such adversities hinder the development of the ADR mechanism in Sri Lanka. It shows, that having low understanding skills within parties to an arbitral agreement makes it difficult to enforce arbitral awards. (Hansen, 2019).

3 RESEARCH METHODOLOGY

This research was done using the qualitative method. It was completed based on 2 main case studies and the cases were collected from the High court, Aluthkade related to challenging arbitral awards to identify the reasons to challenge the arbitral award. Both the cases were analyzed using the content analysis method. To get a further understanding about the arbitration procedure of construction projects in Sri Lanka, data was collected from semi-structured interviews and 6 arbitrators were involved in the process. All arbitrators have conducted at least 4 arbitrary cases and the most experienced out of the lot had 15 years of experience in conducting Arbitration. This research is limited to Sri Lankan multi-story buildings and cases were collected from the past five years. Also, this research followed good ethics like no payment was offered to collect cases, Participants of the interview were the parties who were related to the cases including the project manager, the confidentiality of participants. The anonymity of the cases was maintained, and all participants were 18 years and gender were not considered.

4 RESULTS AND DISCUSSION

4.1 Introduction

Data was collected through semi-structured interviews and case studies. From semi-structured interviews, a) Arbitration procedure and b) Reasons to challenge the arbitral award can be identified. Then two case studies found the reasons to challenge the arbitral award. Both semi-structured interviews and the case studies give a clear idea on which areas have performed negatively and require addressing to make the necessary improvements in the arbitration procedure and the reasons to challenge the arbitral award. This will ensure the results are clear so conclusions can be drawn up effectively and subsequently recommendations developed from the conclusions.

4.2 Semi-Structured Interview

Six interviews were carried out on a semi-structured basis respectively with 6 elected freelance arbitrators in the industry. The elected arbitrators were duly interviewed around 30-40 minutes regarding why the arbitration award is being challenged and the arbitration procedure. The one who had the maximum working experience among all, (a period of 15 years) was interviewed initially and had involved with the maximum number of cases, which counts is between 10 to 15. The next one had experience of 10 years in the industry while all others had experience below 8 years. Apart from the first one, all others had involved below 10 cases while the second arbitrator was involved with the least number of cases.

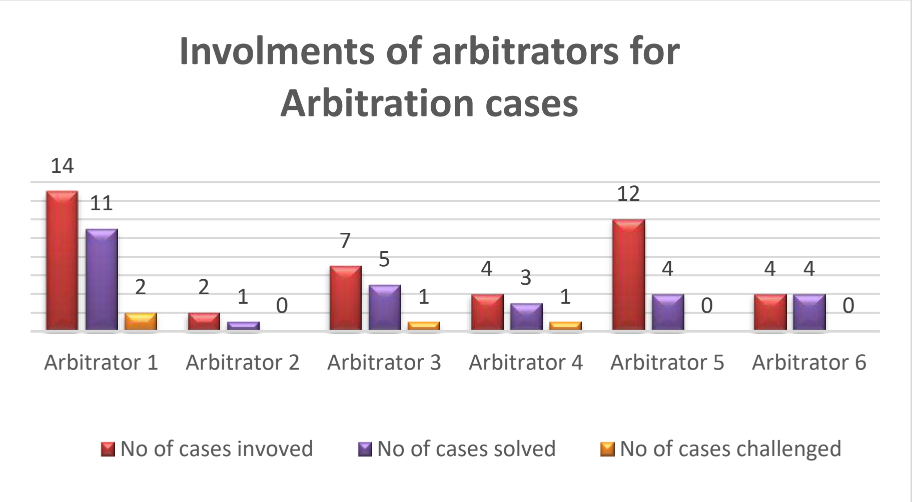

Figure 1. Problems in the current arbitration procedure

4.2.1 Findings - Arbitration procedure in Sri Lanka.

As per all interviewers, the most used arbitration method in Sri Lanka is ad hoc and three arbitrators are there in the panel mostly. If the procedure goes through institutional, Development of

Commercial Law and Practice (ICLP) is the most used arbitrational institute in Sri Lanka. In Sri Lanka, the arbitration procedure goes according to The Act. But all 6 arbitrators suggest some main improvements in this procedure as follows.

Table 1 Problems in Current Procedure

Current Procedure	Problem
1. Fix a date for arbitration meetings	- If an arbitrator is a lawyer, it is very difficult to get a hearing date. - Lack of space in arbitration centers.
2. Appointing arbitrators	-
3. Preliminary meeting	-
4. Statement of the claimant, Statement of response, Statement of reply	- No sufficient period for the response to respond.
5. Oral examinations, written examinations, cross-examinations, and re-examination	- Problem regarding the recording arbitration procedure
6. Witness statement (if parties want)	- Lengthy witness procedure
7. Final submissions	-
8. Issue the award	- Less general knowledge of construction contract law and experiences

<u>Reasons to challenge the arbitral award</u>

According to the findings from interviews, there are some main reasons identified for challenging the arbitral award in the high court.

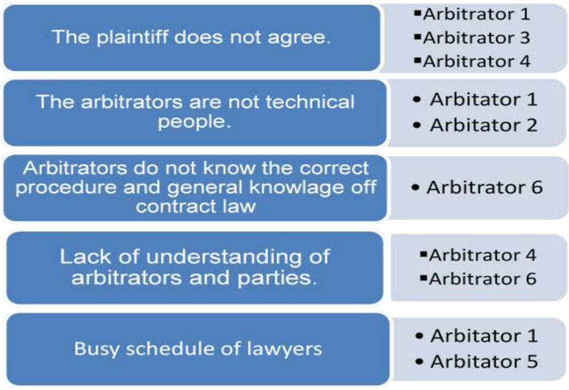

Figure 2. Reasons for challenging arbitral awards

4.3 Case Study

Two case studies were collected from the high court, Aluthkade. The two cases were used to identify the reasons for challenging arbitral awards. The cases are limited to Sri Lankan multi-story buildings and cases collected from the past five years.

Table 2 Summary of case studies

Case study - Summary	Lesson learned
Case 1 ▪ Both Petitioner and Respondent signhed the contract on 3rd December 2014. ▪ Proposed project completion date – 11th December 2016. ▪ Petitioner unable to complet the project as per the singed agreement. ▪ Petitioner received a project termination letter from the respondent on 27th March 2018. ▪ Petitioner referred the case to adjudication but the respondent disagreed. Then the case forwarded to arbitration by the respondent damage claiming 19 million. ▪ Arbitration award was infavour of the respondent recommending to pay 10 million. ▪ Petitioner filed an action against the company under section 32 of the Arbitration Act seeking to set aside the award which was awarded by the Arbitration board on 06.03.2019. ▪ After the inquiry, the court is not seen any reason to set aside the Arbitral Award and Court proceed to enforce the said given Arbitral Award on 06.03.2019	In this case, the judgment is entered in favor of the respondent as per the arbitral award dated 6.03.2019. The petitioner did not provide strong grounds on which an award could be nullified. The court confirmed the given arbitral award was correct after examining the case. This case took nearly one year.
Case 2 ▪ Both Petitioner and Respondent signed the contract on 09th November 2015. ▪ Petitioner was unable to complete the project on the agreed date ▪ Petitiner unable to complet the project on the stipulated time and received a termination letter from the Respondent on 16th May 2019. ▪ Petitioner referred the case to adjudication. ▪ But failing with that both parties referred the case to arbitration on 01st of August 2019. ▪ Arbitration award was in favour of the respondent and petitioner was asked to pay 3million damage claim. ▪ For the purpose of seeking relief Petitioner referred the case to high court to set a side the arbitration award. ▪ After inquiry held at the commercial high court Colombo, the court was in a position that there was no breach of contract according to the facts which have brought before the court. Therefore, the Court proceeds to enforce the said given Arbitral Award dated 2020.01.20	In this case, the judgment is entered in favor of the respondent as per the arbitral award dated 20.01.2020. The court gave judgment saying that there was no breach of a contract. This case shows human nature and attitudes. By referring to the whole matter it is shown that when the respondent asks claims, the petitioner thought the respondent claimed this as revenge before settlement. Also, this case shows the dishonesty of the petitioner.

Both cases were in similar scenario. The Arbitration Board has issued an award in favor of the respondent in both cases ordering petitioner to pay the damage. The dissatisfied Petitioner filed a case against the respondent under section 32 of the Arbitration Act seeking to set aside the award. After receiving the arbitration award it took nearly one year to get the court order to enforce the arbitration award. Reasons stated in both cases by the petitioner to set a side the arbitatin awards are questioning arbitrator's neutrality, Amount of damage calculation was incorrect, Few technical issue relevant to each case. However, the high court agreed on the arbitration award and ordered to enforce the award.

Both cases display that lack of understanding, attitutes, qualities, mis interpretations and lack of knowledge on ADR are the main reasons to challenge the arbitration award in high courts.

5 CONCLUSIONS AND RECOMMENDATIONS

The study findings on reasons and suggestions to improve arbitration procedure is tabulated in table 3. As a summary construction industry stakeholders are lacking in construction contract law, lawyer involvement create unnecessary delay, lack of facilities to conduct arbitration, and lack of administration staff to deal with arbitration cases.

Table 3 Problem, Reasons and suggestions for the arbitration procedure improvements

Problem	Reasons and Suggestions
- No sufficient period for the response to respond.	There should be a sufficient period for the response to respond.
- Lengthy witness procedure	For calling witnesses in the procedure need to change. The current procedure dragged because of the examination & re-examinations of the witnesses by both parties. There should be a proper system for considering witnesses.The main reason is this procedure is too lengthy and time-consuming. As an example, there was an arbitration that continued for 10 years
- If an arbitrator is a lawyer, it is very difficult to get a hearing date.	Lawyers become a reason for dragging the process. It is very difficult to get a hearing date from a lawyer. Therefore, more technical people should involve as arbitrators.
- Lack of space in arbitration centers.	Facilities should improve in the arbitration centers in Sri Lanka. The allocated space is not enough to conduct the number of available arbitration cases.
- Problem regarding the recording arbitration procedure	Usually, the recording arbitration procedure should come within a week. But administrative staff take a few weeks. Without records, arbitrators do not like to have the next hearing.
- Lack of knowledge and experience in construction contract law.	In construction arbitration, professionals are involved. Constrution professional should have required knowledge on construction contract law. If a lawyer involve in arbitration he should have a requeied experience and knowledge in contract law and the construction industry. Furthe they should not adopt unnecessary court proceedings in arbitration process.

Table 4 The main reasons to challenge the arbitral award in the construction industry

Reasons	Mitigatory option
The legal grounds are generated because some arbitrators do not try to mitigate those grounds.	Arbitrators need to consider the reasons which are in the Act. If there is a reason like that arbitrator should reject the case.
Based on human nature and the party's attitudes.	Parties need to agree to pay approved claims if it is reasonable.
Dishonesty of the arbitrator	Arbitrators should reject the cases if they have a conflict of interest.
The arbitrators are not technical people and if they are lawyers and they go only strictly by the law.	Arbitrators need to have the technical knowledge and need to consider technical facts in addition to the written and oral words of the parties
Lack of understanding.	Parties should be educated enough to appoint an arbitrator after studying a particular arbitrator. They need to refer to past cases that were handled by him. Both arbitrators and the parties need to explain their facts clearly to avoid misunderstanding.
Arbitrators have less knowledge of arbitration procedures and principles.	Arbitrators should have good knowledge of good training. Especially they should have a general knowledge of construction contract law and experiences relevant to it. Lawyers cannot adopt the court procedure instead of the arbitration procedure.
Parties hired lawyers	If a dispute arises related to the construction industry, parties should hire professionals.
Lawyers have a very busy work schedule	Lawyers need to give a proper time to the parties to present their cases. Parties have the right to take sufficient opportunity to present their facts. Arbitration centers need to improve their space facilities due to a lack of space in the arbitration centers.

The study aimed to identify the situations where the Arbitral Award is challenging in the construction industry in Sri Lanka. The arbitration Act No.11 of 1995 includes only legally challenging grounds and the purpose of this research is, to find why such grounds are generated. Based on the party's choices they selected the arbitration procedure as a dispute resolution method. And, parties spent money to settle the dispute through this procedure. Therefore, why the parties cannot come to a settlement from the final award? Why not parties consider above grounds at the beginning of this procedure?. Therefore, if the decision becomes again a problem, it will be a messy situation. In that sence the above recommendations are with the main concerns taken from the findings and conclusions of this study. As a guidance to the parties and the arbitrators, the researcher recommends mitigatory options to avoid challenging the award and the improvements of the arbitration procedure.

