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23RD - 25TH OF MARCH 2023

SICET 2023

Civil Engineering | Electrical and Electronic Engineering | Materials Engineering | Mechanical Engineering | Mechatronics Engineering | Quantity Surveying

FACULTY OF ENGINEERING

SLIIT UNI

THE KNOWLEDGE UNIVERSITY

“A MULTIDISCIPLINARY APPROACH TO INNOVATION”

Sri Lanka Institute of Information Technology
Malabe, Sri Lanka

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Vol. 02, 2023

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Preface

As the Chairperson of the 2nd SLIIT International Conference on Engineering and Technology (SICET 2023) organizing committee, I am delighted to deliver this message.

As the second conference in the series, there are many factors making this conference important. The areas we have focused on are Engineering, Technology, Quantity Surveying, Computer Science and Information Technology, Applied Sciences and Statistics. Although our research areas have not changed much since last year, we are catering to a wider research community with the possibility for offering more physical participation than last year. In order to get more national and international participation, we have introduced several modes of participation. However, it has been challenging at the same time. The conference was organized considering the opportunities as well as challenges.

A rigorous process of paper reviews, aligned with indexing requirements was completed with the generous contributions of both local and international experts in respective fields. The pre-conference workshops catered to the demanding areas of research and latest topics. Keynote speeches are delivered by two globally renowned academics.

This fruitful experience would not have been possible without the guidance and advice of Dean, Faculty of Engineering, Prof. Saman Thilakasiri, the patrons of the conference and the Conference board members. The dedication and commitment of my team was excellent, and I am truly amazed by the efforts and care they had for each simple tiny task in organizing. I express my sincere gratitude to the reviewers from around the globe who spent time to give excellent reviews and the academics and professionals who conduct the technical sessions. I am grateful to the resource persons of the pre-conference workshops who went the extra mile to conduct very informative sessions and to the two keynote speakers who travelled thousands of miles to enlighten us on latest technical developments. Lastly, I am thankful to the authors who trusted our conference.

I hope this conference will provide opportunities for awareness of state-of-the art research and become a platform for research collaboration.

On behalf of the conference committee, I wish you all success in your research and innovations.

Dr. Lakmini Malasinghe
Chair, SICET 2023

Message from the Dean, Faulty of Engineering

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 2023 and the organizing committee for excellent job they did by organizing the 2^{nd} version of the conference (SICET 2023) 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.

In 2015 after a thorough inspection of the facilities and the quality assurance system followed, apart from our undergraduate programs, we were given permission to grant MPhil and PhD degrees by the Ministry of Higher Education, Sri Lanka. Since then, we developed our research program and enhanced research in the Faculty. 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. This is an excellent opportunity for networking of the researchers and update your knowledge with the state-of-the-art cutting-edge technologies. We offered six preconference workshops to enhance your knowledge in six different areas. I extend my warm congratulations to the success of the conference and wish all the success for your future endeavors!

Prof. Saman Thilakasiri
Dean, Faculty of Engineering, SLIIT

Message from the Senior Deputy Vice-Chancellor

I am delighted to provide a congratulatory message to the Proceedings of SICET 2023. The Faculty of Engineering at SLIIT is known for its high-quality academic programs and innovative research. SICET 2023 is the second international conference organized by the Faculty of Engineering under the leadership of Professor Saman Thilakasiri, Dean Faculty of Engineering.

SICET 2023 covers established and emerging topics of engineering. It is, therefore, an excellent collection of papers that will have significant archival value. The post-pandemic era has 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 2023 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 endeavors.

Prof. Nimal Rajapakse
Senior Deputy Vice-Chancellor & Provost, SLIIT

Message from the Vice-Chancellor

It is with much honor I convey this message for the 2nd International Conference on Engineering and Technology (SICET 2023), organized by the Faculty of Engineering at the Sri Lanka Institute of Information Technology (SLIIT). This highly anticipated event promises to be a stimulating and thought-provoking platform for researchers to share their latest research findings, innovations, and breakthroughs in the fields of Engineering, Technology, Quantity Surveying, Computer Science and Information Technology, Applied Sciences, and Statistics.

At SICET 2023, we are committed to creating a collaborative and inclusive environment that fosters the exchange of ideas and enables networking opportunities for researchers from different backgrounds and disciplines. As such, we are proud to offer an exciting program that features distinguished keynote speakers, including Prof. Tissa Illangasekare and Prof. Iain Murray, who are experts in their respective fields. Our program also includes several research presentation sessions, and six pre-conference workshops that provide opportunities for researchers to interact and share knowledge.

We have received an overwhelming response from the research community, with over 120 papers submitted for review by our international panel of experts. We are confident that our rigorous double-blind review process will ensure the highest quality of research is presented at our conference. Our ultimate goal is to establish SICET 2023 as the premier conference in Sri Lanka for presenting cutting-edge research in Engineering and Technology fields. And while I applaud the researchers in the Faculty of Engineering for their tireless efforts to boost the Faculty and SLIIT's research profile, volume, and influence, I am confident that these initiatives will yield even greater benefits and positive exposure for the institution.

I would like to extend my sincere appreciation to the Dean of the Faculty, the Conference Committee and everyone else involved with this event for their dedication. We hope that SICET 2023 will provide a vibrant forum for researchers to explore new ideas, exchange insights, and collaborate on innovative solutions. To that end, I welcome you to the 2nd SLIIT International Conference on Engineering and Technology and invite you to join us in advancing the frontiers of Engineering and Technology.

Prof. Lalith Gamage
Vice-Chancellor/CEO - SLIIT

Message from the Chancellor

I am delighted to send this congratulatory message to the organizers of the 2nd SLIIT International Conference on Engineering and Technology (SICET 2023) for their invaluable contribution in collaborating with the event. The conference which is held on 25th March 2023 will be the ideal platform to bring together academics, student researchers as well as industry members to showcase their innovative ideas and interact with peers from a wide spectrum of engineering disciplines.

The Faculty of Engineering of SLIIT has been providing a strong base to nurture inspiring young students to excel highly in their studies by adapting latest teaching methods involving modern technology, research, and innovation. This multidisciplinary approach to innovation addressing a variety of trends in the field of Engineering, Technology, Applied and Natural Sciences, spanning research across Theory, Applications, and Education is a great approach taken by the faculty.

New knowledge and findings cannot be generated without any research and innovation, and SICET conference will allow participants to engage in discussions and exchange ideas of their research outcomes in an open forum. I earnestly hope that in the years to come the faculty can acquire more wisdom, enthusiasm, and expertise from a broad spectrum of related personnel to help maintain its contributions to our society in the field of Engineering.

I would like to express my sincere appreciation to the organizers for their valuable contribution and efforts in establishing such a commendable event and wish all the participants of this year's SICET conference all the success in their future accomplishments.

Prof. L.L. Ratnayake
Chancellor - SLIIT

Acknowledgement

The 2nd SLIIT International Conference on Engineering and Technology is held in Malabe, Sri Lanka. This multi-disciplinary engineering conference featured scientific publications from a wide range of interests such as Aviation Engineering, Civil Engineering, Electrical Engineering, Electronic Engineering, Mechanical Engineering, Mechatronic Engineering, Material Engineering, Engineering Technology, Quantity Surveying, Computer Science and Information Technology, Applied Sciences and Statistics. This conference brings together researchers and practitioners from academia, industry, and government to exchange their research ideas and results and to discuss the state of the art in the areas of the conference.

All papers in this publication have gone through at least a double-blind peer review process conducted by reviewers who are both local and international area-experts. The papers not meeting the conference expectation of quality in terms of innovation and originality have been rejected to keep the overall best quality of the conference.

We are grateful to everyone whose hard work makes this conference possible. We thank all the presenters and authors for these contributions as well as the reviewers and conference organizers for all their support. We hope the papers presented in this publication would bring together innovative academics and industrial experts in the field of Aviation Engineering, Civil Engineering, Electrical Engineering, Electronic Engineering, Mechanical Engineering, Mechatronic Engineering, Material Engineering, Engineering Technology, Quantity Surveying, Computer Science and Information Technology, Applied Sciences and Statistics to a common forum.

We look forward to seeing your intellectual contributions to the 3rd SLIIT International Conference on Engineering and Technology!

On behalf of the Organizing Committee

Dr. S.V.T. Janaka Perera
Technical Program and Publication Chair, SICET 2023

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Keynote Address-1:

Multi-scale Experimentation and Modeling for Problem Solution in Water and Environmental Systems – Challenges and Opportunities

Prof. Tissa Illangasekare,
AMAX Endowed Distinguished Chair of Civil and Environmental Engineering and Director of Experimental Study of Subsurface Environmental Processes, Colorado School of Mines, Golden, Colorado, USA

Abstract:

Meeting the increasing needs of a growing world population, exacerbated by climate change, will continually challenge water and environmental scientists and engineers for years to come. Theoretical, modeling, computational advances, and monitoring and characterization technologies will help meet some of these challenges. Field and laboratory studies for conceptualization, hypothesis testing, and modeling have continued to advance the sciences. However, the data to study some problems cannot always be obtained in the field where many factors contribute to the uncertainty of measurements and model parameter estimates. The primary thesis of this talk is that laboratory experiments conducted at multiple test scales in conjunction with multi-scale models will provide new insights into complex processes and accurate data for reliable predictions. Design and implementation of theory-driven experiments from examples of groundwater contamination, carbon dioxide storage to mitigate global warming, and land/atmospheric interactions applied to food security are presented to show how advances can be made for practical problem solutions. A case is made that addressing water and environmental problems requires laboratory and field studies and modeling interaction. Further, water and environmental scientists and engineers must work in multidisciplinary teams at the disciplinary interfaces of earth, water, energy, and the environment to address current and emerging local and global problems of water and the environment.

Speaker Biography:

Prof. Tissa Illangasekare has a BSc in Civil Engineering from the University of Peradeniya, an M.Eng. in Hydrology and Water Resources Development from the Asian Institute of Technology, a Ph.D. in Civil Engineering from Colorado State University, and an Honorary Doctorate in Science and Technology from Uppsala University. He is a Fellow of the American Geophysical Union (AGU), American Association for Advancement of Science (AAAS), American Society of Civil Engineers (ASCE), Soil Science Society of America (SSSA), the National Academy of Science of Sri Lanka (SLNAS), and a foreign member of the National Academy of Europe. He is the recipient of the 2012 Darcy Medal from the European Geosciences Union (EGU) and the 2015 AGU's Langbein Lecture Award in recognition of lifetime contributions to the science of hydrology. In 2016 he received the 7th Prince Sultan Bin Abdulaziz International Groundwater Prize at the United Nations from Secretary-

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General Ban Ki-Moon. He was appointed to the Nuclear Waste Technology Review Board (NWTRB) by President Obama in 2016. In 2017 he received the Asian Institute of Technology Alumni Association's Distinguished Alumni Award. In 2022, he received the "Lifetime Award" of the Sri Lanka Foundation International (SIF) in California, USA. He was the past editor of Water Resources Research and Earth Science Review and the past co-editor of Vadose Zone Journal. Currently, he serves as an editor of AGU AGU Advances, AGU Perspectives of Earth and Planetary Scientists, and Specialty Chief Editor of Water and Human Health of Frontiers in Water. He was a past President of the International Society of Porous Media (InterPore).

He is a Registered Professional Engineer (PE), Certified Professional Hydrologist (P.Hyd), Board Certified Environmental Engineer (BCEE) with the American Academy of Environmental Engineers (selected by eminence), and a Diplomate of the American Academy of Water Resources Engineering (DWRE). Prof. Illangasekare's research experience and expertise are in numerical modeling and experimentation of flow and transport in porous and fractured media, unsaturated and saturated zone processes, arctic hydrology, land-atmospheric interaction, multiphase flow, carbon storage, aquifer remediation, physical modeling of flow and transport and sensor technologies for environmental applications. In Sri Lanka, he worked on coastal aquifer contamination after the 2004 tsunami and chronic kidney disease of unknown etiology (CKDu).

Keynote Address-2:
Securing critical infrastructure and the IIoT

Prof. Iain Murray
John Curtin Distinguished Professor,
School of Electronic Engineering, Comp and Math Sci (EECMS), Faculty of Science and Engineering
Curtin University, Australia

Abstract:

With the advent of the IoT and its application in industrial settings, there is a significant gap in security policy and implementation as data traverses the traditional Operational Technology (OT) infrastructure and into the IT space. Data gathered in the OT environment now needs to traverse the corporate network to decision makers opening up an array of security and compatibility issues that need to be addressed to keep our critical infrastructure safe.

Speaker Biography:

John Curtin Distinguished Professor Iain Murray AM received his B.Eng (Hons) in Computer Systems Engineering in 1998 and his PhD titled "Instructional eLearning technologies for the vision impaired" in 2008, both at Curtin University. He has worked in the field of assistive technology for nearly 30 years both as a practitioner and researcher. Currently employed as Deputy Head in the School of Electrical Engineering, Computing & Mathematical Sciences, his research interest include; learning environments for people with vision impairment, embedded sensors in health applications, the Internet of Things and assistive technology. He founded the "Cisco Academy for the Vision Impaired" in 2002 to deliver ICT training to vision impaired people globally. He has supervised 19 research students' completions and published in excess of 140 peer reviewed articles in the fields of IoT, engineering education and assistive technology. He is a Member of the Order of Australia, Fellow of the Australian Computer Society, Curtin Academy Fellow and a senior member of the IEEE.

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MATHEMATICS AND INFORMATION TECHNOLOGY

Implementation of Smart Parking System Using Image Processing

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ABSTRACT

In recent years, the number of vehicles in use has shown a steady increase, leading to a clear demand for larger parking areas. However, the traditional methods for detecting occupancy of slots in smart vehicle parking areas are no longer feasible due to the high cost of sensors and the need to monitor larger areas. In response to this challenge, the present study aims to propose a cost-effective, fast, and accurate solution for updating and indicating the real-time number of free parking slots in a parking area. Specifically, the proposed solution utilizes video footage from a camera as the input device and applies the YOLO v3 object detection algorithm for image processing to detect the coordinates of both parking lots and parked vehicles separately. To train and evaluate the model, we used the PKLot database as the dataset and tested the model's performance under different weather conditions. The proposed model achieved an average performance of 88.01%, with the highest performance demonstrated on sunny days and the lowest performance recorded on rainy days.

KEYWORDS: *Convolutional Neural Network, image processing, parking space detection, shortest path algorithm, smart parking system.*

1 INTRODUCTION

With the ever-increasing urban population and the improvement in living standards, the usage of vehicles has increased. According to the past statistics of the Department of motor traffic Sri Lanka usage of vehicles is continuously increasing from 2008 to 2016 according to the department of motor traffic in Sri Lanka. Traffic congestion and difficulty in finding free parking areas are some of the main concerns in metropolitan areas. As a result, parking areas are expanding and the need for monitoring large vehicle parking areas is becoming a necessity.

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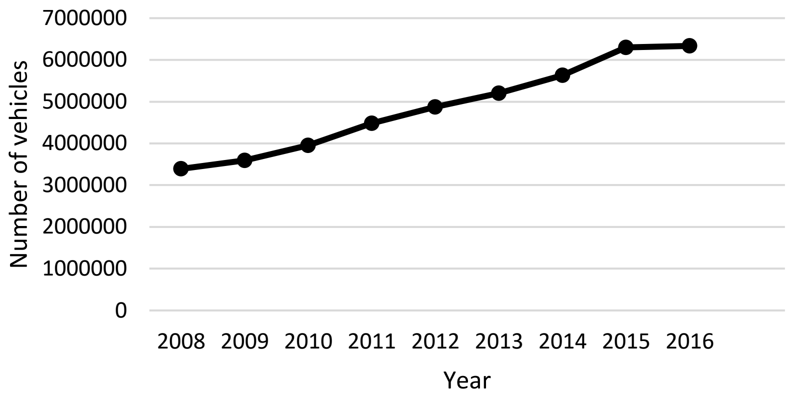

Figure 1: Total vehicle population in Sri Lanka

Nowadays most vehicle parking areas are not running efficiently. Existing parking areas are not efficient and are not meeting the driver's expectations. Because of that drivers may take extra time driving around the parking area on busy days to find a free parking space. Even though the number of parking areas is high, drivers cannot find an available parking space due to the unavailability of the proper status of parking area. Failure to find a free parking slot can cause congestion on the roads, Carbon Dioxide emission, waste of energy, road accidents and an increase in the stress level of drivers. The main problem that always occurs at the car park is wasting time when searching for available parking spaces. These problems are seriously affecting public health and the effective use of resources. In most urban cities, the average search time for an available parking place is around 10 minutes. (Edirisinghe, 2014).

To tackle these problems, smart parking systems have been implemented. The occupancy of the vehicles is detected using sensors. Geomagnetic, ultrasonic, Radio-Frequency Identification (RFID), Internet of Things (IoT) (Aekarat Saeliw, 2019) and magnetic sensors (J. Wolff, 2006) were some of the object detection methods used by past studies. The Canny Edge Detection algorithm is one of the widely used algorithms in the study area (Benjamin Kommey, 2018). High cost, low performance in poor weather conditions, less accuracy and limitation of small parking areas were some of the issues in existing system solutions. There is a dearth of research on solutions which are fast, cost-effective, and suitable for monitoring large area. The study addressed the research question of What is the best solution for overcome in effectivity existing issues of the vehicle parking system using image processing? The aim of the study is to identify problems with existing smart parking systems and introduce an improved and effective method to overcome the issues of the vehicle parking system.

2 LITERATURE REVIEW

Various studies have been carried out related to smart parking areas. Different categories of smart parking areas could be identified based on the technological perspective (Barriga,2019). Smart parking solutions involve several technological components such as sensors, software solutions, and networking infrastructure. Cameras (Lamborinos L. & Dosis A., 2013), ultrasonic sensors (Greg Y. & Cassandras C.G, 2012), cellular sensors (John et.al, 2017), infrared (Vora et al., 2014), radar (Mathews et al, 2014), RFID (Aekarat Saeliw, 2019), laser-based, smartphone sensors and magnetometers (Jones et al, 2017) have been used in past studies as sensors. Sensors were divided into two categories based on the established location. Different studies did the selection of sensors based on criteria invasive, ease of installation, one sensor per slot, several sensors per slot and detection anatomy.

There are various methods to detect vehicles in a parking area. One method is using the Radio-Frequency Identification (RFID) and the Internet of Things (IOT) which can detect the available parking lot. (Aekarat Saeliw, 2019) This IOT based parking system is created by using controllers, sensors, servers, and cloud. Sensors are placed in each parking slot to detect the presence of a car. The sensor will read the number of vacant parking lots and send the data to the microcontroller. Then the microcontroller will display the number of vacant parking spots and display it in the LED display. Therefore, drivers can know the availability of free parking slots before entering the parking area. Figure 2 shows the process of the above-mentioned system.

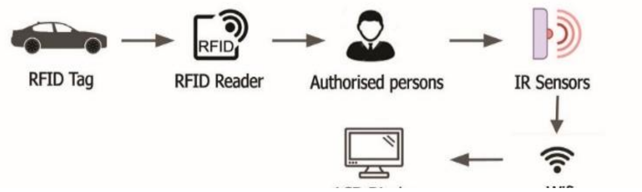

Figure 2. The architecture of Detecting Empty Parking Slot

The problem of this system is the inability of sensors to detect the presence of a vehicle in the bad weather condition. Each slot must have a sensor and having sensors in every parking slot is not cost-effective. Also, it is difficult to maintain a sensor-based parking system. There is another method to determine the vacancy status of parking space, through magnetic sensors by using the effect of Earth’s magnetic field. (J. Wolff, 2006)

Another way is to identify the parking slot using image processing technology. (Benjamin Kommey, 2018) This system consists of some operations such as system initialization, image acquisition, and image processing, data interpretation, and display updates. Cameras take snapshots and pass them to the microcontroller unit (MCU) for communication at regular time intervals. The controller forwards the collected data to the base station over the setup local area network. At the base station, the received images undergo a preprocessing stage. The system can display the result using the method of Luminosity, Canny edge detection, and other techniques. The accuracy of this system depends on information captured from images of the parking space. Most of the research used canny edge detection algorithm for identifying the free parking slots. (Benjamin Kommey, 2018)

3 RESEARCH METHOD

The overall conceptualized solution is shown as follows. When a vehicle is entering to the parking area, it shows the status of the parking area using image processing and object detection algorithms (YOLO v3) by evaluating the footage of the surveillance camera established in the parking area. If there are no free parking slots, the system displays the message "parking area is full". Otherwise, the system shows several free available parking slots and directs the driver to the nearest parking area. After the driver parks the vehicle in the free parking slot the system updates the status of each parking slot and displays the result at the vehicle park entrance.

Checking the availability of parking slots could be further divided into the following steps as system initialization, input Livestream video, get coordinates of the parking area, assigning unique numeric labels to each parking slot, get image frame, identifying the vehicles using object detection, check availability of parking lot and display output.

The video camera is fixed in a position above the vehicles, to acquire the video used to get the vacancy of the car park. An inexpensive compact wireless video camera can be used for this purpose. This camera should be in a position where can see all parking lots and the camera should be fixed more than ten feet above the ground level because the mean pixel value of each vehicle in the parking area must be always captured.

3.1 YOLO Algorithm

YOLO (You Only Look Once) is a state-of-the-art, real-time object detection system. It uses Convolutional Neural Networks (CNN) for object detection. CNN was introduced in the 1990s (Lecun et al,1998) and it could be categorized under deep neural network especially invented for image processing and object detection.

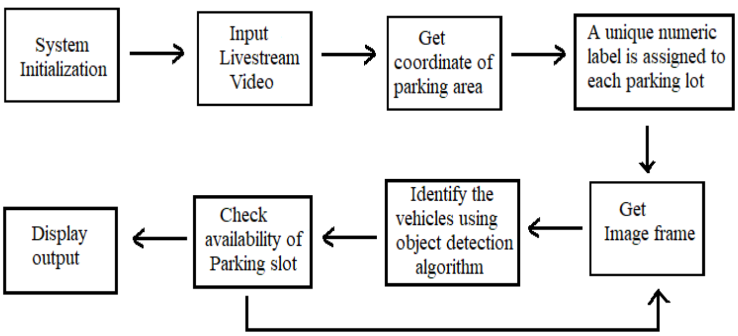

Figure 3. Flowchart of the free parking slot detecting system

It processes data in a grid-like manner and consists of an input layer, a series of hidden layers and an output layer. YOLO name is self-explanatory that it passes the input image through the CNN algorithm only once to get output.

YOLO has versions as YOLO v1, YOLO v2, and YOLO v3. YOLO v3 can detect multiple objects present in an image in real-time by drawing bounding boxes around them, which is the location and predict the class of the object. YOLO v3 was selected for the study because it was more accurate and faster compared to other versions.

3.1.1 Process of object detection in YOLO v3

YOLO v3 applies a single neuro network for the entire image. The image was divided into grid cells and produced probabilities for every cell. Then predict several bounding boxes that cover some area of the image and choose a bounding box according to the probability.

3.1.2 Network Inputs

Network input consists of a batch of images. The shape of the image is represented using four numbers as (n, 416, 416, 3). The first, second, third and fourth numbers represent the number of images, width, height, and number of channels respectively. Height and width can be interchanged and divisible by 32. Increasing input resolution might improve the accuracy of the output after the training. Middle 2 numbers are considered as the input network size. YOLO v3 accept images of any size to the network as all the images will be resized to network size.

3.1.3 Architecture of YOLO v3

YOLO uses convolutional layers. YOLO v3 consists of 53 CNN layers (Darknet -53) and staked additional 53 layers for detection tasks. Detections are made in 82,94 and 106 layers. Each CNN layer is followed by a batch normalization layer and Leaky ReLU. In addition to that YOLO v3 consists of essential elements residual blocks, skip connections and up-sampling. There are no pooling layers in YOLO v3 but convolutional strid 2 layers are present. It prevents losing small features as it considers all numbers in the feature map.

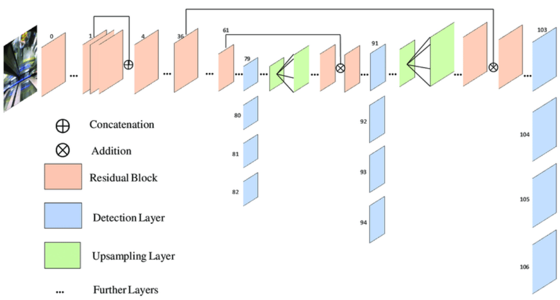

Figure 4. YOLO v3 NNC Architecture

The network makes detections at layer 82,94 and 106 by down-sampling input by following 32,16 and 8 factors respectively. These numbers are known as Network Strides and show the output in 3 separate places in the network. If the network input size is 416 x 416, layer 82, 94 and 106 output sizes are respectively 13 x 13,26 x 26 and 52 x 52. 13 x 13 detects large objects while 52x 52 detects smaller objects.

YOLO v3 applies 1 x1 detecting kernels (filters) to produce the feature maps. 1 x 1 kernel's shape includes the depth which can be calculated by the following equation.

$$\text{Depth of kernel(D)} = (b*5+c) \tag{1}$$

Where b is the number of bounding boxes. YOLO v3 predicts 3 bounding boxes for each cell of the feature map. Each bounding box consists of 5 attributes. Centre X and Y coordinated of the binding box (t_x and t_y), width and height of the bounding box (t_w and t_h) and objectness score of the bounding box (P_0) are five attributes. C is the list of confidence for every class (Lorry, car, van,…) this particular bounding box might belong to (P_1, P_2,P_3,…,P_C). The shapes of the feature map produced in layer 89, 94, 106 are (13,13, D), (26,26,D), (52,52,D). (Kathuria, 2018) Objectness score is the probability that the bounding box contains an object inside.

The network predicted 3 bounding boxes for each cell in the feature map. Each cell predicted an object through its one bounding box if the center of the object belongs to the center cell of the bounding box. This was done during the model training.

During the training, YOLO v3 has one ground truth binding box for one object. The Centre cell of the bounding box was assigned to predict the object. The objectless score for this was 1.

To predict bounding boxes, YOLO v3 used predefined /default bounded boxes called Anchor boxes or priors. Anchors are used to calculating the predicted bounding box's real width and height. In YOLO v3 three anchor boxes were used for each scale (82, 94, 106) to calculate 3 bounding boxes for each scale. K-means clustering was applied to calculate anchors in YOLO v3. Anchors do not predict the definite height and width to eliminate the unstable gradient. Therefore c_x,c_y,p_w and p_h made normalize c_x,p_w by dividing the width of the image and c_y,p_h by the height of the image.

To predict the correct height and width of predicted binding boxes YOLO v3 calculated the offset of the anchor. It is also known as Log space transform. To calculate the center of the binding boxes, YOLO3 version passed parameters through the sigmoid function. Below mentioned equations are used to obtain the height and width of the center coordinates. b_x, b_y, b_w, b_h are the center, width, height of coordinates and t_x, t_y, t_w, t_h are outputs of CNN. c_x and c_y are the top left corner coordinates of anchor box p_w and p_h are the anchor's width and height.

$$b_x = \sigma(t_x)+c_x \tag{2}$$

$$b_y = \sigma(t_y)+c_y \tag{3}$$

$$b_w = p_w e^{tw} \tag{4}$$

$$b_x = P_h e^{th} \tag{5}$$

YOLO v3 center coordinates were passed using the sigmoid function by giving values 0 and 1. Using the below-mentioned equations absolute values of the binding box were calculated.

$$BB_X = b_x * \text{width of image} \tag{6}$$

$$BB_y = b_y * \text{ height of image} \tag{7}$$

$$BB_w = b_w * \text{width of image} \tag{8}$$

$$BB_h = b_h * \text{height of image} \tag{9}$$

To select one bounding box, extract probabilities of bounding boxes to find out whether the bounding box contains a certain class. For that computed the product of P_0 and list of confidences which was $\{P_1, P_2, P_3, \ldots, P_C\}$. The binding box with maximum probability was the relevant class of the object.

The equation for objectness score can be represented as follows where is the predicted probability binding box and between the predicted and ground truth binding box.

$$P_{object} * IoU = \sigma(to) = Po \tag{10}$$

To find the mean pixel value of each vehicle takes the fixed numbers of pixel values inside the vehicle bounding box. Here n is the fixed number of points.

$$\text{Mean of x values } \bar{x} = \frac{1}{n}\sum x \tag{11}$$

$$\text{Mean of x values } \bar{y} = \frac{1}{n}\sum y \tag{12}$$

After segmenting the video into frames, the system use frame of the empty parking area to record the location of all parking slots. According to that frame, the system inputs the coordinates of each parking slot to a text file and labels each parking slot using a unique numeric value.

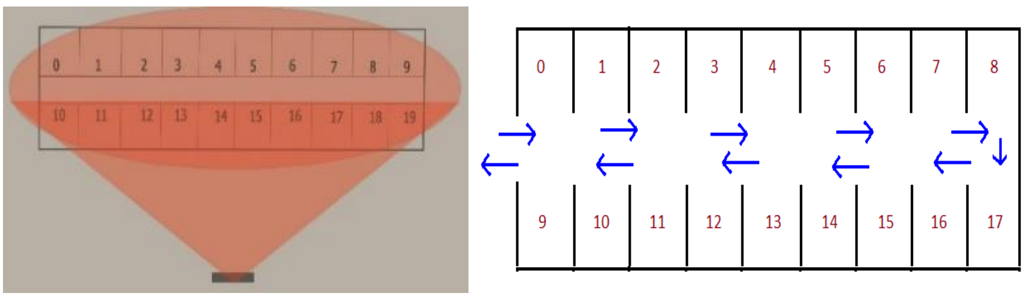

Figure 5. The view of camera position and the architecture of parking area

The maximum number of slots that could be labelled depends on the capture area of the camera and the training model. For the vehicle detection and occupancy of the parking lots, the YOLO v3 object detection algorithm was used. Using the non-maximum suppression technique determines the class of each object. After getting the coordinate of different types of vehicles marked the bounding boxes. The status of each parking slot can be determined by comparing the mean pixel value of each vehicles and the coordinates of bounding boxes. If the mean pixel value of the vehicle is inside the given bounding box then, that parking slot is not empty. Otherwise, it is empty. Sequentially update the status of each parking slot and display it. The vacant parking slot is displayed according to the distance from the entrance to the parking slot.

4 The PKLot dataset

The PKLot database was used as the dataset for this study. The PKLot dataset includes 12,417 images of parking lots and 695,899 images of segmented parking spaces, checked and numbered manually. Both photographs were bought at the Federal University of Parana and the Pontifical Catholic University of Parana parking lots in Curitiba, Brazil. The dataset for parking slots is acquired by following the image acquisition process. This process was executed with a 5-min time-lapse interval for more than 30 days by means of a low cost full high definition camera (Microsoft LifeCam, HD-5000) positioned at the top of a building to minimize the possible occlusion between adjacent vehicles. Here is a short summary of this dataset.

- Photos are taken under unregulated lighting that depicted various climatic conditions (sunny, rainy, and overcast periods).
- Images were taken from different parking lots presenting distinct features.
- Images show a variety of issues, such as shadow effect, over-exposure to sunlight, low light in rainy days, disparity in perspective, etc.

Extensible Markup Language (XML) file containing the position and location (vacant or occupied) of each parking space was created for each parking lot image. (Jiwoong Choi, 2019)

Figure 6: Image of PKLot dataset without boundary boxes

Each image of the database has an XML file associated with the coordinates of all the parking spaces. Example for XML file as follows.

```
<space id="1" occupied="0">
  <rotatedRect>
    <center x="300" y="207" />
    <size w="55" h="32" />
    <angle d="-74" />
  </rotatedRect>
  <contour>
    <point x="278" y="230" />
    <point x="290" y="186" />
    <point x="324" y="185" />
    <point x="308" y="230" />
  </contour>
</space>
```

Findings and Discussion

The following figure shows the marked boundary boxes and the unique id of each parking slot.

Figure 7. Image of PKLot dataset with unique ID

The online system is getting images from the camera while the offline system is getting images from a video file. The performance of the proposed system is measured by using the following equation. (Almeida P., n.d.)

TPS = Total Parking slots, ANC = Actual Number of vehicles, PNC = Predicted Number of vehicles (detected vehicles)

$$\text{Performance}= 1- ((|\ ANC - PNC\ |)/TPS) *100 \qquad (11)$$

The percentage of error in the proposed system can be found by using this equation.

$$\text{Percentage Error} = ((|\ ANC - PNC\ |)/TPS) *100 \qquad (12)$$

For getting the performance of the algorithm, used different images in different weather conditions. It is observed that the average performance is 88.01 %. The accuracy of the proposed system also depends on the type of camera used for monitoring the parking lot. The following table shows the performance of the algorithm in different weather conditions.

Table 1: Accuracy of algorithm

	Total Number of slots	**Actual Number Of vehicles**	**Predicted Number of vehicles**	**Performance**
Sunny Day	80	78	71	91.25%
Cloudy Day	70	68	60	88.5 %
Rainy Day	70	33	22	84.28%

Conclusion

In the current project, the use of a camera as a sensor for video image detection is proposed. This approach offers the advantage of detecting a large parking area at once and detecting the park lots in any weather condition, while being efficient and cost-effective. The number of cameras required depends on the area to be covered. Unlike existing automated parking systems that rely heavily on various sensors, the proposed system uses image processing algorithms to automate parking with footage obtained from surveillance cameras in the parking lot. These algorithms detect empty parking spaces and provide information to drivers.

This method is capable of managing large areas with just several cameras. Camera positions can be adjusted to improve performance, ensuring that each camera captures the entire area of every parking slot for maximum accuracy. Drivers can receive useful real-time parking lot information through a guidance information display. An integrated image processing approach is utilized to reduce the cost of sensors and wiring complexity.

This paper proposes a vehicle and parking space detection method based on an improved YOLO v3 algorithm, which achieves good results. Different scale feature maps are used for object detection, allowing deeper networks to extract more detailed features. The experiments demonstrate that the algorithm improves the accuracy of vehicle and parking space detection in the parking lot. However, factors such as illumination and weather can affect the algorithm's detection performance, necessitating further algorithmic improvements. Future research could focus on developing the same model using multiple cameras to enhance its effectiveness.

Acknowledgement

The Robotics and Imaging Parking Laboratory of Vision Lot database and yolov3 object detection algorithm have been assisted in leading these findings of this study.

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$\boldsymbol{k}$ – Graceful Labeling of Triangular Type Grid Graphs $\boldsymbol{D_n(P_m)}$ and $\boldsymbol{L}$ – Vertex Union of $\boldsymbol{D_n(P_m)}$

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ABSTRACT

Graph labeling is one of the most popular research topics in the field of graph theory. Prime labeling, antimagic labeling, radio labeling, graceful labeling, lucky labeling, and incidence labeling are some of the labeling techniques. Among the above-mentioned techniques, graceful labeling is one of the most engaging graph labeling techniques with a vast amount of real-world applications. Over the past few decades, plenty of studies have been conducted on this area in various dimensions. Grid graphs are very much useful in applications of circuit theory, communication networks, and transportation networks. However, in the literature, there are not many research papers on the graceful labeling of grid graphs except a few on odd graceful labeling. In our work, we prove that triangular-type grid graphs, $D_n(P_m)$ and L – vertex union of $D_n(P_m)$ admit k – general graceful labeling and k – even and k – odd graceful labeling. Further, we introduce combinatorial proofs for them as well.

KEYWORDS: $\boldsymbol{k}$ – *even graceful labeling*, $\boldsymbol{k}$ – *graceful labeling*, $\boldsymbol{k}$ – *odd graceful labeling, triangular type grid graph.*

1 INTRODUCTION

The graceful labeling method was put forward by Alexander Rosa in 1967 this labeling method was originally given the name as β – labeling and later it was named graceful labeling by Golomb (Gallian, 2009). There is a very famous conjecture called the graceful tree conjecture abbreviated as GTC which hypothesizes that all trees are graceful and it remains unsolved. However, the notion of graceful labeling was very much used for decomposing the complete graphs into isomorphic subgraphs. There are a lot of real-world applications of graceful labeling in coding theory, missile guiding codes, x-ray crystallography, cryptography, etc (Deshmukh, 2015).

In our work, we use the concept of natural generalization of graceful labeling which is known as k – graceful labeling which was introduced around 1982.

Despite the large number of publications carried out on the title of graceful labeling, research paper related to the graceful labeling of grid graphs is a bit rare in the literature. In 2013, M. E. Abdel-Aal discusses the odd graceful labeling of $D_n(P_m)$ in a paper on new classes of odd graceful graphs (Abdel-Aal, 2013). S.K. Vaidya and B. Lekha published an article on new families of odd graceful graphs, and there they discuss odd graceful labeling of $D_2(P_m)$ around 2010 (Vaidya & Lekha, 2010). So, we are interested to introduce k – graceful labeling and k – even and k – odd graceful labeling of $D_n(P_m)$ and L – vertex union of $D_n(P_m)$ hoping to apply these labelings to real-world problems in future work. In cryptography for encrypting messages and communication networks for multi-protocol label switching networks.

2 METHODOLOGY

First, we begin by giving the notations and the definitions used in this research work.

Definition 1. k – Graceful labeling. Let $G = G(V, E)$ be a graph with $p = |E(G)|$, where $V(G)$ and $E(G)$ denote the set of vertices and edges, respectively. Graceful labeling of G is a vertex labeling $f: V \to [0, p + k - 1]$ such that f is injective and the edge labeling $f_\gamma: E \to [1, p + k - 1]$ defined by

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$f_\gamma(uv) = |f(u) - f(v)|$ is also injective. Such a graph is called a k – graceful graph. When $k = 1$, it is called general graceful labeling.

Definition 2. k – even graceful labeling. A graph $G = (V, E)$ with q edges is said to admit even graceful labeling if there is an injection, $f : V(G) \rightarrow \{0, 1, 2, \ldots, 2q\}$ such that when each xy edge is assigned the label $|f(x) - f(y)|$. A graph that admits even graceful labeling is called an even graceful graph.

Definition 3. k – odd graceful labeling. A graph $G = (V, E)$ with q edges is said to admit odd graceful labeling if there is an injection, $f : V(G) \rightarrow \{0, 1, 2, \ldots, (2q - 1)\}$ such that when each xy edge is assigned the label $|f(x) - f(y)|$. A graph that admits odd graceful labeling is called an odd graceful graph.

Definition 4. The triangular-type grid graph $D_n(\mathrm{G})$ of a connected graph G is constructed by taking n copies of G, say $G_1, G_2, G_3, G_4, \ldots, G_n$, then join each vertex $U_{i,j}$ with $U_{i\pm1,j+p}$ where $1 - j \leq p \leq n - j$ only in G_i where each G_i is a P_m, path graph of m vertices such that $1 \leq i \leq m$ and $1 \leq j \leq n$, more precisely $D_n(P_m)$. Let $D_n(P_m)$ be a graph with $mn = |V(G)|$, $n^2(\mathrm{m} - 1) = |E(G)|$ where $V(G)$ and $E(G)$ denote the set of vertices and edges, respectively.

Theorem 1: The graph $D_n(P_m)$ is k – graceful for any finite m and n.

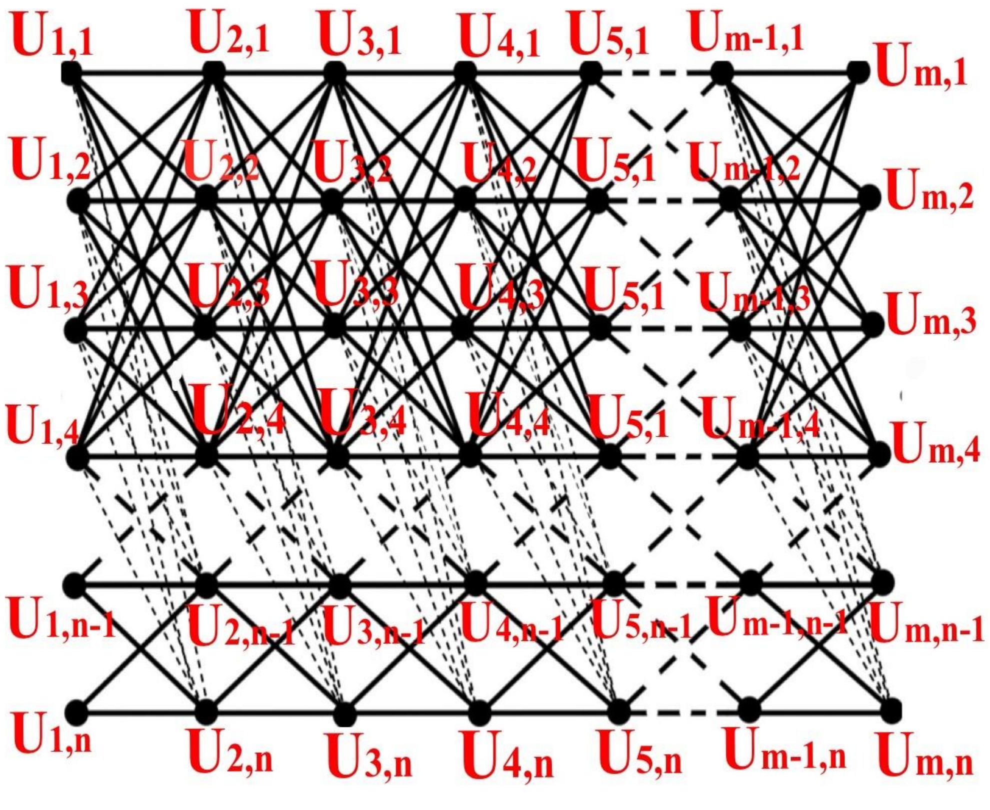

Figure 1. The graph $D_n(P_m)$

Let f be the vertex k – graceful labeling of the above grid graph,

$$f(U_{i,j}) = \begin{cases} \frac{i-1}{2}n^2 + j - 1; \;\; i - odd; \;\; j - 1,2,\ldots,n \\ n^2(m-1) + n^2\frac{i-2}{2} - n(j-1) + k - 1; \; i - even, j - 1,2,\ldots,n, k \in \mathbb{N} \end{cases} \tag{1}$$

Now, we introduce the formula obtained for the k – even graceful labeling for the $D_n(P_m)$.

Theorem 2: The graph $D_n(P_m)$ is k – even graceful for any finite m and n.

Let f be the vertex k – even graceful labeling of the above grid graph,

$$f(U_{i,j}) = \begin{cases} (i-1)n^2 + 2(j-1); \;\; i - odd, \; j - 1,2,\dots,n \\ n^2\{2(m-1) + i - 2\} - 2n(j-1) + k - 2; \;\; i, k - even, j - 1,2,\dots,n \end{cases} \quad (2)$$

Next, we introduce an alternative formula for obtaining k - odd graceful labeling for the $D_n(P_m)$.

Theorem 3: The graph $D_n(P_m)$ is k – odd graceful for any finite m and n.

Let f be the vertex k – odd graceful labeling of the above grid graph,

$$f(U_{i,j}) = \begin{cases} (i-1)n^2 + 2(j-1); \;\; i - odd, \; j - 1,2,\dots,n \\ n^2\{2(m-1) + i - 2\} - 2n(j-1) + k - 2; \; i - even, k - odd, j - 1,2,\dots,n \end{cases} \quad (3)$$

For further investigations, we consider a diagonal extended version of $D_n(P_m)$, we call it L – vertex union of $D_n(P_m)$.

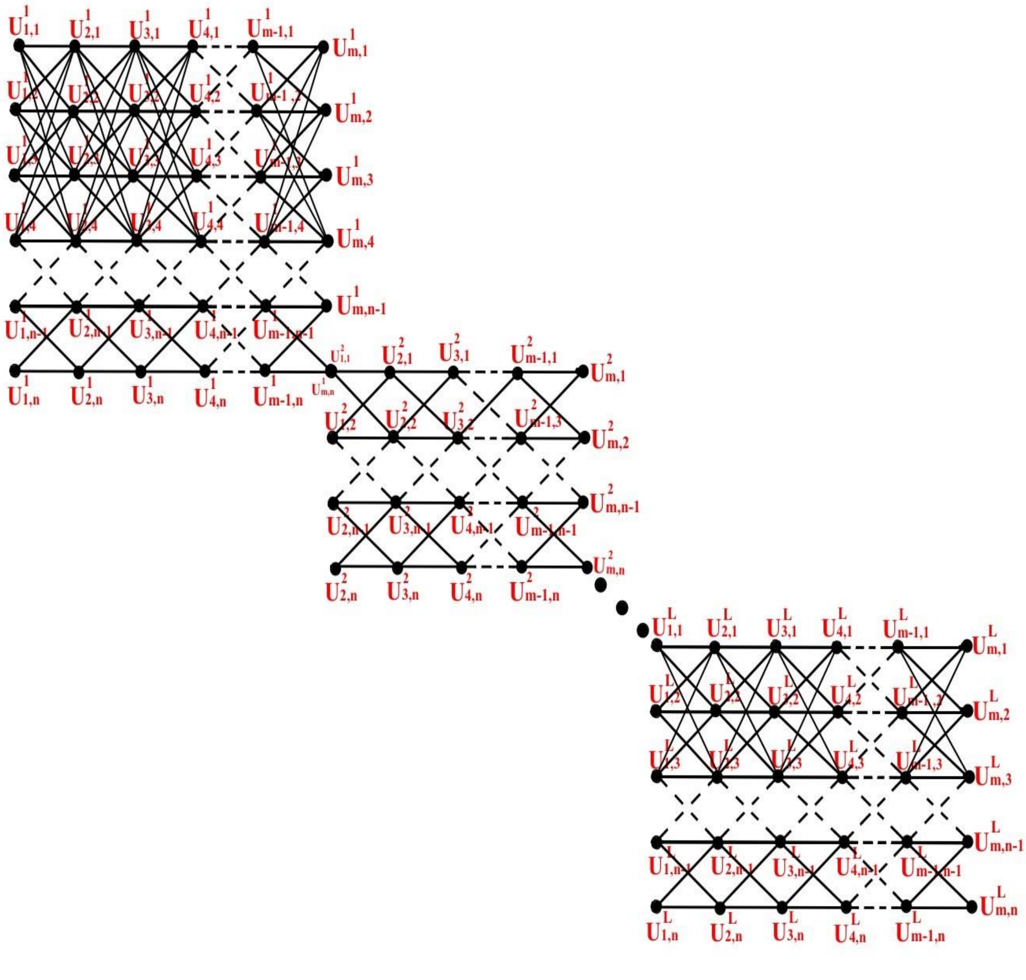

Figure 2. L – vertex union of $D_n(P_m)$

Theorem 4: L – vertex union of $D_n(P_m)$ is k – graceful for any finite m and n.

Let f be the vertex k – graceful labeling of the above grid graph. The formula of the k – graceful labeling for the first($L = 1$) grid,

$$f\left(U_{i,j}^{(L=1)}\right) = \begin{cases} \frac{i-1}{2} n_L^2 + j - 1;\ i - odd, j - 1,2,\ldots,n_L \\ \sum_{L=1}^{l} n_L^2 (m_L - 1) + \frac{n_L^2(2-i)}{2} - n_L(j-1) + k - 1;\ i - even, j - 1,2,\ldots,n_L \end{cases} \quad (4)$$

Note that, when all the grids are the same in size, $\sum_{L=1}^{l} n_L^2 (m_L - 1) = n^2(m-1)l$, where l is the total number of grids.
The formula can be divided into two parts depending on the following factor of the k – graceful labeling for the $L > 1$ grids,

Case 1: $U_{m_{L-1},n_{L-1}}^{L-1} - U_{m_{L-1},n_{L-1}-1}^{L-1} = 1$

$$f\left(U_{i,j}^{L}\right) = \begin{cases} U_{m_{L-1},n_{L-1}}^{L-1} + \frac{i-1}{2} n_L^2 + j - 1;\ i - odd, j - 1,2,\ldots,n_L \\ f\left(U_{m_{L-1}-1,n_{L-1}}^{L-1}\right) + \frac{U_{m_{L-1},n_{L-1}}^{L-1} - U_{m_{L-1},n_{L-1}-1}^{L-1}}{\left|U_{m_{L-1}-1,n_{L-1}}^{L-1} - U_{m_{L-1}-1,n_{L-1}-1}^{L-1}\right|}\left\{1 + \frac{n_L^2(i-2)}{2} + n_L(j-1)\right\};\ i - even, j - 1,2,\ldots,n_L \end{cases} \quad (5)$$

Case 2: $U_{m_{L-1},n_{L-1}}^{L-1} - U_{m_{L-1},n_{L-1}-1}^{L-1} \neq 1$

$$f\left(U_{i,j}^{L}\right) = \begin{cases} f\left(U_{m_{L-1},n_{L-1}}^{L-1}\right) + \frac{U_{m_{L-1},n_{L-1}}^{L-1} - U_{m_{L-1},n_{L-1}-1}^{L-1}}{\left|U_{m_{L-1},n_{L-1}}^{L-1} - U_{m_{L-1},n_{L}-1}^{L-1}\right|}\left\{\frac{i-1}{2} n_L^2 + n_L(j-1)\right\};\ i - odd, j - 1,2,\ldots,n_L \\ f\left(U_{m_{L-1}-1,n_{L-1}}^{L-1}\right) + \frac{n_L^2(i-2)+2j}{2};\ i - even,\ j - 1,2,\ldots,n_L \end{cases} \quad (6)$$

Theorem 5: L – vertex union of $D_n(P_m)$ is k – odd graceful for any finite m and n.

Let f be the vertex k – odd graceful labeling of the above grid graph. The formula of the k – odd graceful labeling for the first($L = 1$) grid,

$$f\left(U_{i,j}^{(L=1)}\right) = \begin{cases} (i-1)n_L^2 + 2(j-1);\ i - odd, j - 1,2,\ldots,n_L \\ 2\sum_{L=1}^{l} n_L^2(m_L - 1) + n_L^2(2-i) - 2n_L(j-1) + k - 2;\ i - even, j - 1,2,\ldots,n_L, k - odd \end{cases} \quad (7)$$

Theorem 6: L – vertex union of $D_n(P_m)$ is k – even graceful for any finite m and n.

Let f be the vertex k – even graceful labeling of the above grid graph. The formula of the k – even graceful labeling for the first($L = 1$) grid,

$$f\left(U_{i,j}^{(L=1)}\right) = \begin{cases} (i-1)n_L^2 + 2(j-1);\ \ i - odd, j - 1,2,\ldots,n_L \\ 2\sum_{L=1}^{l} n_L^2(m_L - 1) + n_L^2(2-i) - 2n_L(j-1) + k - 2;\ \ i,k - even, j - 1,2,\ldots,n_L \end{cases} \quad (8)$$

The formula for k – odd and even graceful labeling of the $D_n(P_m)$ for the $L > 1$ grid are the same and can be divided into two parts depending on the following factor of the k – graceful labeling for the $L > 1$ grid,

Case 1: $U_{m_{L-1},n_{L-1}}^{L-1} - U_{m_{L-1},n_{L-1}-1}^{L-1} = 2$

$$f\left(U_{i,j}^{L}\right)=\begin{cases} U_{m_{L-1},n_{L-1}}^{L-1}+(i-1)n_L^2+2(j-1);\ i-odd, j-1,2,\ldots,n_L \\ f\left(U_{m_{L-1}-1,n_{L-1}}^{L-1}\right)+\frac{f\left(U_{m_{L-1}-1,n_{L-1}}^{L-1}\right)-f\left(U_{m_{L-1}-1,n_{L-1}-1}^{L-1}\right)}{\left|f\left(U_{m_{L-1}-1,n_{L-1}}^{L-1}\right)-f\left(U_{m_{L-1}-1,n_{L-1}-1}^{L-1}\right)\right|}\{2(1+n_L(j-1))+n_L^2(i-2)\}; i-even, j-1-n_L \end{cases}$$
(9)

Case 2: $U_{m_{L-1},n_{L-1}}^{L-1}-U_{m_{L-1},n_{L-1}-1}^{L-1}\neq 2$

$$f\left(U_{i,j}^{L}\right)=\begin{cases} f\left(U_{m_{L-1},n_{L-1}}^{L-1}\right)+\frac{f\left(U_{m_{L-1},n_{L-1}}^{L-1}\right)-f\left(U_{m_{L-1},n_{L-1}-1}^{L-1}\right)}{\left|f\left(U_{m_{L-1},n_{L-1}}^{L-1}\right)-f\left(U_{m_{L-1},n_{L-1}-1}^{L-1}\right)\right|}\{(i-1)n_L^2+2n_L(j-1)\}, i-odd, j-1,2,\ldots,n_L \\ f\left(U_{m_{L-1}-1,n_{L-1}}^{L-1}\right)+\frac{n_L^2(i-2)+2j}{2}, i-even,\ j-1,2,\ldots,n_L \end{cases}$$
(10)

3 RESULTS AND DISCUSSION

The following figures illustrate the above-mentioned theorems and we use those figures to prove that triangular type grid graph and its diagonal extended version admit graceful labeling.

Proof of Theorem 1:

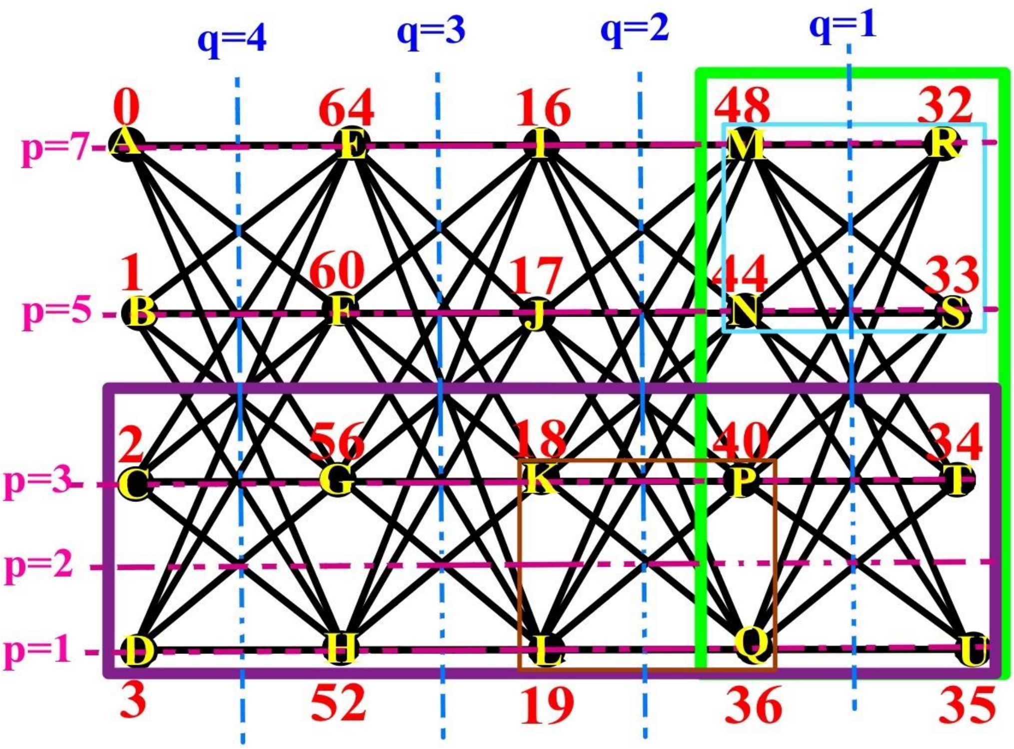

Figure 3. 1 - Graceful labeling of the $D_n(P_m)$

In order to show that graph $D_n(P_m)$ admits graceful labeling, we have to show that no edge label repeats, the maximum edge label that can have is the total number of edges of the graph, and each edge gets a label.

Here, we introduce new reference labels to edge labels for constructing formulas for the edge labels using p and q, and vertices are labeled using block letters for reference edges easily. To obtain the corresponding p or q value of a particular edge set, find the midpoints of that edge set and follow the dotted lines. All the following equations are obtained for considering a column.

First, consider the green column. Considering the horizontally parallel edge labels, QU, PT, NS, MR through $p = 1, 3, 5$, and 7, we can introduce the following formula for all the horizontal parallel edges.

$$The\ edge\ labels\ =\ bottom\ edge\ label + (n+1)\frac{p-1}{2}, p = 1, 3, 5, 7, \ldots \tag{11}$$

Then, considering the zig-zag patterned edges like QT, TN, NR and UP, PS, SM through $p = 2, 4, 6$. We can introduce the following formula,

$$The\ edge\ labels\ =\ bottom\ edge\ label + (n+1)\frac{p-2}{2}, p = 2, 4, 6, \ldots \tag{12}$$

Finally, consider any set of slanted parallel edges like QS, PR, and UN, IM through $p = 3, 5$. We can introduce the following formula for those parallel edges.

$$The\ edge\ labels = bottom\ edge\ label + (n+1)\frac{p-3}{2},\ p = 3, 5, \ldots \tag{13}$$

Since all the Eqs. (11)-(13) are monotonically increasing with p, we can figure out that the highest edge labels must be at the top of any column(green) and minimum edge labels must be at the bottom of any column(green).

Now, consider the purple row. Considering the horizontal edge labels like QU, LQ, HL, DH and TP, PK, KG, GC and the zig-zag patterned edges like UP, PL, LG, GD and TQ, QK, KH, HC through $q = 1, 2, 3, 4$. We can introduce the following formula,

$$The\ edge\ labels = bottom\ edge\ label + n^2(q-1),\ q = 1, 2, 3, 4, \ldots \tag{14}$$

Since Eq. (14) is monotonically increasing with q, we can figure out that the highest edge labels must be on the left-most side of any row(purple) and minimum edge labels must be on the rightmost side of any row(purple).

All in all, we can say that the maximum edge label given by these formulas must be the left-most upper edge label, $U_{1,1}U_{2,1}$ according to Figure 1.

Consider the two squares light blue and brown. The light blue square is the top of the green column and it must contain the highest edge labels of the edges in that column can have. It contains edge labels $11, 12, 15, and\ 16$. $13, 14$ edge labels are in the diagonals of this entire column. Now, consider the brown square and it is the bottom of that corresponding column. So, it must contain the minimum edge labels of the edges in that column can have and it contains $22, 21, 18, and\ 17$. So, the brown square's element is greater than any element in the light blue square. Consequently, this condition is valid for edge labels in any two columns too. This implies that no edge label repeats.

Using the equation 1 for horizontal parallel edge labels through $p = 1, 3, 5, \ldots, 2n-1$, we can obtain the edge label of the $U_{m-1,1}U_{m,1}$ in Figure 1 as follows,

$$The\ edge\ label\ of\ U_{m-1,1}U_{m,1}\ =\ 1 + (n+1)\frac{p-1}{2} \tag{15}$$

Here $p = 2n-1$. $\therefore\ The\ edge\ label\ of\ U_{m-1,1}U_{m,1}\ =\ 1 + (n+1)(n-1) = n^2$. (16)

Using the equation 4 for horizontal edge labels through $q = 1, 2, 3, \ldots, m-1$, we can obtain the edge label of the $U_{1,1}U_{2,1}$ in Figure 1 as follows,

$$The\ edge\ label\ of\ U_{1,1}U_{2,1} = n^2 + n^2(q-1) \tag{17}$$

Here $q = m-1$. $\therefore The\ edge\ label\ of\ U_{1,1}U_{2,1} = n^2 + n^2(m-2) = n^2(m-1)$. (18)

Now, we can confirm that the maximum edge label given by these formulas does not exceed the total number of edges of this graph in Figure 1.

Since we label edges starting from 1 and up until the total number of the edges of that graph and have considered each and every edge label and confirmed that no edge label repeats and the maximum edge label does not exceed the total number of edges, we can conclude that all the edges of that graph must be labeled from 1 up to the total number of edges without repeating. Proof of theorems 2 and 3 can be proved by using the same procedure.

Proof of Theorem 4:

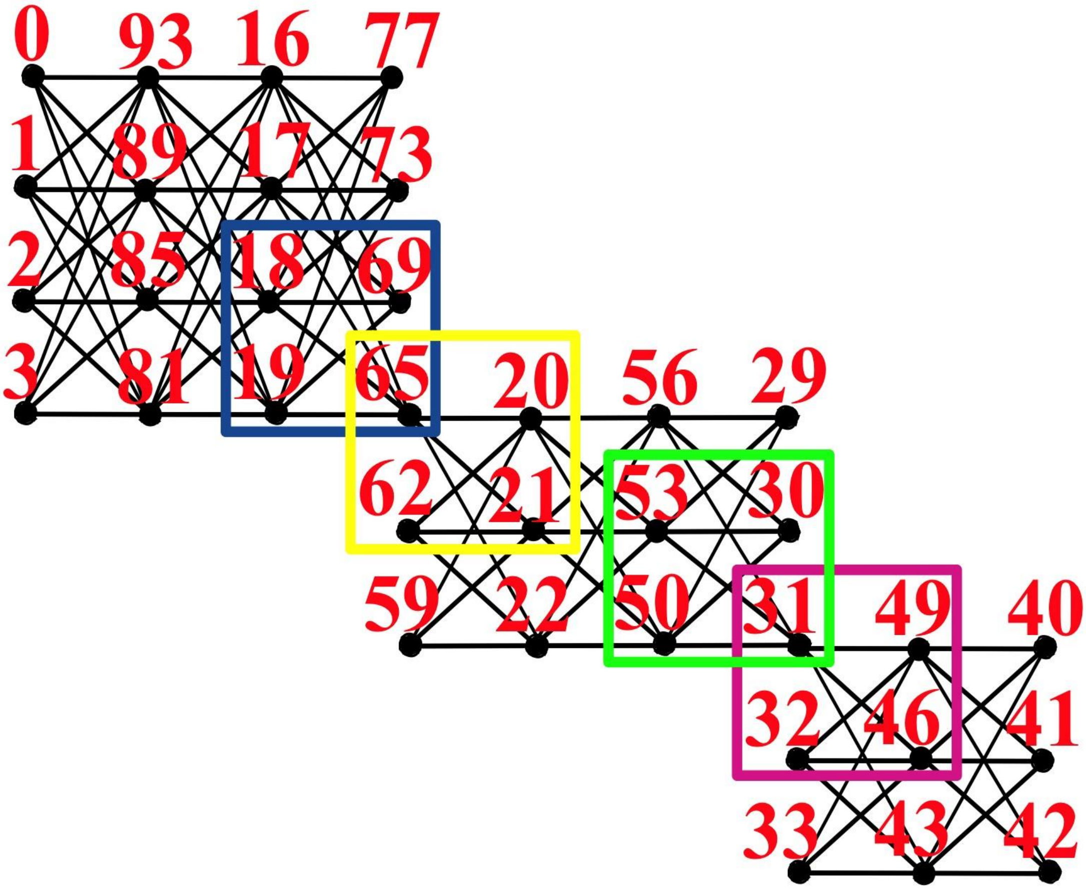

Figure 4. 1 - Graceful labeling of the vertex union of $D_n(P_m)$

Using Theorem 1, we can deduce the proof of this theorem. In order to show that graph $D_n(P_m)$ admits graceful labeling, we need to prove the same thing mentioned in Theorem 1 for column vise and grid vice too. Since the vertex union of $D_n(P_m)$ is an extended version of $D_n(P_m)$ and each grid in Figure 4 has the same characterization which we discussed in the above proof, we can confirm that no edge label repeats in any grid.

Now, we need to show that no edge label repeats in any two grids. For that, consider the blue, yellow, green, and yellow squares in Figure 4. The pink square has the maximum edge labels in the grid $L = 3$, the green square has the minimum edge labels whereas the yellow square has the maximum edge labels of the grid $L = 2$, and the blue square has the minimum edge labels of the grid $L = 1$. Let's compare the edge labels of each square, $blue > yellow > green > pink$. Since the maximum edge labels of $L = 3 <$ minimum edge labels of $L = 2$, this implies that all the edge labels of $L = 3 <$ all the edge labels of $L = 2$ and by using the same conditions, we can show that any edge label in $L = 2 <$ any edge label in $L = 1$.This implies that edge labels vary like this: $(L = 1) > (L = 2) > (L = 3)$. So, we can conclude that two edge labels never repeat throughout the grid.

Using Eqs. (11)-(13), we can show that the maximum edge label of any particular grid equals to $n_L^2(m_L - 1)$. If we take the sum of the maximum edge labels, we get $\sum_{L=1}^{l} n_L^2(m_L - 1)$. Since $\sum_{L=1}^{l} n_L^2(m_L - 1)$ is the total number of edges, we can conclude that this labeling method's maximum edge label does not exceed the total number of edges.

Since we label edges starting from 1 and up until the total number of the edges of that graph and have considered each and every edge label and confirmed that no edge label repeats and the maximum edge label does not exceed the total number of edges, we can conclude that all the edges of that graph must be labeled from 1 up to the total number of edges without repeating. Theorems 5 and 6 can be proved in the same manner.

4 CONCLUSION

Graceful labeling is one of the most engrossing labelings in the literature of graph theory and applications of graceful labeling are even more magnificent. Though there is a large number of research papers in the field of graph theory, there is no certain technique for labeling different classes of graphs. In our research, we proved that triangular-type grid graphs, $D_n(P_m)\ \forall\ m, n$, and L – vertex union of $D_n(P_m)$, admit k - graceful labeling $\forall\ L, m_L, and\ n_L$. We obtained the proof for the gracefulness of these grid graphs from each category and verified that they are graceful. In future work, we hope to apply the k – graceful labeling of this type of triangular-type grid graphs in cryptography and communication networks.

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Application of Peak Over Threshold Approach to Model Extreme Motor Insurance Claims: A Case Study

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ABSTRACT

Prior to the economic recession in Sri Lanka, the motor insurance business grew significantly due to the excessive importation of vehicles. More vehicles on the road and reckless driving increase the risk of extreme claims, which creates a negative impact on the industry. In order to mitigate this issue, researchers attempted to model extreme claims and thereby to provide information for better management of business. The objective of this study is to identify the best fit model for tail of the claim distribution based on data obtained from a pioneer insurer in Sri Lanka from July to December of 2021. The Peak Over Threshold approach of the Extreme Value Theory was applied to model the extreme claims. The claims at 20 percentiles between 79% and 98% were considered as tentative thresholds and the excessive amounts over each of these thresholds were modeled separately as Generalized Pareto Distributions (GPDs) using four different parameter estimation methods. Then the Mean Squared Error (MSE) at each threshold for each parameter estimation method was examined to compare their performances. The threshold and the parameter estimation method with the minimum MSE were selected as their optimum values while identifying the GPD fitted as the best model. The Bootstrap goodness of fit measured the validity of modelling. The extent of claims varied from Rs. 2167.00 to 193,065.00 during the study period with a positive skewness of 2.45 and leptokurtic, which confirmed the existence of a heavy tailed distribution for claims. The best fitted model was the GPD with the shape and scale of 1.02 and 92.09 respectively, which was attained at the optimal threshold of 91st percentile using the Biased Probability Weighted Moment method. The information on the tail helps review existing strategies for the better management of risk due to such extreme claims in future.

KEYWORDS: *Claims, Generalized Pareto Distribution, Insurance, Percentile, Threshold.*

1 INTRODUCTION

With the rapid development of the automobile technology and the fast-paced life styles, travelling by motor vehicles has become an indispensable part of life, but travelling on the road comes with its own share of risks. Due to surge in unpredictable circumstances in day-to-day life, people have been in search of compensation and protection of their vehicles to avoid or minimize the financial risk associated with it. As a remedial measure, the motor insurance business got established under the non-life insurance category. According to the rules and regulations imposed by the Government of Sri Lanka, it is mandatory for every vehicle to possess at least a third-part policy while driving on roads without which it is considered as a serious offence. Over the past few decades, the motor insurance business has grown significantly in Sri Lanka due to the excessive importation of vehicles while becoming one of the most profitable businesses over time.

Non-insurance claims are usually known to be heavy tailed (Beirlant et al., 2004). Extreme motor insurance claims are rare in frequency but there is no assurance that it would not occur in any given instance due to uncertainties embedded in everyday life. Some unexpected events make the motor claim sizes enormous and cause negative consequences on a company's finances which could even lead to its bankruptcy. Many of such incidents are caused by the failures in risk management systems and lack of awareness in implementing amendments to existing strategies for accommodating current demands and trends in a country (Gaio et al., 2015). This urges insurance companies to look for new policies and strategies to handle financial loss due to such extreme claims. For this purpose, knowledge on the

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distribution of extreme claims that occur in the right tail area is required by actuaries to determine appropriate level of critical estimates such as insurance premiums, reserves, re-insurance and thereby to establish proper risk management systems. This stimulated researchers to engage in modelling the tail rather than the body of claim distributions. For many decades, the bulk and the tail data were modeled together using Gamma, Weibull, Exponential and Log-normal distributions. These models seemed to be appropriate for small and moderate claim sizes. However, it was highlighted that these distributions largely overestimate or underestimate the tail probabilities (Lee, 2012).

Accurate modeling of the tail of the claim distribution and separation of extreme claims from non-extreme data are challenging. However, it is an important area of research to assure a profitable non-life insurance business in future.

Having identified the importance of modeling the extreme data, Hogg & Klugman (1984) attempted to fit the tail of loss distribution as a truncated Pareto distribution using two parameter estimation methods viz. Maximum Likelihood Method and the Method of Moment, which is well-recognized and a pioneering research work carried out under the area of modeling the tail. However, according to a subsequent study by Boyd (1988), this distribution substantially underestimated the tail region of the loss distribution.

Several studies have shown that Extreme Value Theory (EVT) is a better approach to deal with the challenges in modeling the tail segment separately from the bulk of the loss severity distribution, as it provides a firm theoretical foundation in modelling extreme events (McNeil, 1997 ; Resnick, 1997). There are two types of approaches under EVT namely, Block Maxima (BM) and Peak-Over-Threshold (POT) method. In the first approach (BM), data are divided into blocks and the block maxima is modelled by fitting it into Generalized Extreme Value (GEV) distribution (Fisher & Tippett, 1928). In the other approach (POT), extreme data that exceed a sufficiently high threshold are considered for modelling. According to Pickands (1975), the cumulative distribution of the exceedances over sufficiently high threshold approaches the Generalized Pareto distribution (GPD). It was observed that the BM method discarded some extreme values that carried certain vital information as it considered only the maxima of each block for modelling, which was seen as a waste of data (Cole, 2001). On the other hand, generally, the POT approach is preferred and more efficient as it considered more extreme data for modelling than the BM, which is especially useful in case of dearth of information in the tail area (Reiss & Thomas, 2002). This approach is widely used in the non-life insurance sector to derive critical estimates (Wang et al., 2020).

In the POT approach, the selection of sufficiently high threshold is critical and challenging. Threshold must be sufficiently high to ensure the reliability of the GPD approximation. However, the high threshold reduces the sample size for modelling and increases the variance of the parameter estimation. This led to conclude that the choice of threshold should strike a balance between bias and variance (Scarrott & MacDonald, 2012). Over the past decades, several approaches have been introduced to select optimal threshold for POT. Scarrott & MacDonald (2012) categorized various techniques used for this purpose into graphical method, rule of thumb, probabilistic approach, computational approach, and mixture models. Dupuis (1999) introduced a threshold selection method based on robustness consideration. Moreover, Bayesian approach was used by Tancredi et al., (2006) who discussed the ways of incorporating threshold uncertainty in the inferences. Thompson et al., (2009) showed that these methods are computationally demanding and complicated to implement in practice. Zakaria et al., (2017) applied the POT method with two approaches to select threshold viz. the rule of thumb and graphical method. Further, Gharib et al., (2017) used the Mean Residual Life plot to select tentative set of thresholds from which the optimal was selected using the Square Error method. However, the use of graphical methods is subjective as it requires substantial expertise to interpret the plots like Mean Residual Life plot (Solari et al., 2017; Thompson, 2009). On the other hand, various methods have been introduced to automate the optimal threshold selection, for instance, Thompson et al., (2009) and years later Solari et al., (2017) introduced a technique for automatic threshold selection based on the Anderson-Darling EDF-statistic and goodness of fit test, which estimated the uncertainty associated with threshold estimation lacking in graphical method. Though there are numerous techniques in literature to choose the optimal threshold for POT approach, Davison & Huser (2015) mentioned that threshold selection is a long standing issue that still remains unresolved.

In the model building process parameter estimation is an essential part. The choice of the parameter estimation methods depends mostly on the sample size available. Incorrect choice of the parameter estimation method would seriously affect the inferences drawn. This makes researchers more cautious on parameter estimation methods under the POT framework because in many practical situations only a few observations are available for modelling the tail. The accurate estimation of the shape (ξ) and scale (σ) parameters of the GPD is as important as the optimal threshold selection. In literature, Maximum Likelihood Estimation method (MLE), the Probability Weighted Method (PWM), and the Method of Moments (MOM) have commonly been used for the estimation purpose (De Zea Bermudez & Kotz, 2010). MLE performs well when the sample size for estimation is large (Deidda & Puliga, 2009; Kang & Song, 2017). Hosking & Wallis (1987) pointed out that Method of Moment performs poorly when the shape parameter exceeds 1. The PWM method performs well for the shape parameter between $0 \leq \xi \leq 1$ and shows excellent performance when $\xi \leq 0.5$ (De Zea Bermudez & Kotz, 2010). Moreover, according to Castillo & Hadi (1997), PWM performs well when the sample size for modelling is small. Rydman (2018) applied the Unbiased Probability Weighted Moment (UPWM) method for parameter estimation of GPD and found that UPWM method is more efficient when the number of exceedances over threshold is small. Zhao et al., (2019) compared the performances of Maximum Likelihood Estimation (MLE), L-Moment, Weighted Nonlinear Least Square Likelihood Moment (WNLLSM), and Weighted Nonlinear Least Square Moment (WNLSM) in estimating the parameters of GPD under the POT method. Kang & Song (2017) used six different parameter estimation methods in fitting GPD and revealed that non-linear least square based method outperforms others. More often, performance of the GPD parameter estimators depends on both the sample size and the value of the GPD shape parameter (Gharib et al., 2017; Kang & Song, 2017). This leads to assume that the methods available for parameter estimations perform well in some situations but otherwise in some circumstances.

Moreover, it is evident from literature that, though the application of POT method is common in the field of non-life insurance, its application is very limited in a country like Sri Lanka especially for motor insurance claims. Therefore, this study focused on the application of the POT method of extreme value theory together with the best parameter estimation method to model tail and estimate the parameters of GPD to get better understanding on the behavior of tail in motor claims distributions. More specifically, this study identify the optimal threshold out of several sufficiently high tentative thresholds required for POT approach based on the mean squared errors of percentiles estimated through fitted GPDs for extreme claims with four different parameter estimation methods and thereby identify the best fit distribution for tail of the claim distribution.

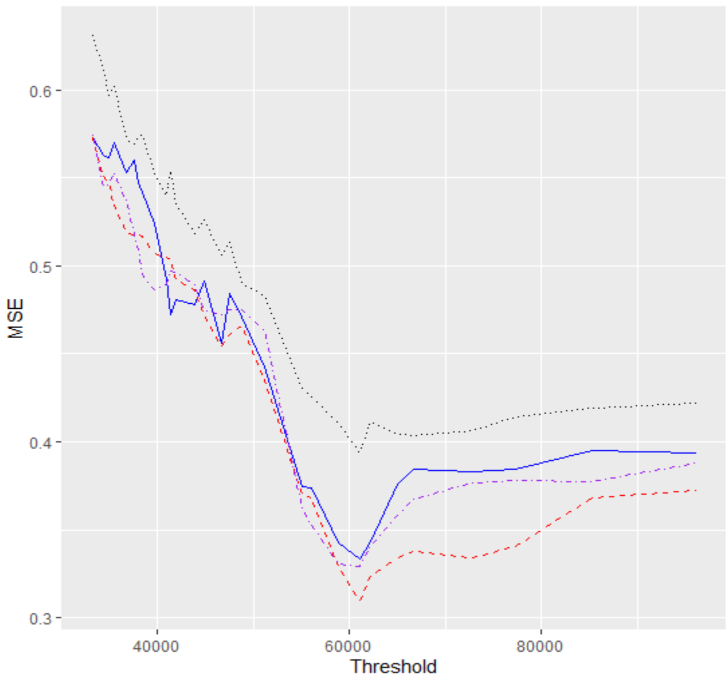
2 METHODOLOGY

This study aimed at comparing the performances of four different parameter estimation methods at sufficiently high tentative thresholds to identify the best fit model for extreme motor claims under the POT framework. The motor claims received by a pioneering insurance company in Sri Lanka from July to December of 2021 were used for this study. At first, descriptive statistics were examined to get an idea on how the claims were distributed over the period of study. Then, the POT approach of the EVT was applied for model fitting as it incorporates more extreme data than the BM method. Under the POT framework, excess claims over a sufficiently high threshold can be approximated by the Generalized Pareto distribution. Therefore, the next step was to find the optimal threshold which separated extreme claims from the bulk. For this purpose, the study initially considered claims at 20 different percentiles ranging from 79% to 98% as tentative thresholds, thus covering the range of percentiles proposed for threshold in literature under the rule of thumb method (Scarrott & MacDonald, 2012). Since a sufficiently high threshold ensures a better fit of GPD, the process was initiated by taking the 98th percentile as the first tentative threshold. Then the excess values above the 98th percentile were modelled as the GPD and the parameters were estimated using the four different parameter estimation methods viz. Maximum Likelihood Estimation (MLE), Method of Moment (MOM), Unbiased Probability Weighted Moment (UPWM), and the Biased Probability Weighted Moment (BPWM). Subsequently, the accuracies of the fitted GPD models under the four different parameter estimation methods were evaluated separately by calculating the mean squared error statistics for which simulated data obtained from the fitted GPDs and the actual data at 10 different percentiles were used. Next, the same procedure was carried out by taking the 97th percentile as the second tentative threshold, a percentile less than the previous threshold. Similarly, the process was continued until the minimum mean squared error for a particular threshold was attained which balances the bias and variance involved in model fitting. Further, in order to ensure that there is no any other threshold which yield the minimum mean squared error, the process was executed up to the 79th percentile. The threshold and the parameter estimation method, which yielded the minimum mean squared error in fitting the GPD, were selected as the optimal threshold and the best parameter estimation method while the model fitted under these conditions was selected as the best fit for extreme motor insurance claims. The optimal threshold selection approach proposed in this study was simple and efficient compared to the one proposed by Thompson et al., (2009) in which 100 tentative thresholds between median and the 98th percentile of data were considered which required considerable computational time. Finally, the Bootstrap Goodness of fit test was conducted to validate that excess values over each threshold follow a GPD. The null hypothesis tested under this test is as follows.

H0: Motor insurance claims over a sufficiently high threshold follow a Generalized Pareto distribution with a positive shape parameter, ξ.

3 RESULTS AND DISCUSSION

It was revealed that the motor insurance claims were distributed with a median of Rs. 22,500.00, which means that 50% of the claims received during the study period were larger than Rs. 22,500.00. The minimum and the maximum claims received by the insurance company were Rs. 2167.00 and Rs. 193,065 respectively. Moreover, the claim distribution was leptokurtic as the kurtosis was greater than 3 and positively skewed with a skewness of 2.445. These properties indicate that the motor claim distribution is heavy tailed. The smallest (79th percentile) and the largest (98th percentile) tentative thresholds amounted to Rs.40,925.00 and Rs. 96,114.40 respectively while the number of claims above the largest and the smallest tentative thresholds were 11 and 98 respectively. That is, only 11 observations were available for modelling the tail when the threshold was set to Rs.96,114.40. The MSE of percentiles estimated through the GPD fitted to excess values over each of the 20 tentative thresholds with each parameter estimation method is presented in the following Figure 1, which enables the comparison of performances of the four parameter estimation methods with the change of sample size for tail. Moreover, Figure 1 displays the optimal threshold for POT approach which yielded the minimum MSE.



…. MLE ——— UPWM -.-.-. MOM ----BPWM

Figure 1. MSE of percentiles estimated through GPD fitted to the excess values over each of the 20 tentative thresholds with the four different parameter estimation methods.

According to Figure 1, it can be seen that the MSEs of GPD fitted with the Maximum Likelihood Estimation method are somewhat higher for all the 20 tentative thresholds compared to those fitted with the other three parameter estimation methods. This is because the MLE performs well when a large sample of data is available for modelling, which was not fulfilled here. The performance of Method of Moment and Unbiased Probability Weighted Moment methods were almost similar and accurate than that of MLE. In contrast, the model parameters estimated through the Biased Probability Weighted Moment method (BPWM) showed somewhat smaller MSEs for almost all tentative thresholds than those obtained from the other three methods. The minimum mean squared errors obtained from each parameter estimation method are summarized in Table 1, which conform well with the profiles illustrated in Figure 1. Further, it can also be seen from Figure 1 that all these four minimum values were recorded at the threshold of 91st percentile equivalent to Rs. 61,056.00. Therefore, out of the 20 tentative thresholds, the 91^{st} percentile was selected as the optimal where the claims above 91^{st} percentile were categorized as extreme and below were non-extreme claims.

Table 1. Minimum MSE of each of the four parameter estimation method

GPD Parameters estimation method	**Minimum MSE**
MLE	0.3934
MOM	0.3290
UPWM	0.3337
BPWM	0.3091

According to Table 1, the BPWM method possessed the minimum MSE compared to other three in respect of the estimation of percentiles through the fitted GPD at the 91^{st} percentile. Moreover, in this study, the BPWM method could be selected as the best parameter estimation method to estimate parameters of GPD as it provided more accurate and reliable estimates especially when a dearth of information prevailed in the tail area. In addition, there were 47 motor claims greater than the optimal threshold of Rs. 61,056.00 which were received during the period of study. The excess claims over the optimal threshold can be best described by the Generalized Pareto distribution with the shape and scale parameters of 1.02 and 92.09 respectively. The positive value of the shape parameter implies that the motor claims distribution is heavy tailed. Moreover, the findings confirm the existing results in the literature that BPWM method is preferred for parameter estimation of GPD when the shape parameter is positive and less than or equal to 1 and the sample size for modeling is small. The p-value ($0.997 > 0.05$) of the Bootstrap goodness of fit test confirmed that excess values over the optimal threshold follow the GPD with a positive shape parameter.

4 CONCLUSION

The demand for motor insurance business has grown significantly with growing risk associated with the increasing number of vehicles on the road and as a financial security to compensate property damage due to unforeseen accidents in future. These unexpected events can sometimes be a huge burden to insurance companies when extreme claims are received from their policyholders. A prior knowledge on the occurrence of extreme claims is really important to introduce measures for a sustainable business. It could be concluded from the study that, the motor insurance claims received during the period of study follow a heavy tailed distribution. Moreover, the extreme motor claims could be best described by Generalized Pareto Distribution with positive shape parameter. The BPWM method would be the best to estimate parameters of the GPD when there is a dearth of information in the tail area. The threshold selection method considered in this study was much simpler and easier compared to some existing approaches in literature. The distribution helps to derive some critical tail estimates like extreme quantiles, by providing useful information to review existing strategies and to introduce timely changes for better management of such risks in future.

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Odd Prime Labeling of Snake Graphs

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ABSTRACT

Graph theory is one of the branches of mathematics which is concerned with the networks of points connected by lines. One of the most important research areas in graph theory is graph labeling, which dates back to the 1960s. Graph labeling is assigning integers to the vertices, edges, or both depending on conditions. Labeled graphs are helpful in mathematical models for a wide range of applications such as in coding theory, circuit theory, computer networks, and in cryptography as well. There are various types of graph labeling techniques in graph theory such as radio labeling, graceful labeling, prime labeling, antimagic labeling, and lucky labeling, etc. In this research, we use one of the variations of prime labeling called odd prime labeling of snake graphs. Recent works on odd prime labeling investigate about families of snake graphs, complete graphs, etc and there they discuss about one odd integer sequence only. In this research, we introduce odd prime labeling method for snake graphs for any odd integer sequence and we give a proof for it as well.

KEYWORDS: *snake graph, odd sequences, odd prime labeling, relatively prime*

1 INTRODUCTION

Graph theory is a branch of mathematics that studies the relationships between objects, called vertices or nodes, and the lines connecting them called edges. Graphs can be used to represent many different types of relationships, including ones between people, roads, and even computer networks. The concept of prime labeling was introduced by Roger Etringer in 1980 and then Meena.S and Kavitha.P worked more on it. The concept of odd prime labeling was introduced by Prajapati.U.M & Shah.K.P and then work on odd prime labeling by many, and researchers Meena.S , Kavitha.P and Gajalakshmi.G are some of them (Gajalakshmi & Meena, 2022), (Prajapati & Shah, n.d.). The odd prime labeling is one of the most recently researched versions and involves labeling the vertices with the set of odd integers $(1, 3, \ldots, 2n-1)$ where n is any positive integer $n \geq 1$, so that any two adjacent vertices are relatively prime.

Odd prime labeling work on simple, undirected, and connected graphs, which is an exciting research area in most recently with a considerable amount of literature on different types of graphs. A graph that allows odd prime labeling is called an odd prime graph.

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Let u, v are adjacent vertices and then the greatest common divisor, $gcd\ (u\ ,v)$ must be 1 so that u and v are odd prime for all adjacent vertices u and v. A snake graph is a type of mathematical graph in which the vertices are arranged in a "snake-like" pattern. This can refer to a variety of different configurations, but one common example is a graph in which the vertices are arranged in a series of consecutive rings, with the vertices on each ring connected to their neighbors in a snake-like pattern. In this type of snake graph, the vertices on the initial ring are connected to the vertices on the another ring. Snake graphs are sometimes used to model networks or other complex systems, and they can be studied using techniques from graph theory.(Carter & Fox, 2022)

Odd prime labeling is new labeling technique which was published by U. M. Prajapati & K. P. Shah around 2018s' and that is introduced in this paper. This paper focus on the Odd Prime Labeling of common graphs such as path graphs, complete bipartite graph, wheel, and other wheel-related graphs, including generalized Petersen graph $P_{\mathrm{n},2}$ (Prajapati & Shah, n.d.).

In 2022, the paper published by Gajalakshmi and Meena , On Odd Prime Labeling of Snake Related Graph prove that some snake-related graphs are odd prime graphs. The odd prime labeling of some new graphs was investigated in this paper. The results show that some snake-related graphs, such as the quadrilateral snake D(Q_n), the triangular snake S(T_n), the double triangular snake D(T_n), the alternate triangular snake A(T_n), the triangular ladder T(L_n), and the open triangular ladder O(TL_n), are odd prime graphs (Gajalakshmi & Meena, 2022). The odd prime labeling problem has many practical applications, including in the design of secure communication networks and in the analysis of chemical compounds. It is also an active area of research in mathematics, with many open problems and ongoing developments. There are two main types of graphs: directed graphs and undirected graphs. In a directed graph, the edges have a direction and are called arcs. In an undirected graph, the edges do not have a direction and are simply called edges.

This paper focus on directed, simple, and connected snake graph $T_{n,m}$ which denotes m , length of the cycle & n, number of cycles. In this research work, investigate a generalized method for obtaining odd prime labeling for snake graph.

Definition 1: Odd Prime Labeling

A graph G with vertex set $V(G)$ is said to have odd prime labeling if there exists an injective function $f\ :\ V(G)\ \rightarrow\ \{1,3,5,\ldots,2|\,V(G)\,|-1\}$ such that for every edge $x,y\in E(G)$, $f(x)$ and $f(y)$ are relatively prime. A graph G that admits odd prime labeling is called an odd prime graph.

2 Materials & Methods

Observation 1:

An odd sequence is a sequence of numbers in which all the numbers are odd. An odd number is any integer that is not divisible by 2. For example, the sequence $\{\,1,3,5,7,9,11\,..,(2n-1)\,\}$ is an odd sequence with the difference of any consecutive numbers is 2 $(d = 2)$, where d denotes the difference of the sequence for any $d = 2, 4, 6, .., 2k$ where k is any integer. In general, so to create an odd sequence, you would simply need to choose a series of numbers that fit this criterion. Odd sequences can be finite, with a fixed number of elements, or infinite, with an unlimited number of elements. Consecutive integers in any order of odd sequence are relatively prime.

Odd Sequence of $d = 2$ $\{ 1, 3, 5, 7, 9, 11 .., (2n - 1) \}$

Odd Sequence of $d = 4$ $\{1, 5 , 9, 13, 17, \ldots , (4n - 3) \}$

:

:

Odd Sequence of $d = 2k$ $\{1, (1 + 2k) , (1 + 4k), \ldots (1 + 2nk - 2k) \}$

Likewise there are infinitely many odd sequences can be found.

Observation 2:

Properties of gcd:

For any non-zero integers a, b, c and any positive integer h, the following hold:

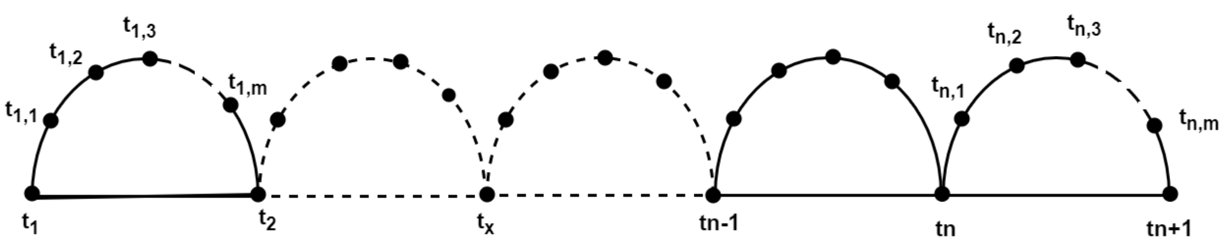
I. $gcd\ (a, a + 2h) = 1$ if a is odd

II. $gcd\ (a, b) = gcd\ (a, a - b)$

III. $gcd\ (a, b) = gcd\ (a + cb , b)$

Theorem:

Snake graph $T_{n,m}$ is an odd prime graph where n denotes number of cycles in graph for any $n \geq 1$ and $n = 1, 2, 3, ..$ and where m denotes number of vertices in the cycle for any $m \geq 1$ and $m = 1, 2, 3, ..$ such that n and m are fixed for a particular given graph. n, m ϵ N (Natural number set).



Proof. We will label the cycles of graph sequentially from t_1 to t_n. Given a cycle t_n consider the vertices in clockwise order as $t_{n,1}$, $t_{n,2}$, $t_{n,3}$, . . , $t_{n,m}$. Let m be the number of vertices in the cycle and

n be the number of cycles in graph. Create labeling starting with initial cycle t_1 in a snake graph by using any odd sequence found as mentioned above.
Label the sequence of vertices of cycle t_n,

$t_{n,1},\ t_{n,2},\ t_{n,3},\ t_{n,4},\ t_{n,5},\ \ldots, t_{n,m}$ respectively.

The vertices on cycle of the snake graph will be labeled with consecutive odd integers.

Similarly label the sequence of vertices of cycle t_{n-1},

$t_{n-1,1},\ t_{n-1,2},\ t_{n-1,3},\ t_{n-1,4},\ t_{n-1,5},\ \ldots, t_{n-1,m}$ respectively.

The vertices on cycle of the snake graph will be labeled with consecutive odd integers.

The labels of the adjacent vertices of cycles in snake graph in both cases are relatively prime. Since Consecutive integers in any order of odd sequence is relatively prime, the labels of the adjacent vertices of cycles in snake graph are relatively prime.

Label the sequence of vertices of path graph $T_{n,m}$,

$t_1,\ t_2,\ t_3,\ t_4,\ t_5,\ \ldots, t_n, t_{n+1}$ respectively.

The vertex pairs of snake graph $(t_1\ , t_2), (t_{2\ ,} t_3), \ldots, (t_x\ \ , t_{x+1}), \ldots, (t_n\ \ , t_{n+1})$ are also adjacent to each other. As well as $(t_{x,}\ \ t_{x+1})$ vertex pair of snake graph adjacent to each other accordingly. Where x is any cycle in snake graph $T_{n,m}$. Vertex pair of snake graph in above has to be relatively prime because they are adjacent with odd integers. Therefore, the pairs of labels that we have to be confirmed are relatively prime on the vertices t_x and t_{x+1} .

Label of vertex in path graph ($t_1 , t_2, \ldots, t_x , t_{x+1}, \ldots, t_n, t_{n+1}$) given by,

$$t_n = 1 + (m+1)(n-1)d \quad (1)$$

Label of vertex in cycle graph $t_{n,1},\ t_{n,2},\ t_{n,3},\ t_{n,4},\ t_{n,5},\ \ldots, t_{n,m}$ given by,

$$t_{n,m} = t_n + md \quad (2)$$

Where d denotes the difference of the sequence for any $d = 2, 4, 6, \ldots, 2k$ where k is any integer.

Label of t_x vertex, $\quad t_x = 1 + (m+1)(x-1)d \quad (3)$

Label of t_{x+1} vertex, $\quad t_{x+1} = 1 + (m+1)xd \quad (4)$

$$\begin{aligned} gcd\ (t_x, t_{x+1}\ ) &= gdc\ (1 + (m+1)(x-1)d\ , 1 + (m+1)xd\ ) \quad \text{(Observation 2)} \\ &= gdc\ (1 + (m+1)(x-1)d\ , (m+1)d\ ) \end{aligned}$$

$$= gdc\ (1 + (m+1)(x-1)d - (m+1)d(x-1)\ , (m+1)d\ )$$
$$= gdc\ (1\ , (m+1)d\ )$$
$$= 1.$$

Greatest Common Divisor (gcd) of vertex pair of snake graph (t_x, t_{x+1}) is 1 which means vertex t_x and t_{x+1} are relatively prime. Therefore the vertex pairs of snake graph $(t_1\ , t_2), (t_2\ , t_3), .., (t_x\ , t_{x+1}), .., (t_n\ , t_{n+1})$ are also relatively prime.
Thus all snake graphs $T_{n,m}$ for any odd sequence are Odd Prime.

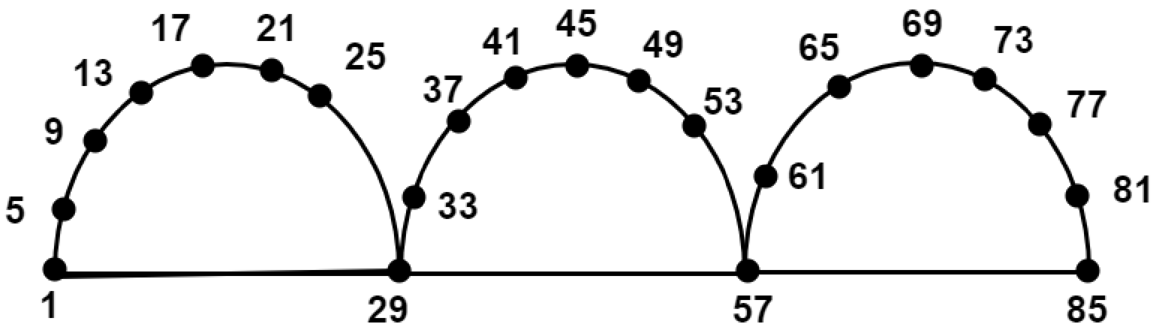


Figure 2 : Odd Prime Labeling of graph $T_{3,6}$ using $(1,5,9,13,..)$ sequence

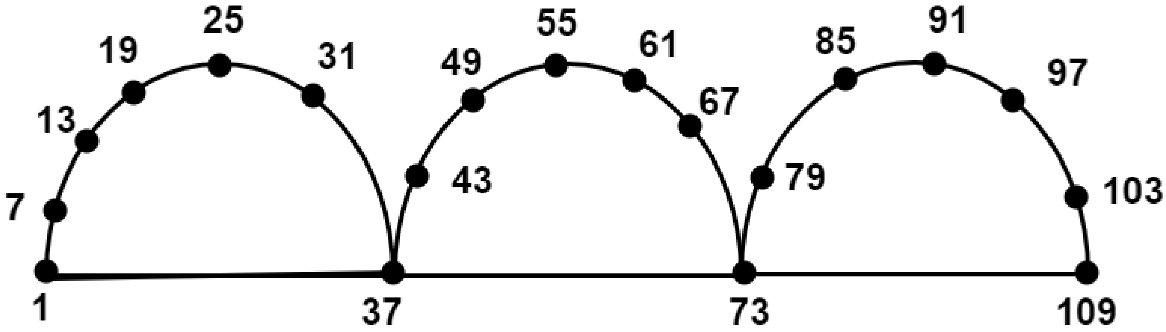


Figure 3 : Odd Prime Labeling of graph $T_{3,5}$ using $(1,7,13,..)$ sequence

3 Results & Discussion

The odd prime labeling is one of the most recently researched versions and involves labeling the vertices with the set of odd integers so that any two adjacent vertices are relatively prime. A new labeling of snake graph has been introduced in this paper called an odd prime labeling of snake graph $T_{n,m}$ by using different types of odd sequences and introducing a general definition.

4 Conclusion

An odd sequence is a sequence of numbers in which all the numbers are odd. In general to create an odd sequence, simply need to choose a series of numbers that fit above criterion. The number of vertices in the cycle (m) and the number of cycles in the graph (n) are varying and the sequence that uses for labeling also can be varying. The snake graph can take different forms depending on the values of n and m. According to the selection of an odd sequence, the labeling of the graph differs. In our paper, we prove that the snake graph can be labeled using odd prime labeling for any odd sequence and introduced a general theorem. Investigating similar theorems for other graphs is an open area of research.

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QUANTITY SURVEYING

Effect of Project Duration Decision at the Bidding Process on Cost Overruns of Sri-Lankan Building Projects

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ABSTRACT

Cost overruns are a significant issue in the construction industry, particularly from the standpoint of clients. Many studies have been interested in the unpredictable situations that lead to cost overruns, with the primary goal of pinpointing the precise causative factors. There is a knowledge gap about whether cost overruns could be prevented through effective decision-making at a project's earliest phases. Therefore, the aim of this research was to critically review if the impact of the project duration decision taken at the bidding process could lead to cost overruns of Sri Lankan building projects, and to provide recommendations of preventive measures to be taken. Deductive research approach and qualitative analysis was used to achieve the four main objectives set for this study. The literature review was able to identify the significant causative factors for cost overrun in the construction industry. The analysis of data collected through questionnaire survey and semi-structured interviews revealed that there are several causative factors for cost overrun, that stem from the project duration being excessive or inadequate : Claims and disputes, inadequate planning and scheduling, unrealistic work schedule, expense due to completion delay and extension of time, and difficulty in predicting the future. This study was able to identify that there is a relationship between project duration decision and cost overrun, where if the project duration decided at the bidding process is excessive or inadequate, it will be causative of cost overruns. Finally, this study has provided preventive measures to avoid cost overrun at the bidding process when deciding the project duration.

KEYWORDS: *Cost overrun, project duration decision, building construction projects*

1 INTRODUCTION

Project efficiency can be determined in terms of how successfully and sustainably project targets are achieved while remaining within the estimated time and budget (Sansoto & Gallage, 2019). Three fundamental criteria are often highlighted with relation to any construction project: Cost, Time and Quality. These criteria which determine the success or failure of projects, have traditionally been referred to as the *iron triangle* of the project management function (Barnes, 1988).

Typically, investors focus highly on the different factors associated with project cost such as return on investment, budget maintenance, profitability etc. (Squires and Greenhalgh, 2012). Therefore, cost management is a function that takes high priority in construction management (Hani, 2014). Phenomena such as cost overrun, albeit being a common occurrence within the industry, have the potential to create excessive wastage and client dissatisfaction if not managed carefully (Zhu et al., 2021). Cost overrun is a major concern in the industry, especially from the perspective of clients (Sindhu Vaardhini et al., 2016). According to Enrica et al. (2021), project cost overrun is the difference between the contract amount agreed upon by the owner and contractor during the signing of the contract and the actual cost of a construction project at completion. The unpredictable circumstances that give rise to this phenomenon has been an interest of many researchers, with high focus on identifying the exact causes of cost overruns and how best to mitigate them.

Past research has identified many causative factors of cost overrun through the use of techniques such as taxonomy formulation etc. (Enrica et al., 2021 ; Malkanthi and Rodrigo, 2021). However, there is a gap in the knowledge of if cost overruns can be avoided through effective decision making at the

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most preliminary stages of a project (Cantarelli et al., 2012). This study analyses the impact of the decision of project duration on cost overruns. Typically, in traditional procurement the project duration decision is taken during the bidding process by the client along with the consultant team. The construction contract and entire project schedule that follows this decision, is highly affected by it. This decision, which will be communicated to all the parties through the contract document, sets the timeframe and target for project completion (FIDIC, 2017). If the period decided on is unrealistic, it may affect the project negatively. Therefore, it is worthwhile to analyze how big of an impact this decision has on the ultimate project cost, and to identify if this impact could lead to cost overruns. Thus, the study aims to critically review if the impact of the project duration decision taken during the bidding process could lead to cost overrun, and to provide recommendations of preventive measures to be taken. The scope of this study is limited to Sri Lankan building construction projects following the traditional procurement route. Therefore, the objectives were implemented as i) to inspect and analyze the key causative factors of cost overruns in the construction industry that have been identified to date; ii) to discern the causative factors for cost overrun in Sri Lankan Building projects that occur as a direct or indirect result of excessive or inadequate project periods; iii) to identify if a relationship exists between project duration decision taken at the bidding process and cost overruns; and iv) to provide recommendations of measures to be taken to prevent this particular type of cost overruns that occur as a result of excessive or inadequate project duration decision.

2 LITERATURE REVIEW

2.1 Construction Projects and Criticality of Cost

A construction project is an intricate collection of ideas, labor, material, technology and plant that is brought together to create or renovate structures such as buildings, monuments, and infrastructure (Chang and Swenson, 2019). The sheer amount of different construction material alone, that is needed to produce a structurally sound and serviceable establishment, ensures that construction projects are very often associated with large investments and rigid cost targets. However, due to numerous phenomena including the many risks and uncertainties linked with construction, cost overrun is a frequent occurrence within the industry (Aljohani et al., 2017). Cost overrun has a largely negative impact on construction projects and although this phenomenon is as old as construction itself, there is still vast improvement needed within the industry if cost overrun is to be avoided completely.

2.2 The Project Duration Decision of a Construction Project

For building projects following the traditional procurement route, the decision of the project duration is typically taken by the client (usually along with the consultant team) during the bidding process of the project. Once the project duration is decided, the client can allow the contractor to prepare a realistic, detailed schedule at minimum cost (Mishra, 2012). A key objective of this study is to identify the causative factors that occur as a direct or indirect result of excessive or inadequate project periods. To achieve this, one must call into question, if the decision taken regarding the project duration during the bidding process had been suitable. Although there is a lot of focus on the different causative factors of cost overrun, there is very little attention given to singular factors independently and there is a lack of research analyzing the relationship between cost overrun and the decision taken regarding the duration (Cantarelli et al., 2012). How this decision could impact the project in terms of cost overruns, has not been intensively studied. In a review of the literature surrounding cost overrun, (Aljohani et al., 2017) found that most studies have not identified the project phases in which the respective cost overruns occur. This research is able to discern if there is a relationship between the decision of project duration taken during the bidding process, and cost overruns. Through the study's fourth objective, the gap in knowledge regarding preventive measures to avoid cost overrun due to project duration decision is also addressed.

2.3 Factors Causing Cost Overruns

The primary goal of reviewing existing literature is to identify and compile the body of knowledge that has already been documented about cost overrun. This research focuses on the Sri Lankan construction industry; therefore, high priority has been given for the studies that are applicable to Sri Lanka. Throughout the years, there are many factors that have been identified as possible causes of cost overrun. To understand these causes better, it is beneficial to examine literature from other South Asian nations in addition to those centered around the Sri Lankan building sector.

Attanayake and Wijekoon, (2012) examined the possible causes of cost overrun in Sri Lankan Road construction projects and came upon 5 main cost overrun factors : Payment delays, Delay in shifting existing utilities, Cost escalation, Frequent design changes during construction, Issues in land acquisition. (Malkanthi and Rodrigo, 2021) identified Lack of coordination between design team and contractor, Delay in providing detailed drawings, Defective designs, Delay in issuing information to the contractor during construction stage, Additional work at owner's request as the main factors of cost overrun in Sri Lankan construction projects. The highest-ranking elements in a study by (Kawmudi and Jayasooriya, 2021) that ranked Limited capacity and experience of the lowest bidder at the time of bidding, Poor preliminary estimations using inaccurate quantity take-offs, Additional expense incurred because of the completion delay, Insufficient early planning as the main causes for cost overruns in Sri Lankan building projects. (Devi and Ananthanarayanan, 2017) observed that the following factors influencing Indian cost overrun in construction projects : Additional works, Unrealistic contract schedule, Disputes on site, Insufficient time to prepare estimate, and Construction delays. In a study by (Ahady et al., 2017), through the use of a quantitative survey among clients, consultants and contractor representatives involved in Afghan building projects, the following were found to be the most crucial sources for cost overrun: Market inflation, Corruption, Fluctuations in the cost of building, Supply shortage of construction material. (Azhar et al., 2008) found that in Pakistan's construction industry, Frequent design changes, Improper planning, Unstable costs of the manufacturing material, and Long periods between designing and time of bidding are among the most critical causative factors of cost overrun. According to a study by (Aljohani et al., 2017) that reviewed the literature from different countries to identify the causes of cost overrun, the following factors are possible causes of overrun : Inadequate project preparation and planning, Unrealistic design development periods, Additional works, Poor project management, Litigation costs. In 2018, the main causes of cost overrun within the UAE construction industry and the available mitigation methods were studied by (Ramabhadran, 2018). His findings proved that the main causes of cost overrun within the UAE construction industry are: Insufficient early planning, Delayed completion, Lack of skilled resources and motivation, Poor productivity. However, a similar study by (Johnson and Babu, 2018) revealed the Design variation, Delay in client's decision making, financial constraints of the client, Poor cost estimation, Following inappropriate procurement methods to be the top five causes of cost variation within the UAE construction industry. Through a study conducted in Iran investigating the causes of delay and cost-overrun in the construction industry, it was found that there were three major factors causing cost overruns (Rezaei and Jalal, 2018). The factors were: Scarcity of labor and skill availability, Domination of the construction industry by foreign firms and aids, Inappropriate nature of contractor policies. A study conducted by (Bekr, 2015) on the factors leading to cost overruns in construction projects in Jordan revealed Schedule delays, Price fluctuations, Design errors, Inadequate planning and scheduling, Frequent design changes to be the most notable causes for cost overrun. (Flyvberg et al., 2018) found that Estimators' lack of experience, Inherent difficulties in predicting the future, Honest mistakes, and Insufficient data are the most common reason behind overruns. A project's size and complexity might make it more difficult to foresee and make decisions accurately, which could lead to a domino effect on how effectively the cost management will be handled later on. It is evident, as numerous studies also acknowledge, that the project decisions made at the preliminary stages of a project are of great importance (Anysz and Buczkowski, 2018; Cantarelli et al., 2012). This is due to the high impact these decisions tend to have on project functions down the line.

2.4 Factors Relevant to the Study

Through the review of past literature, it is evident that cost overrun is a significant concern within not only the Sri Lankan construction industry, but in foreign nations as well. Numerous causative factors for cost overrun have been identified and discussed through past research. The aim of this research is to critically review if the impact of the project duration decision taken at the bidding process could lead to cost overrun, and to provide recommendations of preventive measures to be taken in the context of Sri

Lankan building projects. The first objective set to reach this aim has been achieved, with the identification of key causative factors using past literature. However, these factors have significant classifiable differences from each other, in that, several of them could be entirely avoided if the decisions made at the initial stages of the project are made with caution. In order to achieve the aforementioned aim, as well as to move forward with achieving the second objective of the research, the causative factors that are most relevant to the scope of this research study must be selected. The second objective of this research is to discern the causative factors that occur as a direct or indirect result of excessive or inadequate project periods and inefficient project scheduling. In order to achieve this objective using questionnaire survey, the following factors were filtered out as the ones most relevant to the scope of the research:

1. Frequent design changes (Attanayake and Wijekoon, 2012; Malkanthi and Rodrigo, 2021; Azhar et al., 2008; Johnson and Babu, 2018; Bekr, 2015)
2. Difficulty in predicting the future (Flyvberg et al., 2018)
3. Poor labor productivity (Ramabhadran, 2018; Rezaei and Jalal, 2018)
4. Delays in forming a schedule and planning out work (Kawmudi and Jayasooriya, 2021; Azhar et al., 2008; Ramabhadran, 2018)
5. Delays in following the schedule (Aljohani et al., 2017; Devi and Ananthanarayanan, 2017)
6. Inadequate planning and scheduling (Bekr, 2015; Aljohani et al., 2017)
7. Inflation and / or price fluctuations (Attanayake and Wijekoon, 2012; Ahady et al., 2017; Azhar et al., 2008; Bekr, 2015)
8. Additional works (Malkanthi and Rodrigo, 2021; Bekr, 2015; Aljohani et al., 2017; Devi and Ananthanarayanan, 2017)
9. Expenses due to completion delay and extension of time (Kawmudi and Jayasooriya, 2021; Ramabhadran, 2018; Bekr, 2015)
10. Delay in client’s decision making (Johnson and Babu, 2018)
11. Mistakes in construction (Flyvberg et al., 2018)
12. Claims and disputes (Aljohani et al., 2017; Devi and Ananthanarayanan, 2017)
13. Unrealistic work schedule (Aljohani et al., 2017; Devi and Ananthanarayanan, 2017)
14. Insufficient time for bidders to prepare tender (Devi and Ananthanarayanan, 2017)
15. Lack of coordination between designer and contractor (Malkanthi and Rodrigo, 2021)

3 RESEARCH METHODOLOGY

For this study, the research problem was of whether or not there is an impact of the project duration decision taken during the bidding process, on cost overruns of Sri Lankan building projects. The aim was to critically review if the decision can affect the project so as to cause cost overruns, and if so, to provide the recommendations needed to take preventive measures against it. A literature review was conducted to find and review what factors had already been identified as causes for cost overrun through past research. Through the literature review, the key causative factors of cost overruns were identified and the factors most applicable to Sri Lankan Building projects were analysed further. Upon further analysis, 15 causative factors were selected. Data collection was done through questionnaire surveys and semi-structured interviews containing open-ended questioning. The questionnaire survey was focused on the aforementioned 15 causative factors, to determine if respondents had experienced cost overrun due to project duration decision, and the causes that led to it. The deductive approach was used for this study. Using the deductive approach, it was able to confirm the pre-existing assumption that the project duration decision may have an impact that leads to cost overruns. Qualitative analysis was used to analyse the data collected through the surveys as well as the interviews. Using qualitative analysis, it was possible to observe and interpret the findings to derive the conclusion of whether or not the project duration decision has any impacts that might lead to cost overruns.

Survey candidates were chosen though random sampling of construction industry experts, chosen on the basis of years of experience, knowledge and fields of expertise. The semi-structured interviews were selective sampling. The candidates for the questionnaire surveys and semi-structured interviews were industry professionals of different construction disciplines of at least 5 years of experience and industry experts with over 10 years of experience respectively. The questionnaire survey was shared among 50 candidates, of which 40 responded. This sample was chosen to get the opinions of professionals from different construction disciplines.

4 DATA COLLECTION AND ANALYSIS

The data for this study was collected through a questionnaire survey as well as through semi-structured interviews. For the questionnaire survey, random sampling was done among construction industry professionals, and 40 responses were recorded. The most common designation among respondents is 'Quantity Surveyor', with 13 out of 40 being from that designation. There were no limitations imposed based on the designation of the respondent, as all the chosen respondents were employed in the construction industry. The study did not limit its participants on the basis of years of experience within the Sri Lankan construction industry, however, high focus was given for the survey to be distributed among those with at least 5 years' experience. Consequently, over 70% of the respondents had over 5 years of industry experience. It was mandatory for the respondents to have been involved in Sri Lankan building construction projects and 87.5% of the respondents met this criterion. The 5 remaining respondents were omitted from data analysis. Findings of the demographic data allowed the suitable candidates to be filtered out prior to the primary data analysis.

Analysis of the primary data was able to uncover the main causative factors of cost overrun that occur as a result of excessive or inadequate project duration decision. This analysis was done by filtering the causative factors identified through literature review into 15 factors relevant to the scope of the research. Those factors were then validated through the questionnaire survey by having respondents rank the likeliness of each causative factor occurring due to project period decision. The findings showed that 5 factors were identified : Inadequate planning and scheduling, Claims and disputes, Unrealistic work schedule, Expense due to completion delay and extension of time, Difficulty in predicting the future. Further analysis also uncovered the solution to the third and main objective of the study. Through the responses to the survey, it was found that cost overrun is a factor that is recognized for its impact within the construction industry. It is evident that decision makers actively work towards avoiding cost overrun at the time of deciding project duration. The survey was also able to establish that a strong relationship exists between project duration decision and cost overruns, as findings show that the impact of excessive or inadequate project duration could result in overruns.

Semi-structured interviews allow interviewees to freely share their thoughts relevant to the theme without imposing restrictions on knowledge sharing. For this study, 3 industry experts were interviewed via zoom, a virtual communication platform. The 1st interviewee (hereafter known as ‘Interviewee 1’) is a Chartered Quantity Surveyor with over 24 years of industry experience, specializing in the areas of cost consultancy and contract administration. The 2nd interviewee (hereafter known as ‘Interviewee 2’) is an engineer with over 20 years of industry experience in project management and civil engineering. The 3rd interviewee (hereafter known as ‘Interviewee 3’) is a Chartered Quantity Surveyor with over 10 years of experience in cost consultancy and quantity surveying. The semi-structured interviews commenced with the interviewer’s greetings and introduction of the research study and its aim. This was followed by a round of introductory questioning which set the foundation for the interview. All three interviewees affirmed that they have experienced cost overrun in some building projects they were a part of.

4.1 Excessive or Inadequate Project Duration as a Causative Factor of Cost Overrun

‘The Project Period decision that is taken during the bidding process may have the potential to cause Cost Overrun if the decided project period is excessive or inadequate’. Was this factor considered when deciding on the project duration?”

Following this question, it must first be noted that the statement was affirmed by all interviewees that when deciding on the duration to be given for the project, cost overrun is a general concern. The findings uncovered through the interviews were as follows :

The answers given by Interviewee 1 revealed that although cost overrun is factor that is a generally considered, the client’s preference has a significantly high influence on the project duration, enough to overshadow many of the other general concerns. In certain instances, inappropriately longer project durations had been allowed on the client’s request; longer durations tend to expose the project to more risk and uncertainties. It was also evident that it is similarly true for the opposite, where inappropriately shorter durations are allowed on the client's request, exposing the project to risks that stem from factors such as poor planning, and insufficient time for bidders. A similar point was brought up by Interviewee 3 regarding the client's influence, that the nature of the project and the client's business objectives are two significant factors that sway the project duration decision. It was illustrated further through an example involving a luxury hotel project. At the bidding process, when the duration was being decided, there were several factors considered. Whether or not the duration was sufficient to complete the works had been discussed, among other factors. However, the most influential concern had been regarding the opening day for the hotel. Since the project was to build a hotel, it was imperative that the project was concluded on time for the opening day, because the hotel business in Sri Lanka is seasonal. Due to this factor, there had been a high pressure during the construction stage to finish on time. This example, along with the other views expressed by Interviewee 3 confirmed that the decision regarding the project duration is highly interconnected with the overall project management and could easily influence cost overruns if not taken responsibly. It was affirmed by Interviewee 2 that excessive or inadequate project duration can be a reason, among other reasons, for cost overruns. Furthermore, if an unrealistic timeline is decided for the project, then the contractor may not be able to perform within that timeline, although they may try their level best. Furthermore, the extra effort needed to progress within such a timeline could ultimately lead to the client incurring additional cost. In order to achieve the main objective of this research, the relationship between project duration decision and cost overruns must be identified. These interviews further validate the data that was gathered and analysed through the questionnaire survey. In order to identify if a relationship exists, the interviewees were inquired regarding the impact that project duration decision could have as a causative factor of cost overruns in Sri Lankan building projects. Interviewee 1 expressed that the project duration will impact how much risk the project is exposed to, meaning that if the duration is inappropriately long, the project will be exposed to many uncertainties and risk. Alternatively, if the duration is too low, due to the urgency of work and crashing of program there can be failures that lead to cost overrun. Interviewee 2 restated that the impact will be high, subjected to if the project duration decided during bidding process is unrealistic. Interviewee 3 affirmed that without a doubt, there is an impact as it is a causative factor, however to say if the impact is high or low is difficult without sufficient data.

4.2 Preventive Measures for Cost Overrun Caused by Excessive or Inadequate Project Duration

The final objective of this study is to provide recommendations to prevent cost overruns that occur as a result of the project duration decision. Upon analysis of the findings, the following recommendations can be given as preventive measures to be taken when deciding the project duration:

Table 4.1 – Summary of Recommendations

1	When deciding project duration at the bidding process, project-specific factors such as type of foundation, number of stories of the building, type of finishes, subsurface conditions of the site etc. must be considered when preparing the initial project plan.
2	A typical project plan is not sufficient; Critical planning must be practiced, especially during the initial project stages, so that each aspect of the project is carefully considered and factored into the plan.
3	Project specifications and material requirements should be compared against the material availability. Prior to work commencement, a solid procurement plan must be prepared to avoid disruptions in the workflow.

4	Must conduct thorough research on the location of the site, site topography, social, historical and cultural aspects of the site etc. The project schedule and work plan must be prepared with due consideration to all these factors to reduce unexpected barriers or interruptions to the workflow. Foe example, there may be limitations on transportation of logistics to the site, or the number of work-shifts per day should be decided based on the work target, but also based on if night work is allowed in that particular area
5	When preparing the project schedule, as well as the project budget, must account for potential failures, accidents and delays.
6	Project conditions must be evaluated on a macro-picture, with due consideration to all social, economic and environmental aspects. Then, must conduct research on the availability of the resources and technology to fulfill the required tasks.
7	Must have certainty about project funding. Thorough research must be conducted on funding availability, funding mechanism for the project, feasibility, client's return on investment (ROI) etc.
8	Before proceeding to tendering, considerable amount of comprehensive details must be provided for the bidders to make well-informed decisions and judgements when preparing bids.
9	Good coordination must be maintained between project parties, especially during the initial stages of the project

4.3 Discussion

Through the data analysis, this study was able to confirm that project duration decision, if excessive or inadequate, can be a causative factor for cost overruns in Sri Lankan building projects. It was also confirmed through expert interviews that there is undoubtedly an impact of project duration decision on cost overruns, subjected to if the duration is excessive or inadequate. The factors identified through the literature review was included in the questionnaire survey to gather data from professionals regarding the practical situation within the industry. Each interviewee was inquired regarding the relationship between project duration decision taken at the bidding process, and cost overrun. Through the collected data, it was revealed that a relationship does exist between project duration decision taken at bidding process, and cost overrun. Semi-structured interviews revealed much insight regarding the common occurrence of this phenomenon within the industry. Interviewees were of the view that there may be factors that are not identified by the consultants during the bidding process, as well as unique circumstances that are not accounted for by the contractors when submitting their bids. Such oversights could potentially lead to cost overruns. Interviewee 2 affirms that while the relationship definitely exists, whether or not it is a linear relationship or totally proportionate relationship cannot be confirmed unless proven through calculated data. It can be concluded that relationship is reciprocal, because having a reasonable project duration is a clear governing factor for avoiding cost overrun. The opinions given by the industry experts confirms that there is a relationship between the project duration during the bidding process, and cost overruns of Sri Lankan building projects.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study, conducted on the "Effect of project duration decision at the bidding process on cost overruns of Sri Lankan building projects" revealed that there is a strong relationship between the project duration decision on cost overruns. It was found through literature review, that cost overrun is a fairly common occurrence in the Sri Lankan building construction industry, which, if not managed carefully, can have largely negative impacts on projects. Through the literature review, key causative factors of cost overrun such as "additional works", "insufficient planning and scheduling", "corruption", " supply shortage of construction material", "additional expense due to completion delay" etc. were identified. Through this analysis, the study was able to achieve its first objective: Inspecting and analyzing the key causative factors of cost overruns in the construction industry that have been identified to date.

The second objective of this study was to discern causative factors that occur due to excessive or inadequate project duration. To achieve this objective, 15 causative factors that were most relevant to the research scope were selected. These 15 factors were included in the questionnaire survey for participants to rate the likeliness of the factors occurring due to the project duration being excessive or inadequate. By analysing the findings of the survey, 6 causative factors were derived : Inadequate planning and scheduling, claims and disputes, unrealistic work schedule, expenses due to completion delay and extension of time, difficulty in predicting the future, and delay in forming a schedule and planning out work. It can be concluded that these factors occur as a result of the project duration decided at the bidding process being excessive or inadequate.

To identify and establish a relationship between project duration decision taken during bidding, and cost overruns, findings from the questionnaire survey and the interviews were used. Through the questionnaire survey, participants were asked to rank the impact of project duration decision as a causative factor of cost overruns. The responses showed that a clear majority of participants believe that project duration decision has a high impact, thereby confirming that a strong relationship exists between project duration decision and cost overruns. This is further confirmed through the semi-structured interviews. Interviews were conducted for 3 industry experts and their opinions were analysed to further validate the findings of the questionnaire survey in achieving objective 3. The industry experts confirmed that a clear relationship exists between project duration and cost overrun; They affirmed that project duration decision could lead to cost overruns, subjected to if the decision is unrealistic i.e., excessive, or inadequate. Thus, the main objective of this study was achieved.

5.2 Limitations of the Study

The limitations of this research study were as follows:

- This study was limited to Sri Lankan building construction projects, and the findings may or may not apply equivalently to infrastructure projects.
- This study was limited to projects that followed the traditional procurement path.
- Participants for the questionnaire survey were limited to professionals from the construction industry.
- The questionnaire survey data considered for analysis was limited on the basis of if respondents have worked for a Sri Lankan building project or not.
- The participants for semi-structured interview was limited based on years of experience in the industry; only industry experts with over 10 years of experience were considered.

5.3 Further Research Studies

Avenues for further research unfolded through this study are as follows:

- Further research on establishing the scientific relationship between project duration decision and cost overruns through quantitative analysis

- The causative factors chosen from past literature survey for this study were a limited number which were most relevant to the scope of the study. As further research, other causative factors could also be used and tested to discern if they originate due to the project duration decision.
- Further research on developing a scientific model to determine the most suitable project duration for a particular project.

