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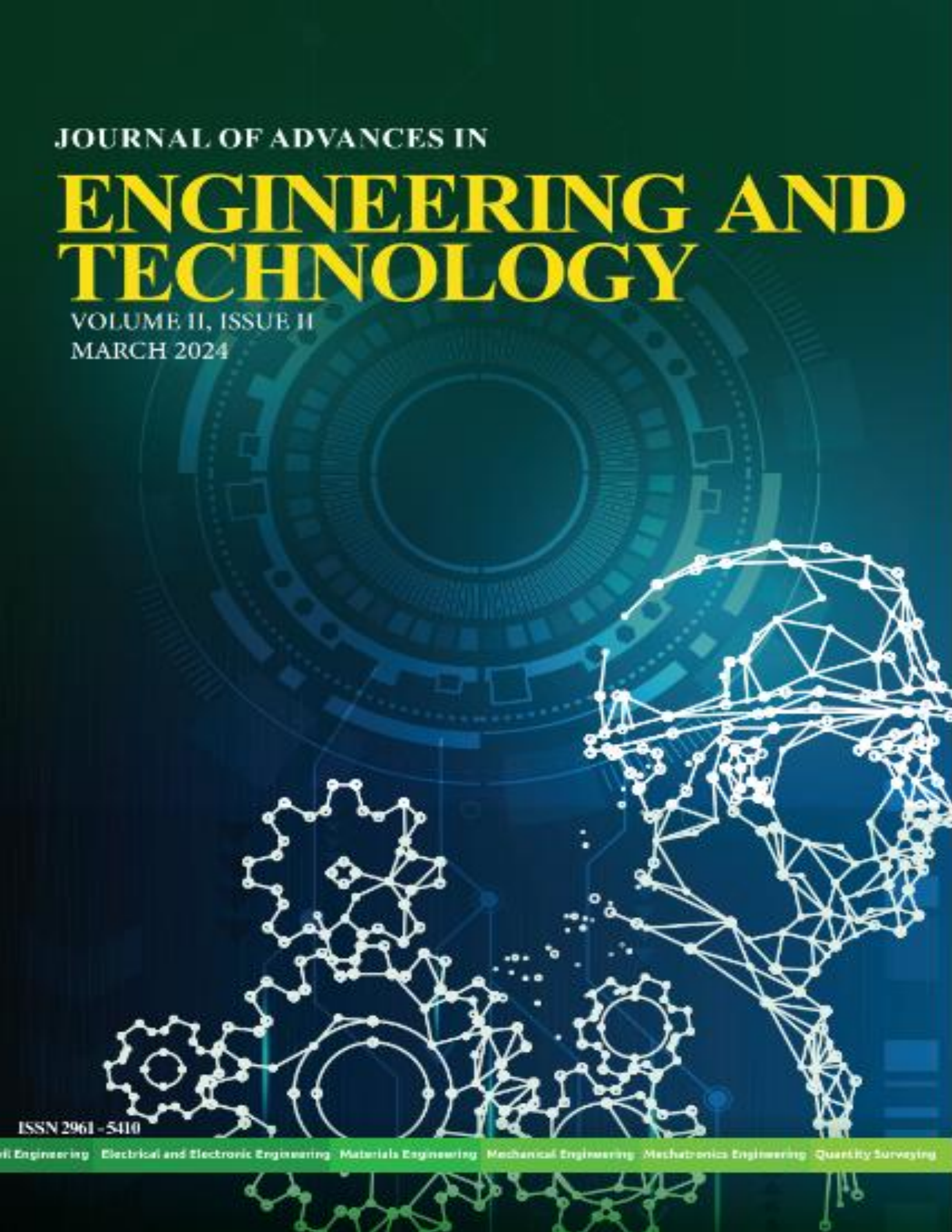

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Impact of Industry 4.0 Technologies on Sustainable Manufacturing

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ABSTRACT

Industry 4.0 (I4.0) and its associated technologies are increasingly becoming a key aspect of the manufacturing industry in an age where sustainable manufacturing has become a fundamental consideration. Despite Industry 4.0 technologies such as robotics, autonomous systems and Internet of Things (IoT) considered dominant enablers of sustainable manufacturing, the precise impact of these technologies on sustainability remains relatively unexplored as the research in this context remains limited. Therefore, the need for meticulous study and the development of a framework for the assessment of I4.0 technologies' impact towards enhancement of sustainable manufacturing is evident. The report contains an extensive literature review on several I4.0 technologies, the Triple Bottom Line (TBL) aspects of sustainability and how the respective I4.0 technologies impact the factors contributing to the TBL aspects of sustainability. Through a combination of theoretically available information and practical case studies in the Sri Lankan manufacturing industry, a conclusive framework is developed on how the implementation of the identified Industry 4.0 technologies contribute to achieving holistic sustainability across the Triple Bottom Line aspects. Additionally, through further study and multiple-criteria decision analysis methods, the most sustainably impactful technologies are determined with regards to the manufacturing industry.

KEYWORDS: *Industry 4.0, Sustainable Manufacturing, Impact of Industry 4.0, Sustainability, Triple Bottom Line*

1 INTRODUCTION

Industry 4.0 can be understood as the variety of initiatives, technologies, procedures introduced and followed in the industry that have brought upon a fourth industrial revolution. The conceptualization of Industry 4.0 was initiated as a strategic implementation by the German government initiative in 2011 across all manufacturing industries. (Kagermann et al., 2013). Further, Industry 4.0, is the industrial revolution brought upon by the combination of the upcoming next generation technologies employed in various sectors of the industry which include Internet of Things, 5G technology, big data analytics, artificial intelligence, and cloud manufacturing.