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Causes for Death and Injuries in Construction Industry in Sri Lanka

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ABSTRACT

The construction industry plays a vital role in the socio-economic development in any country. However, it has been recognized as one of the most hazardous industries in many counties around the world because of the nature of activities and tasks performed at construction sites. Similarly, present-day construction industry of Sri Lanka prioritizes and considers safety as a primary, complex issue due to its high impact on the industry. Accordingly, the aim of this study was to identify the causes for deaths and injuries in construction sites in Sri Lanka and identify actions to mitigate those accidents. The data collection was in the form of documentary review, semi-structured interviews, and questionnaire survey. This study found that the nine (9) most prominent types of accidents that have occurred in Sri Lankan construction sites include falling from heights and scaffoldings, falling debris or objects and machinery accidents. During the last 10-year period 2,135 accidents have been recorded in the construction industry, including both fatal and non-fatal accidents, among which 311 were fatal accidents. As per the study findings, during the period of 2010 – 2020, 14 fatal construction accidents were reported out of every 100 construction accidents. Usually, most of the accidents at construction sites are due to lack of safety at site, working without PPE, inadequate training and lack of supervision. Further, the study also recommends strategies to minimize the identified nine (9) most prominent types of accidents and to improve construction site safety. Findings of this research could help towards reducing the fatal and non-fatal construction accidents in Sri Lanka and to develop safe work environment in the local construction industry.

KEYWORDS: *Construction Industry, Deaths and Injuries, Construction Safety, Sri Lanka*

1 INTRODUCTION

The construction industry plays a vital role in the socio-economic development in any country. Generally, the Gross Domestic Product (GDP) as well as the Gross National Product (GNP) of the economy have been receiving a significant share from the construction industry (Jayasuriya, 2019). However, on the other hand, it has also been recognized as one of the most hazardous industries in many counties around the world because of the nature of the activities and tasks performed at construction sites. The construction projects are being experienced troubles by many risks, complexities, and uncertainties due to frequently happened accidents (Sousa et al., 2014). Therefore, the term "Safety First" is a must-have feature on construction sites, but the frequency of the occurrence of injuries in the construction industry is greater compared to any other industry.

International Labour Organization (2017) discovered that there are at least 60,000 fatal accidents occurring annually, at construction sites across the globe. The rate of fatal injuries at construction industry is much higher in comparison to national average among industries, worldwide. In

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industrialized countries, as many as 25% to 40% of work-related deaths occur in on construction sites, even though the sector employs only 6% to 10% of the workforce (ILO, 2017). Kalatpour and Khavaji (2016) found that the developing countries are the extreme victim of construction accidents due to very low attention to health and safety concerns at construction sites, occupational exposure to hazards is very high and poor quality of record-keeping etc. But most of the developed countries are trying to reduce the damages and losses from construction accidents by preventing, eliminating, and bypassing the possible accidents in construction projects.

At present the local construction industry prioritizes and considers safety as a primary, complex issue due to its high frequency (De Silva and Wimalaratne, 2012). De Silva and Nawarathna (2014), identified that when paralleled with other industries, the construction industry is the most vulnerable due to the recorded number of yearly accidents in between 750-900, among which 50 to 60 were fatalities. Furthermore, according to De Silva and Wimalaratne (2012), more than 30% accidents were symbolized by this annual figure which was approximately 13 times greater compared to other industries. This proves that a plenty of accidents have occurred at Sri Lankan construction sites also.

Accidents are unexpected events that could occur at any circumstance even when the workplace was in safer conditions. The working environment at construction sites changes frequently due to its very nature and parallel to that, the health and safety risks that workers face also change. Therefore, prevention of accidents has progressively evolved to be vital aspect in the construction industry. Accordingly, the aim of this study was to identify the causes for deaths and injuries in construction sites in Sri Lanka and to identify actions to mitigate those accidents. Consequently, four objectives were developed so the research aim could be reached successfully, and those were: to identify the various types of accidents recorded, to identify the resultant deaths and injuries, to establish the specific causes for deaths and injuries in construction sites in Sri Lanka during last 10-year period and to recommend strategies to minimize the accidents resulting from the identified causes. Findings of this research could help towards reducing the accidents in construction sites and developing safe work environment in the construction industry in Sri Lanka.

2 METHODOLOGY

The Ministry of Labour – Industrial Safety Division in Sri Lanka is the only organization with the jurisdictive power to regulate occupational / industrial safety and Health in Sri Lanka. A combination of qualitative and quantitative research approaches was used for this study. Documentary review was conducted by evaluating the statistical data sourced from the Industrial Safety Division, Labour Department of Sri Lanka to achieve the first three objectives of the study. In addition to that, a series of semi-structured interviews and a questionnaire survey were collectively forming the data collection to achieve the fourth objective successfully. For both interviews and the survey, the study sample was determined with 'selective sampling'. The primary findings were cross-referenced with the data collected, as a method of analysis. Preferably, this enabled the research aim to be attained satisfactorily.

The mixed design approach was selected to be ideal for this study since both qualitative data and quantitative data were required in data analysis. As per the study objectives, quantitative approach was required to identify the various types of accidents, their impact, as well as their specific causes during last 10 – year period in construction sites in Sri Lanka. Similarly qualitative approach is required to recommend strategies to reduce the accidents that occur, with the perspectives of project managers, health and safety officers, site supervisors and rest of the site employees. The mixed approach facilitates a more diverse data collection for the study, which in turn enhanced the probability of delivering suitable findings at the end of the study. Since the nature of this research is unique and characteristics were well defined, the participants of the study are required to have at least 5 years of experience in the building construction industry, therefore selective sampling was opted.

As authentic input of individuals based on their experience and knowledge was an essential prerequisite for the research, interviews were conducted. In order to recommend strategies to minimize the accidents resulting from the identified causes, semi structured interviews were conducted as it enables the interviewer to question and clarify at will, deviating from the pre-determined questions on the guidelines when necessary. The criteria were prepared abiding by the relevant ethics in the industry and research. Four (4) semi structured interviews were conducted with selected industry professionals namely a project manager, health and safety officer, site supervisor and an engineer, who possess more than 5 years of experience and knowledge in building construction industry in Sri Lanka.

A questionnaire survey was used to clarify the recommendations that were given by the industry professionals in the semi – structured interviews as well as to validate the suggestions to mitigate the construction accidents. The questionnaire was developed by focusing on the answers given by the industrial professionals during semi – structured interviews as well as the data gathered from the Labour Department. The questionnaire which comprised of 20 questions was divided into three parts to correspond to the objectives of the study. A total number of 67 industry professionals responded to the questionnaire survey, which was distributed among 80 selected industry practitioners representing a cross section of the industry professionals who has exposure in both consultancy and contractor practices. Response rate was 84%, which was at well acceptable level. Relative importance of proposed recommendations was calculated and the ranking of the same was used to select most effective suggestions to improve the construction site safety in Sri Lanka.

3 RESULTS

Results were derived through the data collected through documentary review from the Labour Department, semi-structured interviews, and questionnaire survey. Initially, the nine (9) most prominent types of accidents that have occurred in Sri Lankan construction sites within the last 10-year period were identified. The analysis of the research was then based on the same.

3.1 Various types of construction accidents

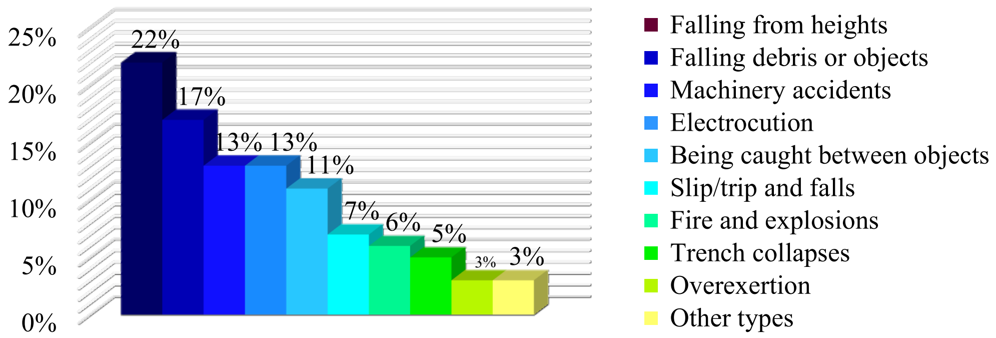

Figure 1: Percentages of types of accidents in Sri Lankan construction sites during 2010-2020
Source: Data analysis performed on the statistics of the Industrial Safety Division, Labour Department of Sri Lanka

"Falling from heights" accidents were the most common type of accidents that occurred in Sri Lankan construction sites, accounted for approximately 22% of all on-the-job accidents of construction workers. This was followed by "falling debris or objects", accounting for 17% in Sri Lankan construction sites. As per the statistics, 13% of accidents were from the "machinery accidents" and "electrocution" categories. Additionally, "being caught between objects", "slips/trips and falls" and "fires and explosions" accounted for 11%, 7% and 6% of total number of accidents that occurred on Sri Lankan construction sites in last 10-year period, respectively. There were also 5% and 3% of accidents caused by "trench collapses" and "overexertion" in construction sites according to the statistical records of the Industrial Safety Division Sri Lanka Labour Department.

3.2 Statistics of deaths and injuries

Table 1: Fatal accidents in construction compared to all other industries during 2010-2020

Year	Number of fatal accidents		Percentage of fatal accidents in construction out of total accidents
	All other industries, except construction	Construction Industry	
2010	44	20	31%
2011	28	32	53%
2012	49	31	39%
2013	49	22	31%
2014	48	29	38%
2015	57	24	30%
2016	52	19	27%
2017	43	25	37%
2018	76	46	38%
2019	44	40	48%
2020	48	23	32%
	538	**311**	**37%**

Figure 2: Percentage of fatal accidents in construction out of total accidents during 2010-2020

Source: Data analysis performed on the statistics of the Industrial Safety Division, Labour Department of Sri Lanka

In the period of 10 years under consideration, a total of 849 fatal accidents were reported across all industries in Sri Lanka. Out of this, 311 of fatal accidents happened within the construction sector. All other industries together reported 538 fatalities. As figure 2 indicates, these numbers amount to 37% of all fatal occupational accidents in Sri Lanka in the last 10-year period of 2010-2020, taking place in the construction industry. As per the statistics, more than one in every three fatal accidents were reported from construction. It is also notable how the fatal accidents in the construction sector exceeded the number of deaths in all other industries in 2011.The gravity of the statistics should comprehend with respect to the number and scale of all other industries in Sri Lanka. As such, the implications are undeniably concerning.

Table 2: Non - Fatal accidents in construction compared to all other industries during 2010-2020

Year	Number of non-fatal accidents		Percentage of non-fatal accidents in construction out of total accidents
	All other industries, except construction	Construction Industry	
2010	1,284	172	12%
2011	1,078	167	13%
2012	1,171	148	11%
2013	1,189	155	12%
2014	1,149	161	12%
2015	1,221	171	12%
2016	1,314	162	11%
2017	1,435	197	12%
2018	1,263	204	14%
2019	1,302	159	11%
2020	988	128	11%
	13,394	**1,824**	**12%**

Figure 3: Percentage of non-fatal accidents in construction out of total accidents during 2010-2020

Source: Data analysis performed on the statistics of the Industrial Safety Division, Labour Department of Sri Lanka

Within the last 10 years, 15,218 non-fatal accidents were reported to the Industrial Safety Division of the Sri Lanka Labour Department. Great care should be taken when considering these statistics, as it is probable that the actual number of accidents occurred, may vary from the number reported by employers. Out of the total number of non-fatal accidents reported, 1,824 occurred in the construction industry. Other industries in Sri Lanka have reported 13,394 accidents. As percentages, these numbers indicate that 12% of all reported accidents were from the construction sector. 88% of the non-fatal accidents occurred in other industries. However, it would inadvertently be noted that the percentage of non-fatal accidents reported to the Sri Lanka Labour Department, are substantially lower than the fatal accidents in the same period. Construction workers getting individual treatments after non-fatal accidents without reporting it as an occupational accident could be a main reason behind this difference.

During the concerned period, there is a very high variation of fatal construction accidents as a share of total fatal occupational accidents ranging from 27% to 53%. In terms on non-fatal accidents, this is not evidenced over the study period. Non – fatal construction accidents as a share of total non – fatal occupational accidents varied from 11 % to 14%, showing a limited variation over the period.

4 DISCUSSION

4.1 Causes of identified construction accidents

Table 3 emphasizes on the specific causes for the nine (9) most prominent types of accidents that have occurred on Sri Lankan construction sites during last 10-year period which were collected through documentary review, of Industrial Safety Division of the Labour Department of Sri Lanka.