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Negotiation as an ADR Technique in the Sri Lankan Construction Industry

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ABSTRACT

The construction industry is complex, and disputes are common in this industry. One primary method used in dispute resolution in the Sri Lankan construction industry is negation. Negotiation is considered a cost and time-effective alternative dispute resolution method. However, the contracts formed based on Construction Industry Development Authority (CIDA) do not include negotiation as a dispute resolution (DR) method. Therefore, this study aims to find the reasons for the failures in dispute negotiation and develop a framework to improve dispute negotiation in the Sri Lankan construction industry. There were two methods applied in this research. Because to avoid being based on a limited set of construction industry-related disputes. Five interviews were conducted by construction industry professionals to organize the data collection through documentaries and selected construction industry professionals are one projects director, one Chartered quantity surveyor, one engineer, one project manager, and one quantity surveyor to cover management level, chief level, and senior level. Then 250 claims were collected relevant to design changes, payment-related issues, time-related issues, documentation, and work quality. Out of those five types of claims, the majority of payment and time-related disputes were resolved unsuccessfully through negotiation. Reasons for those disputes to fail in resolving through negation are negotiation outcome do not have statutory powers, the attitude of disputing parties, lack of negotiation skills, lack of trust towards negotiation, and less documentary information. The study recommends CIDA improve negotiation practices in the Sri Lankan construction industry by providing proper training, including negotiation as a compulsory DR, provide awareness programs to the industry stakeholders on dispute negotiation and its benefits.

KEYWORDS: *Negotiation, disputes, construction industry, Sri Lanka.*

1 INTRODUCTION

In the year 2020, the Sri Lankan construction industry contributed 6.2% of the country's GDP, compared to an average of 7.4% over the preceding decade (Trade.gov, 2022). It implies that the construction industry is a significant section of the country's economy (Mallick and Mahalik, 2008; Thanuja, James, and Raufeen, 2013). Likewise, the construction industry can affect the economy by increasing employment, which in turn increases the gross domestic product (Mallick and Mahalik, 2008). Since the construction industry is mainly depending on people and money, there is a great likelihood that disputes will occur. Therefore, construction industry organizations employ conventional management processes. The process is known as dispute resolution (Thusharika and Abeynayake, 2016).

Alternative Dispute Resolution (ADR) and litigation are the two forms of dispute resolution practices adopted in the construction industry. ADR types include negotiation, mediation, conciliation, adjudication, and arbitration (Saeb et al., 2018) and also Med-Arb, and Arb-Med (Cobo Ordóñez & Mesías Vela, 2018). Out of those ADR methods, negotiation is the cost-effective, discreet, and expedient technique (Dissanayake, Abeynayaka, and Pandithawatta, 2018). Negotiation entails conversation between the parties to achieve an accord. There is no limit to the number of parties ("disputants") that can participate in negotiation; however, the type most frequently studied is two-party negotiation (Peter, Carnevale, and Pruitt, 1992). Alternative terms for negotiation include agreement, deal, concert, and conclusion. The word negotiate derives from the Latin “negtiri”, which means "to do business," and it

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retains this meaning (Merriam-Webster, 2022). This study is looking at ways to improve negotiation practices and find the reasons for the failures in dispute negotiation and develop a framework to improve dispute negotiation in the Sri Lankan construction industry.

2 LITERATURE REVIEW

2.1 Types of Negotiation

Various types of negotiation can be identified based on the behavior and relationship of the parties involved. Ganesan (1993) identified two negotiating styles, including ‘integrative’ and ‘distributive’ negotiations. The negotiation types identified by Pabashini and Amaradiwakara (2016) are ‘integrative’, ‘distributive’, and ‘principled’ negotiations. During negotiations, the term "integrative" refers to persons who work together. This negotiation requires the building of a pleasant connection between the parties and a greater level of trust (Fisher and Shapiro, 2006). Distributive discussions are acknowledged as a challenging form of bargaining. This is also referred to as a win-lose negotiation type. The result of the particular type of negotiation is one side winning over the other (Sandhya and Kariayawasam, 2016). Respecting the value and necessity of ongoing relationships, principled negotiation seeks a just and mutually beneficial resolution of conflicts; it is particularly compatible with the ideals upheld by social workers (Lens, 2004).

2.2 Positive and Negative Aspects of Negotiation.

90 to 95 percent of construction disputes are settled by using negotiations but this statistical data does not reflect according to situations (Yates, 2011). Negotiation is more cost-effective, confidential, and speedy procedure safeguards than other methods (Dissanayake, Abeynayaka, and Pandithawatta, 2018). Further, Pabashini and Amaradiwakara (2016) identified the positive aspects of negotiation as; non-third-party involvement, least cost, speedy resolution, time and cost savings, flexibility, simplicity, and informality, private, preserving the working relationship, Preserving the reputation of the parties and Providing insight into the future dispute resolution. Negative aspects of negotiation include lack of legal binding, need for skilled negotiators, lack of neutral intervention, and non-forced use of parties (Pabashini and Amaradiwakara, 2016).

2.3 Negotiation Practice in the Sri Lankan Construction Industry

Negotiation is essential for every construction project and is a significant tool in helping the project navigate the right path (Abeynayake and Weddikkara, 2014). Although there are a number of possible resolution methods, disputes are always negotiated first before other methods are considered (Cheung et al., 2006; Tam, 1998; Yiu, 2011). Even in Sri Lankan construction, industry negotiation is the initial attempt to resolve construction disputes (Jayasena and Yakupitiyage, 2012; Gunasena, 2010). There are many negotiations that happen almost pre and post-stages of the construction contract to resolve disputes (Ranasinghe and Korale, (2011), Dancaster, (2008)). Marzouk and Moamen in 2009 listed out following attributes for negotiation;

- it prevents dispute(s) amongst project parties
- it keeps good relationships among the project’s parties
- it provides flexibility and control in the resolution

Before starting the face-to-face meetings negotiator should define the scope of the negotiation and clearly set up the expectations highlighting the bottom line of the negotiation (Ren et al., 2011). Through case studies, Ren et al., suggested several points adhere during the negotiation process. They are as follows;

- Getting the parties to the negotiating table.
- Without bargaining over positions should work towards the negotiating goals.
- Focus on Interests mainly by identifying shared and compatible interests
- Negotiation should not affect by human behaviors like perception, emotion, and communication

- Innovative solutions for mutual gain
- Insist on Using Objective Criteria like legal or business precedent, expert judgments, lab testing, efficiency, reciprocity, or standard conditions of contract
- Establish the Best Alternative to a Negotiated Agreement
- Choose Appropriate Negotiation Tactics
- Reach a Settlement
- Limitations of Principled Negotiation
- Overemphasized Cooperation
- Assumption of Common Interests
- Culture Issues

Most of the local contracts are developed based on the Standard Bidding Documents (SBD) prepared by the Construction Industry Development Authority in Sri Lanka (CIDA.govt.lk, 2020). The conditions developed through CIDA contract documents do not have negotiation as a DR (SBD, 2007). Throughout the negotiation, process parties will do more discussions to find solutions to disputes and see the possibilities of managing disputes without escalating (Gunasena, 2010). The whole process is depending on the trust and willingness of both parties to resolve the dispute without leaving the negotiation table until reaching an end or a solution for the dispute (Ren et al., 2002). If the parties fail to succeed in negotiation disputes will refer to a costly, time-consuming proceeding like arbitration or litigation (Chow and Cheung, 2008). Not only the cost but also maintaining the reputation and avoiding emotional stresses better to avoid court proceedings (Cheung et al. 2002; Harmon 2003).

3 RESEARCH METHODOLOGY

The research was based on five semi-structured interviews and 250 construction dispute claims from the Sri Lankan construction industry. Those five interviewees are construction industry professionals having over 15 years of expertise in construction project management and dispute resolution in the Sri Lankan construction industry. Because to avoid being based on limited sets of construction industry-related disputes and cover different management levels. The interview data was utilized as a guide to classify and organize the documentary survey. Since the aim of this exploratory type of research is to produce analytical, rather than statistical, generalizations (Yin, 2014) the claims collected for document analysis will not act as representative data. However, the 250 claims selection was done based on two criteria such as; claims from large-scale construction projects and claims which refer to negotiation as an initial. Most importantly the availability of relevant information about the documents was considered as the initial screening of the selected claims.

A qualitative research strategy was used since the study was focused on an in-depth analysis of the collected data (Bryman, 2012). Semi-structured interviews were used to examine the negotiation strategies and methods adopted in the Sri Lankan construction industry. The claims identified the type of disputes that refer to negotiation and the type of disputes which failed to resolve through negotiation. The collected data was analyzed using content analysis.

4 RESULTS AND DISCUSSION

4.1 Semi-Structured Interview

Interviewees considered negotiation as a voluntary ADR where disputing parties will refer their disputes willingly. It further revealed, that most of the contract documents prepared using CIDA conditions of contracts do not have negotiation as a dispute resolution method. Interviewees explained that the majority of the negotiations conducted are based on the personal strategies adopted by the persons at the negotiation table. Those are scheduling meetings, employing a conflict-specific individual, conducting an analysis using historical data, modifying the project's scope, collecting preliminary information, carrying out site meetings, and proceeding in accordance with the contract documents. As attributes of the negotiation were presented as good communication skills, decision-making capacity, organizational work, listening skills, job awareness, and data management skills. In practice, three methods of negotiating have been discovered. Those are through telephone, face-to-face, and online forums. The most productive negotiations were identified as the on-site meetings.

Common disputes referred to negotiation were identified as design changes, delays in payments, the extension of time, and construction bill amounts. Other disputes referred to negotiation include day work, variation, new rate proposals, contractor progress, land clearance, and change scope. There are multiple documents used in negotiation. Those are requested for clarification, Drawings, Measurement sheets, Breakdowns, Measurement Guides, Contract Documents, Engineering statements, Previous Practices (Bills, Variations), and IPA documentation.

Identified construction disputes for unsuccessful negotiations are; Lack of knowledge in certain areas, Taking a large scale of time, Social problems, Conflicting opinions from different parties, Time, The failure of contract documents, Government regulations, Unethical behavior of professionals, lack of communication, and Document errors.

4.2 Documentary Survey

5 disputes are highlighted in the documentary survey such as; design changes, payment-related issues, time-related issues, documentation, and work quality. With a ratio of 44%, the majority of disputes involve plan-changers, as depicted by the graph, with a disparity of 8% between time-related and planning-related disputes. These issues have a significant impact on the success or failure of negotiations. Disputes over documentation, work quality, and other issues have a lesser impact. Their combined percentages equal 7% -13% of the factors pertaining to payment-related problems. Lastly, conflicts regarding design are common in design-build projects. Whether or not project disputes may be identified depends on the procurement procedure.

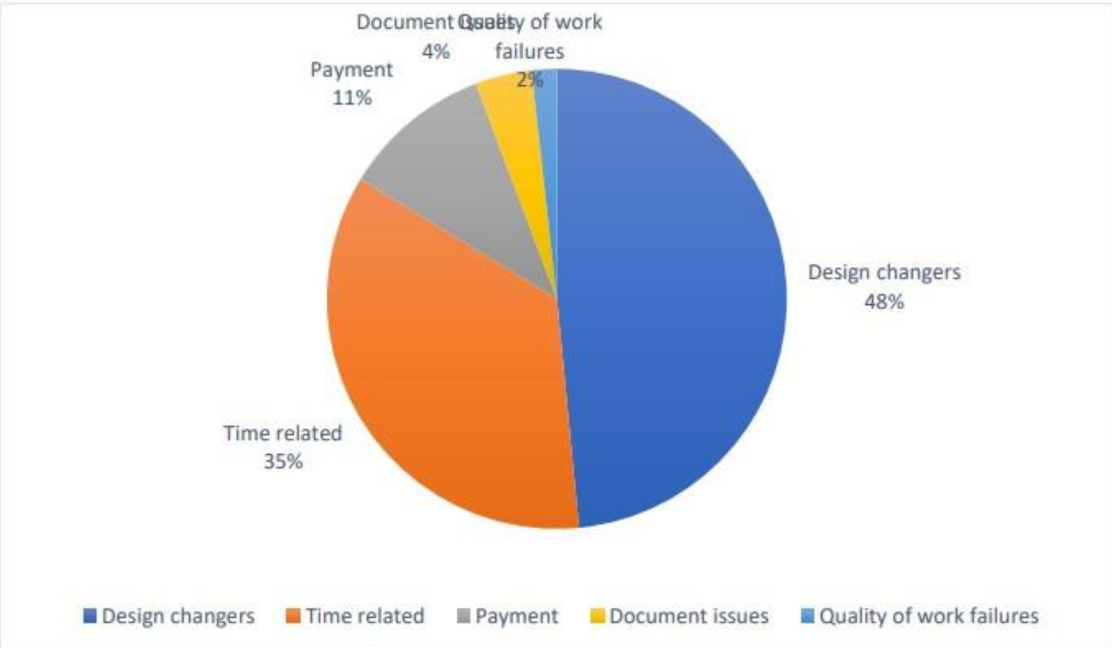

Figure 1- Claim distribution according to the type of dispute

Out of the 250 claims, several disputes relevant to payment, time, and other (design changes, documents, quality of work) issues failed in resolving through negotiation. When comparing Figures 1 and 2 even though there is a larger difference between the number of time and payment-related disputes, when it comes to unsuccessful negotiations both are very much similar (figure 2).

Figure 2- Types of disputes that failed in resolving through negotiation

According to documented data, the majority of time-related disputes arise when the contractor requests an extension to complete the work. The identified reasons for the failure of such talks include the client's activity. The majority of payment-related disputes result from the contractor's loss of earnings, delays, etc. The client is reasonably worried and evaluates its fairness or unfairness. However, most of the failed negotiations are initiated by the contractor.

Reason for the failure in dispute negotiation

Following are the reasons identified for the failures in dispute negotiation from collected data ;

- Negotiation outcomes do not have statutory powers – If parties are willing to accept the negotiation outcome only the negotiation will be successful.
- An attitude of disputing parties – Disputing parties are reluctant to sacrifice to come to an amicable solution.
- Lack of negotiation skills – The representatives of the parties to the dispute do not have enough skills to negotiate.
- Lacks of trust towards negotiation – Disputing parties do not trust the people and the techniques applied in negotiation.
- Less documentary information – Required documents are not available to resolve disputes through negotiation.
- Referring disputes which need expert advice – The disputes which need expert views cannot resolve through negotiation.

Proposed negotiation framework for the Sri Lankan construction industry

Figure 3 presents the proposed negotiation frame developed through this study for the Sri Lankan construction dispute resolution. Before starting the negotiation disputing parties should identify the type of dispute. If the dispute is related to money or time parties should separately study the dispute on the possibilities of resolving it through negotiation.

Then the individual party should find solutions by collecting information relevant to the case within the party. Before starting, negotiation parties should determine the type of negotiation style that will be used in negotiation. Parties should know what the other party is going to claim. Disputing parties together should formulate the negotiation team and organize the date, venue, and other relevant things for negotiation. Finally, negation will be conducted, and failing with negotiation parties should refer disputes to the next level of ADR.

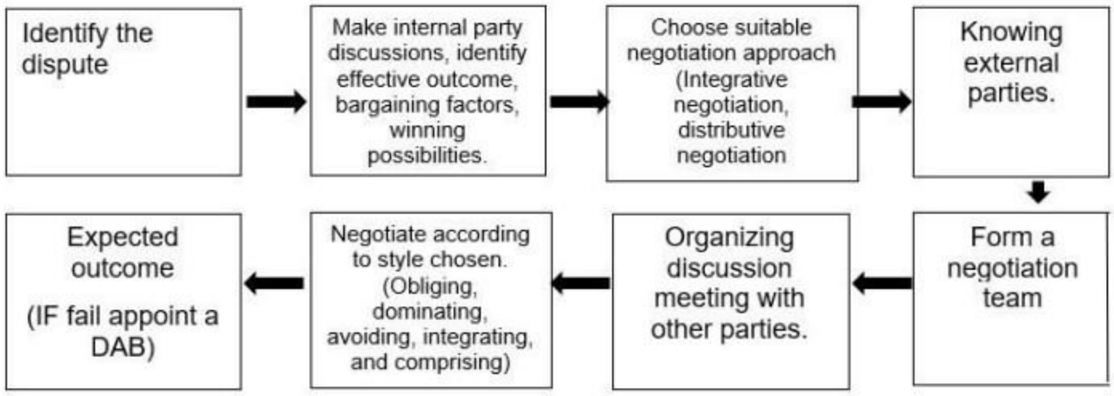

Figure 3 - Proposed Negotiation Procedure

5 CONCLUSIONS AND RECOMMENDATIONS

Negotiating practices used in Sri Lankan construction projects include scheduling meetings, employing a conflict-specific individual, conducting an analysis using historical data, modifying the project's scope, collecting preliminary information, carrying out site meetings, and proceeding in accordance with the contract documents.

According to the data analysis, the most common disputes that refer to negotiation are design changes, payment-related issues, time-related issues, documentation, and work quality. Time and payment-related disputes were identified as the disputes which are difficult to resolve through negotiation. Identified time-related disputes and payment-related disputes are linked. The developed framework can use to resolve disputes amicably.

It was determined that local conditions of the contract document receive less consideration for negotiation. This researcher suggested that CIDA should pay more attention to this section. Promote negotiation-related publications and host workshops on negotiation skill improvement. There is no professional viewpoint on negotiation in the government sector. Further, there is nobody to take responsibility for the failure in negotiation. Therefore, the disputes that failed to resolve through negotiation will immediately be referred to the next level of ADR. Other than negotiation all the other ADR processes take more time and money. This research assists construction industry experts in leading effective conflict resolution practices. To avoid failing a negotiation, one of the most crucial strategies is to develop one's communication skills and engage in team negotiation activities. In addition, it is recommended that, when forming a negotiation team, specialists who are both skilled and responsible are chosen. Following the dispute scale, it is necessary to hold team conversations before the documentation. Getting an overall picture of the various possibilities in the negotiation background might be helpful. Recommends following the negotiation procedure and winning possibility checking chart that was described previously. Checking the chart for winning possibilities, but only for certain types of conflicts.

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The Impact of Labour Motivation on Project Performance with an Insight into the Sri Lankan Construction Industry

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ABSTRACT

Construction labour is a vital resource in the construction industry as they mostly reshape the raw materials into skyscrapers and other living enclosures. In Sri Lanka, the construction industry has been constantly exposed to many uncertainties and challenges. Being a developing country that lead to many socio-economic issues and constant changes in the living standards caused demotivational impacts on the Sri Lankan labour force. Thus, optimizing labour productivity through labour motivation is a significant challenge due to the various category and type of labours. This study aims to identify and evaluate different labour motivational factors in improving the building construction project performances. In accomplishing the aim, the mixed method approach was used and 5 number of interviews, 39 questionnaire responses were taken into the analysis. After the analysis there were 14 most significant labour motivation factors which applicable for Sri Lankan building construction industry. Cost centers for those were collected from the expert interviews and their cost on motivation factors were analyzed the data collected from the questionnaire. After the analysis financial and time cost centers have been identifies as the major cost centers that have been incurred when implementing labour motivational factors. Moreover, checked the association between labour motivational factors and project performance in terms of time saving, cost saving and quality improvement. As a result, they were associated with them. A framework was developed to aid in the selection of best motivational factors in optimizing project performance. As the last part of this study, the motivational recommendations were made to increase the labour productivity. Furthermore, these findings will be useful in optimizing building project performance.

KEYWORDS: *Labour motivation, construction industry, project performance, Sri Lanka*

1 INTRODUCTION

The construction industry plays a significant role in the economy and its growth in locally as well as globally (Export Development Board, 2021). According to Trading Economics (2022), the GDP contribution from construction in Sri Lanka was LKR. 143 035 million (Gnanothayan and Kauškale, 2022). Nowadays, the construction industry in Sri Lanka has been severely impacted by the country's current economic crisis. As a result of these circumstances, the construction industry is dealing with a slew of issues, including material price increases, labor shortages, project delays, and cost overruns. Considering the current economic crisis in Sri Lanka, many construction workers have left their jobs due to poor motivational management by their employers or supervisors. Apart from that, there were strict health guidelines practiced by the construction companies such as confining the workers to site in bubbles, limiting their involvement in entertainment programs as result of the COVID 19 pandemic. Those were also impacted in losses of labour's jobs in return (Vithana et al., 2020; Pathirana, 2020). In literature, labour is defined as "a task that requires the exertion of body and mind or both" (Olabosipo & Ayodeji, 2011). The motivating construction workforce is the best way of achieving higher productivity and completion of works at given timeframe without any delays (Widanagamachchi, 2013). Furthermore, many researchers have identified a number of labor motivational factors that are vital to maintaining project performance through proper labor handling (Osabiya, 2015; Khan, 2012; Chigara and Moyo, 2014; Halwatura, 2015; Widanagamachchi, 2013). The aim of this research is to identify and evaluate different labour motivational factors in improving the building construction project performances. The 4 objectives are to identify the labour motivational factors; to determine the cost of deployed different motivational factors; to investigate the impact of identified motivational factors on

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the project performance; and to develop a framework on utilizing the above identified factors to optimize the building project performance. The study is confined to building construction projects in Sri Lanka.

2 LITERATURE REVIEW

According to Tucker, (1986) identified that the construction sector is one of the largest and most challenging industry in the world and it contributes significantly to countries' gross domestic product (GDP). Looking towards the Sri Lanka, the construction industry is the fourth largest sector in the local economy, accounting for 6-7% of the country's GDP over the last decade. (Jayalath and Gunawardhana, 2017). Umar, (2020) further identified that the construction industry is rapidly expanding in various developing countries like Sri Lanka and is consequently acknowledged as a major source of employment in the country.

2.1 Productivity and Labours in Construction Industry

Labor is the most significant factor in the construction industry because it integrates all other resources in construction projects (Prachi R. Ghate, 2016). However, there are some common issues in the construction industry such as time overruns, cost over runs, substandard quality mainly resulted by poor efficiency (Halwatura, 2015). Improvement of construction labour productivity is vital to expedite the construction of project within the budget while maintaining the quality. As per Idris Jajri, Rahmah Ismail (2010), expanding human capital acquisition among the population is a means of strengthening competitiveness by raising worker productivity and producing higher-quality products at reduced production costs. The lot of researchers have defined labours as “a task that requires the exertion of body and mind or both” (Fagbenle, 2011). In further study the labour has categorized into two part as skilled labours and unskilled labours. Some of the skilled labours in this category are masons, plumbers, carpenters, electricians, painters, scaffolders and tilers. Unskilled labours are defined as that is not required special skilled for the operations. (Moselhi and Khan, 2012). Moreover, human resources have become the most significant factor in project completion owing to the fact that there is a direct relationship between productivity and human resources (Tabassi and Bakar, 2009).

The Cambridge International and Oxford Advance Learner's dictionaries define productivity in general as “the rate at which good s are produced with reference to number of people and amount of materials necessary to produced it". On the other hand, productivity is generally defined as the output to input ratio which means effective utilization of resources (inputs) in producing goods and/or services (output) (Sumanth, 1984) but it can be defined in many ways. In construction sector, it’s usually called labour productivity which known as work units created per man-hour (Attar et al., 2012). The mathematical statement of productivity clearly shows that productivity improves when output rises while input falls or when input falls while output rises (Osabiya, 2015). Productivity increases can be reached if proper labour management, faster set-up of machine and tools, maintain the project quality, proper material handling are met.

2.2 Construction Labour Force in Sri Lanka

Sri Lanka as a developing country, is constantly exposed to new problems and challenges as the earth's resources diminish as a result of population growth and economic expansion (Jayalath and Gunawardhana, 2017). After the end of civil war in 2009, there was a boom in construction which was significantly contributing to the GDP growth of the country and most of projects were through the public sector infrastructure investment (Soyza,2022).

2.3 Motivation Concept and Its History

“The term motivation refers to the psychological process that gives behavior purpose and direction” (Eltom M.A.D, 2007). “Motivation is the study of why people think and behave as they do” (Graham and Weiner, 2013). The concept of motivation, as well as a use of the Hawthorne tests is done in the United States about a century ago. The primary concept of motivation is to induce employee or employees towards a task. Different thing motivates different people, and the employee's age and generation might have an impact on motivation. It's fascinating to examine the varying needs of employees from different generations (Mariusz-jan radlo,2022).

Maslow's Hierarchy of needs is one of the most widely discussed motivation theories. Maslow attempted to view the human needs as a hierarchy, rising from the lowest to the highest, and concluded that as one set of wants is met, another set of wants is realized, this type of need no longer serves as a motivation. Maslow's hierarchy of needs has been categorized for five parts which known as safety, physiological, belongingness and love (social), esteem, and self-actualization (Bob, 2009). There are some other theories also. Equity theory is one of the most important concepts in financial compensation (Pritchard, 1969). According to Equity Theory of Adams, a fair balance should be achieved between an employee's inputs (hard effort, skill level) and an employee's outputs (salary, benefits, etc.). The Adams' equity theory concept is represented as below.

$$\frac{Out\ comes\ by\ a\ person}{Inputs\ by\ a\ person} = \frac{Out\ comes\ by\ another\ person}{Input\ by\ another\ person}$$

Motivating is the capacity to program individuals with a common goal and to sustain a continuous, harmonious relationship among all persons (Widanagamachchi, 2013). For humans, the terms intrinsic or extrinsic motivation are commonly used. It can also be used to describe the causes of animal behavior in theory, but this article focuses solely on human behavior. Motivation can be rooted in a basic need or, in some cases, specific needs such as eating and resting, a goal, or an ideal, according to various theories. Motivation is not the same as volition or optimism. Employees in any organization require something to motivate them. (Attar et al., 2012; Widanagamachchi, 2013; Chigara and Moyo, 2014).

Positive motivation for employees would result in better organizational outcomes. By permitting the measurement of actual performance against the operations-based targets, the formulation of operations-based targets will aid in the providing of strategic feedback.(Malina and Selto, 2001).

The concept of building productivity emerged in the early twentieth century to improve bricklaying operations at that time (Halwatura, 2015). However, it remains a concern in the construction business, and if productivity is there, it saves time and money due to resource efficiency (Graham and Weiner, 2013). Employees are used as resources by organizations to justify power and show the organization as caring for employees and their ethical treatment, while also controlling employees and assuring their productivity. There are several factors influence for the labor productivity and the most important factor is fundamental education for any effective labor force. The food as well transportation and sanitation may as well have an impact towards the productivity (Heizer and Render, 1999).

2.4 Factors Affecting Labour Productivity (Motivational Factors)

Halwatura, (2015) identified lot of factors affecting labor productivity and he listed out 10 critical factors for the motivation in his research. For that he has considered Important index (II) and shown the important of using these methods to motivate the labours. They were listed in the order of importance of overtime, on-time payment, Medical care, social activity opportunities, working in social insurance, job security, opportunity to undertake challenging task, accommodation, bonus at the end of project or year, love and belongingness. Not only Halwatura but also Widanagamachchi, (2013) listed out some other factors which helps to motivate the labours. Employee rewards for job performance, having good two-way communication, treating employees with respect, employing effective discipline and penalty, having high expectations, training, understanding employee behavior, and effective leadership are examples of these. There are some other researchers re-confirmed time to time that the above factors helps to motivate the construction labours (Tabassi and Bakar, 2009; Fagbenle, 2011; Chigara and Moyo, 2014; Ghoddousi et al., 2015). Furthermore, some other factors have been identified by other researchers in their research study. Those are technology, managerial style, allowances / relief, respect for the employee, relations with workmates, teamwork & communication, availability of machines and equipment, (Khan, 2012). Many factors identified through the literature but settled toSixteen (16) motivational strategies after combining the similar strategies.

A literature survey on productivity and factors affecting on labour productivity (motivational factors) in Sri Lanka and also other various countries were illustrated in this chapter. The literature review further aimed at an overview of the construction industry and Sri Lankan context. Finally, the benefits of using labour motivational factors and strategies has been discussed. According to the motivational theories Maslow's Hierarchy of Need Theory, Equity Theory It was discovered that the level of motivation of construction workers is important in order to increase productivity in the construction business.

Moreover, bulk of labour motivational factors and strategies were filtered out into 16. Those are overtime Payments, on-time payment, medical care, working in social insurance, job security, opportunity to undertake challenging task, free or concessionary accommodation, bonus at the end of project or year, love and belongingness, having good two-way communication, performance-based rewards, disciplinary actions and punishment, give high expectations and respect the employees, training, technology and availability of machines and equipment.

3 METHODOLOGY

Any research requires related data, which can be qualitative or quantitative. In this study, a list of labour motivational factors were identified from the previous literature and internet search. Pass researches have done these finding factors from the expert interview. These findings were further enhanced through an expert interview.

Table 1 : Information of the Interviewees

Participants	Experiences (Yrs)
Engineer	15
Civil Engineer	5
Project Manager	15
Charted Quantity Surveyor	10
Charted Quantity Surveyor	15

In conducting this research whenever there is no adequate existing published data expert interviews were conducted to collect the Industry knowledge. Those experts were the constriction professionals as shows in the table 1. Confined findings were included in a questionnaire survey to validate and rank the findings. In this study, the “mixed method” has been used to gain a clear understanding of this study and finalize with less errors. The mixed method studies, allowing for more clear and complete ideas to be encountered with both studies together than with isolated studies of quantitative or qualitative methods. Combining approaches allows for more details in the conclusion and different techniques for data collection and analysis on the same study may improve the validity of the final output. Non-probability sampling was used. Because of the random selection of experts, simple random sampling was used, and it should reflect the true population of Sri Lanka. So, a few people were chosen at random from the population. The population in this study consisted of construction industry professionals. The interview data was analyzed to develop a questionnaire survey and the data collected from the questionnaire survey was analyzed using the Relative Important Index (RII) to determine the significant of each factor in Sri Lanka's construction industry. The questionnaire survey attracted 39 responses from the industry professionals.

Furthermore, the use of labor motivation factors was analyzed using the RII method to gain a general understanding of common usage. CHI SQUARE test also used to check the association of time saving, cost saving and quality improvement between labour motivation factors.

4 DATA ANALYSIS AND DISCUSSION

Five expert interviews were conducted in order to build upon and validate the factors identified through the literature survey and to short list the content for questionnaire survey. That was the prime purpose of the expert interviews. One of the labor motivational factor was rejected based on expert interviews, and a total of 23 labor motivational factors and strategies were finalized. Those were carried out for the questionnaire survey used to collect data for this study.

The findings of this study are based on the Relative Important Index (RII) analysis and Chi-Square Test of quantitative survey responses. In the first section of the questionnaire, demographical data of the respondents were collected. In order to success that, the profession, experience of working, expertise area in his/her organization were given attention majorly. Mostly, engineers, quantity surveyors, project managers and architect from the experience groups between 0-20 have responded to the questionnaire. Rather than that, there were 2% of responses received from the category of more than 20 years. Out of the 39 responders, 15 of them are engineers whereas 13 are QS, 4 responds were coming from PM and Architect was 7. Most of the responders are from the experience groups of 0-5 and 5-10. 6 responders are from 10-15,3 from 15-20 experience categories.

Table 2 presents the RII analysis of the motivational factors to determine the most significant factors.

Table 2 : RII Analysis to Determine Most Significant Factors

	5	**4**	**3**	**2**	**1**	**RII**	**M**	**Rank**
Training	22	17	0	0	0	0.91	0.11	1
On-time payment	17	19	3	0	0	0.87	0.07	2
Technology	18	18	2	1	0	0.87	0.07	2
Overtime Payments	14	24	0	0	1	0.86	0.05	4
Bonus at the end of project or year	14	23	1	1	0	0.86	0.05	4
Availability of machines and equipment	15	19	3	2	0	0.84	0.04	6
Prepare a safety environment	13	21	5	0	0	0.84	0.04	6
Improve the skill levels of labours	13	21	4	1	0	0.84	0.03	8
Give high expectations and respect the employees	14	18	6	1	0	0.83	0.03	8
Medical care	10	24	5	0	0	0.83	0.02	10
Having good two-way communication	11	23	4	1	0	0.83	0.02	10
Group target-based working	9	27	+	0	1	0.82	0.02	10
Performance based rewards	9	27	1	1	1	0.82	0.01	13
Provide better PPE facilities	7	27	3	2	0	0.80	0.00	14
Job security	8	23	6	2	0	0.79	-0.01	15
Free or concessionary accommodation	9	15	15	0	0	0.77	-0.03	16
Isolation some labours and measure them performance individually (who are not performing well)	10	18	8	1	2	0.77	-0.03	16
Provide Foods & Transport	8	17	13	1	0	0.76	-0.04	18
Move the group of people for other projects of the organization with shuffling time to time	5	25	6	2	1	0.76	-0.04	18
Disciplinary actions and punishment	11	12	12	3	1	0.75	-0.05	20
Opportunity to undertake challenging task	5	22	9	2	1	0.74	-0.06	21
Love and belongingness	5	18	15	0	1	0.73	-0.07	22
Open opportunity for some entertainment programs & creativeness	8	13	7	1	0	0.59	-0.21	23

Using all the responses from the questionnaire, Relative Important Index (RII) was applied for all 23 factors and ranked to identified most significant factors and the strategies. 'M' is a Variance in the above table, and weighted values are given. In order of 5 to 1, strongly agree, agree, undecided, disagree, strongly disagree. Mean of RII was calculated to establish variance for those RII values. Thereafter, considering the mean value, the values below the mean were rejected. The most significant factors that will motivate construction labours are those with equivalent or higher values. (0.80 is the relative mean value). There were 14 most significant motivational factors and strategies identified, with training being the most significant with a value of 91%, followed by time payments at 87%, and technology at 87%. The next highest value is 86% for overtime payments and bonuses at the end of the project year. the most significant 14 number of factors and strategies were only retained for further data analysis in this research study.

Further, there were identified various cost centers in implementing the labour motivation factors. The cost centers were financial, time, environment. Financial includes the cost of labours, machineries and overhead cost. In this questionnaire survey, it shows there are many costs in below factors when consider time and financial in accordance with the respondent's interpretations and those are listed here, from high to low. Training, overtime payments, technology, Improve the skill levels of labours, on time payments.

Following that, the cost-savings ratio was considered, but the environment cost was rejected due to the smaller number of responses obtained from the questionnaire. That means, less important to influence motivational factors.

Table 3 : Cost & Time Effectiveness

	Financial cost	Time cost	P	Q
Training	23	23	1.29	1.39
On-time payment	26	12	0.99	2.39
Technology	30	12	1.03	2.72
Overtime Payments	28	15	1.05	1.93
Bonus at the end of project or year	26	11	1.08	2.33
Availability of machines and equipment	25	12	1.17	2.56
Prepare a safety environment	9	14	3.00	1.86
Improve the skill levels of labours	18	22	1.57	1.36
Give high expectations and respect the employees	6	14	3.94	1.88
Medical care	16	9	1.44	2.59
Having good two-way communication	2	15	12.50	2.02
Group target-based working	9	21	3.37	1.46
Performance based rewards	23	11	1.25	2.58
Provide better PPE facilities	20	10	1.30	2.53

$$P = \frac{Cost\ Saving(Financial)}{Financial\ Cost} \qquad Q = \frac{Time\ Saving}{Time\ Cost}$$

As per the above table, all are positive values (P and Q). Considering those we can say that there is a positive impact on the labour motivational factors and strategies. Further, it's like cost and time saving when implement of those strategies but there is no actual way to show that due to those are not quantifiable data but just based on respondent's opinions. Fortunately, there is some positive effectiveness to over the cost saving with financial cost and over the time saving with time cost.

Having good two-way communication is the highest cost-effective factor according to this table and the lowest factor is On-time payment which takes 0.99. In relation to the time effectiveness, the highest factor is using technology and the lowest one is Improve the skill levels of labours. According to these findings we will be able to take decision which factor or factors are most suitable for our project type and what should use or shouldn't be used. Top 10 cost effective factors are having good two-way communication, give high expectations and respect the employees, group target-based working, prepare a safety environment, improve the skill levels of labours, medical care, provide better PPE facilities, training, performance-based rewards, availability of machines and equipment. Top 10 no of time effective factors are technology, medical care, performance-based rewards, availability of machines and equipment, provide better PPE facilities, on-time payment, bonus at the end of project or year, having good two-way communication, overtime Payments, give high expectations and respect the employees. Furthermore, the framework has been developed based on these top 10.

Since cost savings, time savings, and quality improvements have been identified as the most critical factors influencing construction project performance. The Chi-Square test was used to examine the association between time saving, cost saving, and quality improvement between labour motivational factors. Following the hypothesis testing from the test of association using the Chi-Square distribution for the labour motivation factors and cost savings.

	Cost Saving			
	High	Moderate	Less	Row Total
Training	19	14	4	37
On-time payment	9	21	8	38
Technology	22	12	3	37
Overtime Payments	16	18	4	38
Bonus at the end of project or year	14	18	6	38
Availability of machines and equipment	15	20	3	38
Prepare a safety environment	13	18	6	37
Improve the skill levels of labours	13	21	4	38
Give high expectations and respect the employees	9	18	8	35
Medical care	6	21	9	36
Having good two-way communication	12	15	9	36
Group target-based working	17	18	4	39
Performance based rewards	16	17	4	37
Provide better PPE facilities	6	27	6	39
Column Total	187	258	78	523

Figure 1 : Summary of Observed Frequencies

	Cost Saving			
	High	Moderate	Less	Row Total
Training	13.23	18.25	5.52	37
On-time payment	13.59	18.75	5.67	38
Technology	13.23	18.25	5.52	37
Overtime Payments	13.59	18.75	5.67	38
Bonus at the end of project or year	13.59	18.75	5.67	38
Availability of machines and equipment	13.59	18.75	5.67	38
Prepare a safety environment	13.23	18.25	5.52	37
Improve the skill levels of labours	13.59	18.75	5.67	38
Give high expectations and respect the employees	12.51	17.27	5.22	35
Medical care	12.87	17.76	5.37	36
Having good two-way communication	12.87	17.76	5.37	36
Group target-based working	13.94	19.24	5.82	39
Performance based rewards	13.23	18.25	5.52	37
Provide better PPE facilities	13.94	19.24	5.82	39
Column total	187	258	78	523

Figure 2 : Summary of Expected Frequencies

Defined hypothesis,

Ho – No association between labour motivation factors and project performance in terms of cost saving.
H1 – There is an association between labour motivation factors and project performance in terms of cost saving.

Degrees of freedom: (No of columns – 1) (No of rows – 1)
According to this,
Degrees of freedom = (3 - 1) (14 – 1) = 26

It falls within the rejection region because the calculated Chi-Square value of 41.36 is greater than the critical Chi-Square value at 5% significance level on 26 degrees of freedom. As a result, there is enough evidence to suggest that there is a link between labor motivation and cost savings. The results of the chi square test of the association method show that Ho (No association between labor motivational factors and cost savings) can be rejected because the calculated value is greater than the critical value at the significant level.

Accordingly, there is an association between labor motivation factors and project performance due to cost savings. The test result was taken from this as listed below.

Table 4 : Chi-square Test Result

Elements	Test Result
Labour motivation factors and cost savings	Pass
Labour motivation factors and the time savings	Pass
Labour motivation factors and the quality improvement	Pass

According to the above findings, there is an association between labor motivation factors with cost savings, time saving and quality improvements.

To determine the use of motivation factors in Sri Lanka, the RII method was used in the same way as the initial RII analysis. According to this analysis, it observes that some significant factors are not commonly used in the industry in Sri Lanka. For example, some of high significant factors such as bonus at the end of project year, medical care, provide better PPE facilities are not use significantly in the industry. Moreover, those factors are found to be more time and cost effective according to this study. Therefor due consideration shall be given to those motivational strategies in improving the project performance.

On the other hand, it shows that some general uses are not the most significant factors such as medical care. The most frequently used motivational strategies seems to be different from those are highly significant and cost effective.

Figure 3 shows the details of project performance factors and it helps to improve the project efficiency for the contractors who have implement those.

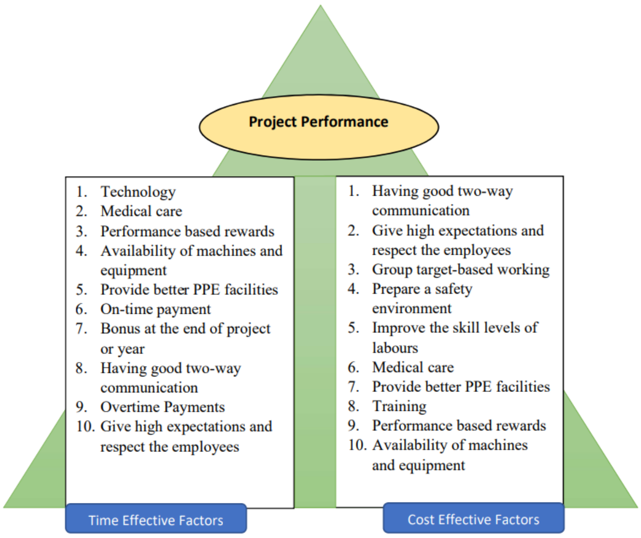

Figure 3 : Labour motivation framework

5 CONCLUSION & RECOMMENDATIONS

This study focusses to identify and evaluate different labour motivational factors in improving the building construction project performances in Sri Lanka, accomplished by achieving four specific objectives. Data was collected and analyzed using the mixed method. In the first, there were listed out 23 labour motivational factors such as overtime payments, medical care, training according to deep literature review and expert interviews. The second objective was to determine the cost of deployed different motivational factors. According to that, the cost of each and every factor were determined and listed the top 10 cost and time effective factors. To fulfil the third objective, the Chi-squared method used to determine the association between cost those factors in order to cost saving, time saving and quality improvements and the result was positive for all. Finally, developed a framework on utilizing the above identified factors to optimize the building project performance.

This section concludes with recommendations for mitigating measures to be implemented in order to adapt to construction projects, with due consideration of both positive and negative impacts in implementing labour motivation factors. According to the findings, this research recommends: to use high cost effective and time effective factors. According to the framework we suggest to use such as technology, medical care, performance-based rewards, availability of machines & equipment and provide better PPE facilities as the major time effective factors. In other hand, there can be used such as having good two way communication, give high expectation & respect the employees, group target-based working, prepare a safety environment, improve the skill level of labours for the cost-effective factors. Finally, there are overall effective factors have been identified with reference with the frame work. Those are having good two-way communication and training.

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Appropriateness of Commercial Mediation as an Alternative Dispute Resolution Method for Subcontractor Disputes in Sri Lanka

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ABSTRACT

Disputes in relation to construction sub-contractors are undeniable and quite diversified in common dispute arena with the legal concerns arising out of Doctrine of Privity of Contracts. Continuation of these disputes can adversely affect the cost, quality, and time metrics in a construction project. The merits of commercial mediation as an alternative dispute resolution method, in this regards Sri Lankan construction industry were less explored. Thus, the aim of this research is to determine the appropriateness of commercial mediation as an alternative dispute resolution method for subcontractor disputes. To achieve this aim, a mixed research approach was adopted. Qualitative data was collected through semi structured expert interviews. Then through a questionnaire survey, quantitative data has been gathered. While qualitative data were analyzed through content analysis, quantitative data were analyzed through relative importance index and descriptive analysis based on central tendency dispersion. Initially, both common attributes of commercial mediation and subcontractor disputes in construction industry were listed out. Then, the inter-relationship between two factors were observed. According to the findings, bespoke and incomplete contracts, subcontractor unawareness and lack of knowledge about contract details, liability and responsibility issues, failure to respond in time, interface issues and lack of coordination were identified as the most significant attributes of subcontractor disputes. Further, it was proven that except the attribute 'having freedom to accept or reject the solution', all the other attributes of commercial mediation were applicable in resolving subcontractor disputes. Hence, the commercial mediation was determined as an appropriate alternative dispute resolution method in resolving subcontractor disputes in construction projects. All the limitations and necessary recommendations for further studies are presented at the end of the study.

KEYWORDS: *Construction subcontractor, disputes, commercial mediation, alternative Dispute resolution.*

1 INTRODUCTION

Subcontractor is a construction company that enters into a contract with the main contractor to carry out some part of the general construction project work. Subcontractors are experts in specialized works, and they have sufficient resources to carry out that particular work (Shimizu & Cardoso, 2002). Therefore, contribution of the subcontractors is immense in the construction industry. Disputes are inevitable in construction projects as each construction project is unique and complexity is different from one to another. Disputes have a significant impact on the time, cost and quality metrics of a construction project which ultimately affects the success of the project (Jaffar et al., 2011). Similarly, disputes are common in subcontracting as well. Subcontractor's effective performance depends on the relationship between subcontractor and main contractor. Thus, interpersonal relationship is just as important as contractual relationship for success of a construction project. (McCord & Gunderson, 2014). Even though the relationship between subcontractor and main contractor is highly important for successful completion of a construction projects. Relationship between subcontractor and main contractor is neglected in the construction industry (Humphreys et al., 2003). In Sri Lanka, negotiation, conciliation, mediation, adjudication and arbitration are often employed as Alternative Dispute Resolution (ADR) methods (Abeynayake & Weddikkara, 2014). Subcontract disputes may significantly rattle the contractual relationships across the status quo while those will leave little time for the rectification due to the potential impacts on the contractual relationships at different layers. Furthermore,

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the nature of solutions may require to be innovative and compromised rather than being confined to the merits of arguments. These concerns along with the financial and time constraints may limit the ability of resolving such disputes through the conventional ADR methods.

Mediation is an informal and voluntarily approached ADR method. It is a private method where settlements are reached amicably. Generally, mediation can be used in any type of disputes in any context (Hietanen-Kunwald, 2018). Commercial mediation is practiced in disputes that are highly technical and mercenary trades like construction industry.

According to Bush and Folger (1994) mediation is a "powerful tool" to resolute disputes satisfying both parties (Bush & Folger, 1994; Moore, 2017). Thus, the need to resolve disputes while maintaining healthy relationships between subcontractors and any other stakeholders of the project arises. Since there aren't any scientific sources which established the applicability or readiness of use of mediation as an ADR method in resolving sub-contractor disputes, there is a knowledge gap that demands on identifying the possibility of such. Hence, aim of this research is set to "determine the commercial mediation as an alternative dispute resolution method for resolving subcontractor disputes". To achieve the aforementioned aim, the objectives of the research study were,

1. To review unique attributes of commercial mediation
2. investigate on the common disputes relating to the construction subcontracts,
3. To investigate on the common and unique attributes of disputes in construction subcontracts and
4. To identify the appropriateness of commercial mediation as an alternative dispute resolution method for subcontractor disputes in Sri Lanka.

2 LITERATURE REVIEW

Subcontracting is common in construction projects which have a high degree of specialization. With the increasing complexity and scale of the project, the use of subcontracting become more prominent (Tam et al., 2011). The subcontracting is necessitated by the general contractor's lack of expertise knowledge, resources, experience, specialized works, and the requirement to economize the processes. According to Hinze and Tracey (1994), in most of construction projects, 80% or 90% of the work is performed by subcontractors.

2.1 Subcontracting Disputes

A Subcontract includes rights and obligations of the subcontractor. It includes different clauses that define various conditions. Hence the subcontract agreement is the source where the right for payment arises (Wong & Cheah, n.d.). According to Hinze and Tracy (1994), timeliness of payment is one of the major factors in causing strife between main contractor and subcontractor. Payment clauses like "pay-when-paid" and "pay-if-paid" could cause conflicting situations between main contractor and subcontractor. Court of law describes these kinds of provisions as conditional contract due to uncertainty of payment date. Withholding a certain percentage of the interim payment for the defective work done by the contractor can be called as retainage. Generally, retainage is released to the subcontractor after the completion and remedying of defects (Clough & Sears, 1994). In some situations, this retainage will not be released to the subcontractor when main contractor has not completed the remedying of defects (Knowles, 2012). Generally, a subcontractor's work schedule is planned according to the expected cash flow. As a result, the payment to the suppliers will be made in accordance with the anticipated cash flow. Therefore, delayed payment by the employer or main contractor affects the whole plan of thesubcontractor. This mostly results in conflicts among parties (Al-Hammad, 1993). Sometimes back charging also can result in disputes. According to Russel (2000), back charging is the practice of holding onto funds from subcontractor payments to compensate for costs paid by the main contractor but triggered by the subcontractor (Russell, 2000). When the obligated task is not performed by the subcontractor according to the subcontract agreement, main contractors tend to back charge from subcontractors (Hinze & Tracey, 1994). According to a study carried out by Kumaraswamy and Chang (1998), variations can result in expensive claims which ultimately turn into a dispute (Kumaraswamy & Chan, 1998).

Source of many subcontracting problems can be a result of the contractual chain of liabilities of the parties involved in the contract. A contract involves legal relations of parties to the contract.

However, the absence of a direct link between the employer and subcontractor causes numerous difficulties. According to a study done by Shivanthi, Devapriya and Pandithawatta (2019), incompleteness of contract has been identified as a critical factor between subcontractors and main contractors in causing disputes. Accordingly, ambiguities in the contract also a fuel for dispute occurrences (Shivanthi et al., 2019). There are some subcontract conditions that strain the relationship between subcontractor and main contractor such as indemnity clauses, takeover of equipment clauses and termination for convenience clauses. Standard forms of contracts have provided adequate protection for onerous set off conditions. However, contractors tend to prepare their own amended or unamended contracts including more onerous set off conditions expressing contractors right to set-off according to country law. This would cause disputes between subcontractors and main contractors (Kennedy et al., 1997). When main contractor and subcontractor enter into agreement, using standard forms of subcontract would be useful in preventing number of disputes. They are made to safeguard the interests of both main contractor and subcontractor. Sometimes subcontractors use overly simple contracts which ultimately lead to disputes as they do not address the risks and uncertainties that arise during the construction. Choudry, Arshad and Gabriel (2012), found out that standard form of subcontracts is used less in the industry (Choudhry et al., 2012). Completed clear work drawings and proper specifications are important for the execution and effective completion of construction works. Incomplete drawings and specifications result in interpretation problems and ultimately cause disputes between subcontractor and main contractor (Al-Hammad, 1993).

Underperforming subcontractors due to lack of experience can be a hindrance to construction projects as there can be many delays ultimately leading to claims and disputes. High density of subcontracting occasionally may lead to higher risks of delays (Sambasivan & Soon, 2007). This can be avoided by preparing subcontractor’s programme aligning with the main contractor’s programme and coordinating with each other (Rodrigo & Perera, 2016). The contractor or subcontractor must carry out construction activities according to a time schedule. Therefore, the main contractor should coordinate his construction activities with the schedule of the subcontractor. According to most subcontracts, subcontractors must get approval for shop drawings or sample materials from the main contractor. However main contractor may delay the approval due to various reasons namely poor management efficiency or delays by the employer. As a result of this, delays of the subcontractor’s work take place which ultimately lead to disputes between parties regarding the cause and effect of the delay (Al-Hammad, 1993).

Moreover, the subcontractor is obligated to provide the specialized work within the time schedule. Work by the subcontractor must be implemented in accordance with the drawings and specifications. Hence there is an expected level of quality of work by the main contractor and employer. Experienced subcontractors commit fewer mistakes in the execution of construction work (Al-Hazmi, 1987). Inexperience and less knowledge of the main contractors can detrimentally impact on the productivity of subcontractors (McCord, 2010). According to Al-Hammad (1993), lack of work quality has been identified as a common problem affecting the completion of construction projects (Al-Hammad, 1993). On some occasions, subcontractors make such low bids for the sake of winning the bid, which lead them to work on low quality standards to avoid cost overruns (Kumaraswamy & Matthews, 2000). This increases the possibility of disputes between subcontractor and main contractor (Ng & Tang, 2008).

Communication can be defined as the passing of information from one to another. Not adhering to rules and regulations, issues regarding work method distribution and scheduling can be a result of poor communication (Senaratne & Udawatta, 2013). Poor communication, personality issues and human nature have been identified as major factors that cause conflicts (Friedman et al., 2000). When there are multiple subcontractors involved in a construction project, it becomes difficult for contractors to communicate with subcontractors (Choudhry et al., 2012). Generally, proper communication between contractors and subcontractors is important for a successful completion of the project. Delays are common when poor communication exists between two parties (Al-Hammad, 1993). The interface between sub-contractor and main contractor is a neglected aspect in the construction industry. The key operation of interface between subcontractor and main contractor is undermined (Humphreys et al., 2003). Interface problems between parties can have a negative impact on the completion and work quality of the construction project (Al-Hammad, 2000). White and Marasini (2014), found out that lack of trust is a significant factor affecting subcontractor – main contractor relationship. Proactive involvement of main contractor from early stages in maintaining relationship and transparency in the process can result in a successful completion of a construction project without many interface problems (White & Marasini, 2014). Therefore, many subcontractor disputes can be found from the existing literature. Apparently, it was found that, none has provided the attributes of the subcontractor disputes but merely present the causes of such.

2.2 Attributes of Commercial Mediation

As described above there can be many disputes in subcontracting attributed to various aspects. Earlier days, disputes in construction projects were settled on site with an informal meeting between disputed parties (Treacy, 1995). All over the world, litigation was considered as standard and default method for resolution of disputes (Astor & Chinkin, 1990). Although litigation was the conventional method it is an expensive and very time-consuming approach. Therefore, ADR was seen as a necessity by the construction community (Treacy, 1995). While ADR methods gaining popularity all over the world, they were included in the standard forms of contract as a means of resolving disputes and conflicts (Jannadia et al., 2000). Negotiation, conciliation, mediation, adjudication, and arbitration are widely used ADR methods in Sri Lankan construction industry (Abeynayake & Weddikkara, 2014).

The importance of mediation is gaining recognition over various countries as an ADR method in construction industry (Brooker, 2010; Jackson, 2010). In the majority of found literature the term “mediation” is used in overall context as an ADR method for construction disputes. However, this does not affect this particular research study as commercial mediation specifically refers to the use of mediation to resolve disputes in the context of business and commerce. Mediation is a voluntary ADR process. In this process “mediator” which is an unbiased and neutral person helps disputed parties to come to mutual settlements. Further mediation is a less formal and non-binding ADR process (Chau, 1992). Compared to litigation and arbitration, mediation is far less expensive (Boulle & Rycrof, 1998; Stipanowich, 1997). Therefore, it offers cost effective and timely solutions due to its less time-consuming process (Hinchey, 1992). If the parties are ready, they can take the dispute to mediation quickly as possible. Mediation attributes such as ability to resolve disputes quickly and providing low-cost solutions are the major reasons why many consider mediation over arbitration. Mediator is a neutral, impartial, and unbiased party only to assist the disputing parties to settle amicably and in a confidential manner (Ashworth et al., 2013). A mediator does not give decisions or decide the outcomes. Settlements are reached through the party involvement (binti Rahmat, 2017). Both parties have the right to check the background, experience, and knowledge of the mediator. Consequently, there is very little chance that the mediator will become prejudiced. (Boulle & Rycrof, 1998). If parties do not agree with the solution provided from mediation, they can ignore the decision and find other means to solve the dispute (Cheung, 1999). Thus, parties have the freedom to accept or reject the solution reached. Furthermore, in mediation when one party is not satisfied with the mediator’s style, attitude or the way mediator handles the process, they even have the freedom to withdraw from the mediation process. The non-binding nature of the mediation is another attractive characteristic. Another quality of mediation which defines its flexibility is the ability to make the solution or settlements reached by mediation a ‘binding decision’ with the presence of lawyers. In this manner, parties would no longer have to squander their time and money on this issue. (Rahmat & Abdul Rahim, 2020). Mediation is popular for its party autonomy, and it can be considered as a form of “distributive justice” (Harmon, 2003). The freedom given to disputing parties to determine the mediation procedure can be highlighted as an attribute of commercial mediation.

Mediation takes place in an informal and non-confrontational environment. Mediation is voluntarily approached. It is used as a dispute resolution method only if parties agreed to it. This means the mediation considers the interests and desires of disputing parties. The legal rights of the parties are considered as a reference to the mediation process (Taylor & Carn, 2010). Unlike arbitration or litigation, mediation takes a non-adversarial route. Cooperation of parties is necessary to remove hostile environment through the dispute resolution process. Mediations is the most appropriate and effective way to achieve amicable settlements. Although mediator has some control over the process, he/she does not decide the outcome (Phillips, 1997). A mediator uses different tactics to bring both parties to a common ground. The mediator only does the role of bridging between disputant parties. To do that, mediator must investigate the dispute and underlying conflicts. Trust between parties is an important factor (Jayalath, 2018). Hence mediator facilitate the parties to discuss the dispute and its underlying conflicts. Generally, less formalities, non-hostile nature, amicable settlements voluntary approach to the process and having the opportunity to discuss underlying conflicts can be identified as attributes of commercial mediation. Litigation is a public formal process with public viewings available for media scrutiny (Bristow & Vasilopoulos, 1995). However, mediation is a private process which is not available for public viewing or media attention (Boulle & Rycrof, 1998). In mediation, parties are treated with confidentiality and immunity from court proceedings (Rahmat & Abdul Rahim, 2020).Therefore secured confidentiality can be highlighted as an attribute of commercial mediation. Thus, it's conclusive that, some of the scientific sources have identified attributes, causes and characteristics of commercial mediation.

3 RESEARCH METHODOLOGY

Mixed methodology enables the investigator to consider a research topic from variety of perspectives, possibly avoiding the limitations posed by using just one quantitative or qualitative technique alone (Mackey & Bryfonski, 2018). Hence considering the research problem, study area and aim of the research, a mixed methodology was adopted for the data collection of this research. As a result, semi-structured expert interviews provide a more comprehensive understanding of subcontractor disputes, their attributes, and commercial mediation while, the questionnaire survey validates the expert interviews' findings. Initially, the current scientific knowledge on the study area is established through the comprehensive literature review. Attributes of the mediation and subcontractor disputes were identified through the literature review. Later expert interviews were conducted to confirm the literature findings on subcontractor disputes and to identify the attributes of subcontractor disputes. Identified attributes of mediation were also verified and filtered from the expert interviews. A content analysis is conducted to analyze the qualitative data. Similarly, further identification and verification of attributes of commercial mediation shall be done. A questionnaire survey was conducted to collect the quantitative data. It included a ranking of the attributes of subcontractor disputes based on their significance in causing subcontractor disputes. Those data were analyzed through the Relative Importance Index (RII). Furthermore, the appropriateness of each attribute of commercial mediation to resolve the attribute of subcontractor disputes was also questioned using a Likert scale. After analyzing the responses for the likelihood of mediation attributes in resolving attributes of subcontractor disputes, appropriateness of commercial mediation as an ADR method for subcontractor disputes has been determined using a descriptive analysis method. Since the study was not build on a hypothesis, but rather tested a preconceived hypothesis, the deductive theory is followed. The design paradigm is pragmatism, and the strategy of inquiry is observational research in hybrid strategies.

4 DATA ANALYSIS AND DISCUSSION

4.1 Profile of the Expert Participated in Semi Structured Interviews

For the semi-structured interviews five experts form the industry were interviewed. For the easy referral, they have been denoted as R1, R2, R3, R4 and R5. The experts were from engineering, quantity surveying and arbitration disciplines. Out of the 5 interviewees R3 didn't respond and express his opinion on commercial mediation as he/she does not possess the expertise on that subject matter.

4.2 Attributes of Commercial Mediation in Sri Lanka

All R1, R2, R4 and R5 agreed on the 9 identified attributes of commercial mediation from the literature review. R3 did not express his/her opinion on the subject matter of subcontractor disputes.

1. Ability to resolve disputes quickly.
2. Provide low-cost solutions.
3. Encourage parties to settle amicably while maintaining the good relationship.
4. Having freedom to accept or reject the solution reached.
5. Voluntarily approached by the parties
6. Less formal process and non-adversarial nature
7. Provide an opportunity to discuss the disputes and underlying conflicts in a setting.
8. Confidentiality is secured.

9. Having freedom to determine the procedure.

4.3 Subcontractor Disputes in Sri Lanka

Interviewees were asked about the common disputes in Sri Lankan construction industry. R1, R2, R3 and R4 all agreed with the literature findings such as payment related disputes, bond related disputes, site safety, contractual issues, design related disputes, delays, workmanship, poor communication, and interface issues. R5 did not express his opinion on subcontractor disputes. R1, R2 and R4 disagrees with insurance related disputes as those disputes are not common in Sri Lanka. Thus, it must be disregarded as the research study is limited to subcontractor disputes in Sri Lankan construction industry. Additionally, R1 highlighted design liability as a common subcontractor dispute in Sri Lanka. R1, R2, R3 and R4 mentioned that there can be testing and commissioning related disputes. Furthermore, R1 stated that Liquidated damages related disputes can take place in construction projects as well. R1, R2 and R3 agreed on this in subsequent interviews. R2 and R3 highlighted warranty issues as a common dispute in Sri Lanka. R4 agreed on this statement. Identified common subcontractor disputes are listed below.

1. Payment related disputes.
2. Bond related disputes
3. Site safety
4. Contractual issues
5. Design
6. Delays
7. Workmanship
8. Poor communication
9. Interface problems
10. Warranty issues
11. Testing and commissioning
12. Bid shopping.

4.4 Attributes of Subcontractor Disputes in Sri Lanka

Based on the identified common disputes, the attributes were explored through the expert interviews. Out of 5 interviewees, 4 of them were asked about the attributes of subcontractor disputes. They all (R1, R2, R3, R4) agreed on 2 major attributes of subcontractor disputes. The first attribute is Subcontractor unawareness and lack of knowledge about contract details and the second attribute is Bespoke and informal contracts. Out of the 4 interviewees R2, R3 and R4 of them agreed that liability and responsibility issues, failure to respond in time, unfair construction practice and main contractor dominance over subcontractors and lack of communication are major attributes of subcontractor disputes. Main Contractor/ subcontractor ignorance, lack of coordination, and interface issues were mentioned by only 2 participants to the interviews which are R3 and R4. R3 suggested risks and uncertainties as an attribute of subcontractor disputes.

The outcome was thereafter explored through a content analysis to settle to the following list of attributes.

1. Subcontractor unawareness and lack of knowledge about the contract details
2. Bespoke and incomplete contracts
3. Liability and responsibility issues
4. Employer main contractor / Subcontractor ignorance
5. Failure to respond in time
6. Main contractor dominance over subcontractor in Sri Lanka
7. Risks and Uncertainties
8. Subcontractor/main contractor faults and incapabilities
9. Lack of communication
10. Interface issues
11. Lack of coordination

4.5 Profile of the Expert Participated in the Questionnaire Survey.

Quantitative data were gathered through a questionnaire survey. Total of 38 respondents were able to participate in the survey. 68% of the participants are quantity surveyors. 16% of the participants are engineers. Rest of the participants are architects, arbitrators, adjudicators, and mediators. 76% of the respondents has the 0 – 10 years of experience in the construction industry. 21% of the participants have 10 – 20% of the work experience. Only 3% of the participants have more than 20 years ff experience. 20 respondents have a bachelor's degree which represent 52% of the respondents. 9 respondents carry a Higher Diploma which indicates the 24% of the respondents. 21% of the sample have a master's degree and only 1 respondent has a doctoral degree.

4.6 RII Analysis

Respondents were requested to rank the attributes of subcontractor disputes based on the significance of causing disputes in a Likert scale. Likert scale was scaled from 1 to 5, 5 being the most significant and 1 being the least significant. Using this analysis, values with positive deviation were considered as the most significant contributors in causing subcontractor disputes. The following Table 1 illustrate the RII analysis carried out to analyze the above-mentioned quantitative data.

Table 1. RII data analysis

Factors	**1**	**2**	**3**	**4**	**5**	**Total**	**A*N**	**RII**	**Deviation**
Bespoke and incomplete contracts	18	9	3	1	7	38	144	0.76	0.0669856
Subcontractor unawareness and lack of knowledge about the contract details	18	7	3	4	6	38	141	0.74	0.0511962
Liability and responsibility issues	5	20	6	5	2	38	135	0.71	0.0196172
Failure to respond in time	7	20	2	4	5	38	134	0.71	0.0143541
Interface issues	8	15	7	5	3	38	134	0.71	0.0143541
Lack of coordination	8	16	4	8	2	38	134	0.71	0.0143541
Subcontractor / main contractor faults and incapabilities	5	14	13	5	1	38	131	0.69	-0.0014354
Main contractor dominance over subcontractor in Sri Lankan construction practice	8	9	13	7	1	38	130	0.68	-0.0066986
Employer / Main Contractor / Subcontractor ignorance	4	13	11	8	2	38	123	0.65	-0.0435407
Lack of communication	3	10	18	6	1	38	122	0.64	-0.0488038
Risks and uncertainties	5	12	7	8	6	38	116	0.61	-0.0803828
Total RII value								7.6	
AVG of RII (from total)								0.6909091	

According to the findings, Bespoke and incomplete contracts, Subcontractor unawareness and lack of knowledge about contract details, Liability and responsibility issues, Failure to respond in time, Interface issues and lack of coordination were identified as most significant attributes of subcontractor disputes in order. Bespoke and incomplete contracts have been ranked as the highest significant attribute of subcontractor disputes in Sri Lankan construction industry. Risks and uncertainties were ranked as lowest significant attribute in causing subcontractor disputes.

4.7 Appropriateness of Commercial Mediation as an ADR Mechanism to Solve the Subcontractor Disputes.

The final objective is achieved through a descriptive analysis of quantitative data, and it was only carried for the above identified significant factors. Accordingly, the short-listed dispute attributes were evaluated against the identified attributes of commercial mediation to assess, the likelihood of appropriateness of the mediation towards solving sub-contractor disputes. This was done through a questionnaire survey and subsequent analysis of the responses.

Following notations were used for the easy referral in Figure 1

Attributes of commercial mediation,

M1 – Ability to resolve disputes quickly
M2 – Provide low-cost solution
M3 – Encourage parties to settle amicably while maintaining the good relationship
M4 – Having freedom to accept or reject the solution reached
M5 – Voluntarily approached by the parties
M6 – Less formal process and non-adversarial nature
M7 – Provide an opportunity to discuss the disputes and underlying conflicts in a setting.
M8 – Confidentiality is secured
M9 – Having freedom to determine the procedure

Attributes of subcontractor disputes,

D1 – Subcontractor unawareness and lack of knowledge about contract details
D2 – Bespoke and incomplete contracts
D3 – Liability and responsibility issues
D4 – Failure to respond in time
D5 – Interface issues
D6 – Lack of coordination

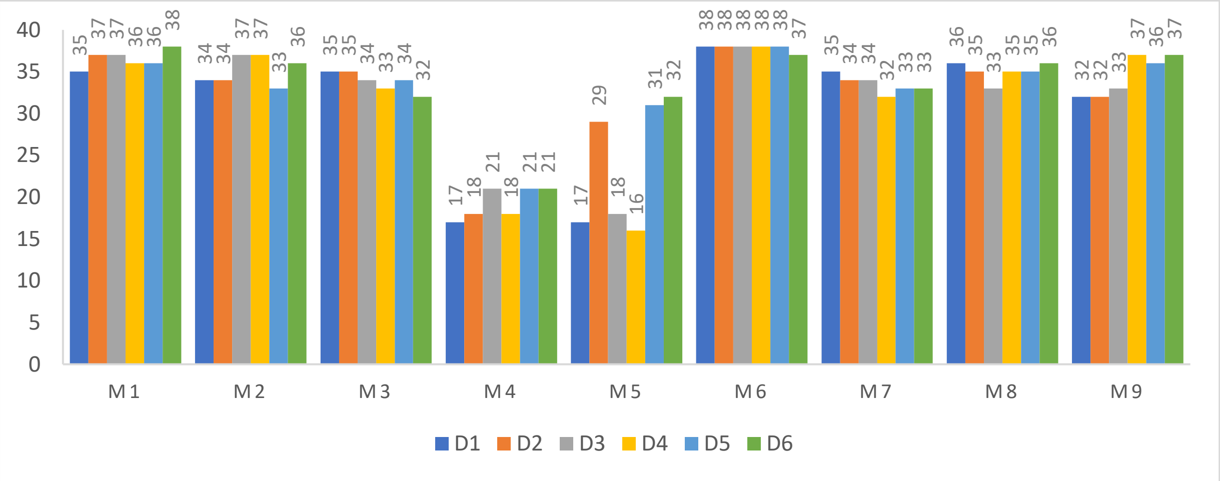

Figure 1 Agreed rate of responses

In the questionnaire survey, respondents were asked to rate their level of agreement with each mediation attribute's contribution to settling each attribute of subcontractor dispute. According to the interpretations shown in Figure 1, it is apparent that most of the attributes in mediation are appropriate in resolving subcontractor disputes incurred due to identified attributes. Majority agree that mediation attributes namely ability to resolve disputes quickly (M1), low-cost solutions (M2), encourage parties to settle amicably while maintaining the good relationship (M3), less formal process and non - adversarial nature (M6), provide an opportunity to discuss the dispute (M7) and underlying conflicts in a setting, confidentiality (M8), and freedom to determine the process (M9) are helpful in resolving all the significant attributes of subcontractor disputes. In each of these attributes, more than 84% of the respondents believe that these attributes of mediation shall be helpful in resolving subcontractor disputes. Mediation attributes such as ‘having freedom to accept or reject the solution reached’ (M4) and ‘voluntarily approached by the parties’ (M5) has an evenly distributed opinions on how much they may help in resolving attributes of subcontractor disputes.

However, attribute ‘having freedom to accept or reject the solution reached’ (M4) has failed to be helpful in resolving subcontractor disputes in overall context. M4 attribute is believed to be appropriate when resolving disputes take place due to liability and responsibility issues (D3), interface issues (D5), and lack of coordination (D6). However, the majority (more than 50% of the respondents) believes that having the flexibility and freedom given to accept or reject the settlement reached is not appropriate in resolving two of the most significant attributes in subcontractor disputes namely subcontractor unawareness and lack of knowledge about contract details (D1) and bespoke and incomplete contracts (D2). Therefore statistically ‘having freedom to accept or reject a solution reached’ (M4) is not appropriate in resolving subcontractor disputes. Moreover, enacting a commercial mediation act can help in resolving the non-binding nature of commercial mediation by providing a legal framework for conducting and enforcing mediation settlements which eventually defunct the freedom to reject a solution reached.

More than 76% agree that mediation attribute ‘voluntarily approached by the parties’ (M5) is significantly helpful in resolving disputes incurred due to bespoke and incomplete contracts (D2), interface issues (D5) and lack of coordination (D6). At the same time many believe that this mediation is not appropriate in resolving disputes took place due to the subcontractor’s unawareness and lack of knowledge about contract details (D1), liability and responsibility issues (D3) and failure to respond in time (D4). Further, Subcontractor unawareness and lack of knowledge about contract details (D1) can be the source itself that avoids the voluntary approach for mediation by the parties. Thus, by raising the awareness about commercial mediation among subcontractors and main contractor may improve the voluntary approach for mediation by the parties. Although, the reason why voluntary approach for mediation by the parties is not helpful in resolving subcontractor disputes take place due to Liability and responsibility issues (D3) and Failure to respond in time (D4) must be further investigated and studied. Overall, the higher percentage of agreed responses (62.7%) are noticeable compared to those who believe that M5 is not helpful in resolving subcontractor disputes. Additionally, closer to 50% of population believe that commercial mediation attribute M5 is appropriate in resolving disputes took place due to the subcontractor’s unawareness and lack of knowledge about contract details, liability and responsibility issues and failure to respond in time. Thus, considering the trendline, voluntary approach in mediation can be considered as appropriate in resolving subcontractor disputes.

Furthermore, through the questionnaire survey the respondents were asked about the effectiveness of commercial mediation as an ADR method in resolving subcontractor disputes. 92% of respondents believe that mediation can be effective in resolving subcontractor disputes. Many believe that through mediation they preserve the relationship between subcontractor and main contractor. Subcontractor & main contractor relationship is important for a subcontractor to continue the work and for their future line of business. Compared to other ADR methods commercial mediation is a constructive ADR process. It enables direct communication between parties. Moreover, most of the respondents prefer it due to its cost-effective solutions. It enables to investigate the dispute from subcontractor’s perspective as well. Remaining 8% of the respondents carry a different opinion from the rest. They believe that despite the attractive attributes of mediation, subcontractor’s lack of awareness about mediation makes it difficult to initiate mediation when disputes take place. As commercial mediation is voluntarily approached by the parties, it becomes difficult to use it in subcontractor disputes in Sri Lankan construction industry. Some does not prefer mediation as it does not provide binding decisions. Therefore, the inquisitorialness of the mediation could have been utilized to solve all most every significant attribute of sub-contractor disputes. Though ‘having freedom to accept or reject the solution reached’ and ‘voluntarily approached by the parties’ recorded the least possibility of solving the subcontractor attributes, the most probable mediation attribute of ‘less formal process and non-adversarial process’ would still work on solving disputes as it indirectly shadows the party autonomy principle in behind. Furthermore, these research findings illustrated that all the attributes of subcontractor disputes attributes within a particular mediation attribute follow the same pattern either it represents a positive or negative tendency.

5 CONCLUSION AND RECOMENDATIONS

This research study was conducted to determine the commercial mediation as an alternative dispute resolution method for subcontractor disputes. The first objective of the research was to review unique attributes of commercial mediation. Total of 9 attributes of commercial mediation were identified; The ability to resolve disputes quickly, Provide low-cost solutions, Encourage parties to settle amicably while maintaining a good relationship, Having freedom to accept or reject the solution reached, Voluntarily approached by the parties, less formal process and non-adversarial nature, Provide an opportunity to discuss the dispute and underlying conflicts in a setting, Secured confidentiality and having freedom to determine the procedure.

Payment related disputes, Bond related disputes, Site safety, Contractual issues, Design, Delays, Workmanship, Poor communication, Interface problems, Warranty issues, Testing and commissioning and Bid shopping were identified as the common disputes relating to construction subcontracting which is the second objective in this research study.

Third objective was to identify common and unique attributes of disputes in construction subcontract. As a result, total of 11 attributes were identified namely subcontractor unawareness and lack of knowledge about the contract details, bespoke and incomplete contracts, liability and responsibility issues, employer / main Contractor / subcontractor ignorance, failure to respond in time, main contractor dominance over subcontractor in Sri Lanka, risks and uncertainties, subcontractor/main contractor faults and incapabilities, lack of communication, interface issues.

In conclusion, 8 out of the 9 attributes of commercial mediation namely; The ability to resolve disputes quickly, Provide low-cost solutions, Encourage parties to settle amicably while maintaining a good relationship, Voluntarily approached by the parties, Less formal process and non-adversarial nature, Provide an opportunity to discuss the dispute and underlying conflicts in a setting, Secured confidentiality and Having freedom to determine the procedure were determined as appropriate in resolving subcontractor disputes. But 'having freedom to accept or reject the solution reached' was determined as not that appropriate in resolving subcontractor disputes. That's because, non-bindingness of the final decision would cause absolute loss in all the time spent, money and other resources during entire mediation journey, owing to dismiss of a conclusive decision. Consequently, it would abandon all attempts at using the ADR procedure and return to the original commencement. Howbeit, as 8 out of 9 (majority) identified attributes of mediation were determined as appropriate in resolving subcontractor disputes which resulting in the achievement of fourth and final objective. However, it is still can be addressed by the enactment of an act on commercial mediation through government or any other authorized legal institutes to cease the renege the set decision. Thus considering 92% of positive respondents' belief, the mediation can be effective in resolving subcontractor disputes. It is conclusive that commercial mediation can be utilized as an appropriate ADR method for subcontractor disputes in Sri Lanka. Likely, it is unfortunate to lose the right of solving subcontractor disputes via mediation with a such loophole. Hence, this research suggests deploying commercial mediation as sub-contractor dispute resolution method while advocating the regularity bodies to endorse the mentioned escape clause.

Accordingly, it is important for the stakeholders including the regulatory authorities, professionals, general contractors, and subcontractors to recognize the mediation as an appropriate ADR method in subcontractor disputes and the importance of commercial mediation compared to other ADR methods. Further, it is vital to popularize the commercial mediation while training the commercial mediators to gain proper recognition to improve the confidence of disputing parties in selecting the mediation as the ADR method. This research was limited to subcontractor disputes in Sri Lanka and future research are recommended for different domains around world.

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Critical Driving Factors Influencing Awareness and Application of Industrialized Building System (IBS) Technology Among the Building Contractors in Sri Lanka

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ABSTRACT

As the commonly applied approach in building construction, conventional construction approach is linked to low quality and productivity, higher danger to employee safety, high reliance on labour and cost and time overruns. Hence, Industrialised Building System (IBS) has been emerged as an alternative for conventional construction by overcoming its shortfalls. Previous studies identified the lack of awareness and application can be taken as most critical factor influencing the application of IBS. Also, there are some of other critical factors which directly influence for this regard. Since a few studies has been focused on evaluating the significance of such driving factors, the purpose of this research was to assess the criticality of driving factors influencing awareness and application of IBS technology among the building contractors in Sri Lanka.

In order to fulfil aim and objectives of the research, deductive approach under quantitative phenomenon was used. The Survey strategy was adopted as the most ideal research strategy as this research focused on evaluating the criticality of driving factors. Questionnaire survey was used as the primary data collection technique. Accordingly, the questionnaire was distributed to 50 randomly selected practitioners from the building contracting organisations, such as Architects, Quantity Surveyors and Engineers to collect the data. Data were analyzed by using Weighted Mean Average (WMA) and Relative Importance Index (RII) techniques.

As derived through analysis, 13 factors affecting the level of awareness and application of IBS, which were identified through literature review were assessed to determine the significant factors. Results revealed that cost of construction is the most significant factor while small contractors' involvement is the least significant factor. As the main implication this research provides a basis to further improve the use of IBS technology in Sri Lanka and introduce different methods to reduce the initial cost of the construction.

KEYWORDS: *Application, awareness, building construction industry, building contractors, industrialised building system, Sri Lanka*

1 INTRODUCTION

Buildings and construction industry plays a vital role in improving the population's quality of life. It is always trying to meet the requirements and needs of the society (Al-Sanad, 2015).

Construction of buildings comes before other types of infrastructure. The commonly employed conventional construction approach, which entails all work being done on-site, is unsustainable since it is linked to low quality and productivity, a significant risk to worker safety, a large reliance on labour, cost and time overruns, and poor project performance (Rahim and Qureshi, 2018). As a result, construction experts began to focus on more potent construction methods. According to a study conducted by Thanoon et al (2003), Industrialised Building System (IBS) technology has been established as an alternative solution for the problems of conventional construction method.

This can be taken as a new construction technology, which use in the construction industry. According to the study conducted by Rahim and Qureshi (2018) IBS is a construction method that involves creating components off-site in a factory-controlled environment before having them moved and quickly installed there. Additionally, it can be deduced from that study that IBS is employed as a

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sustainable strategy because to its short duration and higher quality with fewer on-site operations. When looking at the history of IBS, this method is the Malaysian term for prefabricated construction and was begun in the 1960's Malaysia and become popular in 1998 and used as a solution to improve construction image and performance (Kamar et al, 2009). As the first pilot project, it was built on 22.7 acres of land along Jalan Pekeliling and consisted of the building of 7 blocks of 17-story apartments, 4 blocks of 4-storey apartments, and 40-story shop lots, totalling roughly 3,000 low-cost apartments. (Thanoon et al, 2003).

Thus, this IBS technology, which started in Malaysia, has spread in many other countries in the world today. Thus, the developed and developing countries such as Japan, Argentina, Singapore, Thailand, United Kingdom (UK), Australia, Germany, Netherlands, United States of America (U.S.A), Canada, Denmark, Sweden and Finland have resorted to using this method grants for their own construction (Thanoon et al,2003). The study conducted by Nduka et al (2019) shows as a developing country Nigeria also use this IBS technology in their industry. Rahim and Qureshi (2018) identified faster project completion, waste reduction, improve the quality of the building, reduction of labour and safety, foreign labour workforce and payment reduction, efficient construction process and higher productivity, adverse weatherproof construction, optimal usage of materials and make cleaner and safer environment, decrease whole life cycle cost and space-saving as advantages and lack of involvement from small contractors, ignorance of the technology, higher capital investment, use of heavy equipment and machineries and lack of experience with the technology are mentioned as barriers of using IBS technology.

Despite the disadvantages, it is clear that IBS method is very much beneficial for both clients and contractors than the conventional method. But to use this technology, level of awareness is much needed. When consider IBS technology, research studies conducted by Algumaei and Sarpin (2022), Ali et al (2018), Rozaimi A Samad et al (2020) and Thomas Tarang et al (2022) pointed out lack of awareness as a main barrier of using this IBS technology. Although the awareness and knowledge about the technology is crucial for the implementation to succeed of IBS technology. However, depending on the previous studies, it is clear the assessment and studies that have examined the awareness level of construction specialists mainly construction contractors are at a very low level. Through the studies conducted by Malaysia, Nigeria they clearly identified lack of awareness among the building contractors mainly influences and impact on the application of IBS technology in the construction industry. Although this technology is currently being used in Sri Lanka, the number of studies done in this regard is very minimal. The study conducted by Qi et al (2021) often focused on IBS adoption of structural basis and have not fully experienced the advantages of emerging technologies and it is only limited for the concrete-framed structures. Therefore, awareness of IBS technology among the construction practitioners is at a minimum level. With that importance, this research aimed at assessing and identifying the critical driving factors influencing awareness and application of IBS technology among the building contractors in Sri Lanka.

2 LITERATURE REVIEW

2.1 Importance of IBS for Building Construction

According to the study conducted by Rahim and Qureshi (2018) IBS is a method of building that involves producing components off-site in a factory-controlled setting, transporting, and assembling them into a structure with limited work on the construction site. According to that study as an alternative solution for the problems of conventional construction method, IBS technology was established. The study conducted by Qi et al (2021) stated that a practice of manufacturing and pre-assembling a particular number of building components, modules, and parts before shipping and installing them on the construction site is referred to as off-site construction. Normally IBS construction method is used to assemble building components after they have been manufactured on-site or off-site under controlled conditions and also known by prefabricated construction, off-site construction, and modular construction (Saad et al ,2022). In other way according to the study conducted by Hon et al (2022) mentioned IBS, or innovative building system, is a construction technique developed in Malaysia that uses prefabricated or pre-cast components through off-site construction or modularization. Accordingly, the technology of IBS was defined in this research as "an on or offsite construction method, manufacturing building components in a controlled environment and transported and assembled in to a structure”.

As a construction technology the use of IBS technology in building construction gives much more benefits than the conventional method. In IBS, buildings are constructed quickly, more effectively with minimal on-site activities, and sustainably. According to the study conducted by Rahim and Qureshi (2018) time saving, quality improvement, labour, wastage and cost reduction, reduction of payments by foreign labour, efficient construction process and higher productivity, flexible design, and adverse weatherproof construction can be taken as importance of using IBS technology. In 2022, Algumaei and Sarpin identified time reduction, quality improvement, decrease overall costs, environment friendly and flexibility of designing IBS product as some benefits of using IBS through their study. Reduced project implementation costs, short project completion period, improved level of hygiene and safety at the construction site, reduced requirement on foreign workers and use of quality components identified as advantages of using IBS (Samad et al, 2020). The study conducted by Hon et al, (2022) speed up on-site construction activities, reduce waste, reduce energy consumption, produce better construction quality, reduce life-cycle cost (LCC) and reduce construction cost can be taken as importance of using IBS technology.

2.2 Different Applications of IBS Technology in Building Construction Industry

Most of the developed and developing countries use IBS as a convenient technology, for their construction work. A study conducted by Mohamad et al (2009) clearly described the involvement of Malaysian construction society with the IBS technology. Further to the authors, strong awareness of government encouragement among companies makes good opportunity to going with this technology in Malaysia. As a developing country Nigeria is also use this method for their construction works. The study conducted by Nduka et al (2019) mainly investigated the Critical Success Factors (CSFs) contribution to the implementation of IBS in Nigeria. Mostly this IBS technology is use in Malaysian construction industry and according to the study conducted by Rahim and Qureshi (2018) it clearly mentioned in 1999, Malaysia realized that the oversupply of unskilled imported labor and the lack of skilled local workforce could only be overcome through the use of IBS and “according to the Construction Industry Development Board (CIDB), 2016 the first IBS strategic plan was announced followed by two IBS ‘Roadmaps’ (2003-2010 and 2011-2015)”.

According to a study conducted by Thanoon et al (2003) Japan, Singapore, Thailand, U.K., U.S.A, Australia, Argentina, Germany, Netherlands, Canada, Denmark, Sweden and Finland are identified as experienced countries in IBS technology. Further to the authors identified “majority of the IBS are originated from United States, Germany and Australia and as developed countries Japan, Germany and U.K. indicate that there is a great potential for IBS to progress as evidenced by their growing market share”. According to the study conducted by Rahman and Omar (2006) ‘Brickfileds Secondary School in Kuala Lumpur’ used 75% of pre-fabricated components to construct. In addition to that ‘Jaya Jusco’, ‘Tebrau’, ‘Johor Bahru’, ‘Subang Square’, ‘Subang Jaya’, ‘Millennium Hall’, ‘Seberang Prai’ also can get as examples for the usage of IBS in Malaysian construction industry. In construction of ‘Senawang Police Quarter’, ‘teachers’ quarters in Kuala Kangsar’ and government quarters in Putra Jaya, load bearing wall system are used. And steel structured Kuala Lampur City Center (KLCC) convention center in the prestigious is also constructed according to the IBS technology.

Rozaimi A Samad et al (2020) did their study to found about the successful development of IBS using additional school buildings as examples in Malaysia and Kamar et al (2009) discussed through their study “IBS technology were used as a hybrid construction technique to build national landmarks such as ‘Bukit Jalil Sport Complex’, KLCC, Lightweight Railway Train (LRT) and ‘Petronas Twin Towers’ in Malaysia” and this approach “is begun since early 1960’s in a low-cost housing scheme and today IBS has evolved and used in hybrid construction to build national landmark”. Through this study it also mentioned IBS promote as a sustainable and green construction in UK. The study conducted by Mohamad et al (2009) mentioned “all government projects are essential to use IBS at least 70% of completed project and have a really indicate government encouragement to implement IBS in Malaysian construction industry”.

According to the study conducted by Nduka et al (2019) it recommended a public-private cooperation with favorable monetary policies will help IBS talented contractors. The study conducted by Thomas Tarang et al (2022) identified “67% of the study agreed that IBS contractors are prone to the risk in their business venture as an unstable political climate may cause policy changes and the less stable political climate will be causing a higher risk business and eventually lead to a lesser interest in implementing IBS as the rules and policies keep changing. The changes in political stands will affect the rules, regulations, and policies, making IBS business too risky”.

2.3 Driving Factors Influencing Awareness and Application of IBS Technology in Building Construction

Mohamad et al (2009) identified the vast majority of partitioners are unaware of the range of IBS references and short courses that CIDB provides to aid with IBS implementation in Malaysia. Because of this, their level of awareness of IBS in management and technical activities was quite poor. This study identified IBS knowledge as one of the most important requirements for them to advance and receive greater recognition in the Malaysian construction sector over the short term. The study conducted by Qi et al (2021) discussed some businesses or employees could be reluctant to accept new technologies because they think that doing so will complicate and interrupt their workflow.

Many of research are identified limitations and influences which are mainly impact for the application of IBS construction. Skills shortage, Higher Cost, Lack of small contractors’ involvement, Lack of Awareness are identified as the main limitations which involved the use of IBS through the study conducted by Rahim and Qureshi (2018). The study conducted by Algumaei and Sarpin (2022) identified the biggest issue with IBS adoption in Yemen was a lack of knowledge in terms of the absence of educational programs that address it. The studies conducted by Ali et al (2018) Samad et al (2020) and Thomas Tarang et al. (2022) also identified lack of knowledge and lack of experience among the workers as main barriers to the implementation of IBS construction. Also, the lack of awareness can be taken as internal challenge that IBS contractors have to face.

The study conducted by Hon et al (2022) lack of experience, insufficient knowledge, lack of codes and standard of application, poor cooperation and communication between stakeholders and lack of special equipment or technology are identified. Unavailability of research and educational courses on IBS, unfamiliarity, lack of technology reference, Insufficient IBS manufacturer and inadequate educational course for IBS as well also can be taken as driving factors which impact to the awareness and application of IBS technology (Zakari et al , 2017). In Industrialized and System (2016) clearly mentioned limited understanding is the main barrier for the implementation of IBS construction. The study conducted by Ali et al (2018) it is evident that the primary barriers to the adoption of IBS in Malaysia are a lack of information, awareness, and skilled labor. In addition to that Jaffar and Lee (2020) identified cost of construction, experience and expertise in IBS projects, training, communication, government policies, resource integration, and software use as other key determinants .

In summary 13 driving factors were identified, namely cost of construction, availability of technology, level of cooperation and communication, knowledge and experience, availability of special equipment, involvement of skilled workers, government policies, integration of resources and utilization of software, knowledge level of codes and standard of application, familiarity of technology, availability of research and educational courses on IBS, level of awareness and small contractors’ involvement which were used in subsequent analysis.

2.4 Application of IBS Technology in Building Construction in Sri Lanka

When going with the building construction, there are some building technologies which normally used in the construction industry to achieve better quality and effectivity of the construction. IBS also can take as highly recommended building technology which used in the industry. To going with those technologies level of awareness is much needed. Consider about IBS technology, many research studies pointed out lack of awareness and application as one of major influence. Although the awareness and knowledge about the application of technology is very important for the success of IBS technology. But the assessment and studies that have examined the level of awareness and application among the construction specialists mainly construction contractors are very low. Although this technology is currently being used in Sri Lanka, the number of studies done in this regard is very minimal. Considering the last 10,15 years the studies done in Sri Lanka regarding the knowledge level of contractors about

IBS technology is very fewer. Therefore, the knowledge of IBS technology among the construction practitioners is at a minimum level.

3 RESEARCH METHODOLOGY

A combination of literature review and questionnaire survey instrument was employed in this study. The research design was chosen to examine the research objectives by eliciting their expertise as experts (Rajakaruna, De silva and Bandara ,2008). Deductive approach under quantitative phenomenon was used in this study to gather data on critical driving factors influencing awareness and application of IBS technology among the building contractors in Sri Lanka.

Quantitative research focuses on analysing and quantifying data to summarize the results (Apuke, 2017). In this research theory testing was happened. Here mainly identified certain factors and assessed criticality of driving factors influencing awareness and application of IBS technology. The factors were recognized through literature review in order to assess level of awareness and application of IBS. Since this research intended to assess the criticality of driving factors influencing awareness and application of IBS technology, had intended quantitative outcome and not done any in-depth investigation, quantitative approach was selected.

This research focusing on assessing and identifying the critical driving factors influencing awareness and application of IBS technology among the building contractors in Sri Lanka.

So as the research strategy Survey strategy was adopted. The study conducted by OGOLO in 2019 cited (Yomere, 1999: 159) mentioned survey is "the systematic study of a small or large population in order to understand and be able to predict some characteristics or behavior of the population"

3.1 Method of Data Collection

Reviewing the concept of ‘industrialised building system (IBS) and its different applications in building construction and identifying the factors influencing application of industrialised building system technology in building construction were identified under first two objectives through literature reviews.

To establish third objective, data was gathered through survey study. To collect the primary data in response to the research questions, questionnaire survey was used as a data collection technique for determining the respondents' perception on criticality of driving factors which influencing to the level of awareness and application of the IBS among the building contractors in Sri Lankan construction industry. Questionnaire was conducted among 50 randomly selected professional and experienced practitioners from the building contracting organisations such as Architects, Quantity Surveyors and Engineers to assess criticality of driving factors influencing awareness and application of IBS technology in Sri Lanka (refer Table 1). All participants were selected from grade CS2-C4, private companies, government and semi-government organisations. Random convenience sampling method was used. The questionnaire was considered the nature of the data required for this study. Quantifiable data was found to highlight the criticality of driving factors which influencing for the level of awareness and application of IBS technology.

Table 1. Profile of Respondents

Criteria	No. of participants	Percentage (%)
Designation		
Quantity surveyor	15	45.5
Architect	4	15.1
Engineer	13	39.4
Highest academic qualification		
Diploma	-	-
Higher National Diploma	2	6.1
Bachelor’s Degree	28	84.8
Master’s Degree	3	9.1
Doctoral Degree	-	-
Years of experience		
0 – 5	23	69.7
5 – 10	7	21.2

10 – 20	1	3.0
More than 20 years	2	6.1
Grade / type of organisation		
CS2	7	21.2
CS1	1	3.0
C1	6	18.2
C2	1	3.0
C3	1	3.0
C4	2	6.1
Private companies	6	18.2
Government organisations	6	18.2
Semi-government organisations	3	9.1

13 key factors which affecting the level of awareness and application of IBS were identified through literature review. Those key factors were given to the participants through the questionnaire to categories as very low, low, normal, high and very high.

3.2 Method of Data Analysis

The collected data was analyzed by using statistical analysis in tools in weighted mean average and RII method. Microsoft Excel spreadsheet was used as a data analysis tool.

13 factors were examined, and their mean values and RII values were ranked from highest to lowest. According to Algumaei and Sarpin (2022) state that the study analysis's mean was calculated using the provided formula and ordered from highest to lowest.

$$\text{Mean} = \frac{\sum_{i=1}^{5} \text{Weight of ranked position}(1) \text{ x Frequency of respons (i)}}{\sum_{i=1}^{5} \text{Frequency of respons(i)}} \qquad (1)$$

RII = ∑W / (A*N)
W = Weighting given to each factor by the respondents
A = Highest Weight
N = Total number of respondents

4 DATA ANALYSIS AND FINDINGS

4.1 Current Awareness and Application of IBS in Construction Industry in Sri Lanka

According to the responses provided by the participants it clearly shows most of the contractors generally know about the IBS technology. It says 60.6% participants aware about this technology. But 39.4% of the participants have not any idea (Figure 1) Here the most of them acquired knowledge through the internet. The people who gained knowledge through working experience are very few. In addition, there is a small number of people who have gained knowledge through the awareness programs (Figure 2) Although many people have knowledge about IBS technology, the percentage involved in related projects is very low (Figure 3).

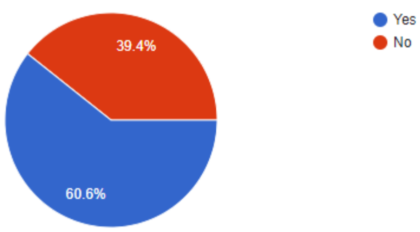

Figure 1. General awareness about IBS technology

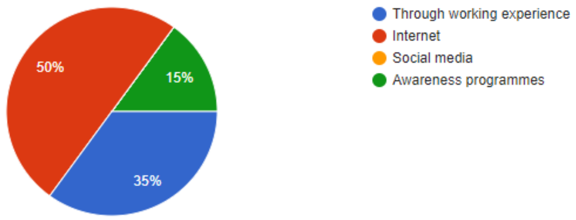

Figure 2. Sources of knowledge about IBS technology

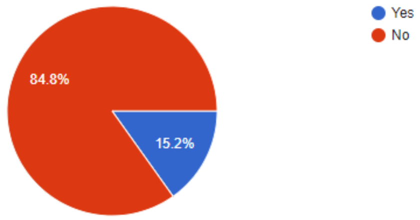

Figure 3. Involvement in IBS construction project

IBS technology is currently being used in Sri Lanka under the name of prefabrication. Through the questionnaire survey, it gives better understanding of the projects that the participants have been involved in so far. Accordingly Middle-income people housing project, Aitken Spence Printing Factory-steel prefabricated project, Kurunegala water supply project, Residence with prefabricated concrete walls and Temporary Industrial Building at Horana can take as examples for applications of IBS.

4.2 Driving Factors Influencing Awareness and Application of IBS Technology in Construction in Sri Lanka

According to the responses, driving factors which influencing awareness and application of IBS technology in Sri Lanka was ranked according to their mean and RII values (refer Table 2)

Table 2. Calculated Mean Scores, RII Values and Ranking of Driving Factors Which Affect to the Awareness and Application of IBS Technology

Driving Factors	Mean score	RII	Rank
Cost of construction	3.333	0.667	1
Availability of technology	2.848	0.570	2
Level of cooperation and communication	2.758	0.552	3
Knowledge and experience	2.758	0.552	3
Availability of special equipment	2.727	0.545	5
Involvement of skilled workers	2.697	0.539	6
Government policies	2.667	0.533	7
Integration of resources and utilization of software	2.667	0.533	7
Knowledge level of codes and standard of application	2.606	0.521	9
Familiarity of technology	2.545	0.509	10
Availability of research and educational courses on IBS	2.485	0.497	11
Level of awareness	2.424	0.485	12
Small contractors' involvement	2.152	0.430	13

According to data analysis, cost of construction was identified as the most critical driving factor (WMA=3.333) (RII=0.667) which affect to the awareness and application of IBS technology. Then availability of technology (WMA=2.848) (RII=0.570) as the second and both knowledge and experience and level of cooperation and communication (WMA=2.758) (RII=0.552) as third highest factors can be pointed out which influence for the IBS technology. Accordingly, availability of special equipment (WMA=2.727) (RII=0.545), involvement of skilled workers (WMA=2.697) (RII=0.539), both integration of resources and utilization of software and government policies (WMA=2.667) (RII=0.533), knowledge level of cords and standard of application (WMA=2.606) (RII=0.521), familiarity with technology (WMA=2.545) (RII=0.509), availability of research and educational courses on IBS (WMA=2.485) (RII=0.497) and level of awareness (WMA=2.424) (RII=0.485) were ranked from higher to lower according to their mean and RII value. As a least critical factor (WMA=2.152) (RII=0.430), small contractors' involvement was identified through the survey study.

When compared with previous studies, it was revealed that the final results obtained from the survey study were completely different. Accordingly, it can be pointed out that the cost of the construction, rather than the lack of awareness, mostly affects the awareness and application of IBS construction in the Sri Lankan construction industry.

In addition to the driving factors which recognized through literature review, the participants of the survey had indicated that the "attitude of the people" also affect to the IBS construction as another factor.

5 CONCLUSIONS AND RECOMMENDATIONS

This paper investigates about the criticality of driving factors which influencing awareness and application of IBS technology among the building contractors in Sri Lanka. Through the literature review 13 common critical factors which influence on awareness and application of IBS were identified. The influence of those factors in the Sri Lankan construction industry was assessed through this study. As results this article reviled cost of the construction as the most critical factor affecting the use of IBS technology in Sri Lanka. Then availability of technology was identified as the second most critical factor and both level of cooperation and communication and knowledge and experience thirdly identified. According to the study, it was concluded that the small contractor involvement has the least impact on IBS technology in Sri Lanka. In addition to that the study was pointed out that between the most critical factor and least critical factor, knowledge and experience, availability of special equipment, involvement of skilled workers, government policies, integration of resources and utilization of software, knowledge level of codes and standard of application, familiarity of technology and availability of research and educational courses on IBS have influence on IBS technology. Then the study recommends that the strategies should be introduced to further improve the use of this technology in Sri Lanka and introduce different methods to reduce the initial cost of the construction.

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The Effect of Timely Delivery of Construction Projects on the Economic Growth in Sri Lanka

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ABSTRACT

Economic growth is the increase in the production of goods and services in the economy from one time period to the next. Construction, as the sector with the biggest multiplier effect, has helped continue to accelerate Sri Lanka's economic growth. Timely construction output generates socioeconomic growth and wealth generation in a country. Delays are one of the major issues in the construction industry in Sri Lanka, which can have an ultimate impact on the growth of the national economy. Therefore, the research aims at investigating the effect of the late completion of construction projects in the public sector on the factors contributing to economic growth in Sri Lanka. A mixed-method approach was adopted, using preliminary interviews and questionnaires as data collection techniques. The collected data was analyzed using manual content analysis and the relative importance index (RII). Twenty (20) factors contributing to the economic growth in Sri Lanka were identified through both literature and preliminary interviews. Among them, Foreign Direct Investment (FDI), external debt, an effective procurement system, open direct assessment, and a proper system of transportation are the most important factors, as highlighted by the respondents. The impact of the delay in completion of public sector construction projects on the identified factors was identified through the questionnaire and classified into three levels: less impacted (RII < 50%), averagely impacted (50% < RII < 70%), and highly impacted (RII > 70%). Including foreign direct investment, credit to the private sector, a proper system of transportation, the material price index, imports and exports, and the service sector overall, twelve factors have been dispersed between 0.65 and 0.70, which represents an overall percentage of 60%. So the findings validate that there is a strong impact on economic growth from public sector project delays. In a nutshell, the research findings revealed that the on-time completion ofpublic sector construction projects strongly affects economic growth, which thereby emphasizes the importance of the on-time completion of construction projects. This study further recommends that in order for a project to proceed well and be completed on schedule, sufficient planning should be done before construction begins with the aid of new technology.

KEYWORDS: *Construction industry; economic growth, time delays, on-time completion, wealth creation; project success.*

1 INTRODUCTION

The construction industry is a vast industry that is focused on construction, demolition, renovation, and maintenance. Graham et.al (2011) has defined the construction industry as the most diverse industry which delivers building construction, industrial construction, and infrastructure projects. In building up the climax in the economy, on-time completion of construction projects makes an immensecontribution. Manoharan et.al (2015) has highlighted that it is common that Sri Lanka has been experiencing time delays arising in the construction filed due to various reasons. When a project is delayed past its completion date, the client suffers a loss of revenue due to the non-availability of production facilities and rentable space. For the contractor, delay leads to a high overhead cost due to the extended period, and the high price of labor, material, plant, equipment (inflation), and so on (Prasad, 2019).

Few researchers have explored the relationship between economic growth and the construction

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sector in Sri Lanka. Apart from that, several attempts have been made by the industry experts regarding the project delays in Sri Lanka. From all of them, none of the findings indicate the chemistry between the on-time completion of construction projects and how it affects the economic growth of Sri Lanka as a developing country. Since many public sector construction projects in Sri Lanka go over schedule, this is a pivotal area to study how on time completion of construction projects in the public sector contributes to the economic growth of Sri Lanka.

The aim of this study was to critically appraise the relationship between the on-time completion of construction projects and the growth of the Sri Lankan economy. In line with the research aim, two research objectives were formed as to identify the contributing factors to the Sri Lankan economy and examine the effect of construction project delays in the government sector on factors contributing to economic growth in Sri Lanka.

2 LITERATURE REVIEW

2.1 Delays in the Construction Industry and Impacts Caused by Delay

Construction project delays are common in every country, whether it is a developing or developed country (Soliman,Ehab 2017). In a World Bank study done in 1990, numbers showed that for the 1627 projects finished between 1974 and 1988, the overrun varied from 50% to 80% of the original time. Project completion delays are a significant problem for Sri Lanka's construction sector as well. In particular, in Sri Lanka, government and semi-government projects have a high inclined rate of delivering delayed projects (Sivarajah, 2021).

Delay is a worldwide phenomenon enacted in the construction industry. Sweis et al. (2008) has explained it is a failure of completing the project on time within the fixed budget. On top of all the details, delays in a project can cause many impacts including cost overruns, infeasibility, arbitration, and litigation (Rahaman, A.H. Memon 2011). Since the delay is related to costs and the anticipated budget for a project, realistic construction time is a dominant factor.

As indicated by Arantes De Silva and Ferreira (2015) disputes are likely to arise as a result of the delayed completion date. Additionally, the parties might need to engage in a legal proceeding to resolve delays. In conclusion, both studies have explained the impact of project delays on contractual and cost factors.

2.2 Factors Contributing to the Economic Growth of a Country

Economic growth is the rise or improvement in the market value of goods and services generated by an economy over a specific period, adjusted for inflation.

According to pervasive literature that examines several theories of economic development in Sri Lanka, an economy's growth could come from a variety of sources such as human capital accumulation, productivity improvements, improvements in human capital stocks,enhanced efficiency of the financial market, and improvements in external performance (Kannangara, 2020). One of the most crucial signs of a healthy economy is economic growth. The nation's economy is becoming more productive due to the rising GDP.

Human resources and economic growth have a strong relationship, and it gives a climax to the economy. It helps the economy by expanding the knowledge and skills of the population (Hicks, 1980). Wheeler (1980) has described that human resource development contributes to sustainability growth by increasing physical investment, labour productivity, in contrast to reducing fertility. Lee and Mckibbin (2014) have expounded that the productivity of the service sector eventually supports economic growth by contributing to the sustained and balanced growth of Asian countries. The industrial sector is another major factor in the economic system. Kniivila (2019) has stated that the development and expansion ofindustries support economic growth by creating massive changes. Sukhadolets et al. (2021) have shown that foreign investment makes a significant contribution to economic development. Furthermore, the study has concluded that economic development is directly correlated with both foreign direct investment and investment in construction. The importance of foreign direct investment as the principal driver of the global economy has been extensively documented in the literature. Inflation can be defined as the rate of price growth over a specific time period. Mamo (2012) has shown that inflation is the most important objective to sustain high economic development.

Export and import is another main factor that supports the economy. Achchuthan (2013) stated that exports and imports have a positive impact on the economic growth of Sri Lanka. The export structure has two categories. They are merchandise exports and service exports. As per the study done by Ajayi LB and Oke MO (2012), moving external debt to economic growth has both a negative and positive impact. Then, in a subsequent study, Sachs and Williamson (1985) demonstrated the role of external debt in the development of infrastructure facilities and the service sector.

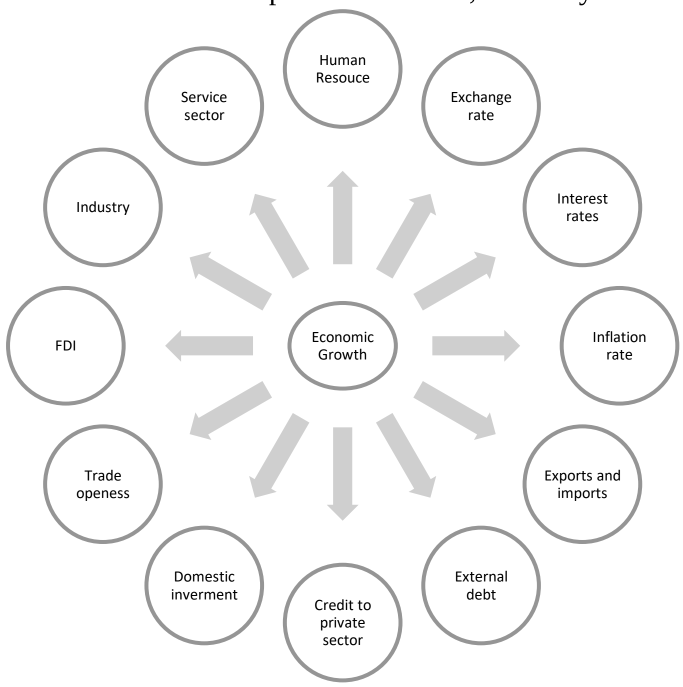
An important financial market indicator, the interest rate has a significant impact on the whole economy. A time of rapid productivity development will usually somewhat offset the long-term expenses associated with a low-interest rate environment. On the other hand, in a time of high-interest rates, the long-term advantages will be countered by slow productivity growth. Singh (2022) explained that interest rates negatively affect economic growth. Chughtai et al. (2015) have cleared the negative impact of the interest rate on the development of a country. Drobyshevsky et al. (2017) have pointed out that interest rates affect the economy in both positive and negative ways. Interest rates have several functions in the economy (Bergo, 2003). It influences inflation, long-term capital accumulation, the potential for economic growth, and many other things. In addition, credit to the private sector has a positive relationship with the economic growth of Sri Lanka (Perera , 2016). Exchange rates affect all citizens, businesses, and governments. Collectively, it can have an impact on inflation, the balance of payments, and investing opportunities. Aslam (2016) has explored the exchange rate as a turning factor in the Sri Lankan economy. Trade openness refers to the direction of an economy, related to foreign trade. Wanogasooriya (2022) has shown that trade openness has a positive relationship with the Gross Domestic Product in Sri Lanka in the short run, while a negative relationship is indicated in the long run. Sayef Bakari (2017) has shown that there is a positive relationship between growth and domestic investments. Figure 1 shows all the factors collectively contributes to the economic growth of a country.

Figure 1. Factors contributing to the economic growth

2.2.1 Importance of the construction industry to the economic growth in Sri Lanka

The construction industry is massive and responsive as well as it compromises with strong linkages with other industries having the highest multiplier effect. The construction industry is just not the infrastructure, it increases productivity and the standard of living by increasing economic growth.

Ramachandra and Rameezdeen (2006) have revealed a positive relationship between economic growth of Sri Lanka and construction output. Furthermore, the study covered Gross Domestic Fixed



Capital Formation respectively and construction output often expands more quickly than the output of other sectors during times of high economic growth.

a) Improved Standard of Living

Olatunji et. al (2020) have clarified that economic growth directly contributes to a rising standard of living. Due to the increase in per capita production of goods and services, there is an increase in per capita consumption of goods and services. The infrastructure can therefore be used for its intended purpose and the economy may benefit when a building project is completed on schedule (Stone, 2017). The ideal indicator would be GDP or GNP per capita, which take into account investments in machinery and industries that raise a country's capacity to produce more and ultimately consume more, raising living standards.

b) Infrastructural facilities extension

Infrastructure is the fundamental, necessary service that must be installed to allow for development (Jodie & Ogunrinola, 2011). Infrastructure can help Sri Lanka's economy develop faster by facilitating it. The Development will be extremely challenging and, in reality, like obtaining a highly rare good that can only be obtained at a very high cost and expense if certain facilities and services are not present. A great deal of theoretical research and practical investigations have been done on the creation and deployment of infrastructures. One of the most significant economic issues inthe current academic and policy cycle is the link between infrastructure development and economic growth (Roller and Waerman 2009). The economic expansion entails higher per-capita gross domestic product. The infrastructure supports enhancing sustainable growth. In order to extend the infrastructurefacilities, the construction industry is doing an immense service.

2.3 Importance of on-time completion of construction projects to economic growth

On-time completion of projects mitigates cost overruns due to time overruns. In the construction sector, efficient time management and on-time completion are crucial components. On-time completion of a construction project will increase the contractor's opportunities. Furthermore, achieving building goals will be beneficial. Additionally, on-time completion maximizes competence (adobe experience cloud, n.d.). Also, the time delays caused a loss in construction productivity, and the loss of construction productivity highly affected the development of the country (Parviz Ghoddousi, 2010).

Olatunji et. al(2020) have found that on-time completion of public sector building construction projects leads to create socio-economic growth, and wealth creation that improves the standard of living.

2.3.1 Socio-Economic Growth

Due to the significance of the timely project completion to economic development and growth, policymakers have primarily used construction as a tool, and adjustments to the share of public spending going toward construction activity have been a feature of various governments' fiscal policy measures. The contribution of the building industry to national output is the largest (Ruddock and Lopes, 2006).

2.3.2 Wealth Creation

The successful completion of construction projects results in the generation of money, socioeconomic growth, and raised living standards (Scheel, 2007). The literature has extensively emphasized the importance of the public sector to the overall economy. The output of the construction industry is said to be directly correlated with the output of the entire country. Additionally, it is noted that when the economy expands, the output of the building industry grows more quickly than the national output and vice versa (Wells, 2006).

3 RESEARCH METHODOLOGY

To flourish the research objectives, the mixed method approach was followed. Thus, it was decided that a mixed-method approach can give a more comprehensive understanding of the research, which qualitative and quantitative could offer separately.

The research is basically about the effect of on-time completion of construction projects on the economic growth of Sri Lanka. To start with a set of preliminary interviews (5 nr) were conducted among the professionals to be to identify the factors contributing to the Sri Lankan economy. Table 01 shows the profile of the respondents of the preliminary interviews.

Table 1. Profile of Interviews

Code	Designation	Years of experience
R1	Project Manager	24
R2	Ch. Quantity Surveyor	24
R3	Ch. Quantity Surveyor	24
R4	Ch. Quantity Surveyor	10
R5	Ch. Quantity Surveyor	18

Secondly, a questionnaire survey was conducted to examine how the factors contributing to the economic growth in Sri Lanka have been impacted due to the late project completion.

The questionnaire survey compromised three main questions which are related to the factors contributing to the economic growth.

In this questionnaire, questions were grouped into two sections. The first section includes the background information of the participants. The second section is based on how the factors related to economic growth have been impacted due to delays in government building projects. Through the questionnaire, 20 factors were checked and the respondents were asked to rank the impact.Impact levels are indicated in table 2.

Table 2. Likert Scale Answers

1	The impact is negligible.
2	Have less impact.
3	Have an average impact
4	Have a considerably strong impact
5	The impact is very high.

Data collected from the interviews were analyzed using content analysis. The analysis was done using a simple content analysis process. First, data was organized by going through the interview recordings. Data were combined and analyzed discussing the recommendations.

RII (Relative Importance Index) has been used in this study to rank the impact of construction project.

<u>Step of RII analysis</u>

Relative Importance Index = $\sum W/ AN$ Equation 1

W- Is the weight given to each factor by the respondents from 1, 2, 3, 4, and 5 for negligible impact,less impact, having an average impact, having strong impact, and high impact respectively,
A- Highest weight
N- No of respondents

4 DATA ANALYSIS AND DISCUSSION

In this research study, the research population was experienced professionals in the construction industry in Sri Lanka which includes 8.88% project managers, marking 4 project managers. 42.20% was engineers including 19 out of 45 respondents.46.70% was quantity surveyors including 21 respondents out of 45 respondents. 2.22% was other financial expertise including 1 respondent out of 45 respondents.

The experiences of the survey respondents were categorized into different periods. 24.40% of respondents had experience from one year to five years, marking 12 respondents out of forty-five respondents. 17.40% of respondents had five to ten years' experience, marking 08 respondents. 10 respondents have ten years' to fifteen years' experience which is equal to 20% of the respondents. 37.78% of respondents have more than fifteen years of experience marking 17 respondents.

4.1 Factors contributing to the economic growth in Sri Lanka

The majority of respondents mentioned that "in Sri Lanka, sectors like construction, agriculture, fishery, poultry, and manufacturing are high labor intensive and hence the impact of the contribution ofhuman factors on economic growth is high". Respondents collectively agreed that to uplift industries and other facilities of Sri Lanka, the service sector has been supporting as an engine. The majority of respondents said that "FDI supports valuable opportunities for Sri Lankan developers while enhancing the economy positively. On trade openness overall idea of the respondents were "Trade openness has the power to spur economic growth by facilitating access to goods and services, improving the effectiveness of resource allocation, and elevating total factor productivity through the spread of information and technology. About the interest rates common idea of the respondents were low-interest rates enhance economic growth while high-interest rates, cause unemployment, low-level investment, and downturn of the economy". High inflation was commented as a mark of unhealthy economy and high inflation increases the unemployment rate, interrupting investment opportunities and increasing poverty. Common Idea came out from the respondents were A strong exchange rate depressed the economic growth and exchange rate has a significant impact on the economies of nations through interactions with other nations". Almost all the respondents specified that positive effect of credit to private on the economic growth. The overall idea about trade openness was that it can affected both positive and negative impacts and removing trade restrictions including import and export tariffs and other technical obstacles that offset Sri Lanka's benefits from trade openness". Majority of respondents clearly pointed out that in Sri Lanka external debt. has played a huge role in developing infrastructure while positively developing the infrastructure.

R1 suggested effective procurement systems, law and order, a proper system of transportation system, and minimization of regulatory protocols as the factors that affect economic growth. R2 explained the significance of having an effective procurement system, foreign policy on government, and the two economic activities. Effective procurement system, law and order were pointed out as factors contributing to the Sri Lankan economy by R3.

Personnel attitudes, material price index, and having an effective procurement system were suggested by R4 the as contributing factors to enhancing economic growth.R5 expounded that the index of industrial production, minimization of regulatory protocols, and ODA as the factors that enhance economic growth.

Starting from regional development to the economic growth of Lanka's effective procurement system and the proper system of transportation have a significant impact.

Low and order, minimization of regulatory protocols, and foreign policy on government have contributed to the Sri Lankan economy both positively and negatively, while providing run other key activities of the economy. Together with the Index of industrial production, the material price index, and ODA have contributed starting from the low level of the economy to the national economy positively.

The analyzed facts of the study show the impact of the contributing factors to tri Lankan economic growth. Nine factors contributing to the Sri Lankan economy could be newly identified through the interviews. Effective procurement system, proper system of transportation, minimization of regulatory protocols, index of industrial production, ODA (open direct investment), law and order, material price index, foreign policy on government were among the highlighted factors.

Human resources was the only factor removed after the experts' ideas pointed out in the interview discussion.

4.2 Impact of delay in project completion on the factors contributing to the economic growth in Sri Lanka

From the literature, twelve (12) factors were identified as the factors that support economic growth. Theyare human resources, interest rates, FDI (Foreign direct investment), exports and imports, credit to the private sector, external debt, industry, service sector, inflation rate, exchange rate, trade openness, domestic investment. Human resource was removed from the interviews and eleven 11 factors from literature and nine 9 factors from expert interviews, all together 20 (twenty) included in the questionnaire survey.

Respondents were asked to rate the impact of project delays on the factors influencing Sri Lanka's economic growth.

Based on the RII values obtained from the analysis, the factors contributing to economic growth were categorized as highly impacted, averagely impacted, and lesser impacted factors. Considered impact level as follows.

- ❖ Low impact (RII<50%)
- ❖ Average impact (50 %< RII < 70%)
- ❖ High impact (RII>70%)

Table 3 shows the calculated RII values of the contributing factors to the economic growth.

Table 3. RII Value of the Contributing Factors to Economic Growth of Sri Lanka

Factors	**RII index**	**Rank**
Factors that have a high impact		
Foreign Direct Investment	0.72	1
Credit to Private Sector	0.72	2
A proper system of transportation	0.71	3
Material Price Index	0.71	4
Imports and Exports	0.71	4
Factors that have an average level of impact due to project delays		
Service Sector	0.68	6
Domestic Investment	0.68	6
Exchange rate	0.68	8
Effective Procurement System	0.67	9
Interest rates	0.66	10
Inflation rate	0.66	11
Industry	0.65	12
Foreign policy on government	0.63	13
Index of industrial production	0.62	14
ODA to GDP	0.62	14
Personnel attitude of the people	0.61	16
Trade openness	0.61	17
External debt	0.58	18
Factors have a low-level impact due to project delays		
Minimization of regulatory protocols	0.48	19
Law and order	0.44	20

As per the analysis of the questionnaire findings, FDI, credit to the private sector, proper system of transportation, material price index, imports and exports are the factors that have been highly impacted due to the late completion of government sector construction projects. The overall analysis shows that among the factors that spur the economy, foreign direct investment, and credit to the private sector is the highly impacted with RII=0.72, followed by a proper system of transportation, the material price index, and imports and exports similarly with RII of 0.71. The findings of the research emphasized that the FDI is the highly impacted factor. The reason may bethe investment-driven nature of most of the public sector construction projects in Sri Lanka. With a delayed completion, investors might change their ideas and decide not to invest in future projects. E.g.: most of the expressway projects.

Credit to private sector is a major factor which have a major lead to the economic growth of Sri Lanka. It is about the financial resources provided to the private sector through loans, purchases of non-equity securities, and other trade credits and other account receivables. When a project slips over the date of completion, it affects the trade credits and loan schemes separately.

Development of transportation system take place in a socioeconomic context. The highly transactional and service oriented functions of main transport activities underline the complex relationship between its physical and human capital needs. When transportation systems are deficient in terms of capacity and reliability due to project delays they can have and economic cost such as reduced or missed opportunities and lower quality of life.

Project delays have a high impact on imports and exports. With the delayed completion of the public sector production complex, they cannot do the exports on time within their timelines. Similarly in imports, with the delays of the public sector construction project, it is difficult to order the materials and their price can be changed.

Out of the thirteen factors in the average category, there are seven factors which are having RII index from 6.50<RII<7.00.It seems they have been considerably impacted due to the delays in the completion of public-sector construction projects. As a percentage of total factors, it is 35%. The service sector has a significant impact on the economic growth of Sri Lanka. With the delays there will be definite shortages in the service sector. As an example delays in a hotel project can be considered.

In addition, delays break the efficiency of the procurement system. The majority of public-sector construction projects are based on external debts. The projects are funded through the World Bank, Asia Development Bank, etc. With the delayed completion they lose the profit margins and expected return on investment. The service sector and domestic investment have RII value-0.684, while the exchange rate is impacted by RII value-0.68. Under the average category effective procurement system has been impacted by RII-0.67. The impact on the interest rates is RII 0.66.

The following Figure 4 shows the relative importance of factors contributing to the Sri Lankan economy.

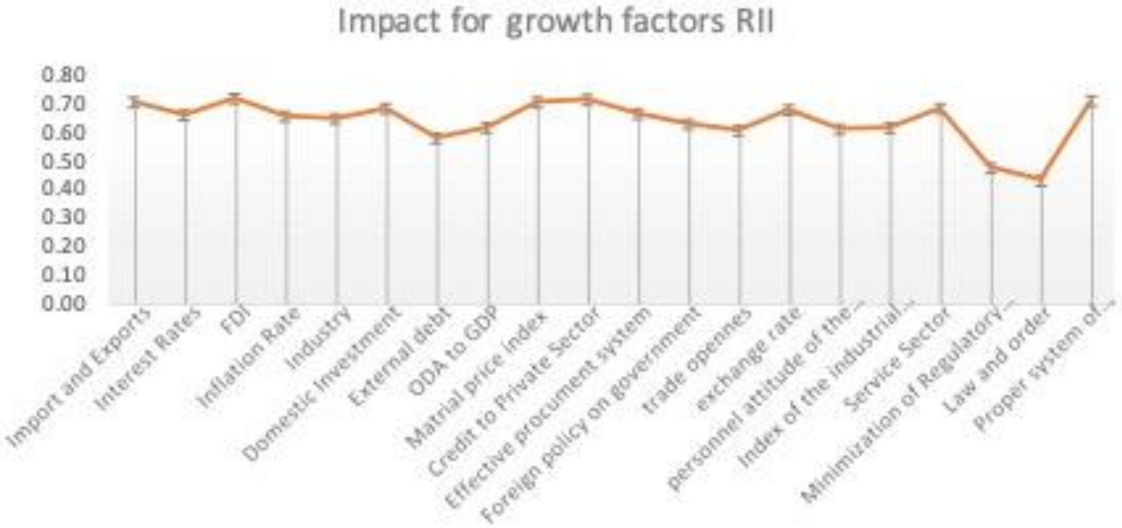


Figure 4. Impact for growth factors

Only two factors out of twenty factors have been ranked as the less impacted and as a percentage, it can be presented as 10%. Same as the other factors minimization of regulatory protocols and law affect the economic growth and however, those have been less impacted from delay completion of public sector construction projects. Sometimes regulatory protocols and law have to amend to continue construction on delayed projects.

Since the majority of the factors from averagely impacted factors have expanded between the RII value of 0.65 and 0.70 altogether 12 factors out of 20 have spread out in between the RII range of 0.65 and 0.72. As a percentage, it can be presented as 60%. Since 60% of the factors have spread out between 0.65 and 0.72 there is a strong impact from the delayed completion of public sector construction projects to the factors contributing to the economic growth in Sri Lanka.

. Therefore, these findings clearly indicate that on-time completion of construction projects is important to enhance the economic growth of Sri Lanka.

5 CONLUSION AND RECOMMENDATIONS

5.1 Conclusion

A county’s economic growth is spurred by a number of factors. Identifying the factors contributing to economic growth in general was carried out in the literature review and their validity inthe Sri Lankan context finding more factors related to the Sri Lankan context were done through interview data.

The factors listed in table 3 were identified as related to the Sri Lankan context.