Upon having an insight of the contents of Industry 4.0, it is necessary to comprehend the practicalities of adopting Industry 4.0 and its impacts on sustainable manufacturing which requires an understanding of sustainability as a concept. As a result of several reports and conferences including the UN Conference on Environment and Development (UNCED) and the Bruntland report of the World Commission on Environment and Development in 1987, the manufacturing industries across the globe have been expected to achieve an equilibrium of economic, social, and environmental objectives which is often considered as the Triple Bottom Line (TBL). The earliest known adaptation by industry leading entities dates back to 1997 by Shell, Nike, Hewlett Packard, IBM, etc. A brief overview of the three aspects of the triple bottom line is as follows,

The economic aspect of the TBL is for an industrial model to generate and maximize profit in a sustainable manner that secures the long-term economic success and survival of the entity. This can be achieved through ensuring that the entity has positive and profitable returns with maximized productivity and liquidity is made available along with other economic factors. As seen in past research studies, adaptation of the environmental aspect must consider all living and non-living factors. Moreover, despite sustainability having multiple aspects, as seen in the 17 different global goals (SDGs), sustainability in the industrial sector is primarily considered to be of the environmental aspect. Gradually it has become evident that disregard for sustainability and singular commitment to profit maximization

is no longer a viable and tolerated design for manufacturing. (Kiel et al., 2017) In turn however, manufacturing organizations in the present day treat sustainability and the adhering to corporate social responsibility as a means of achieving high quality, high yield production with minimal input resources and minimal negative impact to all related stakeholders. The key aim of this research is to address the following primary objectives:

- Study the relationship between the Industry 4.0 technologies and their respective impacts on sustainable manufacturing.
- Create an assessment framework that contributes to the assessment of the impact of implementing Industry 4.0 technologies on sustainability in the manufacturing industry.
- Provide an extensive insight for all stakeholders in the manufacturing industry into the pros and cons of individual Industry 4.0 technologies and the entire concept with regards to sustainability.
- Developing a guideline for the stakeholders related to manufacturing to analyze and assess the risks and limitations of implementing the Industry 4.0 to potentially improve sustainability through utilizing Industry 4.0 technologies.
- Demonstrate the continuous need for methodical research and implementation of Industry 4.0 and the need to take advantage of the positive impacts to strive towards attaining the sustainable development goals.

2 LITERATURE REVIEW

Sustainability in all manufacturing processes has become the primary concern in the ever-developing manufacturing industry of present day in the context of research and development of the said industrial processes. In order to achieve such sustainability, the most common modern-day approach is to introduce advanced technologies including cyber physical systems, big data analytics and several others involving the involvement of IT and automation of the mechanical systems. The implementation of such “next generation” technologies in the manufacturing industry is what has given rise to the concept of Industry 4.0.

2.1 Developments of Industry 4.0 and its Technologies

Despite the absence of a clearly specified standard definition in the present day, Industry 4.0’s origins stem from the German conceptualization in the early 2010s. The fourth industrial revolution, the industrial Internet of Things, smart manufacturing and cloud manufacturing are some of the various terms allotted to be Industry 4.0. The concept is seen as a modern revolutionary era of development in the entirety of the manufacturing industry which involves the advanced automation of manufacturing processes utilizing the plethora of technologies that enhance the pre-existing manufacturing procedures, subsequently yielding numerous benefits. Benefits including increasingly successful commerce, elevated levels of production efficiency, product quality and even improving beneficial working conditions to the labour force indulged in the industries. (Hofmann and Rüsch, 2017) However, the key benefit that is of most interest to multiple stakeholders, is how this revolution affects and impacts the sustainability factors for a sustainable future.

Despite to the diverse range of benefits, limitations and drawbacks are present in the concept of Industry 4.0 as well. The main barrier to Industry 4.0 technologies, can be identified as the visible lack of facilities for adoption in several parts of the world where the economy is relatively less developed than most highly developed industrial nations from which the Industry 4.0 concept originated from and is implemented in. As discussed previously, Industry 4.0 technologies are primarily implementations of the modern ICT systems and concepts with an integration of advanced manufacturing process methodologies. Therefore, the key barriers regarding the implementation of the technologies are economic and infrastructural development in addition to the evident lack of knowledge and regulations that increasingly complicate the convenience of adoption into a country’s manufacturing industry as the technologies are relatively novel opposed to the pre-existing procedures followed and therefore require an adoption phase where all infrastructure and knowledge must be made available for successful implementation. (Saberi et al., 2018)

2.1.1. The foundational constituents of Industry 4.0 technologies

Industry 4.0, despite its various ambiguous definitions, consists of the same key technologies that enable it. For instance, Culot et al. (2020) conducted meticulous research which suggests that Industry 4.0 comprises of 13 central technologies which are seen to be accomplishing one of the two objectives which is either to bridge the physical peripherals and the digital world or to enhance connectivity. Similarly, Gilchrist (2016) in his book "Industry 4.0: The Industrial Internet of Things" further elaborates that the building blocks of Industry 4.0 are primarily constituent of nine individual technologies that influence the manufacturing industry. Another relevant research conducted by Jamwal et al (2021) on the topic of Industry 4.0 technologies for manufacturing sustainability, classifies the key constituents that Industry 4.0 comprises of, similarly to Gilchrist (2016). Hence the key constituent technologies that have been repeatedly seen to be the primary contributors to the concept of Industry 4.0 are identified as follows,

- Internet of Things
- Big data analytics
- Robotics and Autonomous systems
- Cloud manufacturing
- Additive manufacturing
- AI & Machine learning
- Block-chain technology
- Cyber-physical systems

2.2 The need for sustainable manufacturing

Manufacturing industry has always been seen as a function which creates produce through engineering solutions whilst optimizing for the economic value. This perspective has drastically changed in the past few decades due to the essential need to factor and consider the social and environmental aspects of sustainability making the manufacturing function not as straightforward as it once was viewed by the engineers. Developing countries are ever improving to elevate the quality of life for their increasing populace and hence manufacturing capacities need to increase. Similarly, developed countries do not downscale and instead always intend to expand and develop as well, resulting in the manufacturing industry to be an ever-expanding global industry. Therefore, an unsustainable scenario arises which needs to be addressed, hence sustainable manufacturing.

The three pillars of sustainable manufacturing; society, environment and the economy are widely addressed in the present-day industry which is. The three pillars are addressed by several terms including the triple bottom line (3BL), the pillars of sustainability and the 3Ps. The three Ps are essentially a simpler method of identifying the three pillars through simpler terms, society being people, environment being the planet and economy being profit or prosperity. It is crucial to further understand how the three pillars of sustainability are being addressed in order to achieve sustainable manufacturing, hence this is further reviewed in the following sections.

2.2.1. The persistent issues to achieve sustainable manufacturing

As per Alayón et al. (2022) there are estimated twice the number of barriers than enablers in sustainable manufacturing and these barriers can be classified into seven key aspects. Some of which include, contradictory managerial attitudes to sustainable manufacturing concepts, lack of awareness, absence of government policies, lack of financial capacity and the availability of technologically advanced infrastructure.

Furthermore, the need to accommodate the increasing cost of manufacturing is identified to be the main barrier in sustainable manufacturing practices. This is followed by the lack of awareness and lack of a guideline for implementation as key reasons for the lack of implementation of sustainable manufacturing practices.