Table 3: Causes of identified accidents in Sri Lankan construction sites

Type of Accident	Causes and Injury Types
Falling from heights	<u>*Causes*</u> • Unprotected roof edges, floor openings, structural steel, and leading edges etc. • Improper scaffold construction • The whole scaffold structures were not inspected by a supervisor before use • Workers overreaching from scaffolds and high working platforms, that result in imbalance • Workers' overconfidence and taking shortcuts • Inclement weather when performing roof work <u>*Types of injuries*</u> Fractures, intra-thoracic injury, permanent disabilities, bruises, brain injuries etc.
Falling debris or objects	<u>*Causes*</u> • The materials and objects were liable to fall as it is placed at the window edge on an upper floor • No secure fenders/bracings had been installed at the external wall of the building near the podium • Materials were not properly tied not stacked in a balanced way before lifting • Heavy loads unsafety being lifted pass an area where workers were working • Insufficient signage warning for passers-by to keep them out • Inadequate support of panels and nets placed vertically and horizontally to prevent accidental debris, objects, materials falling <u>*Types of injuries*</u> Fractures, concussions, bruises, paralysis, brain injuries, permanent disabilities etc.
Machinery accidents	<u>*Causes*</u> • Failure to carry our routine maintenance of machinery and equipment • Workers not being provided with adequate training to safely operate machinery • Workers not being supervised while operating machines • Workers not following the manufacturers' instructions while operating machinery • Operating machinery without any Personnel Protective Equipment (PPE) • Selection of incorrect equipment and machines for the particular job <u>*Types of injuries*</u> Laceration, bruises, head injuries, broken bones, damage to internal organs etc.
Electrocution	<u>*Causes*</u> • Use electrical equipment while standing on wet conditions • The electric wires were not properly earthed • The power socket was not fitted with an earth leakage circuit breaker

	• Not disconnecting the power supply before carrying out constructions • Improper use of extension and flexible cords and touching a damaged wire cord • Not following manufacturers' instructions when using electronic appliances *Types of injuries* Shock, burns, physical injuries from falls due to contact with electricity, electrocution, vision and hearing damage, brain damage etc.
Being caught between objects	*Causes* • Machinery or vehicles not properly powered down at the time of maintenance or repair • Wearing dangle or loose cloths or jewelleries when working at the job site • Jacks that were not placed on a firm foundation or secured one and walls not secured properly with braces • Employees being pressurized mentally or physically while performing work tasks • Lack of warning signage around worksites where machinery was being operated • Inadequate training or preparation *Types of injuries* Amputations, traumatic brain injury, internal organ damage, spinal, bruises, fractures etc.
Slips/trips and falls	*Causes* • Grease, water or another slippery substance on a floor, platform, or stairways • Boxes, cords, equipment and the like left in walking paths • Poor lighting • Inappropriate safety footwear • Wind driven rain through doorways • Insufficient signage warning for passers-by *Types of injuries* Musculoskeletal injuries, fractures, dislocation of bones, bruises, traumatic brain injuries etc.
Fire and explosions	*Causes* • Improper use or storage of flammable liquids and chemicals etc. • Welding or abrasive cutting techniques used in places not specially prepared for such works • Not following manufactures' instructions while handling or working with the flammable liquids, chemical and gases • Smoking at work and around flammable liquids, combustible materials, gases etc. • Workers are not properly trained and/or supervised • Handling chemicals and flammable liquids etc. without any necessary Personnel Protective Equipment (PPE) *Types of injuries* Burns, lung damages, cancers, loss of vision, smoke inhalation, emotional distress, skin infections, suffocation, disfigurement, etc.
Trench collapses	*Causes* • Placing spoil pile too close to a trench where rock and dirt fall in on employees

	• Failure to provide daily inspection of excavation • Failure by the designated competent person on the jobsite to protect workers from potential cave-in • Hazards created by water accumulating in a trench • Improper shoring and trench boxes to prevent sides of the trench from caving in • Working close to the trench with heavy machinery that vibrates around the trench *Types of injuries* Brain damage from suffocation, traumatic brain injuries, spinal injuries, nerves damage, broken bones etc.
Overexertion	*Causes* • Employees engaging in manually exhaustive tasks for excessive time periods • Workers not being provided with required training on how perform their manual tasks • Workers being tasked with jobs that exceed their physical capabilities • Workers were suffering from health problems • Workers had not enough sleeping hours • Lack of supervision *Types of injuries* Back injuries, muscle strains, sprains, neck injuries, heat exhaustion, joint/tendon, and connective tissue injuries

Source: Summary Findings of the Documentary review of Industrial Safety Division, Labour Department of Sri Lanka

The study identified nine (9) most prominent types of accidents that have occurred in Sri Lankan construction sites in the last 10-year period. "Falling from heights" accidents were the most common type of accidents that occurred in Sri Lankan construction sites, which accounts for approximately 22% of all on-the-job accidents of construction workers. This was followed by "falling debris or objects", accounting for 17% of on-the-job accidents, while 13% of accidents each were from the "machinery accidents" and "electrocution" categories. Additionally, "being caught between objects", "slips/trips and falls" and "fires and explosions" accounted for 11%, 7% and 6% of total number of accidents that occurred on Sri Lankan construction sites in last 10-year period, respectively. There were also 5% and 3% of accidents caused respectively by "trench collapses" and "overexertion" in construction sites according to the statistics.

4.2 Measures to mitigate identified accidents

Table 4 emphasizes on the suggestions that were proposed by the construction industry practitioners during questionnaire survey, which was utilized to minimize above mentioned nine (9) most prominent types of accidents that have occurred on Sri Lankan construction sites over the last 10-year period.

Table 4: Measures to mitigate identified accidents in Sri Lankan construction sites

Type of Accident	Preventive Measures
Falling from heights	• Make sure that fall protection equipment is adequate and maintained. • Organize regular fall preventing training. • Make sure that floor holes and openings are protected by guardrails or floor hole covers

	• A qualified person must overlook and inspect as scaffolds are being set-up, changed, moved, and deconstructed. • For scaffolds that stand higher than 10 feet, above a personal fall arrest system or guardrails are mandatory. • Eliminate the fall hazard by rescheduling, isolating the take or changing the task.
Falling debris or objects	• Make sure loads being hoisted are properly rigged and secured and ensure the rigging equipment is in good condition. • Keep tools and other materials away from open edges, place toe boards and stack materials in a balanced and secure way • Use barricades to block off exclusion areas where workers are not allowed or below the work area where drop hazards may exist. • Make use of nets, canopies, or platforms to catch debris and objects. • Post warning signs at hazardous work zones. • Always wear protective safety gears such as helmet, hard-toe boots etc. while on the site
Machinery accidents	• All workers must be provided with adequate training before start operating machinery. • Follow maintenance schedules and inspection of work equipment / machinery. • Wearing PPE while operating machinery. • Manufacturers' recommendations and instructions should be adhered to, while operating machineries. • A competent person must be supervised to ensure that safety instructions and procedures are followed. • Make sure that appropriate machineries are available to perform tasks safely.
Electrocution	• Ensure all electrical equipment is properly grounded or double insulated. • Inspect electric equipment before use and check extension and power cords for wear and tear. • Use lock-out or tag-out practices to make sure that circuits are de-energized. • Mark warning lines to indicate power line clearance distances, horizontally and vertically. • Use relevant PPE, follow the directions, and obey safety warnings when operating electrical equipment. • Employees should be trained regarding power line hazards and about the available protective measures.
Being caught between objects	• Train all workers to operate their respective machines and vehicles safely. • Refrain from wearing loose or dangling clothing or jewelleries that can get caught by moving parts of machines. • Turn off all machines and vehicles when they are not in use, when changing accessories, and prior to service or cleaning. • Strictly follow the max. Weight limits prescribed when lifting, moving, and storing loads. • Always wear protective safety gears while on the job. • Barriers to keep people away from dangerous machinery/equipment of vehicles.
Slips/trips and falls	• Make wearing work boots with slip and puncture resistance mandatory for workers. • Make sure all areas have adequate lighting to illuminate any potential hazards. • Clean up spills, drips, and leaks immediately. • Remove garbage and debris etc. at regular intervals. • Post adequate warning signs at hazardous areas • Regularly inspect worksites to identify any hazards that could potentially cause slips, trips, or falls.

Fire and explosions	• Ensure that manufacturer's instructions are strictly adhered to when installing, maintaining, protecting and using chemicals, gases flammable liquids etc. • Banning the consumption of alcohol, drugs and smoking by employees at the site. • Make sure that hot works are carried out in a separate area situated well away from explosive substances and the main structure. • Wearing adequate PPEs while handling chemicals, flammable liquids etc. • Ensure workers receive appropriate training on procedure they need to follow in the event of fire/explosion, including fire drills. • Make sure the fire exits and escape routes are clearly marked and kept unobstructed.
Trench collapses	• Ensure proper use of sloping, shoring, benching, trench shield and boxes for protection against any potential collapses. • Keep excavated soil (spoils), equipment or other materials that may fall into a trench, a minimum of 2 feet away from opening. • Use ladders, stairs or appropriate design ramp when going into and coming out of excavations. • A competent person must inspect the trenching and excavation operations. • Eliminate the cave-in hazards due to weather by rescheduling or changing the task. • A qualified person should carefully examine and evaluate soil conditions.
Overexertion	• Use appropriate techniques when lifting and handling heavy loads or material. • Use forklifts, hand trucks and cranes available to move heavy loads around. • Assign different tasks to employees, to increase the variety of physical movements. • Before giving a job, check that the workers are in acceptable physical condition. • Provide adequate breaks for employees. • Ensure workers receive appropriate training to perform the relevant tasks safely.

Source: Summary Findings of the questionnaire survey conducted among construction industry practitioners

5 CONCLUSION

The documentary review utilised statistical data sourced from the Industrial Safety Division of Sri Lanka Labour Department to achieve the first objective. Accordingly, the nine (9) most prominent types of accidents that have occurred in Sri Lankan construction sites in the last 10-year period were identified namely falling from heights, falling debris or objects, machinery accidents, electrocution, being caught between objects, slips/trips and falls, fires and explosions, trench collapses and overexertion. The study emphasized on the specific causes for the nine (9) most prominent types of accidents that have occurred on Sri Lankan construction sites. 2,135 construction accidents (including both fatal and non-fatal accidents) were reported in Sri Lanka during 2010 – 2020, out of a total of 16,067 occupational accidents, representing a share of 13 % of all reported accidents were from the construction sector. During the same period, a total of 849 fatal accidents were reported across all industries in Sri Lanka, while 311 of these accidents were fatal construction accidents, amounting a share of 37% of all fatal occupational accidents. As per these statistics, more than one in every three fatal accidents, were reported from the construction sector. This scenario is quite different, in terms of non-fatal accidents. Out of a total of 15,218 non-fatal accidents reported during the last 10-year period, only 1,824 non-fatal accidents were reported from construction industry, accounting a share of 12% from the total non-fatal occupational accidents during the period under concern. Therefore, it is evident here that the prominence given to site safety of Sri Lankan construction sites yield satisfactory results.

The study was able to identify 16 methods to improve overall construction site safety through semi – structured interviews, and questionnaire survey among industry practitioners. Accordingly, recommendations were made on proposed strategies to minimize construction accidents and to improve construction site safety, utilizing the output of relative ranking process. The following recommendations were suggested accordingly, in order to improve the construction site safety in Sri Lanka.

- Construction companies must not only provide safety training for all the staff, but these trainings must be adequately and progressively provided to increase the workers' knowledge of safety, technicality of work procedure and machinery usage, and create familiarity to the work environment.
- The employer should secure safety protection measures at the jobsite and provide adequate PPEs to the workers and maintain their validity for use.
- The employer is required to enroll qualified and certified safety and health supervisors at his worksites and assure those concerned are aware of their responsibilities and duties toward keeping the worksite safe, and also how to improve it to be healthier and safer for everyone.
- New rules and regulations should be implemented by the regulatory bodies to suit the present industrial situation. In addition, the process of making policies, guidelines, standards etc. is very slow due to lack of resources, experts, and other influences, which need to address appropriately.
- Management should practice a continuous safety development process that includes six steps: creating safety regulations, identify hazard, assess and evaluate risk, decide precaution, record findings and updating in relation to the work condition.
- To prevent unsafe behavior of employees, operating procedure could be formulated, those who violate regulations could be penalized, incentive programs could be developed to reward those who adhere construction site safety protocols, health checks of employees could be conducted.
- Daily safety briefing should be conducted before the work commences and formal safety meetings should be conducted weekly at the project level in order to take necessary decisions on site safety.

6 ACKNOWLEDGEMENT

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Cryptocurrency Price Prediction: A Comparative Study using LSTM, GRU and Stacking Ensemble Algorithm for Time Series Forecasting

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Abstract

Technology has significantly reshaped how humans interact with their tangible and intangible surroundings. Cryptocurrency is considered to be one of the most recent technological inventions which revolutionized how we perceive currencies and their functionality. It has become popular because of its safety, security and anonymity. However, volatility remains one of the major issues with cryptocurrencies to this day. Therefore, the primary aim of this paper is to develop LSTM (Long Short-Term Memory), GRU (Gated Recurrent Units) and a Stacking Ensemble Learning algorithm that efficiently predicts the price of a cryptocurrency for a given period of time. The predictions are then observed and analysed to determine the comparative performance of the said algorithms.