Table 3. Factors Contributing the Economic Growth

From literature	From Interviews
Inflation Rate	Effective procurement system
Interest Rates	Open direct assessment
Exchange Rates	Material price index
Exports and Imports	Index of industrial production
FDI	Minimization of regulatory protocols
Trade openness	Law and Order
External debt	Foreign policy on government
Credit to the private sector	Personnel attitude of the people
Service sector	A proper system of transportation
Industry	
Domestic Investment	

According to the study's findings, the relationship between on-time completions of public sector building projects has a significant impact on the factors contributing to the economic growth in Sri Lanka.

Foreign direct investment and credit to the private sector have been highly impacted due to the delays in project completion (RII=0.72), followed by an efficient transportation system, the material price index, and imports and exports, which have a similar impact (RII=0.71).

Impact factors of the service sector, domestic investment, exchange rate, effective procurement system, interest rates, inflation rate, and industries range between RII value, 0.65< RII<0.70. The industry sector, foreign policy on government, index of industrial production, ODA to GDP, personnel attitude of the people, trade openness, and external debt have been averagely impacted and the values range between 0.50<RII<0.65.

Two of the twenty factors have been identified to be the least influenced, accounting for 10% of the total. Six factors from the averagely impacted factors are distributed between 0.50 and 0.65, accounting for 30% of the total. The majority of the factors (seven factors) from the averagely impacted factors have impact levels in between RII values of 0.65 and 0.68. As a result, a total of 12 of the 20 components have scattered in the RII range of 0.65 to 0.72. It can be represented as a percentage of 60% of the total number of factors.

These findings suggest that the delayed completion of public-sector construction projects has a significant influence on the factors contributing to the economic growth in Sri Lanka. As a result, it can be argued that the timely completion of construction projects is critical to enhancing Sri Lanka’s economic growth.

5.2 Recommendations

The study emphasized a positive relationship between on- time completion of public sector construction projects and economic growth of Sri Lanka.

Based on the study, it can be recommended that careful project planning for public sector construction projects should be done before construction begins to ensure that everything will go as planned and the project will be completed on time. Additionally, contractors need to be familiarized with the construction site for them to understand the topography and prevent problems from unforeseen ground conditions. To avoid overruns and complete the building on time, cost and timeshould be used as efficiently as possible.

Apart from that, this study has identified that it is essential to minimize public sector construction project delays to enhance the economic growth of Sri Lanka. To minimize time delays in public sector construction projects, proper project planning, scheduling, adoption of BIM technology, proper site management, and supervision, and frequent progress meetings can be recommended. Moreover, the study endorses financial controlling, labor management, revising schedules, and material equipment control to minimize and control the public sector construction project delays in Sri Lanka and thereby minimize the effect on the factors contributing to the growth of national economy.

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Study on the Impact of Cost Controlling Techniques in Mini Hydropower Projects in Sri Lanka

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ABSTRACT

Due to the worst economic crisis, Sri Lanka is currently facing sporadic power failures. There is a lack of dollar reserves to pay for the fuel suppliers and the existing national grid network has failed to power the whole nation. The prevailing situation is becoming quite challengeable since there is a huge power crisis due to the shortage of fuel oil which causes to fail whole operations of oil power plants. Therefore, Sri Lanka has relied on hydropower for a majority of its electricity needs. The share of mini hydropower power plants is performing a significant role in contemporary electricity generation considering national policy targets in order to move with sustainable green energy. Consequently, the necessity of the establishment of MHP plants has become higher but there are significant cost overrun factors identified in the construction phase of MHP projects. This research was carried out to identify the cost overrun factors in MHP projects in Sri Lanka. As a result, efficient cost-control measures will be required to address the above matter. Therefore, it was expected to explore the current practices of cost control techniques used in infrastructure projects based on the findings. Various cost control approaches have been created from time to time throughout the last few years. These may include Earn Value Management (EVM), performance reviews, variance analysis, value engineering, site meetings, work programmes, daily material and labor controlling, etc. The data collection process was conducted through questionnaire surveys which are distributed between industry professionals who have enough knowledge and experience regarding the MHP projects. The set of data was converted into quantitative values and collected data from the questionnaire surveys were evaluated by using percentage analysis and weighted score analysis. The results indicates the challenges in current cost control practices and identify the mechanisms to overcome those challenges and determine their effectiveness in mini hydropower project delivery in Sri Lanka.

KEYWORDS: *Mini hydro power, renewable energy, cost overrun, cost control, cost controlling techniques*

1 INTRODUCTION

As a tropical country, Sri Lanka is exalted with abundant renewable energy resources that have fueled the economic growth of the country for decades. (Salim & Rafiq, 2012) Renewable energy is derived from naturally renewable but finite flow sources. Renewable resources have an endless lifespan, but a finite amount of energy per unit of time. (Anon., 2000). Major variants of renewable energy are wind, sunlight, bioenergy, geothermal, solar, hydropower and ocean power that are currently consumed in the major sectors such as electricity, heating, cooling, and transportation. The perceived risks of utilizing fossil fuels have fueled interest in renewable energy (Moriartya & Honnery, 2012) .Though big hydro resources played a major role in the past in terms of renewable energy share, variable renewable resources such as wind and solar are now becoming major contributors in the future (Bull, 2001). Governments in both developing and developed countries have encouraged the utilization of renewable energy sources because of their high level of productivity, less contamination, and maintenance costs. (Li , et al., 2022)The aforementioned variables combine to promote the global renewable energy market by increasing demand for renewable energy.

In the current practice, different cost controlling methods are utilized in the construction industry. But the common problem is that lack of awareness about those cost controlling techniques. (Senanayake, et al., 2021)Hence, it is important to have better insight on the challenges of current cost control practices

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and identify mechanisms to overcome the challenges and determine on MHP projects in Sri Lanka. Controlling project costs is a difficult undertaking that necessitates an understanding of cost-controlling approaches. As a result, construction industry professionals must have a theoretical understanding of cost control approaches. Accordingly, the findings of this study will assist in evaluating the applicability of cost control techniques in the construction phase of MHP projects in Sri Lanka.

2 RESEARCH PROBLEM STATEMENT

Sri Lanka is currently facing a number of issues due to the economic crisis. Since there is a severe shortage of fuel, the authorities of Sri Lanka failed to fulfil the electricity needs of the whole nation. However, most foreign countries have overcome such issues to a certain extent by developing hydropower projects which are considered the least-cost electricity source. As a solution for the power crisis in Sri Lanka, generating electricity using mini hydropower projects is an ideal solution. But still, one of the key challenges of a mini hydropower project can be identified as cost overruns. Most of the mini hydropower plant developers are facing financial problems because of project expenditure exceeding the budget during the implementation stage. These financial challenges prevent the project from being implemented and eventually starting projects. Delay in contracting projects deprives the developer of revenue and the country loses energy. Most of the mini hydropower developers in Sri Lanka face this challenge. As a result, during the feasibility study, it is essential to identify the cost overrun factors and cost controlling techniques applicable in mini hydropower projects in Sri Lanka. (Malkanthi, et al., 2017) Most of the studies have focused mainly on cost overruns, associated with the development of mini hydro power projects. (Górecki & Płoszaj, 2019)Nevertheless, there has been very few research on the study of applicability of cost control techniques on mini hydropower projects especially in Sri Lanka. Therefore, this research gap is yet to be explored. (Hafez, et al., 2015)

3 AIM AND OBJECTIVE

The aim of the research study is intended to be achieved by the following specific objectives.

1. To identify the cost overrun factors in construction phase of mini hydropower projects
2. To explore the current practices of cost control techniques used in the infrastructure projects
3. To investigate the challenges of current cost control practices
4. To identify the mechanisms to overcome challenges in current cost control practices and determine their effectiveness with respect to the construction of mini hydropower projects in Sri Lanka

4 LITERATURE REVIEW

This chapter has discussed the existing literature regarding the areas associated with mini hydropower projects including the electricity demand in Sri Lanka, the importance of renewable energy in Sri Lanka, the contribution of mini hydropower projects in the power sector, the importance of cost controlling, main cost elements in MHP projects, the current practices of cost controlling methods used in the infrastructure projects and cost overrun factors influencing on the final project delivery.

4.1 Electricity Demand in Sri Lanka

Electricity can be considered as the backbone of modern society. It has become an integral part of the daily lives of all the people around the earth. As a result, the demand for electricity is increasing rapidly every year. Fossil fuels are used extensively around the world to meet this demand. (Ceylon Electracity Board, 2021)

As a developing country in the Asian region, Sri Lanka is currently facing challenges in meeting the electricity demand of the country's population. As a country with a low economic growth rate, restricting the use of fossil fuels is a crucial decision that will not only save money on fossil fuel exports from other countries, but also help reduce harmful emissions. It is observed that Sri Lanka's participation in the use of renewable energy resources for the power generation is relatively low compared to

European countries. Thus, an overview of the viability of fully renewable resources to meet the country's energy needs is crucial. (Umayangani, 2019)

4.2 The Importance of Renewable Energy in Sri Lanka

Renewable energy resources are those that can last forever compared to human life. Primary renewable resources include solar energy, planetary energy, and geothermal energy, while secondary renewables include wind, wave energy, biomass, and hydropower.

To mitigate its adverse effects, such as man-made climate change and global warming, it is necessary to reduce usage of fossil fuel and shift from the renewable resources to green energy production. Many governments and environmental groups have taken the lead in reducing carbon emissions by adopting standards and agreements for each country. Furthermore, many developed countries are conducting large-scale experiments and research to improve the efficiency of renewable energy extraction for energy production. As it has become essential for the conservation of the environment, the energy contribution of renewable resources to the overall energy generation of many countries is increasing. (Mittal , et al., 2021)

As a developing country, Sri Lanka has recently embarked on a renewable energy initiative. Due to its geological location, Sri Lanka is in good condition for solar, wind and hydro resources. It receives considerable amount of sun radiation across the country due to its vicinity to the equator, and since it is an island, coastal areas experience a significant wind flow rate. There are significant number of rivers originated and flowing in all directions towards the sea because of the hill-side is in the center of the country which makes perfect for the hydropower generation. It is important to use all available renewable energy sources, as the rising energy demand will lead to an energy crisis in the coming years. (Sri Lanka Sustainable Energy Authority, 2021).

4.3 The Definition of Hydropower

Hydropower is one of the primary sources of converting the compressive energy and kinetic energy of water into more easily usable electrical energy. The prime mover in the case of hydropower is a water wheel or hydraulic turbine which transforms the energy of the water into mechanical energy. Hydropower is a key source of electricity generation in Sri Lanka and practically contributed to all of this until the early 1990s. A significant percentage of the country's vast hydro potential has already been developed, providing the country with significant low-cost power. Hydropower facilities are now used to meet peak and basic energy output requirements. The Standardized Power Purchase Agreement (SPPA) includes a significant number of mini hydropower plants and is expected to join another force in the coming years. (Egre & Milewski, 2002)

4.4 The Contribution of Mini Hydropower Projects in Power Sector in Sri Lanka

Apart from mega solutions such as the establishment of major hydropower plants, the solution to the power shortage is to implement mini hydropower plants. Therefore, the Ceylon Electricity Board has invited private sector investors to generate mini hydropower plants. The CEB provided assistance in the 1990s for the development of the mini hydropower industry, including training and capacity building, pre-feasibility studies and resource assessment as well as essential assistance to the private sector. Since 1997, it has been formalized with the publication of the CEB's Standardized Power Purchase Agreement (SPPA) for the purchase of electricity from Small Power Producers (SPPs). (Ceylon Electracity Board, 2021)

While the power shortage is hampering economic growth, the provision of electricity infrastructure by mini hydropower plants has provided new opportunities for local enterprises. As a developing country, Sri Lanka is experiencing a rapid increase in electricity demand. Compared to fossil fuels, hydropower has long been considered an environmentally friendly and cost-effective source of electricity. Hydropower generation plays an important role, and as the exploitation of large hydropower sources reaches its limits, smaller streams can play a significant role in meeting demand at lower cost. (Morimoto & Munasinghe, 2005) As a result, there is an urgent need to investigate the difficulties of the existing mini hydropower plant and to conduct research on strategies to enhance power generation from these resources. The exiting literature reveals that there is a risk of construction costs for MHPPs.

Therefore, this study was conducted to investigate the challenges of current cost control practices and identify the mechanisms to overcome the challenges and their effectiveness on MHPPs. (Gunatillake & Thiruchelvam, 2003)

4.5 Main Cost Elements Involved in Mini Hydropower Projects

The main cost elements of a mini hydropower projects are identified as preliminary expenses which consist of the cost for getting approvals, the cost of the land, civil construction cost, electromechanical equipment expenses, taxes, contingencies and so on. (Mishra, et al., 2012)

Preliminary expenses

Getting approvals from different authorities such as Local Government, CEB LOI, Central Environmental Clearance, is identified as preliminary expenses. Getting approvals is a time-consuming task which comes as the cost at the end of the process. A common problem in a mini hydropower project is that during the construction phase, the structure has to be altered because of the design problems. Therefore, it is safe to give more consideration in the design stage to get better design rather than spending more time and money on future consequences.

Civil construction cost

According to different feasibility factors, most of the hydropower sites are unique from each other. Therefore, the construction cost for civil works mainly includes cannel construction, powerhouse construction, dam construction and the cost for the access road. Apart from that, the cost for weir, forebay, desilting tank and intake are included.

Electro mechanical equipment expenses

This is the major cost element which makes a big impact on the project cost of mini hydropower. Under electromechanical equipment expenses, the cost component for all the necessary accessories such as turbines, controls, generators, transformer, and switchyard are included. The cost for this equipment is very high due to its high efficiency, fully automated and sophisticated features.

The cost for penstocks

The cost of the penstock includes the fabrication of the penstock with installation and transportation.

Other cost headings

Although most of the hydropower projects are financed through long-term loans, the developer also has to pay interest which is covered as the operative cost. In addition to that, the taxes, project management cost and cost for contingencies are incorporated as other cost components.

4.6 Cost Overrun Factors in Mini Hydropower Plants

Cost has proven to be the most important determinant in project success. Cost overruns in the construction industry are common, and It is common for construction costs to be high and they happen in almost every project. When the actual cost of a project is higher than the original estimate, the cost overrun happens. (Azhar, et al., 2008) The majority of cost overruns occur during the construction stage when forecasting numerous unanticipated events during the design and planning stages. Inadequate site management and monitoring, decision-making disagreements, and client-driven changes have led to project costs exceeding during the construction. (Doloi, 2013)

In the case of mini hydropower projects, the major costs are involved in build up the power plant. In general, initial costs for construction and machinery are higher than the operational and maintenance costs of hydropower projects. As a result, exceeding any project cost has a negative effect on the profitability and financial feasibility of the project. If the additional costs are not for the benefit of the final output of the project, any increased primary investment will result in longer payback periods. With time overruns, project costs will increase due to the price escalation of materials and rising labor rates.

Lack of adequate supervision, inexperienced contractors, inefficient project management team, political interference, external consequences like weather conditions, natural disasters, changes in technical design and pre-feasibility studies, inadequate geological and technical investigations at the project start-up, initial cost estimates based on inadequate information and impractical assumptions, lack of material or transport facilities and the shortage of labor were identified as major cost overrun factors in mini hydropower projects. In addition to that, in case of significant change in the economy of a country or regulatory aspects will impact on cost overruns. (Awojobi & Jenkins, 2016) Design changes, schedule delays and exchange rate fluctuations were the three main factors that had the highest impact on project cost overruns. When comparing these three variables, design changes and schedule delays are the most common cost overrun factors identified in the mini hydropower projects. Due to the high share of import costs associated with mini hydropower projects, exchange rate fluctuations have been identified as specific to the mini hydropower industry, especially in Sri Lanka. Therefore, the study on applicability of cost controlling techniques to manage the final project delivery is a significant research area as a solution for cost overruns. (Jaber, 2012)

4.7 The Importance of Cost Controlling in Mini Hydropower Projects

Cost control is the process of limiting spending in order to avoid excessive spending that affects profits. The construction sector is critical to any country's economic progress because it provides a safeguard for interests in terms of economic and social aspects as well as infrastructure facilities to ensure that these activities run smoothly. (Bahaudin, et al., 2012) Despite the complicated nature of the work performed by the construction sector, cost and time must be effectively controlled and managed if the contractor's expected profit margin is to be met and the project to be done within the budget of the client. Due to the severe economic crisis, there is a potential to impact both clients and contractors' stance toward project cost control. (Chigara, et al., 2013)

The project cost control commences at an early stage of the project life cycle, from formation to construction and beyond. The best time to save money is during the pre-construction phase, when the project is still in its early stages and no significant costs have been incurred. (Bahaudin, et al., 2012) Cost management is the procedure of designing and planning a project to ensure that its construction is valued and tailored to the client's expectations. (Potts, 2008) Current project cost control and monitoring processes are largely used to assess and correct cost deviations from the scope of work, implying that cost overruns have occurred. (Bahaudin, et al., 2012)

Sri Lanka would need to install large capacity to fulfill present and future power demand, which is expected to grow at a rate of roughly 5% per year. (Ceylon Electracity Board, 2021) Most of the large scale water resources have already been used. Therefore, this is the best time to look at other alternative energy sources. Solar energy, thermal energy and mini hydropower are such possible energy sources that can be used to address the problem. Perennial streams and sudden elevation drops in the river valleys create excellent conditions for the MHP generation.

The government of Sri Lanka needs the country to be energy self-sufficient state by 2030. By 2025, the goal is to boost the country's power generation capacity from 4,043 MW to 6,900 MW, with a major increase in renewable energy. Sri Lanka is very rich in terms of water resources and has a proud history over the last 2500 years. (Ceylon Electracity Board, 2021) Low-cost energy is a requisite for almost all the developing countries in the world including Sri Lanka. Adequate power has been an important issue over the last 25 years. Fortunately, there were enough water resources in the country to address the problem at the initial stage.

Due to the capital-intensive technology, hydropower generation requires a substantial feasibility study, a good design and civil engineering works that take a long time to develop and construct. Hydropower projects involve two major cost elements which are identified as costs for the civil works and electro-mechanical equipment costs. Under civil works, the cost should be mainly concerned with dam and reservoir construction, powerhouse construction and canal construction. The electro-mechanical equipment cost includes for turbines, cabling, transformers, and control systems, etc. The capital cost for hydropower projects vary greatly based on site conditions, design choices, and material and labor costs. (Mishra, et al., 2012)

The existing literature reveals that the construction cost of mini hydropower projects cannot be managed since the technical evaluation and financial evaluation of electrical and mechanical equipment is very critical. Cost control should be handled wisely in a mini hydropower project where quality is not compromised, and the result will never be achieved unless the project is disrupted. The project can be delivered on time with proper planning and cost control. (Paish, 2002) When considering the mini hydropower development, the project cost variation is very sensitive. Many projects are implemented by using external funding sources (70% of the project cost is funded by the bank) Therefore, the project cost management is required to run the project smoothly and manage cash flow until the end of the project. Due to the economic crisis, all the tariff rates and expenses are getting increased with inflation. Therefore, it is required to control the cost involved in the construction phase of mini hydropower projects. Furthermore, by controlling the cost of the project, it can provide significant financial benefits to working communities as well. Since there are many unforeseen circumstances involved in mini hydropower developments, it is important for controlling cost. Moreover, cost controlling is a key task to achieve quality and timely delivery of the mini hydropower projects. Therefore, it is crucial to establish proper systematic and comprehensive cost controlling methods. (Saad & Al-Jibouri, 2003).

4.8 Current Practices of Cost Control Techniques Used in the Infrastructure Projects

The progress of a country depends heavily on the construction industry. The success of an individual project is defined by how well it can meet project objectives, including the timely completion of the project and the estimated budget while maintaining the appropriate quality. Project planning and monitoring are both necessary in achieving above mentioned objectives. Cost overrun is a key issue that many contractors face, resulting in lower-guaranteed profits for the contractor and a slew of other issues for all parties involved.

In terms of fuel resources, hydropower has a significant advantage over other major power plants that generate electricity by burning fossil fuels. The establishment of the MHP generation is also gaining popularity around the world due to its abundance of resources. The construction phase of MHPPs involves a variety of costs in conducting pre-feasibility studies. (Hafez, et al., 2015) It is crucial to practice cost controlling techniques to solve these issues. As a result, it is important to investigate the challenges of current cost control practices and identify the mechanisms to overcome challenges and their effectiveness on mini hydropower projects.

Project management involves both project progress and cost control. In MHP projects, there are several cost management methods that can be implemented. It is important for contractors to have an understanding of the effectiveness of cost control measures as well as how to apply them to reduce cost overruns. Controlling project costs is a difficult undertaking that necessitates an understanding of cost-controlling techniques. (Premalal, et al., 2013) There is a primary need to boost construction work while lowering costs at the same time. Theoretical and practical knowledge of cost management approaches is required for the industry experts. There are a multitude of cost-cutting approaches and project management software available, yet they still fall short of meeting the basic target requirements of a project. Cost overruns are widespread all around the world, despite various cost management strategies. (Azhar, et al., 2008) Management should take the appropriate procedures to keep human resources under control. To achieve the objectives, it is important to explore the foundation of knowledge by determining the influence of existing cost-cutting measures on selected management approaches in the Sri Lankan context. (Kawmudi, et al., 2018)

Cost control is the process of managing the construction cost of the project using effective methods and techniques so that the contractor does not lose money while carrying out the project activities. According to available literature, contractors in infrastructure projects use a variety of cost control approaches such as performance reviews, MS project, variance analysis, site meetings, forecasting, work programs, daily material & labor controlling etc. All above listed cost control methods are using very often to monitor the health of the project and to take remedial measures. In addition to that, those techniques are used to control EOT (Extension of time) and control payments on extra works. It is important that the project implementation program should be finalized with contractors, client, and engineer prior to the commencement of construction work. Daily material & labor controlling is used to manage available resources, reduce wastage, and parallel resource allocation. (Hafez, et al., 2015)During the monthly review meetings, it should be discussed the balance works estimation. It will indicate the position of the total cost. In MHP projects, variance analysis, site meetings and work programmes are most commonly used for cost controlling. Since the scale of MHP projects are small, very few staff are being used, and this will limit usage of special techniques for cost control. High level forecasting is another popular technique applied in MHPPs. Since the critical works are engaged in the construction stage of MHPPs, it is safe to assign cost targets for each of structure like dam, canal, forebay, powerhouse, etc. (Górecki & Płoszaj, 2019)

5 RESEARCH METHODOLOGY

The aim of the research paper is to improve the modern cost control techniques for managing the final project delivery of MHPPs in Sri Lanka. The research study relied on quantitative data collected from a questionnaire survey which is distributed among industry professionals working at the MHP projects in Sri Lanka. The questionnaire is prepared with structured questions (close-ended questions) related to cost overrun factors and cost control techniques and open-ended questions related to the impact of cost controlling techniques on final project delivery, challenges in current cost control practices and mechanisms to overcome the challenges in current cost control practices. The questionnaire was given to selected participants who are responsible for cost controlling and who are experiencing the current cost control practices in the MHPPs. This ensured that the data collection methodology addresses the rich information relevant to the study. Since the MHP projects are not widely ongoing in Sri Lanka, the population we can assess is limited. Therefore, only 30 questionnaires were distributed among management personnel with substantial expertise in the MHP sector.

6 RESULTS & FINDINGS

6.1 First Stage of Findings - Descriptive Analysis for Close-Ended Questions

Questionnaire surveys were used to obtain data for the research study. Respondents have been asked multiple scale questions regarding cost overrun factors and current practice of cost controlling techniques in construction phase of MHPPs. The results of the structured questions were studied using descriptive analysis to gain a better knowledge of the data distribution, which made it easier to come up with conclusions.

Details of the sample

It can be challenging to select the most appropriate sample of respondents for a questionnaire survey. When conducting the questionnaire survey focused on the experience of the respondents, hence selective sampling technique was utilized. (D'Addabbo & Maglietta, 2015) Survey participants were selected from professionals who are experienced in mini-hydropower generation in Sri Lanka and were mainly in the professional categories of project managers, quantity surveyors, and engineers. Further, special attention was paid to ensure the reliability of the data by employing more experienced respondents for this survey. The experience of the respondents in their profession is depicted in the pie chart in figure 3.

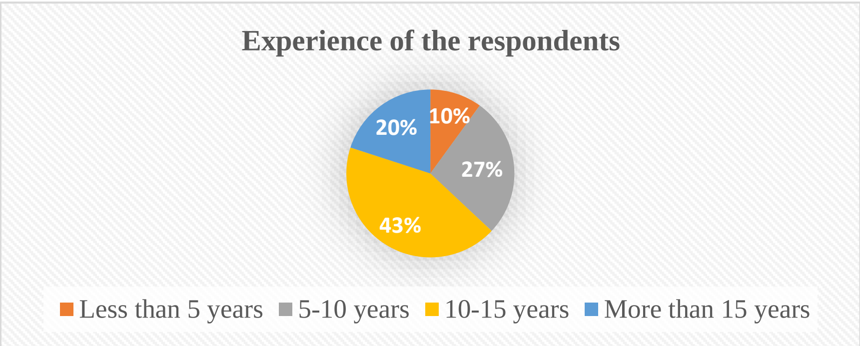

Figure 3: Experience of the respondents

Figure 3 shows that the majority of respondents had worked for more than 5 years in MHPPs, indicating that the survey data was extremely reliable.

Identification of the gravity of cost overrun factors identified in mini hydropower projects

Based on the information obtained from the existing literature, the researcher have identified 13 number of cost overrun factors in MHP projects in Sri Lanka. They are unforeseen circumstances during the project duration, the high cost of imported turbines and generators due to transportation costs and taxes, price escalation of raw materials, significant design changes during the construction stage, low tariff rates from the government, inappropriate government policies, difficulties in approval process, lack of technology and experience, changing the scope of work, fluctuation of exchange rates, and unstable interest rates. The questionnaire survey was used to get the feedback regarding how the professionals are experiencing above mentioned cost overrun factors in construction phase of MHP projects by indicating the gravity of each factor. The opinions of professionals of the industry were evaluated based on the criteria of which they agree on a scale (strongly agree, agree, neutral, disagree and strongly disagree).

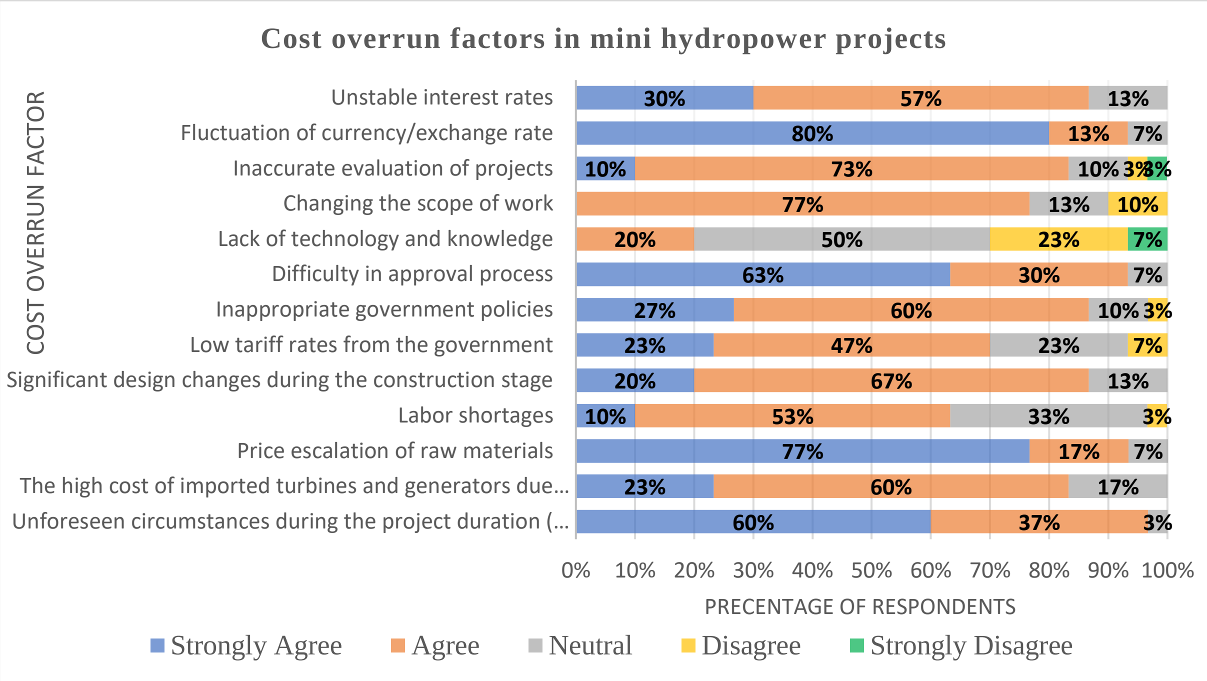

Figure 4: Analysis of the gravity of the cost overrun factors in MHP projects

According to figure 4, it reveals that fluctuation of exchange rates and price escalation of raw materials are the critical cost overrun factors which are 80% and 77% strongly agreed respectively by the respondents who are working in MHP projects. The 63% of respondents are strongly agreed with the difficulty in approval process as second critical cost overrun factor. According to the respondents, 60% of respondents strongly agreed with the unforeseen circumstances during the project duration which is considered as a critical cost overrun factor. Significant design changes during the construction stage has a significant impact on cost overruns in MHPPs which is agreed by 67% of respondents. Not only that, 60% of respondents are agreed with the high cost of imported turbines and generators due to the transportation costs and taxes which is significant effect on cost overruns. Apart from that, other factors also has considerable impact on cost overruns in MHPPs in Sri Lanka.

Identification of the applicability of current practices of cost control techniques in the construction phase of mini hydropower projects

The focus of research study was on the applicability of cost controlling techniques on the construction phase in mini hydropower projects in Sri Lanka. According to the existing literature, 9 cost controlling techniques used in mini hydropower projects have been identified. (Awojobi & Jenkins, 2016)Those techniques are performance reviews, MS project, variance analysis, forecasting, earned value management, site meetings, work programmes, daily material and labor controlling and Building

Information Modelling (BIM). The opinions of participants were taken on scale ranging from very often, occasionally, rarely, very rarely and never to the point being made. By analyzing this data, the study explored the current practices of cost control techniques used in the infrastructure projects and investigated the applicability of those cost control techniques on the mini hydropower project delivery.

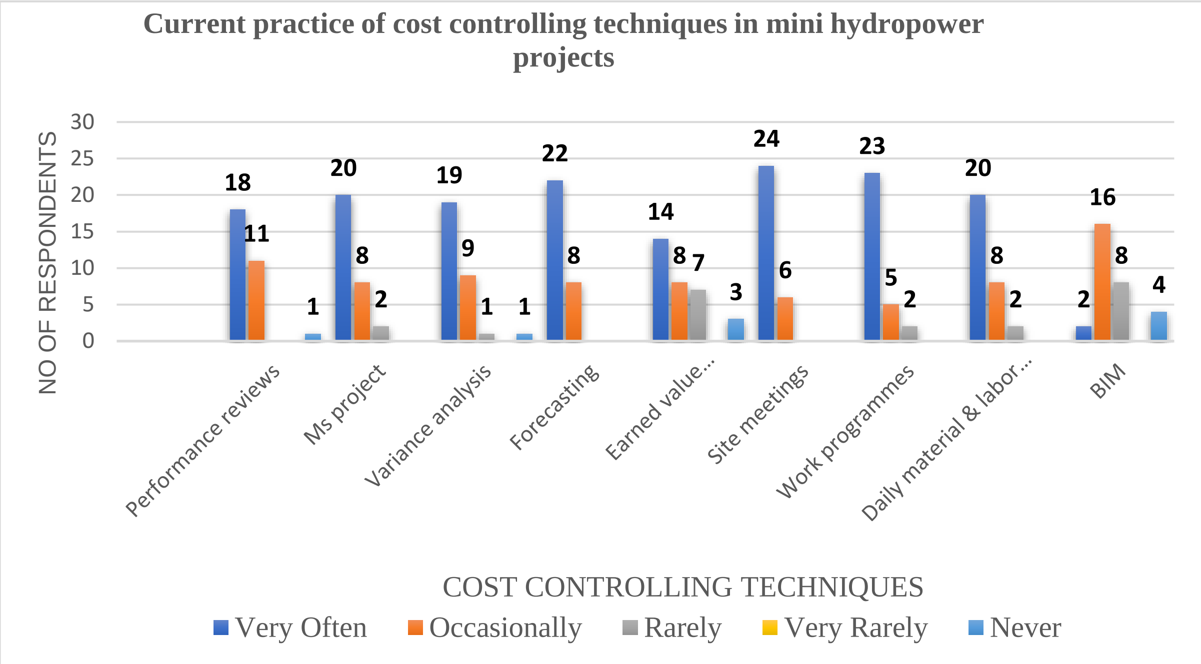

Figure 5: Analysis of applicability of cost controlling techniques in MHPPs

The results of the survey suggest that most industry professionals are aware of the cost control measures available in the MHP sector, however their correct application is not always visible. Techniques for cost control have been highlighted as a method for reducing cost overruns. Forecasting, site meetings, and work programmes were identified as the most prevalent cost control approaches currently being employed by industry professionals. In addition, survey responses revealed that the MS project and daily material and labor controlling were the most widely used techniques in mini hydropower projects. The cost control techniques that are currently used are summarized in Figure 5.

6.2 Second stage of findings – collecting more data on responses to open-ended questions obtained from the first stage of questionnaire survey

The responses to the open-ended questions in the first stage of the questionnaire survey were converted into close-ended questions in the second stage of the questionnaire survey and the questionnaires were sent back to the same 30 number of respondents and feedback was obtained from them.

In the second stage, respondents had been asked structured questions about the challenges of current cost control practices and effectiveness of mechanisms to overcome challenges with respect to the construction of mini hydropower projects in Sri Lanka. The descriptive analysis was used to assess the outcome of close-ended questions to get an understanding of the distribution of quantitative data which has helped to produce the best outcomes for the research study.

Identification of the gravity of suggested challenges of current cost control practices in construction phase of mini hydropower projects

A questionnaire was developed to identify the gravity of challenges using 30 number of responses in order to acquire a fair response based on the information gathered from the literature review. From here on out, a code system will be utilized to signify identified challenges for the ease of the presentation.

Technical Challenges	- TC
Social Challenges	- SC
Environmental Challenges	- En C
Financial Challenges	- FC

Table 1: Codes of challenges

Challenge	**Code**	**Challenge**	**Code**
Poor attitude towards ICT usage	TC1	Complexity of the project	TC9
Traditional thinking pattern and inertia for Innovative ideas	TC2	Lack of resources	TC10
Lack of experienced industry professionals	TC3	Difficulty in approval process	TC11
Improper planning and scheduling	TC4	Rate fluctuation in materials, fuel, taxes & payments	FC1
Wastage of materials	TC5	Unpredictable exchange rates	FC2
Quality aspect of cost information	TC6	Unstable government regulations	FC3
Lack of knowledge on the use of available tools and technology	TC7	Critical ground conditions	EnC1
Rural locations	TC8	Contractor and labor conflicts	SC1

During the second phase of the questionnaire survey, 16 challenges were identified in the data collection. The following line graph consists of the identified challenges represented by the codes as illustrated in the above table 1.

The results from the questionnaire survey was evaluated using the RII (Relative Importance Index), and respondents were given a scale from 1 to 5 to rate the severity of the challenges in current cost control practices and identify the strategies to overcome challenges in current cost control practices and their effectiveness on MHP projects . The survey used a scale since it allows the researcher to simply quantify the responses and determine their actual opinion about the question.

Table 2. Response Scale used in Questionnaire Survey

Response	Scale (A)
Lowest	1
Low	2
Moderate	3
High	4
Highest	5

The formula used for the analysis is given below;

$$\boxed{\boldsymbol{RII = \Sigma W / A \times N}}$$

Where;
ΣW = Sum of all responses
A = Highest weight
N= no. of Respondents

Table 3: Categorization of RII Values

Weighted value (RII)	Gravity of Challenge	Effectiveness of the Mechanism
0.0-0.6	Insignificant	Insignificant
0.6-0.8	Significant	Significant
0.8-1.0	Critical	Highly Effective

Ex: Calculation of RII value for TC7

TC7 - Lack of knowledge on the use of available tools and technology

Table 3: Number of Respondents for TC7

Gravity option		Number of Respondents
Highest	N_1	24
High	N_2	6
Moderate	N_3	0
Low	N_4	0
Lowest	N_5	0

RII $= \Sigma W / A \times N$

$= (5N_1+4N_2+3N_3+2N_4+1N_5)/ A \text{ x } N$

$= (5 \text{ x } 24+ 4 \text{ x } 6+ 3 \text{ x } 0+ 2 \text{ x } 0+ 1 \text{ x } 0) / 5 \text{ x } 30$

$= 144 / 150$

$= \underline{0.9600}$

Weighted value (RII) for TC7 – 0.9600

Similarly, the calculated weighted values for all the challenges are as follows.

Table 4: Calculated Weighted Values for Challenges

Challenge	Code	Weighted values
Lack of knowledge on the use of available tools and technology	TC7	**0.9600**
Unpredictable exchange rates	FC2	**0.9067**
Critical ground conditions	EnC1	**0.9000**
Lack of experienced industry professionals	TC3	**0.9000**
Rate fluctuation in materials, fuel, taxes & payments	FC1	**0.8867**

Wastage of materials	TC5	**0.7933**
Poor attitude towards ICT usage	TC1	**0.7867**
Difficulty in approval process	TC11	**0.7733**
Complexity of the project	TC9	**0.7600**
Improper planning and scheduling	TC4	**0.7467**
Unstable government regulations (low tariff rates from government)	FC3	**0.7400**
Traditional thinking pattern and inertia for Innovative ideas	TC2	**0.5933**
Quality aspect of cost information	TC6	**0.5867**
Rural locations	TC8	**0.5467**
Contractor and labor conflicts	SC1	**0.5200**

X-axis of the graph represents the gravity of each challenge by indicating the scale of 0-1 (RII value) and Y-axis shows the challenges in current cost control practices.

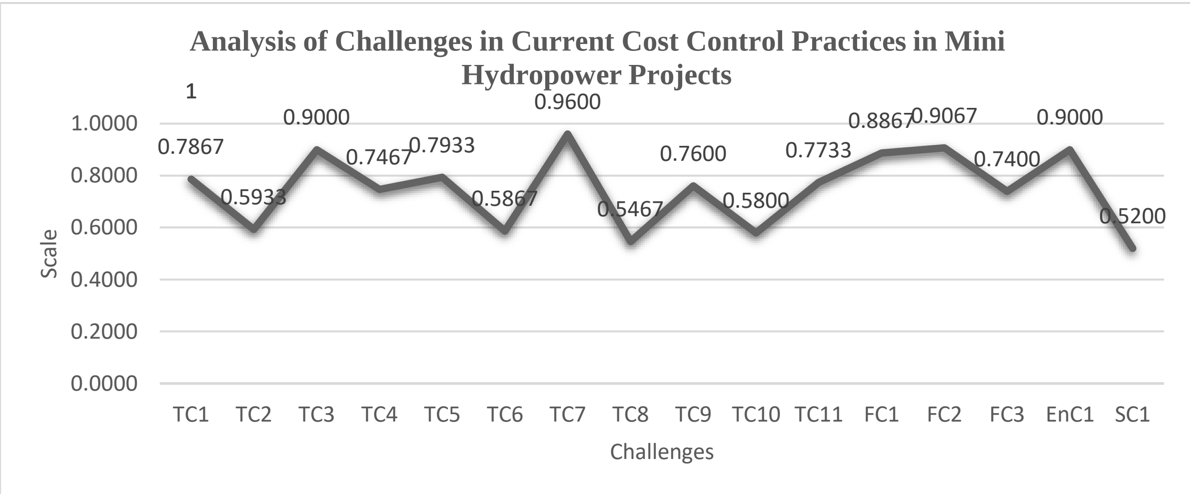

Figure 6: Analysis of challenges in current cost control practices in MHP projects

According to figure 6, it can be clearly seen that the most critical challenge in current cost control practices of mini hydropower projects is the lack of knowledge on the use of available tools and technology which is indicated using (TC7), showing the value of 0.96. Apart from that, lack of experienced industry professionals (TC4), Rate fluctuation in materials, fuel, taxes & payments (FC1), unpredictable exchange rates (FC2), and critical ground conditions (EnC1) are also cause critical challenges showing more than 0.80 RII value. There is an environmental challenge which shows an insignificant effect in current cost control practices in mini hydropower projects. According to the result obtained for the social challenge, contractor and labor conflicts shows insignificant challenge in current cost control practices in mini hydropower projects showing 0.52 RII value. According to the graph, most of the technical challenges show significant and critical challenges towards the current cost control practices of mini hydropower plants in Sri Lanka. Among them poor attitude towards ICT usage (TC1), Improper planning and scheduling (TC4), wastage of materials (TC5), complexity of the project (TC9) and difficulty in approval process (TC11) show significant challenges whereas Lack of experienced industry professionals (TC3), lack of knowledge on the use of available tools and technology (TC7) show critical challenges in current cost control practices of mini hydropower plants. When considering financial challenges, two challenges cause critical challenge in current cost control practices of mini hydropower plants. They are rate fluctuation in materials, fuel, taxes & payments (FC1) and unpredictable exchange rates (FC2) which show the higher value of 0.89 and 0.91 respectively. Unstable government regulation is a challenge which shows significant impact on current cost control practices in mini hydropower projects. However, its RII values is in between the range of 0.6-0.8.

Identification of the effectiveness of mechanisms to overcome challenges of current cost control practices in construction phase of mini hydropower projects

A code system has been employed to represent mechanisms for the convenience of presentation, as mentioned in the previous section.

Mechanisms for Technical Challenges - MT

Mechanisms for Financial Challenges – MF

Table 5: Codes of Mechanisms

Mechanisms	Code	Mechanisms	Code
Proper planning of the time and sources	MT1	Enhancement the awareness of employees	MT8
Use of BIM	MT2	Keep relevant spare parts at site	MT9
Use experts in the subject to get advices	MT3	variance analysis and cost value reconciliation	MT10
Conduct monthly detail review meetings	MT4	Cash-flow analysis and work programs	MT11
Use proper ERP system	MT5	Improve simple systems based on excel or basic software	MT12
Hire the skill workmanship to avoid double work and addition structures	MT6	Government incentives	MF1
Improve the knowledge of project staff	MT7	Publish equations for rate variance in bill payments by CIDA	MF2

The first phase analysis of the questionnaire survey identified 14 mechanisms to overcome challenges in current cost control practices. The following line graph shows the effectiveness of the proposed mechanisms represented by codes, as explained above Table 6.

Ex: Calculation of RII value for MT8

MT8 - Enhancement the awareness of employees

Table 6 Number of Respondents for MT8

Gravity option		**Number of Respondents**
Highest	N_1	21
High	N_2	6

Moderate	N_3	3
Low	N_4	0
Lowest	N_5	0

RII $= \Sigma W / A \times N$
$= (5N_1+4N_2+3N_3+2N_4+1N_5) / A \times N$
$= (5 \times 21+ 4 \times 6+ 3 \times 3+ 2 \times 0+ 1 \times 0) / 5 \times 30$
$= 138 / 150$
$= \underline{0.9200}$

Weighted value (RII) for MT8 – 0.9200
Similarly, the calculated weighted values for all the mechanisms are as follows.

Table 7: Calculated Weighted Values for Mechanisms

Challenge	Code	Weighted values
Enhancement the awareness of employees	MT8	**0.9200**
Use experts in the subject to get advices	MT3	**0.8867**
Conduct monthly detail review meetings	MT4	**0.8600**
Cash-flow analysis and work programs	MT11	**0.8267**
variance analysis and cost value reconciliation	MT10	**0.8133**
Publish equations for rate variance in bill payments by CIDA	MF2	**0.7533**
Proper planning of the time and sources	MT1	**0.7133**
Improve the knowledge of project staff	MT7	**0.7400**
Improve simple systems based on excel or basic software	MT12	**0.7333**
Government incentives	MF1	**0.7000**
Use of BIM	MT2	**0.5933**
Use proper ERP system	MT5	**0.5867**
Hire the skill workmanship to avoid double work and addition structures	MT6	**0.5800**
Keep relevant spare parts at site	MT9	**0.4933**

X-axis of the graph represents the effectiveness of each mechanism by indicating the scale of 0-1 (RII value) and Y-axis shows the suggested mechanisms to overcome challenges.

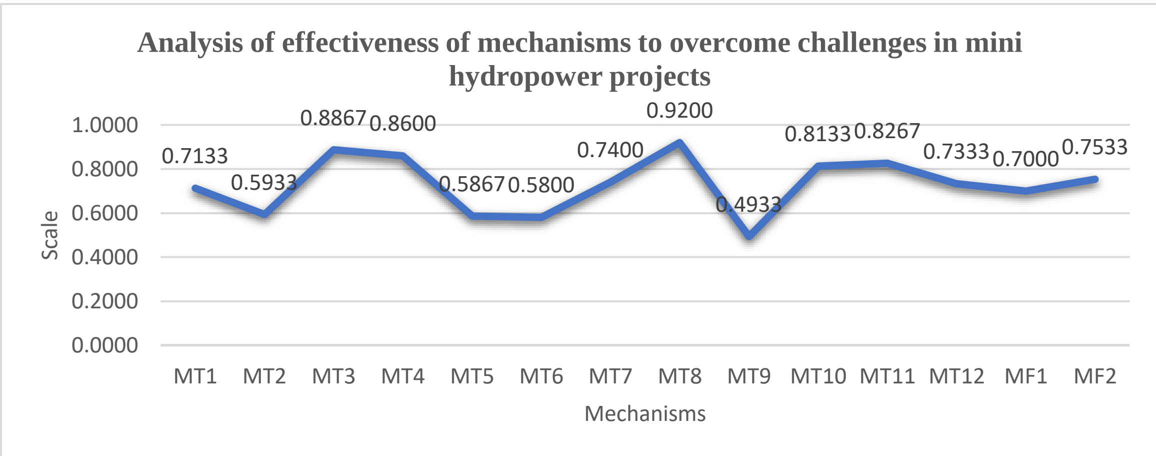

Figure 7: Analysis of effectiveness of mechanisms to overcome challenges in mini hydropower projects

According to the figure 7, it can clearly see that most of the strategies are highly effective but some technical challenges such as using of BIM (MT2), using proper ERP system (MT5), keeping relevant spare parts at site (MT9), hiring the skill workmanship to avoid double work and addition structures (MT6) show an insignificant effectiveness towards the mitigation showing a RII value of under 0.6. Apart from that proper planning time and sources (MT1), improve the knowledge of project staff (MT7), improve simple systems based on excel or basic software (MT12), and provide government incentives (MT13) show a significant effectiveness towards the mitigation of technical challenge by showing a RII value more than 0.6. However, among highly effective challenges variance analysis and cost value reconciliation (MT10) shows a lesser RII value than other challenges. Apart from those, all other mechanisms under each and every aspect show RII values more than 0.82.

7 CONCLUSION

Sri Lanka is plagued by energy shortages, and government investments in large-scale energy development projects are not viable due to the current country's economic downturn. As a result, harnessing renewable energy sources to their full potential through private-public partnerships will help to alleviate the energy crisis to some extent. Many countries are moving toward renewable energy solutions through privatization, and Sri Lanka appears to be following renewable energy solutions in terms of future energy generation plans. Mini hydropower has been considered as the most reliable energy source among renewable energy sources in Sri Lanka. As a result, the demand for MHP plants has increased but these projects show a considerable cost overruns during the construction phase.

Therefore, the first objective of the research was to identify the cost overrun factors in mini hydropower plants. That objective was achieved partially through the literature review and those factors were evaluated through questionnaire survey. It was revealed that most of the mini hydropower projects have faced cost overruns due to the fluctuation of the exchange rates and price escalation of raw materials. As import materials have to be used in the construction of MHP projects, the issue of exchange rate fluctuations will be affected. Not only that, another critical cost factor identified when engaging in MHP projects is the fact that changing the scope of work. Since MHP projects involves critical works, it is difficult to make changes once those work is completed. Moreover, unforeseen circumstances during the project duration is also identified as a major impact on cost overruns. By identifying those factors, there was a need for cost controlling techniques to control costs in the construction of MHP projects. Therefore, it is required to have better understanding on the applicability of cost controlling techniques within the construction of MHP projects.

However, the effectiveness of those mechanisms in Sri Lanka is highly practical but still it is difficult to predict the effectiveness of the mechanisms associated with the speedy approval process and government incentives due to the political instability.

8 RECOMMENDATIONS

This research has explored the impact of cost controlling techniques in mini hydropower project delivery in Sri Lanka through cost overrun factors, applicable cost controlling techniques, challenges in current cost control practices and mechanisms to overcome the challenges. Therefore, the developers should consider to keep the cost of the project within the estimated cost as possible. Otherwise, return on investment will be lower. Apart from that, the return on investment of hydropower projects are fixed, thus only way to optimize profit is by reducing construction and maintenance cost. Further, when a private investor is on board, the main objective of the project will be to reduce the project cost and get a decent IRR. Developer should prepare price escalation since no one know 100% undergrounds soil condition. This can minimize with proper investigation and design before do the project but it is not practical to fully addressed. Therefore, cost controlling should be handle more wisely in hydro project where not compromise the quality ,if not eventually disaster for the project and final outcome will never reach. Furthermore, it is crucial to check the land requirement before executing the project. It has to be followed a community meeting and obtain their expectations. This will help minimize resettlement action plan, expensive commitment with villagers, change of project path and huge cost of alternative design. Experienced estimators shall be worked together with project managers and top level management to fix the budget for projects as the cost is depending on ground conditions, location, technology etc.

9 LIMITATIONS

The research study has mainly focused on the impact of cost controlling techniques in mini hydropower projects in Sri Lanka. Therefore, the research findings are limited to projects in between 1-10 MW. Further, the study has only considered the cost controlling practices used during the construction phase of mini hydropower projects.

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Impact to the Quantity Surveyors Due to the Current Economic Crisis in Sri Lanka

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ABSTRACT

This research focuses on the impact to the Quantity Surveyors due to the current economic crisis in Sri Lanka. The Easter bomb attack, covid 19 pandemic, and political instability can be seen as the proximate causes of the current economic crisis, while there were many structural issues of the local economy which had paved way for the same. As a developing country, the crisis had a stronger impact on the construction industry than other industries of the economy. The main reasons for the collapse of the construction industry are the suspension of construction projects by the government, the increase in the price of construction materials, the lack of investors to invest in new projects, and bottlenecks in terms of wrong policy directives. The professionals in the construction industry were severely impacted by the downfall. Among the professionals in the construction industry, this study focusses on QSs- (Quantity Surveyors). Thirty (30) semi-structured interviews were carried out in terms of data gathering. The survey findings demonstrated the type of organization and working experience of QSs. The collected data were analyzed using techniques of thematic analysis. Moreover, the findings identified factors which were the challenges due to current economic crisis and proposed strategies to help overcome those challenges.

Keywords: *Quantity Surveyors, Sri Lanka, Crisis, Challenges, Strategies.*

1 INTRODUCTION

Sri Lanka is experiencing the worst economic crisis in its history. The crisis hit many sectors of the economy in Sri Lanka. The Sri Lankan government has taken large amounts of credit from international lenders during the past decade. Excessive financing for non-profit development initiatives has plunged the government into debt. According to the Central Bank of Sri Lanka, national consumer price inflation has nearly tripled, rising from 16.8% in January 2022 to 58.9% in June 2022 (Central Bank of Sri Lanka, 2022c). The country must repay almost $4 billion in debt throughout the remainder of this year, including a $1 billion international sovereign bond maturing in July. Sri Lanka's economy is currently experiencing perhaps the worst foreign - currency crisis, which is insufficient to import basic products, meals, and medication (Amarasinghe, 2022). With an annual growth rate of 3.7%, Sri Lanka's economy's growth slowed down to 1.8% in the fourth quarter of FY2021-22. This is far less than the Central Bank of Sri Lanka's predicted growth of 5% (Central Bank of Sri Lanka, 2022b).

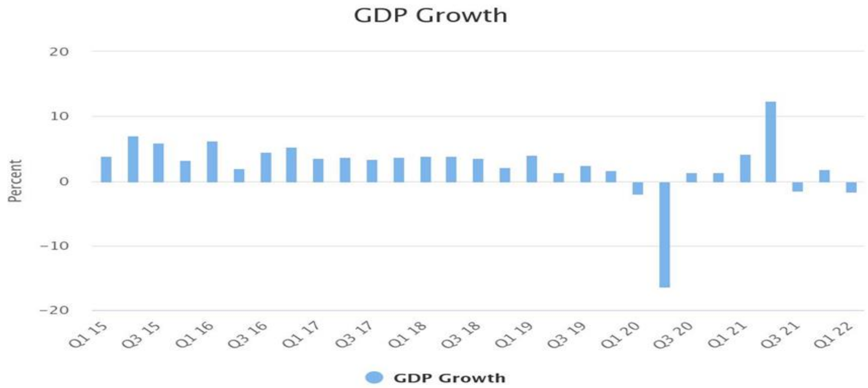

Figure 1. Growth rate in Sri Lanka

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According to the World Bank data, in 2021 Sri Lanka GDP was around 84.52 billion USD. Sri Lanka's GDP shares 0.02 percent of the global economy (World Bank, 2022). GDP in 2018 increased by 0.61% from the previous year to 87.96 billion USD and in 2019 it was recorded $83.90 billion USD, a decrease of 4.62% from 2018. GDP fell by 3.5% from 2019 to 80.97 billion USD in 2020, and it will rise by 4.38% from 2020 to 2021 (MacroTrends, 2022). The Sri Lankan economic crisis has wreaked disaster on the local construction industry and impacted the QSs who work in it. Historically, the construction industry contributed an average of 8-10% to a country's GDP. In 2019 and 2020, the contribution to GDP was only 7.4% and 6.2%, respectively (Wijetatne, 2022a). Many suppliers of construction materials have experienced exceptional price incensement in recent years, with the Sri Lankan rupee's free float, the USD/LKR exchange rate has now risen to Rs.360.25. Which was Rs.186.40 in December 2020 and Rs.203.00 in December 2021, respectively (Central Bank of Sri Lanka, 2022a).The construction industry is now experiencing a wide range of issues because of the present economic climate, many of which can only be resolved by state-level action. Increasing material costs, payment delays, stopped government projects, difficulties importing commodities, and increased interest rates are the main problems the sector is now experiencing (Soyza, 2022).

Ongoing projects cannot be completed because of the high rise in the cost of construction materials due to the rising dollar rate and inflation rates. Some suppliers are also taking advantage of this circumstance by raising their margins. The majority of SOEs (State Owned Enterprises) are not adhering to the 20% price increase that the cabinet also permitted. Table 1 below illustrates how quickly building materials have increased during the previous two years (Wijetatne, 2022b).

Table 1. Price Increase of Construction Materials

Material	**Dec 2020 (Rs)**	**Dec 2021 (Rs)**	**19.04.2022 (Rs)**	**% Increase**
Cement per 50kg Bag	850.00	1750.00	2175.00	155.9
Rebar per M. Ton	165,000.00	250,000.00	595,000.00	260.6
Structural Steel per M. Ton	170,000.00	330,000.00	750,000.00	341.2
0.47mm Zn-Al Roof Sheet per m	1522.00	2,802.05	4,500.00	195.7
Asbestos Roof Sheet per m	846.55	1,127.50	1,711.65	102.2

Payments are delayed while customers try to stabilize their financial situation. Overdue payments in the road, construction, and water supply sectors are thought to reach more than Rs. 100 billion. The gazette has now ceased all state-sponsored government initiatives in an effort to lessen its financial burden. This contains payments from government projects totaling billions of rupees. Due to the paucity of dollars in the local banking sector, the dollar crisis has made it all but impossible to buy the necessary commodities and supplies. When the dollar was floated in an unregulated way, several corporations who had to wait 120 days (about 4 months) after opening Letter of Credits had to endure painful losses. The central bank's high interest rates have also diminished any chances of acquiring new projects. Over 100,000 jobs would be lost because of the current economic crisis, according to the Chamber of Construction Industry of Sri Lanka (CCI), the top representing organization for all those working in the construction sector (Wijetatne, 2022b).

The growth of the quantity surveyor profession has faced countless obstacles during this period. It has developed and weathered the storms to the point that it is now a renowned professional in the Construction sector. Quantity surveyor (QS) is the one who estimates the project costs to provide project owners with the greatest value possible. They make sure that construction activities which carried out in a way to meet client's expectations (Wao, 2015).

Quantity surveyors frequently collaborate on projects with other stakeholders including architects, engineers, project owners, government authorities, insurance providers, and contractors. However, given that the construction business originally emerged in the 1820s, the QS positions have greatly altered through time to accommodate the sector's evolving nature. This adjustment was made in part to fulfill the clients' constantly changing requirements and to outcompete rival construction industry experts like architects and engineers (Wao, 2015). The impacts of the current economic crisis were noticeable in the quantity surveying profession in terms of job orders and development, just like they were in other professions in the construction sector.

The aim of this research is to evaluate the impact of the current economic crisis in Sri Lanka on Quantity Surveying profession and the objectives of the study are identified as:

1. To explore the current economic crisis in Sri Lanka and its impact on the local construction industry.
2. To identify the prevailing professional roles of quantity surveying professionals in the local construction industry.
3. To explore the challenges faced by quantity surveying professionals in the local construction industry due to prevailing economic crisis.
4. To propose recommendations and suitable strategies for them to successfully face the prevailing economic crisis in Sri Lanka.

2 RESEARCH METHODOLOGY

With the conclusion of a comprehensive literature survey to achieve the first objective of the study, semi structured interviews were used to identify the problems QSs faced during the current economic crisis in Sri Lanka. Semi-structured interviews offer a flexible advantage over structured interviews and are more formal than unstructured interviews. Interviews that are semi-structured and involve a questionnaire are more effective and enable interviewers to formally begin the interview. Thirty (30) Quantity surveying professionals were selected on a random basis to collect the data as there was very few literature related to the current economic crisis. During the crisis, the lack of fuel led to reduced or limited transport facilities and increased transportation costs, which make physical interviews an unviable option. Therefore, interviews were planned through online platforms. Prevailing professional roles of QSs in the local construction industry, and the challenges faced by QSs in the local construction industry due to the economic crisis were determined by conducting the semi structured, in-depth interviews.

In qualitative research, it might be challenging to analyze vast amounts of data. In this backdrop, thematic analysis offers simple and convenient options for data analysis. The data is divided into various data sets using thematic analysis. Due to these reasons thematic analysis was used to analyze the data which are collected through semi structured interviews. Results obtained from in-depth interviews were analyzed using thematic analysis to get the final output as a framework for evaluate the impact of the current economic crisis in Sri Lanka on Quantity Surveyors.

3 DATA COLLECTION AND ANALYSIS

3.1 Respondent's Profile

Interviews were conducted among Sri Lankan QSs who are in consultancy organizations and contractor organizations. Thirty (30) semi-structured interviews were carried out in terms of data gathering. The respondents' details were gathered through the first section of the semi-structured interview guideline. The summarized composition of respondent's profile is presented in Table 2.

Table 2. The Composition of the Respondents

Respondents (R)	Organization type	position	Working experience
R3,R5,R6,R8,R10,R12,R21,R22	Building Construction	Contractor QS	1 - 5
R1,R2,R7,R15,R27	Building Construction	Contractor QS	6 - 10
R9,R11	Mechanical Ventilation and Air Conditioning (MVAC)	Contractor QS	1 - 5
R20	Water Supply and Sewerage Construction	Contractor QS	11<
R4	Water Supply and Sewerage Construction	Contractor QS	11<

R13,R14,R23,R24,R25,R26	Consultancy organization	Consultant QS	1 - 5
R16,R28,R30	Consultancy organization	Consultant QS	6 - 10
R17,R18,R19,R29	Consultancy organization	Consultant QS	11<

Respondents were categorized according to their job role as shown in figure 2. The sample contained 57% of respondents who were contractor QSs and 43% of respondents who were consultant QSs.

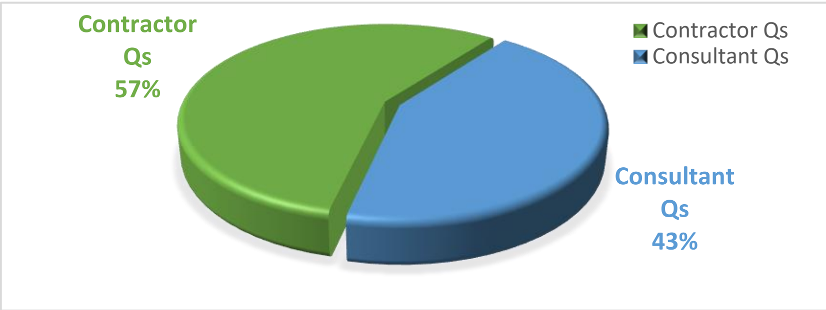

Figure 2. Type of respondent

Among the 30 respondents, there were three categories according to the respondents' experience. The three categories of QSs are those who have worked in the construction industry for 1-5 years (Junior level QSS), 6-10 years (middle level QSs) , and more than 11 years (Senior level QSs). Figure 3 shows the experiences of the respondents.

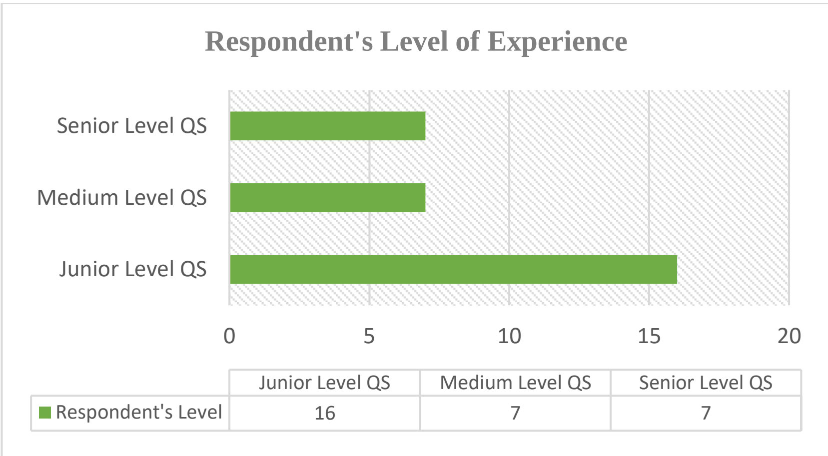

Figure 3. Respondent’s level of experience

3.2 Thematic Analysis

The thematic analysis method is used to analyze the data gathered from semi-structured interviews.

3.2.1 Theme 1 - Impact local construction industry

Data gathered through semi-structured interviews with QSs revealed that the long-term deteriorating economic conditions were responsible for the decline in the construction sector.The main reasons for the economic contraction can be attributed to seven decades of indecisive political leadership and decision-making lapses fueled by corruption and fraud. Also, reasons such as excessive and wasteful spending, and import-based lifestyles of powerful society clusters as well as loss making state enterprises, influenced the economic crisis in the long run. R4 stated that *“it is a manmade crisis that occurred due to years of mismanagement of the imprudent political leadership for more than 7 decades led by corruption and fraud. Also, the government officials who are taking irresponsible decisions are also major stakeholders in the crisis.”*

Irresponsible decisions of the government on reduction of VAT (Value Added Tax) and other taxation, reduction of government revenue and increase in expenditure, central bank’s money printing to cover the budget deficit, external borrowings at high-interest rates, short-sighted decisions such as investing in projects that do not directly generate enough revenue, led the country to be rapidly dragged into the current economic crisis. This was admitted by R2, R4, R5, R9, R21, and R24.

R7, R14, R22, R26, R28, and R29 respondents revealed due to the lack of sustainable spending lead the country's dire financial situation and related problems, many sectors have become vulnerable to crisis situations. Although every country has suffered some setbacks due to the Covid - 19, the economic crisis has affected Sri Lanka more. As the reason for that was the Easter bomb attack, wrong decisions of the government, the ban on the fertilizer imports, the lack of foreign reserves, and the unprecedented Chinese intervention in the development sector could be highlighted. In the face of any economic crisis, the construction sector is the first to be affected in developing countries. Government, as well as private investors, have stopped investing in development projects. During the crisis, focus of all parties was on daily essentials such as medicine, fuel, and energy, hence attention on the construction sector has decreased.

Further R1 illustrated his opinion as *“due to the economic crisis, poverty increased and due to insufficient dollar income, the price of every product began to rise. Every item went up in price by 50%. Because of that, the existence of the construction industry has been affected. In the case of fluctuating prices of raw materials, a shortage of raw materials was evidenced. Due to this, the existence of the construction sector was hampered.”*

Also, R12 and R25 revealed that along with the economic crisis, there was a shortage of energy. Transport facilities were hampered due to fuel shortages, project delays, extended time demands like EOT, material wastage, etc., and R17 stated that *“through this, not only small builders but also the whole construction industry landscape started to change.”*

R23 reported that *“For example, the current economic crisis is more destructive than the economic depression of the 1930s. About seventy percent of the projects in the construction sector have been stopped due to this crisis.”* R27 reported that *“A few years ago, the contribution of the construction sector to the gross domestic product was between 8% - 10% percent, but now it has collapsed to 6% due to the economic crisis.”*

When the construction sector collapses, job opportunities are reduced and thus unemployment increases. Accordingly, the economic crisis has individually and collectively affected all parties involved in the construction industry. Also, the job market competition increases in the construction industry, and new graduates as well as junior professionals with less experience lose their place in the construction industry. The construction sector is also affected by actions such as increased labor mobility. This was admitted by R3, R6, R10, R11, R15, R16, R18, R19, R20, and R30.

Some statements of respondents are stated as follows.

R3	It is a very devastating condition for the construction industry in which most of the employees have been losing their jobs due to the non-continuity of construction projects.
R6	The economic crisis has created the worst situation for the construction industry. Many employees are facing unemployment and also industry is struggling to do their construction with high prices/rates of material, workmanship, and plant.
R10	Material shortage, price fluctuation, fuel shortage are evident and etc. due to this the construction industry is facing lot of problems. Also, the competitiveness of construction-related jobs has increased.
R11	The construction industry has been greatly affected by the Sri Lankan current economic crisis. Fresh graduates and junior proffesionals are more affected by the decline of the construction industry.
R19	The present crisis has arisen due to reasons like the Easter bomb attack, covid-19, and foreign reserve shortage. Due to problems such as material shortage, material price fluctuation, and labor rate increase, the construction industry suffered a setback.

3.2.2 Theme 2 – Impact to the Quantity Surveyors

Many respondents admitted that while the current economic crisis has severely affected the construction industry, it has also affected Quantity Surveyors. Its effect on the QSs has both advantages and disadvantages. According to the data obtained from the questionnaire survey, great disadvantages have happened to the QSs and in some way, favorable conditions are also highlighted.

Advantages / Opportunities for Quantity Surveyors

R27 stated that *"providing an opportunity for foreigners to invest in the construction sector due to the inability of local investors to invest in projects in the construction sector as well as the suspension of development projects by the government."* And the government allows them to operate without any hindrance. Through that, Quantity Surveyors can easily connect with foreign technology and gather new knowledge. Further, contractors are motivated to carry out projects in foreign countries and that would open them up for new technologies and ability to deal with higher industry standards. This was admitted by R1 and R4.

R3, R5, R21, R24, and R26 respondents revealed that in the face of the crisis, about 50% of the Quantity Surveyors lost their job opportunities and due to job uncertainty, they began to pay attention to foreign job opportunities. The QSs would get a higher salary as well as new technical experience, through this.

R4 stated that *"In order to achieve maximum productivity in the crisis, contractors began to pay more attention to budget control and monitoring, minimizing wastage of raw materials and general planning to prevent wastage. In this backdrop, Quantity Surveyors are essential for solving all the financial problems in contract administration and projects, and overall job opportunities for Quantity Surveyors have increased."* R8 also supported R4's opinion as *"The QS were the main character who must address all the financial issues in the sites and the financial background of the company must identified and revealed. Further, QS got the opportunity to act as the contract administrator in the construction companies"*

R2 and R7 revealed that due to the prevailing economic crisis, more opportunities prevailed for an experienced Quantity Surveyor in hiring for jobs. Surveyors with experience in constituting claims (especially fluctuation claims) and handling contracts (contract administration) are eligible for better employment opportunities.

R11 reported that *"the fuel shortage has severely affected the construction sector, where more attention has been paid to hire officials who are at a minimum distance from the project. As a result, there were constant job opportunities within easy reach of the workplace. And as a Quantity Surveyor, you don't have to put in a lot of effort to find labors. As unemployment has reached a high level due to the economic crisis, labor has been readily available. And the labor shortage has decreased."*

Also, due to the shortage of fuel caused by the crisis, companies were motivated to accept e-tenders. Further, the introduction of online programs such as online bid submission and e-procurement, QSs got more advantages. It also saved time and transportation costs and since the restrictions on import goods prevail as a solution to the crisis, the price of paper started to rise rapidly. As a result, more space was given to the use of software than the use of paper. At the same time, cost and time were saved, and QS got the opportunity to gather more knowledge about software like MS Project, costX, and Navisworks. This was admitted by R6, R9, R20, R22, and R29.

R25 stated that although they did not have a strong understanding of economic crisis before, they gained an understanding of various aspects of this crisis. Also, the economic crisis led to a better understanding of price formulas, price fluctuations, and project cost control. This was also admitted by R13, R17, R20, and R25.

Although the data reveals beneficial aspects such as gaining new knowledge and getting foreign employment opportunities for QSs, it is evidenced that some Quantity Surveyors do not have any favorable situation due to the crisis. R5, R10, R12, R14, R15, R16, R18, R23, and R28 revealed that there were no any advantages or opportunities due to the current economic crisis.

Some statements of respondents are stated as follows.

R6	Online working platform have been created to avoid travelling charges. (Ex; Online bid submission).
R8	The QSs were the main character who must address all the economic issues on the sites and the economic background of the company must be identified and revealed. Further, QS got the opportunity to act as the contract administrator in the construction companies.
R17	The need for senior Quantity Surveyors has increased because of the crisis, which necessitates their experience.
R20	Got more knowledge about the price fluctuation side.
R24	Got some Knowledge about software.

Disadvantages / Challenges faced by Quantity Surveyors

10 out of 30 respondents highlighted that due to the current economic crisis, the import of goods was restricted, and the import of certain goods was banned. As a result, there was a shortage of raw materials and VAT has increased to 12%-15%. Inflation has also increased and thereby the prices of materials increased by 3%-4%. The Quantity Surveyors found it difficult to maintain a healthy cash flow in construction projects due to the practical inconsistency of applying price escalation formulas in the crisis.

Accordingly, it has become difficult to build up tender and estimate pricing. And it is difficult for the contractor to offer a competitive price as tenderers should include all risks with their price. Also, due to the increase in daily expenses, the prices of the subcontractors will increase. Also due to reasons such as the increase in wages of the workers, the price of the project will in turn increase more than the estimated price. This makes it difficult to select raw materials before starting the project. This was admitted by R4, R6, R8, R18, R19, R20, and R30.

R22 stated that *"due to fluctuating prices of raw materials, raw material suppliers provide their price lists only for two days. Therefore, finding suppliers is also difficult."*

R5, R6, R7, R4, R11, R12, R13, R14, and R17 revealed that the contractors are unable to carry out construction work due to unexpected price fluctuations. It is not a convenient task to approve payments related to the changes made in the project due to the increase in the prevailing price over the agreed price. Accordingly, it becomes difficult for employers to pay money. Thus, the employer compels to stop the project due to a lack of money. Project abandonment would lead to wastage of raw materials and the government of Sri Lanka also declared abandonment of all government led constructions. The new projects that will come out are very distant and many of the existing projects have been suspended or stopped. Hence routine tasks for Quantity Surveyors like quantity surveying, billing, BOQ preparation, tendering, etc. are stopped. This leads to high levels of unemployment among Quantity Surveyors.

R10 stated that *"due to the high price of software, it is not possible to use the software and even if tenders are made for foreign projects, the possibility of malpractices are high. And due to the shortage of dollars and import restrictions, only minor constructions were done since it is impossible to buy bulk stock."*

R15 reported that *"due to the current economic crisis, the government is unable to pay about one hundred billion for the construction contracts that have ended. This has become a major cash flow problem in the local construction industry and has led to the bankruptcy of many small contractors. Therefore, this affects Quantity Surveyors working with small contractors."*

Employers are unable to restart the projects. Also, employers show reluctance and fear to start projects due to the crisis. Private entities are not interested in undertaking construction projects as the projects incur losses. Hence, Quantity Surveyors do not have many job opportunities in the private sector. Also, Quantity Surveyors will lose jobs due to the stoppage of government projects. Due to 25% increase in the project cost, Quantity Surveyors' remuneration has decreased by 50%. Since there is a decrease in the number of employees, the amount of work per person has increased. And benefits such as overtime and bonus were lost. In the wake of this crisis, there was a shortage of projects due to which mainly the jobs of Quantity Surveyors became uncertain and there was no job security. This was admitted by 13 respondents in the sample.

Some statements of respondents are stated as follows.

R1	Giving an accurate estimate is very difficult in this period due to day-to-day increase in material prices.
R6	Unemployment risk in job, high material prices and price variations create cost variations in BOQs and cash flows, lack of imported materials, high overhead cost, high transportation cost, high charges for VAT and clearances.
R9	Import ban (materials that are not made locally), Difficult to maintain project cash flow.
R11	Payments are not approved when there are variations in a project as prices have increased more than the agreed rates.
R14	Since the government is not allocating funds for the construction projects, the projects had to be stopped and the staff who were working on the project lost their jobs.
R22	The prices of construction materials have become 3- 4 times higher than they were before. Due to this, even a small construction task is too expensive now. Most Sri Lankan people don't have the financial capacity to afford new construction projects.
R29	The fuel shortage affected the transportation of materials. When the materials cannot be transported at the right time, the project is delayed. Also, the project cost increases due to material price fluctuation.

22 out of the 30 QSs interviewed, and there will be no opportunities for QS professionals in the local construction industry in the future (within the next 3 – 5-year time period). R23 stated that "I think in 3 – 5 years construction industry contraction would be approximately at 60 % in total. Local and international investors take more risk in investing their money and they will take their investment to other countries. Skill and un-skill labor shortages would impact the construction industry further. Contractors make their BOQs and payment including high risk and tax, which will directly affect the project Sum. About 50% of contractors stop their business and the unemployed rate increase in the construction industry."

Only 8 QSs thought a good situation will arise for the construction industry and again QS job role will be in demand within 3 – 5 years.

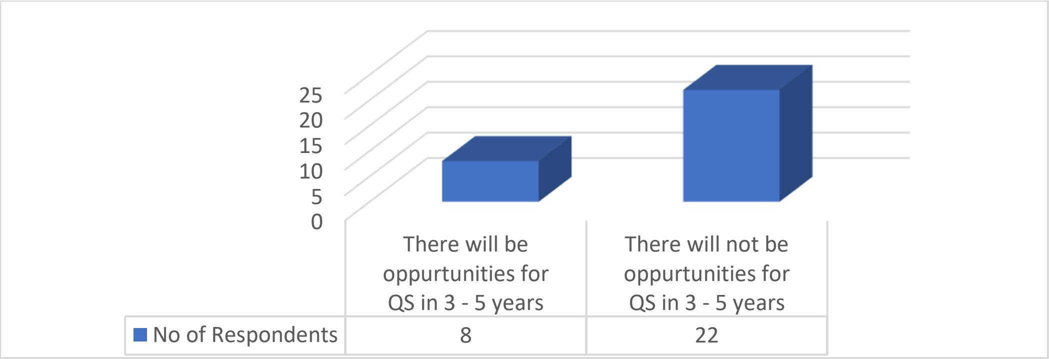

Figure 4. Respondent's opinion

3.2.3 Theme 3 – Strategies

Strategies propose for the construction industry

The construction sector has been severely affected by the current economic crisis and the measures to be implemented in the construction sector to successfully face these challenges are clear from the data obtained through the survey.

R5 and R26 revealed that for this, long-term and short-term planning should be implemented through a system first. Available resources should be deployed for projects that can be profitable very quickly and resources should be used sustainably. Also, attention should be increased to carry out projects faster. And actions such as identifying risks and preparing the risk matrix, changing procurement methods should be addressed.

Also, the construction sector should provide support and space for short-term careers or referrals for foreign jobs. And by getting foreign projects, the company and employees are secured. Policies and technology should be improved so that more foreign investments can be obtained. The impact of the crisis on the company can be reduced by building an agreement between the two parties to make payments in foreign currency for foreign investment projects. Attention should be paid to foreign countries that can expand the construction industry in this way.

R4 stated that *"one policy that can be used to increase the availability of foreign-funded construction projects is to forecast the fuel requirements of the foreign-invested project during the crisis and maintain CEPETCO/IOC capital dollar reserves to ensure a constant supply for each contract only."*

According to the point of view of R19, it is stated *"Banks should offer a special rate of interest for construction projects with further government intervention. Also, while getting a loan, you should win the creditor's trust by presenting an overall repayment plan."*

R4 and R28 revealed that enter into an agreement with the Contractors Union. Government should resort to the conversion of outstanding payments into treasury bonds and advance payment of fixed interest for fixed periods. This will happen until the government receives financial assistance to cover the payments in full. Therefore, the contractors will get some return for their retention money and the government will get relief due to a reduction in its existing payment obligations.

Also, local construction projects which are making losses daily should be stopped until the country recovers. And efforts should be made to restart large-scale contracts with funds that directly generate revenue for the collapsing economy. Foreign, as well as local investments, should be encouraged for the same.

Efforts should be made to reduce the general expenses incurred for the project. Also, methods should be used to prevent the wastage of materials. Raw material wastage can be avoided by manufacturing according to standard measurements and standards of materials. This was admitted by R8, R9, and R19.

In the interviews, 13 respondents described that reserve a dollar payment component from all upcoming foreign-funded projects to import key construction materials. Similarly, tax exemption on such imports up to a specified period to further streamline the construction costs of the domestic industry. If the material cannot be imported, alternative raw materials should be produced in Sri Lanka, and local raw materials should be used as much as possible. For that, local methods of continuous supply of raw materials should be sought. And by applying a control price for raw materials, the government can control the fluctuation of raw material prices. The price fluctuation formula should be modified to match the rate of the current price change by removing import restrictions on essential raw materials.

R3 and R6 revealed that bringing laws regarding timely payments to contractors, privatizing them, and setting up online work environments as much as possible also contribute to reduce the impact of the economic crisis on the construction industry.

R12 stated that *"In this way, the essential basic factor to build up the construction industry by accomplishing every step is to have strong management. Only highly experienced and skilled staff should be used to carry out the projects, and proper understanding should be given to those engaged in the construction industry by conducting workshops and training courses on the current economic crisis in the country."*

Some statements of respondents are stated as follows.

R1	Trying to get foreign projects might be a good strategy to secure the company and employees.
R4	Expanding Construction industry to possible overseas countries. (Ex. – in Africa, Asia)
R7	Compromising with the Contractor's association and convert unpaid payments by the Government as treasury bonds and conduct due interest in advance for certain period. This is until the government gets financial help to fully settle the payments. The Contractor's will get some outcome for their withhold money to survive themselves and the government will get a relief due to reducing its immediate/urgent payment liability.
R9	To solve the fuel problem, you can get the relevant permission and get the amount of fuel per fuel quota.

R11	If import materials restrictions are placed, local substitutes should be introduced.
R22	We should encourage people to invest in projects. One strategy is that we can go for alternative construction methods where they cost less. As an example, currently, contractors are encouraging the use of cement rendering for floor finishing rather than tiling. Because currently there is a scarcity of tiles in Sri Lanka and tile prices are higher than cement rendering.
R30	Relevant regular bodies should work in such a way that the construction industry is protected.

Strategies propose for the Quantity Surveyors

When the economic crisis had a strong impact on the construction industry, QSs were also affected by it, and the way to act by them in the construction industry can be identified by data analysis.

The main cause of the economic crisis is the lack of foreign reserves. Due to the current crisis in the country, more attention should be paid to foreign investment and foreign employment opportunities to successfully face the challenges faced by Quantity Surveyors. Quantity surveyors should be interested in jobs in foreign countries as well as bidding for foreign projects. To get local as well as foreign investments, we should work diligently in this regard. This was admitted by R1, R5, and R9.

R26 Stated *"when tendering domestic or foreign investments, the value should be increased for price uncertainty movements and price fluctuation should be introduced for all contracts, and for that, prices should be assumed based on price fluctuations."*

According to the point of view of R3, it is *stated "Quantity Surveyors should try their best to keep up-to-date on the new rules emphasized by the government regarding the construction industry and minimize losses by using variable order. Also, Quantity Surveyors should learn about various aspects of the construction industry."* This was also admitted by R14 and R29.

R5, R7, R12, and R22 revealed that must be aware of new technology and focus on global innovations. Also, Quantity Surveyors need to develop knowledge of contract administration and its entitlements, which are in good demand in the construction market. Attention should be paid to developing analytical skills with proper frequency tools which are important for this crisis. As there should be a good understanding of the crisis, measures such as participation in related workshops should be resorted to. Also, be aware of less expensive alternative construction measures and alternative construction materials.

R9, R11, and R15 reported that before taking up a project, QSs should ensure that their company has the capacity to undertake the project. Also, while choosing subcontractors, one should be careful not only about the prices but also about their performance and capacity. And for every raw material that needs to be bought, the price should be revised, and the purchase should be made. Methods should be employed to avoid the wastage of raw materials and efforts should be made to expedite the project. That is, when the project is completed quickly, one does not have to face problems such as the increase in the price of raw materials. Furthermore, by estimating the number of raw materials for the relevant phase of the construction project and transporting them at the same time, it is possible to reduce transportation costs and time.

Efforts should be made to manage the waste of raw materials effectively and efficiently and when compared to other industries, the amount of waste generated in the construction sector is large, and therefore, as Quantity Surveyors, waste should be minimized. Also updating with prices of upcoming construction materials on daily basis as Quantity Surveyor in pricing and it is better to do projects for less profit than not to do projects. This was revealed by R22 and R26.

R30 illustrated his opinion that *"In carrying out projects in this way, the suppliers should be given an order of a certain quantity of materials and get a fixed cost for the raw materials, and subcontractors and raw material suppliers should be followed up on a regular basis. Maintaining project cash flow is a key task and daily reports must be maintained and payments must be monitored cooperate with all parties involved in the business and ensure that parties are promptly informed of changes"*

R13 stated, *"IQSSL institutes should conduct workshops on how to deal with unexpected situations and major economic crises so that the Quantity Surveyor should be fully aware of this and thus be able to overcome the challenges and operate in such a crisis situation."*

Some statements of respondents are stated as follows.

R1	Increasing the price contingency component of new tenders.
R2	Government intervention is required to solve the current crisis in the construction field and is required to set cost boundaries for construction materials to control monopolistic suppliers. Need to lift import sanctions on construction materials.
R5	Developing professional skills to suit the country's situation.
R6	Seeking projects abroad for consultancy and outsourcing work and doing freelance work for foreign projects.
R7	QS Professionals must improve their knowledge in Contract Administration and preparation of Contractual claims for which the market has a better demand.
R10	Having a great understanding of every side of the construction sector.
R24	Use new software and technology.

4 CONCLUSION

The first objective, which was to explore current economic crisis of Sri Lanka and its impact on the local construction industry, was achieved through a comprehensive literature survey. The main reasons for the contracting economy can be attributed to seven decades of indecisive political leadership and decision-making lapses fueled by corruption and fraud. Due to the lack of sustainable spending on the country's financial situation and related problems, many sectors have become vulnerable to the crisis. Problems such as construction material price fluctuations, project delays, EOT (extension of time) claims, fuel shortage, transportation problems, materials wastage, and labor rate increase have hampered the growth of the construction industry. The second and the third objectives were achieved through semi-structured interviews. Quantity Surveyor was historically the cost and financial accountant for the construction industry, but the traditional role of Quantity Surveyors has developed into automated measurement and quantification, environmental and sustainability analysis, advice on information and communications technology, taxation and investment advice relating to construction projects, supply chain management, facilities management, legal services, quality management, niche markets etc. There are many alternatives exists at present. The aim of the research is to explore the effect of the current economic crisis on Quantity Surveyors. From the interviews conducted at the data collection stage, many obstacles were found which affected them. According to the data analysis: job uncertainty, job losses, lack of imported materials, difficulty in giving an accurate estimate due to day to day increase in material prices, inability to give a competitive price for tenders, high material prices and price variations create cost variations in BOQs and project cash flows, high overhead cost, high transportation cost, high charges for VAT and clearances, difficulty in maintaining the project cash flow, inconclusive payment process due to variations in a project, frozen bonuses and overtime payments, disappearance of extra private sector jobs are the main challenges which are faced by the Quantity Surveyors due to current economic crisis. To overcome those obstacles, respondents suggested what they are doing at present and what needs to be done in the future. Increasing the price contingency component of new tenders, introducing price escalation for all tenders and for awarded contracts, increasing the flexibility of contractual conditions related to claiming additional costs un-covered by price fluctuation payments until designated period of time in local industry, developing professional skills to suit the country's situation, being a seeker of modern knowledge, focusing on global innovations, trying to engage with local and foreign projects through information and communication technology., doing freelance works for foreign projects, payments should be monitored and project cash flow should be maintained regularly, predicting the rate using price escalation formulas, were identified as proposed strategies. As a Quantity Surveyor, the requirement to learn every side of the construction industry was also among them. Hence the study was able to achive its fourth objective as well.

5 ACKNOWLEDGEMENT

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MECHANICAL ENGINEERING

Analysis of a Solar Thermal Based Hot Water System for a Non-Residential Application

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ABSTRACT

Industries in Sri Lanka rely heavily on the use of hot water for their day-to-day applications. Industries such as hotels and hospitals utilise electrically powered geysers, while industries such as wood treating factories, garment industries, and paper manufacturing industries rely on boilers to obtain heated water. The rising cost of electricity production and the pollution associated with current power generation technologies in Sri Lanka have led to a need for a water heating framework which focuses on harnessing renewable energy. Since Sri Lanka is located in close proximity to the equatorial belt, solar thermal water heaters were selected as one of the most viable options. In this study, a hospital was selected as the base scenario onto which a solar water heating framework was to be designed for. The framework focused on the feasibility of three collector types, *i.e.*, Flat Plate Collector, Evacuated Tube Collector and Parabolic Trough Collector. Initially theoretical efficiencies of each collector type were determined for the average annual solar radiation in Sri Lanka. Finally, RETScreen simulation software was used to perform sizing analysis of each water heating system, analyse each systems financial viability and analyse the reduction in annual Greenhouse Gas (GHG) emissions.

KEYWORDS: *Solar radiation, water heater, solar collector, flat plate, evacuated tube, parabolic trough, efficiency, RETScreen.*

1 INTRODUCTION

The continuous advancement in technology and the increasing growth of the global population has led to an increase in the demand for energy. According to statistical data of world energy published by bp it was discovered that the energy demand for the year 2021 had increased by 5.8%. A large portion of this global energy demand is currently obtained via fossil fuels. According to the figures released, fossil fuels accounted for about 82% of the global energy usage for the year 2021, while the remaining 18% of the global energy requirement was catered via renewable and alternative energy sources such as Hydroelectricity, Nuclear energy, Solar and wind energy. Fossil fuels are supplied to the market in three types, they are coal, natural gas and oil. 36% of the global energy requirement was catered to by Coal, while natural gas and oil both supplied 23% each of the global energy requirement (bp 2022). The major drawback when utilising fossil fuels is the adverse effect it has on the environment. The extraction, refining and end use stages of these energy sources collectively pollute the environment. Since the end use of most fossil fuels is to obtain energy via combustion, it has the most severe impact of all stages (Barbir et al. 1990). Fossil fuels often contain impurities in its chemical composition, upon combustion oxides of carbon, nitrogen and sulfur may be formed and released into the atmosphere (Garrick 2008). The release of these gases into the atmosphere may lead to phenomena such as acid rain, ground-level ozone and global warming. Carbon dioxide, which is a greenhouse gas, is the main contributing factor towards global warming as it has the ability absorb infrared radiation incident on the earth, eventually leading to an increase in the atmospheric temperature (Gupta Ram B. 2010). In the year 2021 a total of 33.9 $GtCO_2e$ (gigatonnes of CO_2 equivalent) was emitted from energy, which is an increase of 5.9% from the preceding year (bp 2022).

In addition to the adverse effects caused by using fossil fuels, another factor that hinders the use of fossil fuels as an energy source is its cost. The cost of oil, natural gas and coal increased sharply in

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the year 2021. According to the statistical figures released, the price of oil rose to 70.91 USD/ barrel in 2021 which was the highest it had reached since the year 2015. Coal was priced at approximately 145 USD / tonne in the Asian region for the year 2021. Natural gas prices experienced the sharpest increase in price with a listing of 18.6 USD / mmBTU in the Asian region, this was a threefold increase of its price in the preceding year and the highest price ever recorded since 2014 (bp 2022).

Industries in Sri Lanka rely heavily on the use of hot water for their day-to-day applications. Industries such as hotels and hospitals utilize hot water for applications such as cleaning laundry, culinary purposes, maintenance purposes and sterilization of surgical equipment in the case of hospitals. The typical temperature of water required for these purposes may vary from 45 – 70 °C (Jayasinghe 2016). Electrical water heaters are typically used by these industries to obtain the required level of heated water. On the contrary, industries such as wood treating factories, garment industries, brewing industries and paper manufacturing industries require relatively higher temperatures of water and on occasions require steam to drive the heavy-duty machinery available at the workshop. The required level of heated water or steam required for these processes are generally obtained from boilers. The feed fuels for these boilers are usually coal, furnace oil or biomass fuels (Siriwardena et al 2020). 49% of the total electricity generated in the year 2021 was accounted for by fossil fuels (*i.e.* coal and oil), while the remaining 51% of the total electricity generate was accounted for by renewable sources of energy. According to a study published by *Withanaarachchi et al*, it was mentioned that 95 % of the total electricity requirement of Sri Lanka was catered to by hydro power plants alone in the year 1995. The figure reduced dramatically to 46.56% in the year 2010 and this was attributed to the increasing requirement of domestic electricity and the rapid development of the industrial sector of the country (Withanaarachchi et al 2014). The downward trend in the ability of the hydro power plants to cater to the demands of the Sri Lankan electricity grid can be seen in the figure above as it was only able to account for 34% of the electricity generated in the year 2021. An increase in the electricity tariff took place in the year 2022, nearly eight years since the last revision of the electricity tariff, in order to account for the increasing cost of producing each unit of electricity ("Explainer: Sri Lanka's electricity tariff hike and how it works | Economynext" 2022). The location of Sri Lanka in close proximity to the earth's equatorial line provides huge potential for extraction of useful solar energy (Renne et al. 2003).

The work carried out in this study aimed at providing a generalised framework that could be adhered to by industries in Sri Lanka that intend to switch to solar water heaters to fulfill their desired hot water requirement. A base case scenario was to be included in the framework, this was done in order to facilitate environmental, economic and physical parameters related to Sri Lankan context. The base case scenario was to be selected from industrial sectors such as a textile industry, hospital or hotel. Theoretical collector efficiencies were to be determined along with the finances involved when setting up each collector type, in order to allow the industrial organisation to make an informed decision when selecting its preferred collector type. Finally, the framework was to provide guidelines required to set up a hot water storage tank, which would serve as the central distribution point of heated water to the required loads of the industry. The process of setting up an auxiliary heating device was also included in the framework to account for the occasions when the required temperatures could not be obtained via solar collectors alone.

2 MATERIALS AND METHODS

It was decided to select a hospital as the industrial application to be analysed for this research project. Kings Hospital, located in Colombo, Sri Lanka was selected as the base scenario to determine the general hot water requirements of an industrial application. Initial analysis of the hospital revealed that the hospital did not contain a centralized water heating system to provide its daily hot water requirement. Instead, the hospital utilized electrically powered geysers to supply its daily hot water requirement. Daily hot water requirements were to be acquired from the said hospital and the number of panels required to provide the required heating and the size of storage tank were to be determined accordingly. The specifications of solar collectors, such as the capacity, cost of installation and the physical dimensions of collectors were to be obtained from suppliers present in the local market where applicable. Information for flat plate collectors were obtained from Alpha Thermal Systems Pvt Ltd while information for evacuated tube collectors were obtained from JFA Sunbird Renewable Energy Pvt

Ltd which are companies that manufacture the said panels in Sri Lanka. However, for the parabolic trough collector, it was decided to use 'Absolicon', a company based in Sweden, as the supplier.

2.1 Theoretical Efficiency Equations of Each Collector Type

The thermal efficiency of a flat plate collector was determined based on predefined equations of heat gain. For the purpose of analysis, it was assumed that the collector being analysed had a unit surface area (*i.e.*, $A_c = 1$ m^2). The equations for efficiency of a collector under steady state conditions obtained from (Duffie and Beckman 2013) are shown below.

$$\eta = \frac{\dot{Q}_u}{I_T A_C} \tag{1}$$

Where, η refers to the collector efficiency, $\dot{Q}_u$ is the useful heat gain by the collector, I_T is the total radiation incident on the collector (W/ m^2), A_C is the surface area of the collector (m^2). The useful heat gain by a collector can be defined as follows (American Society of Heating and Air-Conditioning Engineers, 2019),

$$\dot{Q}_u = A_C F_R I_{T\theta} (\tau\alpha)_\theta - A_C F_R U_L \left(T_{fi} - T_a\right) \tag{2}$$

Where, F_R is the collector heat removal factor, $I_{T\theta}$ i s the total irradiation of collector (W/ m^2), τ is the transmittance of the flat plate cover, α id the absorbance of the plate, θ is the Incident angle (º), U_L is the overall heat loss coefficient (W/ m^2 °C), T_{fi} is the fluid inlet temperature (°C) and T_a refers to the Ambient temperature (°C).. The equation for Collector heat removal factor (F_R) for a flat plate collector can be defined in terms of Collector Flow Factor (F'') and Collector Efficiency Factor (F') as follows.

$$F_R = F'' \times F' \tag{3}$$

The equation for Collector Efficiency Factor F' is defined as follows,

$$F' = \frac{\frac{1}{U_L}}{W\left[\frac{1}{U_L[D + (W - D)F]} + \frac{1}{c_b} + \frac{1}{\pi D_i h_{fi}}\right]} \tag{4}$$

Where, W is the distance between the tubes (m), D is the tube diameter (m), D_i is the internal diameter of the tube (m), c_b is the Bond conductance, h_{fi} is the heat transfer coefficient between the fluid and tube wall (W/m^2 °C) and F refers to the fin efficiency factor. Bond conductance can be defined in terms of thermal conductivity of the bond (k_b /W/m^2 °C), bond width (b /m) and average bond thickness (γ /m)

$$c_b = \frac{k_b \times b}{\gamma} \tag{5}$$

The Fin efficiency factor (F) was defined as follows,

$$F = \frac{\tanh[m(W - D)/2]}{m(W - D)/2} \tag{6}$$

Where the term m is defined by the following equation.

$$m = \sqrt{\frac{U_L}{k\delta}} \tag{7}$$

Where δ refers to the thickness of the plate and the other symbols have the same definition as described earlier. The equation for Collector Flow Factor F'' is defined as follows,

$$F'' = \frac{\dot{m}C_p}{A_C U_L F'}\left[1 - \exp(-\frac{A_C U_L F'}{\dot{m}C_p})\right] \tag{8}$$

An expression for the efficiency of an evacuated tube collector has been determined experimentally and can be defined as follows (Calise Francesco, 2019).

$$\eta = \eta_0 IAM_b + \eta_0 IAM_d - c_1\frac{(T_{fi} - T_a)}{I_T} - c_2\frac{(T_{fi} - T_a)^2}{I_T} - c_3 u\frac{(T_{fi} - T_a)}{I_T} + c_4\frac{(E_L - \sigma T_a{}^4)}{I_T} - c_6\frac{1}{I_T}\frac{dT_m}{dT} - K_d u \tag{9}$$

Where $\eta_0, c_1, c_2, c_3, c_4, c_6$ and K_d are parameters which define each solar thermal collector, these values are generally supplied by the manufacturer. The terms IAM_b and IAM_b collectively represent the incident angle modifier in the case of beam and diffuse radiation respectively. u represents the wind speed, G is the irradiation incident on the surface, E_L is the emissivity of the collector and σ represents the Stefan-Boltzmann constant (Calise Francesco, 2019). A simplified equation for evacuated tube was developed in a study conducted by (Hayek et al. 2011).

$$\eta = \eta_0 - c_1\frac{(T_{fi} - T_a)}{I_T} - c_2\frac{(T_{fi} - T_a)^2}{I_T} \tag{10}$$

Predefined values for the constant parameters η_0, c_1, c_2, c_3, were obtained from Hayek et al. 2011 which contains values from sources such as the manufacturer and the Australian and New Zealand Solar Energy Society (ANZSES).

The equation for useful heat gain for a concentrated collector obtained from (ASHRAE, 2019) is defined as follows,

$$\dot{Q}_u = F_R I_{DN}(\tau\alpha)_\theta(\rho I') - F_R U_L(\frac{A_r}{A_a})(T_{fi} - T_a) \tag{11}$$

Where, I_{DN} is the Direct normal irradiation (W/m^2), ρ is the reflectance of the concentrator surface, A_a is the area of aperture, A_r is the area of receiver and I' refers to the fraction of reflected or refracted radiation received by the absorber A variable 'S' which represents the total absorbed radiation per unit aperture area can be introduced into the useful heat gain equation shown above.

$$S = \frac{I_{DN}(\tau\alpha)_\theta(\rho I')}{A_a} \tag{12}$$

The equation above was substituted into the useful heat gain equation to obtain a new expression for useful heat gain as follows.

$$\dot{Q}_u = F_R A_a S - F_R U_L(\frac{A_r}{A_a})(T_{fi} - T_a) \tag{13}$$

The equation for calculation of Collector heat removal factor F_R is the same as the one illustrated in Equation 3. The equation for Collector Efficiency Factor F' of a concentrated collector is defined as follows,

$$F' = \frac{\frac{1}{U_L}}{\frac{1}{U_L} + \frac{D_o}{D_i h_{fi}} + \frac{D_o}{2k} \ln\left(\frac{D_o}{D_i}\right)} \tag{14}$$

Where, D_o is the outer diameter of receiver (m), D_i is the inner diameter of receiver (m) and K id the thermal conductivity of copper (W/m^2 °C). The equation for Collector Flow Factor F'' is defined as follows,

$$F'' = \frac{\dot{m}C_p}{A_r U_L F'}\left[1 - \exp\left(-\frac{A_r U_L F'}{\dot{m}C_p}\right)\right] \tag{15}$$

The total irradiance of the sun was obtained via data available at the Prediction of Worldwide Energy Resource (POWER) which is maintained by the National Aeronautics and Space Administration (NASA). The latitudinal and longitudinal coordinates of Kings Hospital were entered into the website and the monthly average Global Horizontal Irradiance (GHI) values for the year 2021 were obtained. A copy of the results obtained is available in Appendix B of this report. The average irradiance for the for the year was determined to be 5.52 kWh/m^2/day. This value was converted to its equivalent value in W/m^2 by first multiplying the value by 1000 to get the value in terms of Watts and then dividing the value by the number of sun hours per day, based on the daily GHI values obtained it was observed that an average of 11 sun hours were experienced in Sri Lanka. Note that since both the numerator and denominator are multiplied by 3600 to convert the value to seconds, both terms cancel each other, hence the annual GHI value was determined to be 501.82 kW/m^2. The average annual value of Direct Normal Irradiation (DNI) during the year 2021 was used for the calculation of efficiency of Concentrated collectors. The average value obtained from NASA POWER website was 4.05 kWh/m^2/day, a conversion process similar to that followed for the GHI value conversion was followed and the DNI value was determined to be 368.18 W/m^2 (NASA POWER 2022).

2.2 Manufacturer Specifications of Each Collector Type

Manufacturer specified information regarding the capacity and physical dimensions of solar collectors provided by the three suppliers mentioned earlier were obtained to determine the capacity, physical dimensions and cost of each collector type which will be used for the gross collector area calculation, tank sizing analysis and financial feasibility analysis. Based on information obtained for flat plate collectors from Alpha Thermal Systems the maximum capacity of the flat plate collector available in the market available was 300 litres/ day. This collector has a width of 2030 mm and length 2010 mm with a total of 16 tubes within the said panel. The cost per collector was determined to be 356,250 LKR, which includes the cost of the collector panel only *i.e.*, excluding the cylindrical tank it is provided with. Information regarding evacuated tube collectors obtained from JFA Sunbird revealed that the maximum capacity that could be supplied by one evacuated tube collector unit is 450 litres. The collector has a width of 2400 mm and length 1900 mm with a total of 30 vacuum tubes within the said panel. The cost per collector was determined to be 437,750 LKR, which also includes the cost of the collector panel only. Finally, information obtained from Absolicon revealed that its parabolic trough collector could produce 500 litres of heated water per day. The product which is called Absolicon T160 collector has an aperture area specified by the manufacturer as 5.5 m^2 and uses polymer embedded silver on steel sheet as its reflector material. The manufacturer charges approximately 533 euros per square meter of aperture which converts to approximately 206,500 LKR.

2.3 Heated Water Storage Tank Design Considerations

When considering the design specifications of the heated water storage tank, according to the guidelines published by the American Society of Plumbing Engineers (ASPE) in the year 1980, water storage systems should be able to store between 48.9 to 73.3 litres of liquid per square meter of collector area. However, based on a computer simulation which was run by the University of Wisconsin, the publication states that a value of 61.1 L/m^2 could be considered as an optimum value between the range mentioned earlier (American Society of Plumbing Engineers (ASPE) 1980). The range stated by ASPE was later verified by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in a Handbook published in the year 2012, which stated that a typical liquid system thermal storage should be able to allocate between 40 to 80 Litres of fluid per square meter of collector area (ASHRAE 2012). The formula to determine the tank volume required is given below.

$$\text{Tank volume required} = 61.1 \times \text{Total collector area} \tag{16}$$

Tanks can be constructed in either vertical or horizontal configuration. It should be noted that vertical tanks provide the best performance in terms of stratification of the fluid within the tank, however, if the height available at the location of installation is constrained, horizontal tanks can be used (Kalogirou, 2014). Consideration should also be given to the type of material selected for construction of the storage tank, commonly used construction materials include steel, plastic and concrete (ASHRAE 2012). Materials commonly used for the purpose of heated water storage tank insulation include rigid foam, rigid sheets of polyisocyanurate and fibreglass. The Handbook published by ASHRAE in 2012 provides guidelines regarding the insulation requirements of a storage tank.

$$\frac{1}{R} = \frac{fQ}{A\theta}\frac{1}{(\mathrm{t_{avg}} - \mathrm{t_a})} \tag{17}$$

Where R is the thermal resistivity of the insulation required, f is the specified fraction of stored energy that can be lost in time, Q is the stored energy, A is the exposed surface area of storage unit, θ is the given time period, t_{avg} is the average temperature in storage unit and t_a is the ambient temperature surrounding storage unit. The term $\frac{fQ}{A\theta}$ is referred to as the insulation factor (ASHRAE 2012). The ASHRAE Handbook defines typical insulation factors based on the volume and shape of the storage tank as shown in the figure below.

	Vertical Tank Insulation Factor, W/m²			
Size, m³	D to 3D	D/2	D/3	D/4
0.30	6.62	5.93	6.78	6.21
0.45	7.54	6.78	7.76	7.13
0.95	9.68	8.64	7.76	9.09
1.89	12.21	10.91	12.49	11.45
2.84	13.97	12.49	14.29	13.12
3.8	15.36	13.75	15.74	14.42
5.7	17.60	15.74	18.01	16.53
7.6	19.34	17.32	19.81	18.17
11.4	22.18	19.81	22.68	20.82
15.1	24.39	21.83	24.98	22.90
18.9	26.28	23.50	26.90	24.67

Figure 1. Insulation Factor fQ/Aθ for Cylindrical Water Tanks (ASHRAE 2012)

2.4 RETScreen Simulation Setup

RETScreen was used to simulate the costs involved in setting up the solar water heating project and the savings that the hospital can expect to make if they choose to implement the said system. The analysis was carried out by first entering the latitudinal and longitudinal coordinates corresponding to Colombo, Sri Lanka. The base case was then entered into the software. The base case only consisted of a heating system powered only via electricity. The electricity rate in the country which is 28 LKR/kWh, was also entered into the software. The proposed case was also set to use electricity with the same electricity tariff mentioned earlier, the difference between the two cases would be the addition of the solar collectors to reduce the electricity consumption of the base case. Additional characteristics such as the value of manufacturer specified coefficients such as $F_R U_L$ and $F_R \tau\alpha$ were obtained from the built-in solar collector database available in the RETScreen software. miscellaneous losses were entered as 2%, this value generally indicates the losses the collector may incur if there was shading present due to dust on the collector. The software recommends a value between 2 and 5% for well-maintained collectors.

A cash flow diagram of the project was generated for each collector type using the software. A 20-year project life cycle was considered for the cash flow diagram. Parameters such as the annual inflation rate was set to 2.5%, debt interest rate was set to 5%, debt term was set as 5 years, fuel cost escalation rate was set to 3% and the income tax rate which was 14% for health care services was also entered into the software before generating the cash flow diagram. The total cost of the number of solar collectors required and a user designed cost of 0.1% of the total cost was also entered into the software in order to account for the design and assembly cost of the collector setup.

3 RESULTS AND DISCUSSION

3.1 Analysis of the Selected Industrial Application

As mentioned earlier, a hospital was selected as the industrial application to be analysed for this study and inspection of the hospital revealed that it utilized electrically powered geysers to supply its daily hot water requirement. Geysers were installed in all the rooms of the hospital where patients were admitted to. Additionally, geysers were used in departments such as the culinary department, operation theatres and Cath Labs. It was discovered that the hospital consisted of 72 functional patient rooms, therefore considering the additional applications mentioned earlier, the hospital utilized a total of 90 electrically powered geysers to meet its daily hot water requirement. As mentioned earlier, a centralized water heating system was not present, hence the hot water usage could not be measured directly. Therefore, the total monthly water usage of the hospital was obtained over a period of six months as shown in the figure below.

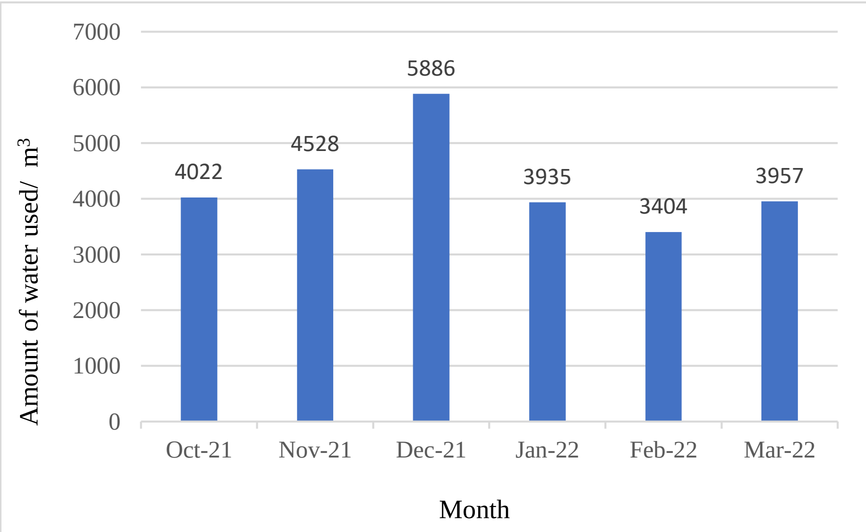

Figure 2. Monthly water consumption of the hospital

An average value for the monthly water usage of the hospital was then obtained as 4289 m^3. Based on the aforementioned applications of hot water, it was assumed that 25% of the total water usage of the hospital accounts for hot water applications. Therefore, the average hot water requirement per month was determined as 1072.25 m^3 which was determined in terms of litres as 35741.7 litres per day. The geyser utilized by the hospital consisted of a 1500W heating element which supplies the heat required to increase the temperature of water. 72 geysers are currently utilized in patient rooms for applications such as bathing, *etc.* it can be assumed that theses geysers are switched on for six hours a day on average. The remaining 18 geysers which are utilized in the kitchen department, operation theatres and Cath lab can be assumed to be switched on for approximately fifteen hours a day on average.

3.2 Efficiencies of Each Solar Collector Type

Based on the theoretical efficiency equations that were derived for each collector type, it was observed that concentrated collectors had the highest efficiency rating (89.9%). Flat plate collectors had the lowest theoretical efficiency (65.8%) whereas evacuated tubes had a more improved efficiency (79.4%) when compared to the performance of a flat plate collector. The reason for concentrating collectors having the best overall efficiency was mainly due to its arrangement, which allows for incident beam radiation to be reflected and focused solely on the fluid carrying pipe. The reason for the comparatively poor performance of the flat plate collector was due to the high convective losses involved during the heating of the fluid in this system. An improvement in efficiency was seen in the case of Evacuated Tube Collectors mainly due to the inclusion of a vacuum in the collector tubes to minimize the aforementioned losses (Duffie and Beckman 2013). Parameters such as the area of collector (Aperture area (A_a) in the case of concentrated collectors), fluid inlet temperature, overall heat loss coefficient of the collector, ambient temperature, heat transfer coefficient of water, thermal conductivity of copper and mass flow rate of water were assumed to have the same value during analysis of each collector type in order to maintain a consistency in the results obtained.

3.3 Solar Collector and Corresponding Storage Tank Requirements

The total number of flat plate collectors required to fulfil the daily hot water requirement of the hospital based on the manufacturer specifications mentioned earlier was determined to be 119 units, the gross area of collectors was then determined to be $485\ \mathrm{m}^2$. A maximum of ten flat plate collectors can be connected in series without producing any significant pressure drop between collectors and without compromising the thermal performance. Attention must also be given to the diameters of restrictor holes in each collector. Restrictor hole diameters at the outlet of each collector should increase from the first collector until it reaches the collector at the middle. The restrictors at the inlet of each collector should decrease gradually starting from the inlet of the collector at the middle of the array (ASHRAE 2012). From Equation 16 it was determined that a tank of volume 29600 Litres would suffice for the flat plate collector system. Using the first diameter and height relationship shown in Figure 1, the length of the tank was determined to be 7.2 m and the diameter was determined to be 2.4m respectively.

The total number of evacuated tube collectors required was determined to be 79 units, the gross area of collectors was then determined to be $360\ \mathrm{m}^2$. In a study conducted by Garg and Chakravertty in 1988, it was discovered that approximately eight evacuated tube collector modules could be connected in series while accounting for a drop in efficiency of about 5%. From Equation 16 it was determined that a tank of volume 22000 Litres would suffice for the evacuated tube collector system. As in the case of the flat plate system, using Figure 1 the tank length and diameter were determined to be 6.3 m and 2.1 m respectively.

The total number of parabolic trough collectors required was determined to be 79 units, the gross area of collectors was then determined to be $428.7\ \mathrm{m}^2$. In the case of the parabolic trough collector, a sharp increase in the pressure drop is observed when relatively high levels of flow rates are utilised, hence the manufacturer suggests setting up three units in series to obtain optimal results. From Equation 16 it was determined that a tank of volume 23800 Litres would suffice for the parabolic trough collector system. Using Figure 1 the tank length and diameter were determined to be 6.48 m and 2.16 m respectively.

According to the insulation factor table shown in Figure 1, the tank volumes in each collector setup is greater than 18.9 m^3, hence a minimum insulation factor of 26.28 is required for each tank. the thermal conductivity of the insulation material computed using Equation 17 was $1.24\ \mathrm{W/mK}$.

3.4 Equity Payback Period of Each System

As mentioned earlier, a financial feasibility analysis was performed using RETScreen. The total price of the collector units and an additional 0.1% of the total cost for each type was considered as the installation cost. The equity payback period for each case was computed based on user defined parameters such as discount rate, inflation rate mentioned earlier. The results of the 20-year project life cycle simulation for each case is shown in the table below.

Table 1. Equity payback period for each collector system

	Flat Plate Collector	**Evacuated Tube Collector**	**Parabolic Trough Collector**
Cost of units / LKR	42,393,750	34,582,250	75,886,570
Equity Payback period / Years	9.0	7.4	12.6

3.5 Sensitivity Analysis of Payback Period for Each System

As mentioned earlier, the equity payback period for the three collector types were generated based on a fuel cost escalation rate of 3%. The effect of varying the fuel cost escalation rate on the equity payback of each system was also analysed using RETScreen simulation software. The fuel cost escalation rate was varied from 0 to 5% to determine the effect it would have on the number of years required to achieve equity payback. The results obtained are shown in the figure below.

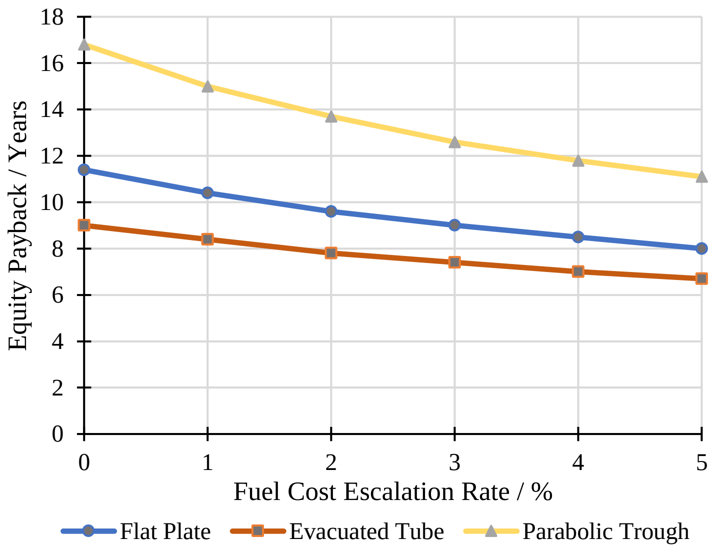

Figure 3. Effect of fuel cost escalation rate on equity payback

Based on the figure above it can be observed that an increase in fuel cost would lead to an exponential decrease in number of years required to achieve equity payback. For the case where there is no increase in fuel cost, the flat plate system would take approximately 11.4 years to achieve equity payback, while the evacuated a system would take approximately 9 years to achieve equity payback and finally the parabolic trough system would take up to 16.8 years to achieve equity payback. For the best-case scenario where the fuel cost would rise at a rate of 5%, the equity payback period of flat plate, evacuated tube and parabolic trough would decrease by 29.8, 25.6 and 33.9% respectively, from the values mentioned for a fuel cost escalation rate of 0%.

3.6 Electricity Consumption Analysis of Each System

The electricity consumption for each case was also obtained using RETScreen as mentioned earlier. The figure below indicates the electricity requirement annually to achieve the required water heating content for the base case, flat plate collector system, evacuated tube system and the parabolic trough system.

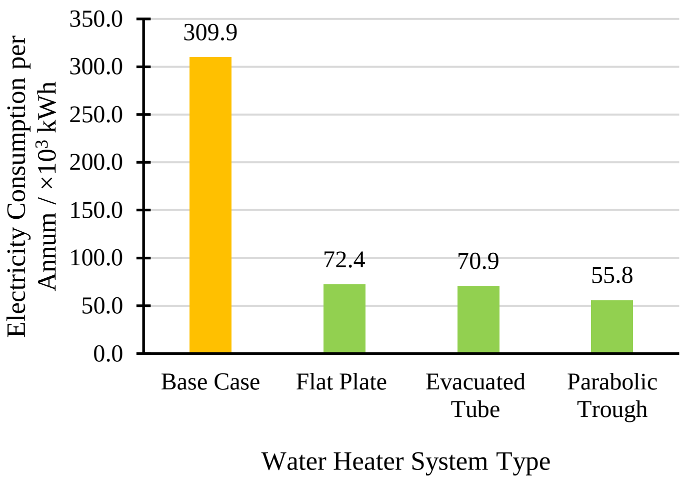

Figure 4. Electricity consumption per annum of each water heating system type

Based on the figure above it can be observed that the base case scenario which involves the use of electricity to obtain the total water heating requirement consume approximately 309,900 kWh of electricity annually. The flat plate system consumes approximately 72,400 kWh of electricity which is a 76.6% reduction in annual consumption, while the evacuated tube system consumes approximately 70,900 kWh which is a 77.1% reduction in annual consumption. Finally, the parabolic trough system consumes the least amount, approximately 55,800 kWh of electricity which is an 82.0% reduction in annual consumption. Note that these values represent electricity consumed solely to heat the required water content, hence actual consumption values may vary depending on the pump work and other electrical components involved.

3.7 Greenhouse Gas Emission Analysis of Each System

RETScreen has a built-in tool that analyses the effect a proposed case would have on the total Greenhouse Gas (GHG) emissions of the project. The software requires the user to enter the generation sources of electricity for the base case defined earlier in the software. As discussed in the introduction of this report, 49% of the total electricity generation in the country was accounted for by coal and oil in the year 2021. While the remaining energy requirement was provided by hydro and non-conventional renewable energy sources. When entering fuel types into the software, coal, hydro and oil were entered as the main constituents. Once the main constituents were entered and their respective fuel mixes, *i.e.*, percentage contribution to the grid, were entered into the software. The software then takes into account parameters such as, CO_2, CH_4 and N_2O emission factors in terms of kg/GJ of each fuel source from its database. In addition to these values the software also determines electricity generation efficiency of each fuel type and determines the total GHG emission factor.

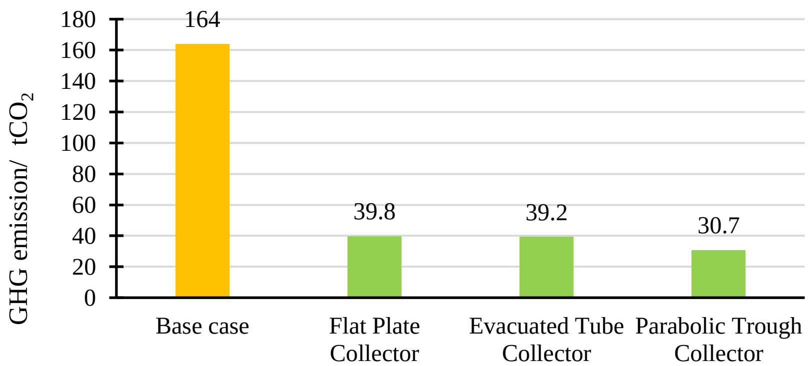

Figure 5. Annual Greenhous Gas emissions of each water heating system type

Based on the figure above it can be observed that the base case scenario which consumed the highest amount of electricity as mentioned earlier produced approximately 164 tonnes of CO_2 equivalent Greenhous Gas. The flat plate system produced approximately 39.8 tonnes of CO_2 equivalent which is a 75.7% reduction in annual emission, while the evacuated tube system produced approximately 39.2 tonnes of CO_2 equivalent which is a 76.1% reduction in annual emission. Finally, the parabolic trough system which produced the least amount due to its very low consumption of electricity, produced approximately 30.7 tonnes of CO_2 equivalent which is an 81.3% reduction in annual consumption.

4 CONCLUSIONS

In this study a suitable non-residential application was selected and the feasibility of implementing a centralised water heating system was analysed. Three types of collectors were considered and evaluated. From the theoretical calculations and simulations, it was concluded that although PTC had the highest efficiency (89.9%), the equity payback was 5.5 years higher than the ETC which had the second highest efficiency (10.5% lesser than PTC), hence the ETC setup would be the most viable option.

5 ACKNOWLEDGEMENTS

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Simulating the Effects of Active Aerodynamics on the Suspension System of a Formula Student Race Car

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ABSTRACT

Active aerodynamics is a growing topic in the automotive industry. With technological advancements at play, it has begun to spread across multiple avenues such as road vehicle ride comfort and the development of active suspension systems. However, the application of active aerodynamics in Formula cars has not been a commonly discussed topic. Furthermore, the effects of active aerodynamics on the suspension system have not been assessed for Formula Student race cars. Therefore, this study looks to obtain an understanding about how actively changing the Angles of Attack of an aerodynamic front wing and a rear wing would affect the suspension system of a Formula Student race car. The study was done by first choosing a wing profile using the XFLR5 software, modelling the front and rear wings using SolidWorks, according to the parametric guidelines of the Formula Student Competition for different angles of attack, analysing coefficients of lift and drag of the wings for each angle of attack using Ansys Workbench, and by performing full-vehicle acceleration and cornering analyses on MSC Adams Car to find how changing these coefficients affects the suspension dampers along the direction normal to the ground the vehicle travels on. This research would help understand the many forces acting on the suspension and to explore further developments in this area such as active aerodynamics in Formula Student race cars in the future.

KEYWORDS: *Aerofoil, Angle of Attack (AOA), Lift, Drag, Formula Student United Kingdom (FSUK), Computational Fluid Dynamics (CFD), Coefficient of Lift (C_L), Coefficient of Drag (C_D), Computer Aided Design (CAD).*

1 INTRODUCTION

1.1 Background

Active aerodynamics is a trending topic in the automotive industry. As a result, applications of active aerodynamics can be observed in various sectors such as racing and road vehicles. Static aerodynamics comes at a price where there is a compromise between the optimal performance levels obtainable by the vehicle aerodynamics in one environment and another. Active aerodynamics seek to improve this by changing the geometric parameters of the wing elements to suit the environment (i.e., straight line, cornering etc.). When implementing such a system, its effects on various vehicle components should first be analyzed. Hence, studies can be carried out to assess how it impacts the different suspension components of a vehicle.

This study was carried out based on a Formula Student race car, to analyze how changing the attack angles of the front and rear wings would affect their downforce and drag coefficients, and as a result, how it would affect the forces acting on the suspension dampers of the car. In this study, the wing profile was chosen after subjecting a group of aerofoils to an XFLR5 analysis. The front and rear wings were modelled based on the selected wing profile using a CAD software. The angles of attack of the modelled wings were changed, and CFD analyses were carried out to calculate their lift and drag coefficients. These coefficients were then used in running two full-assembly simulations on a multibody dynamics software to obtain the results.

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1.2 Objectives

The objectives of this study are to research and develop aerodynamic front and rear wings for a Formula Student race car, to find the coefficients of lift and drag of the wing set-ups using computational fluid dynamics software, and to analyze how these results affect the suspension dampers of a Formula Student race car.

2 LITERATURE REVIEW

Research carried out on the active control of aerodynamic surfaces for ride control in sport vehicles by Carlo Doniselli et al. (Doniselli et al., 1996) have utilized a 12-degree of freedom full car model to analyze the suspension forces. M. Corno et al. (Corno et al., 2014) have conducted research based on a quarter car model, whereas, E. Ahmed et al. (Ahmad et al., 2020) have used the half car model to carry out the research. This research was carried out using the MSC Adams multibody simulation software to obtain the forces acting on the suspension system due to the wide use of the software in the industry and the high accuracy of the results obtained.