2.2.2. The Triple Bottom Line aspects of sustainable manufacturing

The key areas that economic sustainability concerns itself in the manufacturing industry have been identified as manufacturing costs, profit, and investments. The profit aspect deals with the aim to increase revenue and minimize the costs of manufacturing. The investment aspect prioritizes the evaluation of the economic performance improvements as a result of the investments made with the goal to achieve better performances. Finally manufacturing cost aspect includes most aspects of the

manufacturing procedures including operating costs, equipment performance (lifespan and resultant depreciations), etc. In the context of industry 4.0 and the manufacturing industry, it can be seen that the impact of Industry 4.0 has more immediate effects and if implemented correctly can contribute positively to reach social and economic sustainability.

The key areas of concern for environmental sustainability in the context of manufacturing can be classified into four categories. First is the emissions from manufacturing procedures which often include several by-products, wasted energy, etc. The second is the pollution which involves the release of detrimental substances into the surrounding environment. The third is the consumption of resources in a possibly unsustainable manner which could include scarce raw materials, energy, and other such consumables. Finally, it is the impact on biodiversity caused by the manufacturing industry due to the disruption of nature to obtain raw materials, operate the industrial facilities, etc.

Social sustainability is a crucial dimension of sustainability which intertwines with the other aspects in many ways. Social sustainability is the social aspect which often enables the welfare of people and society as a whole through the provision of equal opportunities, equal wealth distribution, human wellbeing and a healthy environment. From research it is seen that the key issues that impact social sustainability in manufacturing include issues pertaining to work management and human rights from within the manufacturing enterprise and externally on the societal responsibilities, and business practices of the entities and any issues concerning the customers.

2.3 Existing models of evaluating the impact of Industry 4.0 on Sustainable Manufacturing

The study of the impacts of Industry 4.0 in the context of sustainable manufacturing is a relatively under researched area, though there have been studies that have come up with models that aim to evaluate the impact of Industry 4.0 technologies.

One such study is done by Ghobakhloo (2020), which studies the opportunities for sustainability through the implementation of Industry 4.0. The study initially undertakes the comprehensive literature review of the fundamentals of Industry 4.0 followed by the creation of a model relationship between Industry 4.0 and sustainability by applying the interpretative structural modelling technique (ISM). The results of the ISM revealed the existence of complicated interdependent relationships between the Industry 4.0 and sustainability factors. In order to assist the ISM, a MICMAC analysis is done which allows for a comparative analysis between the attributes and provides an insight to the driving and dependence powers of the sustainability factors.

Another related research was conducted by Bai et al. (2020) under the topic, “Industry 4.0 technologies assessment: A sustainability perspective”. The aim of the research study is to emphasize the importance for organizations to evaluate Industry 4.0’s impact on sustainability and assist these organizations as pre-existing frameworks for guidance are scarce. Subsequent to the literature review, a framework is developed with regards to sustainability aspects based on the 17 UN Sustainable Development Goals. The result showed big data analysis, cloud and mobile technology to be the most impactful of the 17 identified I4.0 technologies. The general consensus and conclusion reached from the study is for manufacturing organizations to implement and adapt Industry 4.0 technologies since they have a positive impact, but also to evaluate individual technology cautiously since some technology adoptions might not be worth the risk, investment and/or the promised improvement.

3 METHODOLOGY AND EXPERIMENTAL PROCEDURE

The below step-by-step procedure demonstrates the initial steps to be followed in order to initiate the development of the assessment framework to conduct the research.

- Step I – Identification of the problem statement which is to develop a detailed framework and analyzing the sustainability impact of Industry 4.0 technologies’ implementation in the industry.
- Step II – Conduct exhaustive literature review of related studies to the research problem.
- Step III – Identification and establishment of relationships between the identified Industry 4.0 technologies and the contributing factors to manufacturing sustainability.
- Step V – Case studies at manufacturing organizations and obtain expert input
- Step VI – Identify, assess and evaluate the impact of the identified Industry 4.0 technologies

- Step VII – Develop a generic conclusive model of the impacts of Industry 4.0 on sustainable manufacturing and develop a guidance framework for Industry 4.0 implementation

3.1 Initial Deductions from Literature Review

From initial literature review, the key Industry 4.0 technologies are identified to be as additive manufacturing, cyber-physical systems, cloud computing and manufacturing, Internet of Things, big data analytics, autonomous systems, blockchain technology and machine learning concepts.

Subsequently, the need for sustainability, issues hindering the achievement of sustainability, aspects of sustainable manufacturing, and the key concerns regarding sustainability in the sense of the triple bottom line aspects are identified as well as the impacting factors on the TBL aspects of sustainability with their associated weightage contribution to the sustainability aspect.

Table I – Economic sustainability concerns and their associated weightages

Economic Sustainability Concern	Associated Weightage (%)
Manufacturing – Operating Costs	25
Manufacturing – Raw Material Costs	25
Manufacturing Equipment Performance	15
Profitability	20
Return on Investment	15

Table II - Environmental sustainability concerns and their associated weightages

Environmental Sustainability Concern	Associated Weightage (%)
Energy Utilization	30
Raw Material Utilization	20
Emissions	30
Impact on bio-diversity/eco friendliness	20

Table III - Social sustainability concerns and their associated weightages

Social Sustainability Concern	Associated Weightage (%)
Impact on Employment Rate – Work Management	20
Ergonomics	30
Provision of Equal Opportunity and Social Security	15
Employee Skill and Continuous Professional Development	20
Business Practices and Societal Rights	15

The third and final section of the literature review improves the understanding of the barriers leading to the adoption of Industry 4.0 to enhance sustainability, sustainable value creation and identification of previous studies that address the sustainability impact of Industry 4.0 implementations.

3.2 Industry expert input and case study

In order to gain a practical insight to the research problem, it is necessary to study the real-life scenarios in addition to the literature pertaining to the research problem. This need for real life research is addressed through input from industry experts involved in the manufacturing industry through questionnaires and interviews regarding the existent Industry 4.0 technology implementation and the various impacts they could or could not have resulted in.

Case Study I - The first organization where a practical case study is to be conducted is a leading hosiery apparel manufacturer that engages primarily in the production of socks and has an extensive manufacturing facility that utilizes Industry 4.0 technology in specific sections. In order to gain an extensive understanding and insight to the manufacturing organizations' implementations and understanding of Industry 4.0, several key personnel of the operation who are industry experts are to be contacted and input is to be collected with regards to the extent of Industry 4.0 implementation and its impacts on the various concerns pertaining to the triple bottom line of sustainability, enablers and

barriers, and specific historic and performance data of the changes that have been realized through implementing Industry 4.0 technologies for the purpose of comparison and analysis.