Keywords
Cryptocurrency, LSTM, GRU, Stacking Ensemble, Neural Network, Machine Learning, Artificial Intelligence

1 Introduction

The rise of cryptocurrency in recent years has influenced us to re-imagine how society thinks about money. It has attracted a lot of attention because of some unique characteristics as opposed to traditional currency. Being fairly new and completely unregulated, Bitcoin and other Cryptocurrencies has their fair share of drawbacks such as scalability, volatility, security issues etc. It is forecasted that cryptocurrencies will be widely adopted and accepted throughout the modern world within next 20 years. For it to reach that point, risks associated with cryptocurrency shall be assessed and addressed accordingly. One of the major issues with cryptocurrencies, partly because of which it has drawn so much attention is its volatility. Public perception, low adoption rate is some of the major reasons behind its volatile behaviour. Therefore, this paper attempts to predict the price of a cryptocurrency as accurately as possible using three different time series forecasting algorithm. The problem will be approached using LSTM (Long Short-Term Memory), GRU (Gated Recurrent Units) and finally a combination of the two which is called Stacking Ensemble, a special type of meta learning model which combines two well performing algorithm and determines which algorithm is to use at a certain point of time. Stacking Ensemble is known for bringing out the best from the algorithms it uses to learn the context. LSTM is known to perform well on longer sequence of data whereas GRU is known to be computationally efficient. Hence, these algorithms were chosen to solve this linear regression problem.

1.1 Objective

Due to the recent crypto boom, the combined value of cryptocurrencies is increasing on a daily basis. The boom itself was a result of the volatile behaviour of cryptocurrencies. However, it is evident that this boom is a double-edged sword. The volatility that caused the price to soar has also shrunk the market value after a short while. Very recently however, a steady growth has been observed in Bitcoin's price. The total value of all cryptocurrencies has already crossed 2 trillion mark (A. Kahrapal, 2021). Digital currencies are already accepted in some big companies and are expected to be accepted by more companies as we move forward. As a result, they are considered to be a very lucrative investment

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opportunity. Compared to fiat currencies such as Malaysian Ringgit or US Dollar, cryptocurrencies are fairly new and still remains a subject of extensive study. Even though these currencies fluctuate similarly as fiat currencies, what causes these fluctuations is a highly debatable topic. Due to its volatile behaviour, unpredictable factors and wide range of popularity, forecasting its price and behaviour has been a point of keen interest of Machine Learning algorithm developers. Over the past few years, different types of Deep Learning algorithm were applied to accurately predict the price and behaviour of cryptocurrencies. However, it was soon concluded that cryptocurrency time-series forecasting closely relates to the random walk process and it is very complex to accurately predict the price (I. E. Livieris et al. 287, 2021). Moreover, the price of cryptocurrencies over time lacks stationarity. Stationarity refers to a general similarity of pattern which takes place over time. Non-stationary data are always highly volatile which means all features associated with that data unpredictably changes over time. Therefore, a reasonably accurate forecasting algorithm is vital for making a safer investment and understanding cryptocurrencies better in general as these currencies are here to stay. Therefore, this study aims to forecast cryptocurrency price based on previous data using these three different algorithms and comparatively analyse their performance.

2 Neural Networks

Artificial Neural Network (ANN) or simply neural network is one of the most significant and promising technologies of 21st century. However, neural network cannot be considered as a recent invention. The very first concept of an artificial neural network was proposed by Warren McCullough and Walter Pitts in 1944 (L. Hardesty, 2021). The idea, concept and even some terminologies are largely inspired by the functionality of human brain, nature's finest and most complex creation. Artificial neural network's biological counterpart consists of almost a staggering 100 billion neurons. These neurons function as a whole using their massive 100 trillion synapse connections which translates to 1000 synapse per neuron. At its core, artificial neural network attempts to mimic the characteristics of a human brain. The basic element is a Neuron which takes input and produces output based on given constraints. It is very trivial at a single neuron level but when thousands or even millions of neurons are densely interconnected, they can perform complex tasks easily.

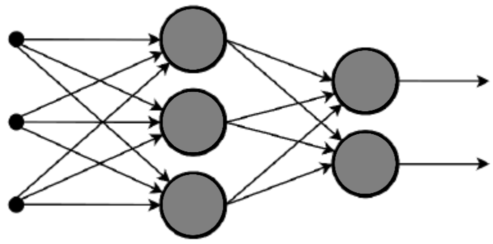


Figure 1. Single Layer Neural Network (Wikipedia)

Modern neural networks consist of several layers of neurons. Neural networks consisting of multiple layers is called Deep Neural Network. A single neuron is usually connected to several other neurons (Figure 1). It receives input from some neurons, processes it and sends it to the rest of the connected neurons. During the training of a learning algorithm, a neuron assigns weight to its incoming neuron connections. While active, the input data is multiplied by the weight and generates a single number result. The result is then passed on to the next neuron until it reaches to the output layer generating a result which is similar to the training data. During this period, the weight and constraints are adjusted to generate an output that complies with training data. This is how a Neural Network functions at a very basic level. However, modern Neural Networks are comprised of more complex procedures to perform advanced tasks.

2.1 LSTM

Long Short-Term Memory (LSTM) was introduced in 1997 to overcome the Vanishing Gradient problem. During that time period, there were other suggested methods to overcome this problem such as Back-Propagation Through Time (BPTT) and Real Time Recurrent Learning (RTRL). However, these methods could not efficiently solve the problem. The LSTM algorithm, however, could learn to bridge the time intervals without losing short time lag capabilities. LSTM makes use of a gradient-based algorithm which implements a constant error value throughout the entire LSTM Neural Network. The constant error flow was implemented using self-connected linear network. A multiplicative input and output gate protects and controls the content of the memory. This results in a complex and efficient memory cell or neuron. The memory cell can be summarized as below (S. Hochreiter and J. Schmidhuber, 1997, p.1735):

$$y^{out_j}(t) = f_{out_j}\left(net_{out_j}(t)\right) \tag{1}$$

$$y^{in_j}(t) = f_{in_j}\left(net_{in_j}(t)\right) \tag{2}$$

Where;'

$$net_{out_j}(t) = \sum_u w_{out_j u} y^u\,(t-1) \tag{3}$$

$$net_{in_j}(t) = \sum_u w_{in_j u} y^u\,(t-1) \tag{4}$$

And

$$net_{c_j}(t) = \sum_u w_{in_j u} y^u\,(t-1) \tag{5}$$

The summation limit u refers to different variables such as input units, output units, gate units or memory cells depending on the state of the network. These units contain information about the present state of the network. For example, an input gate may use information from other gates to determine whether to store or delete its content for the next feed. At time t, c_j's output $y^{ej}(t)$ is (S. Hochreiter and J. Schmidhuber, 1997, p.1735) (Figure 2):

$$y^{cj}(t) = y^{out_j}(t)h(S_{cj}(t)) \tag{6}$$

Where the internal state of the network is:

$$S_{c_j}(0) = 0 \tag{7}$$

$$S_{c_j}(t) = S_{c_j}(t-1) + y^{in_j}(t)g(net_{cj}(t)) \tag{8}$$

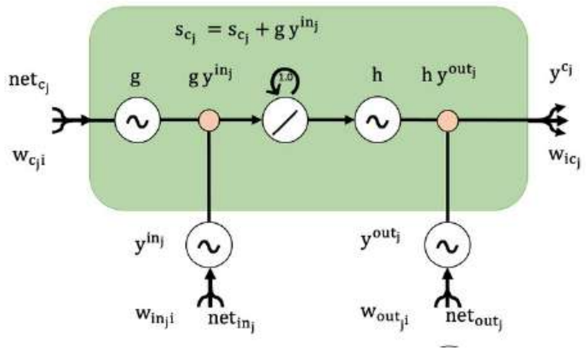


Figure 2. LSTM Memory Cell Architecture (R. Kizito et al. 1)

Gate Units: Gate units are introduced to avoid weight conflicts. The memory cell error flow of c_j is controlled by in_j. out_j controls the error flow from output connections. The network decides which information to keep using in_j and when to access memory cell using out_j.

Learning: A RTRL variation which takes dynamic results caused by input and output gates. Once and error signal triggers a memory cell, it is scaled by the output gate activation. Within the memory cell, the error signal can flow back without any manipulation. However, it is scaled once more by the input gate activation function when it passes through the input gate after leaving the memory cell. LSTM's computational complexity performance is considered to be very efficient which is $O(W)$ where w is the number of input weights.

2.2 Bidirectional LSTM

The concept of a Bidirectional Neural Network was introduced by M Schuster and K Pallial in 1997. The primary goal of this algorithm was to overcome the limitation of a regular RNN. In its very core, Bidirectional Neural Networks are same as a RNN except for one thing. That is another hidden layer which is a identical but reversed input layer. Of these two layers, one works in a positive time direction and the reversed layer works in negative time direction. Simply put, Bidirectional LSTM is two layers of LSTM where one layer works forward and the other working in a backward time direction (Figure 3). The algorithm essentially provides data from both past and future to the Neural Network. Therefore, the network has more context of the data which lets it find hidden connections and correlations between past and the future (M. Schuster and K. K. Paliwal, 1997, p.2673).

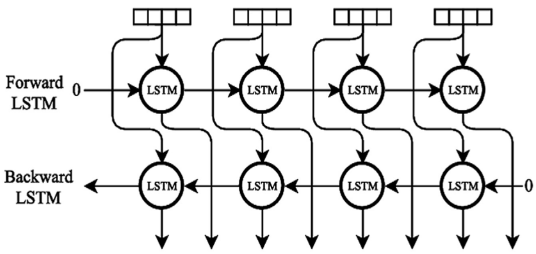


Figure 3. Bidirectional LSTM Architecture (S. Cornegruta et al. 2016, p.17)

Bidirectional LSTMs has proven to be very efficient over time because of its better understanding of the context and time.

2.3 GRU

Gated Recurrent Unit or GRU was introduced by Kyunghyun Cho (K. Cho et al. 2014) in 2014. It was developed based on the principle of LSTM and can be considered a simpler version of LSTM However, unlike LSTM it does not have an output gate and has a reset gate instead. This reset gate modulates the flow of information within the neural network (J. Chung et al. 2014). The gates used in GRU are update gate, reset gate and a current memory gate. GRU is more resource efficient and consumes less time for training than LSTM because of fewer gates as it does not maintain internal cell state like LSTM. The gates of GRU are:

Update Gate: The Update Gate is responsible for determining how much and which information passes through it to future. This essentially prevents the vanishing gradient from happening. The Update Gate can be calculated by:

$$z_j = \sigma[w_z x]_j + [U_z h_{t-1}]_j \tag{9}$$

In the equation above σ represents logistic sigmoid function. x and h_{t-1} represent input and the previous hidden state. W_r and U_r are weight matrices.

Reset Gate: The Reset Gate is responsible for determining how much and which information is to forget. The Update Gate can be calculated by (K. Cho et al. 2014):

$$r_j = \sigma[w_r x]_j + [U_r h_{t-1}]_j \quad (10)$$

The GRU unit is activated by the following equation:

$$h_j^{(t)} = z_j h_j^{(h-1)} + (1 - z_j)\tilde{h}_j^{(t)} \quad (11)$$

Where;

$$\tilde{h}_j^{(t)} = \Phi([w_x]_j + [U(r \odot h_{(t-1)})]_j) \quad (12)$$

where r represents Reset Gate and $\odot$ is an element-wise multiplication. In this above formulation, when the value passed from reset gate is close to zero, the hidden state must ignore the previous hidden state and only accept the current state. This is how Reset Gate effectively filters irrelevant information. The update gate controls the amount of information to be passed over to the hidden state. This is where GRU is similar to LSTM and it helps remember long term information to be utilised during output. In simple terms, GRU lacks memory unit unlike LSTM. Hence, the entire hidden state is exposed and can be taken advantage of. Since it has less gates than LSTM, it can train faster than a LSTM.

2.4 Ensemble Learning Algorithm

Ensemble Learning refers to a learning model where two or more Machine Learning models are combined or generalized to achieve better performance. It is known to improve the result accuracy of different problems such as classification, regression etc. When two or more learning algorithm displays similar performance for a problem, Ensemble Learning algorithm can be used to improve the overall performance and achieve better results. It can also be used to error reduction, choosing optimal features, incremental learning, non-stationary learning etc. Technically, the number of possible ensemble learning algorithm can be unlimited due to a lot of possible combination and approach. However, regardless of possible combinations, the principal concept is same for all applications. There are a different types of Ensemble methods such as Bagging, Boosting, AdaBoost (Adaptive Boosting), Stacking etc. Stacking or Stacking Ensemble was used in this paper and discussed further below.