For the numerical analysis, the Reynolds Averaged Navier Stokes equations are used. Among these equations, the SST-k-ω and k- ε variations are reviewed. According to Z. Deng et al. (Deng et al., 2020), the k- ε model can be used to express important properties in a turbulent flow. Furthermore, although, the k- ε model predicts the drag coefficient more accurately than the k-ω model, according to F. R. Menter (Menter, 1993), when the boundary layers have adverse pressure gradients, and flow separation, the performance of the k-ω model is higher than that of the k- ε model as the SST k-ω model can account for the principal shear stress transport in adverse pressure gradients. Hence, the SST k-ω model was used in this research. This calculation is done in Ansys Workbench.

According to J. Kiedrowski et al. (Kiedrowski et al., 2020), state of the art front wings consist of multiple elements. Furthermore, increasing the angle of attack of the wing elements would cause it to increase the drag coefficient up to a certain point where the wing would begin to stall. Therefore, in this research the angles of attack of one front wing element were changed and the results were taken into consideration.

According to S. Kajiwara (Kajiwara, 2017), passive type of rear wings that utilize three elements have shown to reduce the drag caused by the vehicle drastically. This research utilized three wing elements out of which two were fixed and the middle element was allowed to swing. This has shown to reduce the lap time of the car. However, in this research, two elements have been used to model the rear wing. A fixed main element and a variable, secondary element.

According to V. Kshirsagar et al. (Kshirsagar & Chopade, 2018), the vehicle should be subjected to a wind tunnel test, CFD simulations and a track test. This research focuses on the Computational Fluid Dynamics aspect among these tests.

Based on studies carried out by Shafi Md. Istiak et al. (Flay et al., 2008), Flat et al (Flay et al., 2008), and Shreyas Vaidya et al. (Shreyas Vaidya & Chinmay Kulkarni, 2017), the NACA4412, E423, and the S1223 airfoils are the most suitable airfoils to be used in Formula Student cars. Hence, these wing profiles were considered when selecting an aerofoil for the research.

3 METHODOLOGY

3.1 Selecting a Suitable Aerofoil

As per the referred literature, three aerofoils were shortlisted. They are namely, S1223, E423, and NACA4412. The aerofoil analysis shown in Figure 1 was carried out on the XFLR5 software, and they portray the pressure coefficients of the shortlisted wing profiles. The following excerpts of the graphs drawn by the software depict the Coefficient of Lift (C_L) and Coefficient of Drag (C_D) variations at different angles of attack simulated at an air velocity of 20m/s.

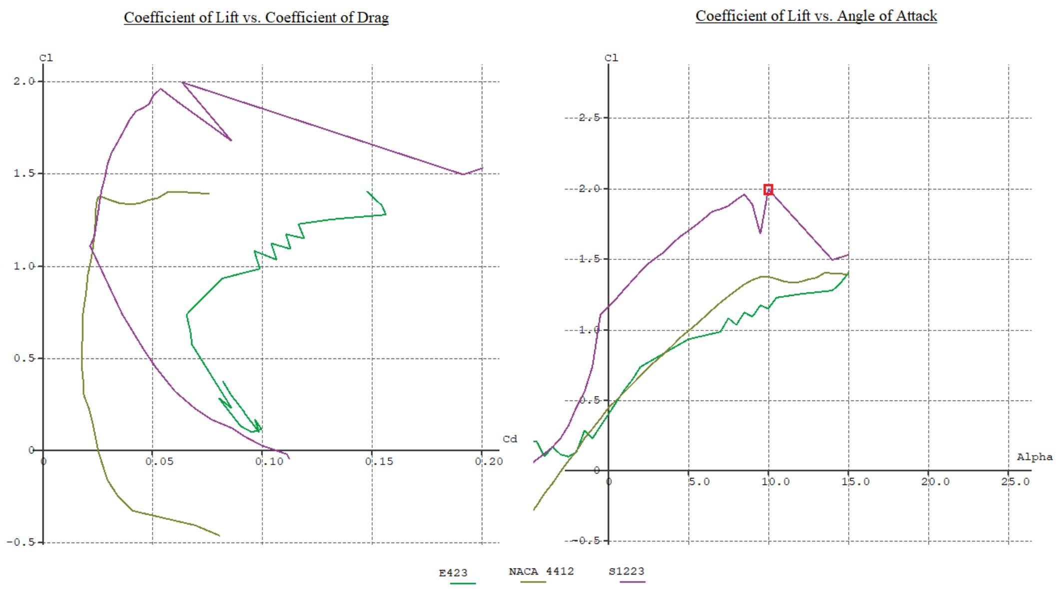

Figure 1. C_L vs. C_D, and C_L vs. AOA of the selected aerofoils

By observing Figure 1, it can be noticed that the S1223 aerofoil provides the best combination between the Lift and Drag Coefficients. Furthermore, it can also be observed that the angle of attack which provides the highest Coefficient of Lift by any of the selected wings, is shown by the S1223 aerofoil at an angle of 10°. This aerofoil will be used in the rear wing elements as well as the front wing elements. The angle of attack will be selected as 10°, based on the results from the XFLR5 simulations carried out.

3.2 Computational Modelling of the Wings

When modelling the front and rear wings on SolidWorks, the parametric guidelines of the FSUK competition were adhered. The span of the front wing was kept at 1520mm, the chord length of the main front element is 500mm, and the chord length of the entire front wing set-up is 700mm. The chord length of the main rear element is 500mm, the chord length of the secondary element is 250mm. The span of the rear wing is 1020mm.

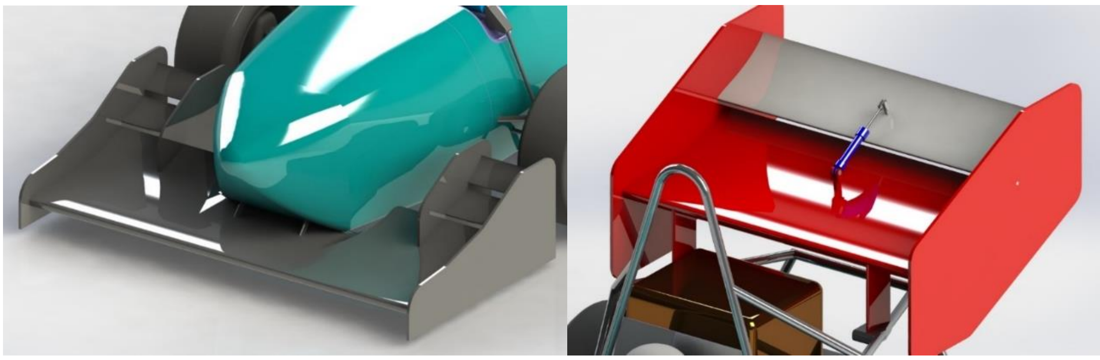

Figure 2. The Front and Rear Wings Modelled for the Study

Figures 2, 3 and 4 show the front and rear wings respectively. The AOA of the second element of the front wing were adjusted to emulate the adjustments made by the active aerodynamic system whereas, the second element of the rear wing was adjusted for the same purpose. In this case, the attack angle of the front wing was changed by factors of 5, starting from 20° whereas, the angle of attack of the rear wing was changed by factors of 10, starting from 20°. Three separate SolidWorks models for the front wing with three different AOAs, and three separate models for the rear wing with three different AOAs were constructed and were used along with the vehicle body developed by the racing team. These models were then subjected to CFD simulations where the lift and drag coefficients were calculated.

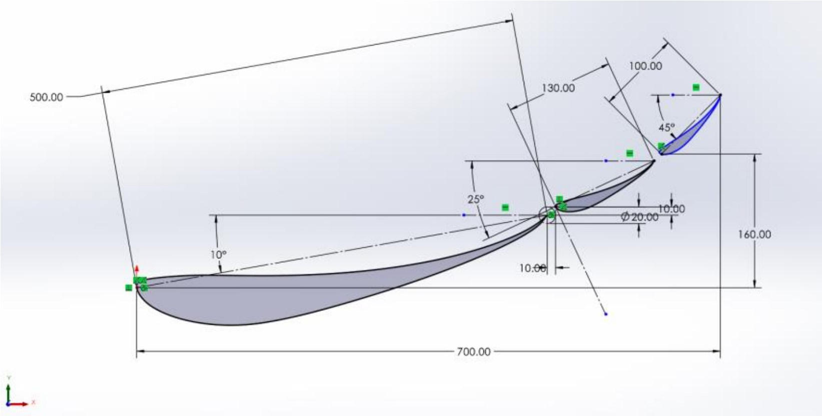

Figure 3. Front Wing Parameters

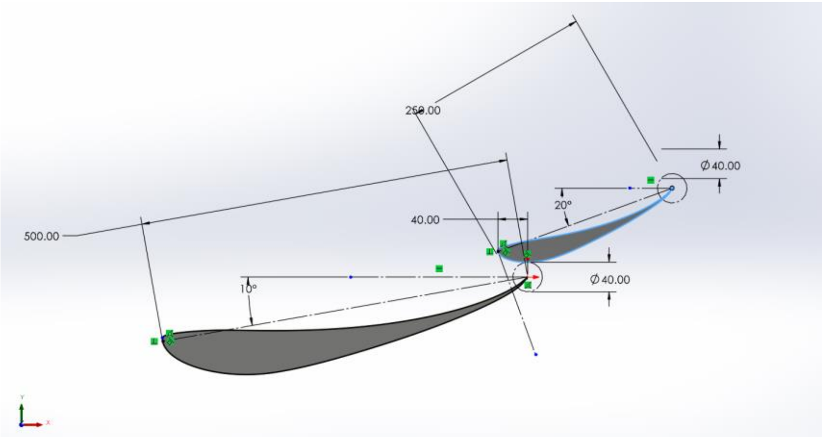

Figure 4. Rear Wing Parameters

3.3 Computational Fluid Dynamics (CFD) Analyses

Table 1. Enclosure Parameters

Dimension	Value
H1	1.25m
H2	7.5m
V3	3.0m
V4	2.5m
Width (Extruded)	3.0m

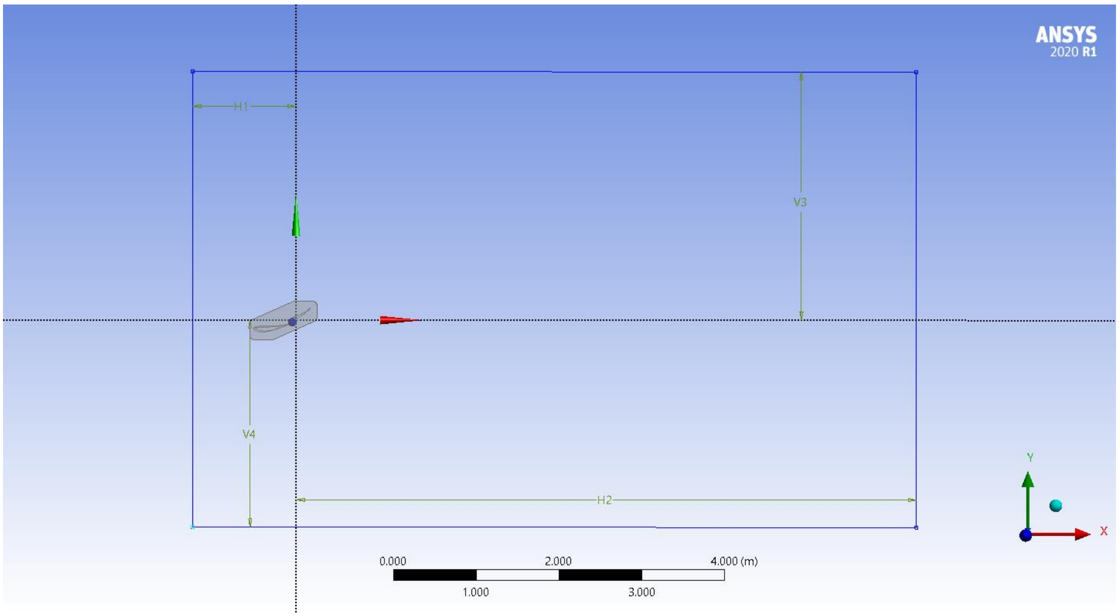

Figure 5. Graphical representation of the computational domain

The CFD analyses for the front and rear wing variations were carried out based on the parameters shown in Table 1 and depicted in Figure 5. Further refinements to the mesh were done by adding another block that was 0.6m in height, starting from the rear edge of the wing. Edge sizing, and inflations were added to refine the mesh. The following are several excerpts from the CFD simulations carried out. The wings were cut in half to reduce the computational capacity required for the simulations. The pressure and velocity acting on the wings were calculated. The contours in Figure 6 show the pressure gradients and the velocity gradients from one of the nine simulations carried out.

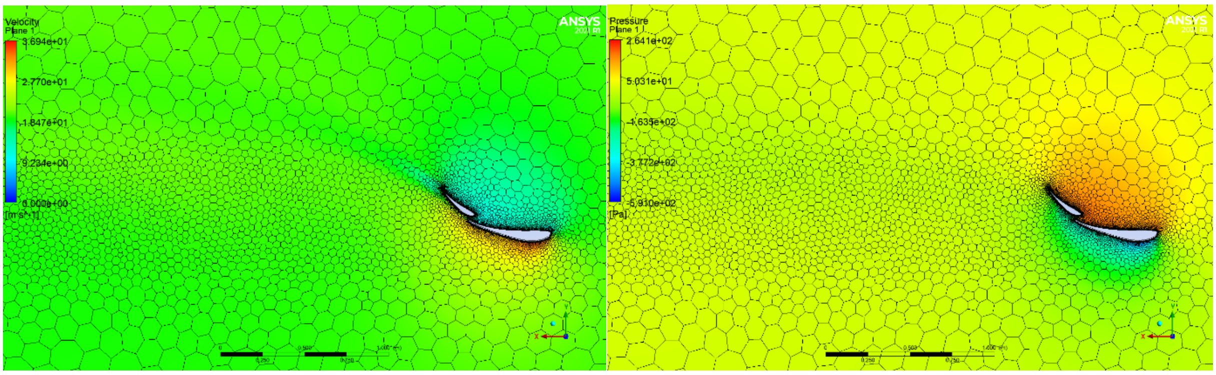

Figure 6. The Hex-Meshed Pressure and Velocity Contours of a 40° Rear Wing

The goal of the simulations shown in Figure 6 was to find the coefficients of lift and drag on the wings, to be used for the MSC Adams simulations. The contours in Figure 6 show the areas where there is high velocity in the front and rear wings. In the high-velocity areas, the pressure is less, whereas, in low velocity areas, the pressure is high. This effect creates a downforce on the wing. This is shown in Figure 6 with respect to the rear wing with an angle of attack of 40°. The Hex Mesh is shown here to depict the refinements of the mesh to improve the accuracy of the study. The simulations for the race car body were carried out on SimFlow and postprocessed using the Paraview postprocessor. The CFD analysis results obtained for different front and rear wing angle of attack combinations are shown in Table 2.

Table 2. Lift and Drag Coefficients and Projected Area required for Adams Analyses

Wing	Component and/or AOA	Coefficient of Downforce $(-C_L)$	Coefficient of Drag (C_D)	Air Speed (m/s^2)	Air Density (kg/m)	Projected Frontal Area (mm^2)
Front Wing	20°	0.30	0.07	20	1.225	238748.28
	25°	0.44	0.07	20	1.225	238748.28
	30°	0.40	0.09	20	1.225	238748.28
Rear Wing	20°	0.49	0.11	20	1.225	240785.84
	30°	0.61	0.16	20	1.225	274851.57
	40°	0.73	0.23	20	1.225	307093.9
Chassis	Chassis	0.31	0.71	20	1.225	947574.6

The coefficients of lift are negative as a result of the forces produced by the inverted aerofoils, towards the ground direction. Hence, this force is known as the 'downforce.' The coefficients of lift (in this case, coefficients of downforce) of the front wing seem to have improved up to 25° and dropped at 30°. The coefficients of lift of the rear wings seem to have improved up to an AOA of 40°. The drag coefficients seem to have improved in the front wings up to 30° whereas, the drag coefficients of the rear wing have increased up to an AOA of 40°.

3.4 Vehicle Dynamics Simulations

Two Adams Car simulations were carried out for nine different Front and Rear Wing combinations. The first type of simulation carried out was a Straight-Line Acceleration Event. This was done to analyse how the vehicle components (in this study, the suspension damper) act when subjected to straight-line acceleration. In this event, a starting velocity of 20kmph at the second gear, and a final throttle of 100 were provided. The vehicle shift gears until the acceleration event is completed after duration of the simulation. The second type of simulation carried out was a Constant Radius Cornering Event for the vehicle. This was done to analyse how the vehicle components (in this study, the suspension damper) react when subjected to a cornering event. For this event, an arbitrary value of 61m was provided as the cornering radius, the starting gear position was given as 2nd, the final velocity was given as 80kmph, and the initial velocity was given as 10kmph. These values were kept constant throughout the entire study. The default parameters of the Adams Car Formula Student race car model were used for the reference model. The Acceleration and Cornering event settings were adjusted as shown in Tables 3 and 4.

Table 3. Acceleration Event Settings

Variable	Value
End Time/Duration	50 Sec
Number of Steps	500
Velocity	20 km/hr
Gear Position	2
Steering Input	Straight Line
Start Time	10 Sec
Final Throttle	100
Duration of Step	0.1

Table 4. Cornering Event Settings

Variable	**Value**
End Time/Duration	50 Sec
Number of Steps	500
Initial Velocity	10 km/hr
Gear Position	2
Duration of Manoeuvre	10 Sec
Final Velocity	80 km/hr
Turn Radius	61m

4 RESULTS AND DISCUSSION

4.1 For a 25° Front Wing and a 30° Rear Wing

- Acceleration Event

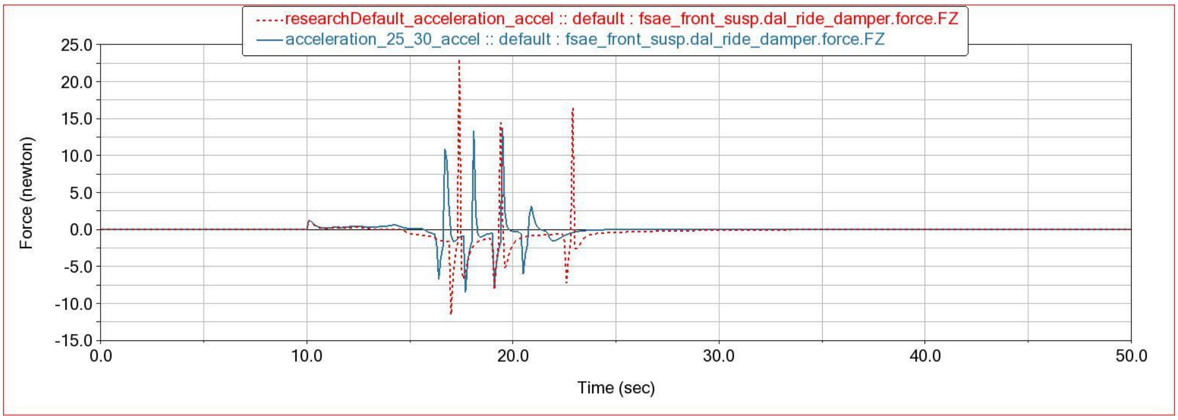

Figure 7. Front-Left Suspension Damper

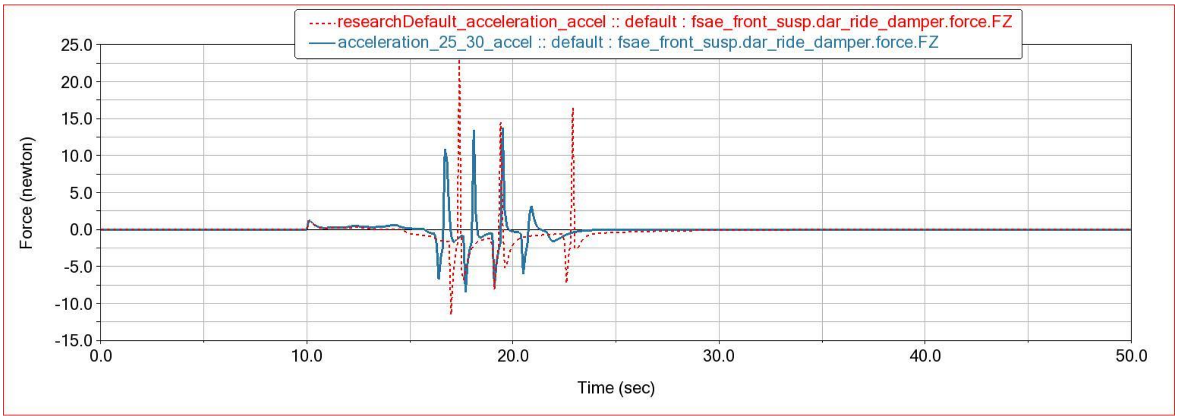

Figure 8. Front-Right Suspension Damper

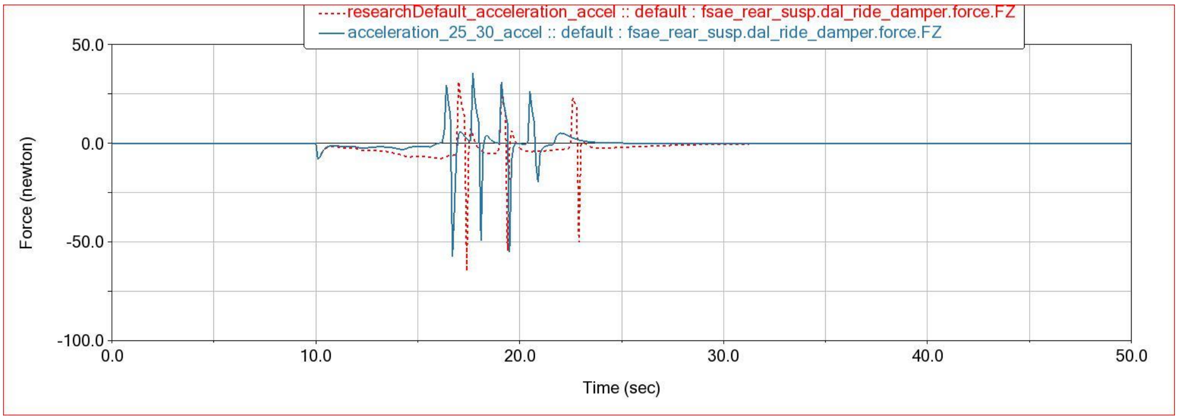

Figure 9. Rear-Left Suspension Damper

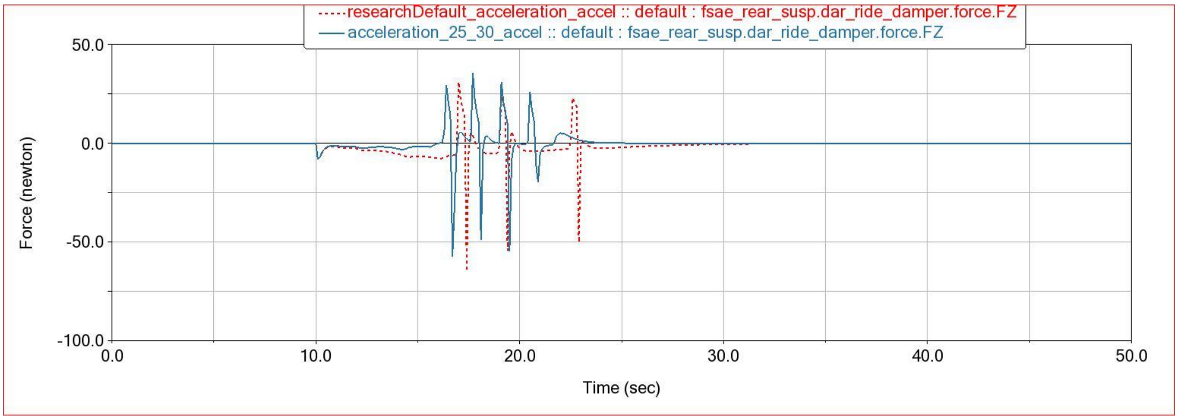

Figure 10. Rear-Right Suspension Damper

In the acceleration event (Figured 7 – 10), it can be observed that the forces acting on the suspension dampers have reduced due to the low downforce coefficient of the newly designed wings. However, it can also be observed that the rate of braking that occurs in the vehicle has improved. The car reaches overdrive at a higher rate. This may be due to the dramatically low drag coefficients recorded by the newly designed wings in comparison to the reference model in Adams Car.

- Constant Radius Cornering Event

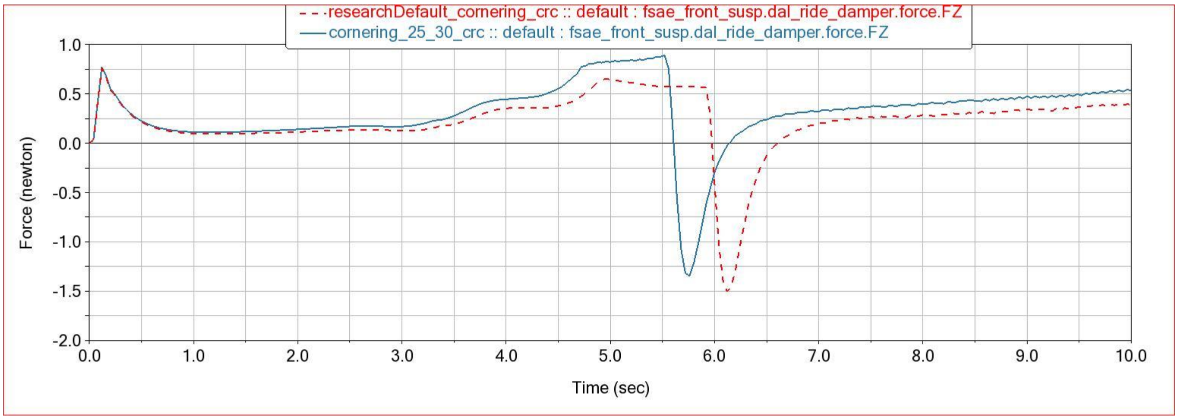

Figure 11. Front-Left Suspension Damper

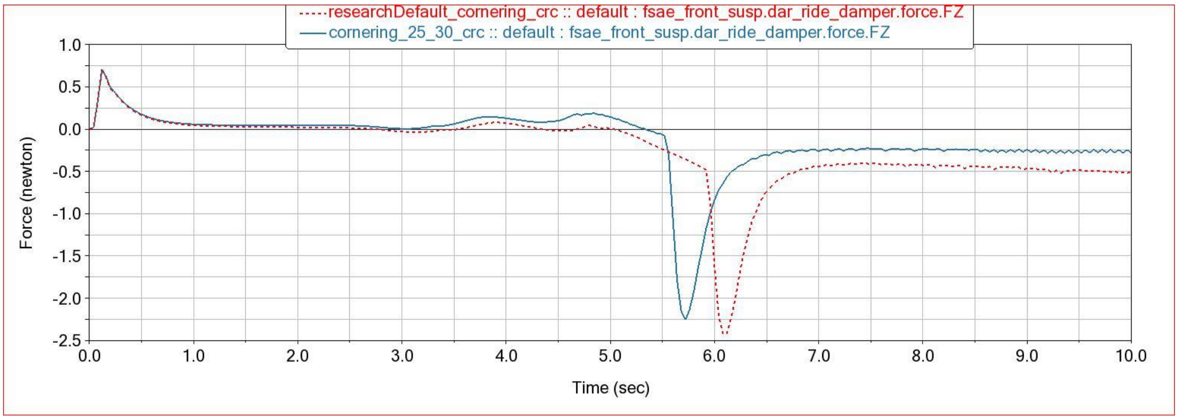

Figure 12. Front-Right Suspension Damper

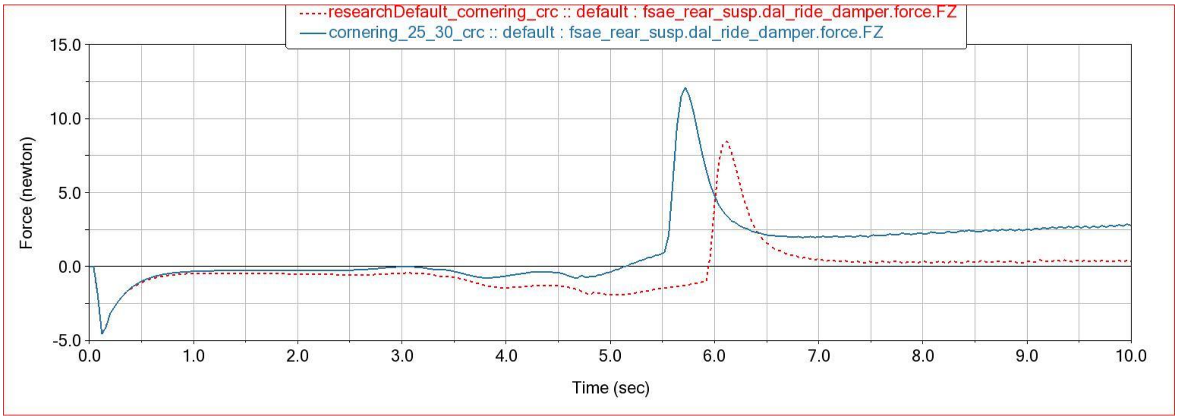

Figure 13. Rear-Left Suspension Damper

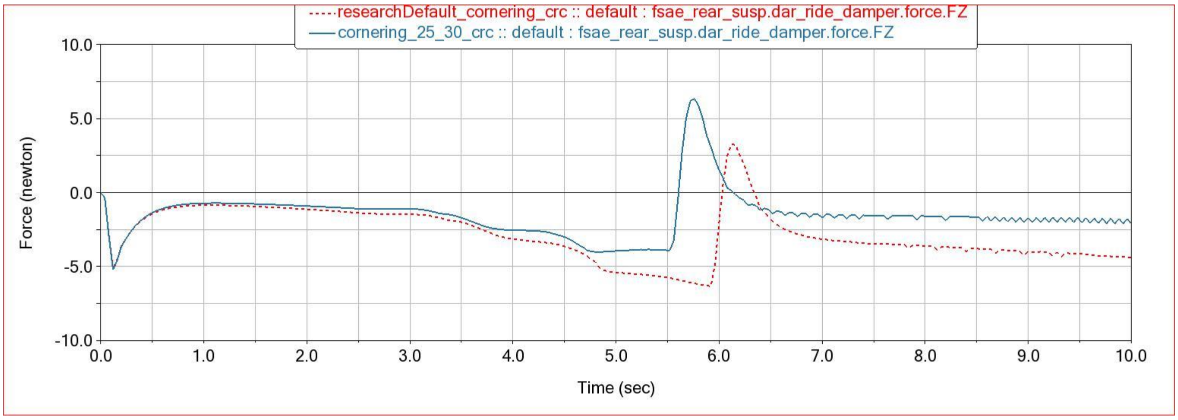

Figure 14. Rear-Right Suspension Damper

In the cornering event (Figures 11 – 14), it can be observed that the forces acting on the suspension dampers are comparatively lower than the reference model. This would be due to the reduced downforce coefficient in the newly designed wings. However, the rate at which the race car approaches the evident force fluctuation has increased in the new design compared to the reference model. It can also be observed that the right side of the race car experiences a higher force due to the centrifugal effect as the vehicle is turning in the left direction. It can also be observed that several dampers experience vibrations during the cornering event. In order to avoid these vibrations, attack angle combinations that show the lowest levels of vibrations may be chosen.

5 CONCLUSIONS

This study was carried out to find out how changing the angles of attack of a rear wing and a front wing would affect the suspension system of a Formula Student race car. The objectives of this study were to research and develop an active aerodynamic system for a Formula Student race car, and to analyse its effects on the suspension system. In order to achieve these objectives, first, a wing profile was chosen, and it was used to model the front and rear wings accordingly. Thereafter, CFD analyses were carried out and the lift and drag coefficients obtained from the analyses were then used to perform acceleration and cornering analyses for the Formula Student race car. From this analysis, the vertical forces acting on the suspension dampers were collected as the result of the study.

- Several combinations of front and rear wing attack angles provide smooth riding with minimum vibrations in the Z direction in cornering and acceleration events.
- According to the study, the combinations for the cornering events are 20° (front) - 40° (rear), 25° (front) - 40° (rear) and 30° (front) - 30° (rear). Among these combinations, 25° (front) - 40° (rear) may stand out due to the high downforce of the wings.
- In an acceleration event, due to the lower drag and the high downforce, 20° or 25° may be chosen as the angle of attack of the front wing, and the angle of attack of 30° may be chosen as the rear wing due to the high downforce coefficient and a lower drag coefficient compared to an angle of 40°.
- Based on the above considerations, a cost-effective method to design the front and rear wings would be to fix the variable element of the front wing at 25° and to adjust the angle of the variable element of the rear wing from 30° - 40° as required.
- However, this should be one out of many considerations when designing an active aerodynamic system.

The obtained results can be used to improve the suspension system of a formula student race car to make way for an active aerodynamic system. Similar research on active aerodynamics can be done in order to develop an active suspension system. Furthermore, other components such as the sidepod grills can be controlled using active aerodynamics and research can be carried out to find out the effects of such elements on various aspects of a Formula Student race car.

The results obtained show a considerable difference in the forces acting on the suspension dampers compared to the reference model. However, the accuracy of the study can be further improved to generate better results. This study was focused on the forces acting on the suspension dampers of the race car. Further results such as the displacement of the suspension caused by the aerodynamic changes, the forces acting on other components, other directions, and fluctuations in other variables can be found out using the same simulation. Furthermore, in this study, the forces were analysed along the Z direction. A reference model was used to compare these plots. However, due to the reference plot not being static in each plot, the clarity of the results were somewhat low. Therefore, methods can be used to keep the reference model plot static while the other plots are drawn according to that and not vice versa. Furthermore, in this study, the focus was on obtaining results to have an understanding about how active aerodynamics would affect the suspension system of a Formula Student Race Car. Hence, the aerodynamic optimization aspect was not prioritized. Therefore, in order to improve the accuracy of the research, the aerodynamics can be further optimized or already optimized aerodynamic data can be used. Furthermore, the forces can be analysed in the X-direction to obtain an overall understanding about the force distribution on the suspension dampers from the XZ plane. Moreover, the material selection for fabricating the front and rear wings can be carried out based on Adams Car simulations such as the ones carried out in this study. In the constant radius cornering event, the radius can be changed according to the corner radiuses of the target race tracks. This would improve the accuracy of the results gathered through the cornering event simulation.

The results from this research can be used in improving the suspension system of a Formula Student race car making way for further developments in its aerodynamic load handling capabilities. Furthermore, the individual damper force fluctuation results can be considered when improving the suspension system for developments such as building closed loop active aerodynamic or active suspension systems.

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Conceptual Design of Short Range - Low Altitude Fixed Wing Unmanned Aerial Vehicle For Landmine Detection

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ABSTRACT

Over the past five decades, landmines are creating serious problems all over the world. Even though many UAVs are being developed for demining, many of them are not available to the humanitarian activities. Designing a UAV for demining from the air is challenging and there are only a few UAVs employed in landmines search in Sri Lanka. This research designs a fixed-wing UAV with a total mass of 47 kg, with 10 kg dedicated to payload. It can fly with a maximum speed of 30 m/s continuously for 40 minutes. This UAV detect landmines using ground penetrating radar in no wetted areas. Several manual calculations and software such as Microsoft Excel, XFLR 5, X-Foil, CATIA V5, and ANSYS 19 were used to complete the conceptual design.

KEYWORDS: *Demining, fixed-wing UAV, design, Performance*

NOMENCLATURE

$\frac{W}{S}$ (N/m^2) - Wing loading
$\frac{W}{P}$ $(N/Watt)$ - Power loading
$(L/D)_{max}$ - Maximum lift to drag
S_{TO} (m) – Take off distance
C_{L_R} - Take off rotation lift coefficient
C_{D_0} - Zero-lift drag coefficient
g (m/s^2) - Gravitational acceleration
ρ (kg/m^3) - Density of the air
C_{Lmax} - Maximum lift coefficient
V_{max} (m/s) - Maximum velocity
V_s (m/s) - Stall speed
η_P - Propeller efficiency
V_{TO} (m/s) - Take off velocity
μ - Rolling friction
$\Delta\alpha_{L0}$ (deg) - Change in zero lift angle of attack
K_E - Engine weight factor
N_E - Engine number
W_E (N) - Weight of the engine of the UAV
UAV - Unmanned Aerial Vehicle
CG - Center of gravity
MAG – Mines Advisory Group
GPR – Ground Penetrating Radar

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1 INTRODUCTION

Landmines and ammunitions are creating significant threat to the people and animals. After the war in Sri Lanka, the landmines remain in the land and it plays a vital role in civilian's security. Children are at the highest risk since, the unexploded bomb can look like a tempting toy to an inquisitive child (Daisan 2020). Since the end of the war in 2009, MAG has cleared more than 882 square kilometers of land, and demined more than 42,000 mines and 14,800 other unexploded bombs in Sri Lanka (Annual Progress Report on National Mine Action Programme 2013). As indicated by Mine Kafon (Hassani, 2011), a Dutch organization evaluated the required time for complete demining of landmines and other explosives utilizing current strategies to be roughly 1000 years. So building up the quickest demining framework is fundamental, and can be conceivable via an airborne demining framework. The landmines can be found everywhere, including forest, desert, sea shore, buildings and so on (Habib, 2007). Since the UAVs are able to fly through narrow trajectories, close to the ground, move faster and perform difficult maneuver, it is widely employed in demining operations across the world by developed countries. Yet this demining process using drones is not widely employed in Sri Lanka and other developing countries (Gerard-Pearse 2018) due to its high cost of production, operation and maintenance. But serious threats like landmines to human lives have to be removed at any cost since many landmines stay in the ground without degrading for decades. So, designing UAVs are important and will ease the demining process.

Since there are many issues yet to be solved on UAV research and its applications, this research area is going to be expanding in the forthcoming years (Francesco Nex 1, 2019). The requirements for demining UAVs to fly at lower altitudes due to GPR sensor limitations necessitates the development of a low-cost air-based vehicle (Goad and Schorer 2008) (Hassani, 2011). Even though certain demining groups are already employing UAVs for monitoring and mapping purposes, the use of drones in the demining industry in Sri Lanka is not well established.

This paper highlights the importance of designing an affordable yet robust fixed wing UAV with GPR sensor for developing countries. The purpose of this project is to design a fixed wing UAV with a landmine searching sensor with a mass of 10 kg. The steps involved in this project for designing the UAV is followed by various stages and methods such as preliminary design, aerodynamic calculation, propulsion system selection, selection of materials and structural calculations and finally weight calculation and performance analysis. The design process starts with mission requirements and mission profile. The mission profile consists of several stages such as take-off, climbing, cruising, loitering, descending and landing.

2 MISSION SPECIFICATION

2.1 Mission requirements

Maximum speed: 30 m/s.
Absolute ceiling: not more than 250 m.
Rate of climb: 1.5 m/s maximum
Take-off run: 150 m.
g limit: more than +7.5.
To be able to carry a variety of sensors with a mass of 10 kg
Stall speed: 21 m/s.
Endurance: 40 minutes.
Range: 15 kms.

2.2 Mission Profile

The mission profile contains five phases: take-off, climb, cruise, loiter and landing. The UAV is designed to search landmines for 40 minutes. The 15 km range is dedicated to complete all the other four phases.

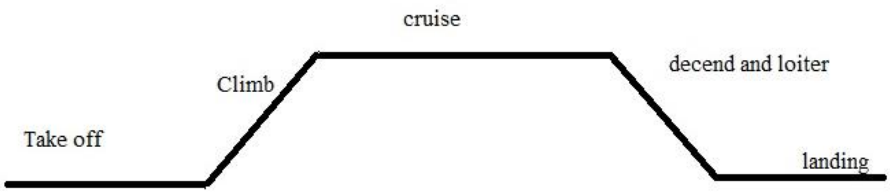

Figure 1. Mission profile

3 METHODOLOGY

The camera-ready paper has to be submitted electronically via the website of the conference (http://www.sliit.lk/sices) where a link to the Conference Management System would be found. Please also refer to the website for deadlines.

The UAV design can be divided into four major steps such as conceptual design, preliminary design, detail design, and test & evaluation (Sadraey 2013). In the conceptual design stage of a propeller-driven UAV, the maximum takeoff weight (MTOW) estimation, constraints analysis and conceptual sketch were carried out. From Raymer (Raymer 2018) using equation 1, the MTOW is estimated. To determine the required wing area and power, equations 2, 3, 4 and 5 are used. Conceptual sketch is modelled in CATIA V5.

Maximum takeoff weight (MTOW) estimation:

$$W_{TO} = \frac{W_{PL}}{1-\left(\frac{W_F}{W_{TO}}\right)-\left(\frac{W_E}{W_{TO}}\right)} \tag{1}$$

Wing loading:

$$\left(\frac{W}{S}\right)_{V_s} = \frac{1}{2}\rho V_s^2 C_{Lmax} \tag{2}$$

Takeoff Run:

$$\left(\frac{W}{P}\right)_{S_{TO}} = \frac{1-exp\left(0.6\rho g C_{D_G} S_{TO}\frac{1}{\frac{W}{S}}\right)}{\mu-\left(\mu+\frac{C_{D_G}}{C_{L_R}}\right)\left[exp\left(0.6\rho g C_{D_G} S_{TO}\frac{1}{\frac{W}{S}}\right)\right]}\frac{\eta_P}{V_{TO}} \tag{3}$$

Rate of climb:

$$\left(\frac{W}{P}\right)_{ROC} = \frac{1}{\frac{ROC}{\eta_P}+\sqrt{\frac{2}{\rho\sqrt{\frac{3C_{D_0}}{K}}}\left(\frac{W}{S}\right)}\quad\left(\frac{1.155}{(L/D)_{max}\eta_P}\right)} \tag{4}$$

Maximum velocity:

$$\left(\frac{W}{P_{SL}}\right)_{Vmax} = \frac{\eta_P}{0.5\rho_0 V_{max}^3 C_{D_0}\frac{1}{\frac{W}{S}}+\frac{2K}{\rho\sigma V_{max}}\left(\frac{W}{S}\right)} \tag{5}$$

In the preliminary design, wing, horizontal tail, vertical tail, engine, propeller, fuselage, landing gear are sized using following methods. The wing design is followed by several steps such as airfoil selection, calculation of wing parameters and selection of high lift device.

The aspect ratio of the wing is selected from the range based on the conceptual sketch and statistics (Raymer 2018). In order to avoid complexities in wing manufacturing, the simple rectangular shape is selected without twist and dihedral. The stall speed is selected from the mission requirements. The maximum coefficient of lift at stall speed is determined from Sadreay (Sadraey 2013). The suitable airfoil shape is selected from (Eppler, 1990). After selecting an airfoil, the wing analysis is carried out using VLM method (NASA-SP-405, 1976) to verify whether the wing alone produce required coefficient of lift value. Since the airfoil is not producing sufficient lift coefficient, the suitable flap and flap parameters are determined using analytical solution given in Sadraey (Sadraey 2013). The lift increment due to flap deflection is calculated using XFLR (XFLR5, 2019) and NASA TN3911 (Laitone 1989).

$$\Delta\alpha_{L0} \approx -1.15\frac{C_f}{C}\delta_f \tag{6}$$

$$\Delta\alpha_{Lo} = \frac{\partial\alpha}{\partial\delta}\, cos\Lambda_{HL}\delta[1 - (a + b\beta)|\delta|] \tag{7}$$

The next component is tail, which includes horizontal and vertical tail. From (Raymer 2018), the tail volume ratio for both tail are determined. And the tail location is determined based on equation 8.

$$l = K_c\sqrt{\frac{4CSV_H}{\pi D_f}} \tag{8}$$

If the tail section is rectangle then dihedral, twist angle, taper ratio and sweep angle should be zero. Since the horizontal tail influences the longitudinal stability, the moment should be balanced. From (Sadraey 2013), the required horizontal lift coefficient is calculated using trim equation 9.

$$C_{L_h} = \frac{C_{m_{owf}} + C_{L\_w}(h - h_o)}{V_H} \tag{9}$$

The airfoil is selected for horizontal tail using equation 9. The tail setting angle is decided based on the trim requirement after calculating the downwash effect due to wing and the longitudinal stability is calculated using equation 10.

$$C_{m_\alpha} = C_{L_{\alpha wf}}(h - h_o)\; - C_{L_{\alpha h}}\eta_h \frac{S_h}{S}\left(\frac{l}{C} - h\right)\left(1 - \frac{d\varepsilon}{d\alpha}\right) \tag{10}$$

For single propeller aircraft, the yawing moment is trimmed by setting the vertical tail at some incidence angle. The initial seizing parameters such as tail volume ratio, aspect ratio and maximum thickness to chord ratio are determined based on the historical data and analytical calculations from Raymer (Raymer 2018).

The engine is selected based on power requirement and is calculated by constraints analysis. The maximum propeller diameter is determined using equation 11.

$$D_P = K_{nP}\sqrt{\frac{2\, P\eta_P AR_P}{\rho V_{av}^2 C_{LP} V_C}} \tag{11}$$

The thrust generated is calculated using momentum disk theory and propeller performance parameters are calculated using analytical approach. After finding these parameters, the suitable propeller is chosen from the manufacturer (Mejzlik, 1974).

One of the crucial components of the aircraft is fuselage. The internal arrangements are carried out based on few parameters and rules such as shape of the fuselage, symmetry, position of fuel tank, payload and other components. The fuselage length to diameter ratio is determined based on historical data available at Sadreay (Sadraey 2013). The shape is determined based on the drag coefficient.

The initial sizing parameters of the landing gear such as height, wheelbase, and wheel track are calculated using analytical approach according to Sadreay (Sadraey 2013). The ground controllability and stability are determined by the analytical method given in Sadreay (Sadraey 2013). The CG of the UAV influences significantly on the position of the landing gear, and the position of front and rear wheel are determined based on tip back and tip forward requirements.

The weights of the components of the aircraft are estimated using the equations 12, 13, 14, 15, 16 and 17. These are based on the statistical methods and empirical relations (Roskam 2018) (Torenbeek, 1982)

3.1 Wing Weight

$$W_W = S_W\, MAC\, \left(\frac{t}{C}\right)_{max} \rho_{mat} K_\rho \left(\frac{AR\, n_{ult}}{\cos(\Lambda_{\,0.25})}\right)^{0.6} \lambda^{0.04}\, g \tag{12}$$

MAC is the Mean Aerodynamic Chord of the wing and taper ratio is λ. n_{ult} is the ultimate load factor. Sweep angle at the quarter chord position is $\Lambda_{\,0.25}$. For safety purpose of the aircraft structure, the ultimate load factor is taken as 1.5 times higher than the maximum load factor (Sadraey 2013).

3.2 Horizontal Tail Weight

$$W_{HT} = S_{HT}\, MAC_{HT} \left(\frac{t}{C}\right)_{\max HT} \rho_{mat} K_{\rho\, HT} \left(\frac{AR_{\,HT}}{\cos(\Lambda_{\,0.25\,HT})}\right)^{0.6} \lambda_{HT}^{0.04}\;\; \overline{V}_H^{\,0.3}\; \left(\frac{C_e}{C_T}\right)^{0.4} g \tag{13}$$

S_{HT} is the horizontal tail area, $\left(\frac{C_e}{C_T}\right)$ is the ratio of the elevator to tail chord and V_H denotes the horizontal tail volume ratio.

3.3 Vertical Tail Weight

The weight of the vertical tail depends on various parameters such as vertical tail area (S_{VT}), material density (ρ_{mat}), tail volume ratio, maximum thickness to chord ratio $\left(\frac{t}{C}\right)_{\max VT}$. Empirical equation 14 can be used to calculate the weight of the vertical tail.

$$W_{VT} = S_{VT}\, MAC_{VT} \left(\frac{t}{C}\right)_{\max VT} \rho_{mat} K_{\rho\, VT} \left(\frac{AR_{VT}}{\cos(\Lambda_{0.25\, VT})}\right)^{0.6} \lambda_{VT}^{0.04} \;\; \overline{V}_V^{0.3} \;\; \left(\frac{C_r}{C_V}\right)^{0.4} g \tag{14}$$

3.4 Weight of the Fuselage

$$W_F = L_F\, D_{f_{max}}^2 \rho_{mat} K_{\rho f} n_{ult}^{0.25} K_{inlet}\, g \tag{15}$$

The K_{inlet} is 1 for the aircrafts except for the one which has inlet on the fuselage. So in my case, it is 1. The UAV has a lighter fuselage as it does not carry humans.

3.5 Weight of the Landing gear

The height of the landing gear, configuration, material, landing run, speed during the landing, weight at landing and ultimate load factor during the landing are parameters that determine the weight of the landing gear.

$$W_{LG} = K_L\, K_{ret}\, K_{LG}\, W_L \left(\frac{H_{LG}}{b}\right) n_{ult\, land}^{0.2} \tag{16}$$

3.6 Weight of the Installed Engine

The required components or installation parts for engine mounting weight is calculated using the empirical relation 17.

$$W_{E\, ins} = K_E\, N_E\, (W_E)^{0.9} \tag{17}$$

Where $K_E\ and\ N_E$ (engine weight factor and engine number) are 3 and 1 respectively.

In the aircraft weight distribution, two parameters are calculated and they are CG and moment of inertia. CG limit is determined using Excel solver option for varying location of the fuel, sensor and systems.

The maneuver diagram is determined based on (Glīzde 2017). The power requirement (P_{req}) curve is constructed using equation number 18.

$$P_{req} = \frac{1}{2}\rho V^3 S C_{D_0} + \frac{\frac{W^2}{1/2\rho VS}}{\pi ARe} \tag{18}$$

4 CALCULATIONS

Conclusions should state concisely the most important propositions of the paper as well as the author's views of the practical implications of the results.

According to equation 1, the maximum take-off weight is calculated as follows,

$$W_{TO} = \frac{W_{PL}}{1 - \left(\frac{W_F}{W_{TO}}\right) - \left(\frac{W_E}{W_{TO}}\right)} = 461\ N$$

The increment in zero lift angle due to flap deflection is calculated according to equations 6 and 7.

$$\Delta\alpha_0 \approx -1.15\frac{C_f}{C}\delta_f = -7\ deg$$

$$\Delta\alpha_{Lo} = \frac{\partial\alpha}{\partial\delta}\ cos\Lambda_{HL}\delta[1-(a+b\beta)|\delta|] = -6.83$$

The location of the tail from CG is determined based on equation 8,

$$l = K_c\sqrt{\frac{4CSV_H}{\pi D_f}} = 1.2\ \ m$$

The required horizontal lift coefficient is calculated using trim equation 9,

$$C_{L_h} = \frac{C_{m_{owf}} + C_{L\_w}(h - h_o)}{V_H} = -0.1263$$

The longitudinal stability is calculated using equation 10

$$C_{m_\alpha} = C_{L_{\alpha wf}}(h - h_o) - C_{L_{\alpha h}}\eta_h \frac{S_h}{S}\left(\frac{l}{C} - h\right)\left(1 - \frac{d\varepsilon}{d\alpha}\right) = -1.4 \quad 1/rad$$

The maximum propeller diameter is determined using equation 11.

$$D_P = K_{nP}\sqrt{\frac{2\,P\eta_P AR_P}{\rho V_{av}^2 C_{LP} V_C}} = 0.67\ m$$

The wing component weight is calculated from equation 12. Since the wing is rectangular in shape, the sweep angle, taper ratio, and dihedral angle became zero.

$$W_W = S_W\ MAC\ \left(\frac{t}{C}\right)_{max} \rho_{mat} K_\rho \left(\frac{AR\ n_{ult}}{\cos(\Lambda_{\ 0.25})}\right)^{0.6} \lambda^{0.04}\ g = 62.23\ N$$

The horizontal component of the weight of the tail is calculated from equation 13. NACA 0009 airfoil is chosen for both horizontal and vertical tails.

$$W_{HT} = S_{HT}\ MAC_{HT}\left(\frac{t}{C}\right)_{\max HT} \rho_{mat} K_{\rho\ HT}\left(\frac{AR_{\ HT}}{\cos(\Lambda_{\ 0.25\ HT})}\right)^{0.6} \lambda_{HT}^{0.04}\ \ \overline{V}_H^{0.3}\ \left(\frac{C_e}{C_T}\right)^{0.4} g = 39.2\ N$$

The vertical component of the weight of the tail is calculated from equation 14

$$W_{VT} = S_{VT}\ MAC_{VT}\ \left(\frac{t}{C}\right)_{\max VT} \rho_{mat} K_{\rho\ VT}\left(\frac{AR_{\ VT}}{\cos(\Lambda_{\ 0.25\ VT})}\right)^{0.6} \lambda_{VT}^{0.04}\ \ \overline{V}_V^{0.3}\ \left(\frac{C_r}{C_V}\right)^{0.4} g = 13.46\ N$$

The weight of the fuselage is calculated from equation 15

$$W_F = L_F\ D_{f_{max}}^2 \rho_{mat} K_{\rho f} n_{ult}^{0.25} K_{\ inlet}\ g = 59.75\ N$$

The weight of the landing gear is calculated from equation 16

$$W_{LG} = K_L\ K_{ret}\ K_{LG}\ W_L\ \left(\frac{H_{LG}}{b}\right) n_{ult\ land}^{0.2} = 68.3\ N$$

The weight of the components used for the installation of the engine is calculated from equation 17.

$$W_{E\ ins} = K_E\ N_E\ (W_E)^{0.9} = 10.5\ N$$

5 RESULTS

In the preliminary design stage of a propeller-driven UAV, initially, the maximum takeoff weight is determined using equation 1, i.e., 47 kg and 10 kg dedicated to payload. The empty and fuel fractions are 0.67 and 0.08 respectively based on the calculations made by equation 1.

The required wing area is 1.2212 sq. m and power is 12.5 HP, calculated from the constraints analysis (Glīzde 2018). Highest power is required for maximum velocity and take-off phase. Using the equations 2, 3, 4 and 5, the power loading versus wing loading plotted in figure 1.

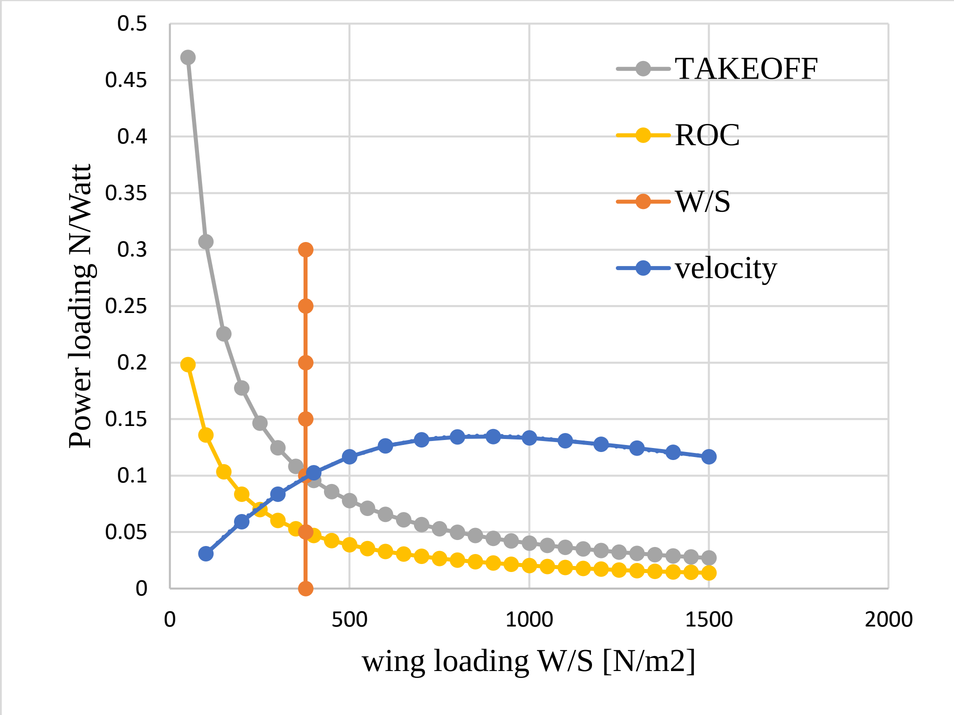

Figure 2. Constraint analysis

The MH 114 airfoil is selected for the wing. The maximum thickness and camber are 13% and 6.4% of the chord length. The maximum thickness and camber are at 28.1% and 50% of chord length respectively. It can be observed from figure 2, the wing lift reduces while comparing it to the airfoil section due to span wise flow and pressure drag. The wing lift coefficient is 30% lower than the airfoil lift coefficient.

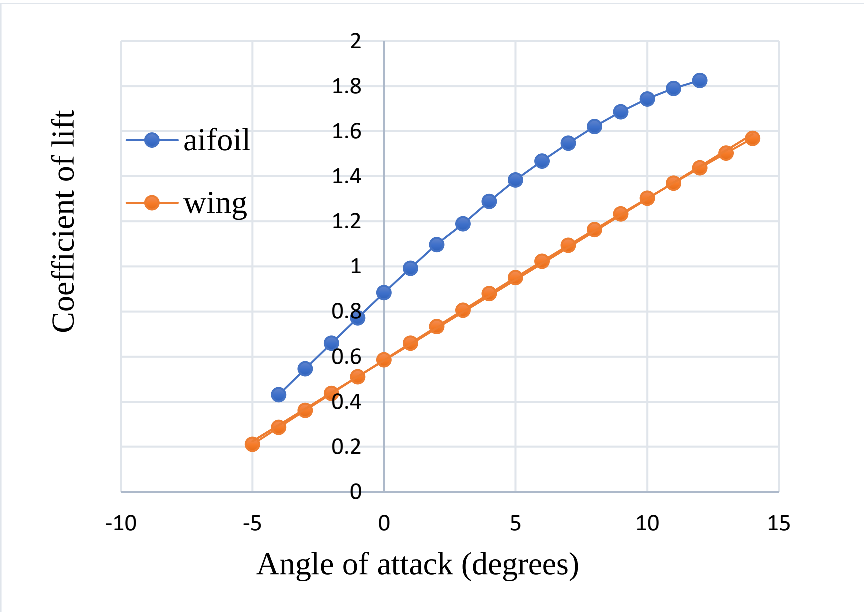

Figure 3. Wing lift and airfoil lift coefficient

The required lift coefficient for the wing at cruise is 0.7141 and it is achieved by setting the wing at 3-degree angle of attack. Since the shape of the wing is rectangle, the taper ratio is 1. The mean aerodynamic chord and the span length are 0.451 m and 2.7 m respectively. Aspect ratio for this rectangular wing is determined by empirical relation given in (Raymer, 2018)

From the historical data, it is decided to dedicate 65 % of the wing span and 30 % of chord to flap. The flap parameters are given in table 1.

Table 1. Flap parameters

Type	Plain Flap
Flap chord C_f	0.135 m
Flap span$(b_f/2)$	0.88 m
The required lift coefficient $(\Delta\alpha_{flap})$	0.8

The zero-lift angle during the take-off is increased when the flap is deflected i.e., camber of the wing increases. The required lift coefficient during the takeoff is around 0.83. When$i_w = 3$, $\alpha_{l=0} = -7.5$ and without flaps, it produces only 0.53 lift coefficient. The required lift coefficient produced after adding flap at 18 degrees was 0.83, and is shown in table 2.

Table 2. Wing lift coefficient with and without flap

Characteristics	Without Flap	With Flap
Flap deflection angle	0	18 degrees
Wing incidence	$i_w = 3$	$i_w = 3$
Zero lift angle of attack	$\alpha_{l=0} = -7.5$	$\alpha_{l=0} = -14.4$
Take off lift coefficient	0.53	0.83

The next major component is tail. The vertical and horizontal tails are placed at the rear of the fuselage and both the tails are in the shape of rectangle. The tail volume ratios are 0.5 and 0.04 for horizontal and vertical tails respectively. NACA 0009 airfoil is selected to both tail sections based on horizontal tail lift coefficient. Since both the tails are rectangular in shape, the complexity of manufacturing is reduced. The static longitudinal stability is checked using equation 10, and is found to be -1.4 1/rad. Since the value is negative, the UAV is longitudinally stable.

The total length of the fuselage and wetted area are 2 m and $1.712\ m^2$ respectively. The drag coefficient is 0.07 when the diameter to length ratio is 0.175.

MVVS 116 CC engine is selected in this research work and it has been designed and manufactured by a Czech company called MVVS (Husička, 1953). The maximum power requirement in this project is 12.5 HP which was the initial requirement to search such engine. The thrust required for each phase of the mission is the next essential need. MVVS 116 CC engine could generate up to 14 HP and the technical specification is given in table 3. The maximum diameter of the engine is 300 mm, the maximum width is 122 mm and the length is 275 mm including the shaft which connects the propeller.

Table 3. Technical specifications of the engine

Bore	42 mm	Maximum power output	14 HP / 6400 RPM
Stroke	42 mm	Maximum Torque	15 N/m / 6100 RPM
Weight of the engine (no ignition system)	3100 g	Fuel	Unleaded 95- octane
Weight of the Ignition system	270 g	Lubrication	Oil with petrol in mixture 1:40

The required propeller diameter is calculated using equation 11 and the performance parameters are given table 4.

Table 4. Propeller performance parameters

Performance Parameter	**Value**
Thrust	193 N
Propulsive efficiency	0.84
Thrust coefficient	0.31
Power coefficient	0.036
Torque coefficient	0.058
Advanced ratio	0.46
Mach number of the tip blade speed	0.62

According to the performance values in table 4, the suitable propeller is chosen.

The height of the landing gear is 0.47 m. The nose gear carries 20 % of the total load of the UAV (154 N) and the main gears carries around 80 % of the total load of the UAV (458 N). The wheel track requirements such as structural integrity, ground stability and controllability for the overturning angle ($\Phi_{ot} \geq 25^o$) are 6m, 0.3 m and 63 degrees respectively. These values may change based on further analysis in the subsequent design phases like preliminary and detailed designs.

The weights of the wing, horizontal tail, vertical tail, fuselage, landing gear and engine installation are 62.2 N, 39.2 N, 14 N, 59 N, 68 N and 11 N respectively, and calculated using equations 12, 13, 14, 15, 16 and 17. The calculated CG location after placing the internal components is 1.12 m from the nose, which is not the same as we calculated in the wing and tail design. This value of the CG must be brought down to 0.85 m (0.15 MAC) based on the wing and tail design calculation. It can be done using excel solver option by adjusting the location of the sensor, fuel tank and other systems. After using excel solver, the calculated location for the fuel tank, sensor and systems are 0.6 m, 0.75 m and 1m from the nose respectively.

Figure 4 shows the flight envelope structural limitations and possible maneuvers of the aircraft. This system is molded by aerodynamics, structure, propulsion and aircraft dynamics. The edges of this flight system are called flight envelope or maneuvering envelope.

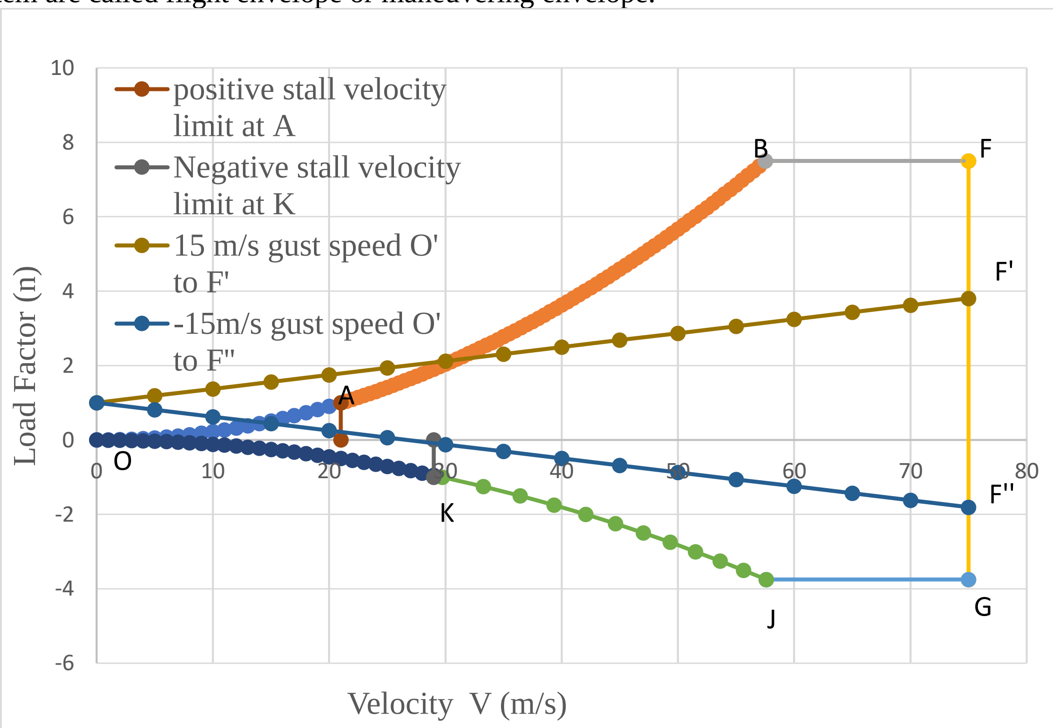

Figure 4. V-n diagram

The negative and positive stall limits, corner load factors and maximum speed limits are calculated based on Glīzde, N. (2017) and is shown in Fig. 4. The maximum positive and negative load factor are 7.5 (point B) and -3.5 (point J) respectively. The gravitational force is one when the aircraft is at cruise condition. The alleviation factor of the gust and gust speed are 0.7 and 15 m/s respectively at cruising at sea level.

The power required versus velocity curve at sea level and 1000 m altitude are constructed using equation 18, and is shown in figure 5.

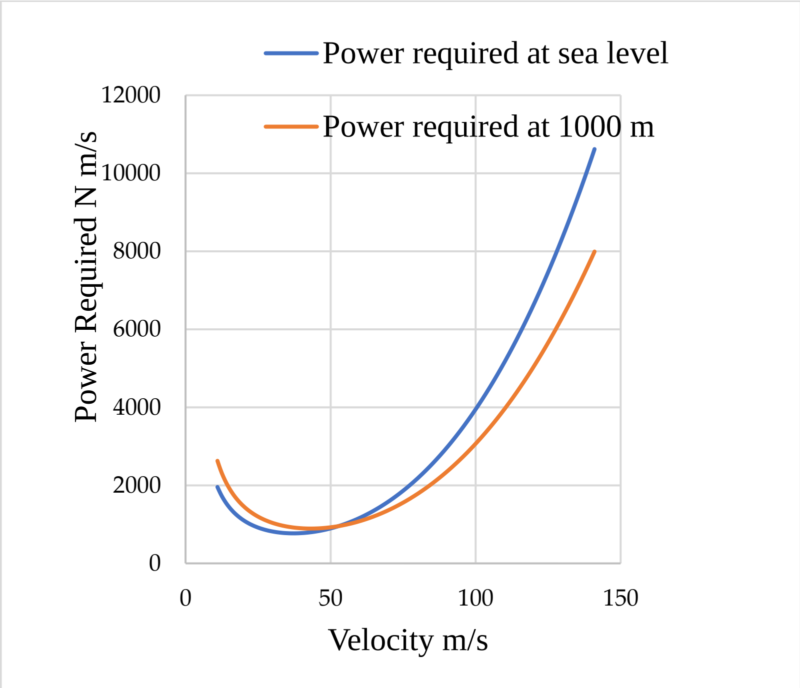

Figure 5. Power required curves

Since the density is lower at 1000 m compared to sea level, the minimum power required at sea level is lower than the power requirement at an altitude of 1000 m. The isometric view of the UAV is given in figure 6 and all the dimensions are in millimeters.

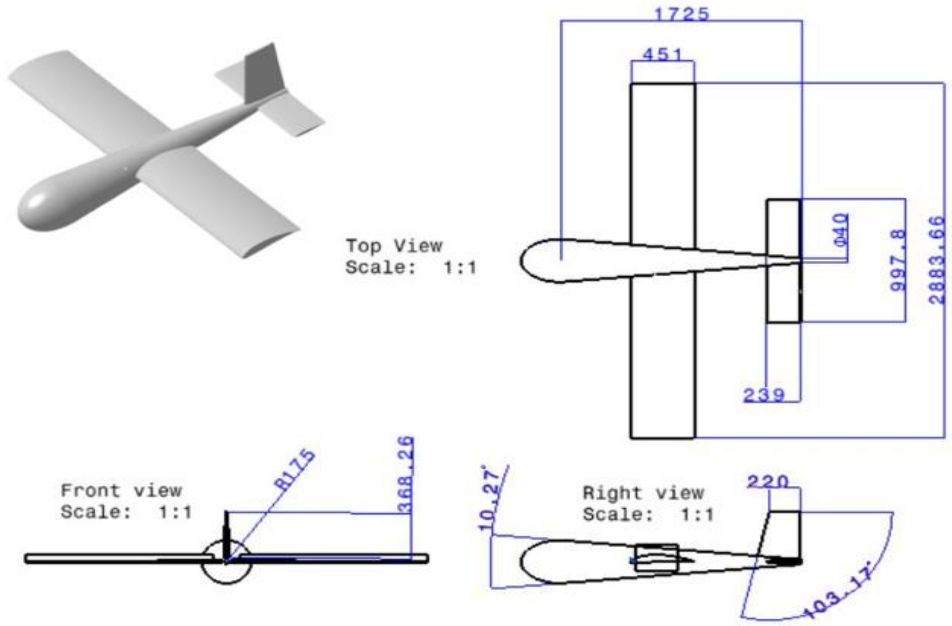

Figure 6. Isometric view

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6 CONCLUSION

A fixed wing was designed to not only for searching landmines but also for humanitarian activities. The conceptual design of the fixed wing UAV is designed with traditional and sophisticated approaches. In this research, a 47 kg weighed UAV is designed with 10 kg dedicated to payload. It can fly with a maximum speed of 30 m/s for 40 minutes; hence the mission specification is achieved. The design started with constraints analysis and followed by sizing of major components & control surfaces, flight envelope and performance calculation. The ANSYS 19 and XFLR software were used for analysis of the components. The future work will focus on optimizing the shape and converting it into a fuel cell-based propulsion system.

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MECHATRONICS AND ELECTRONIC ENGINEERING

Development of a Virtual Platform for Rotary Inverted Pendulum Controlling

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ABSTRACT

Higher education sector is currently moving back towards onsite teaching/learning environment. And most of the universities are adapting some online teaching methods to enhance learning experience of students. Though hands-on experience is delivered through practical classes in physical mode, for control systems engineering undergraduates, it is important to understand the basics through interactive learning. As virtual platforms are well known for providing opportunity for interactive learning, this study was focused on developing a virtual platform, based on a commonly used Rotary Inverted Pendulum System. To benefit students from all the levels, Linear Time Invariant Model, Nonlinear Model and the actual model was considered for the study. LQR controller gains were derived based on the mathematical model, and further modifications were done to produce a Linear Time Invariant model closer to the prototype. Both linear and nonlinear models were observed after applying same LQR gains and the prototype was applied with gains derived for the physical system. The virtual platform visually presents the behavior of the nonlinear model. This platform can be used as a tool for students at every level as it does not require to install any additional software, other than widely used Matlab. Thus, this would be an effective tool to be used along with onsite teaching / learning environment.

KEYWORDS: *Rotary Inverted Pendulum, Virtual Platform, LQR, High Fluidity Simulations*

1 INTRODUCTION

After the unexpected challenges caused by Covid-19 pandemic, the world has never returned to its usual self. People had to change some aspects of their life styles permanently, and it opened new areas of research in the field of Economics, as well as Education. With all the safety regulations coming in to the play, the higher education institutes were forced to change their usual way of teaching in no time. After more than two years of online education, universities are returning to its usual onsite teaching/learning environments. Most of the universities have discovered that the hybrid mode of education will deliver the maximum benefit to the students, and thus, they are adapting some techniques from online teaching inside the onsite environment. With recorded online lectures, students are at ease with the flexibility it offers for studying. Therefore, studies have proven that students favor online education, considering the guidance provided to learn autonomously (Cacheiro-Gonzalez et al., 2019). But there are some other aspects hindering the process of learning in an online environment. Lack of a stable internet connection, lack of interactions and inability to provide hands-on experience are some of them (Cao et al., 2020). Therefore, it is required to focus on an onsite teaching/learning environment and promote an online learning environment only when required. It is important for control engineering undergraduates to have a thorough understanding of the dynamic of systems. To facilitate that, it is important to guide them for self-learning while continuing their studies in onsite mode. A virtual platform form would be an ideal option to increase their engagement in interactive learning.

So far in control systems engineering Inverted Pendulum can be considered as the one of the most popular problems throughout the history. There are number of variations done to this problem and therefore, its applicability ranges from teaching basics to analyzing far more complex systems (Furuta,

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et al., 1991). The inverted pendulum is a nonlinear system, and it is basically categorized in to two main types; rotary inverted pendulum and linear inverted pendulum. Out of these two types, the linear inverted pendulum consists of number of additional nonlinearities, making it far more difficult to be modelled, when compare to its rotary version(Furuta et al., 1991) ,(Chandrasekara & Davari, 2004). Therefore, in this study, a rotary inverted pendulum was used for the virtual platform. In the 3rd world nation, there are universities which cannot afford to buy such Inverted Pendulum apparatus. In order to overcome this issue, many studies have been revolved around remote controlling of existing apparatus in real-time (Jung & Ahn, 2011; Kolencik & Zakova, 2009; Masár et al., 2004; Sukontanakarn & Parnichkun, 2009). Though this approach is very commendable in terms of resource sharing, still there are multiple number of issues. For a system to be controlled real-time, there must be an operator near the apparatus or complex autonomous system to smoothen the process, as there may be multiple number of people trying to control it. Also, for this type of arrangement, it is necessary to have a stable internet connection (good bandwidth and low latency). In terms of autonomous learning, the students can only use the apparatus under specific guidelines and that becomes just another practical to them.

To avoid the issues associated with internet stability, many studies have focused on creating a simulation environment, using linearized versions of inverted pendulum systems. With the obtained state space model, comparisons have been done with the real-time controlled systems to assess the performance (Lima et al., 2006; F. Pan et al., 2010; Y. H. Pan et al., 2014). As these systems are considerably deviated from the physical system performance, nonlinear models have been derived and controlled using various platforms. Some studies have focused on presenting data in terms of graphs with the absence of a physical system (Guo, 2012; Rawat et al., 2018), while some studies have taken a further step to link real time controlling of the actual apparatus to the simulation platform (Demirtas et al., 2013; Yuan & Zhang, 2013). The main drawback of these systems is the absence of visual aids to help the learner. Though these platforms are suitable for students with an understanding of the basics, for the beginners, lack of visualization may hinder the process of the learning. Use of Simscape multibody model has been suggested by many studies, and most of them have used the models for the purpose of robust controlling and to compare the performance of different controllers (Alkamachi, 2020),(Ghayoor, 2020). Comparison of performance of linear and nonlinear models, based on an actual system has been done in some studies, but vast difference between each model were presented as the actual system is a linear inverted pendulum with number of non-linearities (Kumarihami et al., 2021). More advance approach could be observed in research done by Ganganath and the team, as they have succeeded in creating a Simulink multibody model, which is closely resembling the actual system for remote teaching (Ganganath, 2022). A similar approach can be observed in another study, where a digital twin has been created for rotary motion platforms (Traver et al., n.d.). Although these systems are suitable for studying the system performance, exposure given to the students to interact with linear and nonlinear models are minimum.

In this study, main focus will be on creating a virtual platform, where the students can observe an existing system in its linear, nonlinear and real-time model. The platform will use Matlab software as the base, because almost all of the control engineering students have a thorough understanding on using Matlab software. This study has focused on creating a platform to be used without internet, allowing student to use and modify the models as they please. The procedure followed in achieving the task will be discussed under methodology.

2 METHODOLGY

2.1 System Modelling

Dynamic system model of the Rotary Inverted Pendulum unit is depicted in the Figure 1. The pendulum to be balanced is of length l_p and inertia J_p (about its center of mass). The pendulum forms an angle $\propto$ with the Z_0 axis, which is positively increasing in Counter Clockwise (CCW) direction. When the pendulum is at upright equilibrium position, the angle formed is zero. The pendulum is connected to the rotary arm through a pivot joint. As indicated in the Figure 1, the length of the rotary arm is l_r and inertia is J_r (about center of mass of rotary arm). θ is the angle formed between the rotary arm and the X_0 axis, which is indicating a positive increment in CCW direction.

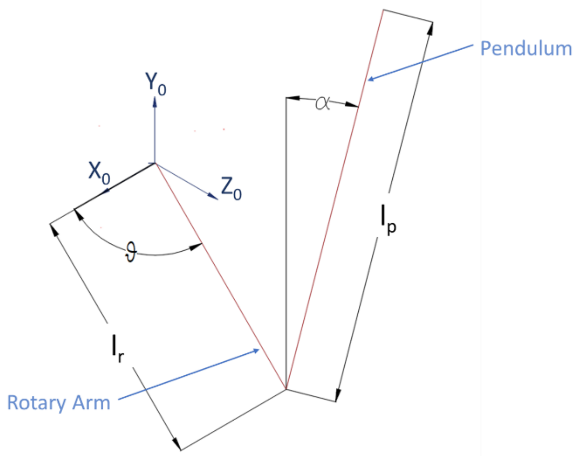

Figure 1. Conventions for Rotary Inverted Pendulum (Inc., 2011)

Lagrange method, which is often used in working with more complex systems like multiple jointed robot manipulators, is used to illustrate the motions of the pendulum and the rotary arm. The Euler-Lagrange equation as in equation 1, was used in the system dynamics.

$$\frac{\partial^2 L}{\partial t \partial q_i} - \frac{\partial L}{\partial q_i} = Q_i \tag{1}$$

In rotary inverted pendulum system $\theta(t)$ and $\alpha(t)$ are the variables. Therefore, Euler-Lagrange equations will be as follows.

$$\frac{\partial^2 L}{\partial t \partial \dot{\theta}} - \frac{\partial L}{\partial \theta} = Q_1 \tag{2}$$

$$\frac{\partial^2 L}{\partial t \partial \dot{\alpha}} - \frac{\partial L}{\partial \alpha} = Q_2 \tag{3}$$

As Lagrangian is the difference between the kinetic energy (T) and potential energy (V) of a system, it can be depicted as follows.

$$L = T - V \tag{4}$$

When equating the non-conservative forces acting upon the system with respect to generalized coordinates to generalized forces, following equations can be derived for the rotary arm and the pendulum respectively. The values of the parameters used in following equations with respect to prototype are given in Table 1.

$$(m_p {l_r}^2 + \tfrac{1}{4} m_p l_p^2 - \tfrac{1}{4} m_p l_p^2 cos(\alpha^2) + J_r)\ddot{\theta} - \left(\tfrac{1}{2} m_p l_p l_r \cos(\alpha)\right)\ddot{\alpha} + \left(\tfrac{1}{2} m_p l_p^2 \sin(\alpha)\cos(\alpha)\right)\dot{\theta}\dot{\alpha} + \left(\tfrac{1}{2} m_p l_p l_r \sin(\alpha)\right)\dot{\alpha}^2 = \tau - B_r\dot{\theta} \tag{5}$$

$$-\left(\tfrac{1}{2} m_p l_p l_r \cos(\alpha)\right)\ddot{\theta} + \left(J_p + \tfrac{1}{4} m_p l_p^2\right)\ddot{\alpha} - \left(\tfrac{1}{4} m_p l_p^2 \sin(\alpha)\cos(\alpha)\right)\dot{\theta}^2 - \tfrac{1}{2} m_p l_p g \sin(\alpha) = -B_p\dot{\alpha} \tag{6}$$

At the rotary arm base, the applied torque (τ) can be described using the equation 7.

$$\tau = \frac{\eta_g K_g \eta_m k_t (V_m - K_g k_m \dot{\theta})}{R_m} \tag{7}$$

2.2 Linear Time Invariant (LTI) Model

To obtain the state space equations of the model, the equations 5 and 6 were rearranged in to a matrix form and linearized. The terms "x" and "u" indicate the state vector of the system and control inputs respectively.

$$\dot{x} = Ax + Bu \tag{8}$$

$$y = Cx + Du \tag{9}$$

$$x = \begin{bmatrix} \theta \\ \alpha \\ \dot{\theta} \\ \dot{\alpha} \end{bmatrix} \tag{10}$$

$$u = [\tau] \tag{11}$$

Thus, the matrices A, B, C, and D will be as follows.

$$A = \frac{1}{J_T}\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \frac{1}{4}{m_p}^2{l_p}^2 l_r g & -\left(J_p + \frac{1}{4}m_p l_p^2\right)B_r & -\frac{1}{2}m_p l_p l_r B_p \\ 0 & \frac{1}{2}m_p l_p g\left(J_r + m_p l_r^2\right) & -\frac{1}{2}m_p l_p l_r B_r & -\left(J_r + m_p l_r^2\right)B_p \end{bmatrix} \tag{12}$$

$$B = \frac{1}{J_T}\begin{bmatrix} 0 \\ 0 \\ J_p + \frac{1}{4}m_p l_p^2 \\ \frac{1}{2}m_p l_p l_r \end{bmatrix} \tag{13}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \tag{14}$$

$$D = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{15}$$

$$J_T = (m_p {l_r}^2 + J_r)(J_p + \tfrac{1}{4}m_p l_p^2) - \tfrac{1}{2}m_p l_p^2 l_r^2 \tag{16}$$

As the Quanser Rotary Inverted Pendulum was used as a reference in deriving the state space model, system parameters were also extracted from the actual system. Thus, the variables in the above equations 10, 11, 12 and 13 must be replaced with the values given in the Table 1.

Table 1. Parameters of the Rotary Inverted Pendulum System

Symbol	Description	Value	Unit
$\boldsymbol{m_p}$	Mass of the pendulum	0.127	kg
$\boldsymbol{l_p}$	Total Length of the pendulum	0.337	m
$\boldsymbol{J_p}$	Pendulum moment of inertia about center of mass	0.0012	$kg.m^2$
$\boldsymbol{B_p}$	Pendulum viscous damping coefficient as at pivot axis	0.0024	N.m.s/rad
$\boldsymbol{l_r}$	Rotary arm length	0.0619	m
$\boldsymbol{J_r}$	Rotary arm moment of inertia about its center of mas	0.000998	$kg.m^2$
$\boldsymbol{B_r}$	Rotary arm viscous damping coefficient as at pivot axis	0.0024	N.m.s/rad

With the parameters from the actual system, the LTI model was built in Simulink environment. The state space model was modified with the addition of a Kalman filter and an AWGN (Add White Gaussian Noise). The complete Simulink model for the LTI system is shown in Figure 2. In addition, a signal generator was utilized for feeding different types of signals to the system.

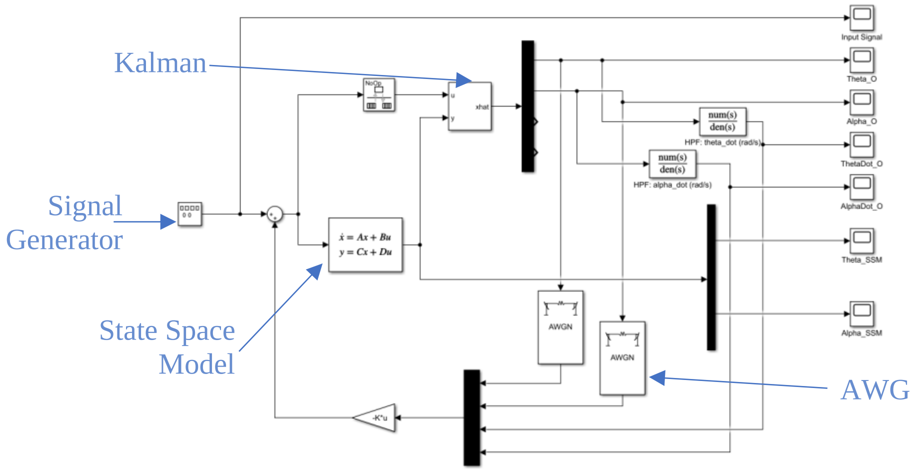

Figure 2. Linear Time Invariant Model developed in Simulink Environment

2.3 Nonlinear Model

The Quanser Rotary Pendulum system was used as a reference to build a CAD model using a 3D modelling software. The 3D model was consisting of all the main components and the movements between them. The rendered 3D model is depicted in Figure 3.

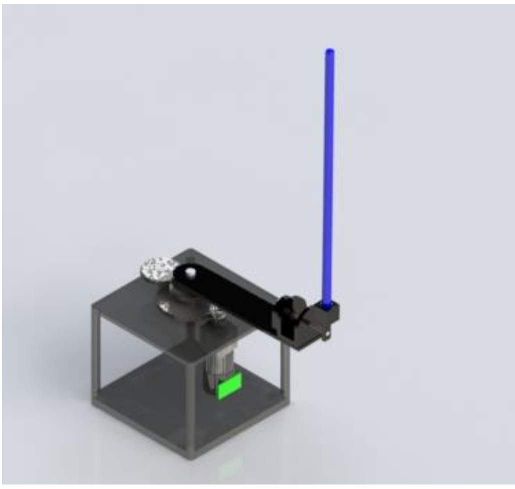

Figure 3. Rendered Image of the CAD Model

The 3D model was then imported in to Simscape Multibody environment, and the extracted model consist of two revolute joints, which is clearly depicted in Figure 4. The block diagram was then modified to be controlled by the LQR gains, and a signal generator was applied to observe the system behavior under different input signals. The complete block diagram in Simulink environment is shown Figure 5.

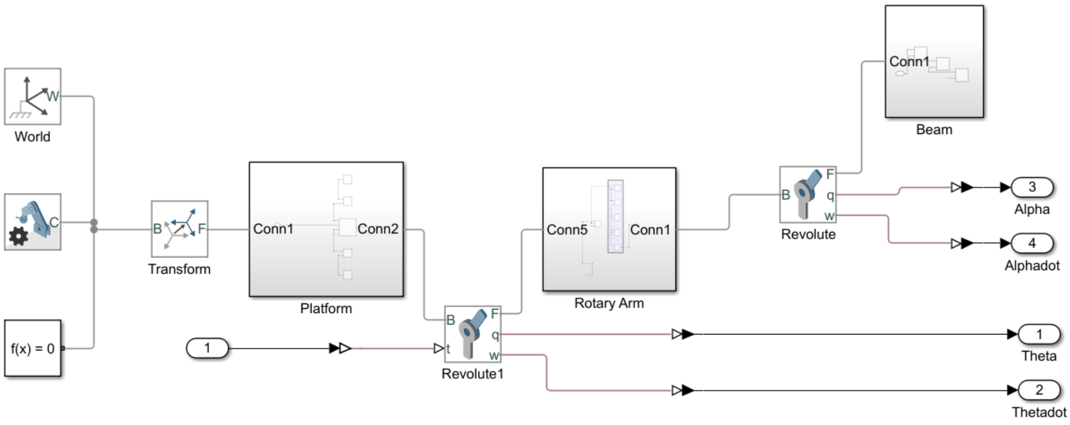

Figure 4. Simscape Multibody Diagram for the Rotary Inverted Pendulum System

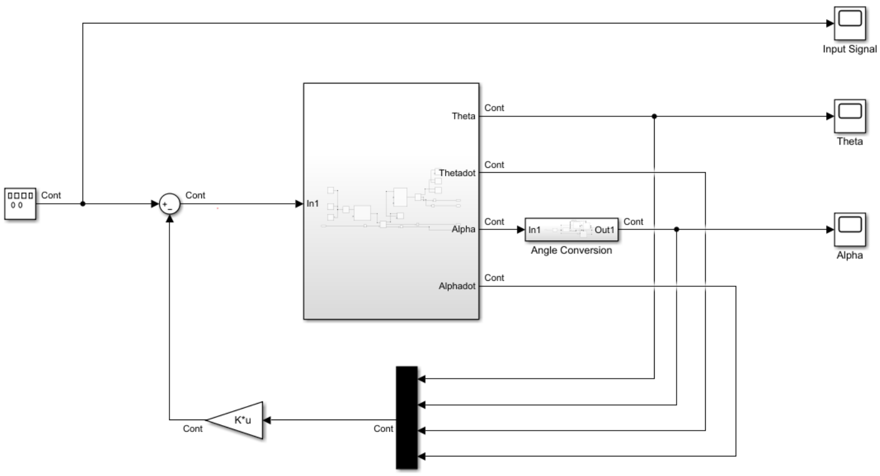

Figure 5. Non-linear Model Controlled using LQR gains

Shown below in Figure 6 is the appearance of the rotary inverted pendulum in Mechanics Explorer environment.

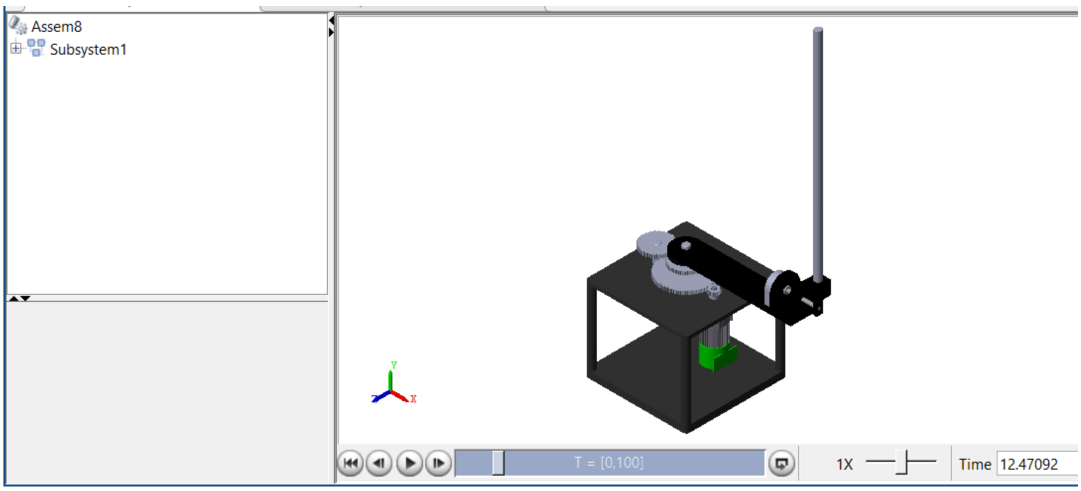

Figure 6. Visual Output of the Behaviour of Nonlinear Model

2.4 Prototype

The prototype shown in Figure 7 was actuated with same input signals, and was controlled with fine-tuned controller gains, considering the safety of the equipment.

Figure 7. Quanser Rotary Inverted Pendulum System

3 RESULTS & DISCUSSION

The LQR gains obtained from the mathematical model was used in controlling the LTI model as well as the nonlinear model. To observe the behavior of each system, signals shown in Figure 8, were fed to the both models using signal generators. In Case 1, the signal generator was producing a signal of amplitude 0 and in Case 2, the amplitude of the signal produced was ± 0.35 at 10 s intervals.

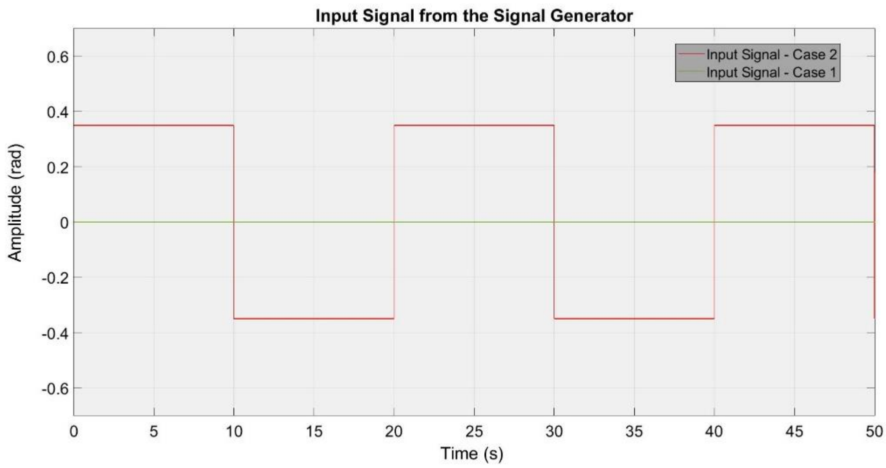

Figure 8. Input Signals from the Signal Generator Block

To compare the performance of both LTI system and nonlinear system under same conditions, the system was operated with same LQR gains, and considered to be operated with same initial conditions, which are shown in the Table 2.

Table 2. Initial Conditions of the Four States

State	$\boldsymbol{\theta}$	$\boldsymbol{\alpha}$	$\dot{\boldsymbol{\theta}}$	$\dot{\boldsymbol{\alpha}}$
Initial Condition	0.0242	-0.0152	0	0

The behavior of both systems when Case 1 input signal (as shown in Figure 8) is provided and its ability to stabilize was observed after applying the obtained LQR gains. It was observed that both systems were stable in terms of rotary arm angle, after 2 s. In terms of the stability of the pendulum, the nonlinear system was quicker to reach the stability but with more oscillations observed from the rotary arm, which is clearly indicated in Figure 9 and Figure 10. The overshoot was higher when considering the pendulum angle, which is clearly indicated in Figure 9. Behavior of the systems are almost similar expect for the overshoot and oscillatory movement at the end of the nonlinear model.

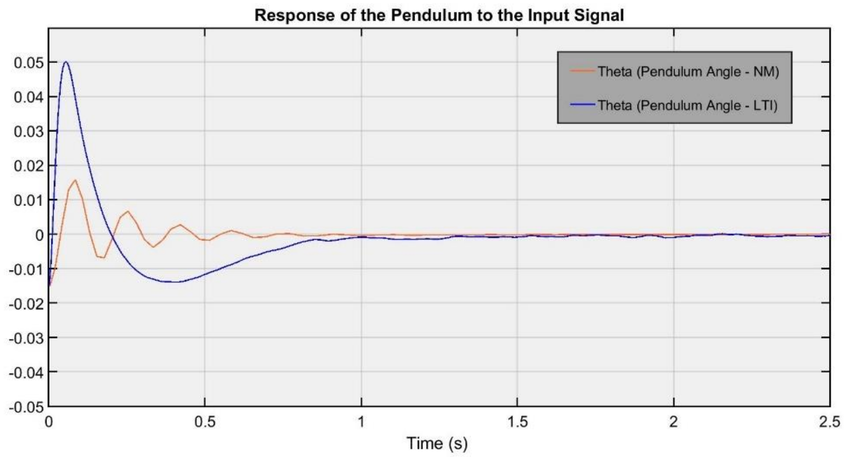

Figure 9. Response of the Pendulum for the Input Signal Case 1 (LTI and Nonlinear Models)

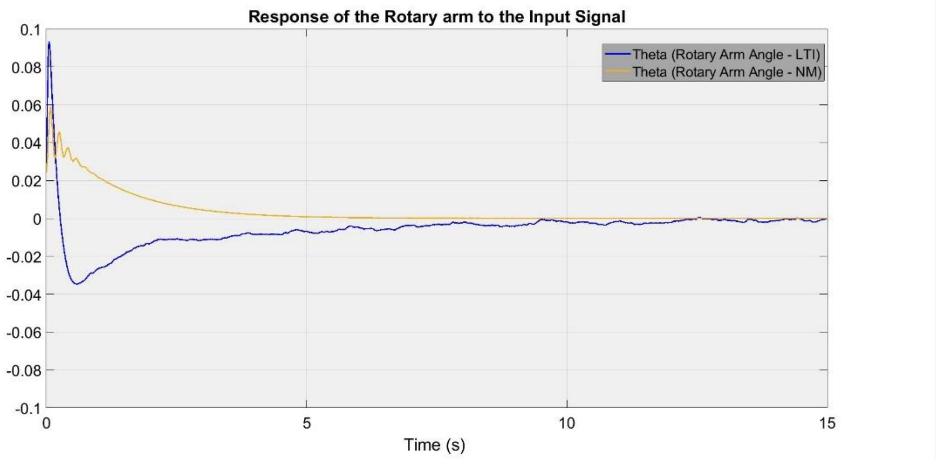

Figure 10. Response of the Rotary Arm for the Input Signal Case 1 (LTI and Nonlinear Models)

When the Case 2 signal (as shown in Figure 8), depicted in Figure 8 was fed in to the both systems, the pendulum was stabilized in less than 3 s, but the overshoot and oscillations are visibly higher in the nonlinear model. The behavior of the pendulum of both systems is plotted in Figure 11. The variation of the rotary arm angle under same conditions is plotted in Figure 12.

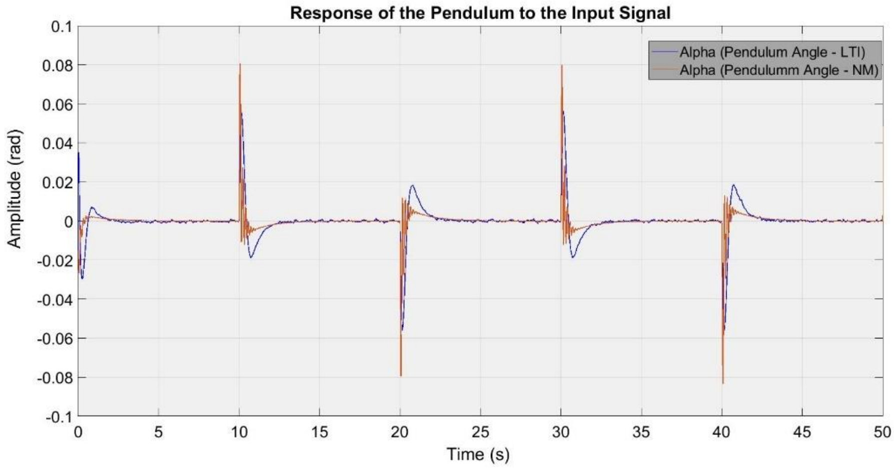

Figure 11. Behavior of the Pendulum for the Signal Case 2 (LTI and Nonlinear Models)

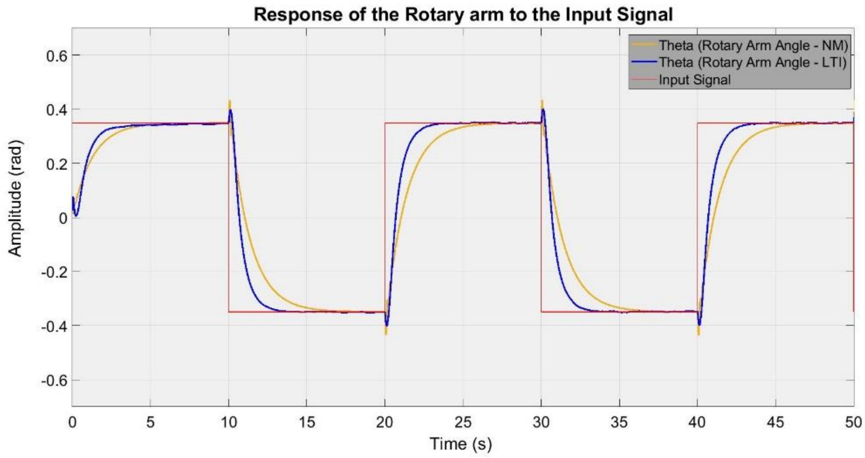

Figure 12. Behavior of the Rotary Arm for the Signal Case 2 (LTI and Nonlinear Models)

When observing the actual system response, for the Case 2 signal indicated in Figure 8, the system response was as in the Figure 13. For the safety of the actual system, the system was tested with more appropriate LQR gains, derived specifically for the actual system, as factors like damping, friction, disturbances…etc., which were not modelled plays a considerable role in the response of the prototype. The actual response in terms of pendulum angle and the rotary arm angle is depicted in Figure 13.

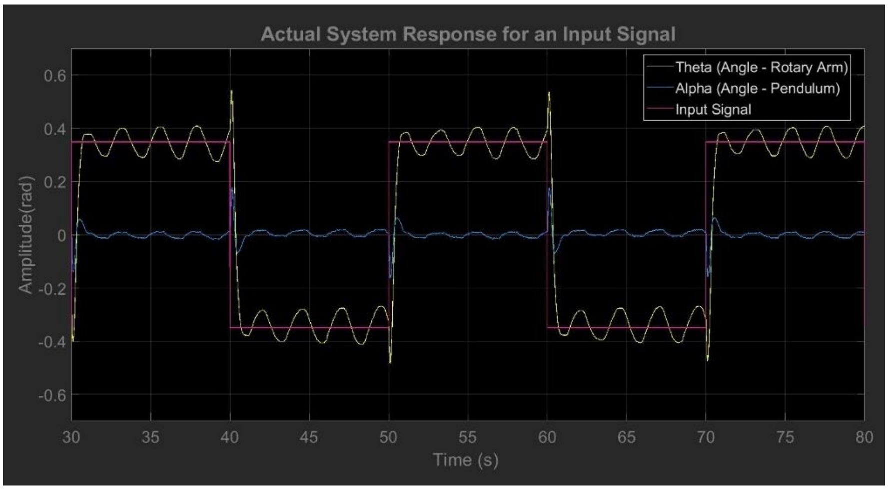

Figure 13. Behavior of the Rotary Arm of the Prototype

It was observed that though the Linear Time Invariant system was modified to attain a closer resemblance to the nonlinear model, there are still some deviations in smoothness when tested with same controller gains. The LQR controller gains applied for the three systems are as in the Table 3.

Table 3. LQR Gains Applied for the Models

Model	LQR Gains (K)			
LTI	-1.0000	12.8555	-1.4385	1.6943
Nonlinear	-1.0000	12.8555	-1.4385	1.6943
Prototype	-5.261	28.16	-2.758	3.219

4 CONLUSION

The use of state space model, nonlinear model and the actual apparatus in a virtual platform, to deliver knowledge on basics of modelling of dynamics system to the beginners in control systems engineering, has been presented in this paper. The availability of the state space model allows the students to improve their understanding on basics. With the addition of other parameters, a linear system closer to the nonlinear model of the Rotary Inverted Pendulum system has been derived, allowing the students to identify the factors contributing to the difference in linear and nonlinear systems. In addition, students who have the basic knowledge can use these systems as a reference to develop their own model from scratch. This platform can be used as a pre lab session for students, who are to perform advanced controlling experiments on the real system. With the visual representation of the system response, the system is more understandable than the graphs.

With already available software the virtual platform provides access to the students anytime, where they can perform different experiments by changing the parameters, which is not possible with the actual system. Matlab Simscape Multibody environment used by the virtual platform is common software, which is already available with the control systems engineering students. Therefore, this platform can be put into use even in the onsite teaching environment as it provides more exposure to the basics of control systems engineering than a simple lab experiment, where students are not allowed to perform experiments, which may threat the safety of the equipment and students. This virtual platform would be a great tool to guide students in various level of understanding towards autonomous learning. There is a considerable difference in the LQR gains applied for prototype from the other two models. This is mainly due to the unaccounted factors like friction, damping and disturbances. In future, the LTI and Nonlinear models can be further improved to resemble the protype closely, by modelling the factors mentioned above.

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Human Following Robot

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ABSTRACT

The main purpose of this project is to develop a robot that can follow a human to help their activities easy in a well-planned manner. The first implementation of this project is to detect a human and follows the human in a single human environment. The last implementation is to upgrade this into a robot that can detect humans in a busy environment. When designing a robot to work as a human follower it must fulfill some requirements. The issues which are more focused to resolve in here are, the size and mobility while tracking the humans and obstacle detection of the robot. There are many human assistant robots that manufacture small scale in size, but they are not capable of well-assistance and also most of the physically large robots find it hard to assist and handle some activities. Most of the humans following robots are designed for single work, therefore people tend to spend more money on buying robots to fulfill various work. Usually, the components that are used to develop human detection robots are expensive and it is one of the reasons why these types of assistants are expensive. Here, one of the problems which is mobility of the robot while tracking was resolved by developing a more suitable structure, improving the motor-control method, and adding a step-climbing mechanism to the robot. As the robot is manufactured to follow a human, a method to identify a human using image processing is implemented. Also, a method of detecting the position of human is also implemented. And also, the power plan design and all the electronic developments including the power supply unit development and also the power level checker as well has been implemented. Finally in order to make it less complex the circuit has made on PCB.

Keywords: *Fuzzy Logic, PID, Structure, Image Processing, Boost Converter, Object Detection, Human Tracking, PCB*

1 INTRODUCTION

Robots were created to assist humans in industrial and day-to-day activities. Typically, robots are created to accomplish tasks that humans might not in certain industrial applications. In addition to industry, the robot can assist and direct humans by working as an assistant. Human assistant robots come in a variety of shapes and sizes to assist people with various tasks. The definition of a person following a robot can also be applied to the human assistant category. This paper is about to build a human following robot by solving the above abstract mentioned global issues. This project is doing in charge with three undergraduate students in Sri Lanka Institute of Information and Technology. In this robot project there were many parts to complete to have a success full and accurate robot.

This robot`s structure is mainly dependent on the step climbing purposes due to that it had to make some changes for the last implementation of the structure. In this paper it was giving big focus for the wheel placement and structure of the robot because the whole robot accurate is depending on them. Another interesting part of this paper is motor controlling of the human following robot. Human following robots' main tasks is to follow the human with accurate manner it should be track the human with precise gape and speed with the follow's human. As a solution for the accurate of any system, in the history of the engineering they were invented several control systems to make the accuracy of the system. Among these control systems there are very common accurate two controllers they were PID controller and fuzzy controller. In this robot project PID controller is used to control the obstacle avoidance part and fuzzy controller for control the turns.

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In recent days, capturing images with high quality and good size is so easy because of rapid improvement in quality of capturing devices with less costly but superior technology. Object detection and tracking is one of the challenging tasks in computer vision. Mainly there are three basic steps in video analysis- Detection of the object of interest from moving object, tracking of that interested objects in consecutive frames and analysis of object tracks to understand their behavior. In order to detect the object first take the necessary and relevant steps together, information from the many computer vision applications. This implemented method can be used for surveillance purpose in many security applications. So, deep learning basics, Image annotation, Object identification and Object tracking is being discussed in this document. After detecting the human, reacting to human movement also identified and moving according to humans' speed also discussed.

The obstacle detection is one of the main parts in the robot since it can detect the obstacles in the environment and interrupt the robot about them to avoid. This is a main part when it is considered the protection of the robot. In this robot, the obstacles were detected using the ultrasonic sensors. The ultrasonic sensor uses a natural phenomenon, which is the sound reflection to detect things. To detection part, mainly the length dimension had been used. And this length was given by the ultrasonic sensor not as a length. Therefore, the calculations need to be done using the output that is being gained by them. And also the development of the power supply and the localization of this robot will be discussed. Power supply is one of the most important units in any kind of an electronic. There are several considerations as such as power distribution, power source selection and power converters. And in the PCB finalizing section, the PCB of the voltage indicator circuit was done. The process of all of these sections will be discussed in the following parts.

1.1 Objectives

- Develop a structure for the robot.
- Configuring the structure for different scenarios.
- Arranging the motor controlling using the inputs.
- Development of obstacle avoidance unit.
- Development of the Power supply units.
- Circuit Integration and PCB designing.
- Human detection using several methods.
- Integration of the programming units.

2 BACKGROUND READING

2.1 Structures of Robots

Yoonchang Sung and Woojin Chung's research demonstrates the need for the robot's construction to be planned in accordance with the human body parts that will be detected by algorithms that follow the human. The width of the structure should match that bodily part's width, as they state. The product's accuracy will thereafter improve (Yoonchang Sung, 2011). Since their robot is built on the robosoft robulab10 robotic platform and has a robust construction, Guillaume Doisy, Aleksandar Jevtic, and Sasa Bodiroza claim that it can hold a maximum payload of 4 kg. They also said that the robot may use a laptop as its central processing unit. The path is clear, they simply need to follow a predetermined path, and they do not need to worry about their wheels because they can only have two motor wheels and one free wheel for their robot (G. Doisy, 2013). The mechanical framework of a robot at Pakistan's Institute of Space Technology has designed for two levels, which are used to arrange the parts. In order to collect superior visual data, the top base is built with the idea that the robot's camera must be set above a particular height off the ground. This camera's height is also adjustable to match different body sizes. The finest achievement is having a camera that can be adjusted, but components that are on the top base of the design shouldn't guarantee that it's bad for a robot that follows humans (M. Hassan, 2015). A project for a three-wheeled omnidirectional mobile robot was completed by Mohanraj, Elango, and Reddy. To travel and make several directional turns, this robot simply needs three omni wheels.

Additionally, the angle between the two chosen wheels may be adjusted by the robot as desired. The angle variable chassis is the primary responsibility for this project (A. Mohanraj, 2016).

2.2 Motor Controlling Methods for Robots

In this proposal, Caroline Queva stated that the pan and tilt motor allows cameras to move in practically all directions. The robot will not want to rotate at that point, and the human will not be missed by the camera. As a result, this technique gives this robot extremely accurate real-time operations. However, there is one problem to this approach. A human may not be followed by the mobile base if they move quickly and perpendicular to the robot (CAROLINE, 2013). The human following robot does not need to have a camera on it as Kazuyuki Morioka showed in the project because he created a concept called "ISpace" with a better arranged, set of cameras. The power that wants to control the camera's motors is then released. However, there is a limitation to this concept: it can only be used indoors. This idea is more accurate because the human subject is not lost to the camera. (2002) K. Morioka As Hosein Marzi explains in the study, robots uses AC motors. They contend that ac motors do not react more quickly than dc motors. This paper applies fuzzy control to flux vector inductor motor performance. Another justification for using fuzzy logic is that it has excellent balancing abilities and can handle several inputs (Marzi, 2007). Research on servomotor modelling and control for secure robots has been conducted by Song and his four project collaborators. This study demonstrates how the nonlinearity of the permanent magnet synchronous motor is decoupled here using the field-oriented control theory (J. Song, 2015). On autonomous underwater vehicles, the lifting control system is implemented using fuzzy logic. Using ADC conversion, fuzzy logic was used in this case for ultrasonic sensors. And this section discusses how precisely to sense distance (A. ZARKASI, 2019).

2.3 Power management and obstacle avoidance

Kazuyuki Morioka demonstrated multiple strategies for identifying items in Fumiaki Hoshino's research. As stated in the project "Human Following Robot based on Control of Particle Distribution with Integrated Range Sensors," accurate ways for identifying objects include LRF, the Likelihood method, and the use of a kinetic sensor (F. Hoshino, 2011). In the essay "Energy Modeling and Power Measurement for Mobile Robots," Linfei Hou, Liang Zhang, and Jongwon Kim explore the power management of mobile robots. And they have recommended using low-power devices whenever possible. And they have developed an algorithm for the power consumption of each robot component (L. Hou, 2018). In the essay titled "UB Robot Swarm - Design, Implementation, and Power Management," the group discusses various strategies for obstacle detection. In addition, they have been used a camera and a mapping system to create a more precise method for detecting obstacles. Even though noted previously, this is an excellent solution, but it consumes more system resources and is a much more complex system (M. Patil). The robot created by the Engineering UG group is a human-following robot that can photograph adjacent objects when it is following a person. It was created using a straightforward technique that employs ultrasonic sensors for detecting. The ultrasonic sensors have been positioned higher on the robot, allowing this strategy to be effective. However, this may still cause some uncertainty on the robot, making the robot less clear (M. Kumar, 2017). The project "Follow Me: A Human Following Robot Using Wi-Fi Received Signal Strength Indicator" conducted by a group of university undergraduates has been powered using a 12V power supply. They have been using significantly more power-hungry components. In addition to applying a mapping system to detect and avoid obstacles, they were required to devise a more effective method for supplying energy (V. Geetha, 2020). Michael Burke's "Gain-scheduling Control of a Monocular Vision-based Human-Following Robot" study uses a LIDAR sensor, which is a Light Detecting and Ranging sensor, as the detection method, according to Willie Brink. A vision-based detection system employing a complicated algorithm has been created. This can provide some data on precision if better LIDAR sensors are developed (M. Burke, 2011). Wei Peng, Jingchuan Wang, and Weidong Chen's study titled "Tracking Control of Human-Following Robot with Sonar Sensors" deployed an ultrasonic sensor ring for both obstacle identification and human detection. They have been creating a particular algorithm for the system to identify between an obstacle and a person when both are identified at the same time. This technique is simpler and more reliable. When the system is used for both cases, however, there may be instances in which the robot is unable to detect the barrier precisely (W. Peng, 2017). In the article titled "Power

Optimization in Mobile Robots Using a Real-Time Heuristic," the power source for robots has been explored. In addition, they recommended using Li-Po batteries rather than other types of batteries. And they have been implementing a power monitoring system that may be put on a robot that follows a human to provide a more accurate technique of measuring the power. However, Li-Po batteries cannot be used in most robots due to their rapid discharge rate (T. Abukhalil, 2020).

2.4 Human detection and tracking

Most variable presentation aspects managed by incorporating the YOLO framework. YOLO's input size and velocity flexibility makes an obvious choice in the RCNN family, when dealing with a diverse set of tiny input images. Research done on object detection using YOLO, the applicable YOLO network trained a portion of 2007 PASCAL VOC data and 2012, focusing on the classes of humans, vehicles, and motorcycles (Koskowich, 2016). Another object tracking research done on event-based tracking learning detection. e-TLD is the name given to their event-based object tracking technology. This paper presents a general method for tracking object using event cameras that implemented rapidly in software, rather than neural networks that requires a lot of training for learning. The incremental SVM update stage of the e-TLD online learning process is well-documented as efficient technique. Although the online TLD's learning capability, the fundamental training procedure is the codebook learning step, which takes less than a minute on a normal PC utilizing efficient sampling algorithms for 500ms worth of data. To account the changes in object appearance during tracking process, online learning also required. When the region-of-interest (ROI) used as an object, binary classifier utilized by the tracker updates. This drifting problem mitigated by updating the tracker, only when the confidence is more than a portion of mean tracking score and the tracking fails, the tracker must reactivate with a higher confidence value. To put it another way, the target will only track if it passes both the detector and a “stricter” tracker (Ramesh, 2015). The application created with the idea that video sequence was captured by camera and that it could be used with offline video. First phase is using motion segmentation, which involves subtracting moving objects by the updated backdrop by performing the morphological processes. This produces binary masks, using white pixel color by corresponding to the foreground and black pixel color corresponding to background. Second phase is tracking the object, which involves assigning detections to tracked objects. Every track's next location is predicted by the current detection's assigned positions, or using the position of previous frame allocated if nothing was assigned to present frame. This application generates a video with each monitored object's bounding rectangle and identity number. It has shown around 92% accuracy in finding humans in collisions (Sadura, 2012).

3 METHODOLOGY

In this section the development of each unit will be discussed. This unit is consisted with several units since the development taken place in several steps. Each part is guaranteed as the pure effort of the group mates. Since this robot mainly has 3 components to be worked, and several objectives to be fulfilled, group members came up with their own way of development steps, which made this project a success.

3.1 Structure Implementation of the Robot

Robot structure was first starting to implement to design as a 3D drawing. Figure 1 shows the fully complete solid work implemented 3D model of the robot. This robot used a chain wheel as the actuator. It used a rubber belt as the chain of the robot. These rubber belts run on a pulley. One side of this robot has five wheels for running the belt. It has ten wheels robot when it used a chain wheel mechanism the robot works as a two-wheeled robot. Of these five pulley wheels two of them were connected to the motors and rest of other three wheels are mounted as free wheels for the robot. The wheels which are connected to the motors are not going to contact the ground. When fixing the motor's connected wheels from this much ground clearance then it can reduce the friction that generate from contacting the wheel with the floor.

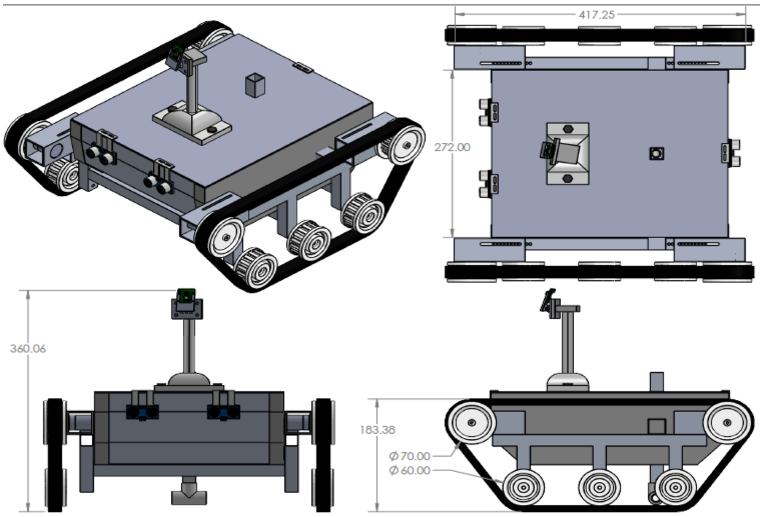

Figure 1. 3D model of robot

Implementing a step-climbing method was a main objective of this project. For this mechanism, it required a two-servo motor, one T joint of PVC pipes, aluminium bars, rubber belts, and MPU-6050 sensor. The mechanism of this function when the robot moves forward and detects the first step by using the front wheels robot can climb half of the first step and the MPU 6050 sensor detects the orientation of the robot gets changed. When the sensor gets the orientation change the method for step climbing activates and motors stop. When robot climb the step again step climbing method deactivate and motors start. Figure 3.15 shows how the step climbing method applies to the structure and how it works.

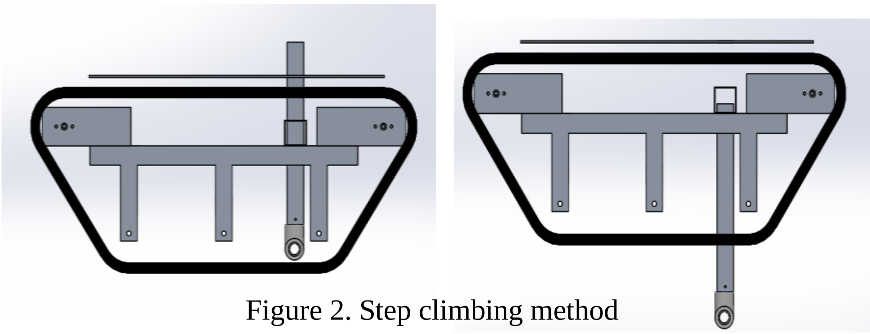

Figure 2. Step climbing method

In figure 3 shows the final hardware implementation of the robot with all the motor placements, step climbing method and sensor mounted.

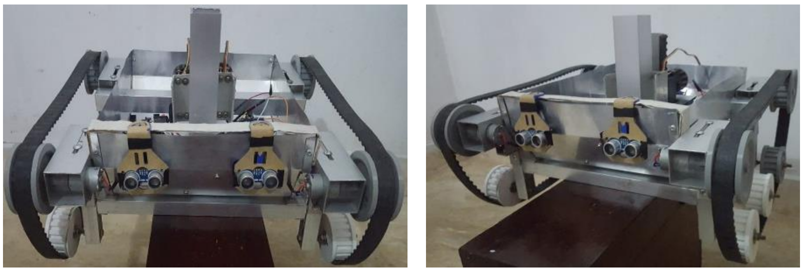

Figure 3. Final structure hardware implementation

When selecting a motor, it has to do some mathematical calculations for select better suitable motor. Due to this robot have to follow humans we have to find the average speed of a human. After having the average speed, it can calculate the test of other parameters. Then the obtained the calculated result we have to compare the result with suitable motors data sheets and select one.

Table 1. Humans` walking speed according to the ages (Cronkleton, 2019)

Age	Meters/second	Miles/hour
20 to 29	1.34 to 1.36	3.0 to 3.04
30 to 39	1.34 to 1.43	3.0 to 3.2
40 to 49	1.39 to 1.43	3.11 to 3.2
50 to 59	1.31 to 1.43	2.93 to 3.2
60 to 69	1.24 to 1.34	2.77 to 3.0
70 to 79	1.13 to 1.26	2.53 to 2.82
80 to 89	.94 to .97	2.10 to 2.17

$$Total\ of\ the\ speeds = (1.35 + 1.38 + 1.41 + 1.37 + 1.29 + 1.19 + 0.95)ms^{-1}$$
$$Average\ speed\ of\ a\ human = \frac{(8.94\ ms^{-1})}{7}$$
$$Average\ speed\ of\ a\ human = 1.27ms^{-1}$$
$$Average\ speed\ of\ a\ human \geq 1.27ms^{-1}\ for\ worst\ case.$$
$$Then\ average\ speed\ of\ a\ human = 1.5ms^{-1}$$

For motor selection it has to follow some more calculations as follows. Required data for the calculation; M = Robot weight =4Kg | r = Wheel diameter = 0.07m | μ= Coefficient of friction on roughly rubber or wood = 0.9

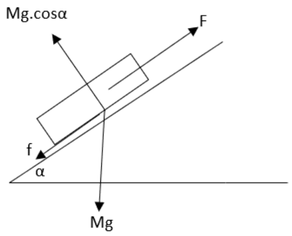

Figure 4. Motor selection calculations

$$F = Mg(sin\alpha + \mu . cos\alpha) \tag{1}$$
$$F = 4 * 9.8(sin0 + 0.9cos0)$$
$$F = 35.28N$$
$$For\ one\ motor\ required\ for = \frac{35.28N}{4} = 8.82N \tag{2}$$
$$For\ one\ motor\ required\ force$$
$$Torque = F * r \tag{3}$$
$$Torque = (8.82 * 0.07)Nm$$

$$Torque\ for\ one\ motor = 0.617Nm, \qquad Torque\ for\ full\ robot = 2.469Nm$$

According to the calculations the selected motor was RK-370CA-14445 12 v gear motor.

3.2 Motor Controlling

This project camera input signals are going to control by fuzzy logic controller and ultrasonic sensors are going to control by using PID controlling method. In this design it selected a fuzzy controller for the camera input signals. This method was selected for the camera inputs because fuzzy logic method is accurate for the one output function and PID is accurate when it has several inputs for control. The Fuzzy controller for the camera signals was built by using matlab software. First, we have to decide which output signals are going to use for designing the fuzzy controller. Fuzzy controllers basically use extensions of some boolean logic scenarios, but this controller just provides the output according to the input due to it having one input source. Here we are going to use mandani method. Mandani method is controlling the PWM signal so that it can control the speeds of the motors then the robot can have smooth bends.