Case Study II - The second organization chosen for a case study is an organization primarily manufacturing industrial tires used in the agriculture, construction, sports and defense industries. Data collected will include an initial assessment of the implemented Industry 4.0 technologies, the enablers and barriers, followed by the impact on the factors affecting the three TBL aspects of sustainability by the Industry 4.0 technologies that are actively utilized. Input is also taken on how the I4.0 technologies that have not been implemented will benefit or not benefit the sustainability of the manufacturing plant, etc.

3.3 Assessment models for Case Studies

Initially, an implementation and readiness assessment of the manufacturing organizations' presently available facilities needs to be performed in order to collect useful and relevant data as per the research problem. In order to do so, the 4 levels of implementation shown in Table IV are used as benchmarks for the identification for each of the identified 8 Industry 4.0 technologies. Utilizing the defined levels of implementation, the organizations' manufacturing facilities can be assessed as to how well or not Industry 4.0 has been integrated as a concept by individually assessing the 8 key technologies. The results are noted through a simple assessment matrix.

Following the implementation assessment, the sustainability impact is to be studied. For the purpose of data collection and initial assessment, a pair-wise comparison matrix will be utilized. The data is collected from the interviews and questionnaires posed to the relevant industry experts at the sites of the case study along with further refinement of the assessment model. Additionally, literature review data from various sources is used to determine the impact in order to make a conclusive model for the sustainability impact assessment.

Table IV – Level of implementation descriptions for implementation assessment

Level of Implementation	Description
Level 0	The manufacturing operation does not have the capability to introduce I4.0 due to barriers or lack of applicability in the area of expertise.
Level 1	The organization has fundamental operations and basic infrastructure that can be upgraded in the near future to realize Industry 4.0.
Level 2	The Industry 4.0 technology has recently been fundamentally implemented with the potential for increased utilization and integration.
Level 3	Advanced Industry 4.0 technology implementation and utilization in the organization with high levels of integration with the other key I4.0 technologies.

Table V – Description of scoring for sustainability impact assessment

Scoring/Weightage	Description
1	Detrimental sustainability impact post-implementation of the Industry 4.0 technology due to various possible reasons.
3	Minor or negligible sustainability impovements post-implementation of the Industry 4.0 technology. I4.0 provides a minimal change in terms of sustainability, despite possible improvement in other areas of the organizations' capabilities.
5	Moderate improvement seen in at least one of the triple bottom line aspects of sustainable manufacturing due to the implementation of the I4.0 technology.

7	Noticeable and significant improvements in multiple aspects in the triple bottom line of manufacturing sustainability as a result of the Industry 4.0 technology
9	Improved sustainability in all triple bottom line aspects and reaped major benefits after implementation compared to previous technologies available at the organization

In order to assess the sustainability impact of an Industry 4.0 technology's implementation at an organization, a scoring method will be utilized to describe the relationship between the I4.0 technology and the sustainability concern/aspect. A description of the reason for the scoring will be attached to provide justification. The above table provides the scoring system to be utilized which ranges between 1 and 9. The scoring and analysis assessment of the sustainability impact will be performed separately for each of the three triple bottom line aspects of sustainability. The final output, however, will be a weighted average between all three triple bottom line aspects.

3.4 Identifying the most sustainably impactful Industry 4.0 technologies

As aforementioned, eight Industry 4.0 technologies are being considered and for the development of a guideline for fundamental implementation and sustainability improvements in manufacturing, they are to be treated as alternatives. Therefore, in order to determine the most impactful Industry 4.0 technology which positively benefits all of the triple bottom line aspects of sustainable manufacturing, multi criteria decision making is to be utilized since it allows for accurate decisions to be made from the data collected in the form of a pair-wise comparison matrix in the previous stages of the study.

Višekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) is a broadly utilized MCDM method that provides a ranked solution to multiple criteria problems which require discrete optimization and resolution of possibly conflicting criteria. In order to carry out the VIKOR method, the below given steps are followed to determine the most impactful Industry 4.0 technology and also to identify which I4.0 technologies address which concern factor most effectively.

3.4.1. Steps to conduct VIKOR analysis

Initially, the criteria must be determined whether it is beneficial or non-beneficial (e.g. higher value beneficial), however as seen in previous sections, the scoring of the criteria is done in such a way that it is always beneficial. Once this is determined, the best and worst values (alternative) must be identified for each criterion for the decision matrix of values to be normalized.

The best value in a beneficial scenario being identified as $f_i^+$and for the worst value in the beneficial scenario as f_i^-. S_j is the utility measure and R_j is known as individual regret and are to be computed as follows,

$$S_j = \sum_{j=1}^{n} \frac{f_i^+ - f_{ij}}{f_i^+ - f_i^-} \times W_j \quad (1)$$

$$R_j = Max\left(\frac{f_i^+ - f_{ij}}{f_i^+ - f_i^-} \times W_j\right) \quad (2)$$

Where W_j is the criteria weight and n is the number of criterion. Following the utility measure and individual regret calculation, Q_j, the overall rank, can be determined as follows,

$$Q_j = \frac{S_j - S^+}{S^- - S^+} \times \upsilon + \frac{R_j - R^+}{R^- - R^+} \times (1 - \upsilon) \quad (2)$$

Where υ is taken to be 0.5 & R^+ = Min(R_j) ; R^-=Max(R_j) & S^+=Min(S_j) ; S^-=Max(S_j)

Once the ranking is completed, two conditions need to be checked for effective decision making.

Condition 1 – Acceptable Advantage in Decision Making

$$Q(A^2) - Q(A^1) \geq DQ \quad (3)$$

Where DQ=1/(j-1) and j is the number of alternatives

Condition 2 – Acceptable Stability in Decision Making

This condition is such that A^1 which is the first ranked alternative must also be the best ranked alternative by the S and/or R value scales as well.