2.5 Stacking Ensemble Learning Algorithm

Stacking Ensemble is also known as Stacked Generalization. It was first introduced by David H. Wolpert back in 1991(D. H. Wolpert, 2009, p.2776). Stacking Ensemble is capable of combining different types of models to produce a more accurate result. The architecture of Stacking Ensemble consists of two types of models. These are Base model and Meta model or Meta-learning algorithm (Figure 4). Base models are models which will be used by the Meta-learning algorithm to make better generalization. The approach is such that the Ensemble learning algorithm can determine how to best combine the base models. In its core, Stacking Ensemble use trainable combiners. The combiners are trained on the base models to learn which model performs well on which period and produces a generalized and usually more accurate results than its base models (T. Schaul and J. Schmidhuber, 2010, p. 4650). Stacking is justified when the base models have similar performance on the same problem. Stacking can be used to improve overall solving accuracy. However, better performance than the base models is not always guaranteed. The performance depends on a number of factors. These factors include but are not limited to base model complexity, proper representation and sampling of training dataset, learning approach of the base models etc.

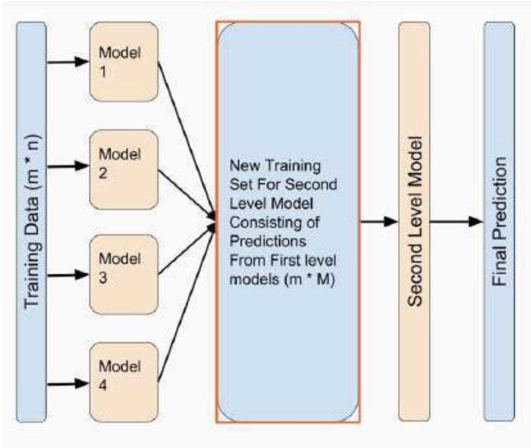


Figure 4. Stacking Ensemble Architecture (S. Cornegruta et al. 6103)

3 Data Acquisition & Analysis

Acquiring clean and relevant data is arguably the most important steps when it comes to training a Machine Learning model. Big data and its potential application are the reason Machine Learning has become mainstream today. It does not matter how big the dataset is, if it is flawed or inaccurate, the ML algorithm, however advanced it is, is bound to yield a garbage output.

Dataset for this project was collected from *www.binance.com* using an Application Programming Interface (API). The collected dataset was of the cryptocurrency called Binance Coin (BNB).

The time line of the collected data is 1 year. It means whenever the API in run, it will collect past 1 years BNB data from Binance website. However, only the last three month's data was used to train and test the ML algorithm. This is because of the limitation of Graphics Processing Unit (GPU). Even though modern GPU's have a very high computational power in comparison to old ones, processing a one year long time sequence would take extremely long time and might even crash the compiler.

Upon collecting the data, it is stored in a text file in the local drive. A total of five data points were collected for BNB which are: *time, price high, price low, price, volume*. *time* refers to the time when the observation was recorded, *price high* and *price low* refers to the highest and lowest price for a given timeline observation. *price* refers to the closing price of the day and *volume* is the amount of trade that took place to and for BNB. The collected data sample can be summarized as below (Table 1):

Table 1: BNB Dataset Structure

Time	Price High	Price Low	Price	Volume
1622381699999	329.11000000	328.04000000	328.58000000	2529.41150000
1622381759999	328.62000000	327.68000000	327.98000000	4581.87200000
1622381819999	328.75000000	327.45000000	327.87000000	1799.25960000
1622381879999	328.00000000	327.63000000	327.63000000	3000.92770000
1622381939999	328.35000000	327.79000000	327.79000000	1873.67880000

3. 1 Data Pre-processing

Data Pre-processing refers to the modifying and structuring the dataset before feeding it to the ML algorithm. Without structuring of some extent, the raw data may cause anomaly in the result. Therefore, it is important to modify the raw data to follow a structure. For this project, only past three month's data will be used to train and test the algorithms. The interval of the collected data was 1 minute. This means that all five datapoints collected were within 1 minute's interval. The data pre-processing includes randomly removing a portion of the data and scaling/normalizing it. Data Scaling is vital to maintain a certain range of the output. Cryptocurrencies are known to be extremely volatile. Therefore, the difference between the high and low price for a certain time period might be extremely fluctuating. This fluctuation might result in a very strange output. Moreover, these fluctuating variables may not contribute equally in the training and end up creating a bias. To avoid this, input dataset in scaled within a certain limit, that is limiting the high and low point of the input to a certain range. In this project, *MinMaxScaler*() was used to transform the data with a limit of [0,1]. This means the highest value is going to be 1 and lowest will be 0. The *MinMaxScaler*() uses the following equation to scale the data:

$$StandardX = (x - x.min(axis = 0))(x.max(axis = 0) - x.min(axis = 0)) \tag{13}$$

$$ScaledX = StandardX * (max - min) + min[24] \tag{14}$$

where *min* and *max* are the range of the features.

The results are calculated and documented in terms of accuracy, mean absolute error, max absolute error and root mean squared error. Accuracy can be mathematically defined as follows:

$$Accuracy = 100\% - ErrorRate \tag{15}$$

Where;

$$ErrorRate = |ObservedV\ alue - ActualValue|\ ActualV\ alue * 100 \tag{16}$$

Mean absolute error can be mathematically defined as:

$$MAE = \frac{\sum_{i=1}^{n} |y_i - x_i|}{n} \tag{17}$$

where y_i is prediction, x_i is actual value and n is total number of samples.

4 Bidirectional LSTM and GRU Architecture

The LSTM and GRU model were given the same input parameters and structure. Essentially, the only difference is the algorithm itself and its underlying functionality. Both LSTM and GRU model are given a generalized summary below. The models are initiated by defining a sequential stack of layers. It creates a linear layer stack of sequential instances. Sequential model can only have a single input and output. Upon defining the model type, the Bidirectional LSTM and GRU layers are implemented. This layer has 100 memory units. Every unit takes up to 200 input weights. It takes a total of 94400 input parameters. This layer also takes the *lookback* value as a parameter. The *lookback* variable defines how many minutes of past data are being taken into consideration for prediction. The algorithm is predicting the highest possible price for next hour taking the *lookback* value, training data and other defined parameters. The next two layer is a dense layer with 100 and 50 memory units each. Dense layers implement the following method:

$$output = activation\ (dot\ (input,\ kernel) + bias) \tag{18}$$

Both these layer uses the *Relu* activation function. *Relu* applies the rectified linear unit activation function. It uses a non-zero multiple of the input and modifies the maximum values of the activation. Kernel refers to the input weights. The bias variable is not applicable for this model. The first dense layer takes 20100 input parameters and the second dense layer takes 5050 parameters. The last or the output layer is another dense layer with *Sigmoid* activation. For values that are less than 5, sigmoid function returns a value close to zero and for values more than 5, it returns 1. The architecture of the model can be summarized as below:

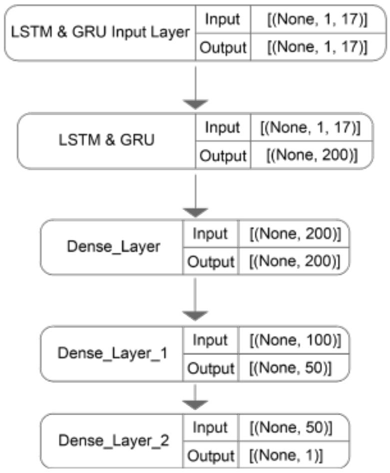


Figure 5. LSTM and GRU Model Architecture

The models are trained using the 'Adam' optimizer. It is a stochastic descent method which depends on adaptive estimation of first and second order moments. Adam is a very efficient algorithm with a optimized memory usage. It is well suited for large amount of data and parameters (D. P. Kingma and J. Ba, 2014). The model's layers, memory units, weights, input size and parameters can be summarized by below table (Table 2):

Table 2: Layer Structure and Parameter

Layer	Output Shape	Parameter
LSTM and GRU Layer	(None, 200)	94400
Dense	(None, 100)	20100
Dense 1	(None, 50)	5050
Dense 2	(None, 1)	51

Learning Rate: Learning Rate is arguably one of the most important hyperparameters in a ML model. This parameter decides the amount of change that is applied when the amount of error is calculated each time with new input weights. It is important because a smaller value may cause the model to take a significant amount of time to train or it may even get stuck while training. On the other hand, a larger value may make the model to consider inappropriate weights to include in the computation. Learning Rate essentially refers to the number of weights which are taken into account during the training process. It is a variable that often is a positive number ranging between 0 and 1. Learning Rate can be defined by the following equation:

$$\mathrm{n_{n+1}} = \frac{\mathrm{n_n}}{1+\,\mathrm{d_n}} \tag{19}$$

Where *n* is the learning rate, *d* is a decay parameter and *n* are the iteration step.

4.1 Stacking Ensemble Architecture

The Stacking Ensemble model implemented in this research is a Linear Regression model. Linear Regression visualizes the relationship between two variables by imposing a linear equation. It can be summarized by the following equation:

$$Y_i = f\left(X_{i,}\beta\right) +\ e_i \tag{20}$$

Where Y_i is the dependent variable, f is function, $X_{i\ is}$ the independent variable, β is unknown parameter and e_i is the error terms.

The meta-learner trains based on outputs from the LSTM and GRU model and the ideal values. Upon completion, the algorithm learns how to best combine the values based on the given training output and ideal values. In terms of implementation, the *LinerRegression*() model works based on least squares or non-negative least squares acting as a predictor. Passing X and Y into this as training data returns the coefficient of determination of the prediction. The coefficient of determination R^2 is defined as $1 - \frac{u}{v}$, where u is the residual sum of squares and v is the total sum of squares.

5 Results and Analysis

Since this is a comparative study, both LSTM and GRU algorithm will be trained and tested on the same dataset and setting. Hence, the parameters such as epoch, learning rate, lookback value will be same for both algorithms. Both LSTM and GRU algorithm was run with two variations of 50 and 100 epochs. The prediction timeline is 1 hour into the future. This means the algorithms will predict the highest price for next one hour. The reasoning behind changing parameter is that it provides a clearer picture of the algorithm's performance.

5. 1 LSTM

Prediction of highest price for next 1 hour

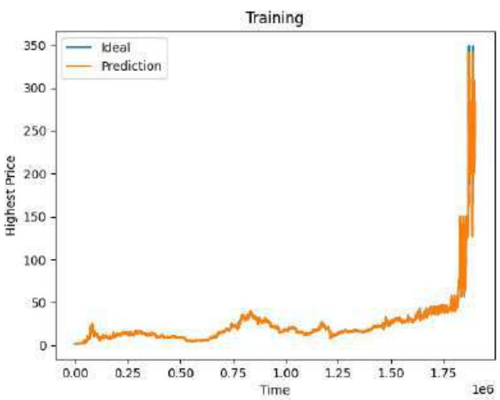


Figure 6. LSTM Training Accuracy

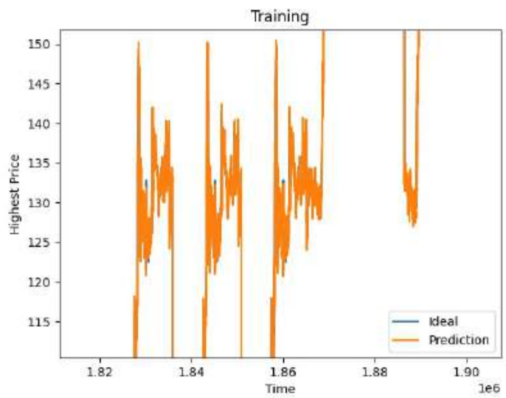


Figure 7. LSTM Training Accuracy (Zoomed in)

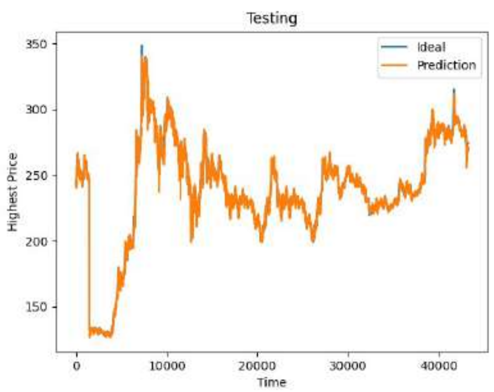


Figure 8. LSTM Testing Accuracy

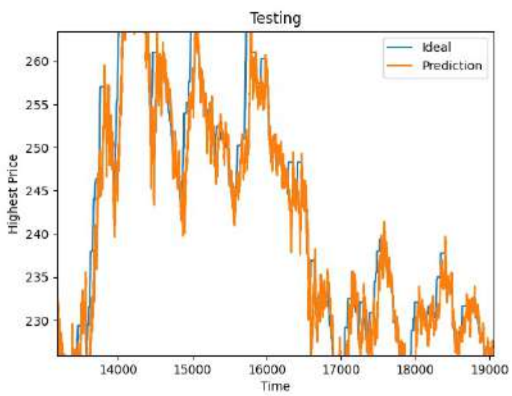


Figure 9. LSTM Testing Accuracy (Zoomed in)