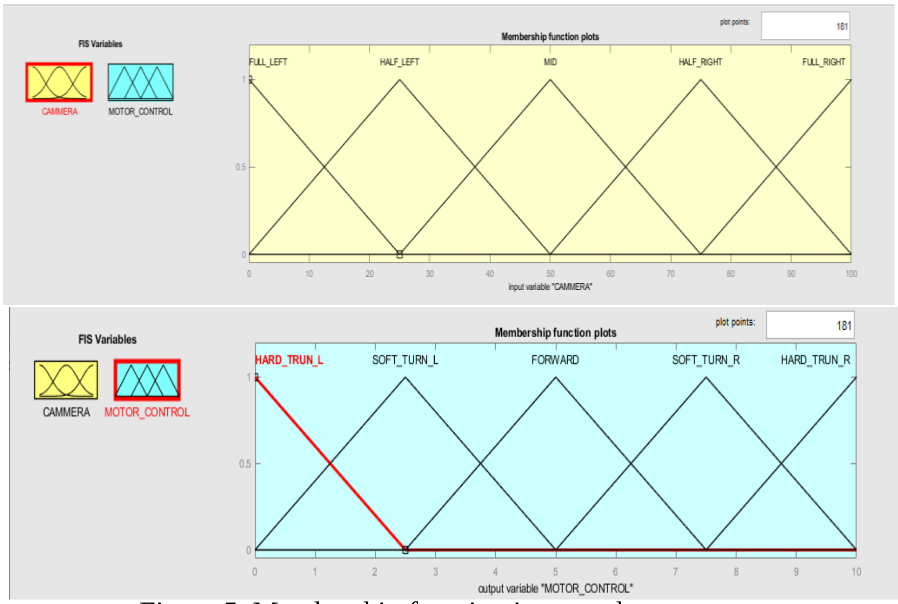

Figure 5. Membership function input and output

In second its implementation is the PID controller for three ultra-sonic sensors. In here this PID controller implemented according to the graph shown in figure 6 step by step.

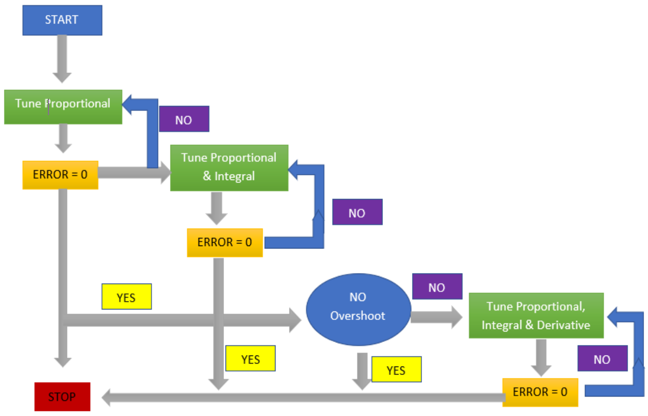

Figure 6. PID control implemented step graph

PID implement calculation.

$70 : X_{PWM}$

$[OUTPUT = ERROR] : Y_{PWM}$

$$\frac{70}{ERROR} = \frac{X_{PWM}}{Y_{PWM}}$$

$$Y_{PWM} = \frac{[X_{PWM} * ERROR)}{70} \qquad (4)$$

$$X - (\pm Y) \qquad (5)$$

In the above equation calculated for obtain an algorithm for PID controller which going obtain from Ultra-sonic sensor inputs. seventy is known distance X also know the PWM. X can vary according to the user requirement. when we have you got to know the set point distance PWM and the output error value that occur from the error signal and when the equations one shows Y PWM value can calculated. in the equation two it explains the new PWM value should be add or substitute to the set point PWM value. When the error has a negative value PWM should be add to the setpoint PWM and when the error gives a positive error the set point PWM should be deduct from the Y PWM. For the equation it used for when X negative the value it will happen what we need from PID controller.

3.3 Power unit development

The main part in power management is to share the power to all over the circuit in an efficient manner as shown in Figure 7.

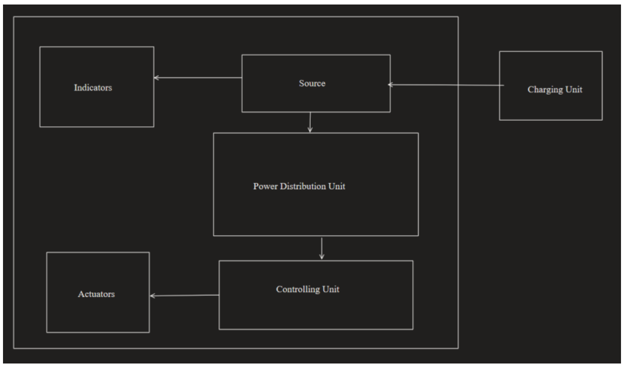

Figure 7. Basic Power Plan

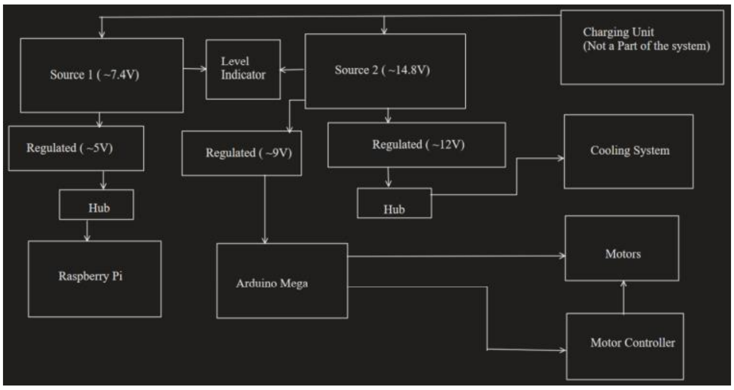

Figure 8. Power Distribution

Power distribution is becoming one of the main parts that control the relevant power needs in the circuit as shown in the Figure *8*. The Power is distributed as follows as in the Table *2*.

Table 2. Voltage and Current Needs of active components

Component	Voltage Needs	Current Needs
Raspberry PI	5V (4.8V – 5.1V)	1.2A to 2.5A
Arduino Mega	7V – 12V	200mA
Ultrasonic Sensors	5V	15mA
Motor Drive (Motors)	12V	1A to 2A

In here the ~7.4V (2 x 3.7V) Li-Po batteries – 2800mAH have been used to power up the Raspberry PI 3 board only. Since it draws maximum current or 2.5A, the single power source was used for it. And this source was used for multiple components, whereas the Arduino Mega, the motor controlling and for the cooling system. The most suitable power supply this is the Switch Mode Power Supply (SMPS). So, in boost converter was selected. When making the circuit of the boost converter, the simulation circuit as in was done and the following Figure *9*, PCB was done on the Ultiboard software.

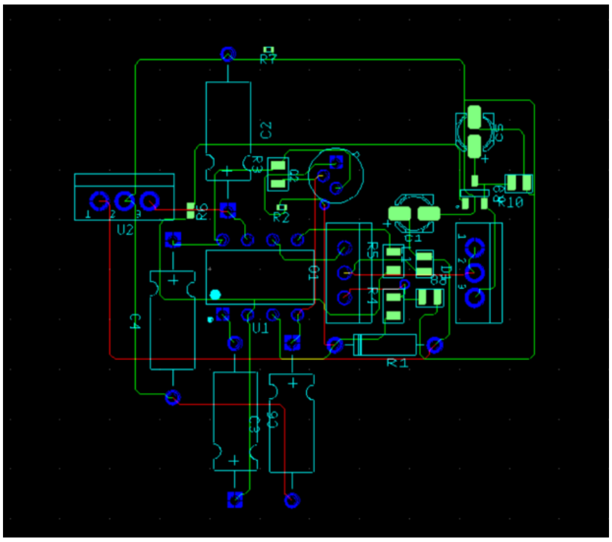

Figure 9. Boost Converter PCB

The voltage indicator was made which gives the voltage level in the batteries, that indicates the low and high levels. This was an important part for the circuit since when the indication comes the users gets to know when to charge the batteries or not. And it was designed as can be seen in the Figure *10*. The PCB of it designed and finalized as in the Figure *11*.

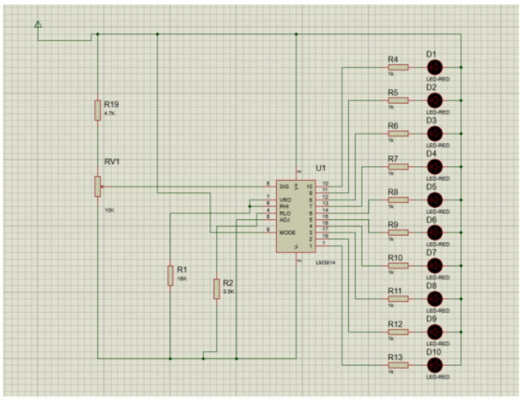

Figure 10. Voltage Level Indicator Simulation

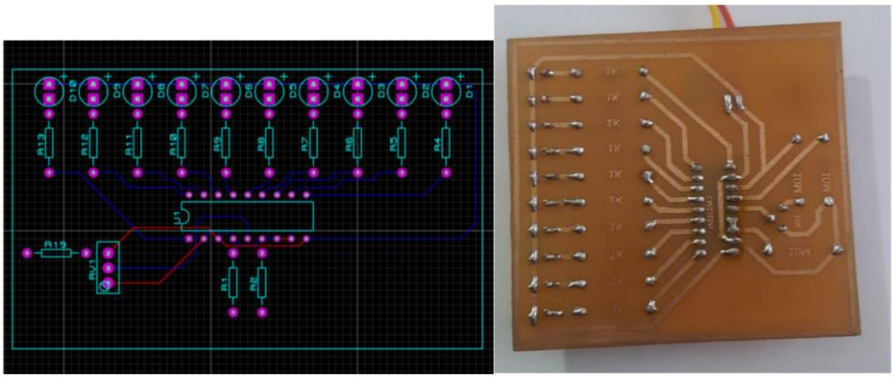

Figure 11. Final PCB

3.4 Obstacle Detection

When detecting an obstacle, it is very important to have several sensors mounted on the robot. Since the ultrasonic sensor (HC SR-04) is being used as the main sensor the sensor placement and number of sensors that are being used is very important. To detect the occurrence of an object, according to the size of the robot the sensor placements are also can be changed. In this human following robot, the robot was designed to have the width of the human walking path. Then the sensors were placed in the robot, that it can have the maximum output from the outside to detect the obstacles as in Figure *12*.

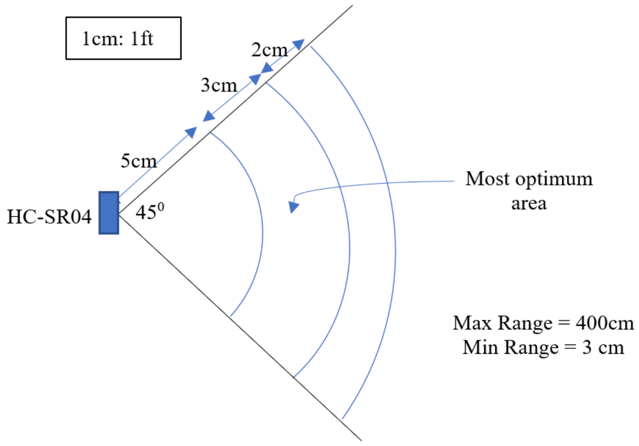

Figure 12. Sensor Coverage

Using these characteristics, there are for ultrasonic sensors have been placed in the robot as follows and the sensor coverage of the robot can be identified like in the following figures, Figure 13, and Figure 14.

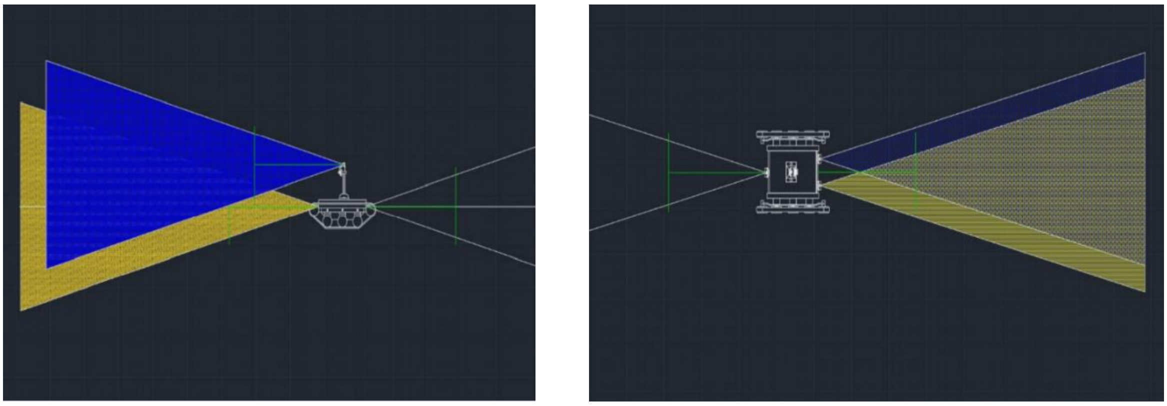

Figure 13. Sensor Coverages

3.5 Human Detection

The first stage is to collect high-quality training data for the model. Therefore, have taken approximately 500 photographs of several people from a variety of angles, clothing types, poses, positions, etc. Then, each image is precisely labelled and created bounding boxes for each. In this instance, chose to annotate only one class, however several classes can be annotated by the software. It will generate an XML file (in format of Pascal VOC) with all bounding boxes and annotations for each image. In order to facilitate the translation to TF.record format (below), the aforementioned program's XML was converted to two CSV files and already generated data are segregated into train and test (80 percent -20 percent). These files have nine columns: width: image width, height: image height, class: Image, xmin: the smallest x value of the bounding box, ymin: the smallest y value of the bounding box, xmax: the highest x value of the bounding box, ymax: the highest y value of the bounding box. Using labelimg software makes it simple to make images in the aforementioned format. TensorFlow 2's Object Detection API simplifies the development, training, and deployment of object detection models. This project utilizes this API to train the model using a Google Colaborative Notebook. Transform the input into a sequence of binary records to feed it to object detection API of TensorFlow. Then, based on selection of an object detection model, generated a specialized file to instruct the training operation done later in this notebook. Chosen among possible training models by altering the selected model variable. I've implemented the first few models of the EfficientDet series for exploration purposes. Each model is assigned a model name, a pretrained checkpoint, a batch file and a base pipeline file. The makers of the TF2 OD repository made available the base pipeline file, which has a specific training configuration for each model type. The pretrained checkpoint is the location of the saved pretrained weights file from the object identification model on COCO dataset by adjusting custom dataset based on these weights. Due to the utilization of pretraining, model did not have to start from scratch when determining which attributes can be used for object detection. Once having the custom data, pretrained checkpoint, and training settings in place, can update the initial pipeline file. In order to train more quickly, can increase batch size to point where the GPU can handle it, and the number of steps to train for. Then needed to remember to decrease by the same number of steps amount as raised the batch size if wanted to keep the training time constant. In the training command, specified both the pipeline file and the directory in which to save the model. Training in Colab will take a long time even if had access to a free GPU. Colab's kernel session will time out after a while of inactivity (around 45 minutes).

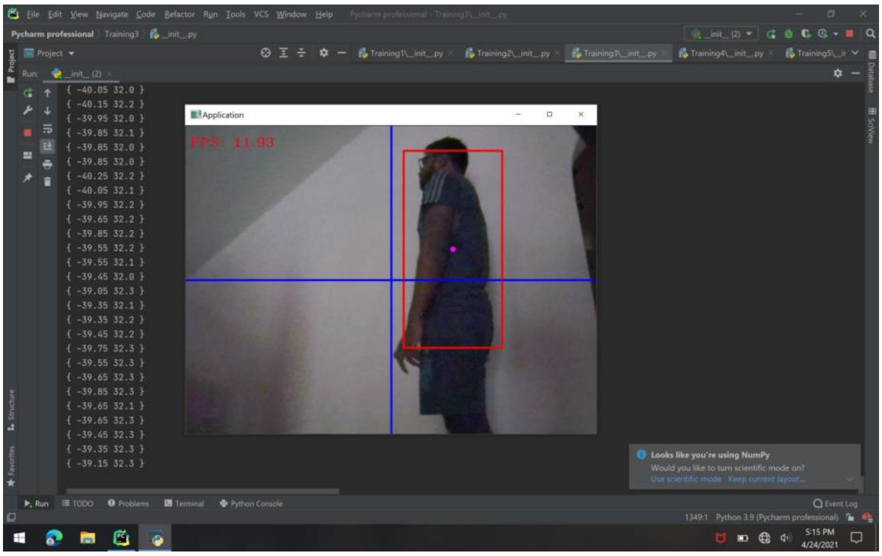

Figure 14. Detection of a person

4 CONLUSION

The future of the world will reconstruct with robotics. Every industry will be automated with robotics. Among them there are robots that are available to help human. In this project also to develop a human following robot that it also a one type a human helping robot. As a future improvement this project can add more features like up to a self-assistance robot. This robot is about following a one human and upload a map to the sever, as in advance future update the team discuss improve this robot up to a rover by using more efficient cameras motors and well as better communication engineering side; or self-assistance robot with more actuators to help human to the day today things more accurately by using an Artificial Intelligence.

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Enhancement of Images Under Low Light Conditions Using Artificial Intelligence

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ABSTRACT

Images taken in low light conditions do not contain all the information well-lit images contain. Various features including the colours of objects, details and the quality are lost. Extracting these features from images is very important for any kind of application of it. This study proposes a model to enhance the features of the image taken under low light conditions, by delivering a solution which improves the quality of the image through Artificial Intelligence. Through the proposed method, the clarity of the image is improved, making it closer to a well-lit image equivalent. Both Image Processing and Deep Learning based techniques are explored, including Convolutional Neural Network (CNN) based generative models. The Generative models considered are Autoencoders (AE) and Generative Adversarial Networks (GANs). The study has been carried out by using several datasets combined together, which include image pairs of well-lit and low light images. A comparison between the two CNN-based generative models is carried out. Through the study, it is quantitatively found, by the Structural Similarity Index and supported by the Peak Signal to Noise Ratio, that the proposed CNN-based Autoencoder model overrides the proposed CNN-based GAN model. This is further supported by qualitative observations of the image results. Both models, however, greatly enhance the low light images, bringing to light features that were not visible beforehand, and also provide results with good colour accuracy. Through this research study, the methods and solutions to enhance low light images have been addressed, as well as providing a comparison between two suitable models, Autoencoders and GANs. The proposed solution is able to address many of the limitations existing in the extent literature.

KEYWORDS: *Autoencoder, Comparative Analysis, Convolutional Neural Networks (CNN), Generative Adversarial Network (GAN), Image Enhancement*

1 INTRODUCTION

In today's technologically advanced world, there is a significant demand for image-based applications. The importance of constantly evolving and improving results from image-based applications cannot be overstated. Image enhancement, as well, is a highly studied topic, and improvements by various methods are rapidly occurring, from the long-studied Digital Image Processing (Maini and Aggarwal, 2010) to more rapidly developing Machine Learning methods (Li et al, 2020). However, images taken at night are of significantly lower quality than images taken during the day. Here, many features can be missed, resulting in less useful information being gleaned from these images. An enhanced image can serve both aesthetic purposes as well as be important for businesses and households. As an example, when considering security, CCTV cameras require a nighttime image from which features such as vehicle details and human features can be observed. A common method used in increasing the visibility of low-cost CCTV cameras at night is with Infrared (IR) technology, in which colour accuracy cannot be achieved to a reasonable level. Colour night vision technology, a less budget-friendly option, has allowed surrounding light, if available, to be used as assistance (Lorex, 2022). However, when there is no surrounding light, CCTV images cannot provide all the required information,

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which is a key challenge to safeguard the occupants of an apartment complex or to ensure a warehouse is secure. Similarly, for images taken by a phone camera at night, a dark image with low visibility of the people and buildings serves no purpose, compared to a well-lit image which can capture the liveliness of the scene. Motivated by the rapid developments in Artificial Intelligence and Machine Learning in Image-based applications, this study has been conducted to enhance images taken under low light conditions, by applying the powerful nature of Convolutional Neural Networks (CNNs). This study will be examining two CNN-based generative models to improve low lit images up to a well-lit, daytime level.

Image enhancement in full colour is an important objective of this project. Black and white enhanced images, while useful, cannot provide all the details that may be required or wanted by the consumer. While colour images can be obtained, it is even more important of obtain accurate colour information, as there is an uncertainty in the colours obtained by the current methods used, as these methods result in an image largely affected by the lighting and the types of illumination in the scene, the poor camera performance and losses that can occur (MacDonald, 2007).

Image enhancement methods that utilize Artificial Intelligence most commonly used CNNs. A study found an algorithm to enhance the quality of weak contrast images, using multi-layer CNN. Here, weak contrast images were generated using public datasets, along with images captured by the authors, and a neural network with a trapezoidal convolutional kernel was used (Wang and Hu, 2019). The study was able to provide an algorithm with a high Structural Similarity Index (SSIM) (Bakurov et al, 2022) and higher Peak Signal to Noise Ratio (PSNR) (Joshi et al, 2016) compared to previous studies. This study, while able to enhance low contrast images, did not generate a well-lit equivalent image. A subsequent study used a newly proposed RSCNN (Remote-Sensing Convolutional Neural Networks) model (Hu et al, 2021) to enhance remote sensing low light images, further improving on the multi-layer model proposed prior. This model, while it did enhance images, did not bring it up to a daytime, well-lit level, instead presenting a well-defined low light image. Another study using CNN-based methods for image enhancement utilized Conditional GANs for semantic segmentation (Wang et al, 2017), to obtain photorealistic images from semantic label maps. Their model tested a day-to-night conversion model and a night-to-day conversion model for semantic segmentation and concluded a day-to-night converter to produce better results. For the study to be conducted, a night-to-day (low light to well lit) conversion process is required. On the other hand, Autoencoders are most commonly used in denoising and image compression tasks. As an example, a study conducted on image noise reduction by the use of a denoising Autoencoder using four different models determined the best model was that which had the greatest number of hidden layers (Yasenko, 2020). Therefore, in addition to CNN-based GANs, CNN-based Autoencoders look promising in providing a solution to enhance nighttime images using Artificial Intelligence. This study will explore CNN-based generative methods for image enhancement, specifically in generating a well-lit image which is able to be presented as a daytime equivalent for a low light, nighttime image. Here, in addition to GAN models, Autoencoders will also be considered for low light image improvement.

To perform the above task, first a suitable data set was collected. This dataset was then preprocessed, and the models for both the CNN-based Autoencoder and GAN models were designed. Following training, testing and validating the models, the two generative models were compared against each other and against past studies by using performance indices such as the Structural Similarity Index Matrix (SSIM), Feature Similarity Index Matrix (FSIM), Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), as well qualitatively by observing the image results. Through this, the most suitable model from the proposed Autoencoder and GAN model can be decided upon.

The size and variety of the dataset used for this project will greatly affect the result. Here, the dataset will include pre-existing sets and those taken by a camera. Instead of considering daytime and nighttime images, medium and low exposure images will be used, for reasons detailed in section 2.1. This is a limitation of the project, and it is assumed that these camera images are a suitable alternative for day and night image pairs.

The following paper will next detail the design methodology of the study. The results will also be presented, including the performance index results and test image samples, as well as a comparison between the generative models and a comparison against past studies.

2 DESIGN METHODOLOGY

This section will explain the selection of the dataset, preprocessing steps, design and development of the CNN-based Autoencoder and GAN neural networks, as well as the selection of the performance indices. Figure 1 illustrates the design methodology for this study. The two generative models were designed parallelly and used the same dataset and image dimensions for an unbiased comparison. Google Colab is used to run the Autoencoder and GAN codes, written in Python, as this environment is cloud based and allows access to computing resources such as GPU runtimes, which was used to carry out the task. A standard class GPU runtime is an Intel Xeon CPU @2.20 GHz, 13 GB RAM, Tesla K80 accelerator, and 12 GB GDDR5 VRAM.

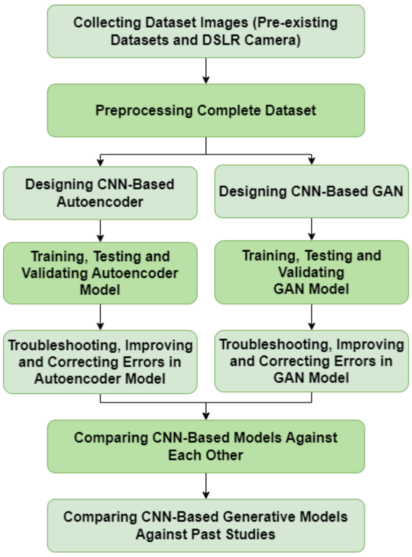


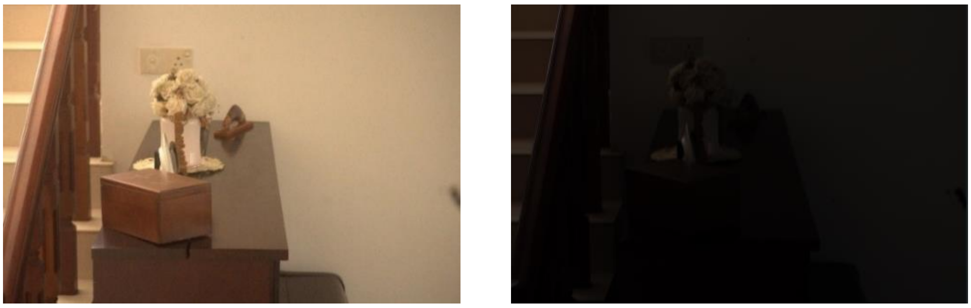
Figure 1. Illustration of Design Methodology

2.1 Dataset Collection and Selection

The requirement of the image dataset compiled is an image pair consisting of a well-lit image and its low light equivalent. It is essential that the two images are of the exact same scene. Therefore, obtaining a day and night image pair proves to be difficult, as many factors can vary as the time passes. To solve this issue, high and low exposure image pairs are considered as an alternative. Here, the low exposure image is low lit, and the high exposure image is well lit. Low exposure allows a lesser amount of light to enter the sensor of the camera, resulting in a darker image. This narrowed down the pre-existing image dataset options. Datasets such as Kaggle Day-Night (Mark, 2021), DeepISP (Schwartz et al, 2018), SID (Chen et al, 2018) and LOL (Wei et al, 2018) were considered. The image pairs obtained are as follows: 17 image pairs from Kaggle Day-Night Dataset, 110 image pairs from DeepISP Dataset, 33 image pairs captured by the author from a DSLR camera, 450 image pairs from LOL Dataset. Image samples are shown below, where Figure 2 shows a high/low exposure image pair taken from the LOL Dataset and Figure 3 shows a high/low exposure image pair taken from a DSLR camera.

(a) (b)

Figure 2. Sample Image Pair from LOL Dataset (Wei et al, 2018). (a) Well-Lit Image. (b) Low Light Image.



(a) (b)

Figure 3. Sample Image Pair taken from DSLR Camera (Author Captured). (a) Well-Lit Image. (b) Low Light Image.

When selecting the datasets, the Dark Zurich dataset was disregarded as the short exposure images, which were in *.raf* format, when converted resulted in an image with a purplish hue.

2.2 Preprocessing

The images selected must be resized to a lower quality, with the images brought to the same size. As the dataset contains high quality images taken from various DSLR cameras and phone cameras, they are of differing dimensions and formats, and cannot be directly passed to the models. Therefore, they are scaled down to a usable size of 200x134 pixels, as this is a size suitable for most of the images in the datasets. This size is reasonable for the Autoencoder and GAN models, which will require higher computation and power if higher quality images are used. The resizing is done by running an image processing script on Adobe Photoshop. Following the resizing, the images are cropped to 128x128, which is a square image. As the images will be undergoing various resizing processes, and the dimensions will be halved multiple times within the model, 128x128 (2^7x2^7) is deemed suitable. Initially, the 128x128 images were directly used, but it was found that resizing these cropped images up to 256x256 dimensions was able to yield better results, without a drastic increase in computation time. Following that, the images are then separated into train and test datasets, and the high exposure images are taken as the target image set while the low exposure images are the data which will be trained to reach target value. The train set consists of 550 image pairs, while the test set consists of 60 image pairs. These are saved as arrays. The shapes of these arrays are then checked, and then saved. In these image pairs, the low light image is the source image, and the well-lit image is the expected, or target, image.

2.3 Autoencoder Model

Autoencoders reconstruct the input by unsupervised learning and are commonly used in denoising and image compression (Bank et al, 2020). The input image is sent through hidden layers (the encoder) to obtain the compressed representation, and this is then sent through hidden layers to obtain the enhanced output image, via the decoder (Cunningham et al, 2020). The Autoencoder Model proposed is depicted in Figure 4.

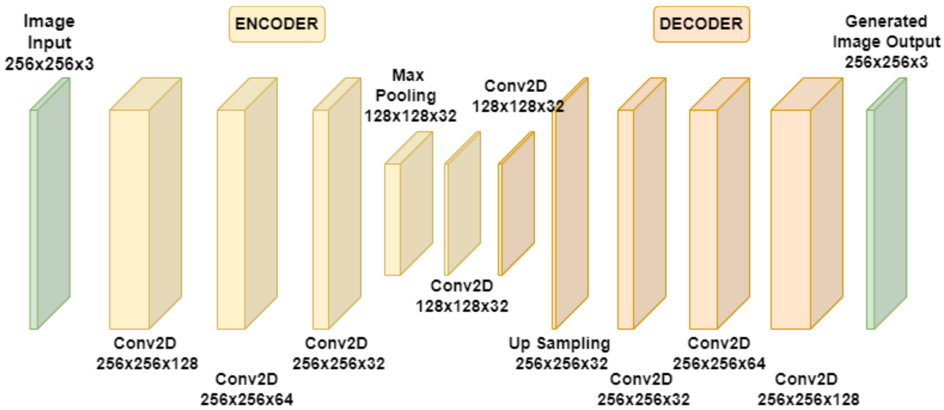


Figure 4. Proposed Autoencoder Model

The architecture for the proposed Autoencoder is shown below in Table 1.

Table 1. Autoencoder Architecture

Layer Type	**Description**	**Output Shape**	**Activation Function**
Image Input	Colored image input	256x256x3	
1st Encoder Hidden Layer (Convolutional)	128 filters, 3x3 kernel size	256x256x128	ReLU
2nd Encoder Hidden Layer (Convolutional)	64 filters, 3x3 kernel size	256x256x64	ReLU
3rd Encoder Hidden Layer (Convolutional)	32 filters, 3x3 kernel size	256x256x32	ReLU
Max Pooling Layer	2x2 max pooling	128x128x32	
4th Encoder Hidden Layer (Convolutional)	16 filters, 3x3 kernel size	128x128x16	ReLU
1st Decoder Hidden Layer (Convolutional)	16 filters, 3x3 kernel size	128x128x16	ReLU
Up Sampling Layer	2x2 up sampling	256x256x16	
2nd Decoder Hidden Layer (Convolutional)	32 filters, 3x3 kernel size	256x256x 32	ReLU
3rd Decoder Hidden Layer (Convolutional)	64 filters, 3x3 kernel size	256x256x64	ReLU
4th Decoder Hidden Layer (Convolutional)	128 filters, 3x3 kernel size	256x256x128	ReLU
Image Output	Colored generated image output	256x256x3	

Many types of layers were considered for the model, but the best results were obtained with the above structure. Here, the Convolutional layer is used along with the ReLU activation, as well as Max Pooling and Up Sampling layers. The convolutional layer can be considered as the backbone of CNN Models. It convolves data and passes on the transformed version to the next layer. ReLU Activation is used in order to prevent the computations from having exponential growth. For this cause, negative values of the matrix are substituted by 0 and the positive values are left as it is. In Max Pooling, for the selected filter size, the largest value in each patch of the feature map of the image is calculated and the image is then down sampled, reducing the dimensions of the image and highlighting the most important characteristics of the image, disregarding the less important factors. Up Sampling, does the opposite, increasing the image dimensions and bringing it back to the original size.

The above Autoencoder model is compiled by using an Adam optimizer with a learning rate of 0.001 and a loss function of Mean Square Error (MSE). Adam is used as the optimizer, as it is considered to be the best and fastest optimizer. For machine learning problems where a continuous output is obtained, such as the one in this study, MSE is the most suitable loss function. This is as it gives us the average of the squared difference between the generated and expected values for the images. The Autoencoder is then trained with a batch size of 50 for 50 epochs, and the results are tested, and the performance index results (SSIM, FSIM, MSE and PSNR) can be obtained.

2.4 Generative Adversarial Network Model

Generative Adversarial Networks have two neural networks competing to generate artificial data that can be taken as real data. A noise input to the generator is along with selected images from the dataset are sent to the discriminator, which tries to differentiate between real and fake images. Through this process, the generated images are finetuned by the model by changing its hyperparameters, until the discriminator is tricked (Hermosilla et al, 2021). The operation of a GAN model is illustrated in Figure 5.

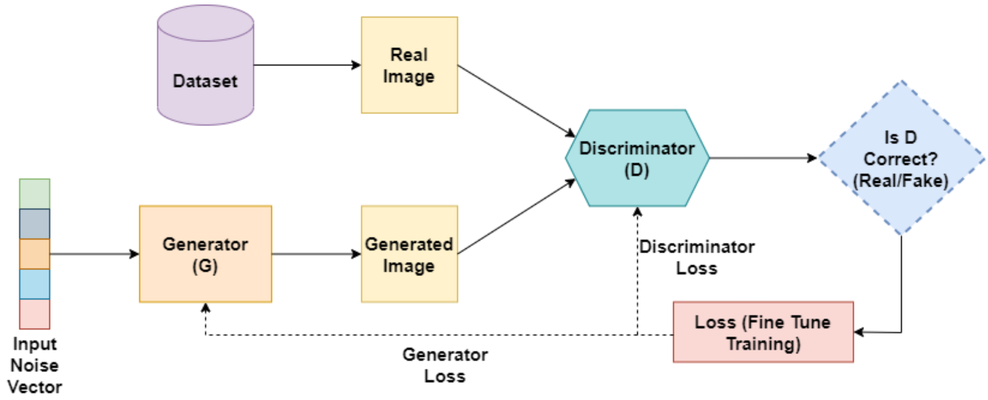


Figure 5. Basic GAN Model

To enhance low light images, instead of a noise input to the generator, the input is instead the low light image equivalents of the real image from the dataset. It is important to note that the images are normalized before they are passed through the training model, resulting in values between -1 and 1. The input to the generator, and thereby the GAN model, is an image of size 256x256x3. The output of the GAN is the output of the discriminator. The output layer of the generator is the same shape as the input layer of the discriminator, which is an image.

The generator model works towards creating a well lit image from the low light image. The generator consists of a model similar to the autoencoder model. Here, the only difference is that an activation function of tanh is used. This is used as the images have been normalized, bringing them to a value between -1 and 1. The tanh activation is the most suitable for this type of image, as it too gives an output between -1 and 1. However, the discriminator takes in two images, the real and fake. Next, real samples are generated, which are the real images from the dataset. These are given a value of 1, indicating that they are real. Following that fake images are generated, which are the predicted images by the generator model. The discriminator model gives an output which determines the realness or fakeness of the image. The Discriminator Model for the GAN proposed is shown in Figure 6.

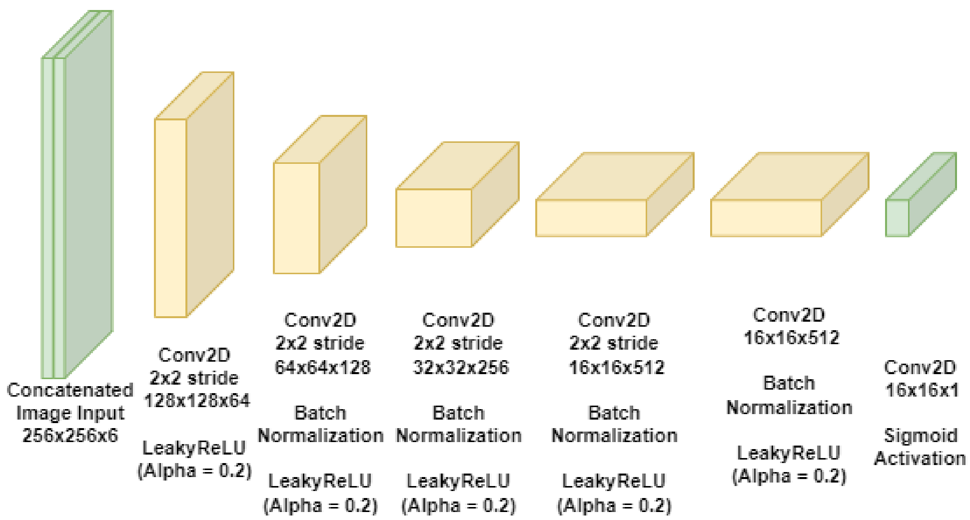


Figure 6. Proposed GAN Model

The architecture for the proposed discriminator is shown below in Table 2.

Table 2. GAN Discriminator Architecture

Layer Type	Description	Output Shape
Merged Image Input	Concatenation of generated image and dataset image (both colored)	256x256x6
1st Hidden Layer (Convolutional)	64 filters, 4x4 kernel size, 2x2 stride	128x128x64
Leaky ReLU Activation Layer	Alpha = 0.2	128x128x64
2nd Hidden Layer (Convolutional)	128 filters, 4x4 kernel size, 2x2 stride	64x64x128
Batch Normalization Layer		64x64x128
Leaky ReLU Activation Layer	Alpha = 0.2	64x64x128
3rd Hidden Layer (Convolutional)	256 filters, 4x4 kernel size, 2x2 stride	32x32x256
Batch Normalization Layer		32x32x256
Leaky ReLU Activation Layer	Alpha = 0.2	32x32x256
4th Hidden Layer (Convolutional)	512 filters, 4x4 kernel size, 2x2 stride	16x16x512
Batch Normalization Layer		16x16x512
Leaky ReLU Activation Layer	Alpha = 0.2	16x16x512
5th Hidden Layer (Convolutional)	512 filters, 4x4 kernel size	16x16x512
Batch Normalization Layer		16x16x512
Leaky ReLU Activation Layer	Alpha = 0.2	16x16x512
6th Hidden Layer (Convolutional)	1 filter, 4x4 kernel size	16x16x1
Sigmoid Activation Layer		16x16x1

In addition to the layers considered for the autoencoder above, the discriminator consists of LeakyReLU as the activation function. Batch Normalization was also used prior to feeding data into the neural network. LeakyReLU is a modified ReLU activation function, but it also plots some values close to zero to be negative, unlike ReLU. Here, alpha is the parameter in the LeakyReLU layer which represents that small negative value. Batch Normalization helps to stabilize the model and make it faster. A sigmoid activation layer is most suitable when the output required is a probability and is used as a value between 0-1 is needed as the output, as a probability of the "realness" of the output image. The above discriminator model is then compiled using the Adam optimizer with a learning rate of 0.0002.

Following that, the GAN model needs to be created, which is resulted by combining the generator and discriminator model. The GAN is then trained, with a batch size of 50 for 50 epochs. For the training process, first only the discriminator is trained, freezing the generator. Through this, the first set of discriminator weights are obtained. Next the generator is trained, keeping the discriminator frozen, and the above discriminator weights are used. Through this, the generator weights are also obtained. This process is repeated for the 50 epochs.

2.5 Comparison of Generative Models

To compare the two models against each other, Structural Similarity Index Matrix (SSIM) (Bakurov et al, 2022), Feature Similarity Index Matrix (FSIM) (Zhang et al, 2011), Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR) (Joshi et al, 2016) will be used.

These values are expected to be used to identify the success of the study, along with a qualitative comparison of the well-lit images to the generated output images.

The SSIM compares the original, clean reference image x with the changed or corrupt image y (Bakurov et al, 2022). The index is calculated as:

$$SSIM(x,y) = [l(x,y)]^{\alpha}.[c(x,y)]^{\beta}.[s(x,y)]^{\gamma} \tag{1}$$

where α, β and γ are weighing exponents. Here, $l(x,y)$ is the luminance comparison, $c(x,y)$ is the contrast-based comparison and $s(x,y)$ is the structural comparison. They are calculated as:

$$l(x,y) = \frac{2\mu_x\mu_y + C_1}{{\mu_x}^2 + {\mu_y}^2 + C_1} \tag{2}$$

$$c(x,y) = \frac{2\sigma_x\sigma_y + C_2}{{\sigma_x}^2 + {\sigma_y}^2 + C_2} \tag{3}$$

$$s(x,y) = \frac{\sigma_{xy} + C_3}{\sigma_x\sigma_y + C_3} \tag{4}$$

where σ is the standard deviation, which represents contrast and μ is the patch average for each image, which is a representation of the luminance. Here, C_1, $C_2$and C_3 are small constants introduced for numerical stability, such that they are a function of the range of pixel values L and the constants K_1 and K_2, which are usually 1x10^{-2} and 3x10^{-2}. These values are calculated as:

$$C_1 = (K_1L)^2 \tag{5}$$

$$C_2 = (K_2L)^2 \tag{6}$$

$$C_3 = \frac{C_2}{2} \tag{7}$$

The SSIM result produces a value between 0-1, and a higher value indicates a higher similarity between the images.

PSNR uses the MSE to find the similarity between the two images (Joshi et al, 2016). This is given in dB, and the equation is as follows.

$$PSNR = 10log_{10}\left[\frac{I^2}{MSE}\right] \tag{8}$$

$$MSE = \frac{1}{[N \times M]^2}\sum_{i=0}^{N=1}\sum_{j=0}^{M=1}(x_{ij} - y_{ij})^2 \tag{9}$$

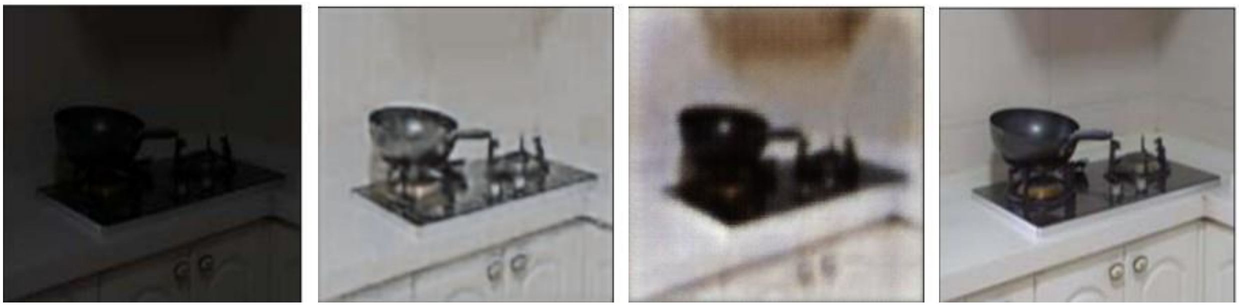
Here, I represents the maximum intensity of the grayscale image (most commonly 2^{8}-1), x is the original image and y is the changed image. x_{ij} represents the intensity of the ij^{th} pixel of the original grayscale image and y_{ij} is the same for the generated image. N and M are the number of rows and columns in the images x and y.

FSIM (Zhang et al, 2011) is used to support the results obtained from the above two methods. A high FSIM value indicates a higher similarity between the two images.

3 RESULTS

The results below are obtained after finetuning the Autoencoder and GAN models, as detailed Section 2.3 and 2.4. Here, the low light images from the test dataset are passed through the models, and the generated images can be obtained. For the GAN model, the test data is passed to the generator instead, to obtain an image result. The below Figures show a comparison between the source image— which is the low light image— to the Autoencoder generated image, GAN generated result, and finally the target, or expected, brightly lit image.

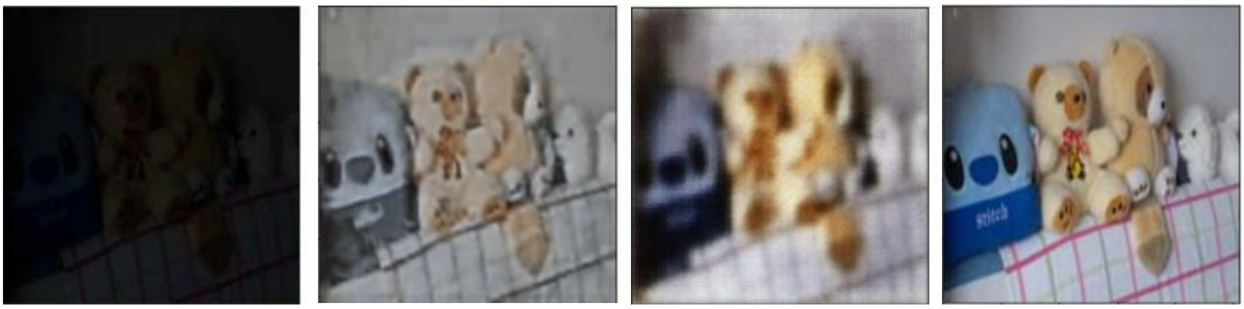
Figure 7 shows a scene depicting a pantry countertop, with the focus on the pan on the stove. As we can see, the generated images 7(b) and 7(c) are much brighter than the source, 7(a). The pan can easily be identified, although it is noted that the Autoencoder produces the pan in a lighter colour than the expected result, while the GAN results in a darker image. It can also be pointed out that the GAN result is not as clear as expected.



(a) (b) (c) (d)

Figure 7. Image 1 Comparison Between Models. (a) Low Light Image (Source Image). (b) Autoencoder Generated Image. (c) GAN Generated Image. (d) Well Lit Image (Expected Image).

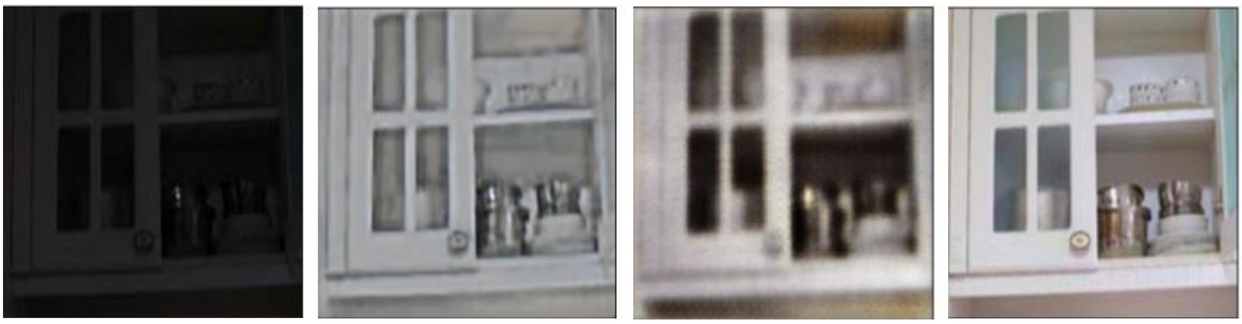
Figure 8 consists of various textures, including a banket and soft toys. As we can see, the brightness as well as the visibility and the differentiation between the various textures has increased in the generated image, as compared to the low light image. The Autoencoder result easily distinguishes between the individual toys, while the GAN produces a more vivid, albeit unfocused, result.



(a) (b) (c) (d)

Figure 8. Image 2 Comparison Between Models. (a) Low Light Image (Source Image). (b) Autoencoder Generated Image. (c) GAN Generated Image. (d) Well Lit Image (Expected Image).

Figure 9 depicts a cupboard with various kitchen utensils and crockery. Here, the GAN produces images that are much darker than the Autoencoder model, but the colours allow the objects to be easily identified in both results.



(a) (b) (c) (d)

Figure 9. Image 2 Comparison Between Models. (a) Low Light Image (Source Image). (b) Autoencoder Generated Image. (c) GAN Generated Image. (d) Well Lit Image (Expected Image).

As shown above, generated images by both the Autoencoder and GAN enhance the images, by brightening the scenes. The objects in the images can be seen clearly without straining. The colors produced by the two models are adequately accurate as well. The Autoencoder model produced a sharper, more distinguishable image, compared to the more blurred image produced by the GAN model. The Autoencoder model, while it produces images that are more visually enhanced than the GAN, results in images that are slightly washed out compared to the GAN model.

The SSIM, FSIM, MSE and PSNR results for the two generative models for the first ten test data images are shown below in Table 3. Here, the original image is compared to the generated image.

Table 3. Performance Index Results for Generative Models

Image	SSIM		FSIM		MSE		PSNR	
	Autoencoder	**GAN**	**Autoencoder**	**GAN**	**Autoencoder**	**GAN**	**Autoencoder**	**GAN**
1	0.89	0.85	0.67	0.64	2.14	42.58	31.94	31.72
2	0.89	0.84	0.66	0.63	2.56	2.58	32.04	32.21
3	0.91	0.84	0.68	0.63	32.04	39.25	32.28	31.98
4	0.9	0.84	0.65	0.63	2.09	41.02	31.9	31.9
5	0.89	0.84	0.63	0.63	0.74	4.09	32.07	32.14
6	0.88	0.82	0.64	0.6	0.29	4.51	31.69	32.3
7	0.88	0.84	0.6	0.63	8.56	10.17	32.64	32.7
8	0.89	0.8	0.61	0.57	6.69	2.06	32.85	32.17
9	0.88	0.86	0.67	0.65	0.83	35.17	31.94	32.25
10	0.91	0.83	0.68	0.64	12.73	3.63	32.29	31.99

The SSIM gives the image quality degradation caused by various processes such as compression and losses due to data transmission. This value should be between 0 and 1, with a higher value indicating a closeness to the original (here, expected) image. Here, the results for the Autoencoder model are all above 0.88, with the highest results reaching above 0.9. For the GAN model, the results are all above 0.8, with the highest at 0.86. Therefore, it is noted that the Autoencoder model produces comparatively better results in terms of the Structural Similarity Index Matrix. This is most likely due to the blurriness in the images produced by the GAN model. FSIM is similar to SSIM, but instead focuses on features of the image. The Autoencoder values vary from 0.6 to 0.68 in these sample test images, while the results for the GAN model vary from 0.57 to 0.65. In terms of Feature Similarity Index Matrix as well, the Autoencoder model shows better performance results. Here, this occurs due to the features not being as distinguishable, due to the less sharp nature of the GAN model results.

The MSE gives the average of the square of the difference between the two images. Here, it is noted that there is a variation depending on the images, with some giving a small value of less than 1, and other images reaching comparatively high errors above 30. Overall, here too it can be noted that the Autoencoder model proposed results in lower errors in terms of Mean Square Error. Here, it is observed that the pixel wise difference can be large in some images for the models, and much less for others. As an example, in Figure 9, the inside of the cupboard, which is expected to be a white, is instead black in the GAN generated result. The MSE in the Autoencoder model can also be accounted for by the less vividness of the colours it produces.

The PSNR gives a ratio of the quality between the original and generated images, and therefore a higher value is preferable. Here, the PSNRs are all around 32dB, for both the generative models, producing extremely close results. The PSNR value is dependent on the MSE value and shows similar results.

A summary of the performance index results on the complete dataset of all test images is shown below in Table 4. The SSIM and FSIM values are converted to percentages, to show the variation more clearly. Higher SSIM, FSIM and PSNR values as well as lower MSE values are favorable.

Table 4. Performance Index Comparison of Generative Models

Performance Index	**Proposed Autoencoder Model**	**Proposed GAN Model**
SSIM	88.20%	83.72%
FSIM	65.73%	62.67%
MSE	14.65	17.70
PSNR	32.31 Db	32.35 Db

Here, there is a 4.5% difference in the SSIM results of the two models, with the Autoencoder showing a higher value. By considering the FSIM as well, the Autoencoder provides a 3% higher value. The Mean Square Error value is higher for the GAN model, showing that there is a larger error produced with the CNN-based GAN model proposed. However, when it comes to the PSNR, the GAN model shows a slightly better value. This 0.04 Db difference though, is insignificant compared to the rest of the values. Therefore, quantitatively, thE Autoencoder model provides better results than the GAN model.

The below table shows a comparison of the pSNR and SSIM values between past studies, which are "Learning to See in the Dark" (Chen et al, 2018), "RSCNN: A CNN-Based Method to Enhance Low-Light Remote-Sensing Images" (Hu et al, 2021), "Trying to See Low Exposure Images using CNN" (Shinde et al, 2021), and the designed Autoencoder and GAN model. Higher PSNR and SSIM values are favorable. The Learning to See in the Dark model was tested on two datasets.

Table 5. Comparison Between Generative Models and Past Studies

Model	**PSNR (dB)**	**SSIM**
Designed Autoencoder Model	32.31	0.8820
Designed GAN Model	32.35	0.8372
Learning to See in the Dark (Sony Dataset)	28.88	0.787
Learning to See in the Dark (Fuji Dataset)	26.61	0.680
RSCNN	28.194	0.825
Trying to See Low Exposure Images using CNN (CNN)	18.2029	0.8143

Therefore, it can be seen that the Autoencoder and GAN models developed within the study provide better results compared to the considered studies, with the designed Autoencoder Model producing the most favorable results.

4 CONCLUSION

Images taken under low lighting conditions are often not able to provide all the information needed, especially when related to security camera images. The purpose of this study is to enhance low light images, to result in images from which useful information can be gleaned. To carry out this task, Artificial Intelligence in the form of Convolutional Neural Network (CNN)-based generative models have been adopted. Here, by collecting a sizable dataset and considering various architectures for the models of these two generative approaches, a suitable architecture was obtained for both an Autoencoder and GAN. By performing a quantitative and qualitative comparison between the results obtained by both the Autoencoder and the GAN model, via observing the generated images visually and also by analyzing the results through performance indices such as SSIM, FSIM, MSE and PSNR along with other factors, the more suitable model for this task was found to be the CNN-based Autoencoder model. Both models, however, were able to greatly enhance the low light images. Here, the Autoencoder model was able to produce an average SSIM (Structural Similarity Index Matrix) result of 88.20%, compared to the average 83.72% obtained by the GAN model. This study into image enhancement using CNN-based generative models will therefore aid in future research in extracting information from low light images.

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ELECTRICAL AND ELECTRONICS ENGINEERING

Object Recognition and Assistance System for Visually Impaired Shoppers

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ABSTRACT

Shopping is indeed effortless for many individuals. However, it could certainly be a struggle and chaotic experience for the visually impaired. Visual impairment causes many societal stigma and inconvenience to visually impaired individuals. Although shopping may sound extremely easy, this is a crucial social activity for many visually impaired (VI) individuals. Visually impaired (VI) shoppers always require assistance when shopping for product identification purposes. This may lead to greater inconvenience as delays, lack of information and product familiarity of shop assistants may occur. Therefore, allowing visually impaired shoppers to independently perform shopping regardless of size and position of the shopping mall is essential. This encourages them to participate in enhanced social activities and perform their daily chores in independence. Although many products have been developed to assist visually impaired shoppers at shopping malls, due to their drawbacks, some of these have seem to undergo failures in producing accurate information to the visually impaired shopper for object identification and caused inconvenience. This project proposes a feasible solution for visually impaired shoppers to perform their shopping at ease and independently. Object recognition has been made possible in order to identify garment items while shopping with no assistance of another individual. The Convolutional Neural Network (CNN) has been used to obtain a sufficiently good accuracy and precision with a validation accuracy of 90%. Some of the novel techniques such as Ensemble Modelling has also been performed in order to reduce any generalization errors of the prediction and achieve a greater accuracy while overcoming all of the drawbacks of the currently existing products in the market. The overall product is proposed to attain maximum consumer population of visually impaired shoppers with satisfaction, reliability, and low cost.

KEYWORDS: *Convolutional Neural Networks (CNN), Ensemble Model, Visually Impaired (VI), Minimal Assistance while Shopping, Principal Component Analysis (PCA)*

1 INTRODUCTION

According to the collection of the most recent information about eye health that was published in 2021 by the official launch of the International Agency for the Prevention of Blindness's Vision Atlas, it reveals that there exists 43 million individuals globally living with blindness and another 295 million people living with moderate-to-severe visual impairment (Orbis, 2022). Furthermore, the According to the World Health Organization (WHO), uncorrected myopia and presbyopia alone are projected to have yearly global costs of lost productivity linked with visual impairment of US$ 244 billion and US$ 25.4 billion, respectively (Who.int, 2022). Therefore, it can be stated that visual impairment affects many major local and global activities.

Shopping may seem effortless for many individuals. However, with the development of the modern world, the complexity of modern supermarkets has seemingly increased. Gigantic shopping malls have claimed to possess stocks with an average of 45,000 products and a median store size of 4,529 square meters (Fmi.org, 2022). Shopping also involves a process of navigating through aisles, locating shelves with desired products, identifying the necessary products or items, and many more.

https://doi.org/10.54389/RRFZ2311

Individuals with visual impairments often rely on another individual for assistance when shopping. This compromises their independence at large. It is also a struggle as it is necessary to inform the store in order to reserve an individual for assistance beforehand or have their own means of assistance. This results in experiencing delays, inconvenience, irritation, and more. Assistants at supermarkets may also not possess adequate knowledge to read out ingredients, may be unfamiliar with aisles and products, and other inconveniences. Due to these difficulties faced by Visually Impaired (VI) shoppers, they may abandon shopping and choose distant alternatives. Although many apps have been especially designed and developed for VI shoppers, this reduces the ability of spontaneous shopping and reduces personal independence of VI shoppers. Therefore, means for VI individuals to shop by themselves independently and reliably is necessary. Many smart solutions such as assistive aids have been implemented to ease the life of VI shoppers and provide convenience to perform their daily activities. However, due to some of their drawbacks and failures, means to assist accurately, comfortably, and reliably prevails.

1.1 Problem Statement

Visually impaired citizens often deal with many challenges in their daily lifestyle and routine. The limited accessibility to many activities and information, societal stigma, requiring assistance of another individual to perform their daily chores can often be a struggle. The problem aimed at is the challenge faced by visually impaired individuals at shopping malls. The need for assistance is mandatory in this situation. However, this too is a struggle. The ability for VI individuals to shop with more convenience, safety, and independence is aimed through this project. It is essential that good quality of life is provided for VI individuals just as much as people with no impairments. It is also important that such solutions are implemented in order to encourage individuals with visual impairments to engage in more social activities. Therefore, affordable, and reliable means to assist individuals suffering from visual impairment has been implemented in this project while overcoming the drawbacks and research gaps of the products and research that have been conducted thus far.

For research purposes, a few YouTubers with visual impairments were followed and gathered information with regard to their shopping experiences. VI YouTuber, ‘Katy’s Eyes’ mentions that shopping requires pre reservation of assistance at the shopping mall where she shops. The assistant is required to navigate the VI shopper along the mall to isles of products, avoiding obstacles, and help identify the necessary products. An instance of navigation along with object identification was captured as follows,

Figure 1. Object Recognition with Assistance while Shopping (YouTube, 2022)

2 DESIGN METHODOLOGY

Firstly, it was necessary to build and train the Convolutional Neural Network Model that comprised of several hidden layers along with the input dataset that was used, namely, the Fashion MNIST dataset comprising of 60,000 training images and 10,000 testing images. Thereafter, the results were visualized, and the Ensemble Model was implemented to prevent any generalization errors of the prediction. Principal Component Analysis (PCA) along with a qualitative analysis was also performed in order to compare the implemented model with all other existing models utilized for object identification.

2.1 Convolutional Neural Network Model

The CNN Algorithm is one of the primary algorithms that can be considered for object recognition. Before reaching the output layer, the data travels through many hidden layers after entering the CNN through the input layer. The output of the network is compared to the actual labels in terms of loss and error. One of the several backpropagation techniques is used to update the trainable weights, and the partial derivatives of this loss with respect to the trainable weights are then calculated. In many CNN models, most of the hidden layers are often common and follow a pattern that can be identified.

The model implemented in this research can be summarized as follows,

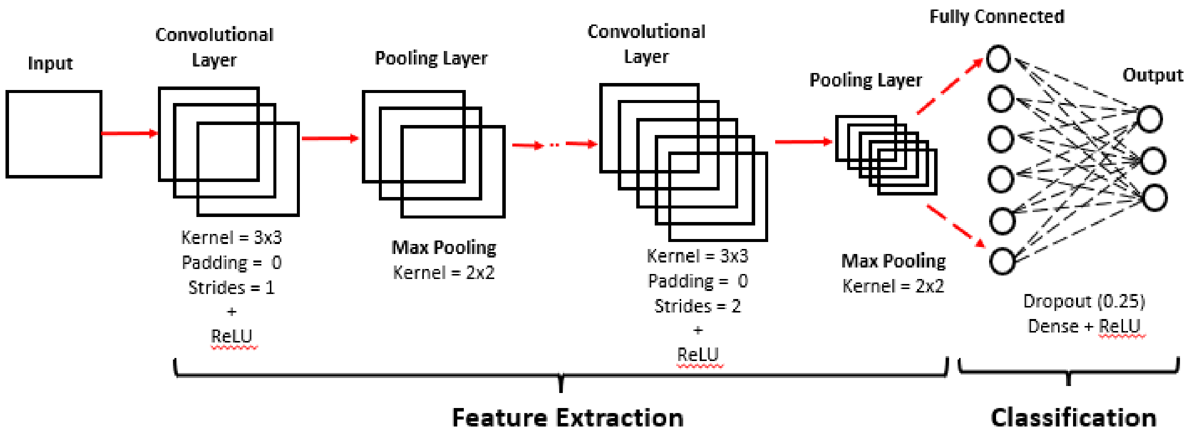

Figure 2. Architecture of Implemented Model

1. Layer Function: Basic function of transformation (convolutional/fully connected layer)
   a) Fully Connected: Functions are linear between the input and the output (For i input nodes and j output nodes, the trainable weights are wij and bj)
   b) Convolutional Layers: Applied to the input feature maps that are 2D (and 3D). The trainable weights are made up of a 2D (or 3D) kernel/filter that iterates through the input feature map and creates dot products using the overlapped areas of the input feature map. The three variables that define a convolutional layer are as follows:
      - **Kernel Size K:** Filter size of 2x2 and 3x3
      - **Stride Length S:** Specifies the amount of kernel sliding that must occur before the dot product may produce the output pixel – used stride 1 and 2
      - **Padding P:** not used in this implementation
   c) Transposed Convolutional (DeConvolutional) Layer: Typically utilized to improve the output feature map size (Upsampling). With the transposed convolutional layer, the input feature map is modified. If the provided stride and padding to the output along with the convolutional kernel of the required size is applied, it will result in the input.

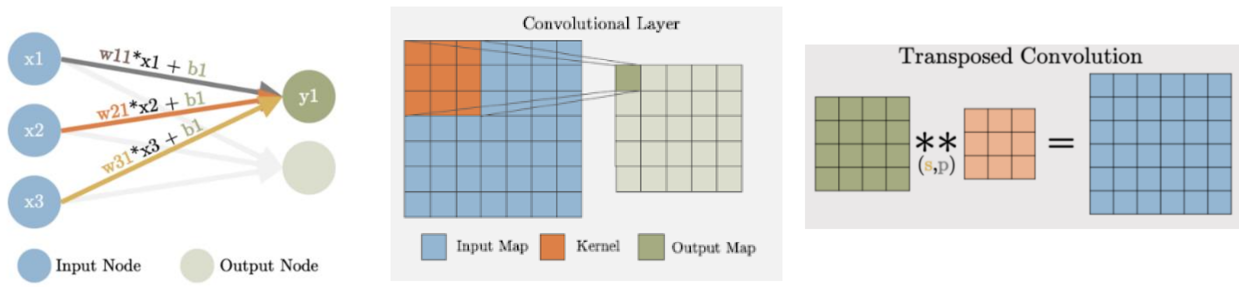

Figure 3. Fully connected layer, Convolutional Layer, and Transposed Convolutional Layer (Anwar, 2020)

2. Pooling: This layer cannot be trained and is used to modify the feature map's size.
   a) Max/Average Pooling: Was used to reduce the input layer's spatial size by choosing the field's maximum or average value, as indicated by the kernel.
   b) UnPooling: this is a non-trainable layer that increases the input layer's spatial area by positioning the input pixel at a specific index inside the kernel's designated output field.

3. Normalization: To prevent the unbounded activation from raising the output layer values excessively, it is typically employed just before the activation functions.
   a) Local Response Normalization (LRN): An untrainable layer square-normalizes the pixel values in a feature map of a particular neighborhood.

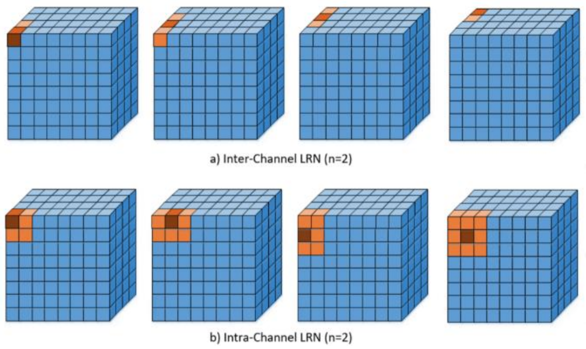

Figure 4. Local Response Normalization (LRN) (Anwar, 2020)

$$b^{k}_{x,y} = a^{k}_{x,y}/(k + \alpha \sum_{0}^{\min\left(W,\ x+\frac{n}{2}\right)} \sum_{0}^{\min\left(H, y+\frac{n}{2}\right)} (a^{k}_{i,j})^2)^{\beta} \tag{1}$$

$$b^{i}_{x,y} = a^{i}_{x,y}/(k + \alpha \sum_{j=\max\left(0, i-\frac{n}{2}\right)}^{\min\left(N-1, i+\frac{n}{2}\right)} (a^{j}_{x,y})^2)^{\beta - n/2)} \tag{2}$$

Equation (1) gives the Intra-channel LRN whereas equation (2) gives the Inter-channel LRN when performing Local Response Normalization.

   b) Batch Normalization: A method of normalizing data that is trainable by learning the scale and shift variables.

4. Activation: So that CNN can efficiently map non-linear complex mapping, introduce non-linearity.
   a) Non-parametric/Static Functions: Linear ReLU
   b) Parametric Functions: tanh, ELU, Leaky ReLU, sigmoid
   c) Bounded Functions: sigmoid, tanh

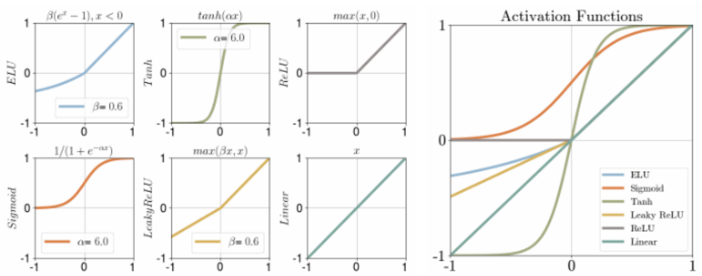

Figure 5. Activation Functions in CNN (Anwar, 2020)

ReLU activation was used in this implementation.

2.2 Implementation of the Model

The CNN Model was implemented in order to identify objects in real-time by following the simple procedure and methodology where firstly, the Fashion MNIST dataset was utilized, and the CNN Model was implemented. Next, Ensemble Modelling was performed and thereafter was tested on a real-time video that was obtained at a shopping mall in a VI shopper's point of view.

Choosing appropriate Dataset

60,000 training images and 10,000 test images of clothing from 10 classes, including t-shirts, tops, pants, pullovers, dresses, coats, sandals, shirts, sneakers, bags, and ankle boots, make up the Fashion-MNIST dataset. Each grayscale image has a uniform dimension of 28x28 (784 total pixels). The visual representation of the data (each class containing in three-rows), is depicted in the figure below,

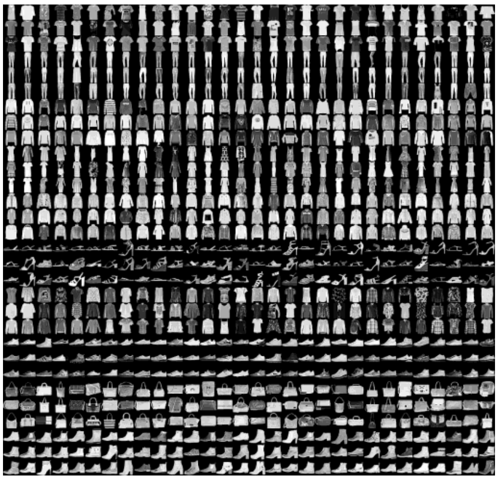

Figure 6. Fashion MNIST Dataset (GitHub, 2021)

Building the Convolutional Neural Network

The architecture of the CNN model that was implemented is depicted in Figure 7 and comprises of 2 convolutional layers, 2 pooling layers, and fully connected layers as seen.

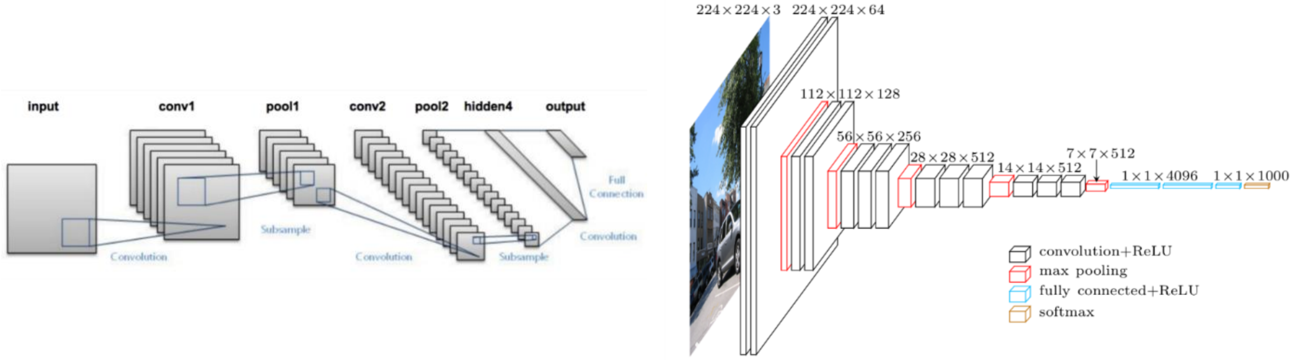

Figure 7. Architecture of the CNN Model Used (Gupta, 2017)

Building the CNN Model was performed as follows,

Build the Convolutional Network

```
In [20]: #Building CNN Model
cnn_model = keras.models.Sequential([
                        tf.keras.layers.Conv2D(filters=32, kernel_size=3, strides=(1,1), padding='valid',activation= 'relu'
                        tf.keras.layers.MaxPooling2D(pool_size=(2,2)),
                        tf.keras.layers.Conv2D(filters=64, kernel_size=3, strides=(2,2), padding='same', activation='relu')
                        tf.keras.layers.MaxPooling2D(pool_size=(2,2)),
                        tf.keras.layers.Flatten(),
                        tf.keras.layers.Dense(units=128, activation='relu'),
                        tf.keras.layers.Dropout(0.25),
                        tf.keras.layers.Dense(units=256, activation='relu'),
                        tf.keras.layers.Dropout(0.25),
                        tf.keras.layers.Dense(units=128, activation='relu'),
                        tf.keras.layers.Dense(units=10, activation='softmax')
                        ])
```

The layers comprised of the following features and hidden layers,

ReLU (Rectified Linear Unit) – As a result, the neural network's computing requirements do not grow exponentially. As the size of the CNN scales, the computational cost of adding more ReLUs increases linearly. **Softmax** – This function serves as the activation function in the output layer of neural network models that predict a multinomial probability distribution. Softmax is used as the activation function in multi-class classification problems when class membership is required on more than two class labels. **Dense Layer** – Each neuron in this basic, dense layer of neurons receives information from every neuron in the layer below it. Based on the results of the convolutional layers, a dense layer is utilized to categorize the images. single neuron in action. Such neurons are found in large numbers inside a layer. **Dropout layer -** This mask leaves all other neurons unaltered while nullifying specific neurons' contribution to the subsequent layer. **Max pooling** is a pooling procedure that chooses the largest element from the feature map region that the filter has covered. The result of the max-pooling layer would thus be a feature map that is smaller and contains the most noticeable features from the preceding feature map. In order to save calculations, the pooling layer basically shrinks the input image's spatial dimension. **Flatten Layer –** to convert multidimensional data into a vector

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d (Conv2D)              (None, 26, 26, 32)        320
_________________________________________________________________
max_pooling2d (MaxPooling2D) (None, 13, 13, 32)        0
_________________________________________________________________
conv2d_1 (Conv2D)            (None, 7, 7, 64)          18496
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 3, 3, 64)          0
_________________________________________________________________
flatten (Flatten)            (None, 576)               0
_________________________________________________________________
dense (Dense)                (None, 128)               73856
_________________________________________________________________
dropout (Dropout)            (None, 128)               0
_________________________________________________________________
dense_1 (Dense)              (None, 256)               33024
_________________________________________________________________
dropout_1 (Dropout)          (None, 256)               0
_________________________________________________________________
dense_2 (Dense)              (None, 128)               32896
_________________________________________________________________
dense_3 (Dense)              (None, 10)                1290
=================================================================
Total params: 159,882
Trainable params: 159,882
Non-trainable params: 0
_________________________________________________________________
```

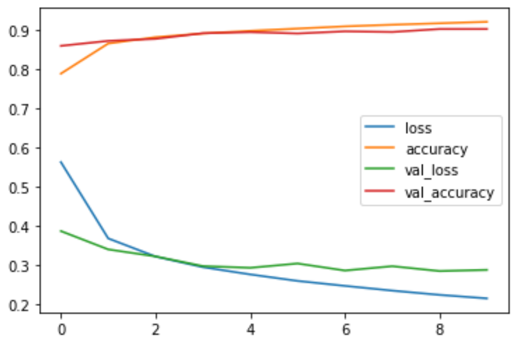

Figure 8. Visualized Architecture and Losses Plot of the Trained Model

2.3 Implementing Ensemble Model

Ensemble Modelling is one of the primary techniques used to lower the prediction's generalization errors in Machine learning and Neural Networks. It uses a variety of modelling techniques or training datasets and build numerous varied models parallelly to predict a result. Thereafter, it combines the forecast in order to evaluate the data accuracy, the data are combined into a single overall forecast. If the base models are varied and independent, the models prediction error will be an all-time low (Kotu et al., 2020).

Ensemble modelling has thus far not been applied to any of the implementations of object recognition of fashion items (especially at shopping malls). With this step being performed, it was able to improve the accuracy of the CNN Model while evaluating it through multiple models with multiple dimensions that captured the images.

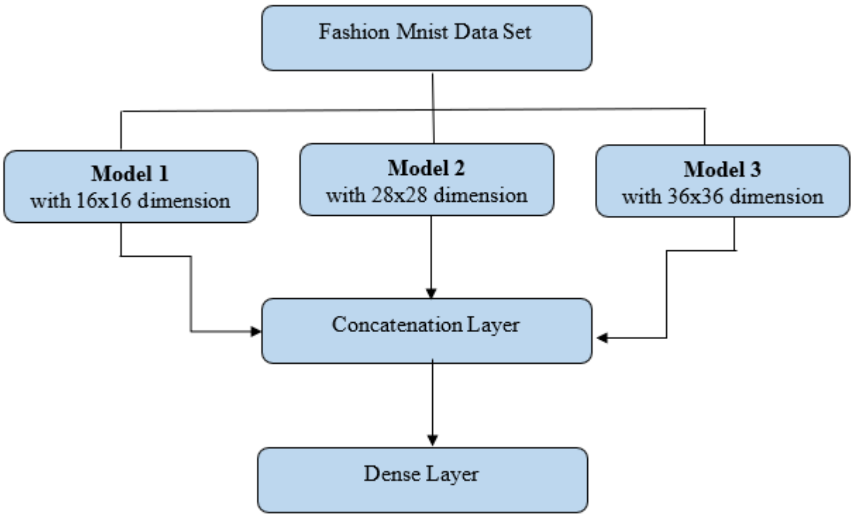

Figure 9. Architecture of the Ensemble Model

The dataset (fashion_mnist) was split and then changed into multiple dimensions of each 16x16, 28x28, and 36x36 after resampling, in order to have 3 models for evaluation. These models were then concatenated using the 'concatenated layer' along with the dense layer in order to produce the output. The dimensions captured the input images and can be visualized as follows,

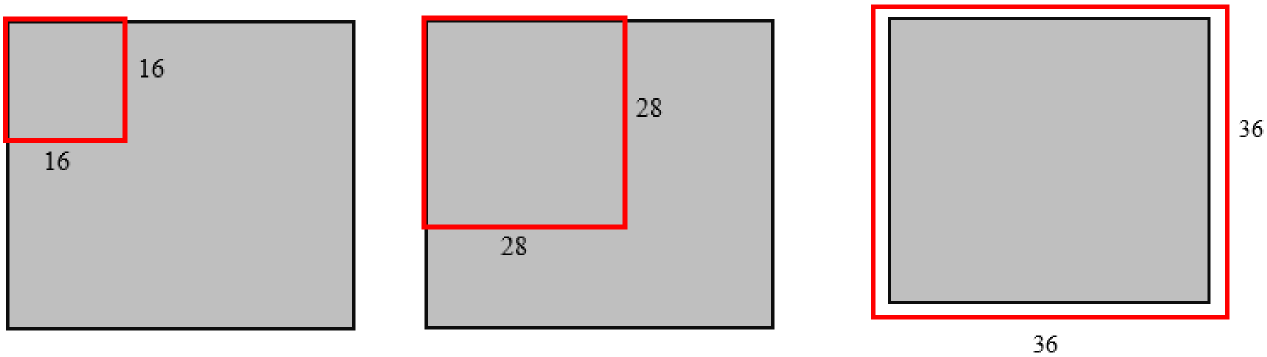

Figure 10. Dimensions of the 3 models implemented by resampling

2.4 Implementing Qualitative Analysis and Principal Component Analysis (PCA)

The Principal Component Analysis (PCA) method was also utilized in order to analyze the large number of datasets with multiple features while preserving the ability to withhold the maximum number of information and features of the multidimensional data. PCA was applied to the data, and it was seen that by taking just 24 features, an 80% of explained variance was obtained for the model as depicted in the plot below,

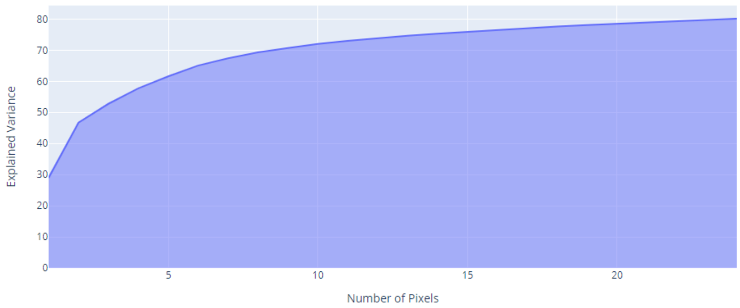

Figure 11. Explained variance as a function of the number of dimensions after PCA

The distribution of data in the 3D space was observed with an explained variance of 80.11%

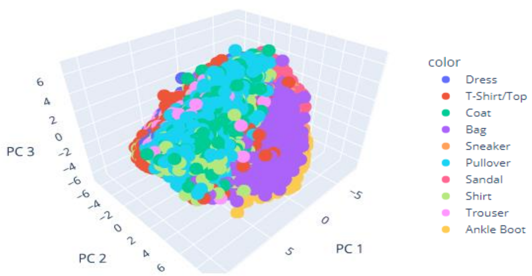

Figure 12. Distribution of data in 3D space

The model was also compared against the Naive Bayes, KNN, Logistic Regression, CatBoost, AdaBoost, XGBoost, and Random Forest models with qualitative analysis. It was observed that the CNN Model depicted the highest accuracy of 90% as visualized follows,

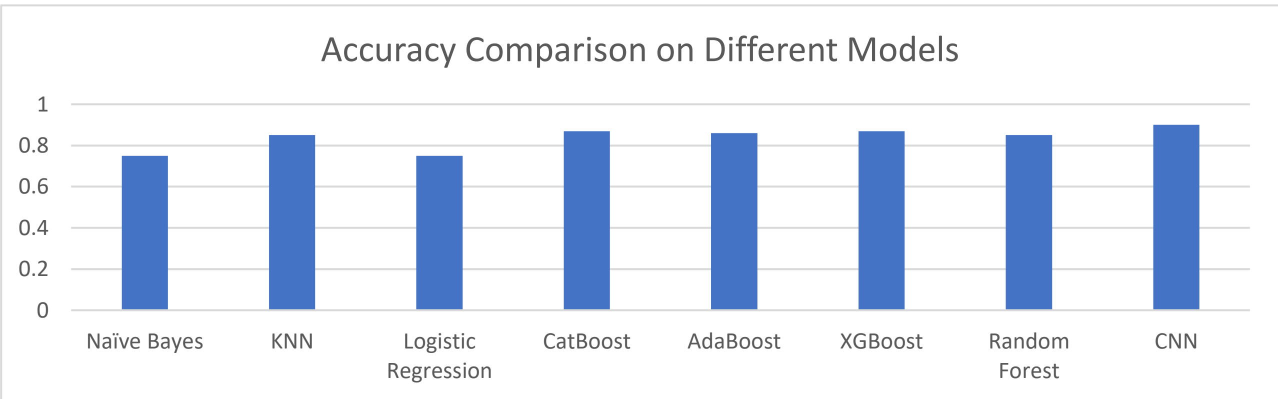

Figure 13. Accuracy Comparison between CNN Model and other Models

3 RESULTS & DISCUSSION

It was observed that the CNN Model depicted a 90% validation accuracy which is thus far the highest number recorder for any model used for object identification. It was also visualized by the aid of a heat map which depicted instances where the identification was performed accurately. The generated heat-map is as follows,

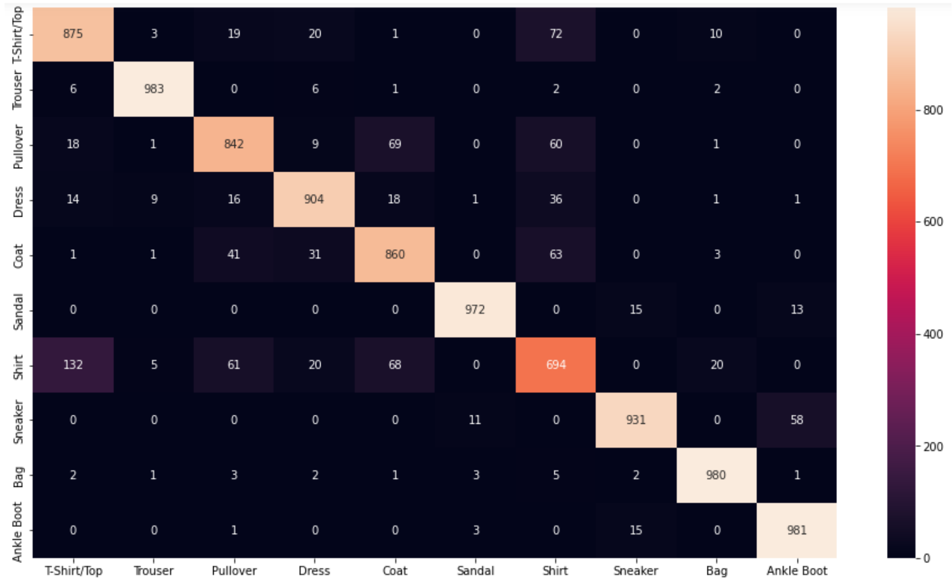

Figure 14. Heatmap generated to visualize accuracy of predictions

Furthermore, the trained model was also implemented on a real-time video obtained at a shopping mall in a VI Shopper's point of view. This video was processed using the Open CV platform and audio output was obtained using Text-to-Speech by converting the produced label texts along with the bounding boxes around the identified objects to speech. This was performed in order to instruct the visually impaired shopper to assist in identifying the garment objects. A few instances of the identified garments are as follows,

Figure 15. Detected Clothing items in shopping mall

4 CONCLUSION

As mentioned previously, the primary constraint of this design and product is to allow and assist visually impaired individuals to shop at their convenience without the help of any other individual. This is intended to save time and efforts of the VI shopper and provide them with comfort and avoid societal stigma. Due to many such devices already existing in the modern world, it was important that a qualitative analysis of such products along with the proposed solution was performed. As discussed in this paper, it was evident that due to the drawback of the devices that currently exists, a solution to avoid these drawbacks was necessary. The product was then designed specifically to achieve this purpose and provide the users with comfort and accuracy. The basic CNN Model was implemented with a validation accuracy of 90% and was then further evaluated using Ensemble Modelling as well as carrying out a qualitative analysis with other models that is currently used for object recognition.

It was noted that the Ensemble Model was not implemented for fashion object recognition thus far and therefore, the results obtained were of immense success in order to enhance the accuracy of the Model. By using an ensemble model with 3 different models that analyses the spatial features in different dimensions, the Model depicted a 92% accuracy for the dataset. This robust classification model is essential to overcome the drawbacks and challenges faced when classifying basic garments for VI shoppers to shop at their convenience.

The qualitative analysis performed amongst the Naive Bayes, KNN, Logistic Regression, CatBoost, AdaBoost, XGBoost, and Random Forest models claimed that the CNN Model was of the highest accuracy with 90% and 92% after Ensemble Modelling. Therefore, it can be claimed that this research has successfully extended the current research and existing products for assisting VI individuals to recognize objects. The audio output to help instruct the VI Shopper and identify objects was one of the greatest advantages of the model. The model is suggested to be implemented on an app that can be utilized by VI shoppers all over the world in order to obtain assistance and independence while shopping.

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A Multifunctional Communication System for Differently Abled People

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ABSTRACT

A person should be able to connect with other people to have a fulfilling life. Having challenges such as being blind, deaf, or mute is a significant concern in this matter. According to world statistics and research, it has shown that 0.2% of the world's population lives with severe deaf blindness. This project aims to design and develop a communication system to improve interactions between a person without any disability and a deaf-blind person or between two deaf-blind people. Each may communicate differently, so this system will have a textual display for those who can see, a speech output for those who can hear, and a tactile braille display for those who cannot see or hear. This system can benefit educational institutes and care homes facilitating people with the above disabilities. The primary purpose of this system is to make the differently abled people feel independent and confident by seeing, hearing, and talking to each other without facing the barriers in the translation.

KEYWORDS: *Visually Impaired, Deaf and Mute, Voice to Text, American Sign Language, Braille Keyboard, Hand Gestures, Convolution Neutral Networks.*

1 INTRODUCTION

Blindness is a visual impairment that significantly limits interaction, education, work, and independence. Deafness is a disability that weakens the hearing and causes them unable to hear, whereas mute is a disability that impairs speech and causes them unable to talk. People with disabilities like blindness, deafness, and muteness face many difficulties in their day-to-day life when communicating with each other and with a person without any disabilities. Due to the high negligence of the public on the importance of learning sign language and braille, the deaf-blind community had to be bound to a specific group where they associated with only a few numbers of people in the society. This situation has deprived many opportunities they would have received and their will to freely associate with the rest of the society.

When considering the Sri Lankan educational institutes, most of the schools dedicated for special need students operate while keeping the students away from their houses. Research carried out in association with the Lady Ridgway Hospital and the Riyanzi Alagiyawanna Special school revealed the following details supporting the project idea,

- Students having a severe deaf-blind condition are not capable of communicating with each other.
- Only a few numbers of hearing aids are available in the schools to be used by the students while they are expensive.
- Minimum human-computer interactions are used for the teaching and learning process.
- Having to allocate a translator to mediate a conversation is a hindrance to communication.
- Some students mentioned they are in need of a system where they can communicate with individuals who are completely unaware of the Sign Language or Braille.

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To address this problem, the project has a system to facilitate communication among impaired persons based on their ability. The device accepts the input message from the sender who has a disability and transforms it to be transmitted throughout the system under the selected mode. Once the message has been transmitted to the receiver, it is transformed again based on that person's preference. As outputs, there is a textual display for those who can see, a voice for those who can hear, and a tactile braille plate for those who cannot see or hear. To achieve this end goal, objectives were identified under three areas. First objective being the development of a Hand Gesture Recognition (HGR) system that detect the gestures related to the American Sign Language (ASL) given by the user and translate it to the required fields of voice, text, or braille to give an output. Second being the design and development of a braille input and output mechanism that take braille as an input and translate it to text, voice or take voice or hand gestures and translate them to braille outputs. Final objective for the design and development of a Voice Recognition System (VRS) for people without disabilities who are incapable of communicating with deaf, blind, or mute people.

The majority of the research attempts on developing an aid for differently abled people has been limited to a single study area, where it only addresses either deaf, blind, or mute scenarios. This novel approach addresses all three areas and developed as a single product could enhance the effectiveness of the communication among above-mentioned community.

1.1 Related Work

Hand Gesture Recognition

The ability to communicate is essential to human existence. It is a simple and efficient way to express ideas, emotions, and opinions. But a significant percentage of the world's population lacks this ability. Sign Language (SL) is an extremely useful tool for deaf and mute persons to communicate in everyday life. Sign Language Recognition (SLR) is an issue that has been researched for decades. Nevertheless, our society is still far from having a perfect solution. Even though developing such technologies can be extremely difficult due to the existence of multiple sign languages and a lack of large datasets, recent breakthroughs in Artificial Intelligence and Machine Learning have played a vital role in automating and upgrading such systems.

The Static Gesture Recognition consists of two distinct operating phases: Training and Recognition. Training is considered an offline activity. It is only relevant when users wish to add new movements to the database of sign motions. The hand movements are detected in real time by the recognizing phase. The backbone of the system is made up of three major modules (V. Nguyen, M. Chew and S. Demidenko, 2015): Pre-Process, Descriptor, and Classifier. During the training phase, a variety of training images are analyzed, described, and stored in the sign database alongside their corresponding text.

Various communities have conducted extensive research on sign recognition. Research on hand gestures can be divided into three categories (Klimis Symeonidis, 2000): glove-based, vision-based, and study of drawing gestures. A new system-prototype called the “Sharojan Bridge” to facilitate deaf-blind community in their communication needs. In the Sharojan Bridge, they used a wearable technology to acquire the hand gestures using the sensors fixed to a pair of gloves (Rastogi, Rohit, Shashank Mittal, and Sajan Agarwal, 2015). “MyVox”; a communication device that has proven to be a valuable tool for an “Usher Syndrome” patient who can now interact with people without the aid of an interpreter (F. Ramirez-Garibay, C. M. Olivarria, A. F. Eufracio Aguilera and J. C. Huegel, 2014). Research was conducted in Spain to enable hard of hearing people to interact effectively with others. The goal of that study was to let deaf and hard of hearing persons communicate with one other without learning sign language. They created a tool that makes use of a 3G mobile device's video calling function (Fernando López, Javier Tejedor, 2006). Research to produce a prototype that can translate signs to voice (Foong, Oi Mean, Tan Jung Low, and Satrio Wibowo, 2008). In this system, it was created utilizing a "Feed Forward Neural Network." For the prototype, sets of universal hand signs were recorded using a video camera and used to train an artificial intelligent tool. Following development and testing, the Neural Network system produced satisfactory results. For 70 input photos, the system achieved a recognition rate of 78.6%. (Prateem Chakraborty, Prashant Sarawgi, Ankit Mehrotra, Gaurav Agarwal, Ratika Pradhan, 2008) provided four basic yet effective approaches for implementing hand gesture recognition:

Subtraction, Gradient, PCA, and Rotation Invariant. The methods used to retrieve the correct matches were successful.

The difficulties in creating sign language recognition extend from picture acquisition to classification. Researchers are currently trying to figure out the optimal approach for acquiring images. Gathering photos with a camera introduces the challenges of image pre-processing.

Voice Recognition

Usually, the voice recognition is accomplished by employing the most popular kind of headphones. Audio streams from regular and blind users should be recorded and at all times while recording, the microphone is placed on the tip of the tongue, allowing ambient noise to be reduced (Extended Abstract: Write Like You Talk? Research on the Effects of Voice to Text Applications When Used as Part of the Writing Process, 2015). When comparing ambient audio levels (acoustic energy in certain circumstances) with newly recorded samples, this might be a good place to start. Speakers tend to leave "artifacts" like as breaths/sighs, teeth speak, and echo, making endpoint detection more difficult. By normalizing and reducing any noise created during encoding, the features can be extracted accurately. East Subtraction using picture averaging filters (E.g., Cepstral mean) (CMS) (A New Technique for Speaker-independent Isolated Word Recognition, 2002). The provision of a keypad-based gadget for impaired individuals who are unable to communicate verbally is the primary aim of this initiative. The ARP9600 is a voice module that enables users to pre-record a voice and keep it in the device memory. Each button on the device is associated with a certain activity and has a pre-recorded voice that could be modified according to the preferences of the user. The acceleration sensor detects any shifts in the orientation of the head, and then transmits that data to the microcontroller for processing. The microcontroller is responsible for controlling the device in left, right, front, and rear directions depending on the direction of the acceleration. Therefore, the device enables users to tap the words they wish to communicate from the device keyboard, which consists of pre-prepared words or phrases, or by using head movements, which are then converted into audio phrases. Additionally, the device also enables users to use a combination of both methods (Python Speech Recognition Module - a Complete Introduction - AskPython, 2021).

Braille System

1. Braille Language

Each braille character or "cell" is made up of six dot places. These dot placements make a rectangle with two columns of three dots each. At any of the six spots, a single dot or any combination of dots may be raised. There are 64 English braille options in all, counting spaces with no dots. When referring to a braille character, the places where dots are elevated can be described. Each dot within a cell is assigned a number. As shown in Figure 1, the dots are generally numbered 1 through 6 from top left to lower left.

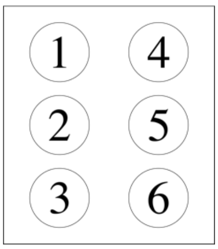

Figure 1. Braille Cell.

The equivalent written text is translated into grade one braille exactly letter for letter. This is the greatest code for beginners to use since it helps them become familiar with the code and understand many of the code's properties as they are learning to read braille. English grade 1 braille includes of the alphabet's 26 regular letters as well as punctuation as shown in the Figure 2. braille for the first grade of English includes all 26 regular letters of the alphabet in addition to punctuation marks.

Figure 2. Braille Characters.

Contracted braille is the usual approach for replicating most textbooks and publications. Cells are used separately or in conjunction with others in this system to generate a variety of contractions or full words. Uncontracted braille, for example as shown in Figure 3, takes twelve cell spaces for the sentence “you like him”. This is how it would look,

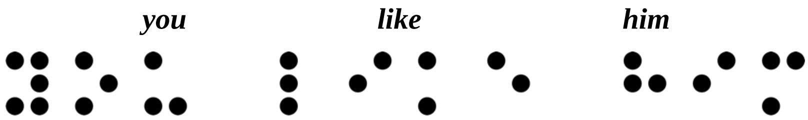

Figure 3. Uncontracted Braille sign for 'you like him'.

This identical phrase would require only six cell spaces to write in contracted braille. This is since the letters y and l are also used for the whole words you and like. Similarly, the letter h and m are combined to make the word him. This is how it would look as in the Figure 4,

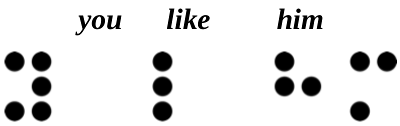

Figure 4. Contracted Braille sign for 'you like him'.

2. Solenoids

A solenoid is an electronic device that features a coil of wire, a casing, and a movable plunger (armature). As soon as electricity is sent through the coil, a magnetic field is created that pulls the plunger in. A solenoid, put another way, is a device that transforms electrical energy into mechanical work. Solenoids can be broken down further into subcategories as in the Table 1 according on its construction, style, and intended use.

Table 1 - Types of Solenoids.

Solenoid	**Details**
DC – C Frame Solenoid	Solenoid construction is referred to as a "C frame" in this context. The DC C-Frame solenoid consists of only a C-shaped frame that encloses the coil.
DC – D Frame Solenoid	A D-frame solenoid's regulated stroke action and compatibility with AC power make it functionally equivalent to a C-frame solenoid.
Linear Solenoid	Most individuals have encountered linear solenoids in the past. To exert a pulling or pushing force on a mechanical component, we use a torsion spring, which consists of a coil of wire wound around a moveable metal core.
Rotary Solenoid	A rotary solenoid is a special kind of solenoid that may be utilized whenever simple automated control is required. Like other solenoids, it consists of a coil and a core, but its function differs from the norm.

2 METHODOLOGY

Figure 5 shows the design block diagram of the entire system. The inputs and the outputs are indicated clearly to have a proper understanding on the intended deliverables of the project. Some of the main potential combinations of blindness, deafness, and muteness that a person may experience will be considered in this approach. The device will accept the input message from the sender who has a disability and transform it to be transmitted throughout the system depending on the requirements. Once the message has been transmitted to the receiver, it is transformed again based on that person's abilities and preference.

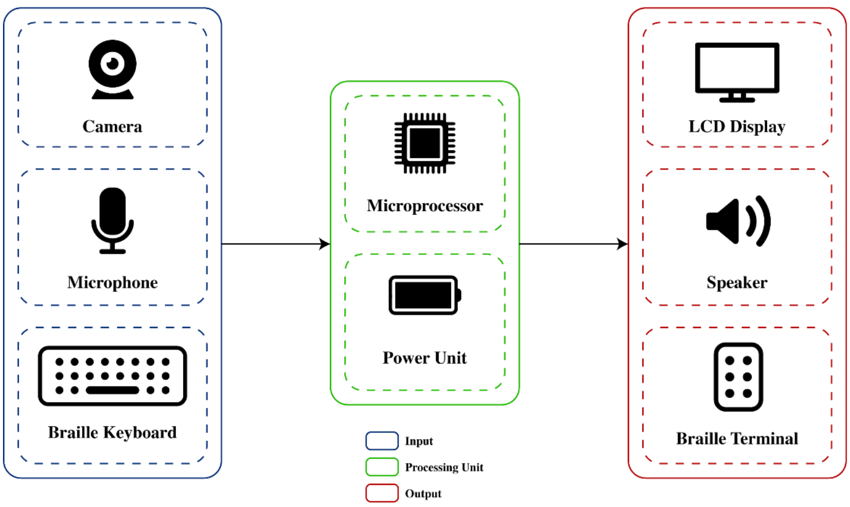

Figure 5. Design Overview.

For example, when considering an instance where two people trying to communicate; one experiencing an inability in both hearing and talking (Person A) while the other person is all deaf, blind, and mute (Person B). In such a case, person 'A' will give inputs to the system using hand gestures (Sign language). Using the hand gesture recognition, the system will identify this message and convert it into a text message which will reconverted into a braille output as per the requirement of person 'B'. This can be done in the other way around when person 'B' tries to respond to the message given by the person 'A'as in the Figure 6.

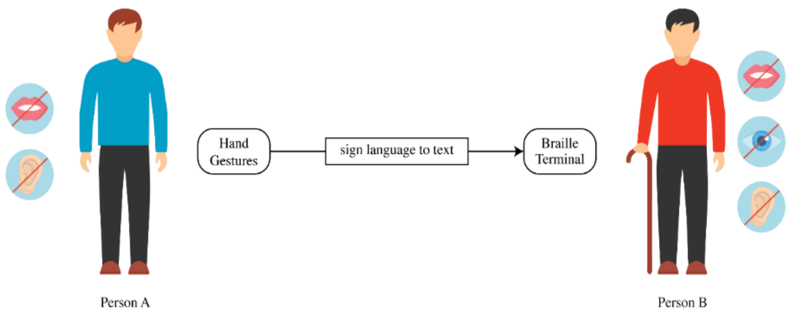

Figure 6. Communication between two differently abled people.

As the proposed design contains three main parts, Hand Gesture Recognition system, Braille system and the Speech Recognition system, each part needs to be discussed separately.

2.1 Hand Gesture Recognition System

Methodology can be divided mainly into 3 parts for the ease of explaining the Hand Gesture Recognition process as follows,

1. Collecting the data and storing them in directories.
2. Training the model.
3. Live prediction of the hand gestures.

Methodology flowchart in Figure 7 further describes the procedure involved in the design methodology from image capturing to the live prediction of hand gestures.

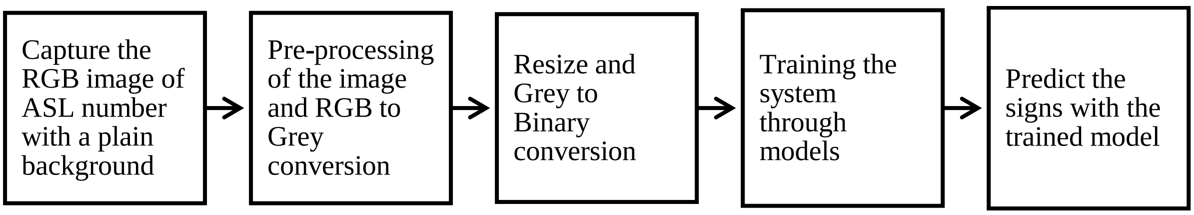

Figure 7. Methodology flowchart for HGR system.

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Collecting the data and storing them in directories.

Sign language recognition is a complex and frequently undervalued problem involving numerous streams of asynchronously integrated multi-modal articulators (hand shape, orientation, movement, upper body, and face). This step involves, creating the database required for the testing and training of the model. This will collect webcam photos using the OpenCV library, generating one or more datasets based on input, putting them in folders, and pursuing them based on classes. Figure 8 shows the capturing of testing images related to the number 1.

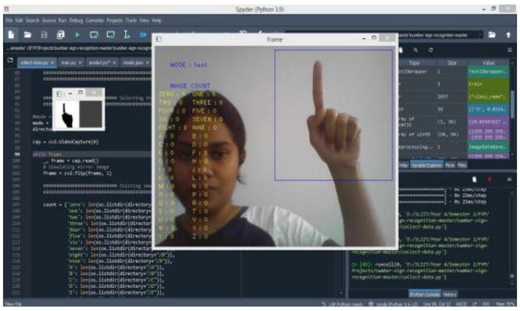


Figure 8. Capturing images.

Those images were subjected to grey scaling, resizing and binary thresholding. After prepossessing, the images were saved in the created destination folder. Addition or removal of the alpha channel, channel reversal, conversion to or from 16-bit RGB color (R5:G6:B5 or R5:G5:B5), and conversion to or from grayscale are all examples of transformations carried out within the RGB space using the Eqs (1) – (2),

$$\text{RGB[A]to Gray: } \mathrm{Y} \leftarrow 0.299 \cdot \mathrm{R} + 0.587 \cdot \mathrm{G} + 0.114 \cdot \mathrm{B} \tag{1}$$

$$\text{Gray to RGB[A]: } \mathrm{R} \leftarrow \mathrm{Y}, \mathrm{G} \leftarrow \mathrm{Y}, \mathrm{B} \leftarrow \mathrm{Y}, \mathrm{A} \leftarrow \max(\text{ChannelRange}) \tag{2}$$

The Eq (3) describe how the function converts a grayscale image to a binary image.

$$\mathrm{dst}(\mathbf{x}, \mathbf{y}) = \begin{cases} \text{maxval} & \text{if} \quad \mathrm{src}(\mathbf{x}, \mathbf{y}) > \text{thresh} \\ \mathbf{0} & \text{otherwise} \end{cases} \tag{3}$$

Processed dataset was used for the final prediction to increase the accuracy of the prediction. Figure 9 shows the processed image after capturing.

Figure 9. Processed images for the number 5 and letter C.

Training the Model

The models are trained with TensorFlow and Keras, and the Convolutional Neural Network is trained on these models. The Sequential model is employed here. This approach is utilized when the user simultaneously has one input and one output. The development of a Convolutional Neural Network is always comprised of four key steps. They are the,

1. Convolution
2. Pooling
3. Flattening
4. Full Connection

The first convolutional layer will modify the image input tensor and produce a convoluted matrix. The generated matrices will be integrated and combined into a single matrix. The 2-D convolution mathematical formulation is provided by Eq (4),

$$y[i, j] = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} h[m, n] \cdot x[i - m, j - n] \tag{4}$$

Where x is the input image matrix to be convolved with the kernel matrix h to produce a new matrix y representing the output picture. The indices I and j are engaged with image matrices, whereas m and n are concerned with kernel matrices. If the kernel size in convolution is 3 x 3, then the indices m and n extend from -1 to 1. The two activation functions are ReLU (Rectified Linear Unit) and Softmax. The activation is linear for input values greater than zero or more precisely as in the Eq (5),

$$R(z) = \begin{cases} z & if\ z \geq 0 \\ 0 & otherwise \end{cases} \tag{5}$$

The primary catch here is that the ReLU function does not activate all neurons simultaneously. The neurons will be deactivated only if the linear transformation's output is less than 0. Compared to the sigmoid and tanh functions, the ReLU function is significantly more computationally efficient since only a limited number of neurons are engaged.

After the convolution, the matrix is subjected to Max-Pooling to reduce its size, which aids in efficient determination. Max-Pooling is employed as the maximum pixel value. The second Convolutional Layer is added to enhance the detection efficiency. The subsequent step is to flatten the layers and connect them to create a complete neural network. The trained model should be fitted to the collected image dataset as the final step in training a CNN model. However, pre-processing must be performed to prevent overfitting. Overfitting nodes from one layer to the following results in high training and low-test accuracy.

Live Prediction of the Hand Gestures

The model will predict the gesture when it was performed inside the region of interest. The predicted gesture will be displayed on the frame real time. The final step of Hand Gesture Recognition is to output the predicted letter as a text. That text will be taken as input to the development carried out by the member 2 in this multifunctional system. Figure 10 shows the prediction window of live gesture related to the number 6.

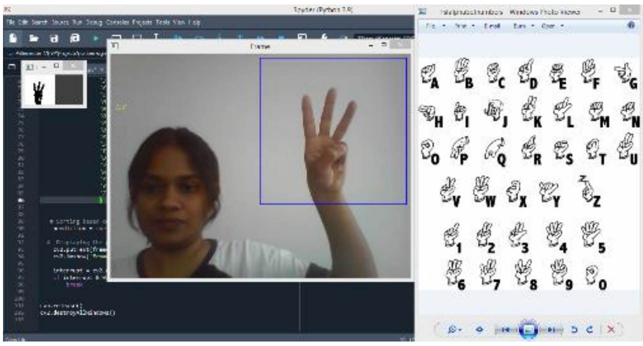


Figure 10. Predicting the live gesture for number 6.

2.2 Voice Recognition System

Here, the focus is primarily on people without disabilities in talking, listening, and hearing but unable to see (blind). The development was initiated by converting audio messages to text and displaying that on a screen.

1. ASL gestures converts to text file then it converts to selected output.
2. Braille inputs converts to text file then it converts to the selected output.
3. Voice inputs convert to the text file and then it converts to the selected output.

Text to Voice Conversion

Several APIs in Python can convert text into speech. A straightforward application called gTTS converts text input into audio that may be saved as an mp3 file. The speech can be delivered at either the speed or slow of the two available audio rates. Text to voice convention helps to convert all text comes from difference inputs to convert to mp3 audio file. It will enable the communication between,

- Deaf people– Normal people
- Blind people – Normal people
- Mute people – Normal people
- Mute people -Blind people

The text-to-speech API of Google Translate is interfaced using the Python library and CLI utility gTTS (Google Text-to-Speech). Write spoken mp3 data to stout, a file, or a byte string for additional audio editing. Alternatively, create Google Translate TTS request URLs in advance and pass them to an external software. Features of the gTTS are customizable text pre-processors that, for example, can correct pronunciation to be used to read texts of any length while maintaining accurate intonation, abbreviations, decimals, and sentence tokenism that are particular to speech.

Voice to Speech Conversion

Conversion of speech to text and display Attached to the microcontroller is a microphone module that does the conversions. Using a microcontroller, the audio signal is transformed into text form.

- Identification of the captured voice signal.
- Send the instruction to the microcontroller through the wireless connection.
- Send converted signal to the display.

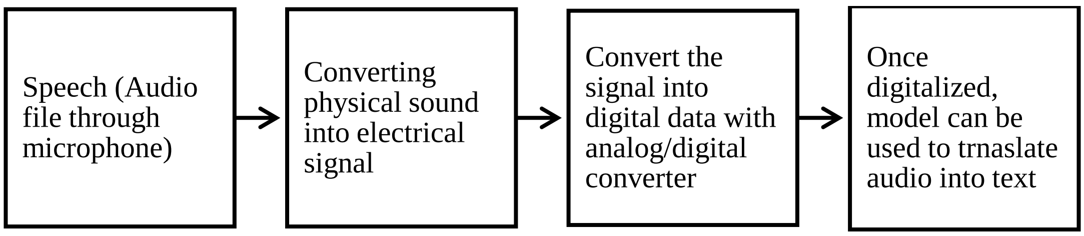


Figure 11. Overview of speech to text.

At its most fundamental level, human speech consists of nothing more than a wave of sound. These sound waves or audio signals have several properties that may be described in terms of acoustics. These characteristics include amplitude, peak, trough, crest, and trough, as well as wavelength, cycle, and frequency. These audio signals are continuous, which means that they include an infinite amount of data points. To transform such an audio signal into a digital signal that can be processed by a computer, the network must collect a discrete sample distribution that comes extremely near to simulating the continuity of an audio signal.

2.3 Braille System

Braille Input System

In this multi communication device, there is a keyboard with 8 keys on it. 1 to 6 keys represent the braille cell and each six dot locations organized in a rectangle with two columns of three dots each. There are two more additional keys and, [#] is for change the character type (example – letters to numbers) and, [TT] is for change the capital simple of the letters. The keys in this keyboard are planned to make using push buttons and add key caps with relevant numbers and icons on it. Tactile push buttons were used for braille keyboard.

Braille Output System

Blind and low-vision readers use a light touch to move from left to right across the page. To detect the raised dots, you'll want to use the softer pads of your fingers, which are more attuned to touch than your fingertips. Many people who can see can learn braille simply by looking at the letters. Although a keen sense of touch is required for reading braille, many people are pleasantly surprised at how quickly their fingers become more sensitive after some practice. 12VDC Push-Pull solenoids, as shown in the Figure 12 were used to implement this physical braille dot output. According to the relevant input, solenoids were come out and blind people can easily touch the surface and get the message. Instead of using these solenoids, 6 LEDs used on this project to demonstrate the braille output mechanism easily.

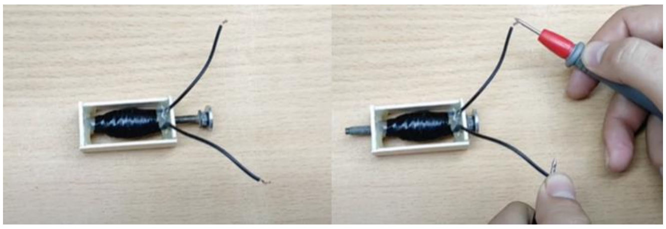
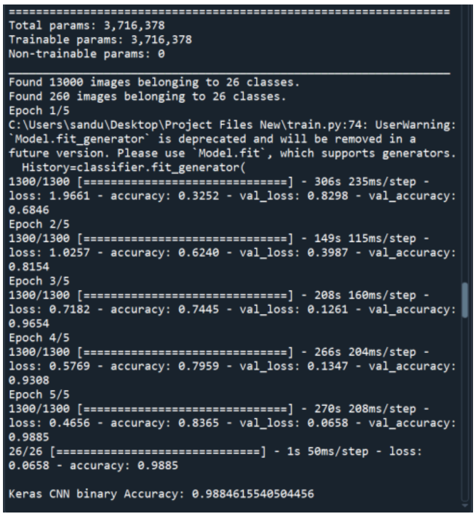


Figure 12. Pull and Push state of the Solenoid.

3 RESULTS

Figure 13 shows the summary of the classifier obtained through `classifier.summary().` At the end of the training, the model was able to obtain an accuracy of 98.85% for the Hand Gesture Recognition System for 260 test images where it could detect and predict letters of the English alphabet.