If one of the conditions is not satisfied, a compromise set of solutions is proposed. If only condition 2 is not satisfied, then alternative 1 and 2 are considered as a compromise set. If condition 1 is not satisfied, the same condition is applied for the subsequently ranked alternatives, until the condition is satisfied. All the alternatives that do not satisfy the condition after the rank 2 alternative will also be included in a compromise set. The above steps to perform a VIKOR have been developed into a MATLAB code, seen below, that can be utilized by entering the decision matrices and weightages.

```
%Decision matrix values entered as a variable array 'dm_array'
%Criteria weightages entered as a variable array 'weightage'
%Variable array 'criteria_bnb' of 0s and 1s entered, indicating whether the
criteria is beneficial or not
v=0.5
dm_alt=length(dm_array(:,1)); %Number of alternatives

%Checking if criteria are non-beneficial for each criterion entered
for c_no = 1:length(weightage) %Number of criteria
    if criteria_bnb(1,c_no)== 1
        fi_pos(1,c_no)= max(dm_array(:,c_no));
        fi_neg(1,c_no)= min(dm_array(:,c_no));
    else
         fi_pos(1,c_no)= min(dm_array(:,c_no));
        fi_neg(1,c_no)= max(dm_array(:,c_no));
    end
end
for altn = 1:dm_alt
  for c_no = 1:length(weightage) %Number of criteria
%Normalizing the decision matrix dm_array and storing it in 'normalized'
   normalized(altn,c_no)=(fi_pos(1,c_no)- dm_array(altn,c_no))./(fi_pos(1,c_no)-
fi_neg(1,c_no));
%Calculating utility measure values
   S_ij(altn,c_no)=(normalized(altn,c_no).*weightage(c_no));
%Calculating Sj, Rj and Qj values for ranking scores
   Sj(altn,1)= sum(S_ij(altn,:));
   Rj(altn,1)= max(S_ij(altn,:));
   Qj(altn,1)=(v*((Sj(altn,1)-min(Sj))/(max(Sj)-min(Sj))))+((1-v)*((Rj(altn,1)-
min(Rj))/(max(Rj)-min(Rj))));
  end
end
Sj
Rj
Qj
```

4 RESULTS AND DISCUSSION

4.1 Determining the most sustainably impactful Industry 4.0 technologies

The VIKOR MCDA method has been utilized to determine the most sustainably effective I4.0 technologies for each triple bottom line aspect for both case studies. The initial step is to normalize the decision matrix in order to calculate S_j and R_j. The data is obtained through the initial implementation assessment and the sustainability impact assessments that are conducted. Normalizing the decision matrix needs to be done for each criterion, by identifying the maximum and minimum values in the criteria and finding the ratio of variation of the element to the maximum difference multiplied by the weight of the criteria. Following the normalization of the decision matrix, the S_j, R_j and Q_j values can be calculated to determine the ranking for sustainability impact. In VIKOR analyses, the lowest output value from the calculations indicates the most preferred alternative and hence, ranked in an ascending manner. The following table is an example of a completed VIKOR analyses conducted for economic sustainability impact of the Industry 4.0 technologies implemented in the hosiery apparel manufacturing organization. The analyses are conducted for each TBL aspect of sustainability and the complete impact ranking results for each case study can be seen in Table VII and VIII.

Table VI – Summary of the VIKOR analyses results for Case Study I

	Economic Sustainability Concern Criteria					S_j	R_j	Q_j	***RANK***
	0.25	**0.25**	**0.15**	**0.2**	**0.15**				
	EC1	*EC2*	*EC3*	*EC4*	*EC5*				
Cyber-Physical Systems	7	7	7	5	7	0.3583	0.2000	0.5792	**4**
Cloud Manufacturing	3	3	5	5	5	1	0.2500	1	**5**
Internet of Things	9	7	7	9	9	0	0	0	**1**
Big Data Analytics	9	5	7	9	9	0.1250	0.1250	0.3125	**3**
Robotics & Autonomous Systems	9	7	7	9	9	0	0	0	**1**
Best Scenario (f_i^+, S^+, R^+)	*9*	*7*	*7*	*9*	*9*	*0*	*0*		
Worst Scenario (f_i^+, S^-, R^-)	*3*	*3*	*5*	*5*	*5*	*1*	*0.2500*		

4.2 Findings from Case Study I

The hosiery apparel manufacturer is an organization that is planning to implement an Industry 4.0 ecosystem with increased sustainability and therefore in a state of transition from second and third generation industrial practices towards an Industry 4.0 ecosystem. The facility did not possess a holistic Industry 4.0 ecosystem, but nonetheless implemented some Industry 4.0 technologies/aspects in its manufacturing processes. Of the eight Industry 4.0 technologies considered in the research study, additive manufacturing as a technology/concept is not applicable due to the nature of apparel manufacturing and thus was not considered for further analysis. Robotics and autonomous systems, along with cyber-physical systems and cloud manufacturing were some key technologies that have been implemented. The most advanced implementation Industry 4.0 technology is divulged to be Internet of Things which also allows for big data analytics. IoT and big data analysis have been the most revolutionary implementations for the organization allowing for multiple improvements which address several concern factors impacting the triple bottom line aspects of sustainability.

In the following table, the rankings of the five Industry 4.0 technologies that were evaluated are summarized and the overall ranking for sustainability have been derived through averaging the results. From the results it can be seen that for case study I, Internet of Things is the implementation that has holistically impacted sustainability the most, followed by the autonomous system and cyber-physical systems implementations being ranked second and third most impactful in terms of the TBL aspects of sustainability. Analyzing the results, the VIKOR analyses yielded similar results to the qualitative data obtained from the interviews with the key personnel at the organization. During the site visit and the associated interviews, IoT was identified to be the most fundamental and beneficial implementation at the organization due to having relatively minimal barriers to implementation. The implementation of the cyber-physical autonomous machinery however was deemed to be the highest beneficial and revolutionary change in the organization but the barriers to implementation persist due to the financial requirements. This is further supported by the fact that the transition to advanced machinery is still at 47% and the transition phase for the machinery in particular will take at least two more years. Another consideration is that big data analytics despite being quantitatively ranked 4, is more of a value addition and complementary to I4.0 technology.

Table VII – Summary of the VIKOR analyses results for Case Study I

Industry 4.0 Technology	**Rank in Economic Sustainability**	**Rank in Environmental Sustainability**	**Rank in Social Sustainability**	***Overall Rank***
Cyber-Physical Systems	4	4	1	**3**
Cloud Manufacturing	5	4	2	**5**
Internet of Things	1	1	2	**1**
Big Data Analytics	3	2	5	**4**
Robotics & Autonomous Systems	1	3	2	**2**

4.3 Findings from Case Study II

Similar to the first case study, the tire manufacturing organization is also in its transition stages of achieving an Industry 4.0 ecosystem with the main focus on achieving holistic sustainability. The first Industry 4.0 technology investigated, additive manufacturing, is not extensively used as of yet, however its implementation has allowed for improvements in production in use, cases including engraving. The use of robotics and semi-automated systems are utilized in the tire material development and tire development sections. Cloud computing and manufacturing is also utilized in a fundamental manner to assist in the production process and the production floor which integrates into the IoT implementations. Similar to the first case study, IoT is the most extensively implemented Industry 4.0 application through use of sensors, cloud computing, databases and many more to enhance manufacturing processes in various manners. The use of IoT also enables the collection of big data that is used for big data analytics through refinement and study. Three of the eight Industry 4.0 applications focused on this research, cyber-physical systems, AI and blockchain management are not present at this facility, and thus further analyses cannot be conducted and therefore, will not be discussed. At the present state of the manufacturing ecosystem cyber-physical systems are considered to be sub optimal since complete automation and no human interaction is not preferred.