5.2 GRU
Prediction of highest price for next 1 hour

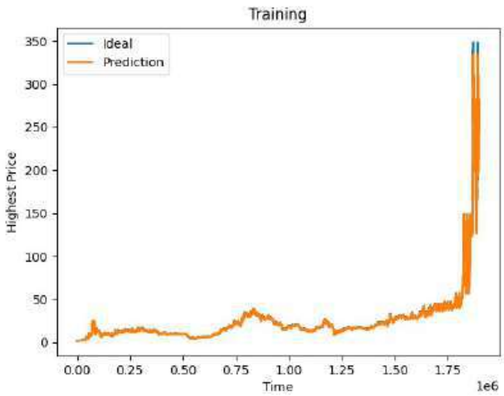


Figure 10. GRU Training Accuracy

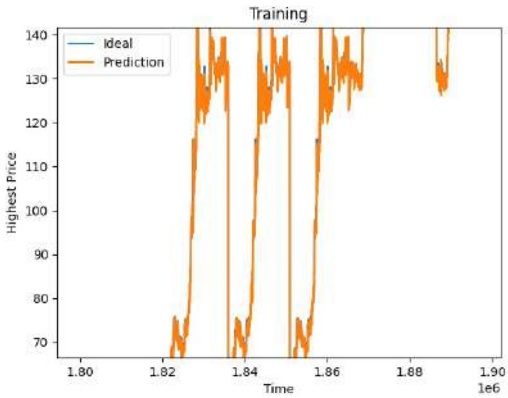


Figure 11. GRU Training Accuracy (Zoomed in)

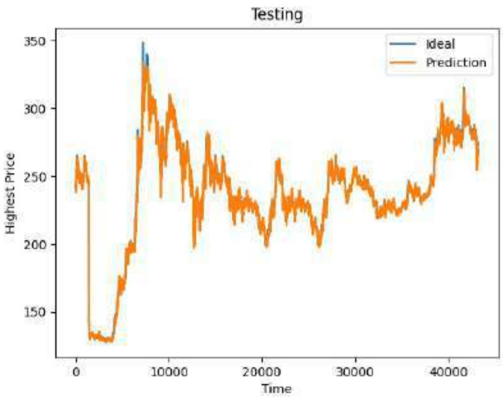


Figure 12. GRU Testing Accuracy

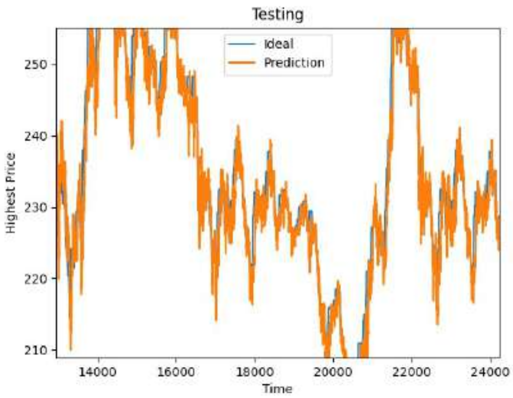
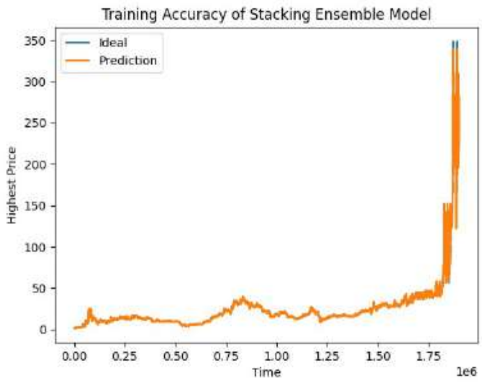


Figure 13. GRU Testing Accuracy (Zoomed in)

5.3 Stacking Ensemble
Prediction of highest price for next 1 hour



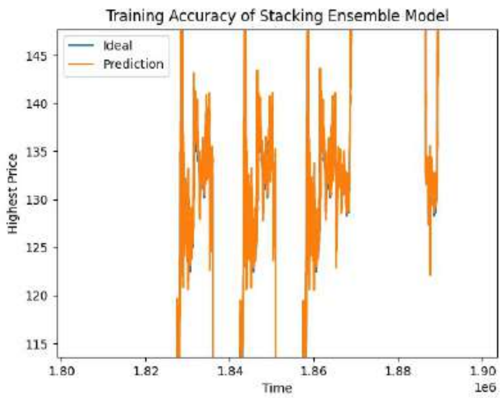
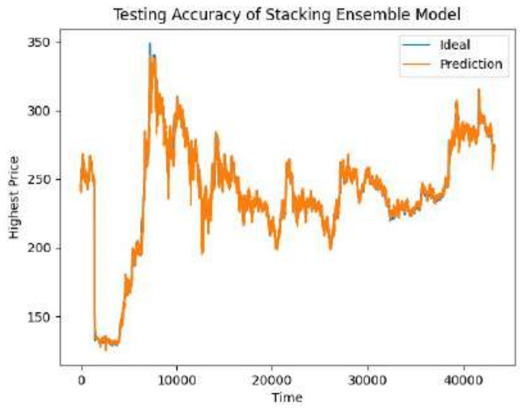


Figure 14. Stacking Ensemble Training Accuracy Figure 15. Stacking Ensemble Accuracy (Zoomed)

5.3 Stacking Ensemble

Prediction of highest price for next 1 hour



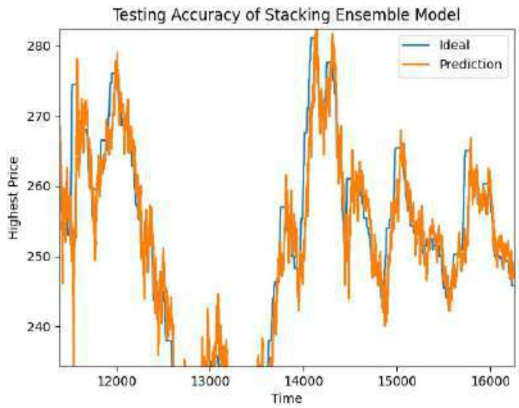


Figure 16: Stacking Ensemble Testing Accuracy Figure 17: Stacking Ensemble Accuracy (Zoomed)

5.4 Comparative Analysis

In the above sections, all results from the constituent algorithms are documented individually (Figure 6-17). However, it is very difficult to interpret individual graphs in a comparative study. In the following graph, the testing result from all algorithms are merged together to portray a clear picture. All numerical results such as training accuracy, testing accuracy, mean squared error etc has been documented in a tabulated format (Table 3).

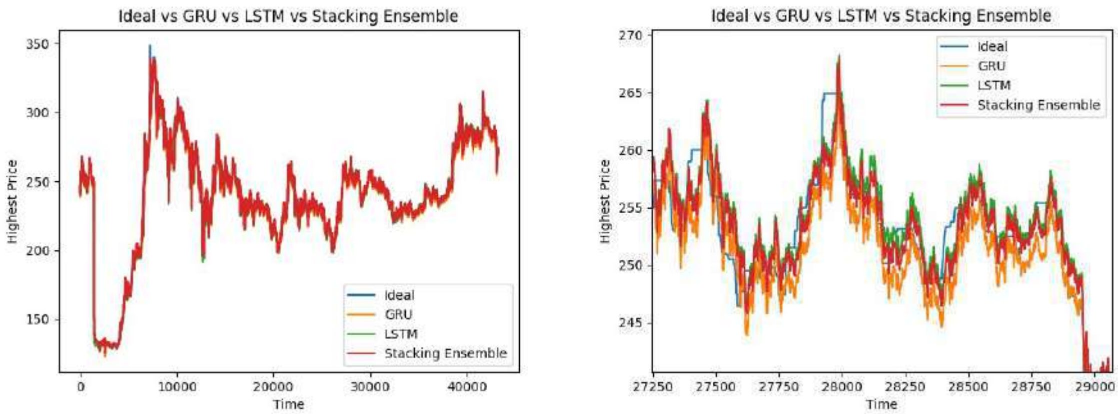


Figure 18: Ideal vs GRU vs LSTM vs Stacking Ensemble Training and Testing Accuracy respectively

Table 3: Numerical comparison between result instances

LSTM		GRU		Stacking Ensemble	
Training Accuracy	Testing Accuracy	Training Accuracy	Testing Accuracy	Training Accuracy	Testing Accuracy
97.53%	98.43%	97.42%	97.75%	99.14%	99.20%
MeanAE Train	MeanAE Test	MeanAE Train	MeanAE Test	RMSE Train	RMSE Test
.35	2.65	.39	3.05	.63	3.31

Table 3: Numerical comparison between result instances

From figure 13, we can see that green and red lines tend to overlap each other which means that LSTM and Stacking Ensemble are producing impeccably similar results. The LSTM model for Stacking Ensemble algorithm was trained with 100 epochs and 0.0001 learning rate and the same goes for GRU. With same parameters and hyper-parameters. It can be concluded that LSTM tends to perform better than GRU in this scenario. The accuracy of GRU tends to fluctuate more than its counterparts which is

consistent over time. The similarity between the results of LSTM and Stacking Ensemble denotes that the meta learning algorithm tends to be somewhat biased towards LSTM which is justifiably correct since LSTM is producing better results than GRU and displaying more consistency over time. The observed trends, non-stationarity and seasonal cycles of the test data over time makes it difficult for the algorithms to keep up. However, despite all these hindrances, Stacking Ensemble displayed promising results which has significant real-world implications.
The table 2 illustrates a comparative numerical metrics of LSTM, GRU and Stacking Ensemble. The LSTM and Stacking Ensemble resembles the graph interpretation showing high level of similarity.
The difference between LSTM and Stacking Ensemble results is quite small in terms of numeric. However, this small gap can make a huge difference in real-world applications. For problems where both performance and accuracy both are important, Stacking Ensemble algorithm can bring out the best from both of its constituent algorithms. Their error metrics, although different, are mathematically similar.
From the analysis above, we can conclude that, Stacking Ensemble performs better than its individual constituents. Even though the difference is very small in number, it can make a huge difference in practical applications.

6 Conclusion

Through this paper, LSTM, GRU and Stacking Ensemble algorithms were implemented to predict the price of cryptocurrency BNB. The overall analysis of the result shows that the predictions are reasonably accurate in different parameters. With almost 99% testing accuracy, Stacking Ensemble Neural Network showed a promising capability to predict even the most volatile of time-series data. The results may not yet be suitable enough to make a real-world decision based on it but it definitely shows a very promising start among other things. LSTM is a very widely used algorithm which is known to produce very good results. From the analysis of this paper, it can be seen that with correct implementation and some trial and error, Stacking Ensemble can overcome the shortcomings of LSTM and GRU, in other words, its constituent algorithms. With proper training data, feature extraction and possible implementation of social signal integration, it can be used to make real world decisions. The neural network, however, has demonstrated some performance issues which can be overcome which will possibly result in a much better accuracy in predicting the future prices.

7 Acknowledgement

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A Study on Local Air Pollution Due to Transport Emissions in Kandy City

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ABSTRACT

Air pollution has become one of the greatest challenges that the world is facing today. According to World Health Organization (WHO)there are 4.2 million annual deaths due to outdoor air pollution. Furthermore, about 90% of global population breathe polluted air. The most harmful cause of outdoor air pollution is recognized to be unorganized traffic management. In the instance of Sri Lanka, Kandy city has been recognized as crucial where necessary actions are required to be taken. This study presents harmful emission values produced by a daily count of vehicles entering the city alongside respiratory diseases and illnesses recorded. Detailed analysis provides pollutant emissions due to unorganized traffic management within Kandy city concentrating over locations from Getambe Junction to Kandy Clock tower and from the city centre towards Mahaiyawa Tunnel and Ampitiya Junction (locations are pinned on figure 1). Calculation of pollutant factors are intended to be done using three main methods namely, Tier 1, Tier 2 and V/C ratio method aided by vehicle fuel type, fuel efficiency, travelled distance and carriageway congestion values. Emission values for pollutants Carbon monoxide (CO), Nitrogen oxides (N_2O, NO_X) and Sulphur dioxide (SO_2) were identified in this study along with PM2.5 and PM10 values. It was to be seen that, over 100,000 vehicle cross Kandy city limits on both weekdays and surprisingly higher values in weekend with each carriageway within the city resulting over a 65% of congestion value. With 31% of daily trips being travel to work, the public transport system fails to deliver its purpose efficiently and effectively. With unorganized traffic management, stagnant and slow-moving vehicles tend to pollute 41% more SO_2 and 14% more NO_X gasses above global standards affecting the first five kilometers from the city center, which claimed to facilitate the zone of highest quality of life. Current records show PM2.5 values in Kandy to read above 50µg/m3 and PM10 values to be as high as 100µg/m3.