```
=================================================================
Total params: 3,716,378
Trainable params: 3,716,378
Non-trainable params: 0
_________________________________________________________________
Found 13000 images belonging to 26 classes.
Found 260 images belonging to 26 classes.
Epoch 1/5
C:\Users\sandu\Desktop\Project Files New\train.py:74: UserWarning:
`Model.fit_generator` is deprecated and will be removed in a
future version. Please use `Model.fit`, which supports generators.
  History=classifier.fit_generator(
1300/1300 [==============================] - 306s 235ms/step -
loss: 1.9661 - accuracy: 0.3252 - val_loss: 0.8298 - val_accuracy:
0.6846
Epoch 2/5
1300/1300 [==============================] - 149s 115ms/step -
loss: 1.0257 - accuracy: 0.6240 - val_loss: 0.3987 - val_accuracy:
0.8154
Epoch 3/5
1300/1300 [==============================] - 208s 160ms/step -
loss: 0.7182 - accuracy: 0.7445 - val_loss: 0.1261 - val_accuracy:
0.9654
Epoch 4/5
1300/1300 [==============================] - 266s 204ms/step -
loss: 0.5769 - accuracy: 0.7959 - val_loss: 0.1347 - val_accuracy:
0.9308
Epoch 5/5
1300/1300 [==============================] - 270s 208ms/step -
loss: 0.4656 - accuracy: 0.8365 - val_loss: 0.0658 - val_accuracy:
0.9885
26/26 [==============================] - 1s 50ms/step - loss:
0.0658 - accuracy: 0.9885