The sustainability impact results obtained from the analyses seen below indicate that Internet of Things is the most beneficial implementation, followed by a compromise group between robotics and big data analytics. Further studying the results, the ranking obtained through the VIKOR analyses is identical to the input received from the key personnel at the organization. The most sustainably impactful is the combination of IoT implementations and the complementary big data analytics. The robotics systems were discussed to be the most socially impactful Industry 4.0 solution implemented due to the great levels of ergonomic benefits it provides the employees, which is one of the organization's key focuses. The combination of IoT and big data analytics were also identified to have created the most opportunities for economic advancements and eco-friendliness in the manufacturing procedures.

Table VIII – Summary of the VIKOR analyses results for Case Study II

Industry 4.0 Technology	**Rank in Economic Sustainability**	**Rank in Environmental Sustainability**	**Rank in Social Sustainability**	***Overall Rank***
Cyber-Physical Systems	4	3	2	**4**
Cloud Manufacturing	4	5	4	**5**
Internet of Things	2	1	1	**1**
Big Data Analytics	1	4	2	**2**
Robotics & Autonomous Systems	2	1	4	**2**

4.4 Further findings, discussion and guideline

As discussed, input was gathered qualitatively from the industry professionals at the respective organizations where the case studies were conducted, and this information with their assistance was utilized to complete the sustainability assessments for the 6 available Industry 4.0 technology implementations. Due to the limitations present in the Sri Lankan industry, two of the eight identified Industry 4.0 technologies, AI/machine learning and block chain technology, were not assessed.

From both case studies it is seen that the Internet of Things (IoT) implementation has been the most sustainably impactful Industry 4.0 implementation in the manufacturing environment. Robotics and autonomous systems are identified to be the second most impactful in both case studies since their implementation often revolutionizes the manufacturing process and provides a multitude of sustainable enhancements. Looking at the enablers and barriers of implementing these technologies, IoT is relatively the easier I4.0 technology to initiate implementation at an organization due to the fact that the financial pressure is significantly lower than overhauling manufacturing processes with advanced robotics systems.

It is crucial to recognize that big data analytics is often considered as a complementary implementation to IoT in many circumstances as IoT enables the acquisition of big data. As a result, it can be deduced from the results that big data analytics is the third most impactful Industry 4.0 technology that can be implemented in a manufacturing organization to enhance sustainable manufacturing. Similarly, cyber-physical systems and cloud manufacturing can be considered to be complementary to robotics and autonomous systems, since the initial transition does not involve direct transition towards implementing cloud manufacturing. This is reflected in the VIKOR analysis and is the reason for the relatively lower rankings in sustainability impact for cloud manufacturing and cyber-physical systems. Additionally, additive manufacturing is a useful yet situational implementation that could positively impact sustainable manufacturing. This is however not reflected in the results obtained from the case studies, since it is not applicable at the hosiery apparel manufacturing company and the implementation is very rudimentary in the tire manufacturing organization.

The fundamental requirements for implementing AI and block chain technology in the manufacturing industry is the need for an already existing Industry 4.0 standard ecosystem. If available, these technologies are supplementary to improve several manufacturing procedures that will promote sustainability. The ability to meet these requirements is not seen in the organizations chosen for the case study and even across the Sri Lankan manufacturing industry, due to several factors including primitive infrastructure availabilities.

Further looking into barriers and enablers of Industry 4.0 implementation for sustainable manufacturing, a key barrier that was identified as a part of the case studies is the lack of willingness amongst the employees to adapt and shift towards an Industry 4.0 ecosystem. This occurs due to several concerns including the anxiety of the possibility of employees being made redundant. This issue needs to be addressed through improving awareness amongst the population and displaying the mutual benefits that can be achieved through implementing sustainable Industry 4.0 solutions and an organization's commitment towards its employees' well-being. The recent COVID-19 pandemic and the subsequent severe economic crisis have also been major barriers in the manufacturing organizations' ambitions of transitioning to Industry 4.0 ecosystems. The need for comprehensive infrastructure to implement Industry 4.0 is also identified and emphasized by the feedback received whilst conducting the case studies. Sri Lanka is a developing nation and does not have universal (and affordable) access to broadband and other utility infrastructures which significantly restricts the improvements that can be made. Thus, it is important to manage these issues by implementing feasible I4.0 technologies that do not require high levels of investment.

5 CONCLUSION

A novel assessment methodology has been developed to assess the Industry 4.0 technologies available at a manufacturing organization and how the respective technologies impact the concerning factors of each TBL aspect of sustainability. Initially, the eight key Industry 4.0 technologies and the sustainability impact factors of each TBL aspect of sustainability were determined through the literature

review. Subsequently, a comprehensive assessment framework was developed for analyzing the manufacturing sustainability impact of each Industry 4.0 technology that is being considered.

The developed framework analysis has been put into practice through means of two case study scenarios, a hosiery apparel manufacturer and a tire manufacturer. Through five interviews with the associated industry professionals and site visits for each case study, data was acquired to perform the sustainability impact assessment for the Industry 4.0 technologies that were implemented. Following the assessments, VIKOR analyses assisted in determining the most sustainably impactful Industry 4.0 technologies for positive impact using the data acquired from the assessments conducted. The results obtained were identical to the input acquired from the industry professionals who were consulted in the respective organizations, displaying the reliability of the assessment and the analysis model.

As a result, Internet of Things was concluded to be the most impactful Industry 4.0 technology that could be implemented in a manufacturing plant due to the several opportunities it presents for sustainable enhancements across the board. A key concern in the completion of this research is the need for case studies of organizations that have diverse and comprehensive implementations of Industry 4.0 technologies in an Industry 4.0 ecosystem which intends to be addressed in future work.