KEYWORDS: *Kandy, Air pollution, Traffic management, Emission, Respiratory, Sri Lanka*

1 INTRODUCTION & BACKGROUND

Breathing sustains life as we breathe to live for another day. Rapid development of technology has neglected the damages caused to mother nature including our atmosphere where we face the consequences today. The World Health Organization points out 4.2 million people die due to outdoor air pollution whereas 9 out of 10 people breathe air with pollutants. Scientists believes that association of air molecules with chemical and microbial pollutants happen to pollute air around us. *(Wei et al., 2010)* Air surrounds humanity providing breathable air to all lives therefore, upholding an environment with quality breathable air is a necessity. Particles originate from roadside soil due to wind turbulences are known to be natural, while anthropogenic particulates are generated by domestic emissions, industrial activities and mainly by automobile vehicle exhaust, tire wear, and road wear. *(Wei et al., 2010)*

The World Heritage City of Kandy regrettably suffers from a rising high air pollution threat over the past decade. Kandy is situated in a valley of mountain ranges, expects to have high air pollution owing to its geographical location and the increasing number of automobiles. The matter in hand is not

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foreign as numerous studies have been carried out in the past. Key highlights would be studies by Illeperuma (2010) since 2002 to 2020. Where he made the bold statement of vehicle emissions to be the main cause for Kandy air pollution threat.

Early testing of pollutants results 55-60% of air pollution to be documented by automobiles with SO_2, NO_2 and O_3 percentages are above expected levels by 41%, 14% and 28% with motorcycles, passenger cars and three-wheelers to have increased by 290%, 300% and 380% respectively for the last decade. Elangasinge & Shanthini (2008) including Illeperuma evaluated PM10 values in Sri Lanka to rise 55% within half a decade. Extensive results from past show around 112,000 vehicles cross the district weekdays which can be roughly translated into around 56,000 entering Kandy city limits daily. Furthermore, 25 sampling sites around Kandy reported Nitrogen oxides, Sulphur dioxide and Ozone (O_3) concentrations had already exceeded standards by 38%, 53% and 40% respectively. A highest PM10 value of 340 μg/m3 was recorded towards Katugastota area with Gatambe roundabout emitting 230 μg/m3 daily. The study on "Kandy city Transport Study" was done by University of Moratuwa with associating University of Peradeniya in the year 2011 points out around 112,000 vehicles cross the study area and 56,000 vehicles entering Kandy city limits daily.

The Sri Lankan situation is no different to other developing countries. As *Abeyratne et al., (2010)* states 60% of total ambient air pollution in Sri Lanka is to be due to vehicular emissions and over the past few years high levels of air pollutants were recorded during the Northeast monsoon period from mid-November to January. Sri Lanka does not have a perfect record in air quality as parts of the island suffers from severe air pollution issues. A key highlight would be cities within the central highlands such as Kandy where pollution records tend to point high. *(Ileperuma, 2010)*. A study done by Illeperuma in 2020 states "Air quality in Kandy is worse than that of Colombo owing to its geographical location." Apart from mother nature, many researchers and environmentalists believe, unorganized and uncontrollable flow of traffic within Kandy city causes bad air pollution the most. As Vilani (2006) points out, "the city of Kandy is situated in a valley between two mountain ranges, expects to have high degrees of air pollution owing to its geographical location and the increasing number of automobiles" which has led to a congested traffic flow within city limits. As latest studies show that, Kandy to be the highest most air polluted city in Sri Lanka revealing its true danger. As a study *(Abeyratne et al., 2011)* points out Kandy holds a daily traffic volume of 106,000 vehicles within $4km^2$ of limited land and resting a population above 250,000 people. It was Illeperuma who made the first steps on proving automobile emissions to cause the most air pollution regardless natural effects. As his study extends, air pollutant percentages collected within different types of monsoons result higher SO_2, NO_2 and O_3 percentages during the north-east monsoon period recording 46%, 43% and 39% respectively. As previously assumed sea winds to gather pollutants around central highlands was proved wrong since south-west monsoon recorded 31% SO_2, 28% NO_2 and 28% O_3. With comparatively lower pollutant values recorded by inter-monsoons, Illeperuma states "the only possible explanation to this observation is transboundary pollution." Traffic congestion in Kandy produces SO_2, NO_2 and O_3 above expected levels by 41%, 14% and 28% during the years 2001-2005. With data acquired from Ministry of Environment (2012) he points out 55-60% percent of air pollution to be documented by automobiles where 20-25% was due to industries and 20% by domestic sources, highlighting the fact that automobiles play the huge roll in air pollution.

2 METHODOLOGY

To answer the emission issue using traffic data would be the sole objective and quest of this paper where current vehicle data and emission factors are proposed to calculate harmful pollutants in the city of Kandy. This was referred to the "Katmandu Model" where vehicle and traffic data were considered to calculate emission values at various locations. Subsequently, a study area was created covering the city of Kandy and all its main corridors that would lead to and from the city centre. The study area was then broken down into six (6) pinpoints to analyze and calculate traffic data and emission data more accurately. Emission factors were referred with respect to fuel type used by each vehicle type in Sri Lanka to proceed with calculations. Thus, the main objective of this paper to study and quantify the emissions put out in Kandy city by vehicular transportation. It would also relate to vehicle data and health risks due to air pollution.

The methodology laid by using vehicle and traffic data to calculate emission values at various locations. Subsequently, a study area was created covering the city of Kandy and all its main corridors that would lead into and from the city centre. The study area was then broken down into six (6) pinpoints to analyze and calculate traffic data and emission data more accurately. Emission factors were referred with respect to fuel type used by each vehicle type in Sri Lanka to proceed with calculations where globally accepted calculation methodologies were used. These data were obtained for the set pinpoints and thereafter analyzed to obtain rich information to graphically interpolate on an open-source GIS software and discuss. Many obstacles did lay at each step such as the acquisition of vehicle and traffic data for the current year (2019) where extrapolation methods were followed using previous research records. Hence the very narrow topic, media such as research papers, journals and other publications were hard to find or refer. Additionally, due to the global pandemic and lockdowns, reaching out to institutions were out of possible as well. This matter also led to lack of updated government reports for the years 2019 and 2020 hence extrapolations methods were to be the only method to drive through.

Kandy district is a vast area of study hence it combines a few major cities consisting dense population. Due to this matter, this study considers a planned boundary around Kandy City central connecting all major entrances and exits towards and out of Kandy City. Geographically, the study area was as shown below. A total of six (6) pinpoints were chosen coveting main traffic corridors in Kandy city namely, Getambe Junction (1), Mulgampola Junction (2), Kandy Girls' High School Junction (3), Kandy Clock tower roundabout (4), Mahaiyawa Tunnel (5) and Ampitiya Junction (6) as illustrated on figure 1 below.

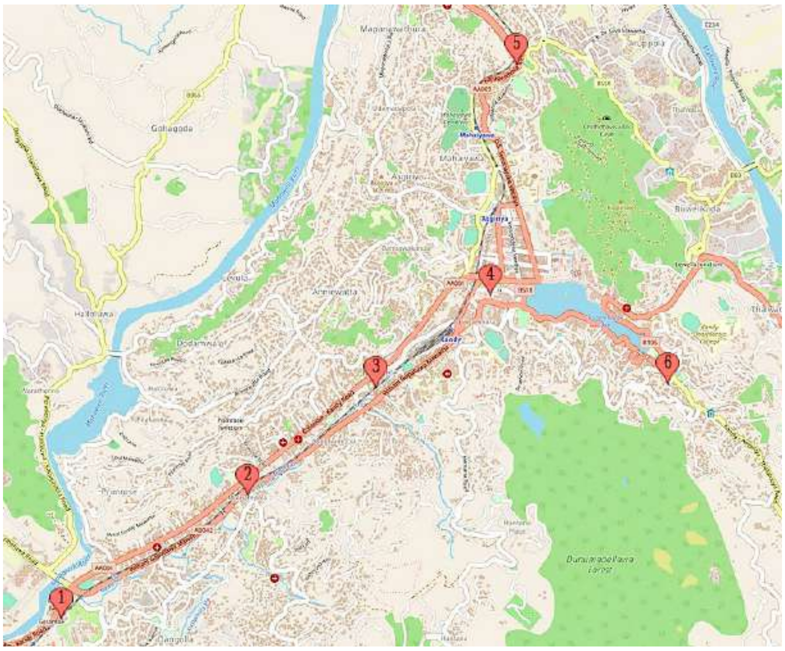


Figure 1. Study Area map consisting of the 6 pinpoints for this research

National Transport Authority have conducted annual statistics for provincial vehicle registrations up to year 2017. With obtained values per annum, linear extrapolation was used to calculate vehicle data for the years 2017 and above. Due to the incomplete data and resources on vehicle and traffic data, extrapolation of data for the years 2018 and 2019 were decided to be feasible and applicable.

With considerable deviations, it was decided to adopt Central Provincial data for continuation as the boundary was more authentic and realistic compared to nation-wide values. After settling on the obtained values from National Transport Authority above, the extrapolation method was used to find current traffic values for Kandy city. The linear projection of all vehicle types was obtained by a continuation from past years. Thereafter, vehicle values for years 2018 and 2019 were obtained using the generated equation of the graph and were tabled as shown by table 1 below.

Table 1. Extrapolated Vehicle data for years 2018 and 2019

Vehicle Type	2012	2014	2015	2016	2017	2018	2019
Bikes	86,887	103,494	127,184	146,131	161,523	**176,915**	**192,307**
Light Vehicles	82,752	102,748	119,609	127,504	130,655	**133,806**	**136,957**
Passenger Vehicles	32,767	38,188	47,107	50,378	53,109	**55,840**	**58,571**
Light Commercial	25,129	29,161	30,650	30,992	32,135	**33,278**	**34,421**
Heavy	23,472	24,019	24,716	25,340	26,279	**27,218**	**28,157**

Further extrapolation results show over 187,000 vehicles cross Kandy city limits daily and there is no reduction for weekend values as weekend data shown an increase of over 700 vehicles. This proves the reduction factor is not as large as expected by the majority and does not exist in real-world calculations. Due to the constant traffic flow with smaller numbers on weekends, the number has managed to overcome weekday figures where vehicle flow shows periodic traffic hikes unlike constant moving flow on weekends. It was noticed that a high number of light vehicles and passenger vehicles to use by-pass roads as well as to share the greatest number of vehicle entries towards the city center. Around 30,000 vehicle units were reduced towards the city through by-pass roads. This scenario was tested back in the year 2011 by University of Moratuwa and University of Peradeniya.

The V/C ratio method would simply calculate the volume over congestion of a particular carriageway. To obtain this ratio, the designed maximum volume of a carriageway must be known and the present vehicle flow on the carriageway must be known as well. these calculations were carried out by the previous study in 2011 which resulted in heavy congestion factors for many roads in Kandy city. Data extracted from the study can be used in reference to this as the flow has increased slightly compared to 2011 values.

3 RESULTS

Table 2. Location based emission values with vehicle-wise (shown in- g/km.per day)

Corridor	Vehicle Type	Weekday				Weekend			
		Emission Values (g/km.per day)							
		CO	NO_X	N_2O	SO_2	CO	NO_X	N_2O	SO_2
Sirimavo Bandaranayake Mawatha	Motorbikes	140218	8978	93	9	122516	7844	81	7
	Light vehicles	29192	2440	87	16	33769	2822	101	19
	Passenger vehicles	20087	18056	339	35	17509	15739	295	30
	Light Commercial	7552	16736	181	10	8881	19679	213	12
	Heavy vehicles	771	26896	98	16	898	31334	115	19
	Total	272kg				262kg			
Katugastota Road	Motorbikes	68826	4407	45	4	60141	3851	40	4
	Light vehicles	14330	1198	43	8	16575	1385	49	9
	Passenger vehicles	9860	8863	166	17	8595	7726	145	15
	Light Commercial	3707	8215	89	5	4359	9660	105	6
	Heavy vehicles	378	13201	48	8	441	15382	56	9
	Total	296kg				284kg			

Sangaraja Mawatha	Motorbikes	100543	6437	66	6	87858	5625	58	5
	Light vehicles	20934	1750	62	12	24213	2024	72	13
	Passenger vehicles	14404	12947	243	25	12555	11286	212	22
	Light Commercial	5415	12000	130	7	6368	14112	153	8
	Heavy vehicles	154109	9867	102	9	644	22471	82	14
	Total	133kg				129kg			

City Centre	Motorbikes	29572	2472	88	16	131129	8396	87	8
	Light vehicles	21375	19213	360	37	35857	2997	107	20
	Passenger vehicles	7355	16300	177	10	18027	16204	304	31
	Light Commercial	969	33803	124	21	9176	20334	220	12
	Heavy vehicles	154109	9867	102	9	1143	39896	146	24
	Total	195kg				188kg			

When comparing weekday and weekend emissions, a rise in CO values can be seen throughout all locations due to its emission factor. The heart of the city still shows high pollution values overall. Weekday results show over 213kg of CO, 81 kg of NO_x and 8kg of N_2O with SO_2 values to be around 1 kg within Kandy city. Second most polluted location was to be pinpoint 1,2,3 of Sirimavo Bandaranayake Mw. Showing almost 200kg of CO, 73 kg of NO_x and 8kg of N2O. Ampitiya junction was to be the third highest polluted location showing 140kg of CO, 52 kg of NOx and 5 kg of N_2O. The pinpoint of Mahaiyawa was to show the least pollution with 97 kg of CO, 35 kg of NOx, 4 kg of N_2O and 0.5 kg of SO_2. Weekend values show a similar pattern with city centre values emerging on top over other locations. City centre values show a weekend reduction of 8.6% CO emissions whereas other pollutants were all increased. Due to the decrease of motorcycles and light vehicles towards the weekend, harmful pollutants from unrefined, small engines have reduced compared to weekday values. Even though CO values increase, NO_x, N_2O and SO_2 emission values show 7.5%, 1.65% and 3.2% reductions respectively.