Keras CNN binary Accuracy: 0.9884615540504456
```

Figure 13. Summary of the Sequential Classifier.

Figures from 14-17 shows the final product that was developed assembling all the systems of Hand Gesture Recognition, Braille System and the Voice to Text Conversion System.

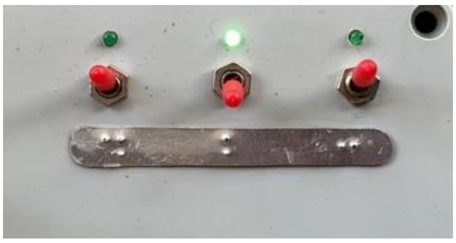


Figure 15. Switches to change the operating mode.

Figure 14. Power Supply.

Switches in the Figure 15 are used to switch between the modes of outputs. Those were the LCD display, speaker, and the braille display.

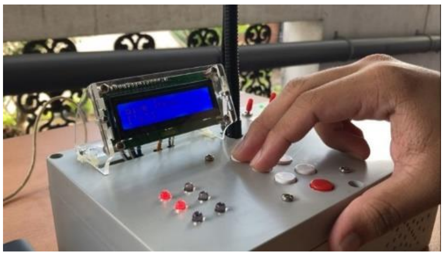


Figure 17. Braille output through keyboard and display.

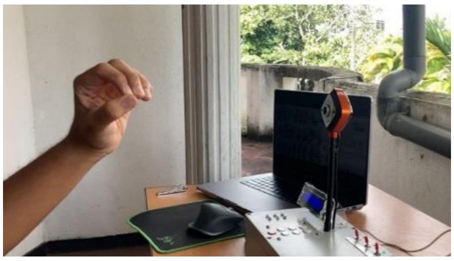


Figure 16. Hand Gesture inputs.

In Figure 16, tactile buttons are used to give the input as braille characters. In Figure 17, the hand gestures are performed in front of the camera are detected by the system and can be converted to both text through the LCD display and voice through the speaker.

4 CONCLUSION

While conducting the designing and the implementation phase, one of the major problems encountered was the need of heavy computational power when training the model; took a long time for the training process. Initially the training set was 3000 per each letter of the alphabet with a total of 78,000 images. But that had to be reduced to 13,000 images having 500 test images for each due to the long hours for training. Also, several lags were observed with the obtained output, especially with the webcam capturing the live frames. Unavailability of the required electronic components like solenoids made some hardware changes in the final product. However, all the intended objectives were successfully achieved with the development of the final product. The Hand Gesture Recognition system was completed with a higher accuracy of 98.85% and capable of detecting ASL gestures performed by the user in real-time. Furthermore, users accessing the braille mode can input braille signs using the braille keyboard and get the output through tactile braille terminal. The application development was simplified while using this tool with Python being the programming language of choice.

Also, there are various possible future developments identified while concluding the project. Major one of them being the use of dynamic hand gestures for the identification and employing Sinhala language for Hand Gesture Detection and Voice Recognition. In conclusion, the project was a success in reaching the end goal as well as bringing something useful to the society. Working on this project provided exposure to new technology areas and a vast amount of knowledge. In addition to technical skills, research and documentation were acquired as soft skills that will be useful in future endeavors.

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Optimum Synchronization of Grid-connected Renewable Energy Source

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ABSTRACT

In the last decades, wind power production has become one of the major concerns to investigate in enhancing the utilization of renewable energy resources in microgrids. Wind power can regulate environmental-friendly power generation which helps to satisfy the power demand in the grid whenever it is essential. This research has been carried out for analyzing behavior of Wind Energy Conversion System (WECS) and appropriate technique for grid synchronization in optimum way. Therefore, this includes the analysis of synchronization procedures and design an optimization technique for synchronization of WECS which is connected to the grid via an inverter. Also, it comprises existing renewable energy systems and applications on synchronization techniques. Mainly, this paper proposes an optimal synchronizing control scheme which verifies deterministic and reliable reconnection to the grid. The control scheme was designed using MATLAB Simulink software and the results were interpreted that the concept is efficient and reliable to optimize the microgrid operations.

KEYWORDS: *Integral Time Absolute Error (ITAE), Phase Locked Loop (PLL), Proportional Integral (PI), Wind Energy Conversion System (WECS), Pulse Width Modulation (PWM), Insulated Gate Bipolar Transistor (IGBT)*

1 INTRODUCTION

Under the present and proposed policies, energy-related CO_2 emissions rise by 6% from 33 Gigaton in 2015 to 35 Gigaton in 2050 (Gielen D. et al, 2019). For an emissions trajectory compatible with the Paris Agreement's 2 °C objectives, emissions must decrease to 9.7 Gigaton in 2050 (Mei L. et al, 2021). 94% of the emission reductions are attributable to the combination of electrification of end uses and renewable energy and energy efficiency (Li J. et al, 2019). As per the research wind power generation for electrification becomes mandatory as it is a clean form of energy. On average, wind turbines capture 60% of the energy that travels through them, compared to solar panels whose efficiency is 18%–22% (Cho C. et al, 2011). The fact that a wind turbine can generate more electricity than many solar panels are therefore undeniable. According to the 6 phases defined by International Energy Agency, Sri Lanka is in 4th phase for Variable Renewable Energy generation. That is the phase of system stability of the power system (Unais H. et al, 2020).

The severity depends on the characteristics of each system in grid integration. To maintain quality and reliable continuous power supply, the key consideration is grid synchronization (Frp M.M.V. et al, 2021). Improper synchronization affects the healthy power system and results in electrical transients that damage power system components (Hansanpor D.P. et al, 2011). Inverters are frequently utilized when grid-connecting distribution generators capture renewable energy. When driving the electricity to the grid, inverters should deliver a steady, sinusoidal AC waveform that complies with utility regulations for grid voltage, frequency, and phase (Liang Z. et al, 2011). Lack of proper synchronization results in grid instability, load imbalances, and grid power outages, and may even cause associated device damage (Soni K. et al, 2018). Therefore, the solution is the optimum synchronization of the wind power generation unit verifying reliable reconnection to the grid.

https://doi.org/10.54389/IORE1011

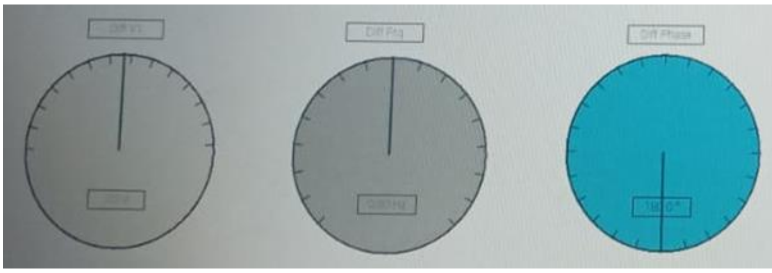

Figure 1: Sync-check controller status before synchronized – Microgrid, University Premises of Moratuwa

Figure 2: Sync-check controller status after synchronized - Microgrid, University Premises of Moratuwa

Figure 1 depicts the phase angle status as shown by the Sync-check controller prior to synchronization during a power outage. It is observable that the indicator at blue dial is pointed towards downward. After synchronization, the Sync-check controller status is shown in Figure 2. It is observable that the indicator at blue dial is pointed towards upward. The difference in voltage, frequency, and phase angle at synchronization should all be reduced to a minimum so that the difference equals zero. From left to right, the third measurement dial in blue depicts the indicator related to phase angle measurement before and after synchronization. At synchronization, the phase angle difference has been reduced such that the generated signal from the inverter is in-phase to its reference grid phase angle.

2 LITERATURE REVIEW

PLL methods and non-PLL methods have been designated for grid synchronization. Power PLL and Quadrature Signal Generator-based PLL techniques are further classifications of PLL methods. DE-PLL and ATD-PLL can compensate for the shortcomings of Power PLL (Liang Z. et al, 2011). ATD-PLL has proven to be faster than DE-PLL even when subjected to frequency and phase shifts. It demonstrates that PLL is also utilized for harmonic attenuation (Han Y. et al, 2018). Synchronization is described as the reconnecting of renewable energy sources to the grid by switching the operation of the islanded microgrid. The coordinated control of several generators is necessary for microgrid synchronization (Sridharan T. et al, 2017). In essence, a synchronizer enables a single machine to synchronize with the grid. The problem is that synchronizing microgrids that use numerous Distribution Generators, energy storage systems, and loads is impossible with a traditional synchronizer (Zhang L. et al, 2015). Here, a coordinated system becomes necessary. Given that a microgrid is made up of several alternator and power electronics-based generators that create power together, the situation is complicated.

This study demonstrates that because single-phase loads and Distribution Generator units are present, the microgrid inherits the phase-to-phase imbalance. It is necessary to keep the values of the phase-angle difference, slip frequency, and voltage differential as little as feasible when AC generators are paralleled (Wang Y. et al, 2011). The manual synchronizing approach, which waits until the synchronizing requirements are met while keeping the frequency and voltage of the microgrid at constant levels, does not produce predictable outcomes. When the frequency difference between two systems is relatively small, it takes extra time for the phase difference to fulfill the criterion (Cho C. et al, 2011). The recovery of the frequency and voltage induced by the droop control is comparable to the active synchronizing control that has been presented in this study. As a result, it demonstrates that maximizing DG synchronization in the microgrid idea is a must (Wu Q. et al, 2017).

The research findings support specific theories about system improvement through parameter optimization. The voltage stability at the Point of Common Coupling has a significant impact on the grid-connected converter's performance (Gielen D. et al, 2019). When a weak AC grid is used for power generation, PCC voltage stability suffers. It demonstrates the effect of PLL-controlled converter current in poor grids. According to the study, PLL-less current control is necessary (Wang Y. et al, 2019). Factors including noise, low voltage ride, and harmonics need to be overcome at synchronization as renewable energy penetration into the grid increases (Mei L. et al, 2021). It has been demonstrated that PLL inverter synchronization technology is used in both single-phase and three phase systems. The use of an adaptive filter is one method to enhance PLL performance (Li J. et al, 2019). This study presents cascaded delayed signal cancellation PLL synchronization to address issues that occur at the highlighted problem of high renewable energy penetration to the grid. The research findings support specific theories about system improvement through parameter optimization (Unais H. et al, 2020). The voltage stability at the Point of Common Coupling (PCC) has a significant impact on the performance of the grid-connected converter. When a weak AC grid is used for power generation, PCC voltage stability suffers. It demonstrates the effect of PLL-controlled converter current in poor grids. According to the study, PLL-less current control is necessary (Sridharan T. et al, 2017).

Conventional power plants offer active and reactive power, inertia response, and synchronization power, voltage backup during faults, oscillation damping, and short circuit capability. Asynchronous operation and the converter-based grid interface are impacted by the wind turbine technology used by DFIG (Han Y. et al, 2018). Active power sources include wind turbines. The current grid code requirements include the capacity to adjust active power, reactive power, frequency, steady state operating range, and fault-ride through. Failure to accurately identify the supply voltage phase angle results in faults including frequency fluctuation, power oscillation, and harmonic currents (Wang Y. et al, 2021). In microgrids, frequency drift monitoring during islanding mode is crucial. Since identifying the proper grid voltage phase angle under fault and distorted voltage conditions is necessary. To provide a steady frequency reference for standalone operation, this is given using an adaptive synchronous reference frame phase-locked loop (Frp M.M.V. et al, 2021).

The switching components of the main circuit can tolerate the high voltage and current flowing through parallel-connected IGBTs. The voltage loop control, the current loop control, and the phase-locked loop control are all part of the inverter control technique (Soni K. et al, 2018). The dc-link voltage is maintained steadily by the voltage loop. The grid side current should have few harmonic components thanks to the current loop, which is also made to swiftly track the active current of the voltage loop (Hansanpor D.P. et al, 2011). The phase-locked loop is intended to align the grid voltage and current in one direction. Both the active current and the reactive current were independently controlled. The proposed control strategy of the grid has been successfully validated by simulation results (Wang Y. et al, 2019).

3 PROPOSED MODEL

3.1 PI Tuning for Optimization

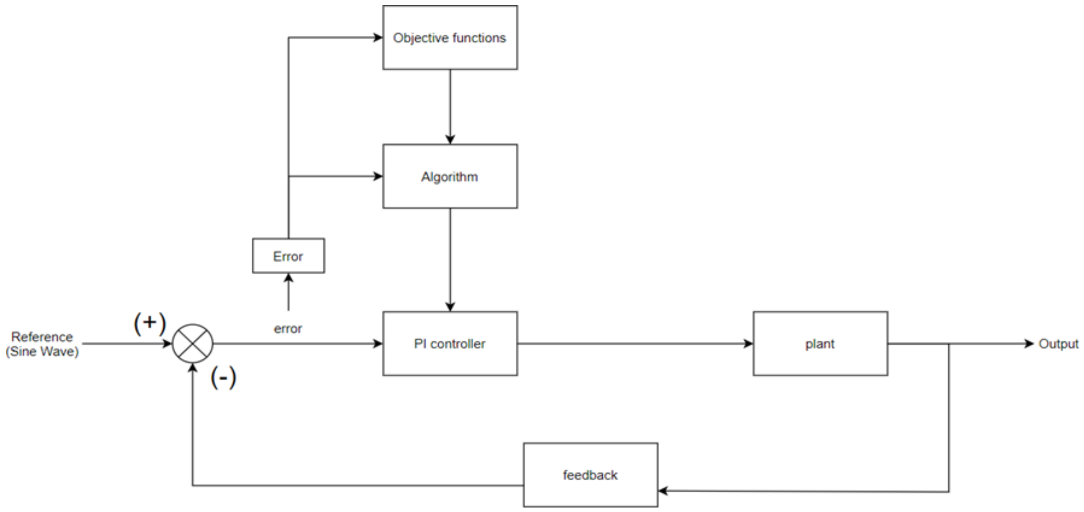

Figure 3: PI tuning - control system

As of Figure 3, the feedback taken from the output is compared with the reference sine wave which is the grid voltage. Then the control system generates an error signal. Next, it goes to the PI Controller. PI controller is used for the design since it compensates the following requirements such that for increasing the gain of the system and for making the system reach stability faster. The PI controller is deployed in PLL which provides the signals to inverter PWM for IGBT switching. PLL consists of a phase detector, filter, and voltage-controlled oscillator. The supreme goal of this whole system is to make the signal output from the inverter in-phase with its reference signal, which is the reference grid. With the tuning of the controller, a fast response can be obtained by optimizing the grid synchronization.

The ISE, IAE, and ITAE are error performance indices. Objective function monitors which would occupy the highest error value, and it should be reduced. First, a random population is created. Later, a series of new populations are produced at each level by the algorithm as of flow diagram depicted in Figure 4. Using members of the current generation, the algorithm creates the next population. The population size and the number of generations would be established prior the execution. Optimization would result in a system with a quick settling time and fewer oscillations.

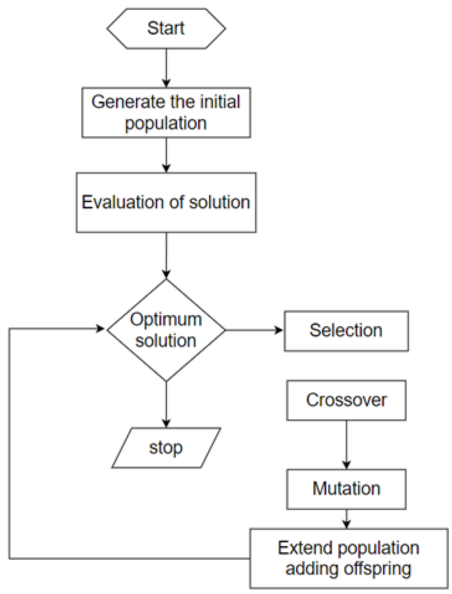

Figure 4: Flow diagram of algorithm used for PI tuning

MATHEMATICAL ANALYSIS

The design method of PI ensures that when $V_d^* = 0$ is reached, the set point is followed by V_d. Once $V = 0$ is reached, it is deduced that the space voltage vector is synchronized along the q-axis. Additionally, PLL is locked on the system frequency. The θ^* becomes equal to θ in this instance. If $\theta^* = \theta$, then $V_d = -V_m cos(\theta - \theta^*)$, according to small angle approximation. The feed-forward frequency regulates the PI-regulator to produce an output signal that equals 0. The Figure 5 illustrates the structure of PLL.

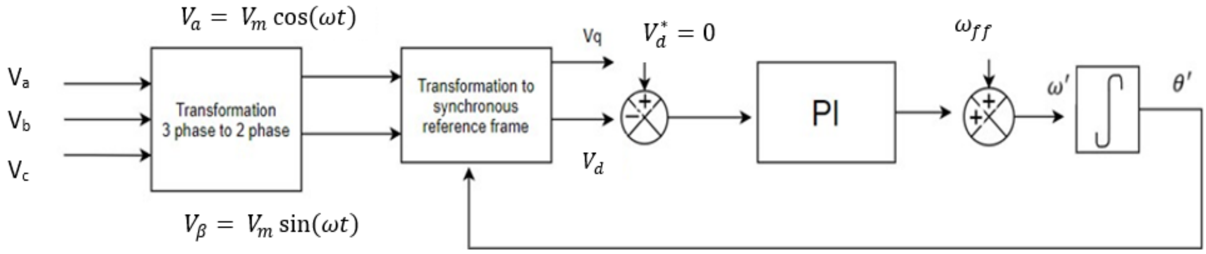

Figure 5: Structure of PLL

θ : Phase angle, θ': Integral of estimated frequency
θ^* : Estimated phase angle
ω_{ff} : Feed-forward frequency
ω' : Estimated frequency (summation of PI output and the feed-forward frequency)

3.2 Equations

V_a, V_b and V_c are the three phase voltage signals. To track phase angle, they are transferred to a stationary system with two phases, V_α and V_β. The phase angle is θ.

The grid voltages can be stated as given below.

$$V_a = V_m \sin(\theta) \tag{1}$$

$$V_b = V_m sin(\theta - \frac{2\pi}{3}) \tag{2}$$

$$V_c = V_m sin(\theta + \frac{2\pi}{3}) \tag{3}$$

αβ transformation matrix is as of $T_{\alpha\beta}$.

$$T_{\alpha\beta} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \tag{4}$$

It can be inferred that two signals are only conveying information about the phase angle of phase V_a, when $V_{\alpha\beta} = T_{\alpha\beta} V_{abc}$ is given by matrix multiplication.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} V_m \sin(\theta) \\ V_m \cos(\theta) \end{bmatrix} \tag{5}$$

3.3 Analysis on Synchronous Rotating Reference Frame

The voltage space vector synchronization with the q-axis is shown in Figure 6.

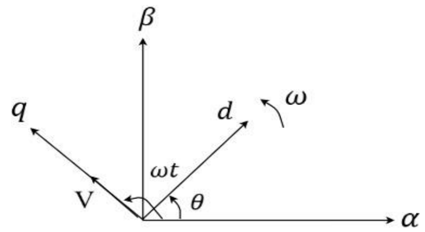

Figure 6: Rotating reference frame

Equation describes the transformation matrix of the voltage vector synchronizing with the q-axis as of (6), where θ^*: estimated phase angle output of the PLL system

$$T_{qd} = \begin{bmatrix} sin\theta^* & cos\theta^* \\ -cos\theta^* & sin\theta^* \end{bmatrix} \tag{6}$$

$V_{qd} = T_{qd}V_{\alpha\beta}$ gives the below matrix.

$$\begin{bmatrix} V_q \\ V_d \end{bmatrix} = \begin{bmatrix} V_m cos(\theta - \theta^*) \\ -V_m sin(\theta - \theta^*) \end{bmatrix} \tag{7}$$

Transfer Function of the plant;

$$G(s) = \frac{2\varsigma\omega_n s + \omega_n^2}{s^2 + 2\varsigma\omega_n s + \omega_n^2} \tag{8}$$

$\varsigma = 0.7, \omega_n = 2\pi f_{grid}$; where $f_{grid} = 50\ Hz$

Therefore, G(s) can be yielded as below.

$$G(s) = \frac{318.31s + 2500}{s^3 + 318.31s^2}$$

3.4 PI regulator gain design methodology

The two terms that make up the PI controller parameters are K_p and K_i which stand for proportional and integral values, respectively. The proper setup of these parameters will enhance dynamic response of the system, eliminating steady-state error, and increasing system stability. The transfer function of PI controller is as mentioned below.

Transfer Function of PI controller;

$$C(s) = K_p + \frac{K_i}{s} \tag{9}$$

5 RESULTS AND DISCUSSION

4.1 MATLAB Simulation Analysis

Figure 7 illustrates the PI tuning block diagram which was designed by using MATLAB Simulink.

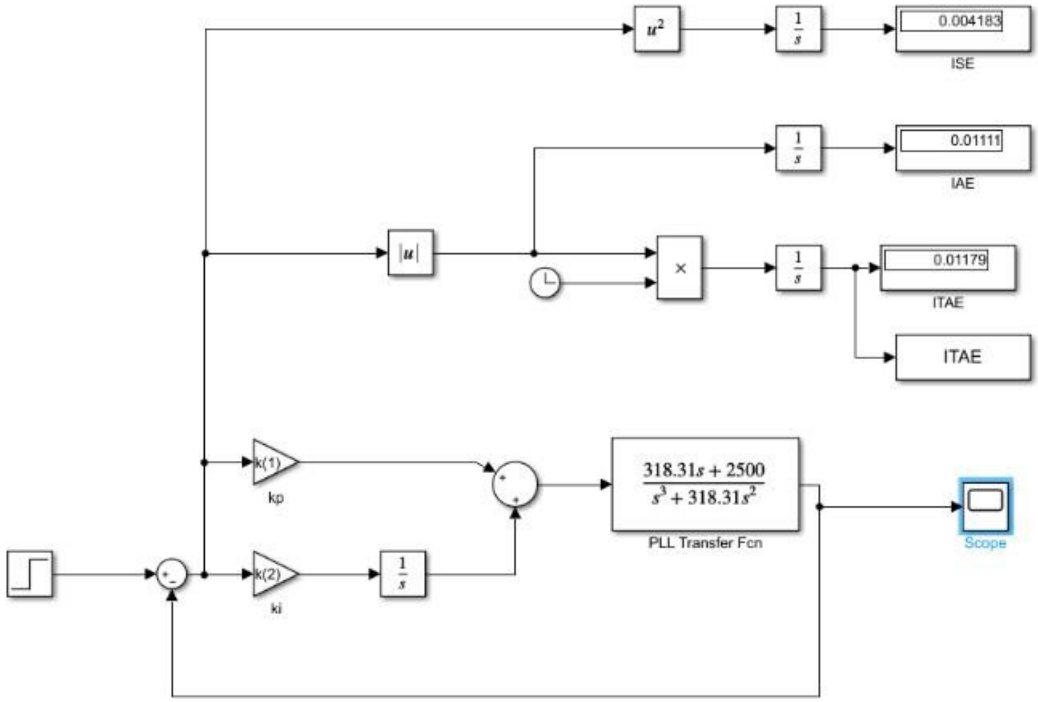

Figure 7: PI tuning-Simulink

The mathematical model of PLL, that is the transfer function, has been used as the plant of the control system. The error performance indices such as ISE, IAE, and ITAE are being analyzed. The objective is to minimize the index depicting the highest error value which will optimize the grid synchronization.

4.1.1 For trial-and-error values and tuned values of gain parameters of PI controller

For values obtained by trial and error and, tuned values of gain parameters assigned directly to PI controller by MATLAB workspace for Simulink model of Figure 7, the output for step response is as of Figure 8 and Figure 9 illustrated below respectively.

i. Before optimizing → K_p=10, K_i=50000

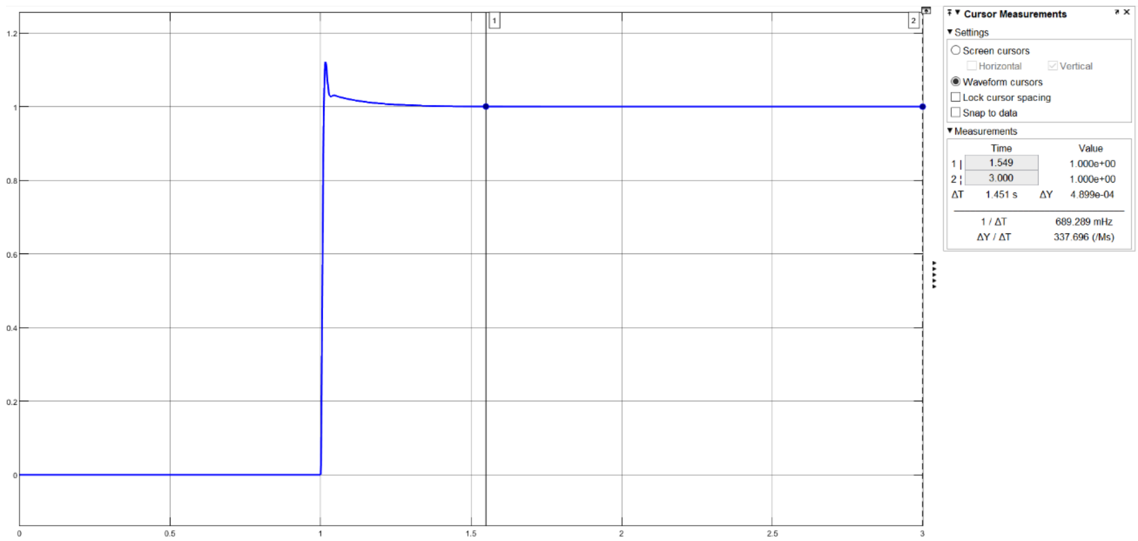

Figure 8: settling time=1.549 s

- Before optimizing, the values selected by trial and error have been assigned for gain parameters. The time to arrive at steady state is 1.549 s as of Figure 8.

ii. After optimizing → K_p=199.8686, K_i=191.8527

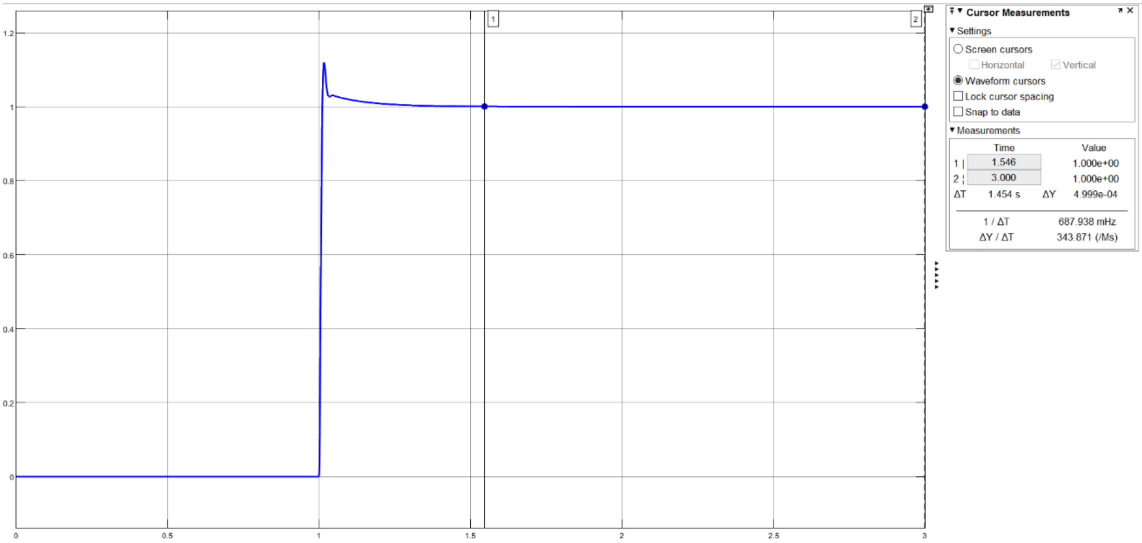

Figure 9: settling time=1.546

- After optimizing, the tuned values have been assigned for gain parameters. The time to arrive at steady state is 1.546 s as of Figure 9.

  Observation - For the optimized K_p, K_i values, the system arrives steady state in a lesser time in comparatively to K_p, K_i values selected by trial and error.

4.1.2 For values selected by trial and error and, tuned values of gain parameters assigned to PI controller of Three-Phase PLL model

When assigned for PI controller of three phase PLL, the results are as of Figure 10 and Figure 11 respectively.

i. Before optimizing → K_p=10, K_i=50000

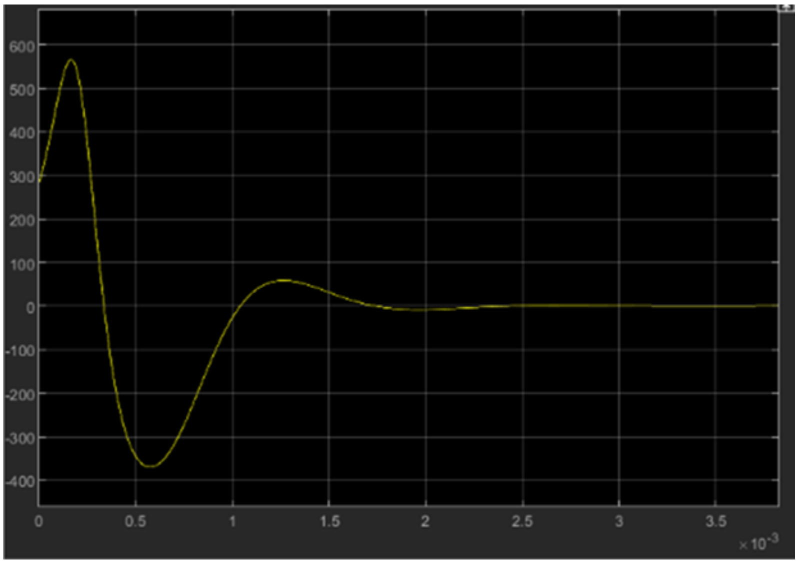

Figure 10: Q output for K_p, K_i values selected by trial and error

For values selected by trial and error of K_p=10, K_i=50000; more oscillations observed as of Figure 10. The settling time is 2.5ms.

ii. **After optimizing →** K_p=199.8686, K_i=191.8527

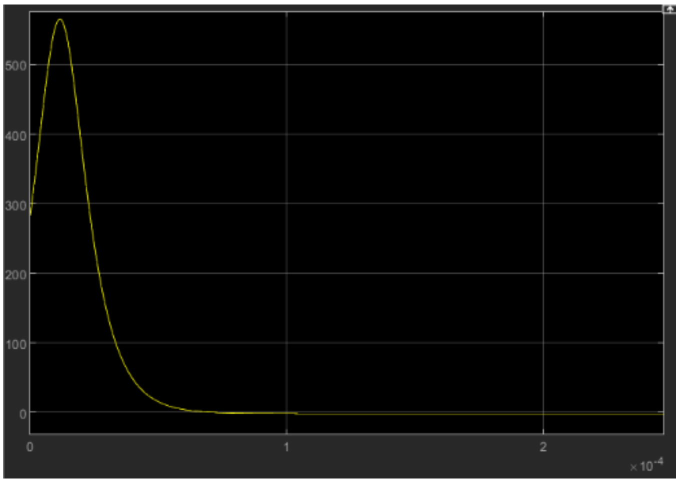

Figure 11: Q output for tuned K_p, K_i

For tuned values of K_p =199.8686, K_i =191.852; less oscillations observed as of Figure 11. The settling time is 0.08ms.

Observation - For optimized K_p, K_i values, the system arrives at steady state in a lesser time in comparatively to K_p, K_i values selected by trial and error

4.1.3 Applications

The tuned values are assigned for PI controllers of two applications.

1. Tuned PI used for PLL in reactive power compensation
2. Proportional Resonant Controller – with Tuned PI of PLL for grid connected inverter

The simulations for the above two applications have been done in MATLAB Simulink and values of gain parameters before and after optimizations were assigned. The results have been shown in the sets below from Figure 12 to Figure 17.

5.1.3.1 Application 1: Reactive power compensation

i. **Before optimizing →** K_p=10, K_i=50000

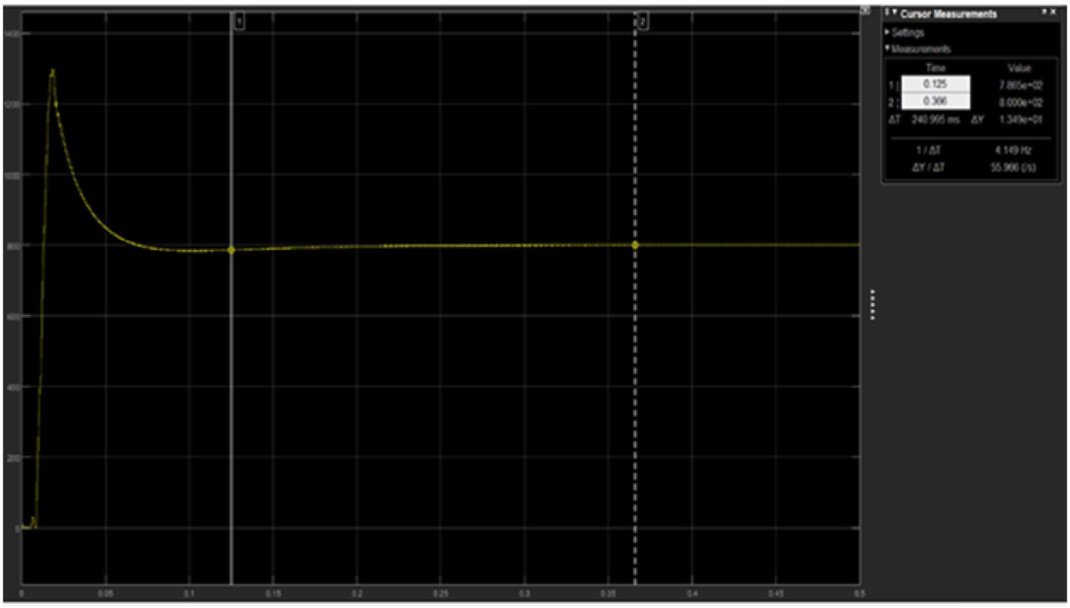

Figure 12: At K_p=10, K_i=50000

The settling time of V_{dc} of inverter is at 0.366 s for values selected by trial and error of PI gain parameters as of Figure 12.

ii. **After optimizing →** K_p=199.8686, K_i=191.8527

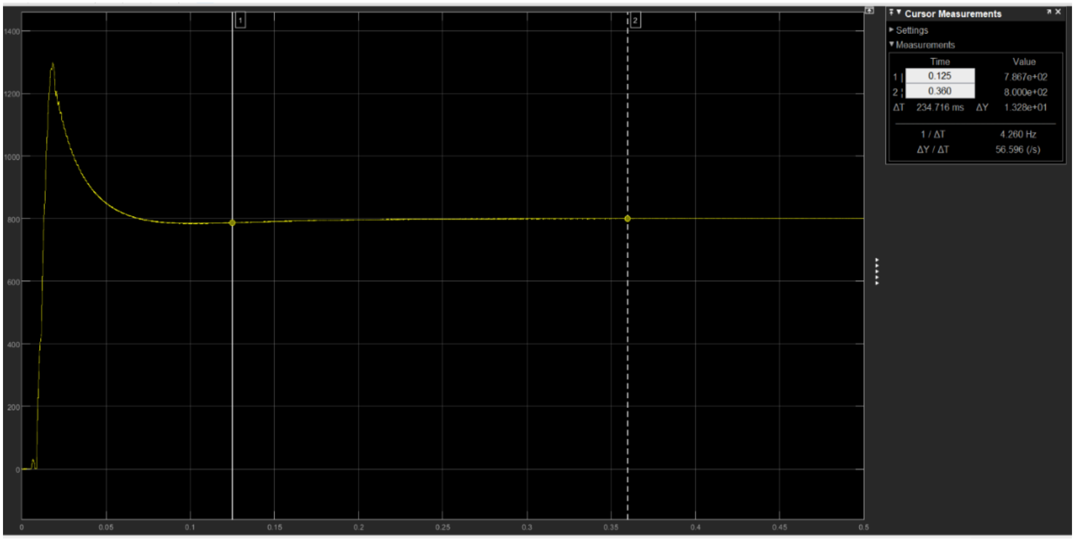

Figure 13: At K_p=199.8686, K_i=191.8527: (optimized values)

The settling time of V_{dc} of inverter is 0.360s for tuned values of PI gain parameters as of Figure 13.

Observation - The settling time of V_{dc} of inverter is less for tuned values of PI gain parameters

5.1.3.2 Application 2: Proportional Resonant Controller – with Tuned PI of PLL for grid connected inverter

5.1.3.2.1 At normal operation without applying sudden variations in reference signal

Inverter current and reference current do not coincide with each other as of Figure 14. For tuned PI values, inverter current and reference current coincided with each other as of Figure 15.

i. **Before Optimizing →** K_p=10, K_i=50000

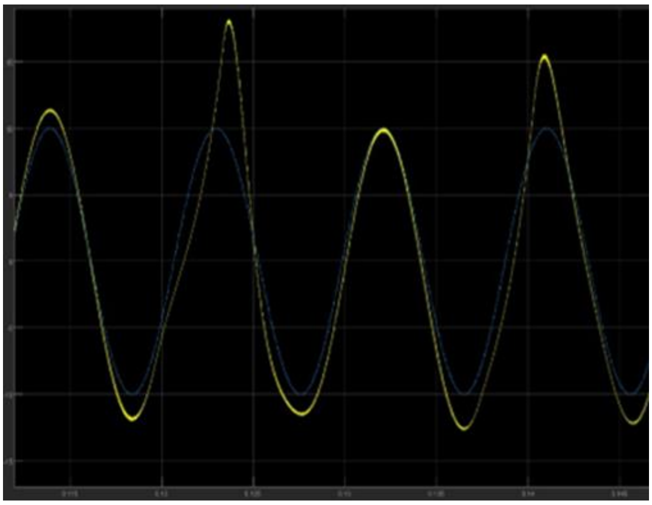

Figure 14: Scope – For values selected by trial and error of PI; Blue- reference signal, Yellow-Output signal from Inverter

ii. **After Optimization→** Kp=199.8686, Ki=191.8527

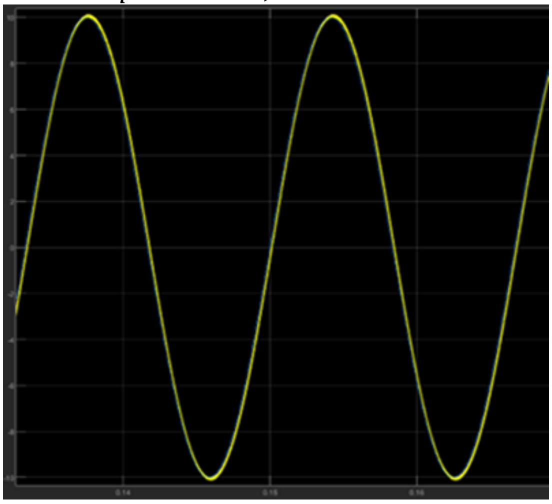

Figure 15: Scope – For Tuned PI; Blue-reference signal, Yellow-Output signal from inverter

As per Figure 14 and Figure 15, observation interprets that the inverter current signal is following its reference signal with negligible steady state error for optimized gain parameters.

5.1.3.2.2 Condition when change is applied in reference signal

For values selected by trial and error of PI, grid voltage and inverter current not in phase as of Figure 16. For tuned values of PI, grid voltage and inverter current are in phase after transition period when change is applied in reference signal as of Figure 17.

i. **Before Optimizing →** K_p=10, K_i=50000

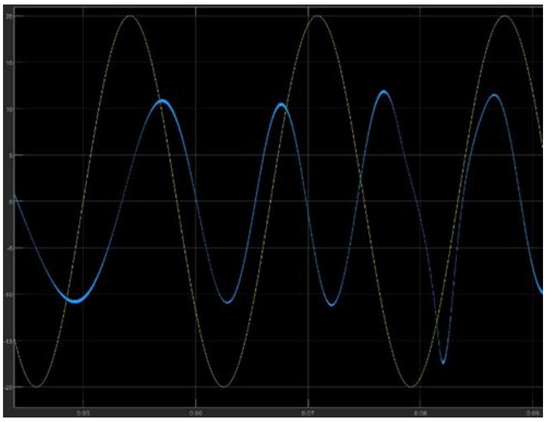

Figure 16: Yellow - Grid voltage, Blue-

Inverter current

ii. **After Optimization→** Kp=199.8686, Ki=191.8527

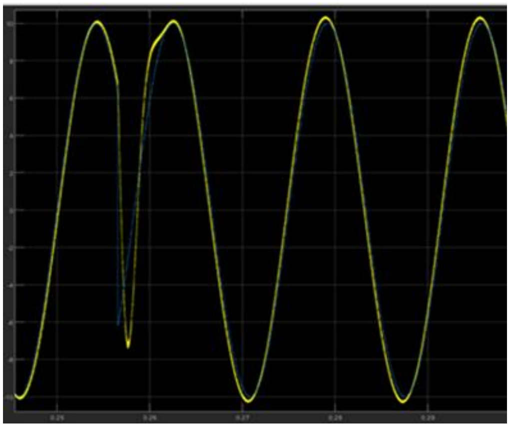

Figure 17: Scope - For Tuned PI

According to Figure 16 and Figure 17, observation interprets that, for 180 degree phase shift is applied to check behavior of the output current, the output signal follows its reference signal after some transition period.

4.2 Hardware Prototype

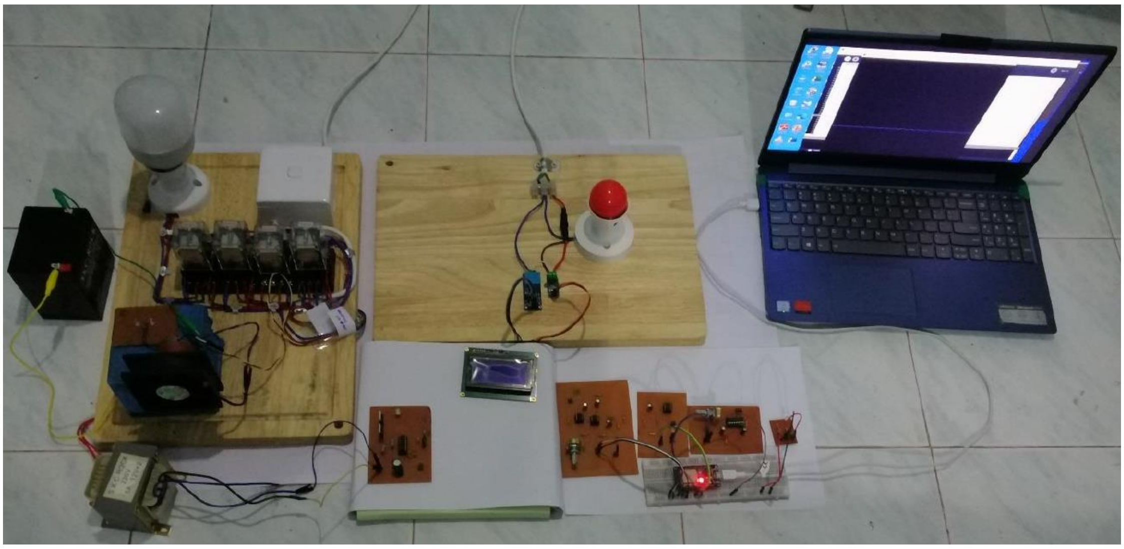

Figure 18: Final Prototype

The final prototype is depicted in Figure 18. The WECS with inverter, transfer switching circuits with relay operation, phasor measurement circuit with LCD display are shown as above. The phasor measurement is done with ESP 32 microcontroller. In addition, synchronization filters with square wave generator, PWM led driver circuit, PLL circuit done using CD4046 can be seen which are used to monitor their behaviors by observing output waveforms to get a thorough idea about their functionalities. Basically, this prototype implementation has been done to give an idea of the concept of how the general systems are operating.

5 CONCLUSION

One important control method identified by the research for grid synchronization is the PLL. The PI controller used in PLL is chosen based on the optimal values. The values that yield the lowest Integral Time Absolute Error are the best values for the PI controller that is used in PLL of grid synchronization. Tuned values and values selected by trial and error have been assigned for the PI controller and comparisons have been done for the time of the system to reach the steady state. It was observed that the system reaches a steady state faster for tuned values for the PI controller in PLL. Furthermore, comparisons have been done by assigning tuned values and values selected by trial and error for PI controllers of PLL in two specific applications such that; for tuned PI used for PLL in reactive power compensation and Proportional Resonant Controller with tuned PI of PLL for grid-connected inverter. In these applications also, it was observed that the system arrived at the steady state faster at grid synchronization for tuned PI values in the controller. In addition, once sudden changes are applied in the reference signal, it was observed that the output signal follows its reference signal after some transition period with negligible steady-state error for tuned PI values. It can conclude that the system reaches the steady state with the best values for gain parameters of the PI controller in the shortest amount of time feasible, providing for the best possible synchronization. As a result, the primary goal of the project of achieving the best possible synchronization between the grid and the wind power plant was accomplished.

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STRUCTURAL ENGINEERING

Physical and Mechanical Characteristics of Lime-based Cementitious Grout

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ABSTRACT

Grout is an essential part in soil and rock anchoring while large amount of grout is consumed in anchoring process and capacity of anchoring can be increased by strengthening the grout. Increasing the strength of the grout or achieving the strength of the cement-based grout by partially replacing the cement with hydrated lime and by adding coir fiber can produce sustainable and structurally acceptable grout. This research study investigates grout with water/solid (w/s) ratio of 0.45, 0.7 while replacing the blended Hydraulic cement (BHC) content with hydrated lime by 35%, 50% and 65% with 1% coir fiber, superplasticizer and silica fume. The results show that flow of the grout is reduced with the addition of lime, fiber. Bleeding is improved in the lime-based grout. Compressive strength reduces with the addition of lime while grout achieves improved strength in long term. Compositions with 35% Lime content showed better performance and w/s ratio of 0.45 had the best compositions comparing the physical and mechanical characteristics. The fiber grout sample with w/s = 0.45 and 35% lime content had the best results with flow of 135mm, final bleeding of 3.75%, bleeding settlement in less than one hour and compressive strength at 7days, 28days are 10.4Mpa, 21.75Mpa respectively.

KEYWORDS: *Soil Anchoring, Lime-based grout, Coconut coir fiber, Mechanical characteristics, Physical properties.*

1 INTRODUCTION

Soil anchoring and rock anchoring are solutions to construct structurally and geotechnically sound structure in a way that it can stabilize temporary or permanent structures such as steep slopes, slopes with weak soils, rock excavations, tunnels etc. In Sri Lankan context anchoring is a currently used method in several occasions such as road constructions, Dam construction, soil slopes etc. Slopes are stabilized by the anchors in a way, the soil anchor resist and mobilizes the loads and forces of the soil mass in the failure plane [Chengyu Hong (2011)]. Typically shearing, chemical adhesion, mechanical interlocking and frictional resistance between anchor-grout are common mechanisms used by this system to transfer loads [B. Benmokrane et al (1995)].

Grout is introduced to the soil and rock anchoring system by pumping the grout under pressure in between soil and anchor shaft interface. The primary intension of grouting is to make a strong bond between tendon and soil or rock interface in order to have a smooth load transition and grout is used to transmit the load from one medium to another. B. Benmokrane et al states load transferring capability of the anchoring system is depended on the factors such as anchor type and cement grout type. Also grout application reduce the corrosion of steel elements used for anchoring. soil anchoring industries

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predominantly using plain cement-based grout, in addition fine aggregate is mixed with plain grout for particular cases of drill holes with large diameter. And also, admixtures and super plasticizers are been used for various circumstances such as to reduce water content, setting retarders, high temperature grouting, improve workability [P.J. Sabatini et al (1999)].

This research investigates the physical & mechanical properties of the grout and studies the behavior of fiber incorporated lime-based grout with the addition of blended Hydraulic cement (BHC) and mechanical abilities of the grout. This study particularly focuses on the coconut coir fiber incorporated grout used for soil anchoring and rock anchoring. This research study aims to introduce Hydrated lime powder as a substitute to cement in the grout mixture. Replace cement with lime and introduce coir fiber to reinforce the grout composition. And studying the characteristics of the fiber modified grout to form a sustainable and economical grout composition.

The lime-based grout and coconut coir which is the incorporated fiber material are natural products. And coconut coir is a feasible product in Sri Lanka. Further the blended hydraulic cement used for this study is a blend of cement and fly ash which is an industrial by product. So, identifying best compositions and in the industrial implementation level most sustainable grouts can be produced and the whole soil & rock anchoring solution becomes a more sustainably improved option. In a phase where the world technologies are moving to sustainable options; A grout composition with natural ingredients and cement reduction can create more feasible and sustainable solution.

2 LITREATURE REVIEW

In grout industry cement is an inevitable substance, majority of the journals are studied addition of artificial fiber materials to the grouts and specific artificial fiber addition in cement-based grout is been investigated majorly. Researches are conducted on cement-based grouts with artificial fibers focusing on enhancing grout characteristics and used for different practical problems. The studies conducted by [Wei-Hsing Huang (2001), Dong Joo Kim et al (2016), Zhenyue Shi et al (2020), Pu Zhang et al (2021), M. Jamal Shannag (2001), Chunjing Zhang et al (2021), Xiaojuan Shu et al (2022)] are used the artificial fibers such as Polypropylene fiber, Plasma functionalized graphene fiber, Polyvinyl alcohol fiber, basalt fiber. In a study natural source of fiber which is polymer modified jute fiber in the cement grout [Chakraborty et al (2013)] and using pre-treated coconut coir fiber added cement grout lightweight cement boards are constructed and achieved recommended mechanical standards [C. Asasutjarit et al (2009)]. Further Chakraborty et al (2013) mentions major components influencing the modified grout which are fiber characteristics, cement matrix and mix design, specimen handling including sample mixing, casting and curing. Pu Zhang et al (2021) says grout, grout type, length and volume fraction are influencing factors of the grout's mechanical characteristics. In addition to mechanical properties several other enhanced properties including impervious and high resisting performance in harsh environments, crack control, controlling catastrophic failures are observed by following authors [Wei-Hsing Huang (2001), Zhenyue Shi et al (2020), Dong Joo Kim et al (2016) and S. Chakraborty et al (2013)] respectively in fibered Cementitious grout.

Limited studies are conducted on fiber reinforced lime-based grouts. Natural fibers are not used in these studies instead artificial fibers such as linen fiber and glass fibers are used as the reinforcing agents [Urs Müller et al (2016), Vasiliki Pachta (2021)]. Vasiliki Pachta (2021) indicates that mechanical characteristics including compressive strength, flexural strength and modulus of elasticity are improved tremendously and further results of the grout showed more matured and improved values in long term. Urs Müller et al (2016) points out flow of the grout which deicides the workability of the grout can be adjusted with the superplasticizers type admixture.

Focusing on the researches based on grouts used for anchoring purposes; Jingke Zhang et al studied calcined ginger nuts grout with fly ash and quartz sand. Authors used several combinations of the materials and concluded the mix with calcined ginger nuts grout with fly ash and quartz sand in a ratio of 1:0.5:0.5 as a suitable mix for earthen structures in the basis of its workability and durability. A study on anchor grout used different percentage of styrene-butadiene rubber (SBR) polymers in cement-based grout on dry and wet conditions and investigated the behavior of grout [Joseph J. Assaad et al (2018)]. Further author concludes that the addition of SBR improved physical properties such as resistance for bleeding and washout loss and improves the mechanical properties such as compressive, flexural and bond strength in aquatic conditions.

As mentioned earlier, in anchoring system capacity of the anchor depends on anchor tendon and the grout. Strengthening anchors and reducing the spacing between tendons are costlier option to increase the capacity of anchor system while increasing the strength of grout is a more feasible and economical option. In overall limited number of literatures studied about the utilization of natural fibers in grout and coconut coir fiber is not fully utilized as a reinforcing agent in grouts. Further literatures shown interest in replacing cement with materials such as fly ash, slag and pozzolan. No interest is been shown for the naturally available lime to replace cement in grout. The broad scope and application of grout makes a more broader research gap. So, this study will focus on coconut fiber reinforced lime-based grout with partial replacement of cement for the application of soil and rock anchoring.

3 METHODOLOGY

3.1 Materials

In the lime-based grout BHC is added to the compositions of hydrated lime, in addition superplasticizer, silica fume is used to improve the workability and strength of the composition respectively and reinforced with coconut coir fiber. The material compositions are designed using the literature data and sample castings are done for the compositions before proceeding to the other tests. Material composition is given in table 1. The control sample is designed with 100% ordinary Portland cement (OPC) and superplasticizer to match with the current industrial practices.

Table 1: Material matrix

W/S ratio	L: C ratio	Fiber	additives	Abbreviation
0.45	Control sample	0%	1% SP, 0% SF	45CS
	0.35:0.65	1%	1% SP, 5% SF	W45L35
	0.5:0.5	1%	1% SP, 5% SF	W45L50
	0.65:0.35	1%	1% SP, 5% SF	W45L65
0.7	Control sample	0%	1% SP, 0% SF	70CS
	0.35:0.65	1%	1% SP, 5% SF	W70L35
	0.5:0.5	1%	1% SP, 5% SF	W70L50
	0.65:0.35	1%	1% SP, 5% SF	W70L65
0.9	Control sample	0%	1% SP, 0% SF	90CS
	0.35:0.65	1%	1% SP, 5% SF	W90L35
	0.5:0.5	1%	1% SP, 5% SF	W90L50
	0.65:0.35	1%	1% SP, 5% SF	W90L65
Fiber: 10mm non-treated coconut coir fiber | W/S ratio – water / solid ratio				
SP – Superplasticizer | SF – Silica fume | L:C ratio – Hydrated Lime: BHC ratio				

The control sample (CS) used in the testing consist of 100% OPC with 1% superplasticizer. Hydrated lime, blended hydraulic cement (BHC) is used and mentioned in all the fibered lime-based grout compositions.

3.2 Test sample preparation

The mixing of grout is done by using a mechanical mixer and the mixing procedure is adopted from ASTM C-305. And same mixing procedure and method is followed for all the samples.

3.3 Experimental procedure

As mentioned earlier sample casting is done for the compositions and suitable compositions are selected for the testing. Then grout mixes are tested for its fresh properties and hardened properties. Following properties are experimented on the different grout compositions to study the behavior of the test specimens.

The physical properties tested are,

I. Flowability of grout
II. Bleeding of grout
III. Wet/Dry density

The mechanical properties tested are,

I. Compressive strength

3.3.1 Flowability of grout

Flowability of grout is tested by using grout spread method, The methodology of the test is adopted form EN 445:2007, clause 4.3.2. Initially Mold is placed over the plate and prevent it from sliding. grout is Poured slowly into the mold up to the top level of the mold. Mold is Steadily lifted from the plate and kept it to spread for a maximum of 30s. After 30s from the lifting of the mold, spread is measured in two perpendicular directions and average of two values is calculated.

3.3.2 Bleeding of grout

Bleeding of the grout is tested according to the standard 79 ASTM C 940 – 98a. After grout preparation, an 800ml fresh grout is added to the 1000ml graduate cylinder and initial volume and time is recorded. graduate cylinder is placed in a level surface without any vibrations and closed it to prevent evaporation of bleed water. Record of water volume segregated in the top surface is recorded in 15-mintues time interval for one hour and in hourly basis for next hours. Finally, after concluding the test, bleed water is poured into 25mi glass graduate and total volume is recorded. Bleeding values in different time intervals are given as the percentage of the total bleed volume. Bleeding of grout specimen is calculated by eq 1 and 2. Bleeding test setup is shown in figure 1.

$$Bleeding\% = \frac{V_2 - V_g}{V_1} \times 100 \tag{1}$$

$$Combined\ Bleeding\ \% = \frac{V_w}{V_1} \times 100 \tag{2}$$

Figure 1: Bleeding test setup

Where Vw is volume of decanted bleed water in mL, V1 is volume of sample at beginning of the test in mL, V2 is volume of sample at prescribed intervals, measured at upper surface of water layer in mL and Vg represents volume of grout portion of sample at prescribed intervals, at upper surface of grout in mL.

3.3.3 Density of grout

Wet density is calculated by weighing the mass of 50mm cubic mold and 50mm cubic mold with fresh grout. Grout mass is taken from the difference and with the known dimension's density is calculated using eq 3. Dry density is calculated by oven drying the casted sample for 24 hours in a temperature of 100 ^{0}C and weighing the mass of the sample, with the known dimensions of the 50mm cube the dry destiny is calculated using eq 3.

$$D = M/V \tag{3}$$

Where D is wet/dry density (Kg/m3), M is wet or dry mass in Kg and V represents volume of the specimen in m3.

3.3.4 Compression test

Compressive strength of the test specimens is tested by the compression test procedure adopted from the standard ASTM C109. Following the standard 50mm cubes are casted for compression test and 3 cubes are casted per composition. Grout is mixed and casted in the molds as given in the standard. Cubes are kept for 16-24 hours from casting for the grout setting and demolded; In case of not achieving the adequate strength, cubes are further kept in the mold for 2 hours. Grout samples are cured for 7days, 28 days testing in a water tank with a maintained temperature of 23^{o}C ± 2^{o}C. compressive strength is calculated using eq 4.

$$Rc = Fc / A \tag{4}$$

3.3.5 Sample casting

Sample casting and curing is done following the sections 3.2 test sample preparation and 3.3.4 compression test. Test samples with water / solid ratio of 0.45 and 0.7 showed satisfactory results while samples of w/s = 0.90 does not achieve its casted properties after the setting time. Samples were not set with in the setting time and inconsistent mixes were obtained with floating fibers on the top surface. Samples of that nature is shown below.

Figure 2: w/s = 0.90 samples

So that samples with w/s of 0.9 is neglected for the further testing and w/s = 0.45 and w/s = 0.7 compositions are tested and investigated throughout this study.

4 RESULTS AND DISCUSSION

4.1 Density of grout

Wet and dry density of grout is measured using the procedure mentioned in section3.3.3 and calculated according to eq 3. The results are shown in figure2.

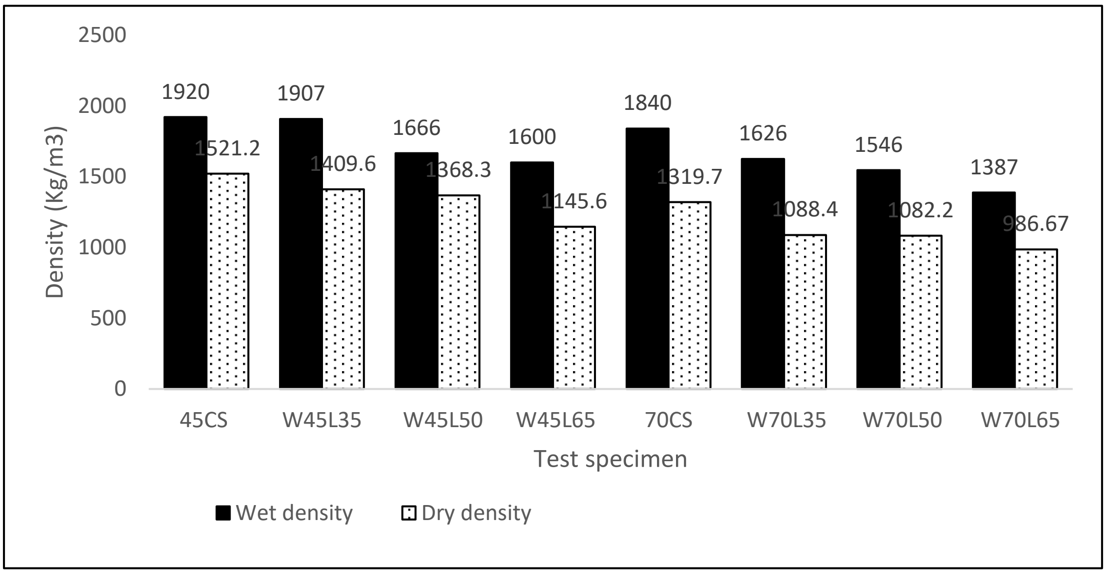

Figure 2: wet and dry density of grout

According to the results shown in figure 3, the Dry density of grout samples is greater than its wet density further a noticeable result is with increment of lime content and water content, both the wet and dry density is reduced. Reasonably after the drying out of water content from the sample will reduce the density and increment of water and reduction in solid content further reduces the density. Composition with 35% lime has wet density of 1907 kg/m^3 and 1626 kg/m^3 for W45L35 and W70L35 respectively. Which are the highest densities compare to other lime added compositions and 45CS has the highest wet and dry density of 1920 kg/m^3 and 1521.2 kg/m^3 compare the all-other composition.

4.2 Flowability of grout

Test results of the grout flowing test is shown in figure 4 below. In figure 4, In the primary axis Flow value of each composition is given and in the secondary axis deviation of flow value of the fibered grout composition compare to its respective control sample is shown as flow deviation percentage.

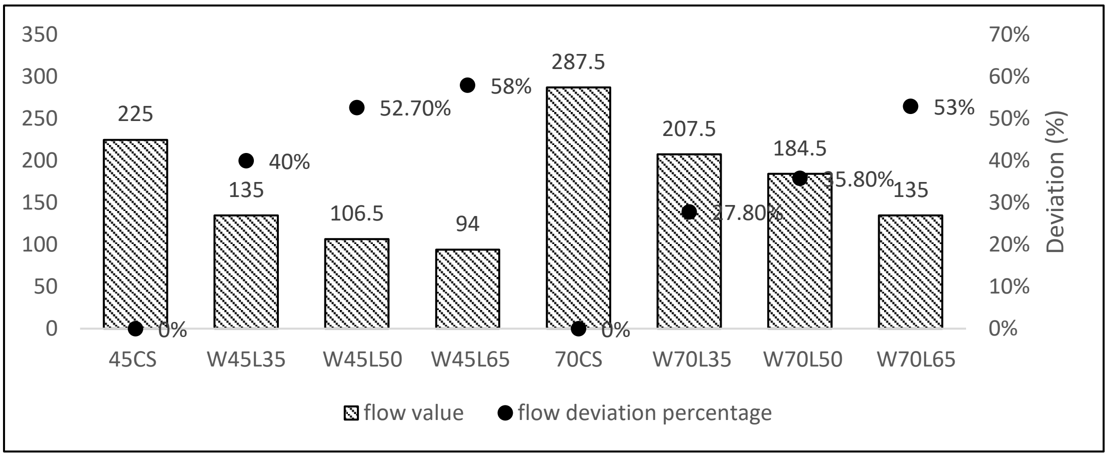

Figure 4: Flow of grout

Figure 4 shows results about the flow of the grout. flowability of grout control samples is observed to be higher values compare to fiber added lime grout samples. Flow of the test specimens increased with the increment of water content and flow decreasing pattern is observed for the increased amount of lime in the composition. Addition of lime and increment of lime content in the samples decreased the flow of the grout sample; due to water absorbing property of lime and L. Gulbe et at also noticed that with the decreasing rate of cement content flow of the specimen is reduced. Both the control samples 45CS and 70CS has acceptable flow values and W45L35 and W70L35 compositions poses a better flow value of 135mm and 207.5mm respectively with minor deviations compare to other two 50% and 65% lime content compositions.

Further an interesting trend noticed, which is flow of the compositions increased when the water content is increased and deviation of the flow values in fiber grout composition compare to its control sample is decreasing with the increment of water content which is shown in the flow deviation percentage points in figure 4. According to figure 3 flow deviation points of w/s=0.45 compositions are notably higher than that of flow deviation points of w/s=0.70 grout compositions. In addition, the workability of the grout can be further improved using admixtures such as superplasticizers [Urs Müller et al (2016)]

4.3 Bleeding of grout

Bleeding of grout is discussed in this part and both final bleeding, bleeding in given time intervals are presented. The bleeding rate of grout in given time intervals which are shown in figure 5 and figure 6 are calculated using eq 1. Final bleeding is calculated using the eq 2 and shown in figure 7.

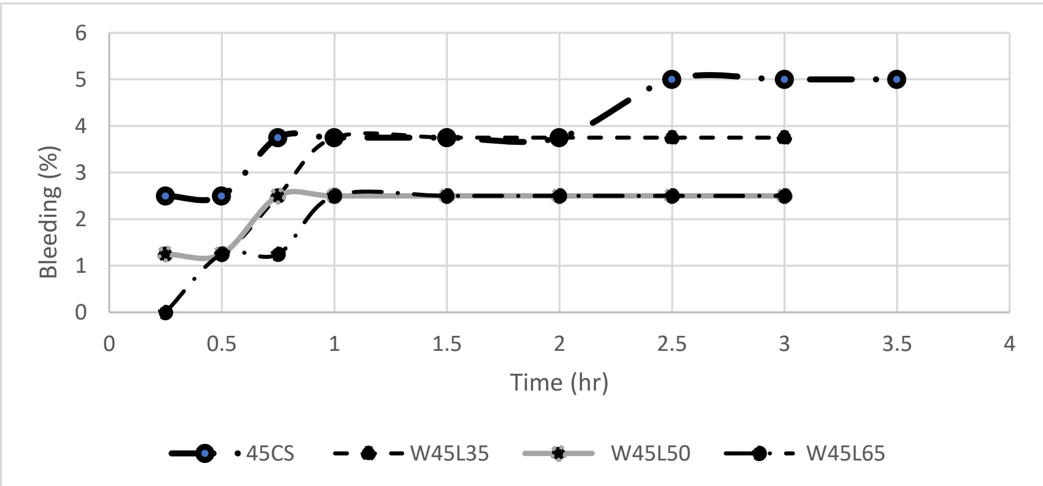

Figure 5: Bleeding rate of w/s=0.45 compositions

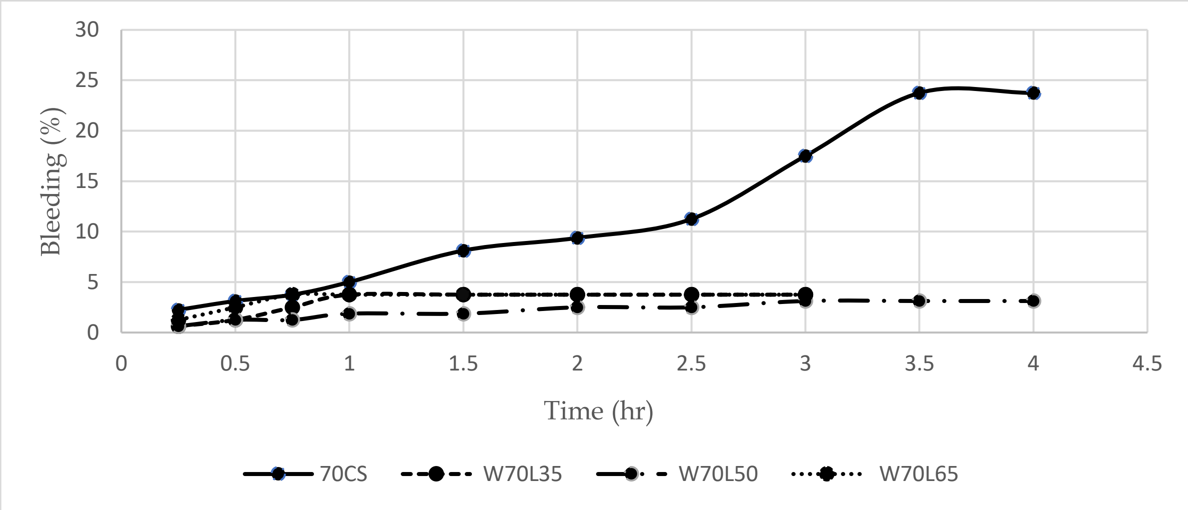

Figure 6: Bleeding rate of w/s=0.7 compositions

Bleeding is an important factor in grout which can directly affects the strength of the grout. Bleeding of the grout combinations are tested according to the methodology given in section 4.3. The readings shows that the control samples(cs) have higher bleeding with higher rate and fibered lime-based grout has a less bleeding value compare to the cs. Further the water content looks to be affecting the bleeding amount; with the increment of water bleeding rate also get increased. Similar results were obtained by Wei-Hsing Huang (2001) and the author observes that excessive water content causes segregation and further states that addition of superplasticizer is also cause for bleeding. In consideration of the grout bleeding rate a notable trend in both the w/s combination is fibered lime-based grout achieves a constant bleeding value in a short period of time compare to control samples which takes 3-4 hours to settle down. Bleeding of fibered compositions with w/s=0.45 is within a range of 1-4 % and fiber grout compositions with w/s =0.7 also has bleeding in similar range. While the control samples having bleeding rate higher than 5% which is not a recommended level of bleeding in industries.

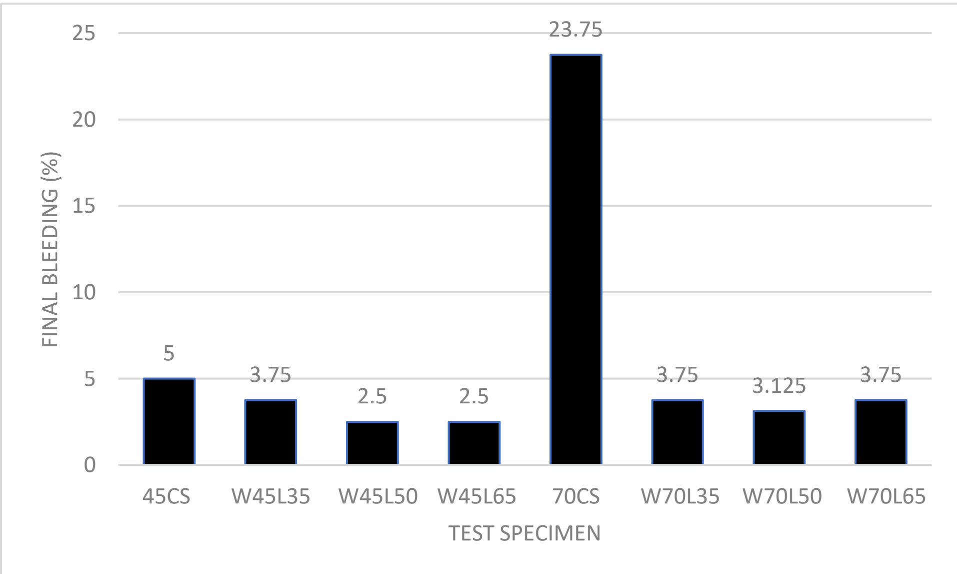

Figure 7: Final bleeding rate of test compositions

Final bleeding chart shows a clear pattern that the control samples have higher bleeding compare to other combination specimens. Addition of silica fume to the fibered specimens is a reason to reduce bleeding by reducing the porosity (M. Jamal Shannag 2001) and further addition of lime which has high water absorption capability is also a reason for low bleeding compare to control sample. In this test results it can observed that the fiber reinforced lime grouts have very low level of bleeding and in an industrially acceptable level while the control samples have an unacceptable amount of bleeding specially 70cs shows a very high final bleeding of 23.75%. In this case coir fiber and lime is a useful addition to the grout composition and it takes the grout to an advantageous position.

4.4 Compressive strength of grout

The compressive test is a primary test to identify the mechanical properties and compression test is done according to ASTM C109 and strength is calculated using eq 4. Figure 8 shows the compression test of a sample and Figure 9 below shows the compression strength at the age of 7days and 28days for the different combinations.

Figure 8: Compression test on a test specimen

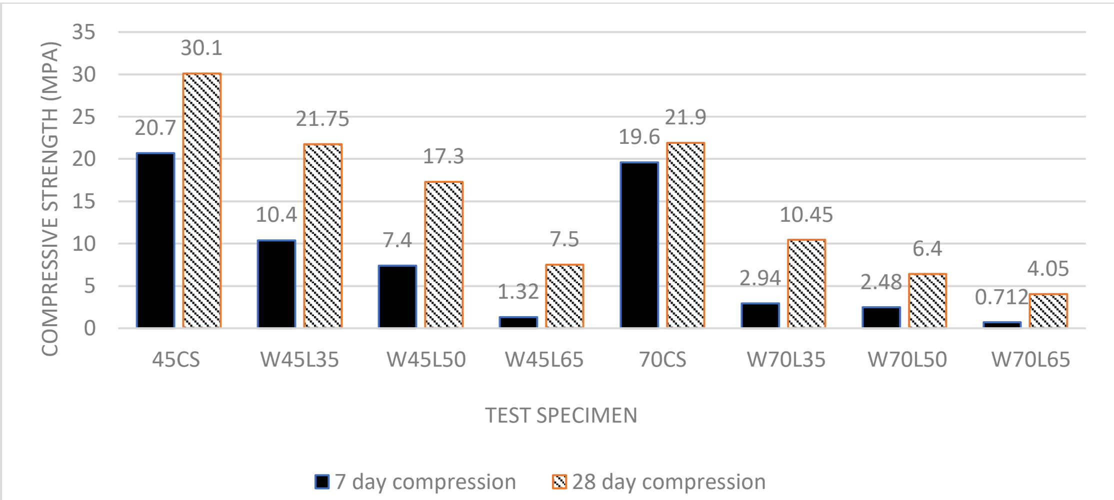

Figure 9: Compressive strength of test specimen

Compressive strengths of the test specimens are shown in figure 9 with the age of 7days and 28days. The control sample, combination with 65% lime powder achieves the highest strength and lowest strength respectively; for both the w/s combinations. Decrement in compressive strength of the samples with the increment of the lime content is been the trend for all the combinations. Further compressive strength reduction is observed in grout samples with increasing water content in the samples. Similar trend is observed by J. Mirza et al (2002) for cement grout. Even though the reduction in compression strength is observed for lime-based grouts, W45L35 and W70L35 has a smaller reduction in strength compare to control sample. And strength deviation of W45L35 and W70L35 compare to other lime-based grouts is high. A common pattern among the lime based fibered grout samples is the increment of compressive strength with age, similar pattern s observed by Vasiliki Pachta (2021) for lime-based grouts. This observation is due to slow reaction of lime in the grout composition.

The compressive strength of 45cs barely satisfies the National Building Research Organization standards and other compositions are not satisfactory. In the lime-based compositions even though the 7days and 28days strength are not satisfactory, further investigation of the lime-based grout sample with compression tests for more aged samples need to be done for better understandings.

The compression tested samples showed a difference in failure patterns for the control samples and fibered grout samples which is shown in following figures. Control samples which have 100% cement showed a brittle behavior and fibered samples showed more elastic behavior which failed in layer-by-layer pattern.

Figure 10: Compressed fiber grout samples

Figure 11: Compressed control samples

5 CONCLUSION

The addition of fiber to grout composition and replacement of cement with lime powder have influenced the physical properties and mechanical properties of the grout composition and comparison with the control sample the fiber grout compositions had an advantage in bleeding test and drawback in flowability and compressive strength. This research can conclude the following.

- Flow of the grout effected by the addition of lime and fiber. Increment of lime powder further decreased flow of the grout. But deviation between flow of fibered sample and control sample is decreased with increasing water content. i.e., Deviation between W45L50, 45CS and W70L50, 70CS are 53% and 36% respectively.
- Bleeding of the control sample is higher compare to other composition. Final bleeding of the fibered sample has a huge difference compare to CS. Addition of silica fume and lime powder reduced the final bleeding of fiber grout and steady the bleeding rate to a constant value in a shorter period.
- Compressive strength of the fibered samples is less compared to CS. Addition of lime powder further reduces the compressive strength. Compressive strength of fiber grout samples improves with age.

Analyzing all the test result the compositions can be ordered in a following way, considering the performance of fiber reinforced grouts. W45L35, W45L50, W45L65, W70L35, W70L50 and W70L65 is the performance order and comparing the results of these compositions further the compositions can be narrow down into 35% lime content grout compositions which had minor variations comparing to the control sample in flow, compression test and better performance in bleeding test.

The 35% lime content grout compositions can go under further testing and it can improve for further improvement in material composition can be done for the future practical applications.

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Durability of Cold Formed Steel Structures used in residential and industrial construction

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ABSTRACT

Cold formed steel is an attractive alternative to traditional construction materials such as masonry and concrete owing to the advantages such as easy fabrication, light weight, reusability of the material and higher level of recyclability. Cold formed steel buildings are also appreciated for better insulation and lower energy consumption during operation. However, durability of the steel was the main concern for stakeholders as corrosive conditions can damage the material and deteriorate the condition of the building. Therefore, it is important to understand the durability of cold formed steel coated with zinc and zinc alloys. In this study, experimental data related to durability studies available in literature was collected and presented through an analysis. The data obtained from literature indicate that if the building envelop was designed appropriately to protect the steel from exposure conditions, the steel can fulfil the expected service life of residential buildings independent of environmental and climatic conditions. Therefore, this study helps to alleviate concerns regarding durability of cold formed steel in residential construction.

KEYWORDS: *cold formed steel, durability, design life, corrosion, zinc alloys*

1 INTRODUCTION

Buildings are designed for a service life as per the recommendations of BS EN 1991 (BSI, 2003). It is expected that a building will function without any deterioration during its service life. However, the service life can be compromised due to exposure conditions of the buildings and the type of materials used. In recent years, cold formed steel is gaining popularity in the construction sector as an alternative construction material to concrete and timber. Lightness of the material, high strength to weight ratio, ability to mass produce, easiness in working at the site and economy in transportation are considered to be the major advantages of the material (Yu, 1999). Cold-formed steel (CFS) members are made using graded structurally sound steel sheets that are rolled by a forming machine to form the required shapes without the use of heat (unlike hot-rolled steel). Several steel thicknesses are available to serve a wide range of structural and nonstructural uses. The thickness of the members can range from 0.01 mm to 7 mm. Typical cold formed sections that are used in structural and non-structural applications are shown in Figure 1. Cold-formed steel (CFS) buildings have dominated the market for internal, non-loadbearing

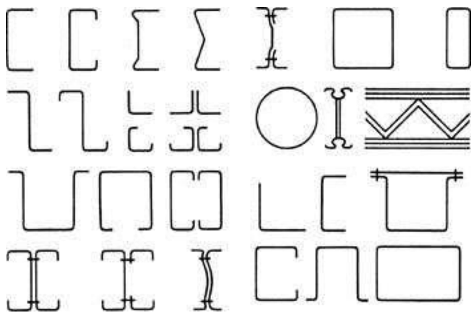

Figure 1: Typical cold formed steel sections

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partition walls in commercial construction because they are lightweight, extremely robust, noncombustible, and rather simple to install. However, the most worried factor about steel is its durability against corrosive conditions when it considered as a load carrying structural element.

Cold formed steel in residential applications is not new to Sri Lanka. Cold formed steel sections have been used in roof construction for more than 40 years. However, it has not been used as a major structural material in construction in the Sri Lankan context till recently. Steel has been used in house construction since 1920s and there has been a surge in steel housing after the world war 2 in the UK (Harrison, 1987). However, these housing units did not meet the thermal insulation requirements of 21st century and many structures used hot rolled steel. In terms of steel protection, most of these structures used paints as a corrosion protection layer. The cold formed steel used in residential construction assembled using several types of sections that can be rolled from the commercially available rolling machines. C section, lipped C section are commonly used in wall frames and floor joists (Figure 2 and Figure 3). Use of Z section in addition to C, lipped C can be found for roof construction (Lawson et al., 2010).

Figure 2: Wall frames in a cold formed steel building

Figure 3: Floor joists in the building

Cold formed steel (CFS) construction is carried out using three common methods such as stick built (fabricating wall frames and floor/roof truss at the site using CFS elements), constructing using panel (panels constructed at the factory and completed with insulating layers and external boards moved to site for assembly) and complete modular unit ready to install. The fabrication of the panels and elements carried out using one or combination of bolting, self-drilling, self-tapping screws, riveting, welding etc. Self-drilling or bolting are more preferred as they offer the material a chance to be re-used after the completion of the service life.

Although steel provides several advantages such as easy construction, higher level of re-usability or recyclability, corrosion in steel considered to be a greater threat to the structure despite many advantages. There are several steel protection methods that have been used to enhance the durability of the material. They are anodizing, galvanizing, powder coating, painting, epoxy coating and duplex coating. Estimated lifetime of different types of coating are given in Table 1. The oldest, basic and cheapest protection method is anticorrosive paints to protect the steel. Due to abrasion or from aging the paint coating can be damaged and corrosion can occur. Although paints are still used for hot rolled steel, it is uncommon to use paints in cold formed steel.

Table 1. Estimated lifetime of different coatings

Types of steel Coatings	Estimated life to first maintenance
Anodizing	~ 10-20 years
Galvanizing	~ 30 to 170 years
Powder Coating	~ 40 years
Paint coating	~ 10-20 years
Epoxy Coating	~ 40 years
Duplex coating	~ 90–150 years

The commonly used coating is galvanization for CFS. Steel profiles conforming to coating as described in BS EN 10346 (BSI, 2006) in the UK (EN 10346 in EU) and AS 1397(Standards Australia, 2021) in Australia are used in the respective countries. In both codes, the zinc coated elements should be dipped inside 99% pure zinc to achieve a coating defined from Z100 to Z 600. Z indicates the zinc coating and 100, 200, 275 to 600 indicate the weight of the coating. In the UK, Z275 is a preferred zinc coating for CFS residential buildings. Similar observations are observed in Australia as well. Sri Lanka adopting Eurocode may conform to similar coating requirements. In 1972, Bethlehem Steel Corporation developed a "Galvalume" steel coating (Coni et al., 2009). This coating consisted of 55% Aluminum, 43.5% Zinc and 1.5% silicon. It was observed that Galvalume steel demonstrate comparability better durability in coastal and marine environment and ability to resist heat better than zinc coated steel (Coni et al., 2009).

AZ 150 (Galvalume coating of 150 g/m^2) can give a similar coating thickness of Z275 (zinc coating of 275 g/m^2). Therefore, there is a greater interest to use AZ 150 steel instead of Z275 in construction industry due to enhance properties of the Galvalume coated steel.

Like painting, powder coating and epoxy coating provide protection to steel from corrosive conditions. These methods do not involve any sacrificial material similar to zinc in protecting steel. However, duplex coating involves an additional painting or powder coating applied on top of galvanized surface. Although it provides better protection than galvanized steel, it may not be an economical choice. Several research studies have been carried out to investigate the durability of different protection methods used in hot rolled and cold formed steel. This study aims to compare the data available from literature on durability of cold formed steel to recommend an appropriate coating method that could be used in the Sri Lanka condition for various climatic conditions.

2 COLD FORMED STEEL CONSTRUCTION IN SRI LANKA

CFS has been used for more than 40 years in roof and temporary construction in Sri Lanka. However, it is relatively new to the construction industry as a structural load bearing element for entire residential construction as shown in Figure 2.

2.1 Ground Floor

Several methods can be adopted to construct the ground floor. Depending on the bearing capacity of the soil, ground floor can be constructed as a slab on grade as shown in Figure 4 or a suspended concrete slab on pad footing as shown in Figure 5. As it is required to install load bearing steel frames on the slab using anchored connectors, a full concrete slab provides more flexibility to the constructing team. However, using concrete slab can increase the energy dissipation through the slabs. Alternatively, a suspended timber composite slab supported by CFS trusses can be used to achieve better insulation.

Figure 4: Slab on Grade (Kampert, 2021)

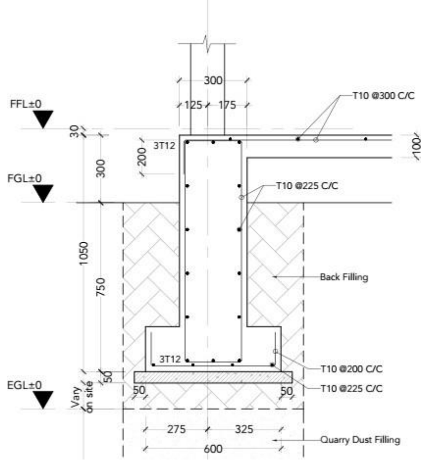

Figure 5: Suspended concrete slab on pad footing

2.2 Wall Frames

CFS residential buildings consist of both load bearing and non-load bearing wall panels. The wall panels were fabricated using lipped C sections or C sections (5) as shown in Figure 6. Inner and outer side of the walls are then covered with fiber board such as oriented strand board (OSB) where an insulative layer was placed between the CFS studs using either rock wool, glass wool or any other appropriate insulative material. In some instances, expanded polystyrene (EPS) boards are placed in the middle of the wall to provide insulation. This formulates the basic wall. In addition to the basic wall, inner surfaces are furnished with either medium or high-density boards while external surfaces are designed to withstand humidity, rain and other climatic conditions. The codes recommend the spacing between CFS studs in load bearing walls not to exceed 800 mm.

2.3 Floors

To achieve better insulation and faster construction, similar to timber structures, CFS residential buildings use CFS beams or CFS trusses/joists. Beams or trusses act as a load carrying member and support the timber deck floor as shown in Figure 7. There is an option to have a ceiling underneath the CFS beam or trusses and the insulation is placed between the ceiling and the timber deck. A similar arrangement is used for roof structures and on top of the timber deck, appropriate roofing material.

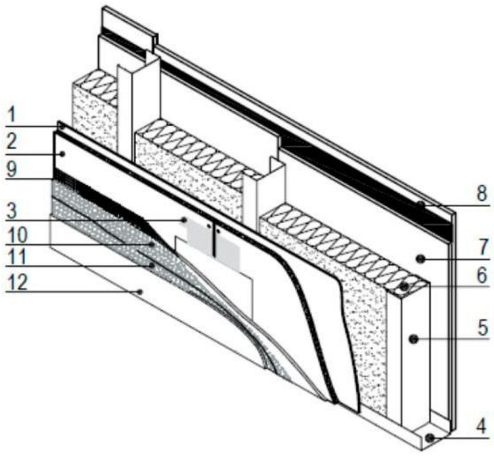

Figure 6: Typical section of a load bearing CFS wall [Reproduced from (Di Lorenzo & De Martino, 2019)]

(a) Truss as a joist (b) C purlin as a joist

Figure 7: Typical Floor in a cold formed steel residential building [Figure 7(a) reproduced from (FRAMECAD, 2022)]

Entire steel used in a CFS load bearing residential building consists steel in an enclosed volume except if any exterior decks constructed using unprotected steel. Designers often make necessary arrangements not to expose the structural steel to external environment. Use of steel in an enclosed volume is referred as "warm frame" as they are less likely to face a drastic environmental changes (Lawson et al., 2010). In order to assess the durability of cold formed steel used in residential construction, data were obtained from the research report RP06-1 published by American Iron and Steel Institute (NAHB Research Center, Inc, 2006), a study by Lawson et al. (2010) in several locations in the United Kingdom, a study by Yoo et al. in Korea (Yoo et al., 2022) and an investigation carried out by LaBoube (2006).

3 CASE STUDIES OF DURABILITY MEASUREMENTS

3.1 Case 1 - Galvanized Steel Framing for Residential Homes (NAHB Research Center, Inc, 2006)

Four test sites were selected by NAHB Research Center to study the corrosion performance of cold formed steels with different types of coatings. The location, environment of the site, type of the foundation ad exterior finish details is given in Table 2 (Site No 1 – 4).

3.2 Case 2: Environmental and Performance of light steel framing building (Baxter, 1990)

One of the earliest light steel frame buildings constructed in 1982 was investigated and reported by Baxter (1990). This Ullenwood building was monitored for five years using galvanized and mild steel test specimen kept inside the wall and loft space. The structure was exposed to oceanic climate with warm summer and cool winter. Baxter (1990) reported the loss in galvanized steel was 0.2g/m^2 peryear where mild steel was observed having a mass loss of 1.26 – 1.62 g/m^2. The data is shown in Table2 (Site No 5).

3.3 Case 3: Student Accommodation Building at Oxford Brookes University (Way et al., 2009)

A demonstration project constructed in 1996 at Oxford Brookes University was investigated for corrosion performance and reported by Way et al. (2009). The site is located in the city of Oxford about 1 km from a river. The study indicated that the depletion of the coating layer was minimal after 5 years when the loss of the coating material was observed between 5- and 10-year period. The study also indicated that the loss of coating mass was significantly higher when they were directly exposed to environmental conditions. The detail of the site is given in Table 2 (Site No. 6).

Table 2: Experimental data obtained from literature and details

Site No.	Location (Distance from water)	Environment	Foundation	Exterior Finish
01	Miami, Florida (Several kilometers)	Humid	Slab on grade	Stucco (similar to cement plaster)
02	Leonardtown, Maryland (25 m from river)	Humid temperate/semi-marine	Crawlspace/Suspended floor	Vinyl siding
03	Long Beach Island, New Jersey (less than 1 km)	Marine	Piers	Aluminum siding
04	Hamilton, Ontario (inland)	Cold winter and industrial	Basement	Brick veneer
05	Ullenwood, England, United Kingdom	Oceanic. Cold winters and warm summers	Suspended ground floor	Masonry
06	Oxford Brookes University, United Kingdom (1 km from river)	Maritime temperate	Suspended ground floor on steel deck	Brick veneer
07	Lisbon Technical University, Portugal	Hot coastal	Slab on grade	Cladding
08	Oahu Island, Hawaii	Tropical	Suspended ground floor	Timber siding

3.4 Case 4: Lisbon Technical University (Way et al., 2009)

Way et al. (2009) reported a study conducted at Lisbon Technical University in Portugal. The site was exposed to hot coastal environment and the samples monitored were kept outside covered by cladding panel on the wall providing an environment of cold air constantly. The surface protection loss was estimated after 5- and 10- year period. The observation indicated the reduction of coating reduces with time as the loss of coating after 5 year period was 1.61 g/m^2 compared to a loss of 2.22 g/m^2 after 10 years. The detail of the site is given in Table 2 (Site No. 7).

3.5 Case 5: Study on coated fasteners by University of Hawaii (Williams et al., 2006)

The University of Hawaii carried out a study on the corrosion resistant nature of zinc coated fasteners and elements. Field enclosures representing actual residential buildings constructed for different exposure conditions were kept at different locations. The climatic conditions are like tropical and exposure to coastal environment that may mimic the conditions of the coastal Sri Lanka as well. The fabricated enclosures were located within 230 m to 1000 m from the coastal line. In each location total climate data was recorded. Details of the site is given in Table 2 (The detail of the site is given in Table 2 (Site No. 7). Qualitative observations made at this site are given in Table 3 (Site No. 8).

4 RESULT AND CONCLUSION

Quantitatively assessed data from seven sites (Site 1 – 7) and qualitative data from one site (Site 8) are compared in Table 3. It can be noticed that the data covers a wide range of climatic and environmental conditions to which the samples were exposed. Among the sites discussed, Miami, Florida (Site 1) and Oahu Island, Hawaii (Site 8) can be considered closely related to coastal area of Sri Lanka while Ullenwood, England can be considered as a climatic condition that may moderately represent hill country of Sri Lanka.

Table 3: Corrosion data from different sites observed from literature

Site No.	**Location (Distance from water)**	**Sample Material**	**Sample Location**	**Exposure duration (months)**	**Mass Loss (grams)**	**Corrosion rate (µm/year)**	**Estimated Life (Years)**
1	Miami, Florida (Several kilometers)	Galvanized 1 (25 µm)	Attic	99	0.02	0.034	367
		Galvalume (41 µm)	Attic	99	0.02	0.066	310
		Galfan (41 µm)	Attic	99	0.04	0.073	280
2	Leonardtown, Maryland (25 m from river)	Galvanized 2 (25µm)	Attic	93	0.02	0.037	367
		Galvalume (41 µm)	Attic	98	0.02	0.066	310
		Galfan (41 µm)	Attic	98	0.02	0.037	554
3	Long Beach Island, New Jersey (less than 1 km)	Galvanized 1 (25µm)	Wall	87	0.02	0.039	320
		Galvalume (41 µm)	Wall	87	0.02	0.075	273
		Galfan (41 µm)	Wall	87	0.02	0.042	488
4	Hamilton, Ontario (inland)	Galvanized 2 (25µm)	Wall	98	0.02	0.035	357
		Galvalume (41 µm)	Wall	98	0.02	0.066	310
		Galfan (41 µm)	Wall	98	0.02	0.037	554
5	Ullenwood, England, United Kingdom	Galvanized (20 µm)	Wall (Cold cavity)	60	1.2	0.034	294
			Loft (Cold frame)	60	0.59	0.017	588
6	Oxford Brookes Univesrity, United Kingdom	Galvanized (20 µm)	Cold loft space	60	0.57	0.016	625
			Wall - Up	60	0.47	0.013	769
			Wall - low	60	1.25	0.035	286
			Below ground floor	60	2.13	0.060	267
			Cold loft space	124	0.63	0.009	1111
			Wall - Up	124	0.45	0.006	1667
			Wall - low	124	1.31	0.018	556
			Below ground floor	124	2.04	0.029	552
7	Lisbon Technical University, Portugal	Galvanized	Cold Wall Cavity	60	1.61	0.045	222
			Cold Wall Cavity	123	2.22	0.031	323
8	Oahu Island, Hawaii	Galvanized	Wall framing	Tightly sealed volumes demonstrated no corrosion. Vapour barrier observed providing additional protection			
			Wall framing	If there was any leak of airflow in the frame, evidence of corrosion was observed			
			Vented attic	Evidence of corrosion was observed when there was a good exposure to chloride rich wind flow			
			Crawl Space	Evidence of corrosion was observed when there was a good exposure to chloride rich wind flow			

The quantitative data given in Table 3 in general represent the most critical exposure conditions. For example, at site no.5, the critical data was observed inside the wall and loft. Considering most of the critical values, some of the experimental data were obtained from the literature are not presented inorder to make a impactful outcome considering Sri Lankan scenario.

Exposure duration and mass loss were recorded by relevant authors(Baxter, 1990; NAHB Research Center, Inc, 2006; Way et al., 2009; Williams et al., 2006). Corrosion rate was calculated using the method given in ASTM G1-03 (G01 Committee, 2017). Equation (1) given below can be used to determine the corrosion rate in galvanized steel elements.

$$Corrosion\ rate = (KW)/(ATD) \quad (1)$$

Where, K = constant = 8.76×10^7 µm/year

W = mass loss in grams

A = area in cm^2

T = time of exposure in hours

D = density in g/cm^3, a value 7.13 g/cm^3 was assumed for zinc, 6.7 g/cm^3 was assumed for Galfan, 3.75 g/cm^3 was assumed for Galvalume.

Corrosion rates shown in Table 3 were calculated using the Equation (1). Site 1 to 4 have used three different types of coating namely galvanized, Galvalume and Galfan. Galvanized coating is applied by dipping the steel inside 99% zinc to achieve the coating. There are two thicknesses that were used. Some samples have used 38µm thick coating while some have used 29µm coating. Durability is proportional to the thickness of the coating(Lawson et al., 2010). Therefore, the thicker the coating, the better the protection. As discussed earlier, Galvalume is a composition developed using 55% Aluminum, 43.5% Zinc and 1.5% silicon. If thickness of the coating is considered, Z275 coating (99% zinc 275g/m^2) and AZ150 (Galvalume 150g/m^2) provide the same thickness of 20µm. The Galfan coating is a composition using 95% Zinc, 5% Aluminium and 0.05% mischmetal (Yoo et al., 2022). It can be observed from the data recorded on similar environmental conditions that galvanized elements demonstrate better resistance to corrosion than Galvalume and Galfan. The data recorded at Hamilton, Ontario show that Galfan shows better resistance than Galvalume in cold and industrial areas. However, conventional galvanized coating indicates a comparable corrosion resistance like Galfan.

4.1 Corrosion observations in wall area

The wall area can fall into two categories. The first category is a well-protected wall like the one shown in Figure 6. The well protected wall area will have a lower level of humidity and dry environment to achieve a higher level of insulative properties. In modern buildings, a U value in the range of 0.15 – 0.25 $W/m^2/^oC$ is expected to meet the stringent energy guidelines (Lawson et al., 2010). Therefore, the walls in general will have a well-sealed environment that reduces humidity and wetness.

Galvanized wall elements record a corrosion rate of 0.028 – 0.035µm/year under different climatic conditions. The rate of corrosion further reduces when the data is obtained for a longer duration as observed from Table 3. It can be also observed that there is no significant difference between cold wall environment and warm frame environment. Lawson et al (2010) proposed an equation that can be used to determine the design life of a cold formed steel element based on the exposure conditions. It was argued that for elements that are in concealed environments to be assumed to have reached the service life once 50% of zinc coating is lost. In cases where the cold formed steel elements were visible and easy to inspect, the service life can be determined based on 80% loss of the zinc coating. The following equations (Equation 2 and Equation 3) were proposed by Lawson et al (2010) to estimate the design life of cold formed steel elements. Equation 2 can be used for concealed steel elements and equation 3 can be used for exposed and visible elements.

$$Design\ life\ of\ concealed\ elements = 0.25\ x\ \left(\frac{Total\ weight\ of\ zinc\ coating}{rate\ of\ the\ zinc\ loss\ per\ year}\right) \quad (2)$$

$$Design\ life\ of\ visible\ elements = 0.40\ x\ (\frac{Total\ weight\ of\ zinc\ coating}{rate\ of\ the\ zinc\ loss\ per\ year}) \quad (3)$$

Design life calculated using equations (2) for wall, attic and loft spaces and the same calculated for exposed members such as below ground floor area using equation (3) by the authors are listed in Table 3.

4.2 Corrosion observations in attic, loft, and exposed elements

Like walls, attic and loft areas under an enclosed environment, spaces show reduced corrosion rates. However, exposed steel such as CFS below ground floor have seen a significant increase in corrosion rate as shown in Figure 8. A lower rate for upper part of a wall (labelled 1) is noticed while during the same period a 6 times higher rate was observed for exposed steel below ground floor (labelled 3). A similar observation was noticed at different durations as shown in Figure 8.

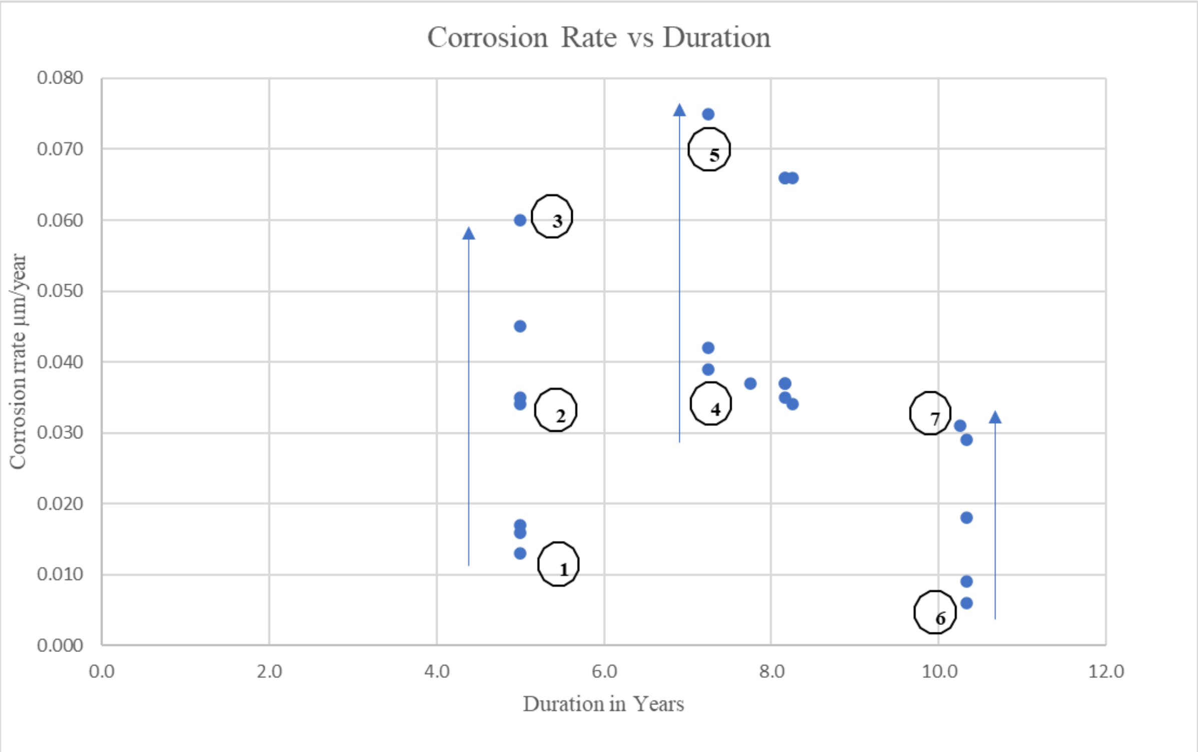

Figure 8: Corrosion rate vs Duration (1- Upper part of a wall, 2- Lower part of a wall, 3 – below ground floor, 4 – Galvanized wall, 5- Galvalume wall, 6 – Upper part of a wall, 7 – below ground floor)

4.3 Conclusion

Comparison of the data obtained from literature can help us to draw the following conclusions at large.

- If the building envelope is properly maintained, Galvanized, Galvalume and Galfan coatings can provide a minimum of 200 years of design life. Residential buildings are designed and constructed for a service life of 50 years. Therefore, like other construction materials, Cold Formed Steel can be considered as an efficient and reusable material for construction.
- Although the exposed elements such as steel below ground floor or under decking show acceptable corrosion rate, frequent observation and maintenance can increase the durability of the material through timely intervention.

- The data presented in Table 3 covers different geographical and climatic conditions. Corrosion rate found in a humid (Site 1), marine (Site 3), cold winter (Site 4) and hot coastal (Site 7) climate conditions show a similar rate of corrosion at different periods considered. This indicate that independent of the climatic or exposure conditions, the details adopted for the design ensuring the protection of the steel helps to achieve better durability.
- Similar to any other materials, appropriate design envelope that protect the material sufficiently can help to utilize the benefits of CFS in residential construction.
- The following procedures can help to enhance the durability of the galvanized steel.
    - Maintaining the exterior of the building to ensure degradation in exterior leads to deterioration of the internal material (As observed in Site 8, a leak on exterior wall can accelerate corrosion of the internal steel).
    - Prevent extended contact with moisture from occurring through water infiltration. Appropriate design methods can be adopted to prevent vapor, moisture and rainwater.
    - Ensure galvanized steel does not come into direct contact with harsh or wet materials, such as at the foundation or in exterior walls. Design procedures adopted to achieve enhanced thermal insulation in general prevent steel from such direct contacts.
    - Prevent water trapped inside the building envelop.

By adopting appropriate design methods and detailing, cold formed steel can make an attractive alternative to other construction materials within Sri Lankan context owing to the facts observed analyzing the durability data obtained from literature. A detailed investigation on durability of cold formed steel in different climatic conditions of Sri Lanka can complement the research.

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Development of Coir Fiber Reinforced Polymer Reinforcing Bars for Concrete Structures

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ABSTRACT

At present, global warming increment and petroleum reserve depletion have been a major threat to the environment. These occur due to various human activities. Construction industry contributes 40 % for the global carbon emission. From that 10% is contributed from the manufacture of cement and the rest is contributed by the other requirements in the construction industry. Therefore, scientists are now more focused to involve bio-based products to minimize the emission of carbon. This resulted in, paying more attention towards the natural composite materials that can be used instead of artificial materials. Scientists are eager to find natural materials which are locally available. The structures built today, does not survive the entire service life of the structure. This is due to corrosion of steel, especially in coastal areas. So, in order to overcome this, use of a natural material which can provide the same tensile strength can be used. Over the past few decades engineering materials like composites, plastics, ceramics has dominated the engineering industry. There are new polymer materials introduced such as glass fiber, carbon fiber and aramid but they are not eco-friendly. The main problem associated with these is the high production cost. Therefore, new composites which are environmentally friendly should be found in order to replace other materials. Even though there has been much research published on different natural fiber composite materials, here an attempt has been made to use coir to produce reinforcement bars in order to combat corrosion

Keywords: *coir, composite, corrosion, petroleum, fiber glass, aramid*

1 INTRODUCTION

Structures exposed to extreme environmental conditions such as coastal structures, bridges etc deteriorate due to corrosion of steel. Reinforced concrete could be a durable method of construction until it gets the exposure of acidic environment. Alkaline environment of concrete helps the steel to form a dense gamma ferric oxide layer which could prevent the steel from corrosion. However, chloride ions and carbon dioxide penetrate the concrete cover and destroy the passive layer of the steel and accelerate expansive corrosion(Chung, 2000; Tharmarajah et al., 2015a, 2011a). It is important to develop new technologies which are environmentally friendly rather than developing materials or products which are insecure to the environment. Therefore, more attention is paid towards the natural fibers with the increase of environmental properties. at the moment, utilization of petroleum products is at a high rate. Due to this high usage, the depletion of petroleum reserves has increased. More number of harmful by-products are released to the atmosphere which are not eco-friendly. Scientists and environmentalist suggest that replacing these products with natural fiber (NF) materials will guide the world to a better place minimizing environmental pollution. Another, matter of the petroleum products is the

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expensiveness of the products due to their high production cost. (Ali and Chouw,2013). The introduced new materials to replace steel rebar include fiber glass, carbon fiber and aramid fibers. The main problem associated with these introduced materials is the high production cost. There are many NF materials available in the surrounding such as jute, coir, hemp, sisal etc. which can be locally produced. The main objective of this study is to use coir, to produce reinforcement bars as replacements for steel reinforcement. To do this coir itself cannot be used directly. Therefore, a composite material should be prepared with the inclusion of coir. Coir composite should be made into shapes of bars in order to be included as reinforcement therefore, a process like pultrusion should be involved.
There were studies(Archila et al., 2018; Chin et al., 2020; Ganesan et al., 2020; Haryanto et al., 2021; Mali and Datta, 2020, 2018; Muhtar, 2020; Muhtar et al., 2020; Puri et al., 2017; Ramaswamy and Mathew, 2019; Terai and Minami, 2012) investigated use of cut bamboo bars as a reinforcement in concrete structures. However, all these studies evaluated the use of bamboo strips directly taken from bamboo grass without any pre-engineering. Instead of using the natural fibers directly these fibers could be made into composite materials with the use of a resin such as polyester resin, epoxy resin etc. which will increase the mechanical properties of the fiber. There are several studies (Adeniyi et al.,2019; S. Kumar, Shamprasad M.S., Varadarajan Y.S., et al,2021;Ali et al.,2012) conducted which exhibits the potential of coir fiber's tensile behaviour related to the construction industry.

2 BACKGROUND

Corrosion of steel is a major problem influencing the long-term survival of a concrete structure. Corrosion of concrete normally occurs due to two main processes they are Carbonation and chlorination.in the presence of chloride, the steel protective passive layer is destroyed and unprotected steel areas dissolve. Steel corrosion is an electrochemical process in which iron (Fe) is removed from the corroding steel and dissolved into the surrounding solution, where it then appears as ferrous ions (Fe^{+})(Zhao and Jin, 2016). The ferrous ions typically react with hydroxide ions (OH^{-}) and dissolved oxygen molecules (O_2) to form rust, a solid by product of the corrosion reaction. The formation of corrosion products involves substantial volume increase this makes the volume of corrosion product greater than that of original steel bar. Therefore, expansive stresses are induced around corroded steel bars causing possible cracking, spalling of concrete cover and loss of bond between steel/concrete. (Ashour et al,2011).

There is a possibility to control the rate of corrosion by changing the resistivity, oxygen concentration and temperature. Better quality concrete, cathodic protection, corrosion inhibitor admixtures, and anti-corrosion coating are a few of the traditional measures used to combat the corrosion of reinforced concrete(Chung, 2000). Anti-corrosion chemicals provide only temporary protection. Cathodic protection is costly and has its own disadvantages, and repair processes frequently have short service lives and require frequent reinstallation. As a corrosion resistance technique, Coatings are applied on steel reinforcement to prevent the corrosion of steel re-bar. These consists of sacrificial coatings and epoxy coatings. Sacrificial coatings are coatings that are sacrificed for corrosion instead of the main metal. These include less noble metals such as Zinc and cadmium. Epoxy coatings are developed as resin material. For example, in the study (W. Fan, et al,2020) has used polyaniline (PANI) and cerium oxide (CeO2) to produce epoxy coating for steel rebar. But these coatings are exposed to damages when handling and placing which results in producing spots aiding corrosion to take place. therefore, this method is not competitive enough to prevent steel from corrosion. In contrast to non-sacrificial coatings, even if sacrificial coatings fail during production, transport, or service, the underlying metal remains protected.

Usage of composite materials have gained a lot of interest in the construction industry. Development of Fiber-reinforced plastics (FRP) is one result of the development of the usage of composite materials in the recent years due to the corrosion resistant nature of the materials. FRP bars demonstrate corrosion resistant nature, lightweight, and have a high tensile strength. Similarly, natural fibres such as coir and jute fibre demonstrate potential to be used in construction applications as a reinforcing material or as an additive to enhance properties of cement grout or concrete. Cor is one of the cheapest and mostly available materials in nature. Coir fibers are predominantly made of natural plant materials such as cellulose, lignin and Pectin. Coir fibers are strong, light in weight, highly durable and easily withstand heat and salt water. It is used o manufacture coir robes, mats, carpets, among other things. Typical properties of coir fiber is shown in table 1.

Table 1. Typical properties of jute fibre

Parameter	Value
Diameter	12–20 μm
Tenacity	10 g/Tex
Fibre length	13-29 mm
Density	1.4 g / cm^3
Moisture Regain	10 %
Modulus of elasticity	2-8 GPa
Breaking Elongation	30%
Tensile strength	95-118 Mpa (Romli, Alias, Rafie, & Majid, 2012)

There were several types of bonding agents such as polyester, epoxy, silicone resin, polyamide resin and alkyd resin that can be used for the production of bars. For the composite material, coir fiber was used as the reinforcing material and the polyester resin was used as the Binder. Polyester demonstrate adequate resistance to water and several chemicals, resilience to weathering and ageing, moderate temperature resistance (up to 80°C), good wetting to glass fibres, minimal shrinkage (4–8%) during curing, and linear thermal expansion (100– $200 \cdot 10^{-6}$ K^{-1}). Similarly epoxy demonstrate a good heat resistance, adhesion to a variety of substrates, low shrinkage during curing, corrosion resistance, high tensile, compression, and bend strengths. Considering properties of resins and economic feasibility, it was decided to use polyester resin for the research purpose.

3 METHODOLGY

It was decided to produce 12mm Coir Fiber Reinforced (CFR) bars of 1000mm in length according to ASTM standards. After a thorough investigation the polyester resin was taken as the binding material for the composite material. In this study, we decided to combine fibres and resin in the proportion shown in Table 2 to evaluate the strength of bars made of Coir fibres. For each proportion, 3 number of bars were produced and tested at lab for tensile strength and modulus of elasticity.

Table 2. Composition of the bars

Name of the specimen	fibre: Resin (V/V)	No. of bars	Resin Volume(ml)
S-20	80:20	3	23.04 ml
S-30	70:30	3	34.56 ml
S-40	60:40	3	46.00 ml

For the production of the CFR bars, a rope manufacturing machine (Figure 1) was used. It was ideal to use a pultrusion method to produce the bars to achieve better strength and workmanship. However, the facility to produce bars using pultrusion method was not adopted. The fibers were separated to required size and was rolled into the machine to make the ropes for the required size.

Figure 1- Coir Rope making Machine

The twin spindle coir rope making machine (Figure 2) was used to make 10mm diameter coir ropes. Next these produced ropes were bath in a resin basin. This phenomenon is expected in the pultrusion process in this process the fiber ropes are sent through a resin bath and hardened.

Figure 2- Twin spindle coir rope machine

The coir rope was dipped inside the resin bath to bond the fibers together to form the shape of a bar. Coir and resin volume was calculated to obtain the compositions as presented in the table 2. The exact amount of resin was applied on the rope by tying the rope between two poles as figure 3. A hardener was used at 1:100 ratio to harden the bar after resin bath. During resin bath, the rope was rotated by 180 degrees to distribute the resin evenly across the rope to achieve well rounded bar. Finally, the resin coated jute fibre rope was sand coated before drying the resin. Sand coating is used in fibre reinforced polymer bars to enhance the bond strength between the bar and concrete (Figure 4).

Figure 3- Application of Resin

Figure 4- sand coated hardened Coir Bar

4 EXPERIMENTAL INVESTIGATION

4.1 Test Procedure

ASTM D7205 on Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars (ASTM D7205/D7205M-21, 2021) was used to carry out the tests on fabricated Coir fiber bars. The code recommends minimum anchorage length La of 300 mm was used to anchor the bars inside the wedges of the tensile testing machine. Free length (L) between anchors was maintained at 400 mm. The test method is developed to obtain longitudinal tensile strength and elongation data. By conducting a tension test, variety of data is obtained. The tensile properties of the bars depend on the following factors: constituent materials, void content, volume percent reinforcement, methods of fabrication and the architecture of fiber reinforcement. similar to that the results obtain from the tensile test depends on the specimen preparation, specimen conditioning, environment of testing, specimen condition, environment of testing, specimen alignment and Gripping. The apparatus must comply with the relevant standards according to the ASTM d702 standard. In respective of the sampling and test specimens, according to ASTM d702 standards at least 3 specimen samples should be tested. Otherwise, the procedures outlined in E122 should be consulted. The geometry of the specimens should also comply with the ASTM d702. According to the ASTM d702 the strain rate to be used 0.01 min^{-1} test environment temperature is normal Laboratory temperature of 27 ^{0}C.

Following the guidelines provided by ASTM D7205, the tests were carried out using a universal testing machine (Figure 5).

Figure 5- Testing the coir fiber using the Universal Testing machine

5 RESULTS AND DISCUSSION

This study mainly focused on developing an alternative bar using coir to replace the traditional steel reinforcement to reduce the corrosion risk. If it is possible to replace steel with natural fibre bars, it can enhance sustainability of reinforced concrete structures while preventing corrosion related problems. Figure 5 shows the stress vs strain behaviour of coir fibre bars with different composition.

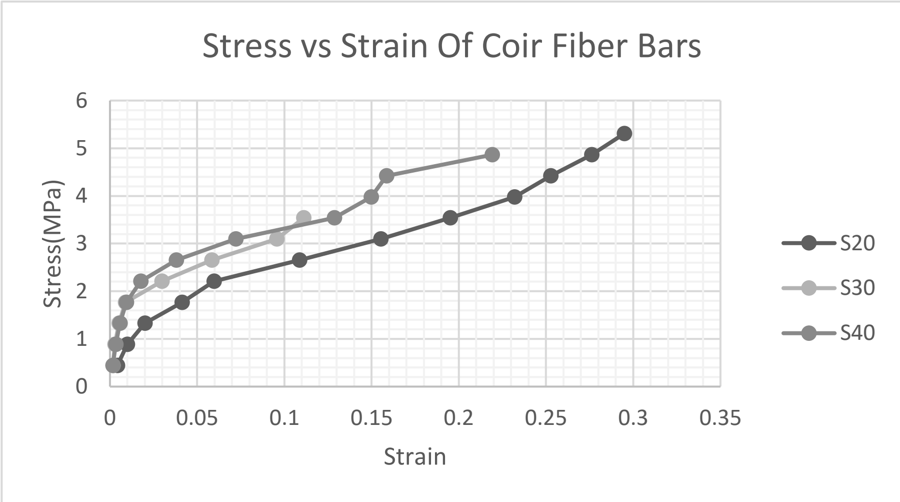

Figure 6: Stress vs strain behaviour of Coir fibre bars

It can be observed that the bar with highest fibre content demonstrates higher tensile stress. Literature on FRP reinforced materials show that with the increase in fibre content, tensile strength of the bars increases. However, this requires a considerably a higher number of specimens tested for each composition. Therefore, three specimens were tested for each composition and the average stress, strain and modulus of elasticity is reported in Table 3.

Table 3. Average Stress strain values

Sample		Max stress (MPa)	Max strain	Average Stress (MPa)	Average Strain
S20	01	5.31	0.225	4.72	0.277
	02	4.42	0.285		
	03	4.42	0.290		
S30	01	4.86	0.226	3.98	0.155
	02	3.54	0.130		
	03	3.53	0.109		
S40	01	3.54	0.148	4.13	0.186
	02	3.98	0.191		
	03	4.86	0.219		

Unlike steel, natural fibres can show a greater variation (Figure 6) when it comes to mechanical and physical characteristics. A similar observation was made in the experimental investigation. Continuously testing bars made of fibres from different sources and increasing the number of bars tested can help to obtain an acceptable tensile strength. Modulus of elasticity obtained from stress strain behaviour indicate a modulus of elasticity of 17.04 N/mm^2 for 80% fibre and 25.68 N/mm^2 for 70% fibre and 22.20 N/mm^2 for 60% fibre. The modulus of elasticity obtained indicate that the bars made of Coir fibre possess a much lower modulus of elasticity than steel (1/7000). This indicates that the modulus of elasticity values are really very low values.

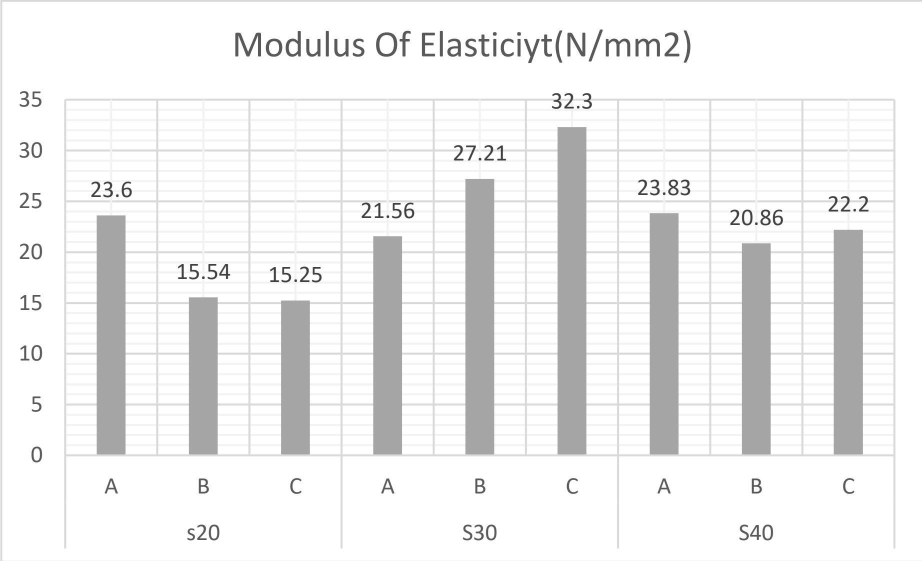

Figure 7: Variation of modulus of elasticity

In the manufacturing process of the coir bars the fibers were randomly placed along the length of the bar, this showed a tensile strength of 3.98 -4.78 Mpa for uniaxial tensile test. Romli et.al, (2012) tested the tensile strength of a coir-based composite made of coir and epoxy resin of 15% of the fiber weight. In this Research a factorial study was conducted varying the curing time, coir fiber volume and compression loading. The specimen was tested according to the ASTM D638 Type I standard. The test element was fabricated by placing fibres pre-impregnated with the matrix on top of each other. Untreated Coir fibre plates demonstrated a strength of 55 MPa. Therefore, it is possible to achieve a greater strength with coir fibres. However, the challenge remains having the fibre arrangement and fibre overlapping in an appropriate level to achieve a much more desirable strength. this could be achieved at to some extent by following a manufacturing method such as Pultrusion.

A research study (Zaman & Beg, 2013) that evaluated mechanical and physical characteristics of Coir fiber–reinforced polypropylene-based unidirectional composites that were prepared by compression molding. Based on fiber loading, 30 wt% fiber-reinforced composites had the optimum set of mechanical properties. Treatment of the coir fiber with tetra methoxy orthosilicate after the alkali pre-treatment enhanced the mechanical properties and water desorption of the resultant composites, resulting from the improved adhesion between the coir fiber and polypropylene matrix. According to this study the coir fibers were subjected to a pre-treatment process before the manufacturing of the composites.in the manufacturing of the composite 6g of polypropylene granules had been used and the fibers had been placed unidirectionally. Tensile strength and tensile modulus of the coir fiber composite was measured according to ASTM D 638-03 procedure using a Shimadzu Universal Testing Machine. The untreated coir fiber resulted in giving a tensile stress about 35 MPa while the treated coir composite gave a tensile stress about 40 Mpa. Deterioration in tensile strength at higher fiber content is a direct consequence of poor fiber/matrix adhesion, which leads to micro-crack formation at the interface under loading and non-uniform stress transfer due to the fiber agglomeration in the matrix. Therefore, it can be observed that a significant difference between tensile strength and flexural test can be obtained in FRP elements.

Considering 55 MPa observed for 15% polyester resin reinforced coir fibers, the coir fibre reinforced bars tested by authors show a strength of 4.72 MPa. The huge difference can be attributed to the method adopted when manufacturing the coir fiber bar. Therefore, the below mentioned modifications could help to achieve higher tensile stress values for the coir fiber bars

(i) Adopting a better manufacturing process such as Pultrusion
(ii) Development of a technique to lay fiber arrangements with higher level of resin impregnation between fibers
(iii) Enhance the lapping arrangement of the Fibers

(iv) Use different types of resin matrixes to identify the resin that provides better tensile stress.

With further experimental investigation there is huge potential to improve the coir fiber bars to replace steel rebar. Additionally, novel manufacturing processes and surface modification methods can increase the mechanical properties of the bar making it a next level construction material in the future. These CFR bars have the potential to be the next generation materials for structural applications in the construction industry, hence allowing the structures to sustain up to their designed life expectancy without requiring for renovation within the building service life

6 CONCLUSION

The main objective of the study was to produce a reinforcement with the use of coir to replace the steel reinforcement in concrete structures which are subjected to corrosion. For this purpose, it was decided to prepare coir fiber reinforced bars with use of coir and a resin matrix. Coir fibers were combined with polyester resins to make a composite bar with fiber volume percentage of 80%,70% and 60%. Uniaxial tensile test was performed on coir fiber reinforced bars according to the ASTM standard helped to achieve the following conclusions

- Coir fiber reinforced polymer bars were tested using the universal testing machine for showed an average tensile stress of 4.72 Mpa for 80% by volume, 3.98 MPa for 70% by volume, 4.13 Mpa for 60% by volume. As reported for other FRP bars, strength should increase with the increase of fibre content. Therefore, the fluctuation in strength between 70% fibre and 60% fibre indicate that there is a possible increase in strength with the addition of fiber volume, further studies with a larger number of samples should be carried out to achieve consistent results.
- The tests carried out in this study and the literature demonstrated, indicate the possibility of using coir fiber reinforced polymer bars instead of steel reinforcement in concrete structures. Implementation of natural materials in the construction industry modifies and develops the sustainability of the construction industry. Moreover, limits the emission of Co2 gases that leads to global warming potential.
- It is also observed that through this study that the coir fiber bars need a huge improvement in the manufacturing process of the bars. Furthermore, these coir fiber bars require an investigation to improve the strength of the bar through proper arrangement of the fibers and enhanced resin impregnation between the fibers.

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GEOTECHNICAL ENGINEERING

Strength Gain of Organic Soil Deposits Subjected to Increase in the Effective Stress

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ABSTRACT

Organic soil has weak shear strength properties in its natural texture. However, a significant gain in strength can be achieved in such soils by increasing the effective stresses using preloading techniques. This research focuses on the organic soil deposits in Sri Lanka by analyzing the data from Colombo-Katunayake Expressway (CKE) project and Elevated Highway (EH) project spanning from New Kelani Bridge to Athurugiriya. As a developing country, Sri Lanka is facing a huge challenge due to its limited land available towards the infrastructure development. Therefore, construction should also be directed on organic soils despite of considering its weak shear strength properties as the soil can be modified to enhance its properties. To predict the strength gain of organic soils subjected to effective stresses, empirical correlations are used such as Skempton and Bjerrum equation (1957). As depicted in such correlations, the ratio of undrained shear strength and effective overburden pressure is observed against the Plasticity Index (PI) using field data. From the results of the analysis, it is discovered that using empirical correlations is very conservative for organic soils within the Sri Lankan context. Particularly, use of empirical correlations is very safe but beyond the economic considerations. In the extension of the research, an argument is generated to validate the use of PI to predict normalized shear ratio. To validate the argument, SPSS statistical software was used to perform the multiple regression analysis having PI, natural void ratio and organic content as the independent variables. From the statistical analysis, it was found that using only PI to predict the strength gain is not conservative for Sri Lankan organic soils subjected to effective stresses. These generated results are identical to conclusions drawn governing the inorganic soils in the state of Missouri (2011).

KEYWORDS: *Shear Strength, Plasticity Index, Organic Soil, Sri Lanka, Colombo Katunayake Expressway, Elevated Highway, Effective Stress*

1 INTRODUCTION

In many developing countries like Sri Lanka, infrastructure development plays a crucial role due to the growth of population. Nevertheless, the limited land availability in those countries demands the construction to be implemented despite of considering about the soil condition. Therefore, soils having identity to organic soil deposits such as peat should be treated and improved to be utilized in infrastructure development.

In comparison to the mineral soils, organic soils have widely varying properties such as high void ratios, high moisture content, high compressibility, and low permeability (Baker et al., 1988). Dealing

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with such soils is a great risk in the field of construction since there is a possibility of geotechnical failure due to their weak shear properties. The weak natural texture of organic soil deposits can be significantly improved using chemical stabilizers but, it cannot be accepted for a developing country like Sri Lanka due to higher cost of implementation. Therefore, remedying methods such as application of effective stresses on soils by preloading techniques can be defined as a sustainable option in terms of economical and serviceability aspects. When the effective stress on the organic soil deposits is increased, pore water from the voids will be dissipated vertically leading to gain in shear strength of the soil. However, due to low permeable properties of the organic soils, the densification by pore water dissipation will be a time-taking process and in such a case, introducing Prefabricated Vertical Drains (PVD) is helpful to increase the rate of pore water dissipation.

Due to the weak soil texture of organic soil deposits at its fundamental stage, a special attention should be enforced when predicting their strength for the industrial applications. According to the current practice in the Sri Lankan industry, the empirical equations such as Skempton and Bjerrum (1957) are widely used to predict the strength gain of organic soil deposits subjected to effective stresses. They are mainly focused on evaluating the undrained shear strength of the soil using the Plasticity Index (PI). Use of such empirical correlations directly in the presence of Sri Lankan organic soil is a fact to open the third eye since they were originated in bottom-up environmental and soil conditions. In addition to the Skempton and Bjerrum equation, Table 1.1 shows some of the existing relationship which were introduced by assessing the relationship of strength gain in organic soil deposits.

Table 1.1 Some Published Empirical Correlations for Strength Gain Predictions

Equation	Reference	Remark
$\frac{S_u}{\sigma_v'} = 0.11 + 0.0037PI$	(Skempton and Bjerrum, 1957)	NC Clay
$\frac{S_u}{\sigma_v'} = 0.11 + 0.0037PI$	(Chandler, 1988)	OC Clay
$\frac{S_u}{\sigma_v'} = 0.129 + 0.00435PI$	(Worth and Houlsby, 1985)	NC clay
$\frac{S_u}{\sigma_v'} = 0.11 + 0.0037logPI$	Kempfert and Gebreselassie, 2006)	NC soil, PI < 60%
$\frac{S_u}{\sigma_v'} = 0.23 \pm 0.004$	(Larsson, 1980)	Soft Sediment Clays, PI < 60%
$\frac{c_u}{\sigma_v'} = 0.45(\frac{I_p}{100})^{0.5}$	(Bjerrum and Simons, 1960)	NC Clays

Where,
Su = Undrained Shear Strength
σ_v' = Effective Overburden Stress
PI = Plasticity Index

Under the normally consolidated state, the initial stability of the soil is critical due to low undrained shear strength of the organic soil deposits. Edil et al. (2000) presented his journal to estimate the strength parameters of organic soils compared to the inorganic soils and to quantify the undrained behavior of such soils under normally consolidated and over consolidated states. For the estimation, he used triaxial test, consolidated undrained (CU) test, and a special consolidation cell to estimate the coefficient of lateral pressure at rest (k_0). From the results, Edil et al. (2000) stipulates that, compared to inorganic soils, organic soils have a lower k_0 value hence, the stability of the soil at the natural state is comparatively low. Further, he revealed that even though the organic soils are supposed to behave like a “drained” soil due to higher porosity and hydraulic conductivity, it will be rapidly converted to “undrained” when it is subjected to an increase in the effective stresses. Therefore, he further extended his research to analyze the behavior of such soils under effective stresses by estimating the normalized undrained strength for normally consolidated soils carrying the organic content as the independent variable. The results indicate that, unlike in CU test, the normalized undrained shear strength of a soil does not vary with the organic content, type of soil and level of consolidation. Edil et al. (2000) concludes his research showing that, compared to inorganic soils, a significant strength gain can be achieved on organic soil deposits by pre-loading the ground. Colleselli et al. (2000) contributed to establish the same conclusion made by Edit et al. (2000) by evaluating the compression characteristics of soils. For the analysis, he extracted soil with peaty characteristics from three locations of Northern Adriatic Coast, Italy representing normally and over consolidated states. The samples were subjected oedometer test by varying the load increment ratio and the results stipulates that, the soil samples in the over consolidated state have a significantly lower secondary consolidation settlement than the normally consolidated sample. Hence, it can be identified that, pre-loading can significantly enhance the soil strengthening properties.

However, Edil et al. (2000) and Colleselli et al. (2000) both failed to identify the field behavior of soft soils whereas Hussein (2000) addressed. He has tested the soft soil behavior of embankments in Kuala Perlis, Malaysia under two construction rates : South embankment at a slow construction rate and the North embankment at a rapid construction rate which are identical to each other in dimension. The settlement of each embankment was monitored using settlement gauges. From the results, Hussein (2000) concluded that the field behavior of both the embankments were identical, and differences were noted due to construction techniques and rate of construction. He did the test without using any ground improvement techniques. Hence, according to the strength parameters he obtained, it can be identified that higher strength of such soils is achievable from ground improving techniques such as pre-loading and step-loading.

Pre-loading leads the organic soils to consolidate and achieve significant gain in strength from its weak soil texture. Preloading can be applied as a fill, as a vacuum preload or as a combined fill and vacuum load. To predict the improvement of soft soils, coefficient of consolidation can be tracked either by monitoring the pore water pressure dissipation or by monitoring the settlement. The general equation used to estimate the coefficient of consolidation suggested by Terzaghi and Barron cannot regain accurate predictions as they assume coefficient of consolidation in the horizontal and vertical direction as constant which are not constants to a soft soil under practical considerations (1948). The tests were conducted to check the effectiveness of fill surcharge, vacuum load, and combined method. To predict the improvement, monitoring the degree of consolidation was used in the tests which demanded to find the ultimate settlements. However, the usual practice of predicting the ultimate settlements using the oedometer test was found to be not very reliable hence, the prediction was done by field settlement monitoring data. As a result, Chu et al. (2012) found that even though the surcharge application from a fill can achieve a significant shear strength gain in soft soils, it is a time-consuming process compared to vacuum loading. But, under vacuum loading, a maximum of 80kPa can be applied hence, if the desired surcharge is more than 80kPa vacuum preloading is not a viable option. Combined fill and vacuum load method addresses these problems, and it can improve the shear properties of soft soil in a comparatively lesser time span. In conclusion, it was identified that among the proposed methods to apply a preload on soft soils, combined method is the most viable option. Also, Perforated Vertical Drain (PVD) installation was found to be accelerating the pore water dissipation further.

This extensive study is mainly focused on identifying strength gain predictions by assessing the relationship between Normalized Shear Ratio (NSR) vs Plasticity Index (PI). According to the published correlations, they exhibit a linear relationship as depicted in Table 1.1. To examine the validity of published empirical correlations for inorganic soils in the state of Missouri, Kang et al. (2011) assessed the inorganic soil data from several sites within the state to observe their field behavior. He collected soil samples from Warrensburg, New Florence, Set. Charles and Hyati (Pemiscot) representing three out of four geological zones in the Missouri, United State. With the contribution of sample data from 10 boreholes, statistical analysis was performed, and the results show that, St. Charles and New Florence site behave non-linearly even though Warrensburg and Pemiscot behave linearly as depicted from Figure 1.1-1.4. Data dispersion in the scatterplots generated by Warrensburg and Pemiscot were distributed widely on the plot hence, it produced a low coefficient of correlation and St. Charles and New Florence resulted in polynomial correlations with mid-range coefficient of correlation. The generated results were compared with the back calculated values from the published empirical correlations and the values from the empirical correlations were lesser than those that were obtained from the field analysis. Therefore, he established that the use of empirical correlations is conservative.

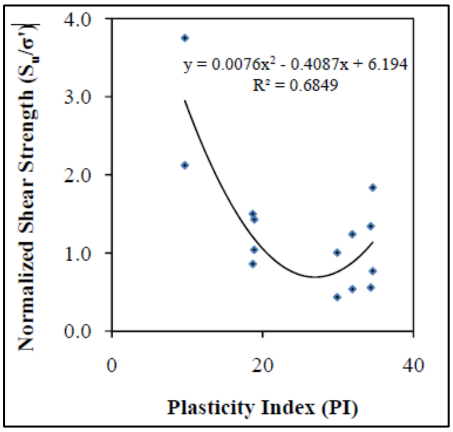

Figure 1.1 NSR vs PI of Warrensburg site

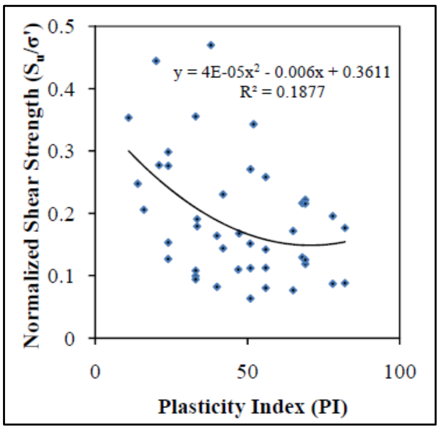

Figure 1.2 NSR vs PI of St. Charles site

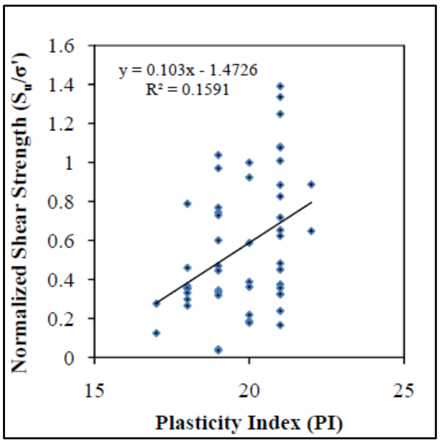

Figure 1.3 NSR vs PI of New Florence site

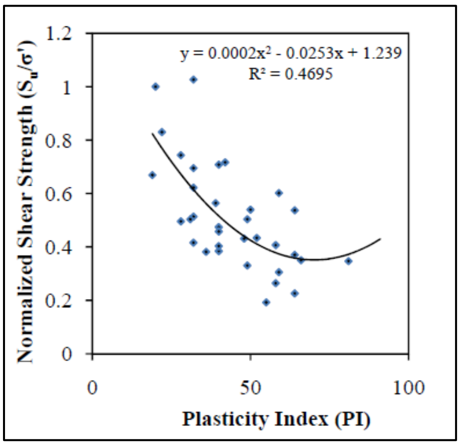

Figure 1.4 NSR vs PI of Pemiscot site

Further, he assessed the spatial correlation of data sets by considering the soil types from all the sites to increase the sample size. According to the results generated by Kang et al. (2011) in his journal, MH and CL soil types were shown a second order polynomial relationship and for CH, it was linear (refer table 2.1). Based on the above results and observations, it has been concluded that there is no uniform correlation to explain the behavior between S_u and PI. Further, it is also concluded that, using PI only to predict S_u is not reliable.

As explained by Kang et al. (2011) for inorganic soils in the state of Missouri, it should be accepted that the published co-relations were derived under different environmental and soil conditions hence, their applicability within the local context should be validated. Having that in the research problem, this research is conducted to address the question of using empirical correlations within the Sri Lankan context and to identify their drawbacks for the Sri Lankan organic soils.

In this research, the strength gain of organic soil deposits subjected to increase in the effective stresses is tackled by observing the behavior of Normalized Shear Ratio (NSR) and Plasticity Index (PI). To contribute a strong argument as research output, data is analyzed from two sites in the Sri Lankan context which are Colombo-Katunayake Expressway (CKE) project and Elevated Highway (EH) project. CKE project was constructed on marshy and waterlogged land plot linking the Katunayake international airport with Colombo through a 25.8km run. Construction of embankments over soft soils such as organic soils, peat, and clay is one of the major challenges encountered in the CKE project (Hsi et al., 2015). Same as the CKE project, EH project which spans from new Kelani bridge to Athurugiriya is also constructing over organic soil layers hence, this research governs both the sites to make a strong conclusion about the strength gain prediction of Sri Lankan organic soil deposits subjected to effective stresses.

2 METHODOLOGY

Initially, the pre-construction and post-construction data were extracted from the borehole logs of Colombo-Katunayake Expressway (CKE) project. Based on the availability of data, raw data of 10 borehole locations were contributed for the analysis. Among the extracted data, Plasticity Index (PI), Organic Content (OC), Plastic Limit (PL), Liquid Limit (LL), natural void ratio, unit weights of the soil layers (dry unit weight, bulk unit weight) and shear strength properties of organic soil layers (friction angle, cohesion) were prominent to proceed with the analysis. Sample depths of organic soil layers which had PI greater than 100 were omitted from the analysis by considering them as theoretical outliers (Kaliakin, 2017).

The following equations were used when calculating the saturated unit weight (γ_{sat}) of the soil layers and topsoil properties. For the calculations of the topsoil properties, energy method proposed by Bowles (1997) were used as shown below.

$$\gamma_{sat} = \gamma_{dry} + \left(\frac{1+e_o}{e_o}\right)\gamma_w \tag{1}$$

$$C_N = \sqrt{\frac{95.76}{p_o'}} \tag{2}$$

$$\eta_1 = \left(\frac{E_r}{70}\right) \tag{3}$$

$$N_{70}' = N_{field} C_N \eta_1 \eta_2 \, \eta_3 \eta_4 \tag{4}$$

Where,

C_N = Overburden Correction Factor
p_o' = Effective Overburden Pressure at the Test Depth
E_r = Energy Ratio of the Standard Penetration Test (SPT) Set Up
N_{field} = Field SPT-N Value
N_{70}' = Corrected SPT-N Value
$\eta_1, \eta_2, \eta_3, \eta_4$ = Correction Factors

The Bowles (1997) method was used to calculate the wet unit weight (γ_{wet}) of the coarse sand layers at the top of the soil profile and a conservative value of 3.5kN/m^3 was added to obtain the saturated unit weight (γ_{wet}) (British Standards Institution, BS 8002:1994 – Code of Practice for Earth Retaining Structures).

To initiate the analytical procedure, the dependent and independents were identified as follows.
Dependent Variable – Normalized Shear Ratio (NSR)
Independent Variables – Plasticity Index (PI), Organic Content (OC), natural void ratio (e_o), Liquid Limit (LL), Plastic Limit (PL)

Among the above variables, the behavior represented by NSR, and PI was taken as the emerging pair as the same relationship was checked in most of the empirical correlations for the strength identifying applications. The empirical correlations shown in Table 2.1 was chosen from the depicted relationships in Table 1.1 to compare the scatter generated by the field data from due to its wide use in the Sri Lankan context and their relevancy to the Skempton and Bjerrum equation (1957).

Table 2.1 Summary of the Correlations

Empirical Correlation	**Equation**
Skempton and Bjerrum (1957)	$\frac{S_u}{\sigma_v'} = 0.11 + 0.0037PI$
Bjerrum and Simons (2006)	$\frac{S_u}{\sigma_v'} = 0.45(\frac{PI}{100})^{0.5}$
Worth and Houlsby (1985)	$\frac{S_u}{\sigma_v'} = 0.129 + 0.00435PI$

Followed by the analysis of the field behavior with the existing empirical correlations, statistical analysis was conducted using SPSS statistical software. It was used to establish the arguments generated from the analysis of field data. In the outset of the statistical analysis, the reliability and validity of the data set was checked by evaluating the Cronbach's alpha referring the results to the following scale.

After checking the normality of the data dispersion using histograms of variables, correlation analysis was conducted to evaluate the relationship between each independent variable with the dependent variable. The strength of the relationship was measured using the Pearson correlation coefficient (R) and the following scale was used in parallel.

To ensure the relationship between the selected independent variables for the statistical analysis is minimum, multi-collinearity tests were conducted. The test was done following two main criteria in particularly by assessing the Pearson coefficient, tolerance, and Variance Inflation Factor (VIF). For higher degree of multi-collinearity effect, R should be higher than 0.79, tolerance not lesser than 0 and not higher than 0.2 and the VIF higher than 5.

After confirming the independency of the independent variable using multi-collinearity tests, multiple regression analysis was performed. In the multiple regression analysis, the statistical outliers were checked by assessing the standard residual of the data set. Thereafter, the linearity of the plot and the scatter was observed to identify the behavior of the variables and their data dispersion in a scatterplot. The model summary for the data tool was generated to evaluate the Durbin-Watson value and the R square value to identify the interest of the independent variables to the dependent. Finally, the coefficient summary was generated to observe the significance of the independent variables. According to (Pallant, 2020), significance beyond the limit of 0.05 was expected to be strict with the argument.

Finally, to represent the reliability of the generated results in a different site condition, the pre-construction data of Elevated Highway (EH) Project was contributed to the research. The chart shown in Figure 2.1 shows a graphical representation for the methodology executed in the research.

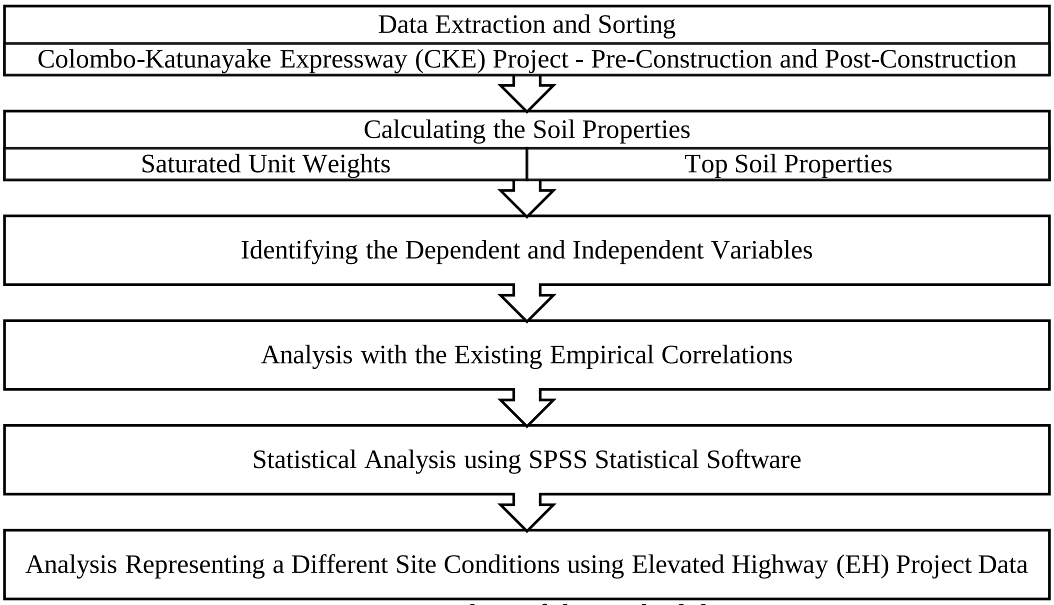

Figure 2.1 Chart of the methodology

3 RESULTS

Initially, the pre-construction data of Colombo Katunayake Express (CKE) project used to identify the behavior of the data set by observing the scatterplot of Normalized Shear Ratio (NSR) vs Organic Content (OC). As shown in Figure 3.1, two distinct phases of the data set were identified as 0-32% and 39-55% in terms of the OC. The research was mainly conducted on the OC range 0-32% since a typical OC in the Sri Lankan Context lies below 50% (Karunawardena et al., 2011).

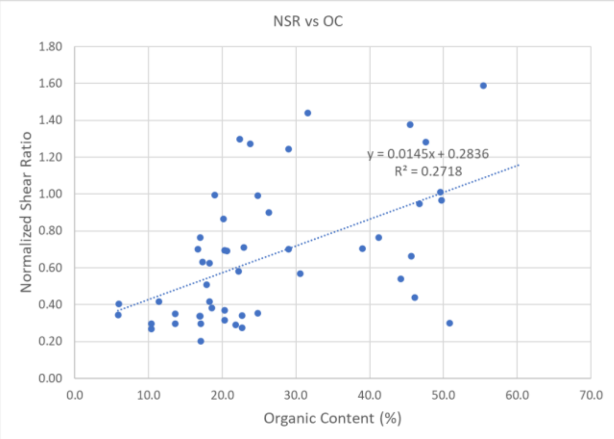

Figure 3.1 NSR vs OC graph

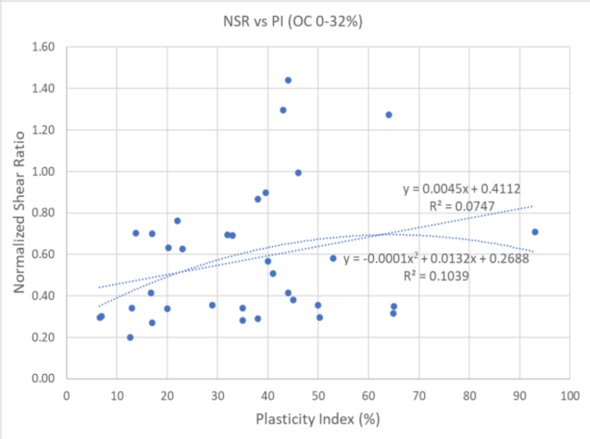

Figure 3.2 NSR vs PI graph in 0-32% OC range

When observing the behavior of NSR vs Plasticity Index (PI), the non-linear behavior was also observed since Kang et al. (2011) discovered non-linear behavior of inorganic soils in the state of Missouri. To identify the field predictions along with the widely used empirical correlations, back calculated values of the empirical correlations were compared, and according to Figure 3.3, it was identified that the prediction of the field are considerably higher than the prediction generated by the empirical correlations. The post-construction data of CKE project also generates the same results. To validate the results further, Elevated Highway (EH) project data were also used to check their NSR vs PI behavior with the empirical correlations. The results further established the results generated from the CKE project.

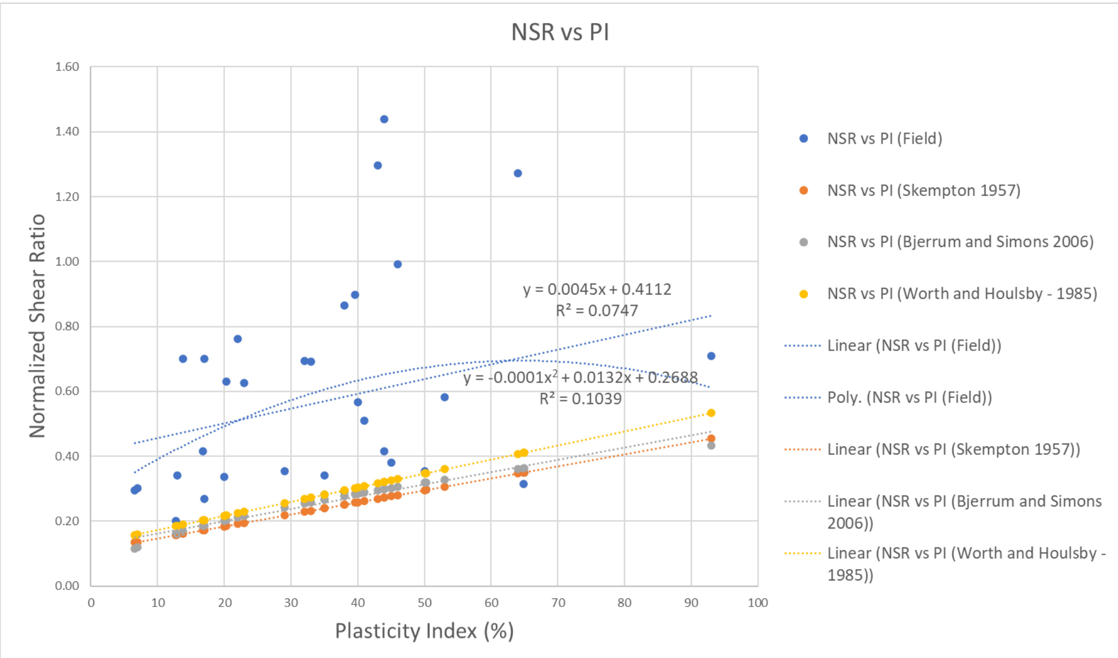

Figure 3.3 NSR vs PI field with empirical correlations – CKE Pre-Construction

The research was further extended to identify the applicability of using only PI to predict the strength gain predictions in compliance to the current practice in the industry. To serve the purpose, SPSS statistical software was used by feeding pre-construction data of CKE project. Initially, the reliability and validity of the data sets were checked by evaluating the Cronbach's alpha (α). According to the generated results, α was 0.778 with a significance of 0.778. Further, the normality of the histograms was checked, and the results exhibit that the data dispersion is normal.

After identifying the reliability and normality of the inserted data, correlation analysis was performed using NSR as the dependent and PI, OC, e_o, LL, PL as the independence variables.

Table 3.1 Summary of the Correlations

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.148	.126		1.175	.247
	Plasticity Index (%)	.002	.003	.118	.681	.500
	Organic Content (%)	.007	.007	.205	.979	.334
	Natural Void Ratio	.070	.050	.341	1.413	.166
a. Dependent Variable: Normalized Shear Ratio						

As depicted in Table 3.1, it was identified that the correlation between NSR and all the independent variables have moderately strong Pearson correlations. Furthermore, the inter-correlation matrix was evaluated in the multi-collinearity test to identify the relationship between the independent variables. As shown in Table 3.2, the Pearson Correlation Coefficient in the inter-correlation matric is lesser than 0.9 hence, the risk multi-collinearity is low. Further, the tolerance and the Variance Inflation Factors (VIF) were evaluated, and the results depicted for the favor of lower degree of multi-collinearity.

Table 3.2 Summary of the Inter-Correlation Matrix

Independent Variable 1	**Independent Variable 2**	**Pearson Correlation**
Plasticity Index (%)	Organic Content (%)	0.513
Organic Content (%)	Natural Void Ratio	0.591
Natural Void Ratio	Plasticity Index (%)	0.837

In the outset of the multiple regression analysis, the data set was checked for any statistical outliers and the results exposed that there were not any statistical outliers since the minimum and maximum standard residual lied between -3.29 and +3.29. After confirming the plot does not have any statistical outliers, model summary was generated to evaluate the R square value. From the results generated, it was identified that only 36.3% of the variants in the NSR predicted from the independent variables. Also, the significance ($P > 0.05$) of the coefficient summary shown in Table 3.3 exhibits that the variables are not making unique contribution to the prediction of dependent variable.

Therefore, it is proved that from the statistics, using PI only to predict the strength gain of organic soil deposits within the Sri Lankan context is not conservative.

Table 3.3 Summary of Coefficients

Correlations							
		Normalized Shear Ratio	Plasticity Index (%)	Organic Content (%)	Liquid Limit (%)	Plastic Limit (%)	Natural Void Ratio
Normalized Shear Ratio	Pearson Correlation	1	.457**	.538**	.505**	.483**	.583**
	Sig. (2-tailed)		.002	.000	.001	.001	.000
	N	43	43	43	43	43	43
**. Correlation is significant at the 0.01 level (2-tailed).							

4 DISCUSSION

To demonstrate the behavior of strength gain predictions, Normalized Shear Ratio (NSR) vs Plasticity Index (PI) scatterplot was drawn from the field data of pre-construction stage of CKE project. NSR was used as the dependent variable of the research to predict the strength gain of organic soil deposits subjected to increase in effective stresses. The rational to use NSR as the dependent variable was, as it represents the ratio between undrained shear strength (S_u) and effective overburden pressure ($\sigma_v^/$), it is not vulnerable to the effect of $\sigma_v^/$ fluctuations. The comparison between the field behavior of NSR vs PI with the back calculated values of empirical correlations articulates the fact that the NSR predictions are much lower than the regression line generated from the field observations (Figure 3.3). Therefore, a soft conclusion can be made as “using empirical correlation is very safe but not economical for Sri Lankan organic soils”.

To establish the soft conclusion further, post-construction data of CKE project was contributed to the research, and it also generated the same results obtained using the pre-construction data as, using empirical correlations for organic soil deposits is conservative. However, a proper conclusion cannot be drawn only from the site investigation data from a single project. At the outset of the research, it was anticipated to use a machine language to predict the validity of the soft conclusion, but getting a reliable result was a problem due to the lower amount of complete data sets presented in the data logs. Therefore, Elevated Highway (EH) project which spans from New Kelani Bridge to Athurugiriya was blended to the research to ensure the same results in a different site condition. As shown in Figure 4.1, it also contributed to the same conclusion that was drawn from the CKE project as it generated the regression line explicitly above the predictions from the empirical correlations. Therefore, it can be identified that using the empirical correlations to predict the strength gain of organic soil deposits within the Sri Lankan context is very safe but beyond not economical.

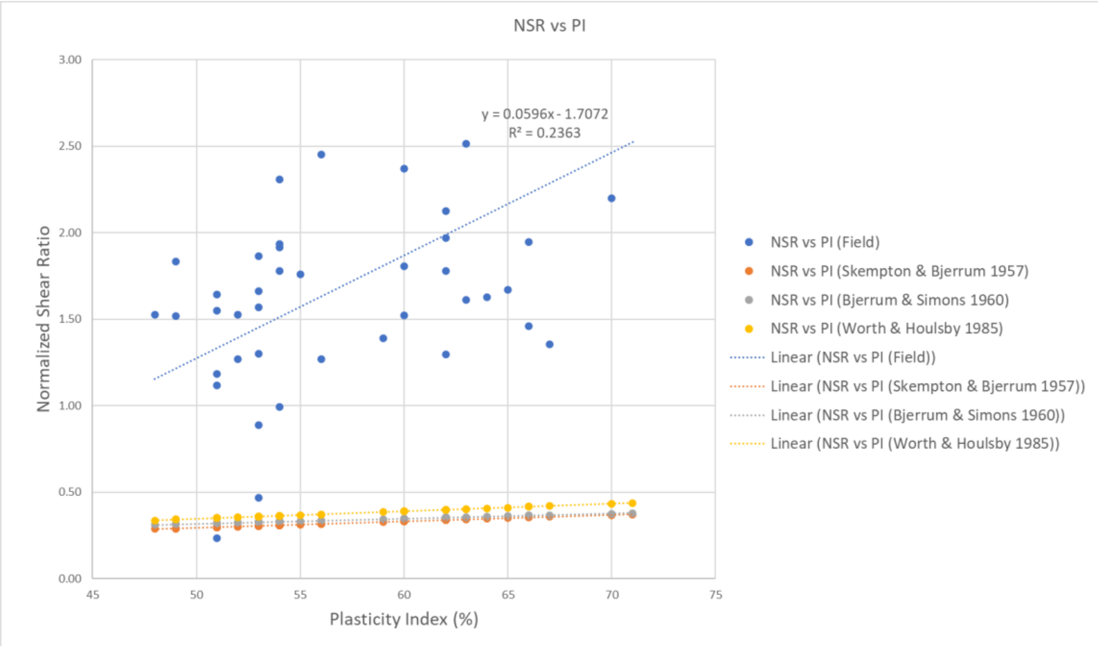

Figure 4.1 NSR vs PI field with empirical correlations – EH project

Kang et al. (2011) has observed the same behavior using inorganic soil samples representing four site conditions in the state of Missouri, United States and he has generated the same results as obtained in this research addressing inorganic soil deposits. In his conclusions, he stipulates that the strength gain predictions of inorganic soils in the state of Missouri are significantly below the regression line generated using the field data and hence, use of empirical correlations are conservative. The same conclusion is drawn for organic soil deposits addressing two site conditions in the Sri Lankan context. In addition, Kang et al. (2011) discovered that for St. Charles and New Florence sites, the NSR vs PI behavior was non-linear hence, when conducting this research for organic soils, the non-linear behavior has also checked by assessing the Pearson correlation coefficient. However, it was discovered that the behaviors are linear as it generated a good correlation in terms of the Pearson coefficient as shown in Table 3.1.

The research was extended to an extensive statistical study to identify the validity of PI to predict the empirical correlations. To serve the purpose, the data sets extracted from the pre-construction stage data logs were inserted to SPSS statistical software having NSR as the dependent variable and PI, LL, PL, OC and e_o as the independent variables. Before proceeding with the descriptive statistics, an argument was made to run throughout the statistical analysis as "using PI only to predict the strength gain of organic soil deposits within the Sri Lankan context is not conservative". Under this argument, it was anticipated to perform the multiple regression analysis but to influence the reliability and accuracy of the conclusions, several tests were conducted before proceeding with the multiple regression analysis. As presented in the results, the data sets fed into the software were reliable since the Cronbach's alpha value is 0.778 and the significance is less than 0.005 according to the F value test in the ANOVA table. Therefore, the internal consistency requirements were satisfied to give credible results from the analysis.

According to the correlation summary shown in Table 3.1, all the independent variables seem to have a positive and strong correlation with the dependent variable (NSR) since the Pearson correlation coefficient lay nearly 0.5. To ensure the correlation between the independent variables are minimum, multi-collinearity tests were conducted governing two criteria. However, before the conductance of the test, LL and PL were omitted from the analysis since those independent variables explain another independent variable which is the PI [PI = LL-PL]. From the multi-collinearity test results, it can be concluded that the independent variables consist with a low risk of multi-collinearity. The generated tolerance and VIF values support the same conclusion by resulting that, there is a lower degree of multi-collinearity effect in the analysis.

Finally, to address the argument, multiple regression analysis was performed. The coefficient summary illustrated in Table 3.3 shows that the significance of PI to explain the dependent variable

(NSR) is greater than 0.05. According to Pallant (2020), generating a significance greater than 0.05 means that the variable is not making a unique contribution to predict the NSR.

Kang et al. (2011) has concluded his research with the same conclusion in which, using PI only to predict S_u is not reliable by evaluating the spatial correlation of inorganic soil types collected from the state of Missouri, United States. He further established that there are many factors that influence on the strength gain prediction thus, abiding with PI is not very reliable. Same as that, this research conducted using organic soil deposits subjected in increase in effective stresses drawn the similar conclusions. From the model summary depicted in Table 3.3, it explicitly identified that the selected independent variables represent the dependent variable only 36.3%.

Despite of relying only on PI to predict the strength gain of organic soils, there are many other factors which explain the shear strength of soils. According to Trauner et al. (2005) and Matsuo & Shogaki (1988), ground water table, geological condition, sample disturbance, clay content has a significant effect on the prediction of S_u. The fluctuation of shear strength of organic soils was not addressed in this research and hence, it is recommended to include these variables and investigate further on this research area.

Limitations

In this research, some of the data used in the analysis of CKE project were obtained from the direct shear test results. Therefore, the results may have been subjected to slight fluctuations due to the sample disturbance and errors which are possible during the test conductance.

The density data related to the backfill layers were lacking hence, the energy method proposed by Bowles (1996) was used based on the field SPT N values. Also, the borehole logs for unavailable chainages were chosen from the vicinity of the selected chainage. However, the results are still conservative since the ground profile deviation for 100m is not very accountable.

Lack of data to perform the cross-validation analysis from python is a limitation faced in the research and further investigation on sites in the Sri Lankan context are encouraged to validate using machine language.

5 CONCLUSION

It is necessary to check the reliability of the empirical correlations used within the Sri Lankan context since they are originated under the foreign environmental conditions. In this extensive study, Colombo-Katunayake Expressway project (CKE) and Elevated Highway (EH) project data are contributed to identify the behavior of strength gain predictions by assessing the relationship between Normalized Shear Ratio (NSR) and Plasticity Index (PI). To make the analysis reliable, SPSS Statistical software was used to ensure the validity of using only PI for the strength gain predictions.

The empirical correlations currently practicing in the domestic industry rely only upon the PI value to predict the strength gain in organic soil deposits. With reference to that, analysis using the empirical correlations and field relationship between NSR and PI shows that, using such relationships are very safe but beyond the economical limits. From the descriptive statistics, the inter-correlation matrix explicitly shows that there are other independent variables such as natural void ratio (e_o), Organic Content (OC) that make strong correlations with NSR. Hence, the use of PI alone for the strength gain predictions cannot be validated for Sri Lankan organic soil. Therefore, to predict accurate strength gain predictions for organic soil in the domestic constructions encountering both safe and economical aspects, further investigations are demanded while concerning the contribution of the other index soil properties.

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Using Coconut Fibre To Improve The Tensile Characteristics Of Concrete

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ABSTRACT

Even though the building industry is modernizing in terms of technology and materials used, construction costs have risen, as has the environmental impact. The behavior of coconut fiber in a concrete structure is described in this paper. Coconut fiber increases a range of technical qualities in concrete. Sustainability is a generally accepted concept in today's construction industry. Coconut fibers have the highest tenacity of any natural fiber. They can be used for reinforcement in low-cost, basic concrete structures. The experiment will be conducted out on concrete with fibre inclusion in four different mix proportions (0%, 2%, 4%, and 6% by weight of the cement). This experiment will assess the compressive strength and split tensile strength of coconut fiber-reinforced concrete after 7 and 28 days. This test is sufficient for M20 and M30 grade concrete. According to this study, CFRC with a fiber fraction of 2% had the best Split Tensile Strength. Additionally, adding coconut fibers reduces the compressive strength of concrete.

KEYWORDS: *CFRC, Coconut Fibre, Compressive Strength, Split Tensile Strength*

1 INTRODUCTION

Concrete is the building material that is utilized around the globe in the most significant quantity.; however, concrete rebars are highly expensive. Nowadays, reinforcement cost is increasing day by day. In Sri Lanka, reinforcement prices are higher with inflation compared to the past. So, if people can use coconut-reinforced concrete instead of rebar concrete, it's a significant win for low-cost construction. Also, people use too much reinforcement for unnecessary concrete structures. Coconut fibre reinforcement is an excellent alternative solution for that low-cost construction. As a result, utilizing fibres as structural concrete is excellent for low-cost construction. The high costs, rarity, and corrosion problems are all significant impediments to producing high-performance concrete with steel fibres. Coconut fibre can be used as a concrete reinforcement material because it is the natural fiber with the highest degree of ductility (Majid Ali et al, 2012). According to R R Singh (2018) coconut fibre reinforcement concrete is good for low-cost construction. Different solutions concentrating on decreasing traditional construction material costs have been brought forth.as well as other infrastructure. One of the most popular ideas has been gathering, manufacturing, and using non-traditional local building materials, such as the idea of utilizing some industrial waste as construction materials. Coconut fibres may be obtained at a fair cost and with minimal environmental impact by utilizing local people and technology. The use of fibres as a kind of concrete improvement is particularly appealing to developing countries where traditional building materials are scarce or prohibitively expensive. As a direct consequence of this, the idea of fiber-reinforced concrete was born.

Coconut fibre improves a variety of concrete characteristics and properties. Among these properties, tensile characteristics are significant. The sustainability of coconut fibre is a widely accepted

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idea in today's construction. Natural fibres are less expensive and more widely available than synthetic fibres. Coconut fibre can be found in every nook and corner of Sri Lanka. Coconut fibre offers superior physical and chemical qualities compared to other natural fibres. It is also recyclable, inexpensive, long-lasting, and possesses the highest tenacity of any natural fibre. Coconut fibre is a good alternative for concrete fibre reinforcement because it is readily and widely available in Sri Lanka. A lot of people tend to be on a coconut plantation. Using coconut fibre in concrete is an excellent way for people to get into a new job market. People can find new jobs in the market. It also provides a good source of revenue for farmers.

The purpose of this experiment is to save expenses, help the environment, and ensure the long-term viability of the project by increasing the tensile strength of concrete by using coconut fiber.

1.1 Literature Review

One such fibre is coconut fibre, a byproduct of the coconut industry and has been studied for its potential as a reinforcement material in concrete. Several studies have investigated the mechanical properties of coconut fibre reinforced concrete (CFRC).

Majid Ali (2012) investigated some of the mechanical properties of CFRC. He studied mix proportions of 2%, 3%, and 5% fibre content by weight of cement, and fibre lengths of 2.5cm, 5cm, and 7.5 cm. Depending on the length and composition of the fibers, the characteristics can change, and the strengths of CFRC can change from those of ordinary concrete. The experiment proved that adding coconut fibres to concrete may significantly increase its flexural toughness in all conditions properly considered.

Sanjay Kumar (2019) investigated the compressive and tensile properties of coconut fibre concrete at 1 % to 5 % by the weight of fibre cement. They studied about M20 Grade concrete only. This experiment found CFRC may be used to increase ultimate strength and durability since the addition of coconut fibres results in a sufficient increase in strength, although the increase in strength is discovered to vary on the fibre content. Among the multiple strength parameters tested some of properties of coconut fibre concrete at various percentages (1 % to 5%) by fibre cement weight. In this research, they show after adding the coconut fibre; the compressive strength was improved percentage improvement for M20 grade concrete after 7 days and 28 days.

Neeraj (2020) investigated the compressive strength of coir fiber reinforced concrete, as well as the split tensile strength and flexural strength of coir fiber reinforced concrete. In this study, they looked at the weight of cement in concrete mix designs. This test was performed on M25 grade concrete. The tensile strength of coir-reinforced concrete has been experimentally investigated. Adding fibers clearly enhances compressive strength, however increasing fibers by more than 6% diminishes compressive strength. When compared to regular concrete, the fracture strength and flexural strength of coir reinforced concrete with fiber content rise gradually by 4% and 5%, respectively. The strength diminishes at this threshold.

The mechanical characteristics of coconut fiber reinforcement were researched by (Noor Md,2020), as stated in the study. In compared to other types of fiber-volume reinforced concrete, he discovered that concrete containing 3% coconut fiber provided the ideal combination of mechanical qualities. In addition to this, he analyzes coconut fiber reinforced concrete, which has exhibited a lower number of cracks, both in their development and in their breadth.

The reviewed studies suggest that adding coconut fibre to concrete can improve its mechanical properties, such as flexural toughness, compressive strength, and split tensile strength. However, the optimal conditions for using coconut fibre in concrete, such as the fibre content and length, require further investigation. Also, there is a research gap between previous researches. Therefore, this study aims to investigate the carried out on concrete with fibre inclusion in four mix proportions (0%,2%,4 %, 6%) by the weight of the cement. This research was carried out for the M20 and M30 grades of concrete.

.

2 MATERIALS AND METHODOLOGY

All materials should be selected according to the British standard (BS882:1992).

2.1 Materials

During the preparation of the concrete mix, the following materials were used.

2.1.1 Cement

The strength class 42.5 M of OPC (Ordinary Portland Cement) should be adopted in all the experimental procedures.

2.1.2 River sand

River sand should be used as a fine aggregate, and the fine aggregates used should be pure and devoid of any other pollutants.

2.1.3 Coarse aggregates

Coarse aggregates should have a maximum size of 20mm, and they should be clean and tough.

2.1.4 Water

Colorless, odorless, and tasteless, and free of organic content, water should be consumed.

2.1.5 Coconut Fibres

Coconut fibres Figure 1 were taken from the Kurunegala region, washed, sun dried, and dust was removed before being analyzed for their qualities. Except for water treatment, coconut fibers do not need any pre-treatment. Coconut fibre lengths used as approximately 4 cm to 6 cm.

Figure 1. Coconut Fibres

2.2 Methodology

A concrete mixer was used to cast concrete, which is made up of cement, water, coarse and fine aggregates, and coconut fibres. The percentage of each element in the mixture determines the properties of the final hardened concrete. All the quantities were measured by weighting. All the moulds were thoroughly cleaned and oiled before to casting. Before casting, moulds were carefully tightened to the proper dimensions. A few stages are involved in testing the compressive strength of a concrete cube. The concrete being tested is poured into 150 x 150 x 150mm moulds. Then, three equal-thickness layers of concrete were poured into the mould, and it was then tamped down with a tamping rod 35 times. For the cylinders were tamped down with a tamping rod 25 times. The top layer was leveled after compression. All the specimens were then let dry for 24 hours without being disturbed before being cured. Moulds were then removed, and samples were then placed in tanks for curing.

Also, for the split tensile strength used, cylinders 150mm in diameter and 300mm in length. After 24 hours, the test specimens are remoulded and placed in curing tanks to find the compressive and split tensile strength.

From the schematic representation, one can easily visualize and understand the research methodology employed in the study.

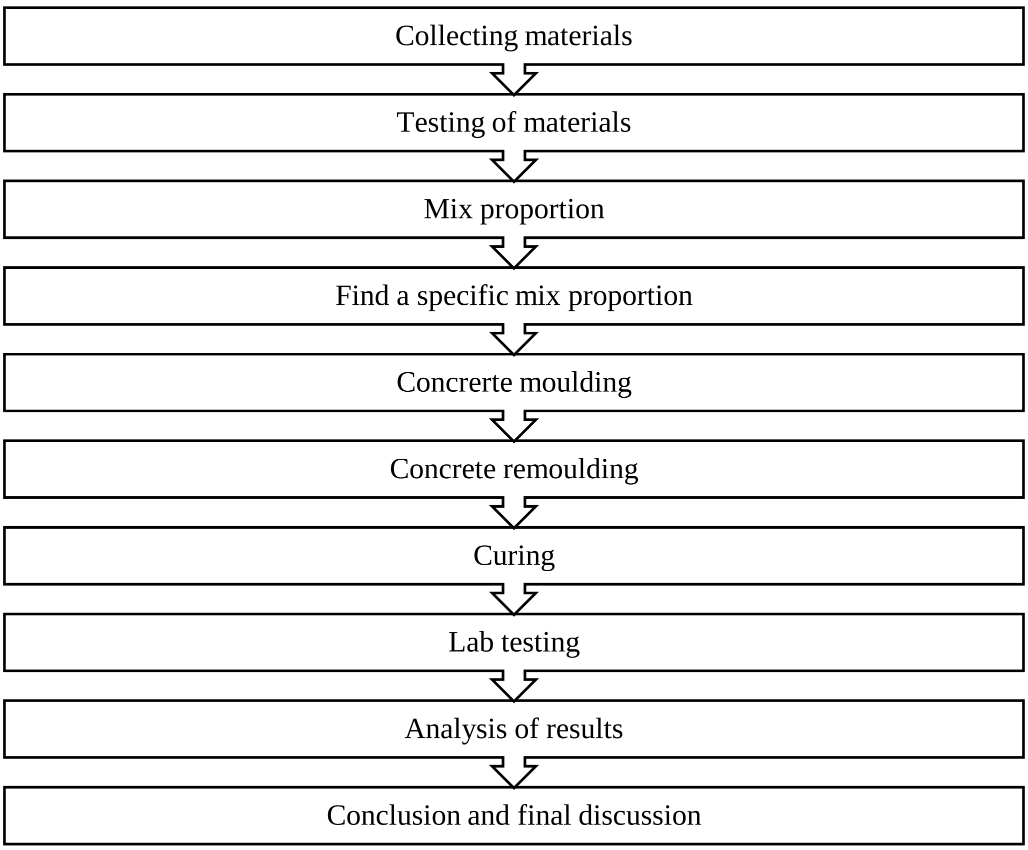


Figure 2.Schematic representation of methodology

3 RESULTS

3.1 Grade 20 Concrete Results

The results of Grade 20 concrete are shown in Table 1.

Table 1.Grade 20 Concrete Results

Coconut fibre proportion	**Average compressive strength(N/mm²)**		**Average tensile strength (N/mm²)**		**Slump Value (mm)**
	7 Days	28 Days	7 Days	28Days	
0	17.25	28.47	1.51	2.28	120
2	15.07	27.19	1.71	2.5	0
4	12.41	23.16	1.259	2.03	0
6	9.05	12.48	1.06	1.70	0

At 7 days, the compressive strength of the concrete decreases from 17.25 N/mm2 for plain concrete to 9.05 N/mm2 for concrete with 6% coconut fibre proportion. Similarly, at 28 days, the compressive strength decreases from 28.47 N/mm2 for plain concrete to 12.48 N/mm2 for concrete with 6% coconut fibre proportion. At 7 days, the average tensile strength of the coconut fibre-reinforced concrete increases from 1.51 N/mm2 for plain concrete to 1.71 N/mm2 for concrete with 2% coconut fibre proportion, decreasing slightly with further increases in the proportion of coconut fibre. However, at 28 days, the average tensile strength increases significantly, from 2.28 N/mm2 for plain concrete to 2.50 N/mm2 for concrete with 2% coconut fibre proportion, and then decreases gradually with further increases in the proportion of coconut fibre.

3.2 Grade 30 Concrete Results

The results of Grade 30 concrete are shown in Table 2.

Table 2.Grade 30 Concrete Results

Coconut fibre proportion	**Average compressive strength(N/mm²)**		**Average tensile strength(N/mm²)**		**Slump Value(mm)**
	7 Days	28 Days	7 Days	28Days	
0	28	36.6	1.76	2.86	120
2	21.88	31.3	1.82	3.135	0
4	20.2	29.1	1.67	2.22	0
6	9.35	24.75	1.14	1.94	0

At 7 days, the average compressive strength of the coconut fibre reinforced concrete decreases from 28 N/mm2 for plain concrete to 9.35 N/mm2 for concrete with 6% coconut fibre proportion. Similarly, at 28 days, the average compressive strength decreases from 36.6 N/mm2 for plain concrete to 24.75 N/mm2 for concrete with 6% coconut fibre proportion. At 7 days, the average tensile strength of the coconut fibre-reinforced concrete increases slightly from 1.76 N/mm2 for plain concrete to 1.82 N/mm2 for concrete with 2% coconut fibre proportion. At 28 days, the average tensile strength increases significantly, from 2.86 N/mm2 for plain concrete to 3.135 N/mm2 for concrete with 2% coconut fibre proportion. It is also interesting to note that the slump value (Table 1 and Table 2) of the concrete decreases with an increase in the proportion of coconut fibre, indicating that adding coconut fibre can reduce the workability of the concrete.

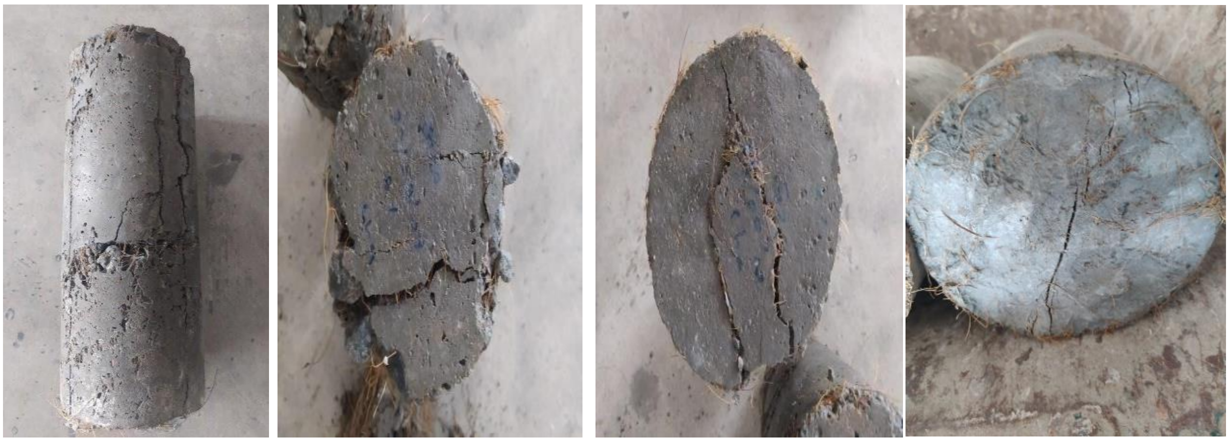
3.3 Crack Pattern

Plain Concrete

(A) (B) (C)

Figure 3.Plain Concrete Cracks

CFR Concrete



(A) (B) (C) (D)

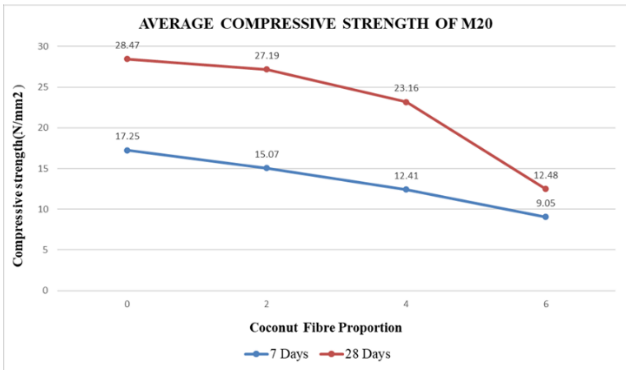
Figure 4.CFRC Cracks

Observation

The plain concrete specimens had a typical fracture as shown in Figure 3 propagation pattern throughout testing. When the CFRC specimens were studied, however, fractures as shown in Figure 4stopped propagating, resulting in the ductile characteristic of CFRC. Coconut fiber can improve the crack resistance and ductility of concrete by creating a network of fibers that distribute stresses more evenly and reduce the formation of cracks. Additionally, the crack pattern in coconut fiber-reinforced concrete can vary depending on the percentage and aspect ratio of the fibers. This can lead to a more controlled and predictable crack pattern, which can improve the overall durability and lifespan of the material.

4 DISCUSSION

4.1 Compressive Strength



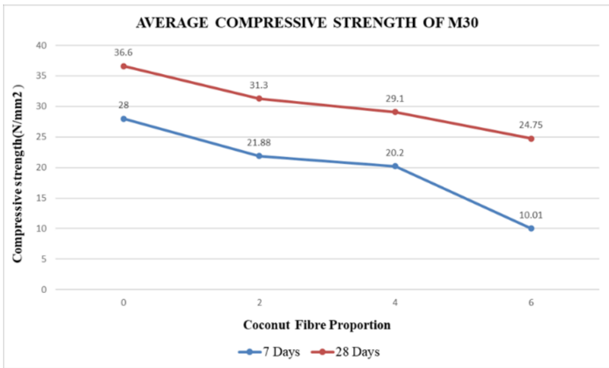


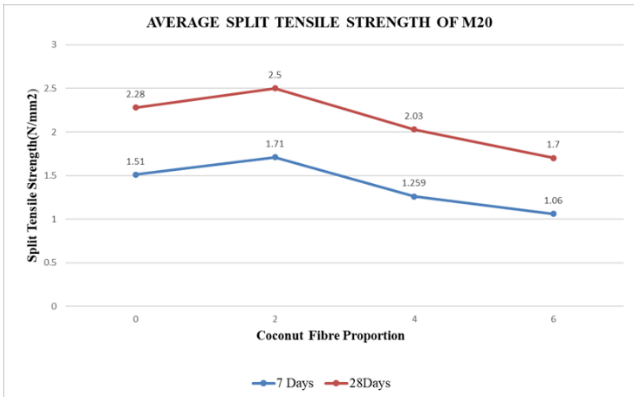
Figure 5. Compressive Strength of M20

Figure 6. Compressive Strength of M30

Observation

According to Figure 5 and Figure 6 The maximum value for the compressive strength of grade 20 and grade 30 obtained for 0% addition of the control mix for 7 days and 28 days. The material's compressive strength dropped when more fiber was added to it. This could be because of the fact that when the fibers are first introduced, the finer aggregates enter the surface pores in the fiber, improving the initial bonding between the fiber and mix. But when more fibers are added, bulk fiber is formed in the mixture, which weakens the connection. As a result, there is an ideal fiber-cement ratio that must not be surpassed to prevent a reduction in compressive strength.

4.2 Split Tensile Strength



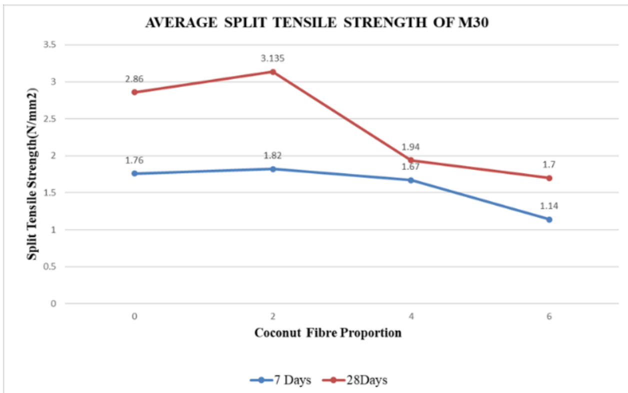


Figure 7. Split Tensile Strength of M20

Figure 8. Split Tensile Strength of M30

Observation

According to Figure 7 and Figure 8, it can be observed that the split tensile strength increases in proportion to the amount of fiber content, with the rise reaching its peak at 2% of the total fiber content. On the other hand, the graph begins to slope downward when the fiber content is raised above this point. This is why the dislocation of atoms and molecules that are present in concrete is what causes tensile failure to occur. However, once the fiber is included, it begins to function as a binder and helps to keep the ingredients together.

4.3 Slump Value

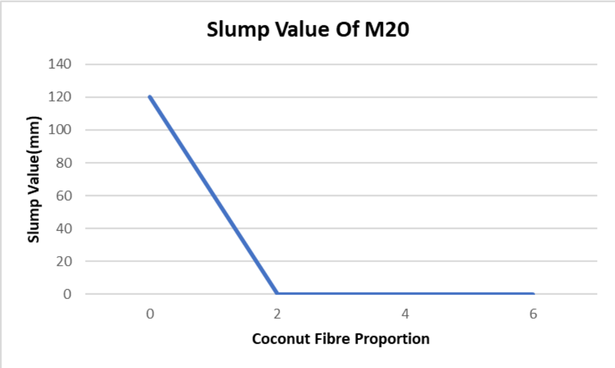


Figure 9. Slump Value M20

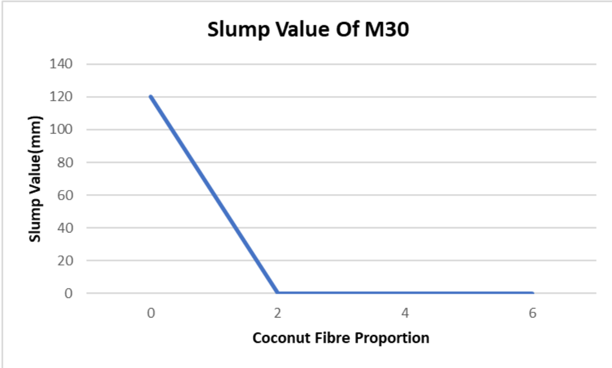


Figure 10. Slump Value M30

Observation

According to Figure 9 and Figure 10 the increase in the surface area of the fibre is the primary reason for the reduction in a slump. This increase leads the concrete to agglomerate around the fibres, which in turn results in a lower slump. In addition to the coarse aggregate, the mortar must also cover the fibres; hence, a reduction in a slump will be noted if the mortar fraction is inadequate.

5 CONCLUSION

Based on the results of the study, it can be concluded that the addition of coconut fibre to concrete has a significant impact on its mechanical properties, particularly its tensile strength. The use of coconut fibre as a reinforcement in concrete is a sustainable and environmentally friendly approach since it uses agricultural waste that is widely available. Incorporating coconut fibre also reduces the weight of the concrete, making it a suitable option for lightweight structural applications. This research's main scope is to use coconut fibre to increase the tensile strength of concrete while saving money and the environment and ensuring long-term sustainability.

The use of coir fibers, which are agricultural waste and are widely available, as reinforcing elements in concrete helps to prevent environmental pollution. Coir fibers come from coconuts. Because coconut fiber has a low density, it contributes to the overall reduction in weight of fibre-reinforced concrete, which enables the material to be utilized effectively as lightweight structural concrete.

In general, coconut fibers are a relatively low-cost alternative to construction materials. This is because coconut fibers are a natural byproduct of the coconut industry and are readily available in many tropical regions where coconuts are grown.

In this work, the maximum compressive strength of concrete at a particular aspect ratio of fibres and at a specific 0%. Compressive strength of concrete decreases after adding coconut fibres. It can be concluded that adding coconut fibre will reduce the number of ingredients to achieve the same strength, and thus, it becomes economical.

There is a maximum 2% increase in the split tensile strength that occurs when the fibre content of the material is increased. However, the tensile strength is found to decrease once this value has been exceeded with the fiber content of the material in question. This is due to the fact that the dislocation of atoms and molecules that are present in concrete is what causes tensile failure to occur.

The durability of coconut fibre addition in concrete can depend on several factors, such as the quality of the fibre, its dosage, and the curing conditions of the concrete. Generally, natural fibres like coconut fibre may have a lower resistance to moisture and chemical attack than synthetic fibres, which can affect their durability over time. To improve the durability of concrete with coconut fiber, it is recommended to use high-quality fibres with low moisture content and to ensure that the concrete is properly cured and protected from exposure to harsh environmental conditions.

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Computational Approach for Determining the Variation of Coefficient of Secondary Compression in Secondary Settlement Prediction of Soft Soils

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ABSTRACT

Secondary consolidation settlement takes place in soils after the completion of primary consolidation settlement, which is due to the dissipation of pore water pressure under the applied loads. The secondary settlement usually occurs due to the plastic adjustment of the soil particles and most commonly takes place in organic fine grained soils or soft soils. Hence, it is important to accurately estimate the secondary settlement in soft soils as the final stability of infrastructures built on soft soil grounds mainly depends on the amount of secondary settlement that takes place after the end of primary consolidation settlement. The coefficient of secondary compression (C_α) is a governing parameter in predicting the secondary settlement which is the slope of the consolidation curve for void ratio versus time. Also, various empirical correlations have been found by the past researches to find the value of the coefficient of secondary compression. In most of the instances, the secondary settlement is estimated by considering the coefficient of secondary compression as a constant value. However, the C_α value shows a variation with time and this could affect the secondary settlement estimation. Hence, it is necessary to investigate how the variation of coefficient of secondary compression affects the estimation of the secondary settlement in soft soils.

In this study, the settlement data obtained from the Weligama Bay Marriot Resort and Spa project, Sri Lanka, is compared with the settlement values obtained from a computer generated programme. The progarmme simulates the settlement by considering the variation of the coefficient of secondary compression and by considering a constant coefficient of secondary compression value. The results show that the consideration of varying coefficient of secondary compression (with time) gives more accurate results than considering a constant coefficient of secondary compression in settlement prediction in soft soils.

KEYWORDS: *Secondary Settlement, Primary settlement, Consolidation, Coefficient of secondary compression, Soft soil*

1 INTRODUCTION

Secondary consolidation settlement is the continued deformation in the soil structure that takes place after the dissipation of excess pore water pressure under applied loads (after the end of primary consolidation settlement). Secondary settlement is more significant in clayey soils and in soft soils such as peat but, negligible in sandy soils where only the primary consolidation settlement is significant due to the quick dissipation of pore water pressure under applied loads.

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Soils having an organic content above 75% are classified as peaty soils (Huat et al., 2014). Due to this high amount of organic matter, peaty soil exhibits a high compressibility and moisture content while the shear strength and the bearing capacity is low (Adnan et al., 2007).

The table 1 shows the basic properties of peaty soil based on a research conducted by (Kawa et al., 2019).

Table 1. Basic properties of peaty soils (Kawa et al., 2019)

Index Properties	**Range**
Natural moisture content (%)	414-674
Specific gravity	0.95-1.34
Initial void ratio	7.99-9.64
Fiber content (%)	90.2-90.49
Organic content (%)	88.6- 99.0
Ash content (%)	0.94-11.39
Bulk density (kgm^{-3})	1035.66-1040.41
Linear shrinkage	29.81-30.14
Liquid limit	202.30-220.65

Secondary compression, usually referred as creep, can be expressed by the coefficient of secondary compression $C\alpha$, which is a critical element of prediction of long term settlement for designing roads and foundations (Garoushi, 2017). The coefficient of secondary compression can be identified as the slope of the secondary compression on e-log t per load cycle of time (Head, 1986).

Mesri et al., (1973) has stated that for normally consolidated natural soils, the coefficient of secondary compression is influenced by factors such as time, consolidation pressure, precompression, sustained loading, remolding, shear stresses, rate of increase in effective stress, sample thickness and temperature.

They also classified the secondary compression based on the C_α value as shown in Table 2 below.

Table 2. Secondary compression based on C_α % (Mesri et al., 1973)

C_α % (Per log cycle)	**Secondary Compression**
<0.2	Very low
0.4	Low
0.8	Medium
1.6	High
3.2	Very high
>6.4	Extremely high

Many past researches have been conducted to study the variation of coefficient of secondary compression (C_α) with the above factors when estimating the secondary settlement.

Head (1986) found that the coefficient of secondary compression increases with the increment in the vertical effective stress in highly organic clays and in peat. Where, C_α is independent of the vertical effective stress in inorganic clays. In a recent study done by Huayang et al. (2016) on three different soft soil types, it was found that the C_α depends on the vertical effective stress and the initial void ratio. Past research also has been conducted to find the C_α variation with time.

In a study done by Fox et al. (1992), the Compression- log time curves showed that under a constant vertical effective stress value, the coefficient of secondary compression was not constant but increased with Log time. Mesri and Vardhanabhuti (2006) also states that the characteristics of coefficient of secondary compression vary with time. Mesri and Vardhanabhuti (2005), states that as the variation of secondary compression is not constant in Log time and hence, calculating C_α as slope of e – log t pre one cycle of time is not accurate because the slope is changing from cycle to another. In fact, coefficient of secondary compression decreases with time under constant stress in all the cases.

In a research done by Garoushi (2017) on secondary compression of clay soils, he states that the coefficient of secondary compression is directly proportional to the time corresponding to the end of primary consolidation for all loading stages. He also concludes that C_α is not constant with time on Semi-logarithmic scale, instead it decreases. Another conclusion of the study is that an over-estimation of the coefficient of secondary compression in clay soil was observed when calculated from the standard oedometer test results.

However, not much research has been done on considering the variation of coefficient of secondary consolidation with time, in estimating the secondary consolidation settlement. This research focuses on settlement prediction at selected locations in Weligama Bay Marriott Resort & Spa project in Sri Lanka using actual geotechnical parameters obtained from borehole logs and laboratory experiments. The settlement simulation is done for two cases, first, by maintaining a constant C_α value and second, by varying the C_α with time. The settlement variations obtained are then compared with the actual field settlement data in order to identify the accuracy of considering C_α variation in secondary settlement prediction in soils.

1.1 Aim of the research

The aim of the research is to determine the accuracy of considering the variation of coefficient of secondary compression with time, in predicting the secondary consolidation settlement in soft soils.

1.2 Objectives of the research

The main objectives of the research are,

- Simulation of secondary consolidation settlement at selected locations by considering a constant value for the coefficient of secondary compression.
- Simulation of secondary consolidation settlement at selected locations by considering the variation of coefficient of secondary compression with time.
- Comparison of settlement data obtained from the above two methods, with the actual field settlement data.

2 METHODOLOGY

2.1 Selected study area/location

The Marriott Resort & Spa, Weligama is located in the Colombo - Hambantota – Wellawaya road and is a famous holiday destination in Sri Lanka. The construction commenced in the year of 2012 and was open for public on 2014/06/24. By that time, the primary consolidation settlement has completed which is 730 days from the start of the construction. However, by the time an unexpected settlement was experienced by the structure, which was predicted to be an ongoing secondary consolidation. Hence, it was decided to conduct a field investigation which commenced on 4th May 2022 .Six boreholes were marked and Standard penetration (SPT) tests were carried out along with other field/laboratory experiments and the settlement at 8 locations around the borehole areas were measured. Figure 1 shows the aerial view of the investigated area while Figure 2 shows the borehole locations at the investigated area.