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Measuring Burnout: A Validation Study of The Oldenburg Burnout Inventory for The Sri-Lankan IT Sector

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ABSTRACT

Burnout is a psychological syndrome emerging as a prolonged response to chronic interpersonal stressors on the job. WHO defines burnout as an "occupational phenomenon" and is included in the 11th revision of the International Classification of Diseases (ICD-11). Research reveals the existence of this burnout phenomenon across a range of occupations, such as healthcare professionals, teachers, athletes, pilots, IT professionals etc. A study conducted by Yerbo, a mental wellbeing platform revealed that 2 in 5 of the workers in the IT industry show a high risk of burnout.

At present, there are few tools available to measure burnout. After the Maslach Burnout Inventory (MBI), the Oldenburg Burnout Inventory (OLBI) is considered the most widely used measure of burnout and is also freely available. The current study is aimed at determining the measurement validity of the OLBI in the local context based on IT professionals.

To determine the content validity of the OLBI, an expert panel was employed. In order to examine the construct validity and concurrent criterion validity, a questionnaire-based study was conducted among 161 (n = 161) randomly chosen IT professionals. MBI and DASS-21 were used to explore the convergent and divergent validity of the OLBI.

Four items were deemed not essential to measure burnout based on content validation. The MTMM analysis revealed adequate evidence of the existence of both convergent and divergent validity of the OLBI.

The current study was able to provide evidence of content, concurrent criterion and construct related validity of the OLBI in the Sri Lankan context based on IT professionals. These findings suggest that OLBI can be used as a reasonable tool to measure burnout among IT professionals in Sri Lanka. Availability of such a tool will undoubtedly help organizations in ensuring their workforce is healthy and productive.

KEYWORDS: *Occupational burnout, Content validity, Construct validity, Criterion validity, Oldenburg Burnout Inventory, Multi Trait Multi Method Matrix*

1 INTRODUCTION

Burnout is a commonly used metaphor to describe a state or process of mental exhaustion, similar to the smothering of a fire or the extinguishing of a candle (Schaufeli & Buunk, 2003). The APA dictionary of psychology (n.d.) defines burnout as physical, emotional or mental exhaustion accompanied by decreased motivation, lowered performance and negative attitudes towards oneself and others. Herbert Freudenberger (1974) is considered to be the father of the Burnout Syndrome (Schaufeli & Buunk, 2003). Freudenberger, working as a psychiatrist at a New York clinic for drug addicts stated that burnout manifests in many different symptomatic ways which vary in symptoms and degree from person to person (Freudenberger, 1974). He further explored physical and behavioral signs of burnout which included feelings of exhaustion and fatigue, suffering from frequent headaches, sleeplessness and shortness of breath etc. Subsequently, other scholars began to define this phenomenon of burnout in a more structured manner. The most often cited definition of burnout is, "Burnout is a syndrome of emotional exhaustion, depersonalization, and reduced personal accomplishment that can occur among individuals who do 'people work' of some kind" (Maslach & Jackson, 1986, p. 1). Another definition of burnout emerged including physical symptoms and not restricting burnout to the helping professions as the previously cited definition did, which defined burnout as "a state of physical, emotional, and

mental exhaustion caused by long-term involvement in situations that are emotionally demanding" (Pines & Aronson, 1988, p. 9). Burnout consists of a sense of disengagement with which, exhaustion and a belief of not being able to do their job role and other work-related activities.

1.1 Burnout among IT professionals

A study conducted by Yerbo (2022), a mental wellbeing platform revealed that 2 in 5 of the workers in the IT industry show a high risk of burnout. According to the same study, 42% of IT professionals with high levels of burnout-risk are considering quitting their company in the next six months while 62% indicated they feel physically and emotionally drained. The report goes on to point towards a possible burnout crisis in the IT industry, with poor outcomes for workers and companies (Yerbo, 2022). Having to work late hours, imbalance between work and personal life, workers being forced to adhere to anti-patterns, mounting work pressure and many other factors account for burnout among professionals in the IT industry (Yerbo, 2022).

Although the IT workforce has a strong sense of personal pride and accomplishment (Cook, 2015), they feel the strain in terms of feeling physically and emotionally drained (Yerbo, 2022). Not being able to relax after the workday is over and feeling physically and emotionally drained. (Yerbo, 2022) seem to capture the exhaustion that constitutes burnout among IT professionals. The feelings of being less competent and achieving less than required at work also contribute to burnout among IT professionals (Cook, 2015; Yerbo, 2022). Further, being less engaged in work and not seeing the value or purpose in what they do, also seem to contribute towards burnout in IT professionals (Yerbo, 2022). A sense of "limitless jobs" among IT professionals which is primarily caused by the ever-increasing number of interactions at work where communication leads to more communication and the role conflicts between tasks also contribute to burnout (Evenstad, 2018).

Hayes (2003) reports that 71% of managers working in Information Technology (IT) believe that burnout is a serious problem for their company. Interestingly, Pawlowski et al. (2007) conducted a study in which an "overwhelming majority" (p. 622) of the participants saw ineffective IT management and supervision as a root cause of burnout. Further, Hayes (2003) uncovered a range of deficiencies in management which contributes to burnout in the IT workforce which includes inability to manage internal politics effectively, poor project planning / management skills, lack of communication and lack of supervisor support. Cook (2015) also revealed that organizational politics plays a role in causing burnout among IT professionals. In the interest of how leadership can have an impact on burnout among IT employees, Hetland et al. (2007) suggest that the leadership style (passive-avoidant leadership , transformational leadership, etc.) is associated with the levels of vulnerability for burnout among IT employees. It has to be noted that while these causes of burnout may not be unique to the IT profession, it certainly has an impact on burnout in the IT workforce.

1.2 Effects of burnout in the workplace

Suñer-Soler et al. (2014) conducted a study based on 11,530 Spanish speaking healthcare professionals from Spain and Latin America which revealed a considerable prevalence of adverse professional consequences associated with burnout. The study identifies a significant association of burnout with absenteeism and turnover intention. The same study reveals the process of withdrawal, otherwise known as depersonalization which constitutes burnout, is also significantly associated with committing mistakes (Suñer-Soler et al., 2014). It has also been reported that feelings of personal accomplishment influenced absenteeism. In comparison to job satisfaction, absenteeism is increased by high role stress and decreased by high personal accomplishment, workload, peer support etc. (Iverson et al., 1998). Another study based on 142 nuclear physics institute employees revealed that absenteeism was not only related to feelings of personal accomplishment but positively associated with feelings of exhaustion (Petitta & Vecchione, 2011).