Considering independent vehicle emissions, motorcycles have led at all locations with the highest numbers recorded. Motorcycles emit around 100kg a day at any given location stretch with peak values to be 154kg at city centre. The second highest harmful vehicle type was the three-wheeler (light vehicles) producing around 25 kg a day with peak values up to 30kg. A common issue for both vehicle types would be the use of poor-quality engines with small cylinder capacities that revs up to high rpm values to produce power in order to make a move on. This causes extreme high pollutant and emissions to travel a small stretch of road which would be the case identified in Kandy city. Passenger vehicles remain comparatively low as for their refined engine technologies as mentioned earlier that keeps daily emission values around 15kg. Considering weekday and weekends total pollution, weekday values tend to be overall high with weekend values to show certain hikes on certain locations due to the constant traffic flow over a weekend day compared to weekday partial hikes. Therefore, when observed, weekday values tend to produce higher values overall in many traffic hotspots. The highest concentration was recorded at the heart of the city which was at the clocktower where 284kg was noted on weekends and 296kg on weekdays. The main corridor of Sirimavo Bandaranayake Mawatha was second in concentration with 262-272kg values. The end of the lake round in Kandy where the road leads to Ampitiya is to have the third highest with 188-198kg of pollutants gathering daily. finally, the road leading to Katugastota, the Mahaiyawa road recorded the lowest pollutant value with 129-133kkg pollutants value on a daily basis.

Weekday and weekend traffic values show minor deviations that affects the overall pollutant composition. As for weekend values, there can be seen a reduction of motorbikes and light vehicles as travelling requirements towards the city centre is reduced on weekends due to work holidays. On contrast, private vehicles such as passenger vehicle ratio has increased. Total motorcycle population has only decreased by 3% where passenger vehicles have increased by 4%. Goods vehicles, and ither heavy vehicle types including route busses have increased over the weekend due to special projects, goods transport etc. The weekend traffic variation is not clear as the compounds remain largely unchanged. This can be clearly identified and discussed by identifying the number of vehicles at each location tested. This reduction has affected local pollutant percentages as CO emissions have reduced by 4% yet increased NOx gases by 4% as well. As mentioned earlier, the impact of NOx gases would affect the environment directly compared to CO gases. A key highlight would be the huge partition of pollutants owed by motorcycles on both weekends and weekdays where weekdays percentage to take up almost 3 quarters of total pollutants by all vehicles. the refined engines of passenger cars show account for only 10-15%. Due to the low number of heavy vehicles, they emit low percentages of pollutants corresponding to almost 1% on weekdays. However, the weekend scenario changes its course due to the variation in traffic and vehicle type. Goods and construction vehicles, lorries and busses have increased on weekends thereafter showing a 11% increase in pollutant percentages. However, motorcycles tend to be the highest environmental pollutant vehicle due to small, cheap, basic engines that are not ecofriendly to use.

However, the main focus of this study would be the determination of emission values. Cumulative sum of all pollutants with respect to the location were taken beforehand plotting to the Graphical Interpolation Software (GIS) (maptive.com).

Figure 2. Measured volume of vehicle for each corridor.

Data plotting began with vehicle count tracking study locations. Figure 2 plots out vehicle volumes measured at each corridor entering/leaving Kandy city. It was observed that Sirimavo Bandaranayake Road and William Gopallawa Road shares around 44,000-45,000 vehicles a day which adds up to a portion of city centre traffic which records a missive 150,000 vehicles a day. Though these values are two-way traffic data, for a small city as Kandy, the congestion is above global standards. Both Sangaraja Mawatha and Mahaiyawa roads show intermediate traffic values of around 60,000-70,000 a day. Figure 3 below illustrates, the derived emission values with radii in proportion to the severity of pollutants emitted. Naturally, the city centre was to emit the highest pollutants a day with Getambe junctions surprisingly showing high values as well. Sirimavo Bandaranayake Mw. Was second highest in emission values since the long stretch of road. As a result, both locations show above 250kg/km values within the day. Ampitiya road comes third with slightly less emission values. Mahaiyawa road shows the lowest emission values of around 100-150kg/km a day hence the loss of motorcycles and light vehicles observed within that stretch. As City centre and Getambe junction to be in the red zone while the rest of Sirimavo Bandaranayake Mw. To be in the orange zone. A relatively calm yet not safe blue zone is to be Mahaiyawa road with intermediate yellow zone to be the Ampitiya junction road.

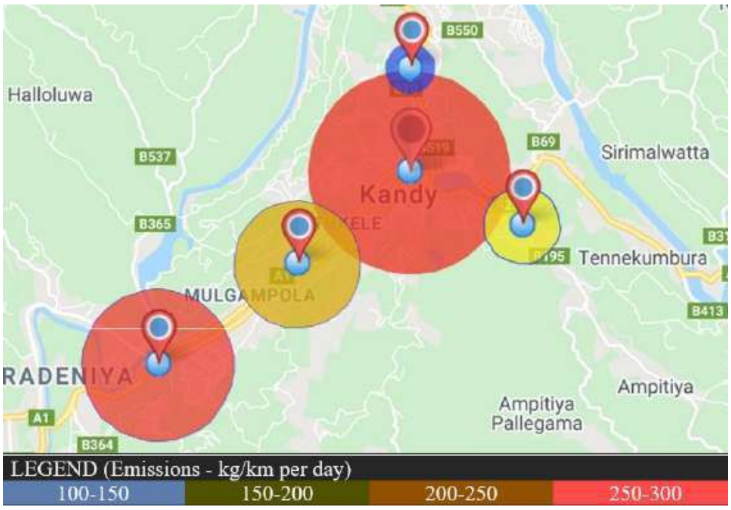


Figure 3. Severity of emission values between pinpoints

Emission calculations were also done using the V/C ratio method as well. the results show the congestion factor and the amounts of Carbon emissions emitted correspondingly. Both conditions have been plotted on figure 4 below. The flow condition is illustrated by the smaller radii with the color corresponding to its congestion factor. The larger radii would symbolize the emission values in proportion to the pollutants emitted as well.

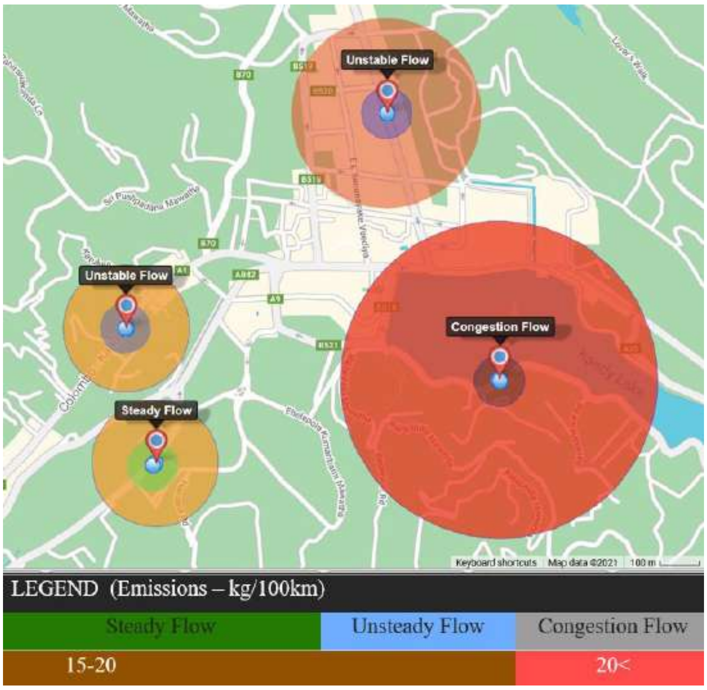
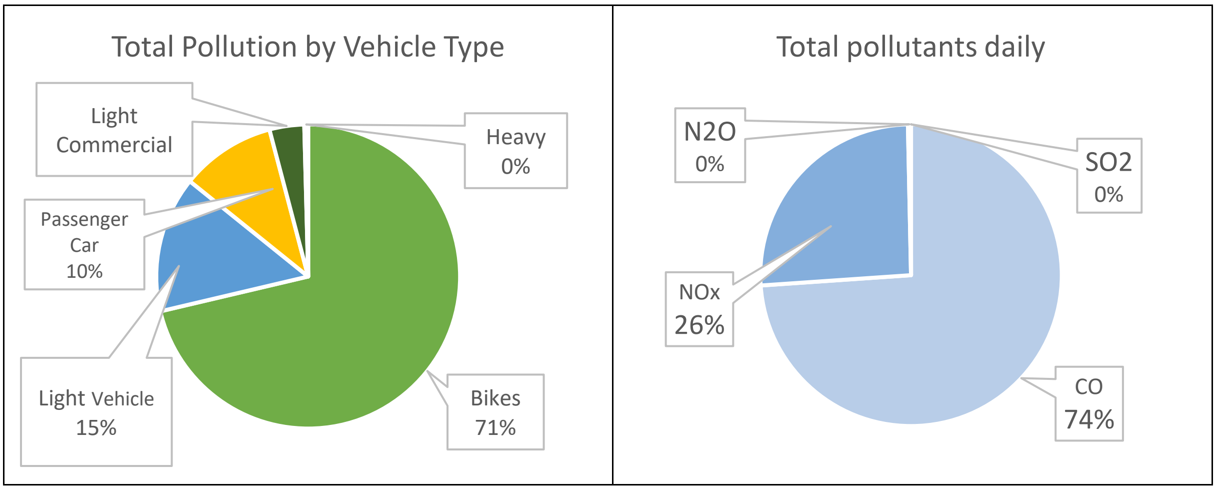


Figure 4. Carbon emission adapting V/C ratio method

William Gopallawa road was the only location with a steady traffic flow while the rest of Kandy carriageways were above designed values. Sangaraja Mawatha was showing congestion flows which was the worst-case scenario to be expected while Sirimavo Bandaranawake road and Adhahana maluwa road (Mahaiyawa Road) were to be unstable flows which was slightly better than a congestion flow. The results were not impressive as all main carriageways in Kandy were to be out of control showing high traffic flow values. The resulting Carbon emission values were also not within acceptable margins as well. As every location showed over 15kg/100km values with Mahaiyawa Road and Sangaraja Mawatha showing over 25kg/100km a day which include those locations to be in the red zone in figure 4.

Table 3. Emission results based in graphical form



Charts in table 3 would analyze the potential threat to Kandy with respect to the vehicle type which is crucial in this results stage. A key highlight would be the huge partition of pollutants owed by motorcycles on both weekends and weekdays where weekdays percentage to take up almost 3 quarters of total pollutants by all vehicles. the refined engines of passenger cars show account for only 10-15%. Due to the low number of heavy vehicles, they emit low percentages of pollutants corresponding to almost 1% on weekdays. However, motorcycles tend to be the highest environmental pollutant vehicle due to small, cheap, basic engines that are not ecofriendly to use. Daily values show CO emissions to be 74% with NOx gases by 26% with negligible SO_2 and N_2O gasses. The impact of NOx gases would affect the environment directly compared to CO gases.

4 CONLUSIONS

Many developing cities face the threat of air pollution whereas the historical city of Kandy was proven to be another victim. The results concluded showing the huge negative impact of air pollution faced by the city and the aftermath from it. Due to a very high volume of vehicles crossing city limits on both weekdays and weekends, many locations were to be over polluted in contrast to global standards with carriageways to over assist vehicles beyond the designed flow and to emit high values of emissions due to the vehicle types used. Derivations were calculated for the year 2019 extrapolating data from 2011 to 2017. IPCC emission calculation methods were followed aided by fuel type, fuel efficiency and travelled distance. Weekday and weekend traffic, pollutant values with percentages were key results obtained. A health risk analysis was carried also carried out to strengthen the argument. Over the period from 2011, almost over 50% of vehicles have increased producing 60% more CO and 50% more SO_2 and N_2O pollutants. The city was to emit over 900kg of pollutants daily with the heart of the city to be the most polluted. Respiratory diseases were to be filed as the 3rd leading cause of hospitalization and 4th leading cause of death in Kandy district establishing the degree of threat.

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