Figure 1. Area selected for investigations

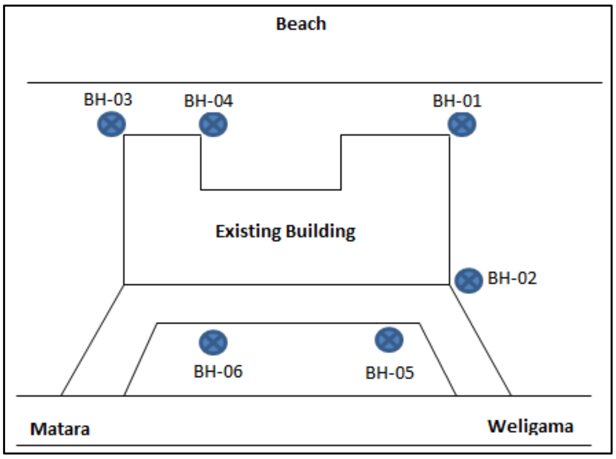

Figure 2. Borehole locations

The ground water table was determined from the measurements taken from an open borehole and found to be fluctuating with rainfall conditions and temperature variations of the area. The settlement monitoring locations are shown in Figure 3 and the soil profile of each location is consisted of a peat / peaty clay layer which confirm the idea of an unexpected ongoing secondary consolidation that is common in peaty soils. Table 3 shows the peaty clay layer thicknesses at various settlement monitoring locations.

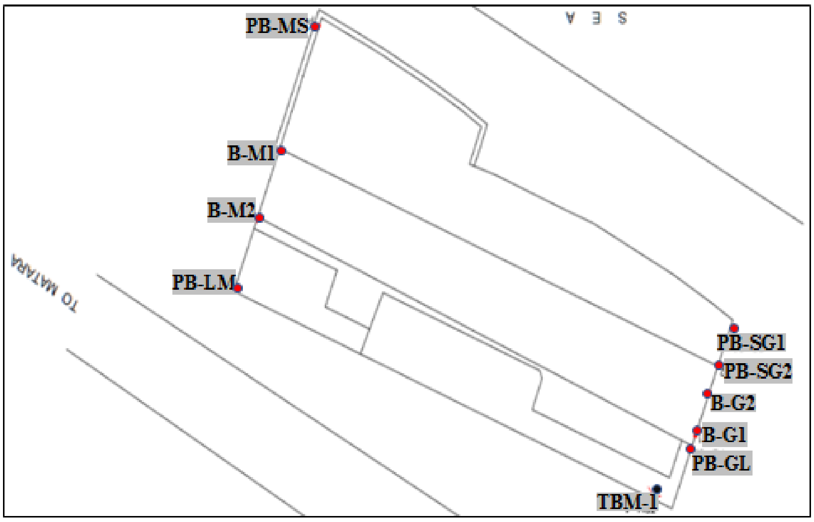

Figure 3. Settlement monitoring locations

Table 3. Peat layer thicknesses at the settlement monitoring locations

Settlement location	Thickness of the peat layer (m)
PB-SG1	6.5
PB-SG2	6
B-G2	6
B-G1	6.5
PB-GL	7
B-M1	3.5
B-M2	3.5
PB-LM	3

2.2 Basic procedure

The data collected from the borehole investigations and the data collected from the field / lab experiments at the settlement monitoring locations, were fed in to a computer generated programme to estimate the secondary consolidation settlement variation at each time interval starting from 2920 days to 3416 days from the start of the construction, which is the duration where the actual settlement monitoring was also carried out.

The settlement simulations were carried out in two different approaches where;

1. A constant coefficient of secondary consolidation was used

And,

2. A time dependent coefficient of consolidation was used.

2.2.1. Approach 01

An empirical correlation has been proposed by Karunawardane (2007) to predict the corresponding C_α values using the respective C_c values for soft/peaty soils in Colombo district, Sri Lanka. Figure 4 shows the empirical correlation proposed by Karunawardane (2007). However, Eq (1) shows an empirical correlation proposed by Vidurapriya et al., (2020) to predict the coefficient of secondary consolidation based on the respective C_c for southern peaty soils. As the soil in the study area is also from the southern part of the country, Eq (1) is used to predict the constant C_α values at each settlement monitoring location as shown in Table 4.

$$C_\propto = 0.0331 C_C \tag{1}$$

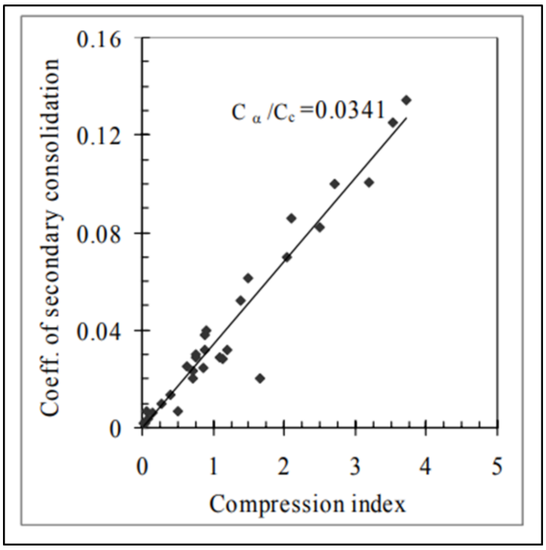

Figure 4. Empirical relationship proposed by Karunawardane (2007)

Table 4. C_{α} values used in approach 01

Settlement location	**Average C_C value**	**Predicted Cα value**
PB-SG1	0.778	0.02575
PB-SG2	0.778	0.02575
B-G2	0.778	0.02575
B-G1	0.778	0.02575
PB-GL	0.778	0.02575
B-M1	0.625	0.02069
B-M2	0.625	0.02069
PB-LM	0.625	0.02069

The Eq (2) below was used to calculate the secondary consolidation settlement where, S_S = Secondary consolidation settlement, $C_{\propto}$ = Coefficient of secondary consolidation, H = Thickness of the peat layer, e_p = Void ratio at the end of primary consolidation, t_1 = Time at the end of primary consolidation and t_2 = Time at secondary consolidation. The data shown in Table 2 and 3 were fed in to a computer generated programme as the H values and C_{α} values respectively, for each location and the e_p vale was also obtained from the respective laboratory results for each location. Parameter t_1 was considered as 730 days which is the time of end of primary consolidation settlement. Parameter t_2 varied from 2920 days to 3416 days with a time interval of 0.2 days in order to calculate the secondary consolidation settlement values at each time interval to obtain more accurate results.

$$S_S = \frac{H\ C_{\propto}}{1 + e_P}\left(\frac{t_2}{t_1}\right) \qquad (2)$$

2.2.2. Approach 02

The approach 02 uses the same secondary consolidation Eq (2) and same data as in approach 01 except the C_{α}.

In approach 02, the C_{α} varies with each time interval and found by using Eq (3), where, $C_{\propto m\ (n)}$ = Coefficient of secondary consolidation at a given time, $C_{\propto}$ = Coefficient of secondary consolidation at the end of primary consolidation, $t_{p(n)}$= The time at which the secondary consolidation settlement is measured, t_p= Time at the end of primary consolidation (Both the times are measured from the start of the initial loading).

$$\frac{C_{\propto m\ (n)}}{C_{\propto}} = 0.0138\left(\frac{t_{p(n)}}{t_p}\right) + 1.7278 \qquad (3)$$

3 RESULTS AND DISCUSSION

The secondary settlement was simulated for 8 locations as discussed in section 2, the settlement variation found by approach 01 (Constant C_{α}) and approach 02 (Varying C_{α} with time) are compared with the actual field settlement data obtained for each settlement monitoring location. Figures 5 to 12 show the settlement comparison by considering constant C_{α} and varying C_{α} with the actual field settlement variations of all the selected locations.

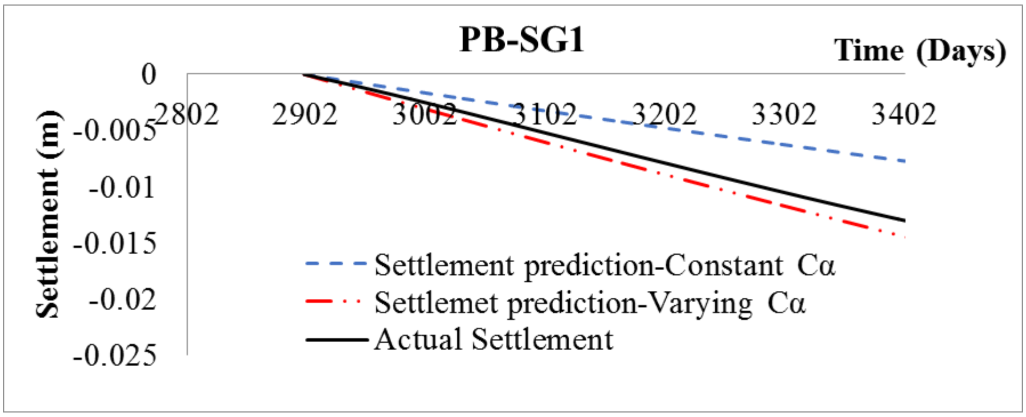

Figure 5. Settlement variation comparison for location PB-SG1

Figure 5 shows the secondary settlement variation at location PB-SG1 where the peat layer thickness is 6.5m. The results show that the secondary settlement is under predicted when a constant value for the coefficient of secondary compression is used and the prediction with a varying C_α is closer to the actual settlement variation. The difference between the maximum settlement values for the constant and varying C_α values is nearly 6.4mm. The difference between the maximum actual settlement value and the maximum settlement value with a constant C_α is nearly 5.1mm while it is only 1.4mm for varying coefficient of secondary compression.

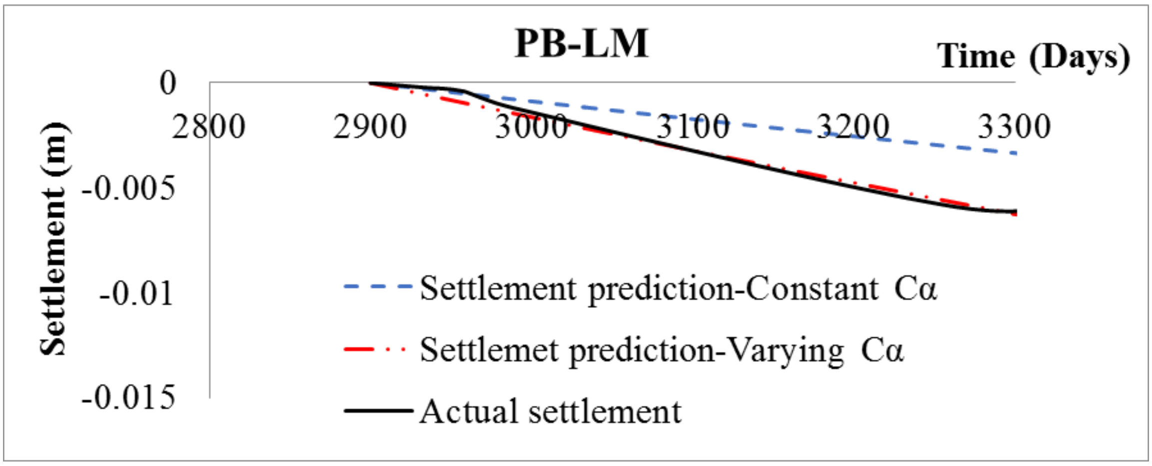

Figure 6. Settlement variation comparison for location PB-LM

Figure 6 shows the secondary settlement variation at location PB-LM where the peat layer thickness is 3m. The results show that the predicted secondary settlement is very low when a constant value for the coefficient of secondary compression is used and the predicted settlement with a varying C_α is almost same as the actual settlement variation. The difference between the maximum settlement value for the constant C_α value and the actual settlement value is nearly 3.3mm.

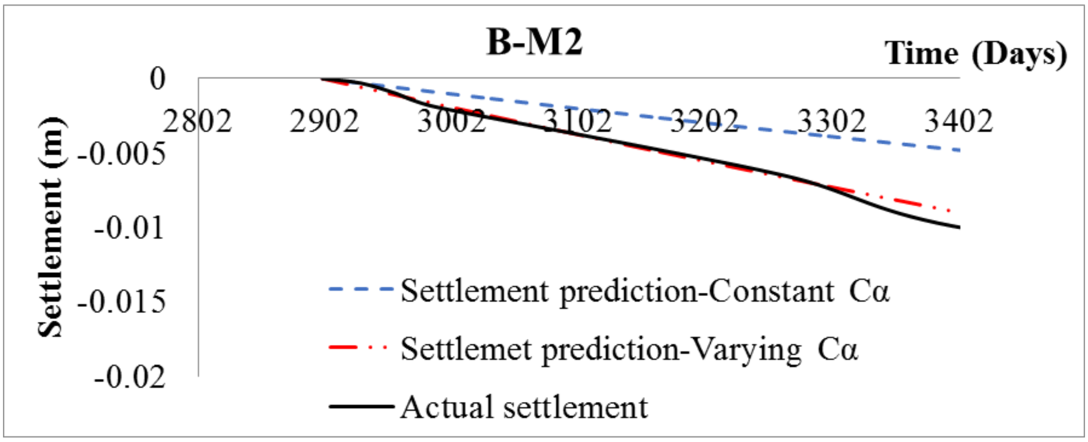

Figure 7. Settlement variation comparison for location B -M2

Figure 7 shows the secondary settlement variation at location B-M2 where the peat layer thickness is 3.5m. The results show that the secondary settlement is under predicted when a constant value for the coefficient of secondary compression is used and the prediction with a varying C_α is closer to the actual settlement variation until 3302 days and then shows a sudden deviation of nearly 1mm. The difference between the maximum settlement values for the constant C_α value and actual settlement is nearly 5mm.

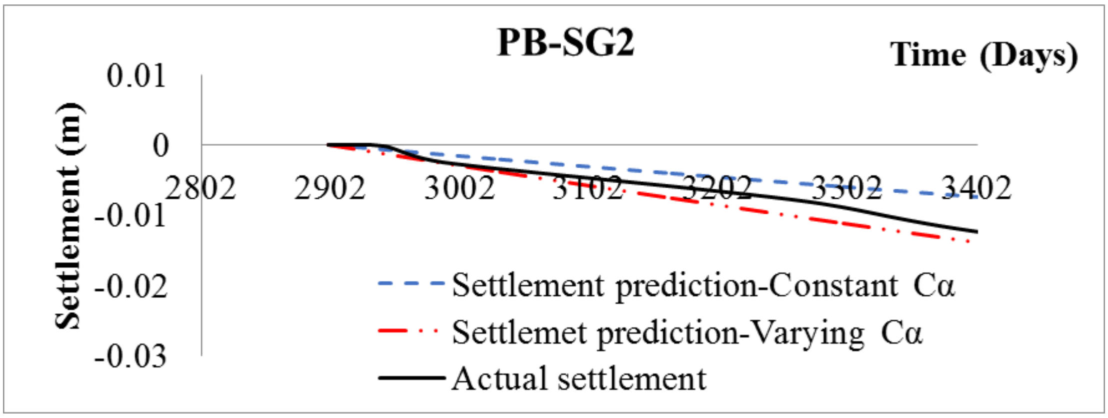

Figure 8. Settlement variation comparison for location PB-SG2

Figure 8 shows the secondary settlement variation at location PB-SG2 where the peat layer thickness is 6m. The results show that the secondary settlement is under predicted when a constant value for the coefficient of secondary compression is used and the prediction with a varying C_α is closer to the actual settlement variation. The difference between the maximum settlement values for the constant and varying C_α values is nearly 6.5mm. The difference between the maximum actual settlement value and the maximum settlement value with a constant C_α is nearly 4.8mm while it is only 1.6mm for varying coefficient of secondary compression.

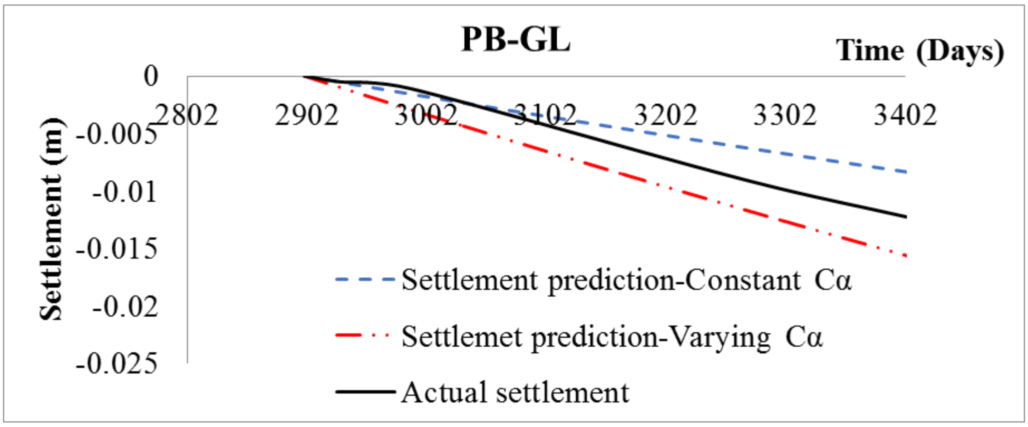

Figure 9. Settlement variation comparison for location PB-GL

Figure 9 shows the secondary settlement variation at location PB-GL where the peat layer thickness is 7m. The results show that the secondary settlement is under predicted when a constant value for the coefficient of secondary compression is used. However, the values for a constant C_{α} are almost same as the actual settlement until nearly 3100 days. The prediction with a varying C_{α} is closer, but over predicts the actual settlement variation from the beginning of the period till the end.

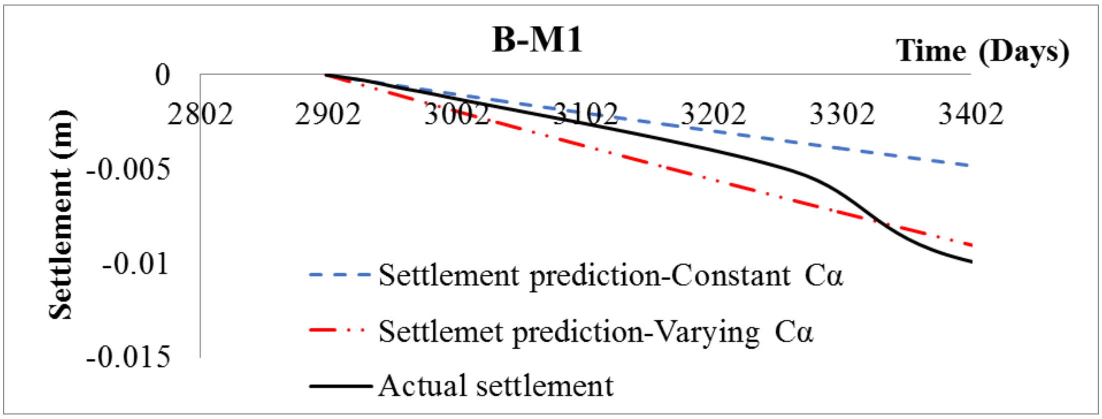

Figure 10. Settlement variation comparison for location B-M1

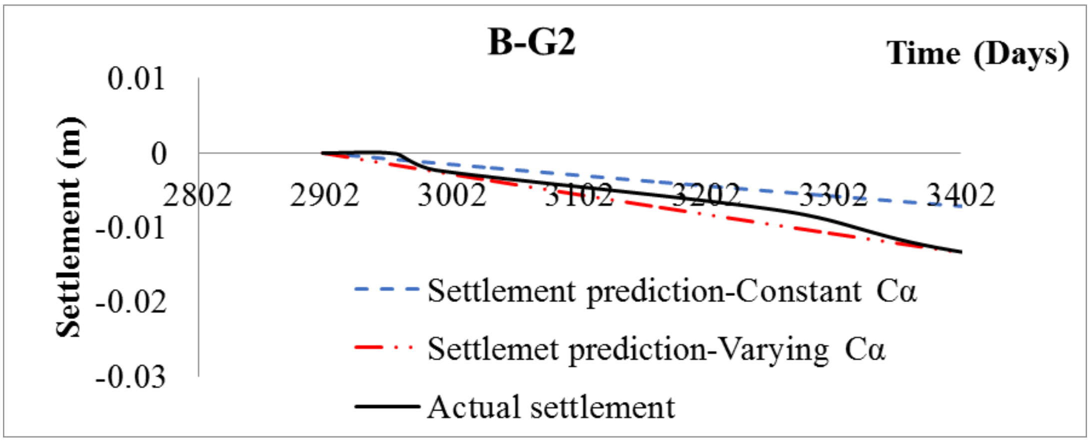

Figure 11. Settlement variation comparison for location B-G2

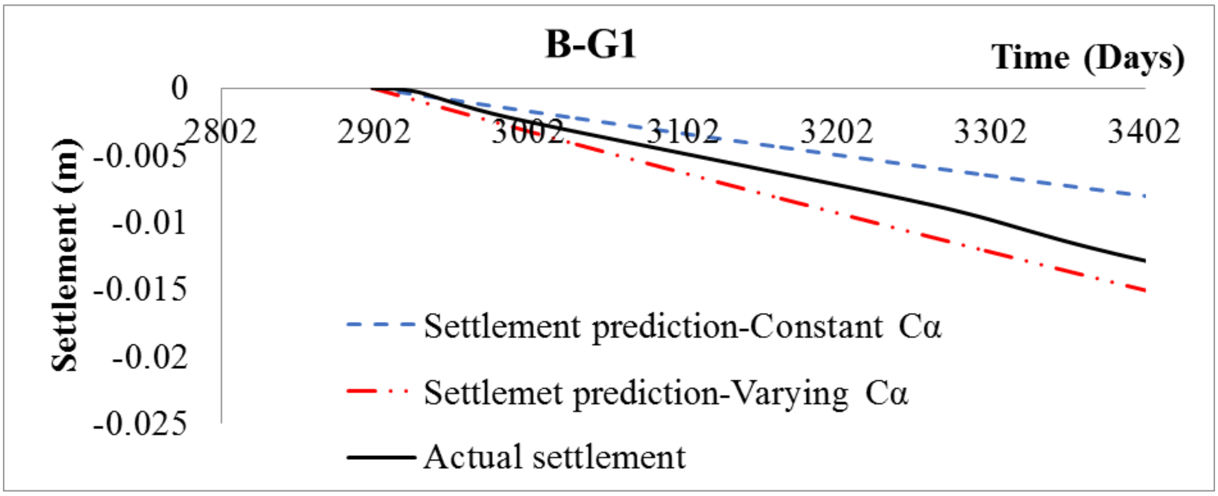

Figure 12. Settlement variation comparison for location B-G1

Figures 10, 11 and 12 show the settlement variations at locations B-M1, B-G2 and B-G1.The secondary settlement prediction with a constant C_α value predicts a settlement that is comparatively very less than the actual field settlement. However, with a varying C_α , the predicted secondary settlement is higher than the actual settlement in these locations. This slight increment could be justified by considering the safety aspects of the locations as the superstructure (Marriott hotel premises) has undergone an unexpected settlement after the end of the construction period (after the end of primary consolidation settlement).

4 CONCLUSION

The actual settlement variation at 8 locations at the Weligama Bay Marriott Resort & Spa project, Sri Lanka, were compared with the settlement predictions obtained from a computer generated programme by considering the C_α variation with time and by considering a constant C_α throughout the time period. The results showed that the settlement predictions were more accurate and closer to the actual settlement predictions when the C_α variation with time, was taken in to consideration while considering a constant C_α would under predict the secondary settlement variation in soft soils. The main reason for this is that the coefficient of secondary compression varies with the varying factors such as ,time, rate of effective stress, consolidation pressure, precompression and sustained loading. Hence, considering a constant value for C_α is not reliable and would give inaccurate predictions for the secondary consolidation settlement values. In this study, for all the eight cases, where the secondary settlement was predicted, the settlement were under predicted when a constant secondary compression value was considered. Therefore, it can be concluded that considering a constant C_α for secondary settlement prediction is unsafe and hence, the consideration of C_α variation with time is recommended in this study.

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TRANSPORTATION ENGINEERING AND CONSTRUCTION MANAGEMENT

Effect on Time Management Due to Variations in Road Construction Projects in Sri Lanka

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ABSTRACT

Variations are reoccurring and inevitable incidents in construction projects. It alludes to any adjustment in project scope at any instance of construction process. There are numerous causes of variation depending upon different parties involved, complexity of project and the type of project. These variations are acknowledged to affect different viewpoints of the projects. The thesis evaluated the effect of time management due to variations in road projects in Sri Lanka to diminish them. In order to achieve the study objectives, a basic survey of literature review was done accompanied with a quantitative survey with industry experts were carried out to gather data on impact of time management due to variations in construction projects. Through the writing study, 50 causes of variation orders were recognized but, they were shortlisted since there were so many similar causes. Out of them design faults were identified as the major cause of variations. When it comes to the impact on time overrun, it was discovered that variations affect on time of a project adversely. Finally, mitigation strategies for variations have been proposed in the study. The recognized results from literature overview were moreover subjected to a test by the 33 specialists in the industry including contractors, consultants, and clients to be more precise. The results were analyzed using SPSS. The study's final recommendation is that to all parties to get involved, to reduce variation orders beginning with the initial design phase, manage variation orders during the construction phase using an efficient change management system, and adopt various technologies to speed up the variation management procedure.

KEYWORDS: *Variations, Time management, Sri Lanka, Road project*

1 INTRODUCTION

The construction industry has a symbolic influence towards globally as well as on economy in a country. According to Silva (2021) Sri Lanka construction development contributes 7.1% to GDP of nation and considered to be one of the major financial development variables of Sri Lanka. Therefore, if a variation in a construction project happens it directly affects towards the country economy. Especially variations on time management effect on both project cost and then on the profit of the project. Variation is simply a change and the variation in construction projects are inevitable. One of the most important aspects of variation is influence on time management. Time management is defined as the time spent on the progress over the projects. As define by per the Westland (2006) time management define as, "Time management is the process of recording and controlling time spent by staff on the project". Time management is vitally important in construction projects because it helps to breakdown, assign tasks and complete projects on time.

When numerous variations in a venture increase, so the risk of misjudge between the included parties may happen. Such a misguided judgment may happen since individual or more of the parties

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needs complete information of the variation process, the costs included in executing adjustments, or the lags, clashes, and obstructions of the development course of actions which can unfavorably influence project coordination. Effect of varieties on time administration for development industry are either favorably or antagonistically influenced. Basically, the project cost and profit get influenced by time variety. Company reputation gets harmed, and clients may have a misconstrue towards the company. In the event that the project goes out of scope with the time variety, at that point the control of project may get destitute. So, it is exceptionally much vital to oversee the time appropriately without letting it to be changed.

1.1 Aim of the project

The aim of this study is to assess the impact of variations which affect time management of construction projects related to road sector in Sri Lanka.

1.2 Objectives of the project

- To examine origin agent, types and causes of variations that is prevalent on road development ventures in Sri Lanka.
- To determine the extent of impact of variations on time management.
- To identify preventive measures of variations with support of project management applications.

1.3 Scope of the project

There are various projects which are right now underneath improvement in Sri Lanka. In arrange to attain the communicated goals of the study, the scope would be as well tremendous to handle. In this context, the research will be limited to Road development projects in Sri Lanka.

1.4 Research gap

Various research have been done with reference to the key words of the selected topic worldwide. Most of the previous studies have analyzed the impact of overall project performance due to variations but not sticking to time management. Ranasinghe (2012) carried out research to determine trends of causes for variation orders in road projects in Sri Lanka. The study included causes of variations and ranked them based on number of frequencies of occurrence, percentage variation for each cause using a relatively importance index. Takar (2020) has done a study on impact of variation order in construction projects. The study contributes types of variations, effects on variation on cost, quality, time, and organization. The research was done regarding overall construction projects but not specifying road projects. Chin and Hamid (2015) have done research practice of time management on construction industry. This paper includes details on importance of time management in construction industry. Dolage and Pathmarajah (2015) have researched on topic “Mitigation of Delays Attributable to the Contractors in the Construction Industry of Sri Lanka - Consultants’ Perspective” which determine reasons for construction delays in Sri Lanka. Karunasena et al. (2017) have published a journal on challenges in highway construction projects in Sri Lanka where different areas of challenges have addressed regarding expressways. Edirisinghe, Marsh, Borthwick and Cotgrave (2020) have done research on “Significant causes of disputes in construction industry in Sri Lanka.” The paper mainly focused on types of disputes arise in a project and selection of the most suitable dispute resolution methods. Yadeta (2014) have assessed impact of variation orders on public building projects in Addis Ababa. There, author describes only public projects and variation orders. It does not address any time management issue on road projects. Depending upon above information it can be clearly seen that most of the papers and articles have published on impact of variations on a project, impact of time management on projects. Variations in Sri Lankan construction projects and other country projects may get different due to constructional law, cultural difference. Also, a less focus have been attempted show how variation and time management interrelate and specially how they make an impact on road construction industry in Sri Lanka. Therefore, this paper would help to fill the vacuum regarding above mentioned matter.

2 LITERATURE OVERVIEW

2.1 Introduction of variations

The time administration of a development project from initiation to completion holds an extraordinary significance because it straightforwardly influences the project cost and quality. Cost, quality, and time are the key components in a venture, and they are depended upon each other. However, due to many reasons a project can be varied from initial plan. Ndihokubwayo (2008) says “Variation orders can potentially occur on all construction projects. They occur due to several reasons that include finance, changes in the minds of parties involved into the contract, weather conditions and feasibility of construction, statutory changes, product improvement, and discrepancies between contract documents.” Yadeta (2014) determines “Variation is inevitable in construction projects due to the complex nature of the construction industry.” Edirisinghe et al, (2020) proposed their review regarding reasons for disputes in Sri Lankan construction industry where they identified major factor of cause were variations. Further, they stated that the key to the variations was budget. When variations affect to the project cost there is a high risk of arising a dispute. Halwatura et al, (2013) express their point of view as most of the road improvement ventures in Sri Lanka have gone through a colossal amount of variety orders. The client had to spend more than initial budget to get over with in most cases. In some cases, wrangle about and inconsequential delays happen due to varieties. Sun and Meng (2009) alluded to a variation in development projects as changes to design, development process, and adjustments to the project program in preexisting conditions, assumptions, or necessities.

2.2 Origin agents, types and causes of variations

Ndihokubwayo (2008) distinguished 2 sorts of variations to be specific, beneficial variations and detrimental varieties where beneficial variations are that lead to esteem enhancement whereas detrimental varieties are driven to deterioration. Four origin specialists were recognized thru the consider i.e., Contractor related, client related, consultant related and unspecified. Moreover, he states that occasion of variation unfavorably impacts the execution of development ventures by, being responsible to cost and time attacks. The occurrence of varieties can impact for the most part of quality of works. Yadeta(2014) sorted out list of causes of variations according to the frequency of occurrence. The study of Halwatura and Ranasinghe, (2013) recognized that misguided estimation is the dominant cause of variety orders inside the street improvement trade in Sri Lanka. For case, the specialists fail to carry out palatable examinations at the beginning during the site investigation and design organize. Subsequently, many location conditions rise within the development organize. Further, clients fail to provide competent proficient staff to carry out examinations and estimates. Hence, a number of inconsequential varieties happen during the construction phase. Apart from primary cause, most often, the opinion of the client isn't considered and not recorded. Contractors and specialists are hesitant to point out client’s insufficiencies, considering their stability within the development industry. Underneath variables causing variety, there are three categories these are owner related components, contractor related factors, and specialist related factors. (Chalchissa, 2021).

2.3 Impact of variations on time management

Ndihokubwayo (2008) has ranked adverse impacts of variations on project performance and which the time overrun has occupied rank number 2. The study of Yadeta(2008) has stated that delay in completion of works is major impact of variation. Delaying of completion may result in cost overrun and in productivity. This proved that variations affect the venture unfavorably, drive to being delayed within the project finalization. Osman, Omran and Foo (2009) have found from their research completion schedule delay bears 4th prominent impact of variations. The results gotten can be considered exceptionally significant to the construction industry as at whatever the point there are variations or extra works all along the construction phase, it ordinarily brings around additional work or demolition or adjustments to be accomplished by the contractor which interferes more cash for the contractor: in turn it will result in project cost increment and may also influence the complete project’s time plan. Pathiranage and Halwatura, (2010) realized that Sri Lankan Road construction projects usually go through an average of 70% time overrun compared to the authentic (planned) project duration. The study investigated financial problems, insufficient site management, contract modifications, worse weather conditions, incomplete documents, shortage of site labor and material make projects delayed. Hanna et al. (2002) mentioned that variation orders increase efficiency losses and efficiency is characterized by the sum of yield. The adversity of efficiency in this way involves a catastrophe of time and related delays. Priyantha et al. (2011) moreover, realized that due to the extra works, changes to arrangements and levels/dimensions variations result with the need of additional time to complete the works.

2.4 Recommended measures to minimize variation orders

According to Yadeta (2014) there are some ways of mitigation or minimizing of variations. The main strategy was to complete designs and contract documents at the tendering phase. Also, works should be executed along with an experienced and dedicated supervisor. Improving interaction within included parties was another strategy proposed. Diverse parties included in a project to perform work so, a fine communication between the parties is vital. This should be done since interaction can increment project performance during the processes of a project. Yadeta (2017), recommended strategies to minimize variations and ranked them according to the efficiency. Accordingly, it was recommended to carry on a detail site investigation before tendering process which was highest ranked. So that, automatically other strategies can be accomplished. Incomplete design and drawings will head to additional works where a variation can be arisen. By appointing well experienced supervisors, it can be known about risks the project will face beforehand. As per Halwatura and Ranasinghe, (2013) the examination should be done appropriately by qualified and experienced skillful staff at the beginning stage (within the pretender period) and sufficient planning in development is required by all included parties before work begins at the site. The estimation work should be formulated. Further, consultants should guarantee that the designs and specifications drop within the initial financial limits. Further, all parties ought to estimate unanticipated situations. Specialist coordination is required at the planning stage, and utilization of an experienced specialist to create a proper plan and drawings.

2.5 Initial results obtained from the literature overview

Following Table 1 shows the causes of variation orders which acquired from literature survey. From literature survey it was found that variations can be happen under 4 main categories. They are,
• Owner related variation causes • Contractor related variation causes • Consultant related variation causes • Unspecified variation causes. Based upon above main 4 categories following listed are the most common causes.
Ruben Ndihokubwayo [1], Andualem Endris Yadeta [2], R.U. Halwatura and N.P.N.P. Ranasinghe [3], Haimanot Chalchissa [4].

Table 1. Causes of variation orders

Causes of Variation Orders	Source [1]	Source[2]	Source[3]	Source[4]
Difficulty in rapid decision-makingprocess	√	√		√
Change in design by the parties		√	√	√
Insufficient drawing details	√	√		
Change in specifications	√	√		√
Destitute in procurement process	√	√		√
Scarcity of communication	√	√		√
Unforeseen problems	√	√	√	√
Design faults	√	√	√	√
Contractor's desire on high profit		√		√
Absence of parties' involvement in design	√	√		
Change of plans or scope (including timeplans)	√	√	√	√
Lack of strategic planning	√	√	√	

Contractor's lack of required testimoniesand professionalism		√		√
Consultant's lack of judgment and professionalism	√	√		
Consultant's lack of required testimonies	√	√		
Poor coordination within involved parties	√	√		√
Varying site conditions		√	√	
Unawareness with local conditions		√	√	
Void of skills (including labors)		√	√	√
Transition in budgetary conditions	√	√	√	√
Technological variations	√	√	√	√
Climate conditions	√	√	√	

3 MATERIALS AND METHODOLOGY

The initial information for this study was gathered from a literature overview. Advance, a set of questions were distributed among experts within the road development ventures in Sri Lanka. The writing survey was done by reviewing the online sources, and construction administration and designing journals. The quantitative analysis is supposed to be done in online form. To achieve the research's goals, the questions were divided into five parts: General information (company and respondent profiles) make up section 1. The prevalence of variants in road construction projects is covered in section 2. Causes of variation orders are covered in part 3. Implications of variation on time management are discussed in section 4. Lastly, strategies to minimize variations are discussed in section 5.

4 RESULTS

This study examined how variations in road construction projects in Sri Lanka impact on time management. The outcome of the analysis is presented in this chapter. The Statistical Package for Social Sciences was used to examine the data collected. Science (SPSS).

4.1 Respondents' profile

All parties who serve as clients, consultants, and contractors were provided with 14 questions. Thirty-three responses were responded which was sufficient for data analysis and discussion of the study. The professionals from various parties involved in Sri Lanka's Road construction industry who were working on projects were the target respondents of the survey. According to Table 2 below, among the responders, 23 (69.7%) were contractors, 7 (21.2%) were consultants, and the other 3 (9.1%) were clients or owners' representatives.

Table 2. Type of the organization

Type of the organization				
		Frequency	**Percent**	**Cumulative Percent**
Valid	**Consultant**	7	21.2	21.2
	Contractor	23	69.7	90.9
	Owner/ Client	3	9.1	100.0

According to Figure 1, the majority of respondents (69.7%) worked as contract administrators, followed by 27.3% of site engineers, 6.1% of project managers, 21.2% of quantity surveyors, and rest were consisted of technical officers, structural and planning engineers, site surveyors and safety officers.

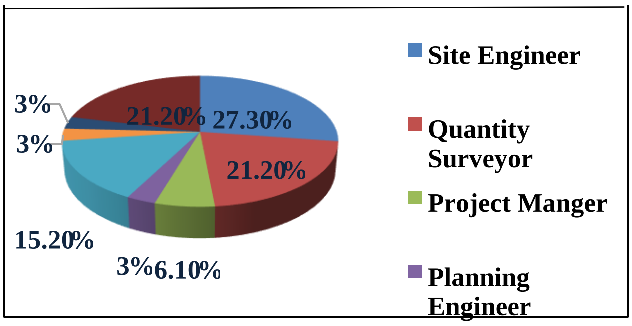

Figure 1. Current position of the organization of respondents’

The majority of responders had 0 to 5 years of experience, according to their years of experience. 57.6% of respondents have less than five years' experience, 21.2% have six to ten years' experience, 12.1% have eleven to fifteen years' experience, and 9.1% have more than fifteen years' experience.

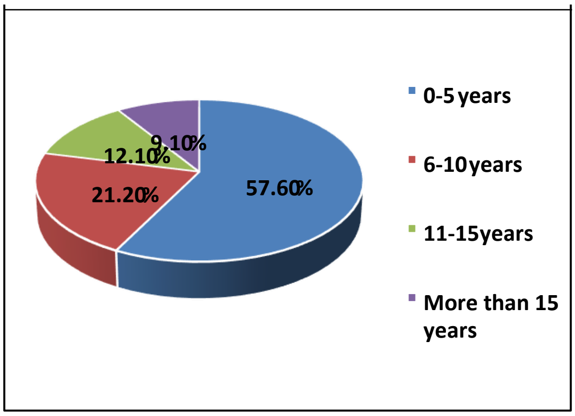

Figure 2: Professional experience in road construction projects

4.2 Factors causing variations

Under factors causing variations there were 5 categories upon their nature. These categories were further sub categorized for precise data collection.

- Variations which occur due to site conditions
- Variations which occur due to involved parties
- Variations which occur due to technical factors
- Variations which occur due to procurement process
- Variations occur due to local conditions

A mean score of 0 indicates that respondents strongly disagree with the measuring variable used in this study, a number between 1 and 2 indicates that respondents are disagreeing, and a score between 2 and 3 indicates that respondents were neutral.. Respondents who gave the statement a mean score of 3.00–4.00 indicated agreeing and a mean score of 4.00– 5.00 strongly agreed with it.

Under variations which occur due to site conditions three factors were subjected into consideration. In item 1- Right of Way (ROW) which means difficulties faced in land acquisition process was ranked 2nd with the mean score was 3.6970. It means majority of the respondents were agreed upon the statement. In item 2- Delay in obtaining permits from local authorities and insufficient coordination between the parties of relevant authorities; usually from electricity board, telecommunication and water authorities ranked in 1st with a mean of 3.8485. As in last, varying site condition ranked in 3rd. Based upon above statements it can be seen site conditions impact on a considerable range on variations.

Table 3. Variations which occur due to site conditions

Variations which occur due to site conditions						
	N	Minim um	Maxim um	Mean	Std. Deviation	Rank
Right-of-way	33	1.00	5.00	3.6970	1.01504	2
Delay in Obtaining Permits from Local Authorities	33	2.00	5.00	3.8485	1.00378	1
Varying Site Conditions	33	1.00	5.00	3.3030	1.04537	3

According to the table 4 inefficient co-ordination within parties score a mean of 3.5758 which is most likely to be agreed on the statement. The disputes arise between the parties may directly affect on project variation when they are not coordinated properly by involved parties. In the 2nd score delays in engineers' decision making has taken place. Most respondents have agreed that prompt decision making process could be a cause. As in 3rd rank inadequate detailing provided by consultants specially about the site conditions, the population of the relevant area, and other engineering details. The item number 4 shows that contractor's lack of required testimonies and professionalism is not really affected on a variation.

Table 4: Factors which influence involved parties to get into a variation.

Variations which occur due to involved parties						
	N	Minim um	Maxim um	Mean	Std. Deviation	Rank
Lack of Communication	33	2.00	5.00	3.151 5	.83371	4
Delays in Engineers decision making process	33	3.00	5.00	3.363 6	.60302	2
Poor coordination within involved parties	33	2.00	5.00	3.575 8	.86712	1
Contractor's lack of required testimonies and professionalism	33	1.00	4.00	2.697 0	.98377	5
Inadequate detailing provided by the consultants	33	2.00	5.00	3.303 0	.76994	3

Table 5 represents variations which occur due to technical factors. Rank no1- Required equipment and tools not been available scores a mean of 3.5455 which means most respondents have agreed that the lack of availability of tools and equipment can cause a variation. Furthermore, the inefficiency of these equipment also may cause to arise a variation. The mean score 3.5152 implies that most of the respondents have agreed that lack of skills including staff also a major cause of variation. The workmanship may not be available as per specifications. Other than that lack of technically competent and experienced staff has also impacted on variations.

Table 5: Variations which occur due to technical factors

Variations which occur due to technical factors						
	N	Minim um	Maxim um	Mean	Std. Deviation	Rank
Scarcity of skills including labor	33	2.00	5.00	3.5152	.93946	2

The required equipment and tools not being available	33	2.00	5.00	3.5455	.75378	1
Health and safety considerations	33	1.00	5.00	3.4242	.93643	3
Lack of technical competent staff	33	1.00	5.00	3.1212	1.05349	4

According to the table 6 it can be observed that procurement process causes a considerable impact when comparing to other variation causing factors, as they clearly show a higher mean value. The design faults have scored a mean of 4.0303 which means most of the respondents have strongly agreed that design faults cause variations. The rank 2nd and 4th describe causes which are more over similar to 1 st rank while in 3rd place respondents have agreed that alteration of plans including time plans most probably time extensions, cause variations. Other than that poor estimation and transition in budgetary conditions have also been impacted on variations. Value engineering (mechanism of saving cost for mutual benefit) the mean score of 3.4848 implying the most respondents have agreed that the mechanism of saving cost for mutual benefit is one of the reasons for variations.

Table 6: Variations which occur due to procurement process

Variations which occur due to procurement process						
	N	Minimum	Maximum	Mean	Std. Deviation	Rank
Change of plans including time plans	33	1.00	5.00	3.7879	1.08275	3
Insufficient project objectives	33	1.00	5.00	3.0909	.97991	10
Design faults	33	3.00	5.00	4.0303	.80951	1
Change in design by the parties	33	2.00	5.00	3.9091	.84275	2
Change in specifications	33	2.00	5.00	3.7273	.76128	4
Value engineering	33	2.00	5.00	3.4848	.83371	7
Additional preliminaries due to time extension	33	2.00	5.00	3.5758	.96922	5
Poor estimation	33	2.00	5.00	3.4848	1.06423	7
Transition in budgetary conditions	33	1.00	5.00	3.5152	1.03444	6
Changes in project duration	33	1.00	5.00	3.3030	.95147	9

In table 7 represents the other considerable factors causing variation orders. In the 1st rank the changes due to price inflation and fluctuations in foreign exchange rates have impacted considerably on variation. The climatic conditions mostly during the rainy seasons work cannot be carried out in open areas. Change in government regulations and unawareness also a main reason behind variations. Moreover, the ban imposed by the government currently (2023) on importing of construction materials and equipment has adversely impacted on the industry.

Table 7: Variations which occur due to socio, economic, and local conditions

Variations which occur due to socio, economic, and local conditions						
	N	Minim um	Maxim um	Mean	Std. Deviation	Rank
Climatic conditions	33	1.00	5.00	3.848 5	1.00378	3
Sociocultural factors	33	1.00	5.00	3.121 2	.92728	7
Changes in government regulations	33	2.00	5.00	3.848 5	.79535	3
Unawareness with local conditions	33	1.00	5.00	3.181 8	.84611	6
Unforeseen problems	33	2.00	5.00	3.666 7	.88976	5
Changes in price due to inflation	33	1.00	5.00	3.939 4	.99810	1
Foreign exchange rate fluctuations	33	1.00	5.00	3.939 4	.96629	1

4.3 Effect of time on overall project performance due to variations

Time administration is a most important key component in road construction project. According to the findings it can be observed that that time has been negatively impacted by variations. Regarding the 1st item variation plays a major role when delaying of projects. The majority have agreed that occurrence of variations is inversely proportional to efficient time management. It means when variations increase it will allow a project to be inefficient in terms of time management. Most of the respondents have neutralized their opinions but still majority has extended that they disagree with the statement. So, it represents that when a variation is handled carefully so as the time plan will also be according to the provided schedule. But when comparing with the previous statement a little contrast can be seen between these. The time is directly proportional to the cost of the project. Majority of the respondents have agreed on the statement. Usually when the time is incurring the overhead costs, labor wages get increased eventually.

Table 8: Effect of time on overall project performance due to variations

Effect of time on overall project performance due to variations						
	N	Minim um	Maxim um	Mean	Std. Deviation	Rank
Excessive variation orders result in incurring unnecessary time	33	1.00	5.00	3.1515	.87039	4
Reducing time duration of construction projects will results reduction on project cost	33	1.00	5.00	3.3030	.88335	2
No matter how carefully a variation order is administrated initial time plan will be altered	33	1.00	5.00	3.0000	1.00000	5
The reduction of variability in construction operations can contribute to efficient time management	33	2.00	5.00	3.5758	.79177	1
The occurrence of variation orders is the major factor of delay in delivery in construction projects	33	1.00	5.00	3.2424	1.03169	3

4.4 Mitigation strategies to minimize variations

To overcome these issues some mitigation strategies have been proposed in the paper. The procurement process which means, precise designs and documents should be present. Also, before initiating the project scope, objectives should be clearly understood by the parties.

Coordination among parties, proper communication also plays a major role. Other than these even though parties get early warnings on variations it could be/ not be identify the issue in advance. This might happen due to unawareness with local conditions. Using modern technologies like BIM, lean principles also that might be because of the lack of knowledge about it between parties.

5 DISCUSSION

Based on the results which gained from both case study and the literature survey the eight most important factors causing variation orders can be discussed as follow.

1) Design faults

According to the findings, design issues brought on by errors and omissions result in delays, and the waste of public expenditures because they necessitate redesigning during the implementation stage. If it isn't fixed during the design phase, it may cause delays and productivity losses and, it might show up during the construction phase.

2) Unforeseen problems

The second most significant reason for order variation in road construction projects was discovered to be unforeseen site characteristics/unexpected ground conditions and terrain as a result of ineffective site inspections. The findings proved that while conducting proper site or subsurface studies, the responsible party, probably the consultant, do not learn much about the site conditions during the design stages. As a result, contractors frequently run upon unexpected subterranean or concealed circumstances throughout some projects, which can lead to variations and have a significant impact on the amount of time and budget needed to complete their work.

3) Change of plans including time plans

One of the primary reasons for construction project variation is changes to the planning including time plan. This is the result of poor project definition planning or a lack of owner participation in the design process. Through this study it was discovered that one of the factors that has a significant impact on project implementation is the client's additional scope of work.

4)Transition in budgetary conditions

The owner's financial issues have an impact on the project's overall development and quality. As a result, work plans and specifications are modified. Due of the dependency of laborers and subcontractors on the contractor, construction projects may be significantly altered by the contractor's financial issues. Such challenges during a project will lead to variation orders, which may also have an impact on the project's quality and progress.

5) Technological variations

The construction process evolves as a result of technological improvements, including construction methods may alter to meet quality and safety standards.

6) Changes in specifications

Due to insufficient project objectives, changes in specification are a typical occurrence in construction projects. If the client's requirements change, the construction phase will also change.

7) Climatic changes

Poor weather conditions might affect project construction, which could result in adjustments, delays, and higher expenses.

8) Delay in obtaining permits from local authorities or insufficient coordination between various departments in utility shifting and placing.

Finding the effects of variation order on time management was the study's second goal. To do this, the study organized the impacts from the literature, sought for professional input, and then set out to identify the effects of variation ordering based on respondent responses.

The results demonstrate that the most significant effect of variation orders on time of road projects is time extension (time overrun). Small variations may not affect overall project completion, but they will slow down development, according to Arain and Pheng (2006b). However, frequent minor and substantial variations have a negative impact on the project and create delays in its completion. Even while contractors typically use the free floats in the construction schedules to account for the implementation time for variations, there are occasions when they become continuous and of a degree that prevents them from fitting within the floats. Every project assigns a contingency payment to account for potential project variations while retaining the total project cost because it is predicted that some project variations may cause the project cost to increase. However, frequent and significant deviations cause the contingency sum to cost more than expected.

Another most common issues in the construction sector which occurs due to variations is the delivery of construction projects being late. All individuals and organizations participating in the project are impacted by delays. This is certainly relevant for the owner's company because postponing the project's commencement would make it more difficult to generate the anticipated project revenue and will increase financial expenses. The obligations assumed based on the delivery date specified in the contract may also put the owner in a difficult situation. On the other hand, extending the project's execution period typically forces contractors to deal with cost overruns caused mostly by the following factors: additional management personnel costs, material cost inflation, finance cost growth, contract penalties, etc.

According to the results obtained from both literature overview and case study the main strategy proposed was to conduct site investigations and preparing of precise design documents during procurement processes.

Conducting site investigations prior to initiation of the project will minimize the risk of variations which occur due to contrasting geographical features and other circumstances. Being more aware during the procurement processes is an important task because variation in design may lead to rework which incur cost and time also. Defining project goals and scope of the work plays an important role when it comes to minimization of variations. Each individual should have an idea about the project so that he/she can contribute as required. Since various parties are including proper communication should be at its maximum potential. Because if a party propose an opinion and if it does not go through with other parties properly not only variations even misunderstandings and contradictions may occur. Moreover, working with experienced staff (both technical and labor) will lead to resolve negative effects of variations as in getting specialized labor for machinery and equipment handling and specially knowing their potential.

Apart from that using modern construction methods, integrated procurement methods (i.e., lean principles, BIM technology) would minimize variations in the industry.

6 CONCLUSION

The first objective of the study was to find prevalence, causes and origin agents of variations in Sri Lankan Road construction industry. The most common cause was disputes arise in designing stage. The same opinion was headed by authors in literature survey too. Therefore, based on the data obtained from both studies' variation seems to be a major problem in Sri Lankan Road Construction projects and the main effect of it on works are omission of works. The client has a higher responsibility when compared to other parties throughout the project.

The second objective of the study is to find out how much impact does the variation affect on time of a project. As in both studies variation results negatively in overall project performance.

Even if it's a minor or major variation incurring of excessive time could not be neglected. Since project cost, time and quality are interconnected if time is altered definitely the project cost and quality will be altered. Apart from that if a project experiences a time overrun the reputation of the organization will get damaged so as disputes and conflicts may arise between involved parties. For efficient time management project management tools could be used.

According to the third objective of the study there were various strategies proposed to minimize variation orders in the industry. Conducting site investigations at an initial stage of a project is most important. The whole process should be involved by well experienced and technically qualified staff. Defining project objectives and scope in a clear manner at an earlier stage so that everyone knows their duty prior. Precise procurement processes including design documents, proper estimations play a major role when minimizing variations. Better coordination with involved parties in every stage of the construction also play a vital role. Ensuring that designs and specifications are on point before commencing major stages of the process in important. Since road construction directly deals with the public and other stakeholders, management of them should be done carefully and in a polite manner.

According to the study's findings, variation orders are one of the biggest issues with Sri Lankan Road construction projects and have a big impact on their success. The first issue that needs to be addressed in order to minimize variation orders and their impacts is effective management of construction modification, which calls for both engineering and project management expertise. The design stage through the construction phase is all considered possible causes of variable order in this study. The researcher advises that thorough planning should be done at the beginning of the project by all stakeholders involved.

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Development of Roughness Prediction Model for Sri Lankan Expressways

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ABSTRACT

Expressways play a pivotal role in industrial and export development in Sri Lanka by providing access to the production sector in addition to the passenger transport in between transport hubs. A reliable pavement performance prediction model is essential for pavement management systems to optimize the cost of maintenance and rehabilitation planning. In this study, pavement roughness prediction of expressways in the long-term performance was conducted using International Roughness Index (IRI) which is used as a global parameter to measure the ride comfort of road users and the unevenness of pavement. Firstly, initial IRI values for Sri Lankan expressways were established by using current data and found that, it varies between 0.90 to 1.45 m/km. Secondly, IRI prediction model developed with cumulative traffic volume, considering outer lane IRI as the dependent variable due to higher deterioration rate compared to inner lane. Moreover, it was found that, there is a good relationship between IRI with cumulative traffic with R-squared of 0.60. Further, it can be concluded that, the outcomes of this study can be effectively used for Sri Lankan context in long term performance evaluation and expressway maintenance planning.

KEYWORDS: *International Roughness Index, Expressways, Pavement Deterioration, Cumulative traffic*

1 INTRODUCTION

Road's assets develop as a consequence of facilitating trade by improving access to education, business, health, and other community services. An efficient road transport would lead to higher incomes and economic well-being (Perera et al., 2019). As a result, enhancing road quality increases personal and community mobility, and drives economic growth. Maintaining roads at a higher quality level generates socio-economic benefits, such as reducing transport costs by minimizing vehicle damage and travel time, making trips to farms or markets easier, and increasing visits to commercial centers, among other benefits (Kothari et al., 2022). As the World Bank notes, road infrastructure is one of the most important public assets in any country (The World Bank, 2017). Proper monitoring and maintenance

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schemes can ensure the preservation of road strength, quality, and safety, regardless of whether the road is paved or unpaved. Reliable road condition monitoring is crucial in achieving a better-quality road network within a region or country.

Pavement condition is an important aspect of road maintenance decision making. The need of quick identification of pavement condition deterioration is highly important to road agencies. If a road agency is unable to make timely repairs to pavement that is in the early stages of deterioration, the condition of the pavement will rapidly get worsen, resulting significant increments in maintenance cost due to the need of more costly rehabilitation methods or requiring reconstruction of the affected road segments (Pasindu et al., 2020). The use of pavement condition data to support maintenance and resurfacing strategies and to justify budget needs, becomes more critical as more data-driven approaches are being used by the road agencies. Both manual data collection techniques and automated data collection techniques (used techniques are line and area scanners, ground-penetrating radar, acoustic sensors, optical imagery, LIDAR, etc.) are used for this purpose (Denis, 2014).

In Sri Lanka, there are more than 300 km of expressways in different environments and terrain conditions (Road Development Authority, 2017). Predicting pavement performance of such roads are challenging due to lack of data availability and complexity of contributing factors on deterioration. An accurate pavement performance prediction model with the capability of assessing local deterioration patterns with heterogeneous traffic composition would be a handful tool in road asset management systems. Various researchers proposed different performance prediction models for expressways, but due to lack of adoptability of such models to Sri Lankan context, those are no longer accepted. Moreover, there are no real field investigations conducted in Sri Lanka to predict the performance.

To cater that problem, this study is focused on developing pavement performance prediction model to adopt in maintenance decision making. The objective of this research is to identify the factors related to pavement deterioration and to use the collected data from expressways to forecast the roughness progression with the relevant explainer variables traffic volume.

1.1 Roughness as a Pavement Condition Evaluation Metric

Road pavements are designed and maintained to ensure its primary objectives are achieved during its life cycle, i.e. a) to have adequate structural capacity to withstand the vehicular loading on the pavement which is referred as the structural performance and b) to ensure the rider comfort and satisfactory skid resistance are available which represents the functional performance of the pavement. Pavement roughness can be measured by using various indices such as Ride Number (RN), International Roughness Index (IRI), Half-car Roughness Index (HRI), Mays Ride Meter (MRM), Quarter-car Index (QI), and Present Serviceability Index (PSI) (Múčka, 2017). Among those, International Roughness Index (IRI) is globally accepted as a suitable parameter to measure the pavement roughness as an indication of cumulative vertical displacement recorded due to the irregularities on the pavement over a measured distance and normally represented in m/km or mm/km (Múčka, 2017). Roughness also refers to the longitudinal profile of a pavement as shown in Figure 1.

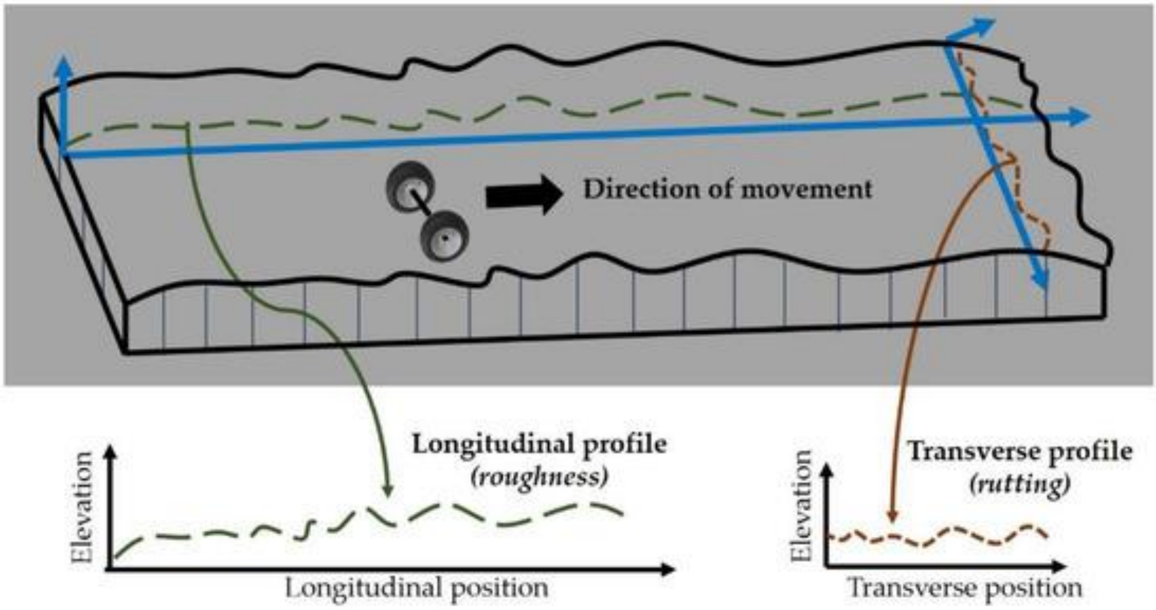

Figure 1. Pavement Roughness Derivation from a Longitudinal Profile *(Gkyrtis et al., 2021)*

The acceptable roughness values can also be established based on the operational speed of the road, as the resulting vibration induced by the pavement roughness would be affected to an extent by the speed of the vehicle (Yu et al., 2006). This is an important consideration for road agencies as the definition of the maintenance thresholds can be varied depending on the type/hierarchy of the roadway within the network. For example, to initiate rehabilitation works, an expressway which would have higher operational speeds (90-100 km/h) would have a lower maximum acceptable IRI value (e.g. 3-4) compared to the IRI threshold (8-10) of a low volume rural road which would have lower operating speeds (30-40 km/h). Table 1 illustrates the IRI thresholds for different roadways concerning operating speed.

Table 1. IRI Thresholds for different operating speeds *(Yu et al., 2006)*

Ride Quality Level	**IRI Thresholds at Different Speeds (m/km)**					
	20	**40**	**60**	**80**	**100**	**120**
Very Good	< 5.72	< 2.86	< 1.90	< 1.43	< 1.14	< 0.95
Good	5.72 – 8.99	2.86 – 4.49	1.90 – 2.99	1.43 – 2.24	1.14 – 1.79	0.95 – 1.49
Fair	9.00 – 11.39	4.50 – 5.69	3.00 – 3.79	2.25 – 2.84	1.80 – 2.27	1.50 – 1.89
Mediocre	11.4 – 16.16	5.70 – 8.08	3.80 – 5.40	2.85 – 4.05	2.28 – 3.24	1.90 – 2.70
Poor	> 16.16	> 8.08	> 5.40	> 4.05	> 3.24	> 2.70

The relationship for equivalent IRI values corresponding to different speeds is given as in Equation 1 (Múčka, 2017).

$$IRI(v_2) = \left(\frac{v_1}{v_2}\right)^{0.5} IRI(v_1) \tag{1}$$

Where, this choice of IRI values should meet the condition of the same quarter-car model suspension relative velocity response for two different velocities. For example, for two road speed limits, v_1 = 50 km/h (local roads) and v_2 = 110 km/h (highways), IRI (110)/IRI (50) = 0.67 should hold.

1.2 State-of-Practice: Application of IRI Progression Modelling in Expressways

Expressways are known to be an important integral part of a road network in a country since it is operated with higher speeds generally between states/provinces with a comfortable riding quality. Therefore, it is important to use a metric having good precision and repeatability, to monitor expressways. The roughness measurement devices are also categorized based on their accuracy and the data collection frequency. The ASTM standard E 950 (ASTM, 2003) defines roughness into four categories from Class I to Class IV based on the precision level, sampling interval, bias etc. Since Class I & II measurements measure the actual road profile with high precision, those are adopted to measure IRI in expressways.

Typically, a Network survey vehicle is equipped with a digital Laser Profiler (DLP) which has the capability of estimating various data types in higher accuracy and precise levels. Most of the equipment can collect data for 3.6 m width at once and it reduces survey time and costs due to the ability to collect data at expressway operational speeds (usually up to 100 km/h). These laser measurements produce outputs such as roughness, rutting, longitudinal profile, faulting, transverse profile, raveling and macro texture (ARRB, 2000). Table 2 illustrates the overview of the pavement condition metrics which can be measured by laser profilers.

Table 2. Overview of Pavement Condition Metrics Measured in Laser Profilers

Pavement condition metrics assessed	**Attributes measured for each metric**	**Laser Profiler Type(s) / Road agency**
Roughness	Longitudinal profile	ROMDAS Laser Profiler (ROMDAS Data Collection Ltd, 2011) ARAN System (Sršen, 2002) PaveProf V2.0 (PaveTesting® Ltd, 2011) LCMS-2 (Pavemetrics, n.d.) Laser Profiler NTUA (Loizos & Plati, 2008) Haweye-2000 (ARRB, 2000)
	Profilograph Index (PI), Ride Quality Index (RQI), Half Car Ride Index (HRI), Ride Number (RN)	PaveProf V2.0 (PaveTesting® Ltd, 2011)
Rutting	Rut type, Width (single or double), depth, cross section area and percentage of deformation	ARAN System (Sršen, 2002) PaveProf V2.0 (PaveTesting® Ltd, 2011) LCMS-2 (Pavemetrics)
Faulting	Elevation difference	Haweye-2000 (ARRB, 2000)

Moreover, various studies worldwide have implemented IRI based measurements in their expressways and superhighways as presented in Table 3. From that it can be observed that initial IRI threshold is in between 1.6 – 3 m/km while maintenance threshold is in the range of 2.7 – 4.3 m/km for expressways.

Table 3. IRI Thresholds for Expressways and Superhighways in Worldwide

Country	**Road Type**	**IRI Limit Specification (m/km)**	
		New Roads	**Maintenance Intervention**
Australia	Freeways	1.60	3.50
	Main roads (100 km/h)	1.90	3.50
Russia	Speed > 50 km/h	1.90	4.30
Czech Republic	National highways	1.26	2.76
Missouri, USA	Highways and first-class roads	2.20	4.20
Norway	Highway	2.00	3.50
New Zealand	Highway	-	3.82
Philippine	National primary roads	3.00	-

The performance prediction models can be classified into two categories as deterministic and probabilistic models (Lytton, 1987). The deterministic models are either empirical or empirical-mechanistic (M-E) models consisting of primary response, structural performance, functional performance, and damage models (George et al., Models for Predicting Pavement Deterioration, 1987). The probabilistic models include Markov chain (MC), Bayesian regression, and survivor curves (Lytton, 1987) (Carnahan et al., 1987).

Empirical models are developed by implying the regression analysis which generates the relationship between parameters such as pavement age, cumulative traffic load, climate condition, pavement aging effect, etc. The roughness deterioration rate differs with the climate condition, traffic density has developed for empirical modelling as shown in Table 4.

Table 4. Empirical IRI Deterioration Models for Expressways

Reference	Factors Used	Key Findings
(George, MDOT Pavement Management System, 2000)	AC overlay thickness, (TOPTHK), CESAL, Pavement age	Regression equation: $IRI = (3.095 + Age^{0.3571} (1+CESAL^{0.3054}))\ TOPTHK^{-0.3235}$ Pavement age is the most significant predictor of deterioration. Power models found to be the best representation.
(ARA, I. E. D. , 2004)	Pavement age, fatigue cracking $(FC)_T$, transverse cracks $(TC_s)_H$, Patches $(P)_H$, Freezing Index (FI)	Model: Bituminous treated base $IRI=IRI_0+0.0099947(age)+0.0005183(FI)+0.00235(FC)_T+18.36\{1/(TC_s)_H\}+0.9694(P)_H$
(Albuquerque & Núñez, 2011)	Modified Structural Number (S), ESAL (N), Climate (C)	$IRI_{(HMA)} = -173.4 + e^{(5.177 + 0.001 * C - 0.002 * S + 0.005 * N)}$ To reach IRI intervention IRI of 3.5m/km this model would take 9 years.
(Paterson, 1987)	Structural Number (SNC), ESAL, pavement age, Wearing course type	Regression Model: $IRI=[IRI_0+725(1+SNC)^{-4.99}\times ESAL]\times e^{0.0153AGE}$

2 DATA COLLECTION

In this study, the entire expressway network in Sri Lanka is selected as the study area which consist of 312 kms in length (Figure 2), and Table 5 shows a summary of details of expressway network. IRI data is collected from Planning division, Road Development Authority, Sri Lanka and IRI data consist in 100 m sections from year 2017 to 2021, measured by Hawkeye 2000 laser profiler (ARRB, 2000) which is a Class-I roughness measuring equipment as per ASTM Standard (ASTM, 2003). For the analysis, raw IRI data were segmented to 1 km sections. Moreover, Traffic data is collected from the Statistics Reports published by National Transport Commission, Sri Lanka (National Transport Commision, 2023).

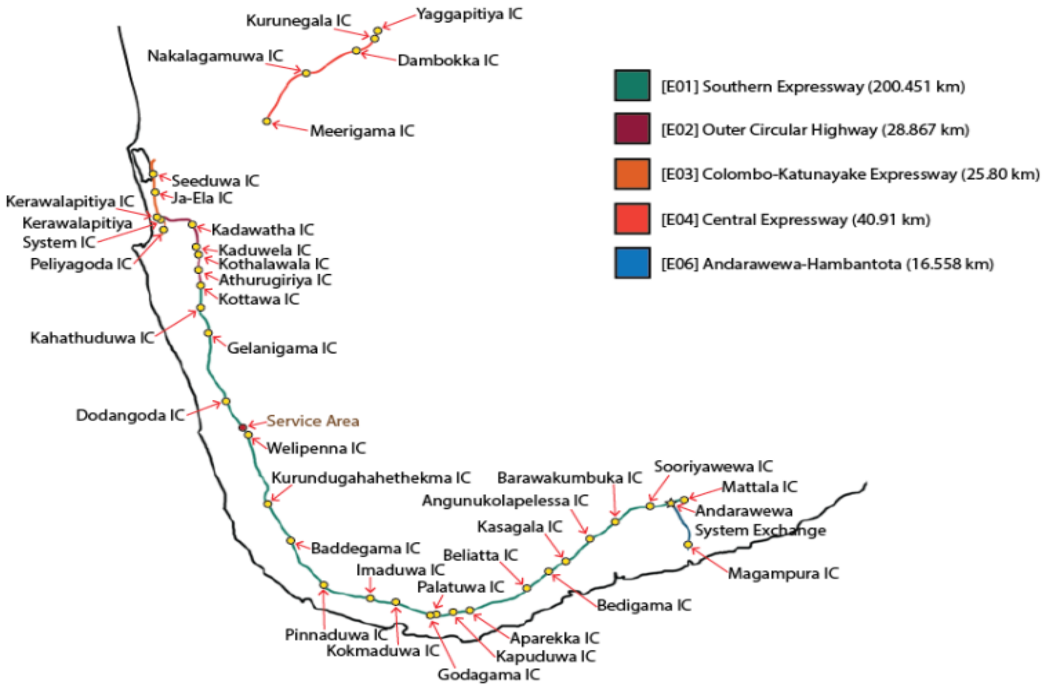

Figure 2. Expressway Network in Sri Lanka *(Road Development Authority, 2017)*

Table 5: Expressway Network in Sri Lanka *(Road Development Authority, 2017)*

Expressway	Segment	Length (km)	Year of Opening
E01 Southern Expressway	Kottawa To Galle	100.0	2011
E01 Southern Expressway	Galle To Matara	36.0	2014
E01 Southern Expressway	Matara To Mattala	64.0	2020
E02 Outer Circular Expressway	Kottawa To Kaduwela	11.0	2014
E02 Outer Circular Expressway	Kaduwela To Kadawatha	8.7	2019
E02 Outer Circular Expressway	Kadawatha To Kerawalapitiya	8.6	2019
E03 Colombo to Katunayake	Colombo To Katunayake	25.6	2013
E04 Central Expressway	Kurunegala To Meerigama	41.2	2021
E06 Magampura Expressway	Andarawewa To Hamabantota	15.1	2019

3 ANALYSIS & RESULTS

3.1 Initial IRI of Expressways in Sri Lanka

Firstly, the data analysis was conducted to find initial IRI of expressways in Sri Lanka. Initial IRI is defined as the IRI value of a pavement within first six months after the construction or a rehabilitation/overlay operation. All expressways in Sri Lanka are multilane roads and it is essential to decide the lane which shows a greater variation in IRI, for the study. Thus, a comparative analysis is conducted on IRI deterioration for inner lane and outer lane separately. Figure 3 shows the deterioration pattern on Southern Expressway (EA01) from Kottawa (0+000) to Galle (100+000).

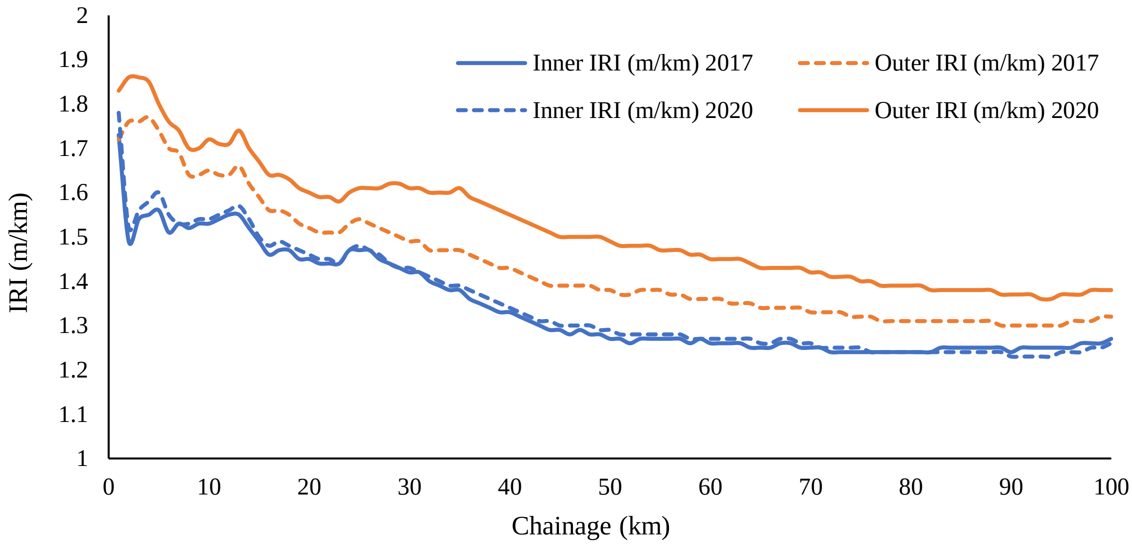

Figure 3: IRI deterioration of inner and outer lanes on Southern Expressway in Sri Lanka

From the results, it can be clearly observed that IRI deterioration on outer lane is higher than the IRI deterioration in inner lane. Further, a statistical analysis is conducted to validate the hypothesis by comparing the two populations of IRI differences in inner and outer lane and the summary of results shown in Table 6. Furthermore, Figure 4 shows the normal distribution curves of inner and outer lane separately. From the results it can be concluded that IRI deterioration difference of outer lane is higher than the inner lane.

In Sri Lanka, lane discipline is not well-maintained by road users in most of the Class A and B roads due to the driver behavioral factors and heterogeneous traffic composition. However, compared with Class A and B roads, lane discipline is observed to be more adopted in expressways since the inner lane is used only for overtaking maneuver while the outer lane is used for travelling. Hence outer lane is used by most slow-moving vehicles such as heavy vehicles and higher traffic volume can be observed. Contra verse, since the inner lane is used only for overtaking maneuver, lesser traffic volume can be observed. Therefore, these results show that the outer lane is more critical in deterioration modelling in expressways. Hence for the IRI deterioration modelling, IRI of outer lane is used as the pavement condition evaluation metric in this study.

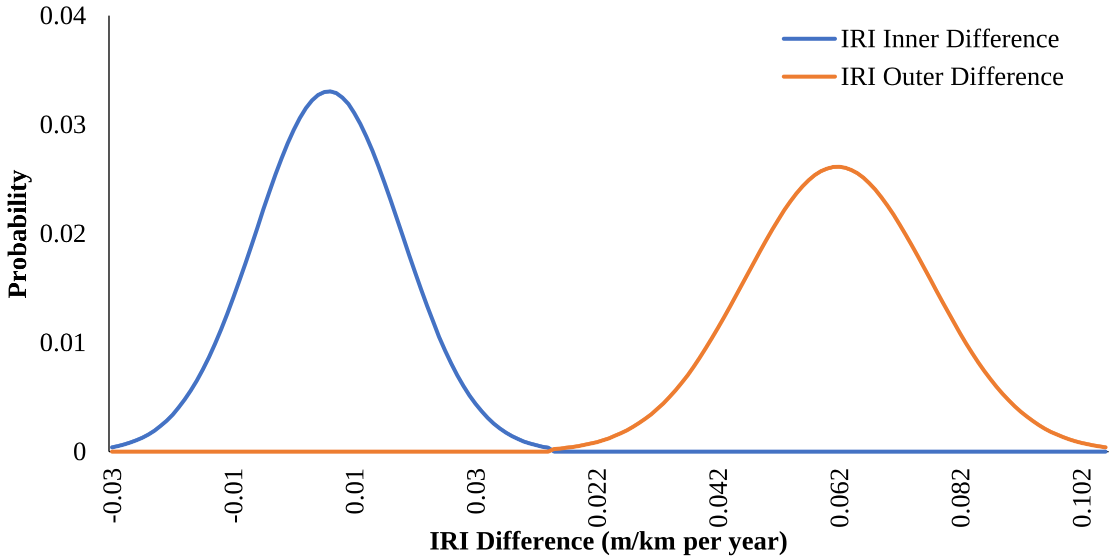

Figure 4. IRI difference for inner and outer lanes of E01 (Kottawa to Galle section) from 2017 to 2020

Table 6. Summary of Statistical Analysis between Inner and Outer Lane effect to IRI Progression

Statistical parameter	Inner lane IRI difference (m/km per year)	Outer lane IRI difference (m/km per year)
Mean	0.006	0.062
Observations	100	100
Hypothesized mean difference	0.05	
Z-statistics	3.12	
Z-critical one tail	1.64	

Considering the Sri Lankan context, three expressways' initial IRI data was available to evaluate the initial IRI as presented in Table 7. From that, it can be observed, initial IRI varies from 0.90 – 1.45 m/km. Moreover, the box-whiskers plot presented in Figure 5 shows the variation of initial IRI among the selected expressway segments.

Table 7. Initial IRI values of Sri Lankan Expressways

Expressway	Description	Chainage		Opening year	Average Initial IRI (m/km)	Standard deviation (m/km)
		From (km)	To (km)			
E01 Southern Expressway	Matara to Mattala	136.0	200	2020	1.11	0.09
E02 Outer Circular Expressway	Kadawatha to Kerawalapitiya	19.7	28.3	2019	1.08	0.07
E04 Central Expressway	Kurunegala to Meerigama	37.1	78.3	2021	1.19	0.14

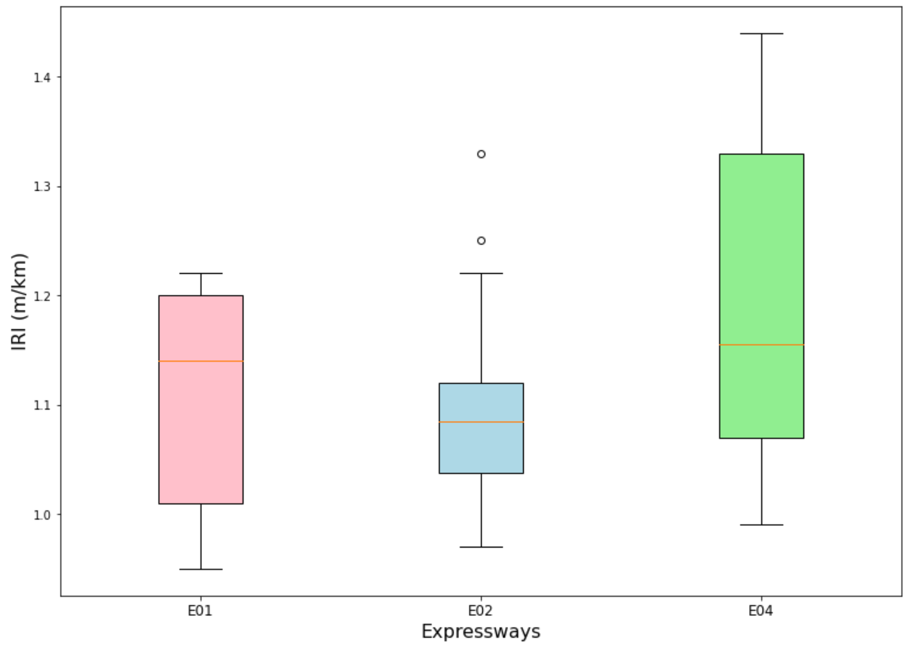

Figure 5. Boxplot of Initial IRI for Sri Lankan Expressways

3.2 IRI progression curve for Sri Lankan Expressways

Secondly, IRI progression is evaluated with the cumulative traffic volume on expressways from the latest rehabilitation. The annual traffic volume data was segmented for interchanges and evaluated by using simple linear regression analysis. IRI value on outer lane is used as the dependent variable and cumulative traffic volume used as the independent variable. Cumulative traffic value is presented in millions of vehicles. The results shown that, there is a good relationship between IRI with cumulative traffic with R-squared value of 0.60. Equation 2 illustrates the relationship while Figure 6 shows the graphical representation. Moreover, Table 8 presents the summary of the regression analysis.

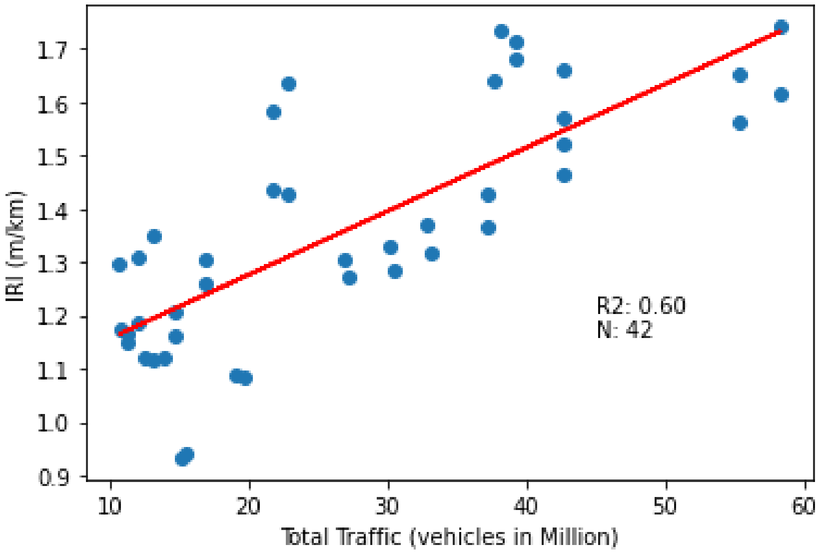

Figure 6:IRI vs Cumulative Traffic in expressways in Sri Lanka

$$IRI(i) = 1.04 + (0.02 \times Cum\_Traffic) \qquad [R^2=0.60, N=42] \qquad (2)$$

Where, IRI(i) is the IRI value of the expressway section in m/km, Cum_Traffic is the total number of vehicles traveled on the expressway from the construction or latest rehabilitation in unit of million vehicles.

Table 8: The statistical summary of IRI vs Cumulative Traffic model

Statistic			**Value**		
R-squared			0.60		
No. Observations			42		
F-Statistics			60.66		
Probability (F-statistics)			0.00		
Model parameters (method-least square)					
	Coefficient	Standard error	T-statistics	P > |t|	95% CI
Constant	1.037	0.047	21.917	0.000	[0.942, 1.133]
Cum_Traffic	0.012	0.002	7.788	0.000	[0.009, 0.015]

Further, a analysis is conducted to develop a non-linear relationship between IRI with cumulative traffic. However, it was found that there was no significant improvement in non-linear analysis in terms of model fitting. Figure 7 presents the variation of R-squared with the degree of non-linear polynomial functions. From that, it can be concluded that the linear model is a better interpreter for the IRI progression with cumulative traffic in expressways.

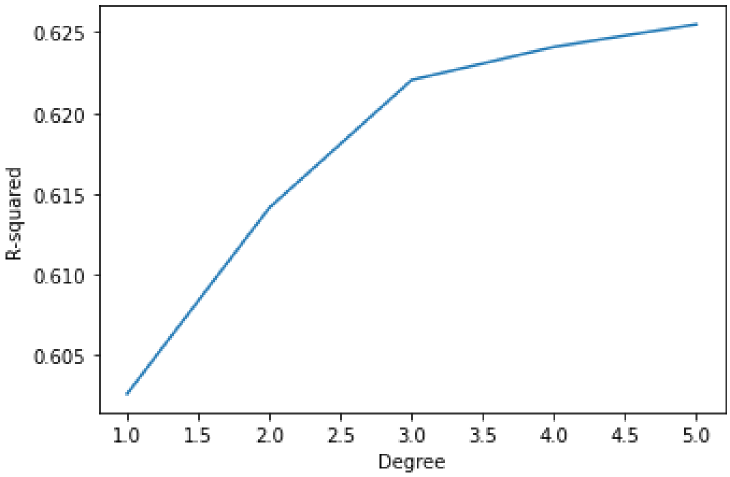

Figure 7: Variation of R-squared with Degree of Polynomial functions

4 CONLUSION

In this study, Sri Lankan expressway network is selected as the study area to develop a roughness prediction model for expressways. IRI is selected as the roughness measurement metric while cumulative traffic data used to develop the prediction model. Firstly, the initial IRI range was established by considering IRI value within the first six months after a rehabilitation activity. It was found that initial IRI vary between 0.90 to 1.45 m/km which agrees with the practice worldwide. Secondly, IRI prediction model developed with cumulative traffic volume prevailing on expressways. For this analysis, outer lane IRI is considered as the dependent variable since it was shown that IRI deterioration in outer lane is relatively higher than that in inner lane due to heavy vehicle and higher traffic volumes. It was found that there is a good relationship between IRI with cumulative traffic while the model shows R-squared of 0.60. Further, it was elaborated that the linear model is effective in interpretation since higher order polynomial functions doesn't produce significant improvement in the prediction model. Finally, the findings of the study would promote the use of pavement roughness as the objective quantitative approaches to predict pavement performance of local expressway conditions which would enable to adopt pavement maintenance management systems for their maintenance planning and ensure the roads are maintained in a more efficient manner.

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OPTIMUM ROUTE PLAN FOR EFFECTIVE COLLECTION OF AN INDUSTRY LEVEL BY PRODUCT/WASTE

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ABSTRACT

Effective waste management is critical for sustainable development in manufacturing industries, especially in managing industrial waste. Industrial waste can be transformed into high-quality products through circular economic practices, promoting sustainable development. This research aims to develop a methodology to identify an optimal route plan for collecting and distributing industrial waste and products, promoting circular economy practices. To achieve this objective, waste generated by a selected industry needs to be investigated to determine its potential for reuse in other industries. Data on the quantity and variety of waste generated daily was collected, and industries that use waste as a resource to develop their products were identified. The linkage between industries that demand waste as a raw material and those that generate waste can be established using a Geographical Information System. The study focuses on concrete demolition waste and aims to link metal crushing, aggregate suppliers, and concrete block manufacturing industries. The optimized route plan would benefit third-party sub-distributors, reducing transportation costs and facilitating effective transportation. Additionally, it would enable new entrepreneurs to establish industries and maintain a good supply chain, creating jobs.

KEYWORDS: *Optimum Route Plan, Concrete Waste, Algorithm, Waste Collection*

1 INTRODUCTION

The fundamental reason behind this study is the requirement for an effective supply chain for the products and wastes produced by various industries. The main objective of this study is to create a general method to find an optimum route plan to effectively collect and distribute products/wastes throughout the relevant industries. The major outcome of this study would be an algorithm to be used for ICT tool, that could represent all the related industries and the least time-consuming routes to reach their destinations. The system would be able to provide numerous benefits for sustainable development worldwide. Koisicek and Tesar's (2012) paper provides an analysis of a module enterprise information system aimed at developing an optimum route plan to improve the transportation system, considering various constraints such as fuel, capacity, movement costs, pickup costs, number and type of mobiles, roadmap graph types, initial locations, initial fuel, and locations. In this study, a comprehensive system to improve the supply chain management will be developed.

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Mahavar V. et al. (V, 2019) have proposed an optimum route plan for a city using GIS technology to facilitate effective transportation and reduce traffic congestion. They used Q-GIS and ArcGIS network analyzing tools to analyze road network data. Their research helped to determine the service area coverage of facilities by finding the shortest routes and reducing travel time and distance. These findings were used to improve the supply chain management system of this study.

Finally, Kumarage S.P. (2018) research shows that crowdsourced travel time data and transport planning operations can be identified using data from the Google Distance Matrix API. They developed a method for estimating traffic flow based on machine learning for urban roads. Their research provided valuable insights into using journey time data, which was used to identify the optimal route and develop an effective transportation system for this study.

2 METHODOLOGY

This study aims to establish an effective waste management system that promotes a circular economy by identifying waste-demanding industries and waste-generating industries. The methodology involved identifying waste-demanding and waste-generating industries, developing a case study methodology, creating a database, and developing a general methodology. The following steps were taken to achieve the objectives of the study:

The first step involved identifying industries that could use waste materials as raw materials for their production. The study identified these industries based on their product demands and their willingness to use waste materials in their production process. Additionally, the study identified the locations of these industries and the waste materials required from other industries.

The second step involved identifying industries or ongoing projects that generate waste material that could be used as raw material by another industry. The study identified these industries based on their waste production rates, waste composition, and the potential demand for their waste materials.

The third step involved selecting a waste material as a case study and developing a methodology to establish an effective supply chain between the industries. The methodology was designed to ensure continuous supply and demand throughout the industries, and an effective transportation system was deemed essential. The case study methodology was developed based on the following steps:

- Analyzing the waste material properties and the requirements of the waste-demanding industry.
- Assessing the transportation requirements and costs.
- Establishing a communication platform between the waste-generating and waste-demanding industries.
- Developing a monitoring system to track the waste material flow and the production of the waste-demanding industry.

The fourth step involved creating a database that included all the details about the waste materials generated by the industries and the industries that used the waste materials in their production. The database was designed to collect data and information on the daily or weekly demand of the industries and their production capacities. Additionally, the database provided a platform to purchase and sell materials between industries.

The final step involved developing a general methodology that incorporated the case study methodology and the database. The general methodology provided an effective supply chain throughout all the relevant industries and ensured continuous supply and demand. The general methodology was based on the following steps:

- Analyzing the waste material properties and the requirements of the waste-demanding industries.
- Assessing the transportation requirements and costs.
- Establishing a communication platform between the waste-generating and waste-demanding industries.
- Developing a monitoring system to track the waste material flow and the production of the waste-demanding industries.
- Utilizing the database to collect data and information about industries and their demands.
- Providing a platform to purchase and sell materials between industries.

There are various materials like demolished concrete, porcelain waste, timber dust, polystyrene waste, and chemical wastes, etc. generated by industries that can be used as raw materials for other industries. As mentioned earlier concrete waste has been chosen as the focus of the case study.

In this case, demolished concrete debris has been chosen as the raw material for the block-making industry, as it is generated by ongoing building and road construction projects. Therefore, the system being introduced must be capable of effectively collecting and distributing the material to various industries. Additionally, the block-making industry requires crushed concrete, which must also be taken into account when developing the optimal route plan.

Furthermore, there is an intermediary requirement for these materials, which is an important factor to consider when selecting the case study material.

2.1 Data collection for the case study

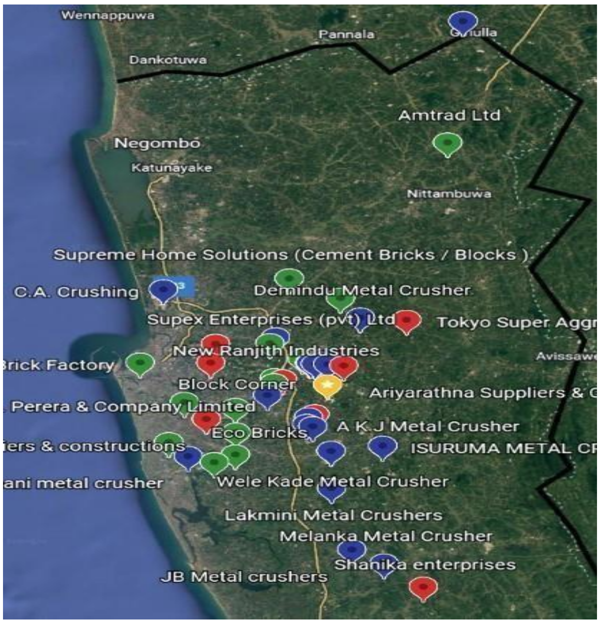

Figure 1: Locations of the case study

Destinations	Representative color
Metal crushers	Blue
Aggregate suppliers	Red
Brick Manufacturing industry	Green

Figure 2: Color notations

Data collection of buyers

Table 1: Data collected from the block manufactures

Company name	**Location**	**Output capacity (Pcs) /per day**	**Have you ever tried crushed concrete as a Material ?**	**If it is effective and meeting the same strength requirements are you willing to ?**
Supreme home solution	No,31/2, Kandy Rd, Kadawatha	1500	No	Yes
Supex Enterprises (pvt) Ltd	No 99/C, Mabima Heiyanthuduwa, 11618	4000	No	Yes
My cement block industries	267/2, High level Rd, Maharagama, 10280	1500	No	Yes
Dahara International cement block	Millewa road, Millewa	4000	No	Yes

Data collection of Intermediaries (Metal crushers)

Table 2:Data collected from the metal crushers

Company Name	**Location**	**Crushing variants (up to now)**	**Max. Output Per day (Lorry cub)**	**Stocking capacity (lorry cub)**
Isuruma Metal crusher	Tummodera - Puwakpitiya Rd	6’x4’	12	-

Datyarathne metal crusher	Gemunu Mawatha, Homagama North	6’x4’, demolished concrete	20	50
Jayakmala metal crusher	2471/A, vaikkiya Wasththa Rd, Kaduwela 10640	6’x4’	90	20
Isuru metal crushers	No 382, Yakala Rd, Kaduwela 10640	6’x4’, 6’x9’	135	-

2.2 Developing a methodology to have an effective transportation.

The theoretical methodology that exists to execute the optimum route plan is the “Transportation Problem’’ **-** “A specific kind of linear programming issue called the transportation problem seeks to reduce the price of conveying a good from M suppliers to N destinations.’’ – Google

Notations for the locations

C–Optimum route (less traffic and shortest distance)
O–Construction sites (concrete debris sellers)
D–Buyers (Block makers), Intermediaries (Metal crushers)

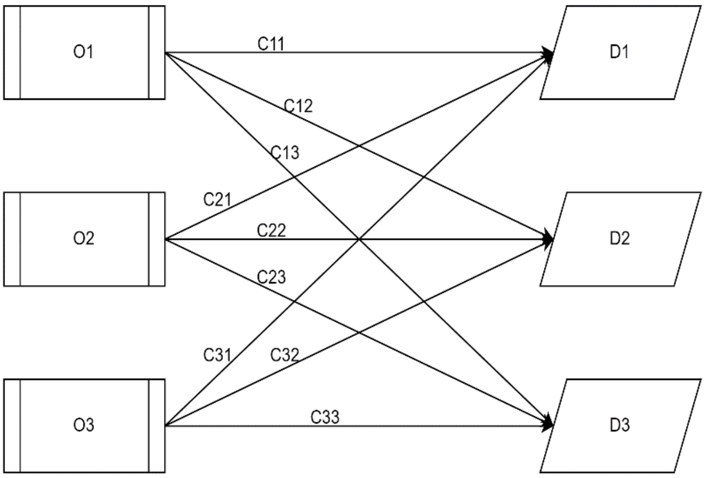

Figure 4: Representation of the theory of Transportation problem

(1)	D1	D2	D3
O1	C11	C12	C13
O2	C21	C22	C23
O3	C31	C32	C33

D – Intermediary (Metal crusher)
O – Concrete debris seller
C – Optimum route

(2)	D1	D2	D3
O1	C11	C12	C13
O2	C21	C22	C23
O3	C31	C32	C33

D– Buyer (Cement block maker)
O – Intermediary (Metal crusher)
C – Optimum route

Figure 5 : Processors of the theory of transportation

This is a representation of a methodology to execute an optimum route plan and probably it would work for a few chosen industries but not for all. So that is where it requires a proper methodology to execute an optimum route plan.

3 RESULTS

Given the technological advancements of today's world, it is advantageous to create a general methodology for finding the optimal route using web-based applications. Google Maps' GIS and Google API are two identified methods for determining the shortest and least congested route, as well as the nearest company to the transporter.

Both of these systems require a specific format for executing the optimal route, which can be achieved through a web-based mobile application carried on the transporter's device. To this end, an algorithm has been developed based on a specific case study.

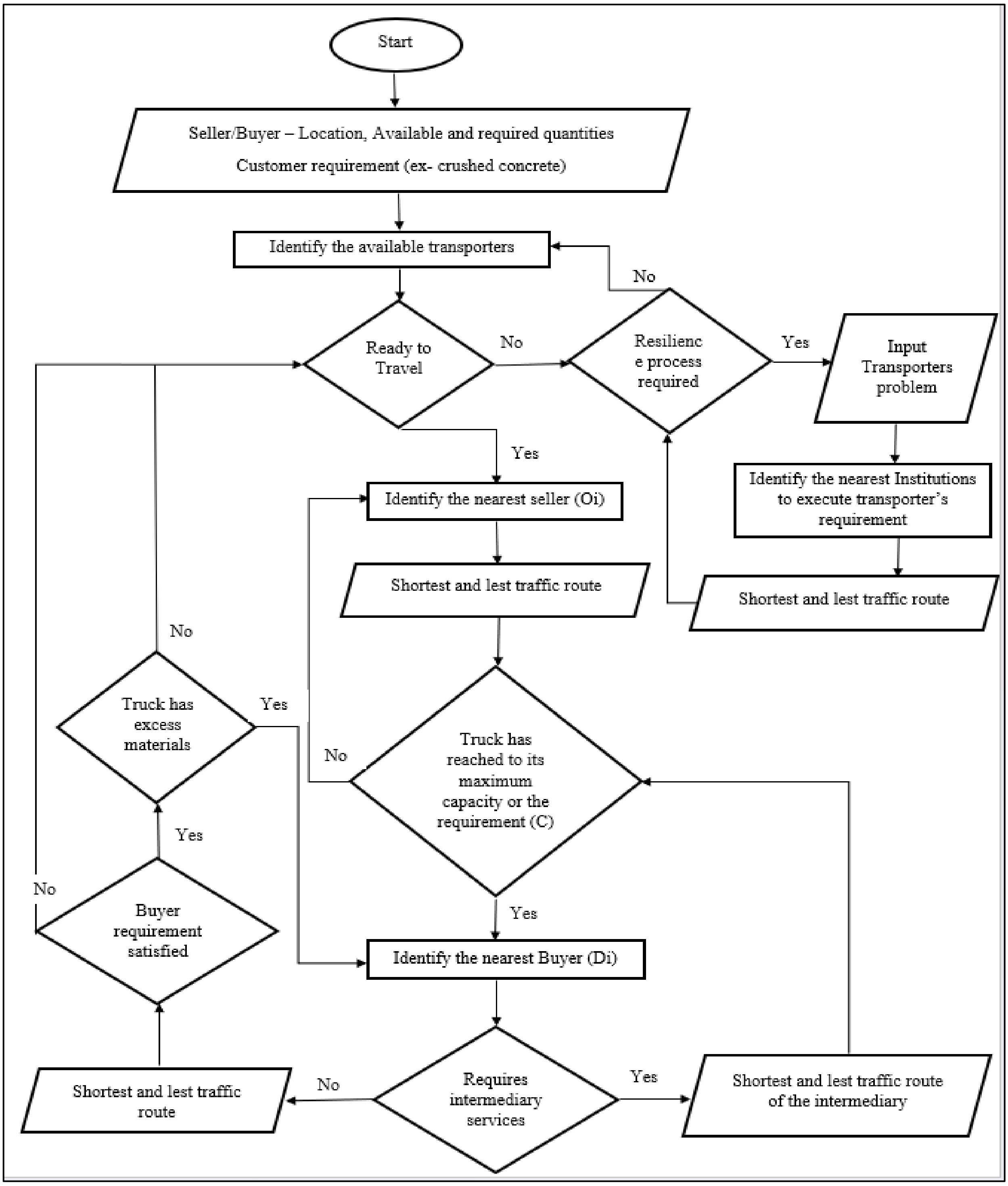

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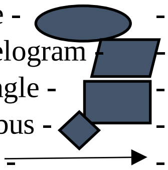
Figure 6 : Algorithm for the case study

3.1 Algorithm

The assumption that have been considered when creating the algorithm – There is a continuous demand and supply for the material.

Notation of Algorithm



Ellipse - - Starting node
Parallelogram - - Inputs/Outputs
Rectangle - - Processing (Active state)
Rhombus - - Decision node
Arrow - - Control Flow

3.2 Data

1) Available vehicles (Trucks) – Truck Capacity (C)
2) Origin Locations (Oi)
3) Destination Locations (Di)
4) Available Routes – The roads which has no restrictions for heavy vehicles, shortest and less traffic route.
5) Supply quantities from each origins (Xi) – X1, X2, X3…Xn
6) Distributive quantities for each destinations (Yi) – Y1,Y2,Y3…Yn

3.3 Truck capacity equations

X1+X2+X3+…+Xn =< C
Y1+ Y2+Y3+…+Yn =< C

3.4 Example based on hypothetical data to demonstrate the mobile application of the algorithm

Inputs -
Seller – Project/ Building Construction by seller 1
Location - 278 Union Pl, Colombo 00200
Available Material – Concrete test cubes
Available quantity – 3 Lorry cubes

Buyer – Project / Buyer 1
Location - 56/1 Pagoda Rd, Nugegoda 11222
Required material – Crushed concrete
Required quantity – 4 lorry cubes

- There is a requirement of intermediary

Intermediate party – intermediate party 1
Location – 436/3, Hokandara 10012

Process – Identify the available transporters by there feedbacks and send details about the route and work which has to be done.

If "transporter is available to travel'' – Give an **output** - the seller's details (ex:-Location - Samson Metal Crushers & Company, 436/3, Hokandara 10012, Graphical representation of the Route)

Or else – "Procced to the resilience requirement''

- After the truck is been loaded by sellers available quantity

If "The driver confirms that the truck has reached it's maximum capacity (C)" **Process** - Check for the intermediary requirements

Output – The intermediary details (The optimum route, location, contact details)

After the concrete has been crushed and loaded as per the requirement of the buyer,

If "The truck has reached its maximum capacity and it has no requirement of intermediary services"

Output – The buyer details – (Graphical representation of the Route, Location - 56/1 Pagoda Rd, Nugegoda 11222

If "The buyer requirement is satisfied" - the driver could end the work

Or else "The driver is being asked to travel again''

This is the algorithm that has been created to demonstrate the procedure of the of the web based mobile application. In order to have a continuous procedure requires a data-base which collect and stores all the data and information.

The research by Koisicek and Tesar's (2012) shows that the Route Planning Module (RPM) is a subsystem of ERP (Enterprise Relation Management), CRM (Customer Relation Management), or Supply Chain Management (SCM). Transportation for supply and distribution needs to be well-planned to achieve sustainability goals. Mainly, the system requires a database that includes information about customers, employees, goods, locations, etc. and a way to collect all that information. For the process of transportation planning, a list of merchandise, a list of initial locations, a list of available vehicles, etc., must be maintained. All the lists are composed of detailed information such as the dimensions of the cargo space, the maximum weight of cargo, the places of loading, the quantities, etc. The system that is going to be executed must be able to provide the desired output information, such as a list of generated routes with their descriptions, an assigned vehicle and driver, and a list of merchandise. The result should be dynamic in the sense that the data can be modified during the journey (e.g., the state of being transported, shipped, or waiting for transport) according to current conditions, and the information should be able to be shared with the relative parties (sellers, buyers, and transporters)

3.5 Data Base

The most convenient option for a database is to create a website to share and web database to store all the required data and information in according to have a successful and continuous procedure for the system.

3.6 Optimal route

The transporter has to drive to several locations so, when choosing the location, it should be the nearest located company which require services and the route that is been chosen to drive must be shortest one and the least congested one. We can easily obtain those facilities from the Google Maps and API system provided by the Google.

3.7 Finalized system

As mentioned earlier, executing the whole procedure, requires a database that includes all the details and data that must be used as inputs/outputs for the algorithm. The main inputs for the mobile application would be data from the Web database (supplier or buyer -- location, quantities, etc.). The main process through this mobile app would be to identify the locations of transporters, suppliers, and buyers as per the information given by the website and provide graphical information of the route that has to be taken by the driver. The information about the optimal route can be taken by the Google API system from the identified routes, and the mobile app could directly merge with the Google Map facilities. When using Google Maps facilities, the important part is to restrict the routes where it does not allow heavy vehicles and the routes where it has less width to drive heavy vehicles.

Also, keeping an active procedure it requires a resilience procedure to overcome the problems that occur during transportation. The mobile app would be able to identify the driver's problem through their feedbacks and to develop the connection with the nearest institutions like garages, service centres, hardware, etc. The system would have the same operating stage after the resilience procedure for the vehicle.

4 DISCUSSION AND CONCLUSION

This research project aims to address the need for an efficient supply chain for both products and waste generated by various industries. The primary objective is to develop a general methodology that ensures effective collection and distribution of materials throughout the relevant industries.

The initial phase of the project revealed that there are numerous materials that generate waste, as well as materials that can be repurposed as raw materials in different industries. Hence, it is crucial to have an efficient collection and distribution system for these identified materials. To develop a general methodology, a preliminary method based on one material is required. Demolished concrete debris has been chosen as the case study for this project, among various other materials like porcelain waste, timber waste, and chemical waste. Concrete debris generated from construction sites can be used as raw materials for the concrete block making industry.

The system that will be developed must meet several outcomes, including efficient transportation, continuous operation, value addition for materials, and cost estimation for delivered products. An IT-based solution has been chosen, given the prevalence of technology worldwide. Developing a mobile application will provide drivers with graphical information about their routes, making transportation more efficient. This can be done using API and GSI maps provided by Google services. The data required for the mobile application, such as location and available routes, will be collected and stored. Additionally, the system will require a web database for administration and efficient and continuous procedure. The database will collect information about customers, employees, goods, locations, etc. Furthermore, the website will provide more in-depth details on the uses of the materials, how they may be utilized as alternatives to manufacture other products, and how the world benefits from their contribution.

If the system is properly implemented, several benefits will be achieved, including reduced fuel consumption, reduced industrial waste, added value to waste materials, and the creation of new jobs for drivers and entrepreneurs.

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WATER AND ENVIRONMENTAL ENGINEERING

Determination of the Growth Curve of *Chlorella* sp. under Optimum Conditions in Automated Growth Chambers for Biofuel Production

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ABSTRACT

Microalgae have a great potential for producing biofuels because of their capacity to accumulate high content of lipids. *Chlorella* sp. is the mostly applied microalgae sp. for biofuel production at the industrial level. The current study aimed to determine the optimum conditions for mass culture *Chlorella* sp. and to generate a growth curve to determine growth patterns over time. The samples were collected from *Chlorella* pure cultures available in the laboratory. *Chlorella* colonies were identified morphologically. Liquid cultures were prepared in BG 11 medium, The effects of four different temperatures (20°C, 25°C, 30°C, and 35°C), two light intensities (6000 lux and 2000 lux.) under aerated and non-aerated conditions on the growth of *Chlorella* cultures in 250 mL flasks (n=3) were studied using a custom-designed automated growth chamber using Arduino technology. The culture growth was monitored by determining the cell density (cells/ml) and light absorbance (750 nm) at 0, 96, 192, 288, and 384 hours after inoculation. and After 16 days, cells were harvested (6000 rpm, 5 min, room temperature) and the dry biomass (g/ml) was measured after oven drying at 70 °C. Optimal conditions for the efficient mass culture of *Chlorella* sp. were found as 30 °C temperature, 6000 lux light intensity with aeration conditions. Under those optimum growth conditions, 6L photo-bioreactors were designed. Absorbance and cell density (cells/ml) of *Chlorella* sp. were monitored with time to develop the growth curve of *Chlorella* sp. The growth of isolated *Chlorella* sp. was characterized by an exponential phase from 8.86 to 45.41 hr after inoculation with a specific growth rate of 0.06 hr^{-1} and a doubling time of 11.46 hr. The *Chlorella* growth rate was 0.027 hr^{-1} without optimum conditions, and the doubling time (Tg) was 25.6 hr.

KEYWORDS: *Automated Growth Chambers, Biofuel, Chlorella, Growth Curve, Microalgae, Optimum Conditions*

1 INTRODUCTION

Fossil fuels have played a vital role over the last few decades in domestic, transportation and industrial sectors despite they are less eco-friendly and nonrenewable. It has been estimated that fossil fuels will be depleted in less than 50 years and that will greatly affect the global socio-economy. As a result, renewable energy has grown significantly to meet energy demand by rising population and development across the world. Biofuel is a renewable and long-term energy source that can be used to replace fossil fuels. Biofuel is a kind of fuel that originated from plant oils, animal fats, and

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microorganisms. Biofuels are available in both liquid and gaseous forms. Bio-alcohol, bio-diesel, and bio-oil are examples of liquid biofuels.

Microalgae are unicellular photosynthetic microorganisms found in freshwater and marine habitats that have a high lipid content in their cells and the ability to synthesize biofuels. Each microalgae species has unique growing conditions that must be optimized in order to achieve high yields. Growth chambers with diverse conditions can be applied to determine the optimum growth of microorganisms to find their exponential growth.

Microalgae biomass consists of three key biochemical components, carbohydrates, proteins and lipids or natural. Microalgae possess properties such as rapid growth rate with short generation cycles, short harvesting life, efficient photosynthesis, and contain high lipid content in certain species. They can convert nutrients in a medium or wastewater into biomass and Microalgae are utilized to extract high-value bio-products such as lipids, proteins, carbohydrates, pigments, antioxidants, cosmetics, dyes, pharmaceuticals, functional food, food additives and others. They are useful for CO_2 mitigation, wastewater treatment, biofuel and biofertilizer production as well. There are numerous techniques to transform microalgae into biofuel through transesterification of lipids, fermentation of the algal biomass, anaerobic digestion, and thermochemical conversion.

Chlorella sp. is the most cultivated eukaryotic microalgae which belong to the family *Chlorellaceae*. Various *Chlorella* strains have proved to be acceptable for biodiesel synthesis. *Chlorella* sp. is the widely used species for commercial production of Biodiesel industries in a number of countries such as the USA and China.

In Sri Lanka, fossil fuels are used as the major source of energy, especially as the only source of liquid fuel, and their prices directly influence on the country's socio-economy and development. Sri Lanka imported 1,094,586 MT of crude oil from January to December 2021, while other petroleum imports were 2173168.037 MT, for a total of Rs. 287,310,530,708 spent (Central Bank of Sri Lanka, 2022). In 2022, the country is facing a severe economic recession and the importation of petroleum fuel has been identified as a great dependency of the country which affects on the well-being of its population. Therefore, it is imperative to investigate environmentally benign, renewable, and low-cost alternative fuels in order to achieve sustainable socio-economic development of the country. Microalgae species have been isolated and identified in various environments of Sri Lanka (Sandani *et al.*, 2020) and few studies have been conducted to identify the potential of some species including *Chlorella* species for biodiesel production. In this research, the key endeavour was to measure optimum growth conditions and growth curve of *Chlorella* sp. in order to apply for industrial scale cultivation and lipid extraction for biofuel production by using automated growth chambers.

2 METHODOLOGY

2.1 Designing a Novel Growth Chamber for Microalgae Production

A novel Growth Chamber was designed to incubate liquid cultures and culture plates of microalgae and cyanobacteria in 470mm x 395mm x 355mm sealed Rigifoam boxes under controlled conditions of light intensity, temperature and aeration using Arduino technology (will be patented). The boxes were illuminated with 12V white LED light strips, The temperature within the growing chamber was controlled with the installation of a cooling system (Thermoelectric Peltier TEC1-12706 Cooler Kit). Air was supplied with BOYU U-9900 Air Pump with a filter system to prevent contaminations. Light intensity and temperature were continuously monitored using a photometer (Brannan light meter) and temperature sensors (Adafruit DHT11 sensor). The effect of light intensity, temperature and aeration can be measured. The data was received by the Arduino board and transferred into ESP 8266 board. Transferred data were saved in the cloud through the internet (Figure 6).

2.2 Determination of Optimum Light Intensity, Temperature and Aeration

Four identical growth chambers with 20, 25, 30 and 35 ℃ were constructed as described in the above section. Each chamber was separated in the middle using a Rigifoam partition creating two identical sub-chambers. In the two sub-chambers, two light intensities (6000 lux and 2000 lux) were adjusted and six cultures of *Chlorella* sp. in 250 mL conical flasks were placed. Among these flasks, three flasks were supplied with filtered air and the rest was kept without aeration. A control was set up by keeping a 250 mL *Chlorella* sp. culture under room temperature, ambient light and non-aeration conditions. Flasks were shaken twice a day. The culture growth was monitored by determining the cell density and cell biomass at 0, 96, 192, 288, and 384 hours after inoculation.

2.3 Determination of Absorbance and Cell Density

The absorbance of the liquid cultures was determined at 750 nm wavelength by using a spectrophotometer (Jenway 6305) at 0, 96, 192, 288, and 384 hours. A calibration curve was developed between the absorbance and cell density using a serial dilution up to 10^{-6}. Cell density was determined using the Neubauer hematocytometer (Marienfeld 0642110) counting method.

2.4 Harvesting and Determination of the Biomass

After 16 days, microalgal biomass was extracted from cultures by centrifuging at 6000 rpm for 5 minutes at room temperature. The cell pellet was separated using a micropipette and dried in an oven at 70 ^{0}C for 3 hours to obtain dry matter.

2.5 Determination of the Growth Curve of *Chlorella*

In a 2 L Conical Flask, 1800 ml of growth medium (BG-11) was prepared and 200 ml of inoculum was added. The culture was kept under optimal growth conditions determined from the previous experiment (30 ^{0}C, 6000 lux, and aerated). A Neubauer hematocytometer was used to assess initial cell density, and a UV/Vis spectrophotometer at 750 nm wavelength was used to assess absorbance (Griffiths *et al.*, 2011). Cell density and absorbance were monitored continuously at appropriate time intervals in triplicates taken from the sample. The growth curve was plotted between the natural logarithm of cell density vs time and the exponential growth period was determined. The specific growth rate (µ) was calculated using the formula,

$$\mu = \frac{lnN_1 - lnN_0}{t_1 - t_0} \tag{1}$$

Where N_1 and N_0 are the numbers of cells at times t_1 and t_0. Doubling time (T_g) was calculated using the following formula,

$$T_g = \times \ln(2) \times \mu^{-1} \tag{2}$$

2.6 Statistical Analysis

Effects of the studied factors on the growth of *Chlorella* sp. were determined using the General Linear Models procedure using SPSS Statistical software (version 26.0). Regression Analysis was conducted to determine the exponential growth curve.

3. RESULTS AND DISCUSSION

3.1 Effect of Light Intensity, Temperature and Aeration on Biomass Growth

Direct counting of cells is a relatively accurate procedure to determine the cell concentration and growth of a microalgae culture. However, it is a time intensive procedure. Turbidimetric methods, e.g., optical density, are very practical and simple methods to apply. Therefore, the cell concentrations were determined using a calibration curve. Aside from that, biomass weight was assessed at the end of the experiment to determine the cell growth of the cultures. The effect of studied factors, temperature, light intensity, and aeration and their interactions were significant on the cell density at different time periods. Table 1 shows the significance of the effects of factors at 384 hr after inoculation. Cell proliferation and metabolite production are both influenced by temperature. According to Carlsson and

Bowles, (2007), the optimal temperature for the growth of *Chlorella sp.* is 30-35 ℃. Figures 2 and 3 indicate the impact of temperature on microalgae cell density and biomass with different light intensities and aeration conditions. Maximum cell density and biomass yield was found at 30 °C followed by that at 35 °C. The results show that cooler temperatures slow down the growth rate of *Chlorella* sp. There was a significant difference between the cell growth under two light intensities i.e., 6000 lux light intensity resulted in higher cell density and biomass than that by 2000 lux. (Figures 2 and 3) According to Cheirsilp and Torpee (2012), light intensity below 5000 lux is appropriate for the growth and biomass production of *Chlorella* sp. When compared with aerated cultures, non-aerated cultures showed significantly lower cell density and biomass.

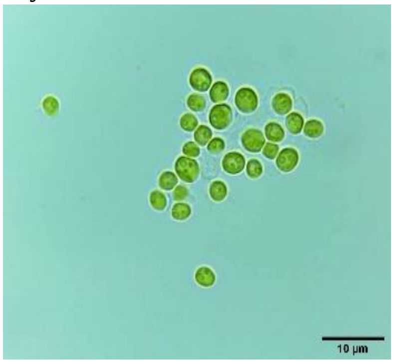

Figure 1. Microscopic view of *Chlorella* sp. (1000x magnification)

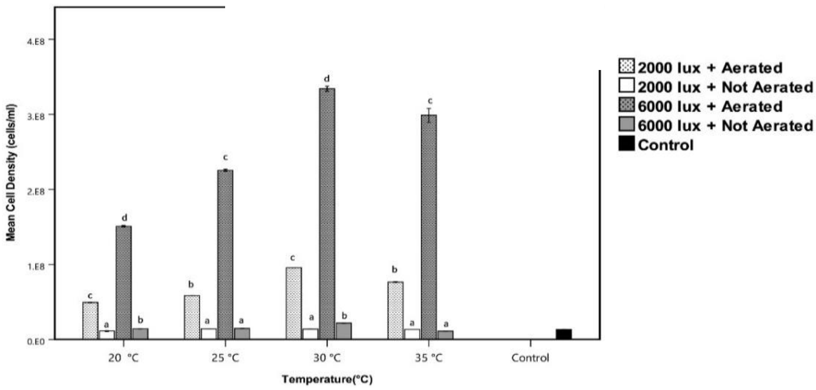

Figure 2. Effect of different temperatures, light intensities and aeration on mean cell density of *Chlorella* sp.

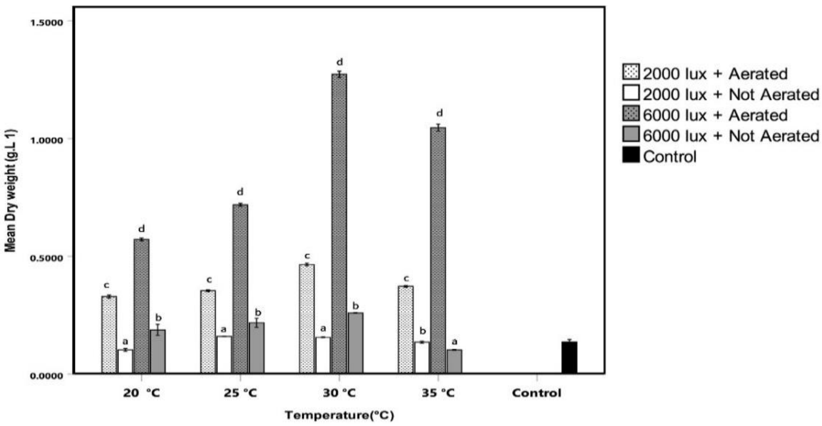

Figure 3. Effect of different temperatures, light intensities and aeration on mean dry weight of *Chlorella* sp.

Table 1. Effects of factors and factor interactions on cell density after 384 hr after inoculation

Source	Type III Sum of Squares	df	Mean Square	p
Temperature (°C)	$2.4x10^{16}$	3	$8.1x10^{15}$	0.000
Light (lux)	$1.0x10^{17}$	1	$1.0x10^{17}$	0.000
Aeration	$2.5x10^{17}$	1	$2.5x10^{17}$	0.000
Temperature * Light	$8.7x10^{15}$	3	$2.9x10^{15}$	0.000
Temperature * Aeration	$2.1x10^{16}$	3	$7.2x10^{15}$	0.000
Light * Aeration	$9.7x10^{16}$	1	$9.7x10^{16}$	0.000
Temperature * Light *Aeration	$8.5x10^{15}$	3	$2.8x10^{15}$	0.000

df- Degrees of freedom, F- F distribution, p- Probability value. Each value is the mean of three replicates

All of the aerated treatments outperformed the control treatment, which was maintained at room temperature and exposed to ambient light without aeration. When compared to aerated treatments, non-aerated treatments showed lower cell density and biomass. Aside from the 384-hour time interval, there were statistically significant differences between the conditions at the 96-hour, 192-hour, and 288-hour time intervals (data not shown). Figures 2 and 3 indicate statistically significant differences between treatments, with the aerated condition recording the maximum cell density and dry weight production at 30°C temperature and 6000 lux light intensity, which were then used to determine the growth curve of *Chlorella* sp.

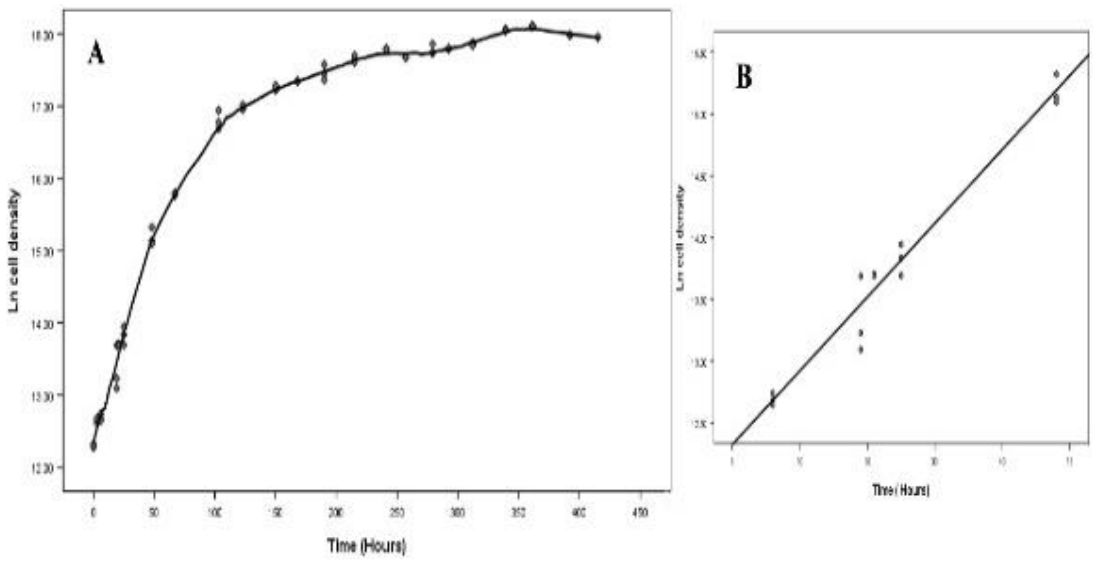

Figure 4. The growth curve of *Chlorella sp.* under 30°C temperature, 6000 lux light intensity with aeration conditions.

A: Growth curve of *Chlorella* sp. as ln cell density vs time (h), B: Exponential phase of the growth curve

Growth Curve of *Chlorella* sp.

Microalgae can grow rapidly if given enough nutrients and the right conditions. The availability of nutrients, temperature, light intensity, photoperiod, aeration, and pH all have a direct impact on algal growth. The growth rates of the microalgal species vary under similar environmental conditions. Figure 4 shows the growth curve of *Chlorella* sp. cultured in BG-11 medium in a 2L conical flask and aerated at 30 °C for 19 days under a 16/8 photo-period in 6000 lux light intensity and Figure 4 b shows the exponential phase of the growth curve which was obtained between 8.86 hr and 45.41 hr. According to the results, the specific growth rate (μ) of *Chlorella* sp. was 0.06 hr^{-1} and the doubling time (T_g) was 11.46 hr. A similar specific growth rate was obtained by Doucha *et al.* 2012 for the production of high-density *Chlorella* culture grown in fermenters. The *Chlorella* growth rate was 0.027 hr^{-1} without optimum conditions, and the doubling time (Tg) was 25.6 hr. The temperature of four growth chambers were maintained accurately (Figure 5) and it can be confirmed that all the *Chlorella* cultures were maintained at provided temperature.

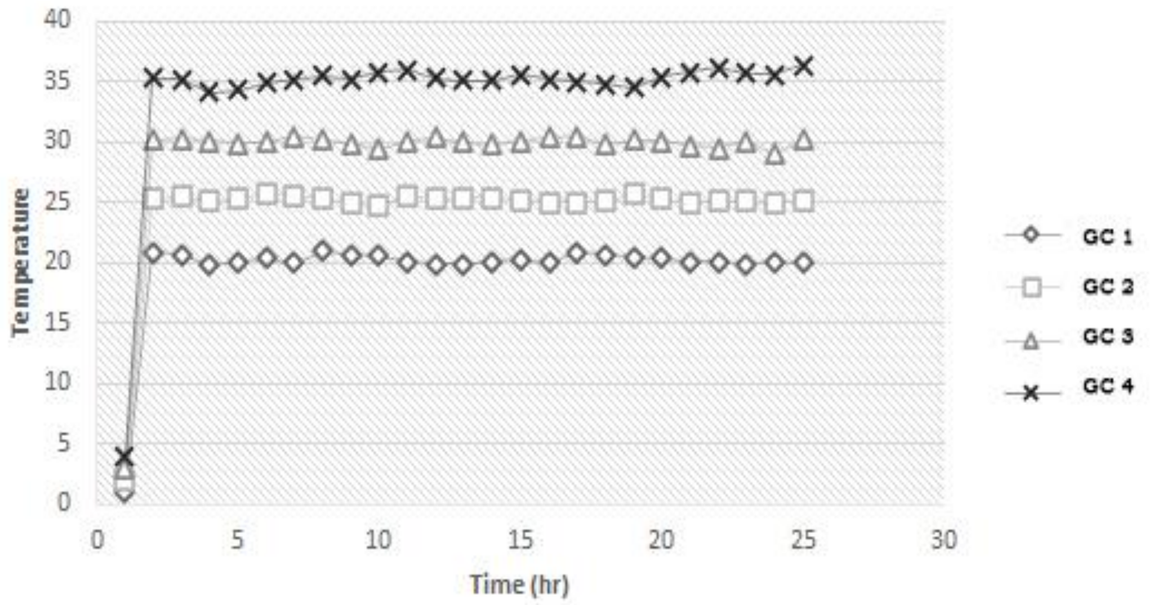

Figure 5. Optimization of temperature in growth chambers
GC 1 - Growth chamber 1, GC 2 - Growth chamber 2, GC 3 - Growth chamber 3, GC 4 - Growth chamber 4

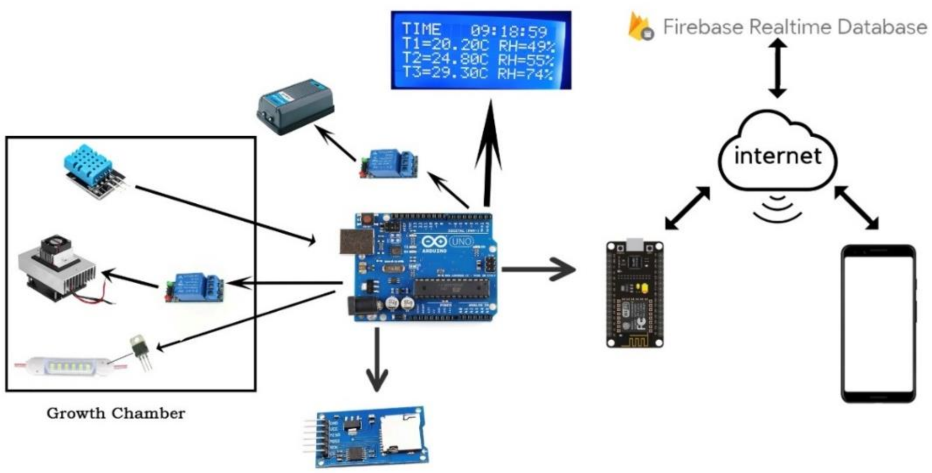

Figure 6. Diagram of Real-Time Monitoring System

4. CONCLUSION(S)

In this study, *Chlorella* species were successfully isolated from wastewater ponds and pure cultures were prepared. Optimum conditions for the efficient mass culture of *Chlorella* were found as 30°C temperature, and 6000 lux light intensity with aeration conditions. Under the optimum growth conditions, the growth of *Chlorella* entered the exponential phase and was found between 8.86 to 45.41 hr after inoculation. The isolated *Chlorella* sp. was characterized with a specific growth rate of 0.06 hr^{-1} and a doubling time of 11.46 hr. These findings are useful for the mass culture of *Chlorella* sp. at the industrial scale for biofuel production

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Health, safety, and environmental impacts of road infrastructure projects in Sri Lanka; Impact analysis on ongoing and temporarily suspended road works

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ABSTRACT

Road networks are considered to be the primary mode of transport in Sri Lanka. Road infrastructure plays an important role in the country's economy. The work environment of construction projects is generally considered one of the most dangerous places for work. The current economic recession faced by Sri Lanka has led to the temporary suspension of road works. The aim of this study is to identify the main types of health, safety, and environmental issues that occur in the construction of different ongoing and suspended road infrastructure projects in Sri Lanka. Questionnaire surveys, discussions, and site observations were carried out to collect data from road projects of different classes. Data analysis was done using the SPSS (Version 28) statistical software. The findings of the research indicated that vehicle collisions were the most common type of occupational accident faced in road construction in Sri Lanka. The fatality rate caused due to poor health and safety management of road construction works was compared with the construction of buildings and other developing countries. The results obtained from the study also identified that negligence was the main factor that influenced low safety standards on-site, which in turn impacted the performance of the construction project. Measures taken by construction companies of different grades to improve health and safety standards were also studied in the research. It was also evident that suspended road projects had an adverse effect on the environment, as it was seen that these sites possessed a loss in diversity, high chances of sediment erosion, and a rise in mosquito breeding locations. The findings of this research highlight the need of prioritizing health and safety in road projects and also enable construction companies to handle construction work in a way that minimizes environmental damage occurs.

KEYWORDS: *Health, safety, road construction, Sri Lanka*

1 INTRODUCTION

The working conditions of the construction industry are quite harsh and require a crucial amount of physical strain to be exerted by each working individual. The majority of construction workers use hazardous tools and equipment. Over the years, construction has undergone several improvements and transpositions but is still considered a risky profession due to the high number of accidents that take place. It has been found that the construction industry accommodates an exceptionally greater number of severe accidents or deaths in comparison to other industries of Sri Lanka (Rameezdeen et al., 2006). Furthermore, a study conducted by the National Institute for Occupational Health and Safety (NIOSH) of the United States shows that from 2003 to 2017, 67 percent of work-related deaths occur in the construction industry (*Highway Work Zone Safety | NIOSH | CDC*, 2021).

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Accidents in the field of construction can take place due to many reasons. Falls from heights, being struck by or against objects or machinery, electrical-related injuries, transport-related injuries, fire, and explosion are some of the key accidents identified in construction sites (Ahamed et al., 2011).

OHS issues do not only affect the office staff and laborers of the construction firm but also the public residing in the vicinity of the road construction project (Xing et al., 2018). The lack of information regarding occupational accidents in Sri Lanka is a grave and critical issue.

The aim of conducting this research was to identify the main types of health, safety, and environmental issues that occur in the construction of different ongoing and suspended road projects in Sri Lanka.

Unfortunately, Sri Lanka is currently battling the worst economic recession since its independence (McLoughlin, 2022). Due to this current economic crisis faced by Sri Lanka, many road and bridge infrastructure projects have been temporarily suspended. The effect of the ongoing economic recession on the health and safety aspects of such projects needs to be investigated.

2 METHODOLOGY

2.1 Study Area

The study was limited to Expressways (Class E), Main roads (Class A and B), and Secondary Minor Roads (Class C and D). The projects included in the study were managed by construction companies that acquired grades of CS2, CS1, C1, C2, C4, and SP1 in highway and bridge construction that have been implemented by the Construction Industry Development Authority of Sri Lanka (CIDA). Data were collected from a total of 52 road and bridge construction projects. Out of which 27 projects were ongoing, and 25 projects were suspended.

2.2 Primary and Secondary Data Collection

This research involves the collection of primary data. Data was obtained through questionnaire surveys, conducting interviews with compliant persons, and site observations. It focused on health and safety issues faced by the office staff of the construction firm, construction workers, and neighboring communities. The questionnaire consists of open-ended and close-ended questions. Linkert scales were used in the questionnaires so that the respondents can simply choose an option that best aligns with their perspective. The questionnaires were divided into three sections. The first section gathered general information related to the road project. Company grade, name of the project, duration of the project, road class, and project area information were included in this section. The next section was based on personal information such as the designation and years of experience of the respondent. The third section of the questionnaire included details such as the number of accidents that have been recorded on-site, penalties imposed on employees that violate the health and safety rules and regulations, PPE provided on-site, training programs conducted for employees, health issues faced on-site, and impacts of accidents and injuries to the project or construction firm. The questionnaire also comprised of questions where respondents have the ability to express their own views on improvements in the health and safety of road projects. The responses obtained from the surveys were analyzed using excel functions and SPSS software to obtain the perspective on the health and safety of road construction from officials of the construction companies, laborers as well as the neighboring communities. Secondary data was collected through a comprehensive literature survey from journals, health, and safety standards, books, government websites, and official web pages.

2.3 Data Analysis

2.3.1 Population and Sample

According to the Planning Division of the Road Development Authority (RDA), a total of 122 roads and bridges are under construction in Sri Lanka. Equation (1) was used to obtain the sample size of the study (Latupeirissa et al., 2021).

$$n = \frac{N}{(1+Ne^2)} \tag{1}$$

Where: n = Sample size; N = Size of the population; and e = Desired margin of error which is considered to be 10%. According to Equation (1), a sample size of 55 is required.

2.3.2 Shannon-Weiner Index

SWI which is also known as the Shannon Diversity Index was used to estimate the diversity of the plant species available in the site area of suspended road infrastructure projects (Rain 2022). A high value of SWI indicated that the site possessed a high plant diversity, which is considered as a sign of an unpolluted environment (Das et al., 2012).

$$H = -\sum_{i=1}^{n}[(p_i)\ln(p_i)] \qquad (2)$$

2.3.3 Soil Runoff

The empirical formula founded by Inglis and Desouza in 1929 was used to calculate the annual runoff due to rainfall at the suspended site locations (Praveen et al., 2016).

$$R = \frac{(P-17.8)\times P}{254} \qquad (3)$$

Where: R = Annual runoff; and P = Annual rainfall.

2.3.4 Corrosion Rate

The corrosion rate of steel reinforcement bars was calculated using Equation (4) in order to identify the severity of the environmental impacts caused due to the products emitted by the corrosion of steel (Umeozokwere et al., 2016).

$$C_R = \frac{k\times\Delta w}{A\times T\times\rho} \qquad (4)$$

Where: C_R = Rate of corrosion; Δw = Weight loss due to corrosion; A = Exposed surface area; ρ = Density of mild steel = 7.86 g/cm^3, T = Time of exposure; k = Constant for unit conversion = 8.76 x 10^{-4}.

2.4 Correlations and Significance

Standard statistical tests such as One-Way ANOVA and Pearson Correlation were used to understand the relationship between variables. The significant difference between two or more variables was evaluated using one-way ANOVA. Pearson correlation was used to identify the linear relationship between two variables. IBM SPSS V28 was used to conduct these statistical tests. A significance level of $P < 0.05$ was considered when conducting the analysis for all cases.

3 RESULTS AND DISCUSSION

3.1 General Statistics of the Samples

The study included data collection related to health and safety aspects followed in ongoing and suspended road infrastructure projects. Sri Lanka has classified roads into different classes. Figure 1 shows the road classes covered in the study and the percentage of responses obtained from each road class.

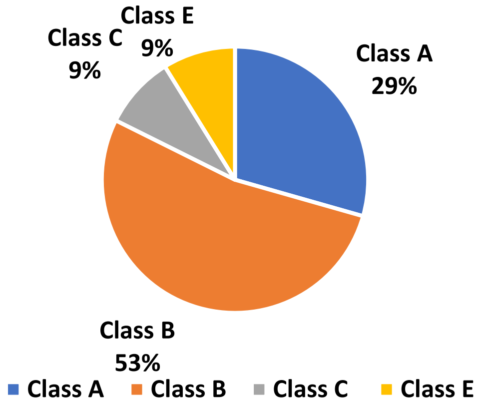

Figure 1: Responses obtained from different road classes.

This study is focused on 52 road and bridge construction sites that are ongoing and suspended due to the current economic recession. The names and locations of projects will not be mentioned due to confidentiality.

3.2 Health and Safety Aspects of Ongoing Road Infrastructure Projects

3.2.1 Accidents and Injuries Caused due to Poor Health and Safety Standards

Falls from height, vehicle collisions, electric shocks, fire-related injuries, and struck-by or struck-against objects are some of the common accidents that occur in the construction industry. Figure 2 shows the average number of accidents that occur in a project per year due to poor safety standards in ongoing road construction works. There is a significant difference between the type of work-related accidents and the frequency of occurrence ($P = 0.02 < 0.05$).

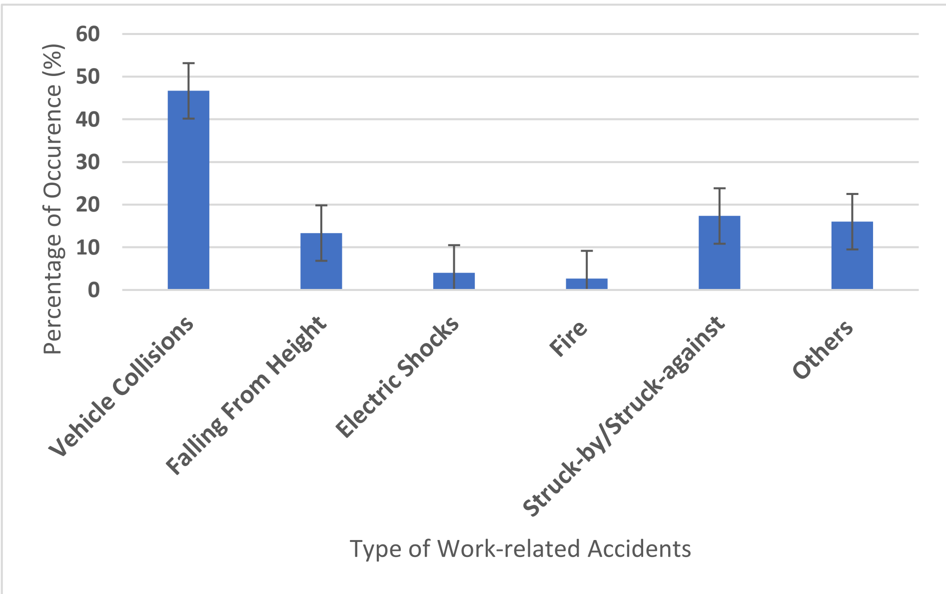

Figure 2: Percentage of occurrence of work-related accidents

Previous studies stated that most fatalities in road construction projects occur due to the collision of vehicles (Shah and Alqarni, 2018). The study conducted on road construction projects in Sri Lanka showed similar results. According to Figure 2, the most occurring accidents on road projects are vehicle collisions. These collisions include construction workers being struck by a vehicle or mobile equipment and vehicles colliding with other vehicles due to the traffic caused by the ongoing road construction works. It can be seen that 47% of the work-related accidents occur due to collision of vehicles, followed by 17% of the accidents caused due to being struck by or struck-against various objects, and 13% of the accidents resulted due to falling from height. Accidents caused due to the collision of vehicles can occur due to various reasons. The use of mobile equipment that is not in good working condition, hiring of unqualified flagmen, and drunk driving are the main reasons that lead to vehicle collisions (Pegula, 2013).

Many studies done in the past have proven that falling from heights is the most common accident that occurs in building constructions. The review conducted by Nadhim et al. in 2016 stated that masons, carpenters, and roofers were the most common trades exposed to falling from heights. A building's structural height and increasing wind pressure at top levels are some of the factors that lead to falling from heights (Nadhim et al., 2016). Since road projects possess low structures compared to buildings and as it does not involve roofing the percentage of occurrence of falling from heights is less in the construction of roads.

3.2.2 Personal Protective Equipment (PPE)

As stated in the article written by Jhonson in the year 2020, the use of correct PPE can be used to protect construction staff members and laborers from various health and safety risks that can occur at the site (Johnson, 2020). It was observed that only 72% of the ongoing road projects involved in the study provided all personnel at the site with safety helmets, safety boots, high-visibility jackets or safety vests, and gloves. However, 28% of the construction projects did not provide the staff and laborers with all the basic PPE, which indicates poor health and safety standards followed on the site. Discussions held with the safety managers of ongoing projects revealed that gloves, safety harnesses, and safety goggles are provided to the workers on request, depending on the work they are engaged in. It was also noted that the use of earplugs and dust masks is not seen among workers involved in road projects in Sri Lanka. This can lead to serious illnesses such as hearing loss and lung cancer.

3.2.3 Penalties Imposed for Violating OHS Standards

It was observed that certain construction companies imposed penalties on staff members and construction workers for not adhering to the safety rules of the site. As discussed with Project Managers, Safety Officers, and Engineers at the site it was stated that penalties were mainly imposed on workers for not wearing proper PPE which is been provided to them for free. This is a good practice followed by most of the road construction projects included in the study to reduce the number of fatal and non-fatal injuries occurring on-site. Table 1 shows the penalties imposed for various projects.

Table 1: Penalties Imposed

Penalty Imposed	Number of Projects
Rs. 500 per labourer. Rs. 1000 per office staff	21
Suspension after 3 warnings	5
Immediate Suspension	1
Salary deduction of 3%-5%	2
Salary deduction of 5 %	2
2 written warnings, 5% salary deduction for 3rd warning, suspension after 3rd warning	1
No Penalty	7

Table 1 shows that 54% of the construction companies involved in the study levied Rs. 500 per laborer and Rs. 1000 per office staff member for violating health and safety standards. Hence, it can be stated that the most common type of penalty imposed was charging Rs. 500 from laborers and Rs. 1000 from office staff members. However, it was seen that certain projects imposed penalties on laborers only. This is an unfortunate biased action followed by many industries today.

In most developing countries, the main types of penalties imposed due to violating standard health and safety rules are fines and imprisonment. In the year 2015, Slowey stated that the owner of the construction company in California and the project manager of the relevant project was sentenced to two years of prison after a construction worker was killed due to a collapse of a concrete retaining wall. Furthermore, a project manager of another construction company in the United States was charged $ 1.8 million for exposing workers to asbestos (Slowey, 2015). In addition, breaching safety standards in India will result in three-month imprisonment or a fine of INR 2000 from all employees involved in the affair (Labor Department, Government of Uttar Pradesh, 2022). These studies show that the level of penalty imposed depends on the severity or the nature of the violation. However, through the results obtained in this study, it is evident that construction companies involved in road and bridge projects in Sri Lanka do not implement this method. This in turn may have a negative effect on the health and safety aspects of the project as the severity of violations is not being addressed.

3.2.4 Factors that influence Health and Safety Standards of Ongoing Road Projects

The opinions of office staff members such as Engineers, Technical Officers, Quantity Surveyors, and Safety Officers of construction companies on the factors that influence the health and safety of road construction projects are shown in Figure 3.

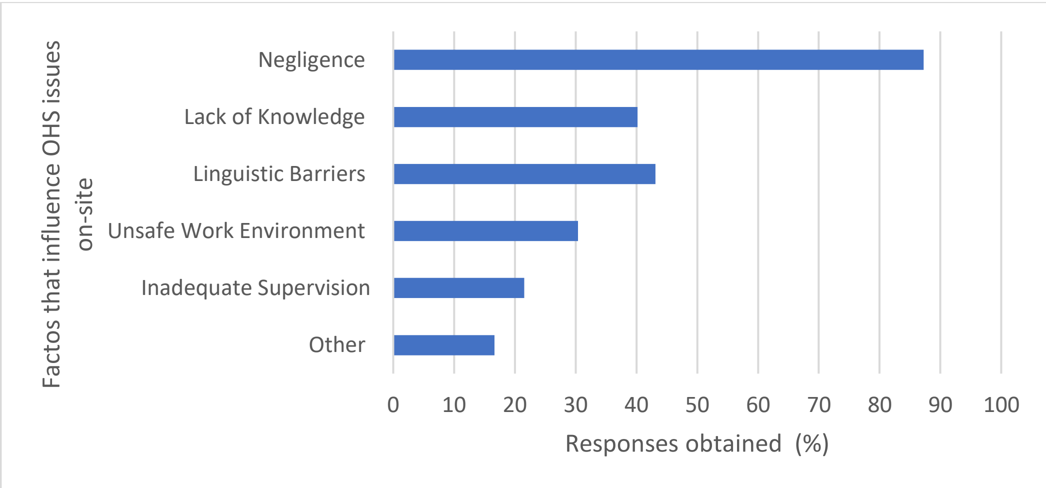

Figure 3: Office staff members' view on factors that influence the health and safety of road projects

The results in Figure 3 show that 87% of the respondents think that the negligence of workers, as well as site supervisors, accounts for the cause of accidents and injuries that take place on-site. This was observed during site visits, as there were unattended power cables lying on the site premises. This act of negligence may cause serious damage to lives as employees can get electrocuted if there are any shortages in the power supply. Furthermore, a study conducted by Ahamed et al. in 2011, also established that the negligence of employees is the most common root cause of construction accidents.

43% of the respondents also stated that linguistic barriers have also affected the safety on-site. Due to the multicultural nature of Sri Lanka, people from different ethnic backgrounds can be found in the working environment. Thereby, different languages are spoken in the working environment, which sometimes proves to be a challenge as not all workers are fluent in all languages, and this can result in miscommunication and misunderstanding. For example, if safety instructions are exchanged between a supervisor and a laborer that suffer the challenge of a language barrier, the instructions may not be delivered properly, resulting in dire consequences.

Lack of knowledge is another major factor raised by 40% of the respondents. Past studies have identified that workers were unaware of the safety rules followed by the construction company. In addition, the study stated that workers showed a dislike towards wearing PPE since they did not possess a good understanding of the risks associated with not wearing PPE while at work (Vitharana et al., 2015). Furthermore, unsafe working environments and inadequate site supervision also influence poor health and safety standards in road construction projects.

3.2.5 Impacts of Poor Health and Safety Standards on Road Projects

Poor health and safety standards not only impact the lives of people but also has an indirect influence on the performance of the construction project. The office staff members of different road works expressed their views on the impacts of poor health and safety on the project in the following manner.

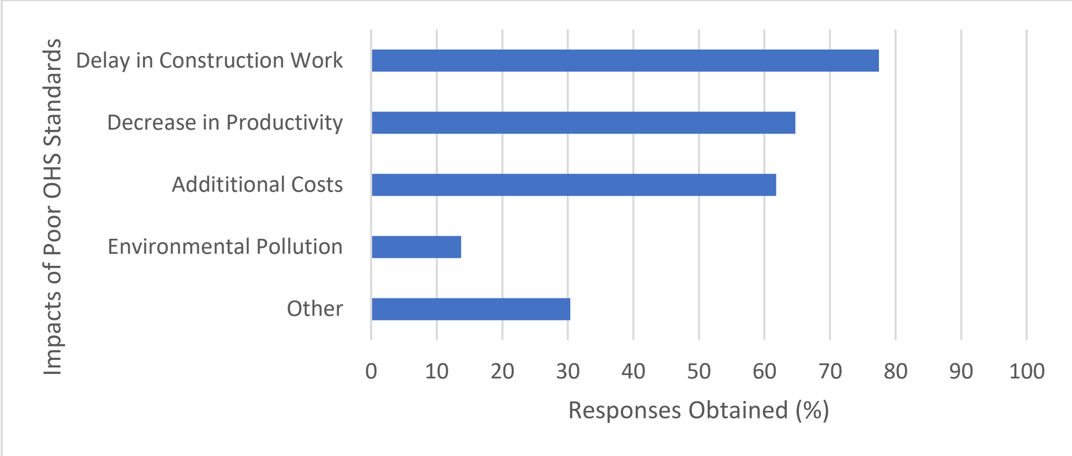

Figure 4: Staff members' view on the impacts of poor health and safety standards followed in road projects

As seen in Figure 4, delay in construction works received 77% responses, followed by 65% responses for the decrease in labor productivity. A study conducted by Handoko et al. in the year 2020, has proved that practicing good health and safety standards on-site has a positive effect on improving the performance of employees. For example, the use of safety helmets during construction work, not only protects the worker from head injuries but also protects the worker from the scorching sun. This in turn will enable the worker to focus and complete a wider range of work.

Maintaining good health and safety standards on-site is a cost for the construction company. However, the cost incurred will be greater if any work-related accidents occur (Handoko et al., 2020). It has also been stated that the compensation paid for a fatality caused due to a work accident in Sri Lanka will be increased to 2 million LKR (Ministry of Labor and Foreign Employment, 2022).

Even though environmental pollution received a low number of responses, it is evident that construction activities cause dust and noise pollution. Dust emissions resulting from road construction activities such as excavation, drilling, concreting, and material transportation are proven to have an adverse effect on the environment as well as the human lungs which may lead to diseases such as silicosis, bronchitis, and asthma (Xing et al., 2018).

3.2.6 Health Issues Faced by Staff Members and Neighborhood Communities

In addition to minimizing the probability of the occurrence of work-related accidents on-site, the construction company involved in the road project is also obliged to maintain the health of employees as well as the neighboring communities. Figure 5 shows the percentage of the employees of the construction companies and the neighbors residing in the vicinity of the road project that has been affected by poor health and safety standards practiced on the site.

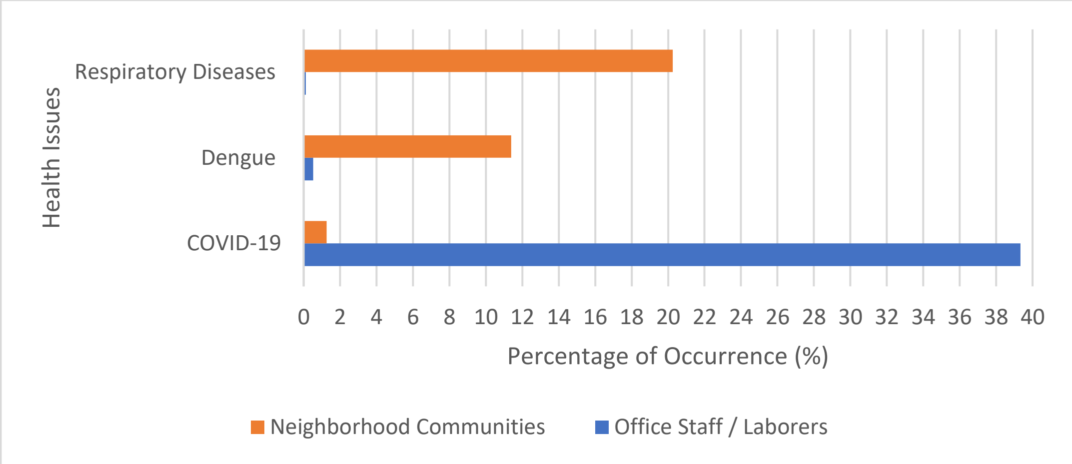

Figure 5: Health Issues faced by employees of the construction company and neighborhood community

It can be observed that 39% of the employees involved in the ongoing road projects involved in the study were impacted by the COVID-19 virus. Furthermore, 20% of the respondents stated that they have been affected by various respiratory diseases such as asthma due to the dust emitted by nearby construction activities. The results shown in the graph of Figure 5 also state that neighbors suspect the spread of dengue is due to site conditions. However, the low number of dengue cases that have been reported on-site does not tally with the neighbors' view. Therefore, further investigations must be carried out to find the reason that caused this discrepancy.

3.3 Health and Safety Aspects of Suspended Road Infrastructure Projects

Around 70% of construction projects including highways and roads have been haltered until there is an increase in the state's revenue (Jayasinghe, 2022). Since the suspended road and bridge projects did not involve any contract staff members or laborers, it was observed that the health and safety impacts were at a minimum. The only people that could have been impacted by the health and safety of these projects were those who entered the site premises for non-work-related reasons. Discussions held with residents in the vicinity of the suspended projects revealed that children and teenagers in the area use the site premises to play cricket and various other games. Broken-down safety signs and barricades were observed in almost 80% of the suspended road projects that were visited. Therefore, the unauthorized entry of persons should be prevented in order to avoid unfortunate fatal or non-fatal accidents from occurring. In addition, accumulated stagnant water was seen in all the suspended sites that were visited. The accumulated stagnant water was calculated as a percentage of the total site area and the following results were obtained.

Table 2: Percentage of accumulated stagnant water with respect to site area of suspended road projects

Percentage of accumulated stagnant water with respect to total site area	**Number of suspended road and bridge projects**
0 – 10%	15
10% - 20%	8
20% - 30%	2

This accumulated stagnant water aids the spread of the dengue virus. According to the studies conducted by the World Health Organization(WHO), it has been stated that an infected *Aedes Aegypti* has the ability to fly up to 400m during the day (*Dengue and Severe Dengue*, 2019). The average distance to the nearest residence of suspended road works was calculated to be 365m which is less than the distance flown by an infected mosquito. Hence, this can lead to the spread of the dengue virus within the neighborhood communities. Therefore, necessary precautions must be taken by construction companies to avoid the spread of such deadly diseases.

3.4 Environmental Impacts of Suspended Road Infrastructure Projects

The impact on the progress of road construction projects due to the current economic crisis in Sri Lanka is highly evident as it is a prominently discussed topic today. However, unfortunately, no one has raised their concerns about the environmental impacts caused due to the suspension of these construction projects. Table 3 shows the main environmental impacts that could occur due to unattended construction sites.

Table 3: Key Environmental Impacts and their Frequency of Occurrence

Key Environmental Impacts	Frequency of Occurrence
Soil erosion due to rainfall	4%
Soil erosion due to wind	4%
Reduction in plant diversity	28%
Contamination of groundwater	20%

3.5 Quantification of Environmental Impacts of Suspended Projects

3.5.1 Shannon Weiner Index

A rough estimate of the SWI was calculated for the suspended projects in order to check the diversity and richness of the site. The results showed that suspended road and bridge construction sites possessed low SWI values, which means these sites were found to have low diversity. It was also observed that the richness levels of the suspended construction sites were low. The low richness and diversity can result in low quality of ecosystem's services such as maintaining the soil conditions, purifying the soil that is run through soil, and also the supply of food (Rafferty, 2019).

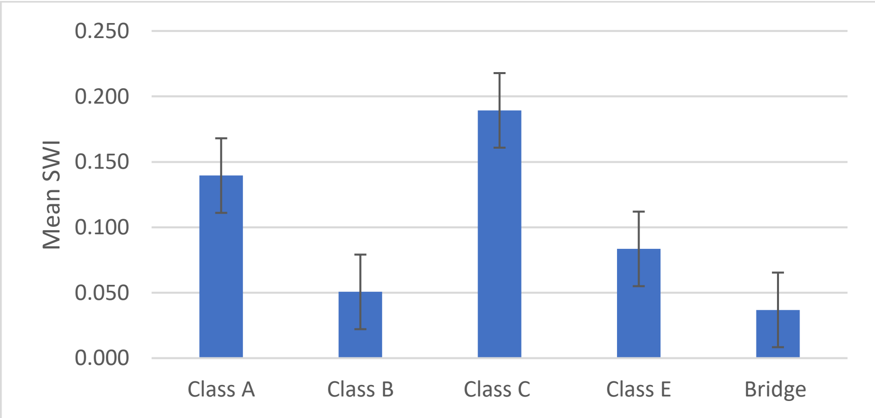

Figure 6: Comparison of Road Types and SWI

The average SWI of construction projects of bridges and different road classes is shown in Figure 6. There is little or no significance between the mean SWI and road types (P = 0.052 >0.05).

3.5.2 Iron Input to the Environment due to Corrosion

During site visits, it was observed that many suspended road projects possessed steel formwork and reinforcement bars that have been corroded with time. 12mm, 16mm, 20mm, and 32mm mild steel reinforcement bars are commonly used in road construction works. Therefore, the corrosion rate for these commonly used bar sizes was calculated to analyze the effect of corrosion on the environment. Table 4 shows the rough estimate calculated for corrosion rates of different bar diameters.

Table 4: Corrosion rates of different bar sizes

Bar Diameter (mm)	**Corrosion Rate (10^{-5} mm/week)**
12	6.99
16	5.24
20	4.19
32	2.62

A study conducted by Javaherdashti in the year 2000, also stated that a tonne of steel can turn into rust in 90 seconds. Escaping products from corrosion can result in environmental pollution, causing dangers to human health. Furthermore, the damage done to materials due to corrosion can result in safety concerns in the final product as well as additional costs for the construction company (Javaherdashti, 2000).

3.5.3 Soil Erosion due to Rainfall

Rain hitting on bare soil can result in soil erosion. The annual runoff levels in the suspended site locations were calculated in order to analyse the probabilities of soil erosion. The calculated runoff levels ranged from 101.47cm to 505.82cm. The mean annual runoff was obtained to be 192.55cm.

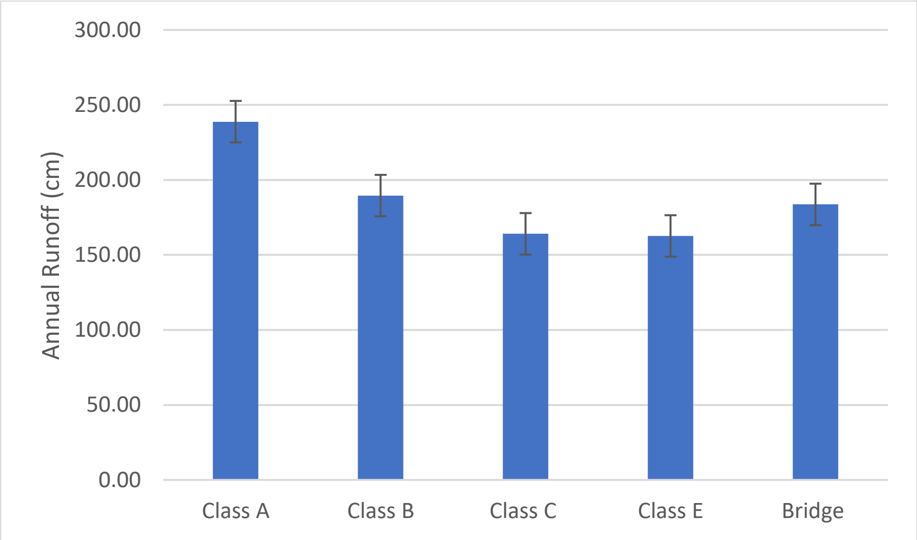

Figure 7: Comparison of Road Types and Runoff

Figure 7 shows the annual mean runoff due to rainfall of bridges and different road classes. The results obtained indicated that there was no significant difference between the runoff levels and respective road classes ($P = 0.604 > 0.05$).

4 CONCLUSION

Poor health and safety practices in road and bridge infrastructure projects have led to an unfortunate number of construction accidents and health issues in Sri Lanka. The aim of this study was to identify the main types of health, safety, and environmental issues that occur in the construction of different ongoing and suspended road projects in Sri Lanka and to perform an analysis of how the stakeholders of different road works have been impacted.

According to the study conducted on ongoing road projects, it was established that officials of the construction company, laborers, and residents living in close proximity to the site are the main stakeholders affected by poor health and safety management in road construction sites. The results obtained from the analysis indicated that vehicle collisions were the most common type of accident faced in ongoing road and bridge projects, followed by struck-by/struck-against objects and falling from heights. According to the responses obtained, COVID-19 was the main health issue faced by office staff members and laborers of the construction firm. However, the responses obtained from neighborhood communities stated that respiratory diseases were the main health-related issue faced by them. It was also proven that the poor health and safety standards followed on-site caused delays in construction work, a decrease in worker productivity, additional costs for the construction company, and also increased environmental pollution. Furthermore, the study also recognized that construction companies with higher grades took precedence in taking necessary measures to improve the health and safety conditions of the site. The measures taken include conducting toolbox meetings, providing good site supervision, providing appropriate and good quality PPE, and using machinery and equipment that are of good working condition.

The ongoing economic crisis faced by Sri Lanka resulted in the temporary suspension of highway and bridge projects. The health and safety aspects of such projects were analyzed by visiting these sites. The study established that suspended road projects had a long-term impact on the environment. The quantification of these environmental impacts resulted in addressing the possibility of sediment erosion, biodiversity issues, and the breeding of mosquitoes.

The unfavorable impacts on human lives, the environment, and the economy caused due to poor health and safety conditions followed by construction firms can be mitigated or minimized if necessary measures are taken by the involved parties. The findings of the research highlight the need of prioritizing health and safety in road projects in order to improve the productivity of the construction industry of Sri Lanka.

Furthermore, the consideration given to environmental issues that have arisen due to the suspended road projects is low. Therefore, the outcomes of this study will enable construction companies to handle construction work in a way that minimal environmental damage occurs.

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Microplastic Content in Non-Point Source And Point Sources of Colombo And Suburbs – Experimental Study on the Impact of Seasonal Variation

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ABSTRACT

Microplastics, which can enter aquatic environments through various sources, are small plastic pieces that are less than 5 mm in length. There are two types: primary and secondary microplastics. Sri Lanka has limited studies on microplastics in inland water bodies, so this research aims to quantify the levels of microplastic pollution in Colombo's surface waters in a spatiotemporal manner.

Samples were taken from Beira Lake, Dutch canal network, Talangama canal, in wet and dry seasons. Microplastic concentrations were determined using NOAA guidelines and an optical microscope. Statistical analysis was performed using IBM SPSS version 21, including One-way Anova and Pearson correlations to identify significant differences and correlations.

The study found that Dutch Canal had the highest average microplastic concentration of 12.7 mg/L during the wet season, and the lowest of 4.2 mg/L during the dry season. Both Dutch Canal and Talangama canal showed significantly higher microplastic concentrations during the wet season than the dry season, while the opposite was found in Beira Lake. The statistical analysis showed significant differences between microplastic concentrations in wet and dry seasons in all three water bodies. The microplastic levels in Beira Lake were higher on the surface water during the dry season (4.32 mg/L) and wet season (13.77 mg/L) compared to point sources (4.05 mg/L and 11.68 mg/L, respectively). Furthermore, Dutch canal's point sources showed higher during the dry season (8.47 mg/L) than the wet season (11.51 mg/L) and concentration of microplastics on the surface water was higher during the wet season (5.73 mg/L) than the dry season (7.16 mg/L). Talangama canal had similar patterns to Beira Lake.

The study found microplastic contamination in urban and semi-urban surface waters at levels comparable to some industrialized countries, highlighting a concerning issue.

KEYWORDS: *Microplastic pollution, Seasonal impact, Sri Lanka, Urban, Colombo*

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1 INTRODUCTION

Plastics are utilized in a wide range of items, and production of them has dramatically increased in recent years (Shamskhany et al., 2021). Plastic waste can be found everywhere (from mountaintops to seafloors) due to inefficient or nonexistent end-of-life plastic management. Stormwater, rivers, wastewater discharge, and wind are just a few of the different ways that plastic is conveyed to freshwater and marine habitats. Plastics can persist in aquatic environments for centuries, or millennia, due to their sluggish degradation processes. (Shamskhany et al., 2021)

Microplastics, which are microscopic fragments of plastic less than 5 mm (0.2 inch) long that are found in the environment because of plastic pollution, have gotten a lot of attention in the last ten years (Manzoor et al., 2021). Microplastics are classified into two types: main and secondary. Primary microplastics are microfibers shed from clothing and other materials, such as fishing nets, as well as minuscule particles produced for commercial use, such as those found in cosmetics. Secondary microplastics are created when larger plastic objects, such as water bottles degrade. The primary environmental elements that contribute to its disintegration are the sun's rays and ocean waves. Many of these goods quickly contaminate the environment as they travel through rubbish. To make microplastics, carbon and hydrogen atoms are linked together in polymer chains (Stanley and Morgan, 2022). The USGS (The United States Geological Survey) currently classifies materials into five categories: fibers, foam, fragments, beads/pellets, and film.

Furthermore, due to its protracted decomposition, which varies depending on the kind, plastic is a significant cause of pollution in the air, water, and land. Some plastics disintegrate quickly, while others take years or decades to do so. Plastic degradation has been categorized into photo-oxidative degradation, thermal degradation, ozone degradation, catalytic degradation, mechano-chemical degradation, and biological degradation depending on the physical, chemical, or biological agents that caused it (Manzoor et al., 2021).

Density is one of the physical characteristics that is commonly linked to the distribution and mobility of microplastics. The density of plastic in freshwater and marine settings varies depending on the type of polymers used, and biofouling, or the development of biofilms on the surfaces of particles, can have a substantial impact (Lagarde et al., 2016).
Physical and chemical toxicity may be caused by microplastics. This may lead to bodily harm that causes stress and inflammation, or it may obstruct the digestive tract, which would restrict food intake or breathing (Kolemans et al., 1970).

The increased quantity of microplastics in these habitats, combined with their distinguishing characteristics, has allowed them to access marine biota such as phytoplankton and other species at the bottom of the food chain before rising the food chain. When these compounds enter these organisms, they accumulate in all their organelles and tissues, causing a variety of negative effects, notably oxidative stress. However, due to the rate at which microplastics are accumulating in the environment and the intricacy of the numerous species in the food chains, the various scientific initiatives aimed at lowering the detrimental effects of microplastics on life forms have not been as effective as hoped. Another significant impediment has been identified as the timescale required to establish microplastic biodegradation. As a result, to analyze the possible environmental dangers and toxicological impacts of microplastics across different trophic layers, more efficient scientific methodologies must be implemented. This is owing to a lack of understanding about the ecotoxicological effects and environmental fate of microplastics derived from either primary or secondary sources. Researchers must precisely quantify the rates at which large plastic particles disintegrate into microplastics, as well as the mechanisms underlying these degradative processes. However, in recent years, an increasing number of micropollutants have been found in the water cycle, which are known to have long-term effects on the ecosystem (Lagarde et al., 2016).

There are several rivers, lakes, and canals in Sri Lanka, and they offer drinking water as well as being important for human daily activities. Microplastics are an increasing issue as a pollutant capable of damaging aquatic species in Sri Lanka. While freshwater microplastic research has grown in recent years, much about the sources and delivery pathways of microplastics in aquatic settings remains unknown.

The goal of this project is to investigate the contamination caused by microplastics in southwest Beira Lake, the Talangama canal, and the Dutch canal in Colombo. To assess microplastic contamination in inland water bodies in and around Colombo, as well as to investigate the seasonal impact on microplastic pollution. (Wet season vs. dry season) Only three large bodies of water will be sampled. This research looks at the relationship between the amount of microplastic and seasonal changes. The samples will be taken twice, once during the wet season and once during the dry season. Representative samples will only be collected from lake/canal inlets and the water's surface.

2 MATERIALS AND METHODOLOGY

Water bodies from urban and suburbs were selected. It was expected to sample from the Talangama canal, Dutch canal, and Beira Lake. All water bodies were sampled once in the dry season as well as once in the wet season. Surface water and lake/canal inflow samples were collected. After collecting the samples all the laboratory tests were done and at the end, the analytical data was taken.

2.1 Study area

Beira Lake - The Sri Lanka Land Reclamation and Development Corporation Beira Lake is an important feature in Colombo's downtown. The Beira Lake is divided into four primary basins due to its distribution around the city: East Lake (containing the floating market), West Lake, South-west Lake, and the Galle Face Lake. (Karunarathne et al., 2022) The South-West side of Beira Lake (Figure1) was chosen for sampling in this study because the sewage network and wastewater treatment facilities on the west side of Beira Lake are ancient and inefficient. As a result, polluted water immediately enters the lake, resulting in poor water quality in the southwest lake.

Figure 1 Location of Sampled Southwest Beira Lake (a-b) View of Beira Lake (c-d)

Dutch canal - The Dutch Canal (Figure 2) is a network of many canals, with several locally including five canals. They are,

1. Heen canal
2. Kinda Canal

3. Dematagoda Canal
4. Kirulapone canal
5. Dehiwala Canal

Figure 2 Locations of sampled water ways(a-b), Heen Canal(c), Kinda Canal(d), Dematagoda Canal(e), Kirulapone Canal(f) and Dehiwala Canal(g)

Talangama canal – Talangama Canal (Figure 3) is a man-made canal in Sri Lanka western province that connects the Talangama Lake estuary to the Kelani River estuary through the Chandrika Kumarathunga Road. As a result, the water quality of the Talangama canal has been polluted, and the surrounding land has become extremely contaminated due to the increasing trend in anthropogenic activities. The area near the CINEC junction and roughly 800m were chosen for sample since it is a heavily inhabited region with one of the best and well-maintained jogging tracks on the island. There is also an outdoor gym and a large parking lot. The track is over 2.5km long and provides plenty of space. It is located along the lake canal and provides beautiful views.

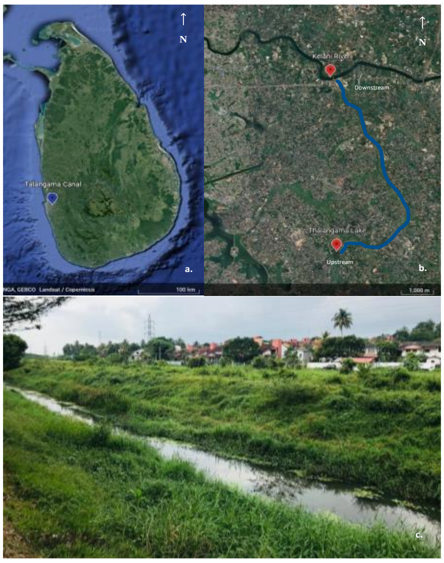


Figure 3 Locations of sampled water way (a-b) and view of Talangamam Canal near the Malabe CINEC Junction

2.2 Rainfall Data

For define the wet season and the dry season the recent 4 years were selected. After plotting the maximum daily rainfall in a month vs month, the dry season and the wet season were defined. Rainfall data were collected from the Meteorology Department of Sri Lanka (https://www.meteo.gov.lk).

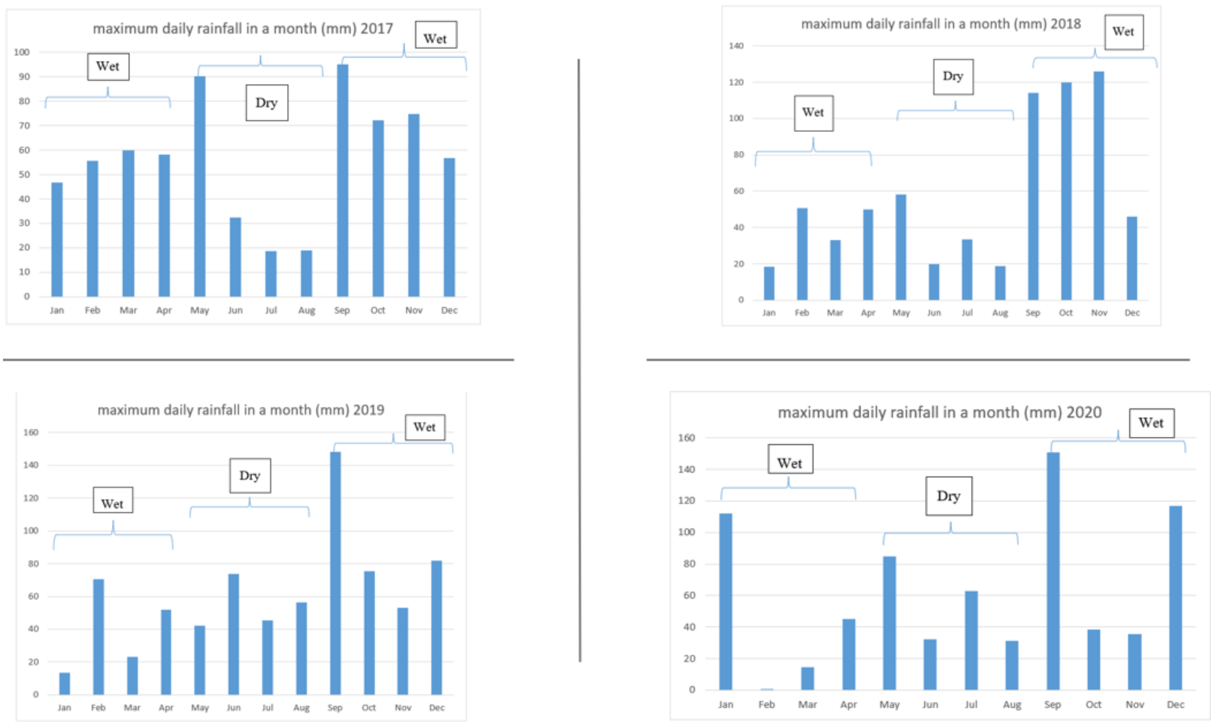


Figure 4. Maximum Rainfall in a month (mm) per year; 2017,20118,2019,2020

The data of maximum daily rainfall recorded monthly for each year display some key features of rainfall distribution in Colombo. The month will highest daily rainfall can be observed to be September for 3 of the 4 years where only in 2018, the maximum daily rainfall was recorded in November. The lowest recorded maximum daily rainfall is far less predictable as results show July, August, January, and February for years 2017, 2018, 2019, and 2020, respectively. Another interesting feature about the minimum daily rainfall monthly value is that for 2017 and 2018, respectively in July (18.7mm) and August (18.8mm) falls in the dry season while for 2019 and 2020 respectively January (13.3 mm) and February (0.1mm) falls in the wet season. This deviation highlights the somewhat unpredictable nature of rainfall. However, these deviations are far less scattered when evaluating from an overall perspective. Rainfall data of 2021 is not taken due to the deviation compared to last five years. As present in the graphs **May to August** duration is the **dry season** of the year and **rest of months** are in the **wet season**.

2.3 Sampling

When collecting water samples, a rope with a bucket (a plastic 4liter bucket) was utilized, and 1L well-cleaned water bottles were used to store water samples. Freshwater samples (1L) were collected at each sampling station. These samples were transported to the Sri Lanka Institute of Information Technology environmental Laboratory and stored at room temperature for further examination. For calculating reasons, the drains were believed to be a point source entry to the main lake. There were multiple inlets in a specific area that connected directly to the west Beira Lake.

Samples are taken from water surface and lake/canal inlets. The sampling for dry season was done in June (Beira Lake, Talangama Canal) and in August (Dutch Canal). Sampling for wet season was done in October. Representing the Dutch canal, 25 samples were taken from 5 different canal of the Dutch canal. Surface water samples were collected in densely populated areas and at every 100m-by-100m distance. This could not be done with Hume pipes since they could not be found in a 100m-by-100m area.

Table 1 Sampling details

Location	No of samples from Canal/Lake inlets	No of samples from Surface water	Total samples	Sampling conducted Month for dry season	Sampling conducted Month for wet season
Southwest Beira Lake	13	12	25	June	October
Dutch Canal	9	16	25	August	October
Talangama Canal	5	5	10	August	October

2.4 Laboratory Analysis (Determination of Microplastics)

Wet sieving: The water samples were sieved through 5mm and 0.3mm steel mesh, respectively. Following that, the water sample was rinsed with distilled water. It aids in the removal of all remaining solids from the sieve as well as the removal of salt from the sample. The steel mesh was then rinsed with distilled water, and any items that remained in the 5mm steel mesh were removed. Microplastic containing organic solids consists of materials that pass through a 5mm mesh but remain in 0.3mm.

Transferring Sieved Solids: It was measured in 250ml beakers and weighted to the nearest 0.1 milligrams. The solids from the 0.3mm mesh were put into the beaker with a spatula. The remainder was rinsed with distilled water and put to the beaker. The solids-containing beaker was placed in a dry oven at 90°C for 24 hours or more to eliminate all moisture from the sample.

Wet Peroxide Oxidation (WPO): The beakers containing microplastic and natural materials received 20ml of aqueous 0.05 M Fe (II) solution. The same beaker was then filled with 20 ml of 30% hydrogen peroxide. The mixture was then allowed to cool for five minutes before proceeding to the next phase. The dish was then covered and roasted to 75°C on a hot plate. The combination was removed off the hot plate when gas bubbles were visible on the surface of the solution. Another 20 cc of 30% hydrogen peroxide was added if natural materials were visible. If necessary, repeat the operation until no organic materials are visible. To raise the density of the solution, 6g of salts were added to the sample. The mixture was then placed back on the hot plate until all the salt had been dissolved.

Density Separation: After cooling down, the mixed sample of Wet Peroxide Oxidation (WPO) solution was put to the 100ml funnel (with a rubber tube sealed the bottom of the funnel) and covered the funnel top. It was kept overnight. Then, all floating materials were collected into a 250ml beaker. The floating material was filtered using filtration equipment and allowed to air dry.

Gravimetric Analysis: To determine the mass of microplastics, Eq. 1 was utilized, where m_{mp} is the mass of microplastics, m_{fpp} is the mass of dried filter paper with particles, and m_{efp} is the mass of empty filter paper.

Equation (1) → $m_{mp} = m_{fpp} - m_{efp}$

Microscope Exam: A microscope is a device that was used to examine small objects on filter papers. This lens bends light toward the eye, causing an item to look larger than it is. 4X/0,10 zooming was used to identify the microplastic particles and for qualitative analysis.

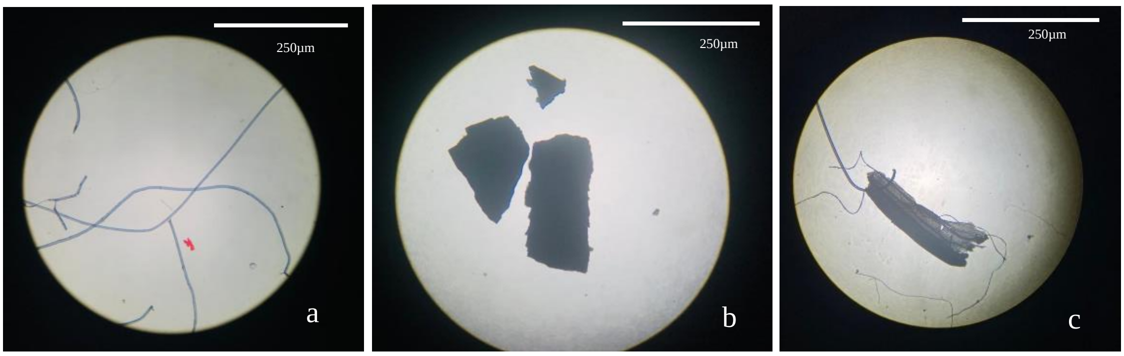


Figure 4. Microscope view of founded microplastic particles, Fiber (a), Fragment (b), Films (c)

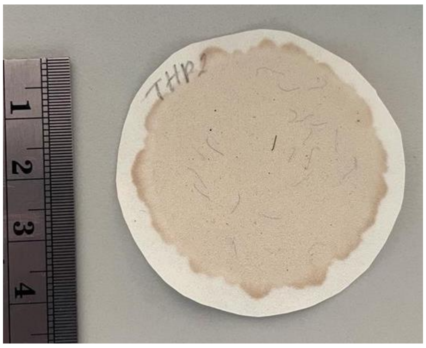


Figure 5. Visible Microplastics particles on Filter papers

2.5 Determination of water quality parameters

A turbidity meter was used to measure the turbidity (HACH 2100Q portable turbidity meter). Water samples were diluted with distilled water to determine the turbidity of water in the high turbidity range. Because the working solution is ten times as dilute as the stock, it is sometimes referred to as a "10X" dilution. In this situation, the dilution factor is 10. Using this calculation, combine 100 mL of stock with 900 mL of pure water.

The pH of water samples was determined using a pH meter (HACH HQ411D laboratory single input pH meter). pH value of a sample was evaluated by utilizing pH paper to see if it was acidic, alkaline, or neutral. This was performed by dipping the pH paper into a sample and watching the paper's color change. A color-coded scale is included in the publication, with different hues denoting different values.

2.6 Data Analysis

Using IBM SPS software, significant differences between two groups and more than two groups were discovered using the t-test and one way ANOVA (IBM SPSS Statistics 21). For all statistical analyses, $P < 0.05$ or $P < 0.1$ was selected as the significant level.

3 RESULTS

3.1 Microplastic Concentration vs Season

According to the graph (Figure 11), the highest average microplastic concentration (12.725 ± 5.122 mg/L) was found in Dutch Canal during the wet season and the lowest (4.183± 4.092 mg/L) was found in Dutch Canal during the dry season.

The bivariate correlations with Pearson's coefficient were used to examine the relationship between the microplastics concentrations of these three water sources and the seasonal changes. A correlation was observed between microplastic concentrations and the season. (Pearson's coefficient =1)

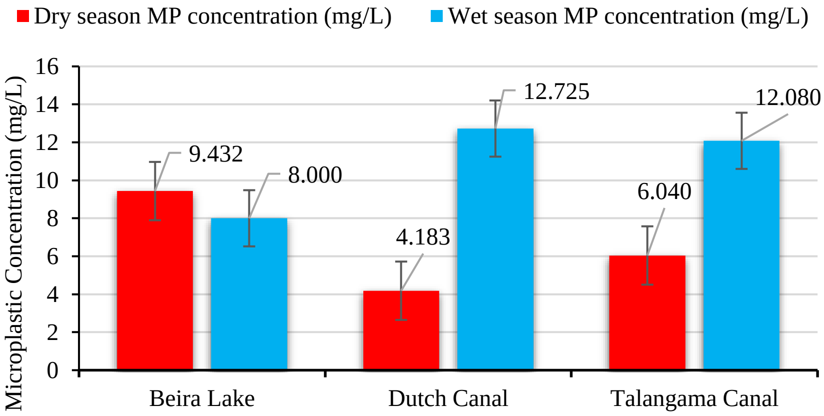


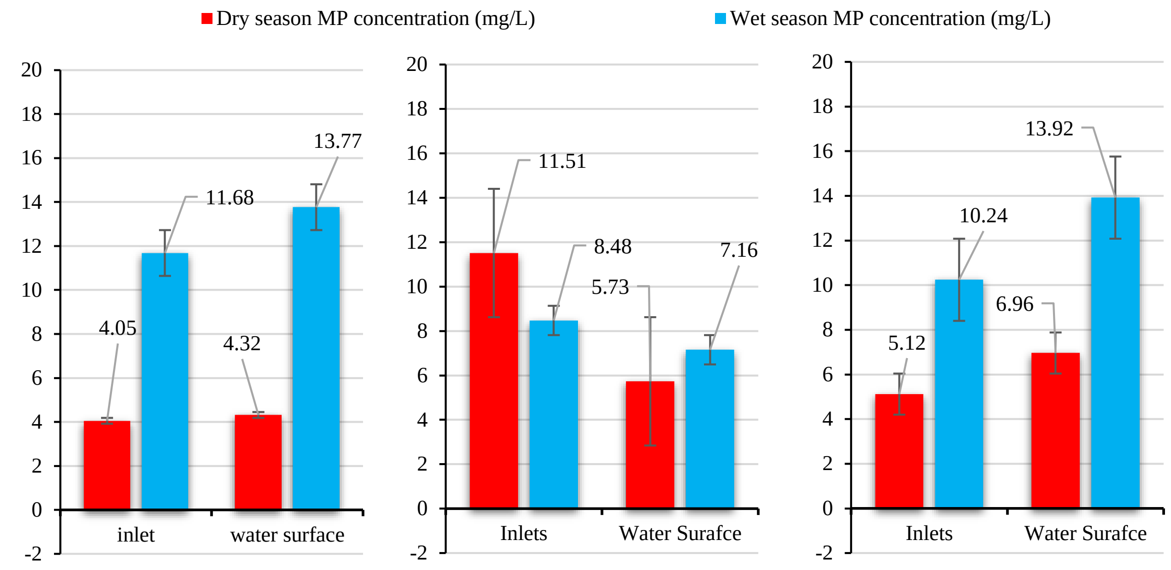
Figure 5 Microplastic Concentration vs Seasonal variation in Beira Lake, Dutch Canal, Talangama Canal

In Dutch canal (wet; 12.725 mg/L, dry; 4.183 mg/L) and Talangama canal (wet; 12.08 mg/L, dry; 6.04 mg/L) the microplastic concentration was increased in wet season than dry season. This may happen due to the ground surface microplastic will be washed and collected to those sources when the rainfall starts because the water that will be collected in the cannels, culverts, and drains will be at a greater level. But in Beira Lake (wet; 8 mg/L, dry; 9.432 mg/L) opposite happens. This may be due to the industrial wastage coming from culverts and drains in wet season are lower than in dry season and it may be due to accumulation of microplastic in water and low flowrate of water to the ocean in dry season.

3.2 Spatiotemporal Variation of Microplastic

For Beira Lake, as evidenced in Fig. 3a, in microplastic concentration in water surfaces (dry – 4.32 mg/L, wet-13.77 mg/L) is higher than the concentration in point sources (dry- 4.05 mg/L, wet-11.68mg/L) in both dry and wet seasons. Furthermore, a statistically significant ($p<0.05$) microplastic concentration was observed in both point sources and water surfaces during the wet season compared to the dry season. The reason for this may be all the surface runoff comes to water surface during the rainy season since the Beira Lake is in urban area.

For the Dutch Canal, as evidenced in Fig. 3b, the microplastic concentration of point sources was higher during the dry season (8.47 ± 4.91 mg/L) than the wet season (11.51 ± 5.46 mg/L), while in contrast the microplastic concentration of water surfaces was higher during the wet season (5.73 ± 3.67 mg/L) than the dry season (7.16 ± 4.56 mg/L). In both sources, a statistically significant difference was not observed during the two seasons ($p>0.05$). The reason for this may be all the surface runoff comes to water surface during the rainy season since the sampled area is highly pollutant. According to Yang and Cheng (Yang and Cheng, 2017), higher summer temperatures have a greater negative impact on output in low-temperature regions than in high-temperature regions, implying that adaptation to warming may have been actively undertaken in high-temperature regions. Lower industrial waste may come through point sources in the dry season than in the wet season.



(a) Beira Lake **(b) Dutch Canal** **(c) Talangama Canal**

Figure 6. Microplastic Concentration in Wert season and Dry season of (a) Beira Lake, (b) Dutch Canal, and (c) Talangama Canal

For Talangama Canal, as evidenced in Fig. 3c, in microplastic concentration in water surfaces (dry – 6.96 ± 3.26 mg/L, wet-13.92 ± 6.51 mg/L) is higher than the concentration in point sources (dry-5.12 ± 2.33 mg/L, wet- 10.24 ± 4.67 mg/L) in both dry and wet seasons. Furthermore, there was no statistically significant variation in microplastic concentration ($p>0.05$) between the wet and dry seasons in both point sources (0.065>0.05) and water surfaces (0.059>0.05). The reason for this may be all the surface runoff comes to water surface during the rainy season since the sampled area is densely populated.

4 DISCUSSION AND CONLUSION.

Microplastics have emerged as a significant contributor to the pollution caused by plastic. The water, the soil, and the air all contain trace amounts of microplastic. The air and the water are two of the primary mediums via which microplastics are transported. Toxic components that are contained in microplastic have the potential to be absorbed by environmental components as the microplastic is being transported. It poses a threat to a wide variety of plant and animal species. The majority of microplastics came into being because of man-made processes. Most of the plastic Urban water bodies are subject to pollution, and there is a pressing need for a great deal more research to be carried out to discover the forms, origins, and availability of microplastic in densely populated places.

Microplastic concentrations in the Dutch and Talangama canals were higher during the wet season than during the dry season. This may occur because when the rainstorm begins, the ground surface microplastic will be washed and gathered to those sources since the water collected in the cannels, culverts, and drains will be at a higher level. In Beira Lake, however, the opposite occurs. This could be because industrial waste from culverts and drains is lower in the wet season than in the dry season, or it could be due to the accumulation of microplastic in water and the low flowrate of water to the ocean in the dry season.

Microplastic concentrations in water surfaces of Beira Lake are higher than concentrations in point sources in both dry and wet seasons. Because Beira Lake is in an urban region, all surface runoffs may reach the water's surface during the rainy season. In both dry and wet seasons, turbidity at water surfaces is higher than concentration at point sources. The increase in turbidity during the wet season can be attributed to the increase in turbidity, which causes runoff and solids collection from the urban surroundings.

In both dry and wet seasons, the concentration of microplastics on water surfaces of Talangama Canal is higher than the concentration in point sources. Because the sampled area is densely populated, all surface runoffs may come to the water surface during the rainy season. In both the dry and wet seasons, the turbidity of the Talangama canal was higher on the water's surface than at point sources. The increase in turbidity during the wet season can be attributed to run off and solids collection from the surroundings.

The Dutch Canal and the Beira Lake are both in urban areas, but they have two different variations of microplastic pollution with seasonal variations because the Beira Lake is cleaned once a month and the Dutch Canal system has not been introduced with a microplastics treating or removal system. When compared to Beira Lake, all five canals sampled in the Dutch canal system are highly polluted.

It may investigate the microplastic content of aquatic life and sediment samples from the canal/lake to improve this study and evaluate the impact of microplastic contamination on the environment.

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