Madigan and Kim (2021) presented that burnout is negatively associated with job satisfaction while burnout is positively associated with the teachers' intention to quit. It has been reported that burnout and job satisfaction together explained about 27% of the variance in teachers' intentions to quit and that burnout accounted for the majority of this explained variance (Madigan & Kim, 2021). Iverson et al. (1998) also revealed significant evidence where burnout is negatively associated with job satisfaction.

Thomas and Douglas (1997) were among the first authors who found empirical support for the relationship between burnout and performance, in which a negative relationship between burnout and performance was observed. Further, a study conducted based on nurses and police officers found that the relationship between burnout and in-role performance was negative and significant (Bakker & Heuven, 2006). However, there is still speculation regarding the relationship of burnout with self-rated performance, subjectively and objectively assessed performance; the general argument is that burnout is differentially related to the above three forms of performance measurements (Shirom, 2003). According to Shirom (2003), the negative relationship between burnout and job performance is likely to be explained by burned-out individuals' impaired coping ability and their reduced level of motivation to perform.

1.3 Effects of burnout on personal health

Research suggests that employees who are chronically fatigued and cynical about their work report more psychological and physical health problems (Schaufeli & Enzmann 1998, Shirom et al. 2005). Several studies also revealed that burnout was associated with a variety of somatic symptoms or otherwise known as subjectively reported health related problems including sleep disturbances, recurrent headaches, gastrointestinal problems, circulatory and heart problems, musculoskeletal pains and excessive sweating (Kahill, 1988; Gorter & Eijkman, 2000; Shirom et al., 2005).

A study conducted on a nationally representative sample of 3,000 Finnish employees revealed that burnout was related to an increased prevalence of depressive and anxiety disorders and alcohol dependence among male and female employees (Ahola, 2007). Burnout may overlap with anxiety since high levels of emotional exhaustion may raise an individual's level of anxiety in stressful situations and may weaken their ability to cope with anxiety (Winnubst, 1993). Hakanen and Schaufeli (2012) reported that burnout predicted depressive symptoms and life dissatisfaction in their three wave, seven year prospective study of almost 2,000 Finnish dentists. According to Peterson et al. (2008) self-reported depression, anxiety, sleep disturbance, memory impairment and neck and back pain most clearly discriminated between burnout groups from non-burnout groups.

Further, Burnout has been found to be an independent risk factor for infections such as common cold (Mohren et al., 2003) and type 2 diabetes (Melamed et al., 2003). In addition, studies have found relationships between burnout and dependance on alcohol (Cunradi et al.,2003; Winwood et al. 2003) and suicidal ideation (Sonneck & Wagner, 1996). It is also argued that people often distract themselves from situations that may cause distress, like burnout, by engaging in health impairing activities such as smoking and consuming alcohol with the intention of alleviating distress in the short term, but at the expense of deteriorating the state of health in the long run. (Schwarzer & Fuchs, 1995).

2. BURNOUT CONCEPTUALIZATION

Burnout is a psychological syndrome emerging as a prolonged response to chronic interpersonal stressors on the job (Maslach & Leiter, 2016). The World Health Organization (WHO) defines burnout as an "occupational phenomenon" and is included in the 11th revision of the International Classification of Diseases (ICD-11) and it goes on to note that it is not classified as a medical condition. According to WHO (n.d.), burnout is a syndrome conceptualized as resulting from chronic workplace stress that has not been successfully managed.

The problem of burnout first surfaced in the caregiving and human service occupations such as health care, mental care, mental health, social services, the criminal justice system, religious professions, counseling and education (Maslach, 1982/2003). At the early stages of burnout related research, a more qualitative approach and an exploratory nature could be observed (Freudenberger, 1974). However, work attitudes and behavioral aspects were emphasized by the subsequent researchers who came from an industrial-organizational psychology background (Maslach & Pines, 1978). This descriptive and exploratory work established the three dimensions of burnout experience; exhaustion, cynicism and inefficacy. (Maslach & Leiter, 2016)

Several self-report tools are available to measure burnout. However, there are few tools that are more commonly used to measure burnout. This section focuses on two such self-report burnout assessment tools : Maslach Burnout Inventory (MBI) and the Oldenburg Burnout Inventory (OLBI).

2.1 Maslach Burnout Inventory

The Maslach Burnout Inventory (MBI) is considered to be the primary burnout measure which continues to be the most widely used and is considered the "gold standard" for work on burnout (Schaufeli et al., 2009). The MBI was initially published in 1981, at a time when the burnout phenomenon was attracting a significant amount of interest but had minimal guidance in-terms of theory or empirical research (Maslach & Jackson, 1986). Following the initial publication, different versions of MBI surfaced which catered to different user groups. However, there are three well-established primary versions of MBI namely, MBI-Human Services Survey (MBI-HSS: Maslach & Jackson, 1981), MBI-Educators survey (MBI-ES: Maslach et al., 1986) and MBI-General Survey (MBI-GS: Schaufeli et al., 1996)

MBI measures burnout based on 3 dimensions. They are namely; exhaustion, cynicism or otherwise known as disengagement and inefficacy (Maslach & Jackson, 1981). The following section discusses these three dimensions related to burnout in detail.

2.1.1 Exhaustion

Exhaustion is the first dimension of burnout. The individual stress component which often leads to feelings of being overextended and depleted of one's emotional and physical resources is depicted via the exhaustion dimension (Maslach & Jackson, 1981). Work overload and personal conflict are major sources of exhaustion (International Stress Management Association. Conference, 2006). Work overload is the single best predictor of the exhaustion dimension in burnout (Maslach et al., 2006). The clean imbalance between job demands and the individual's capacity to fulfill those demands cause work overload which leads to exhaustion (Maslach, 2006).

2.1.2 Cynicism

The interpersonal context component is represented by the cynicism dimension. It refers to a negative, indifferent or excessively detached response to various aspects of the job. According to Maslach and Jackson (1981), cynicism is often a product of overload of emotional exhaustion. As cynicism develops people tend to move away from doing their best at work to doing the bare minimum. Gradually the quality of work and performance decline as cynicism towards work increases (Andersson & Bateman, 1997).

2.1.3 Inefficacy

Inefficacy represents the self-evaluation component of burnout (Cordes and Dougherty, 1993; Maslach, Schaufeli and Leiter, 2001). The feelings of lack of accomplishment, incompetence, and lack of productivity at work are generally considered to influence lowered sense of self efficacy (Bandura, 1997). The lack of job resources, social support and growth opportunities generally intensify the feelings of inefficacy. (Maslach, Schaufeli and Leiter, 2001).

2.2 Oldenburg Burnout Inventory

According to Demerouti et al. (2001) The MBI has one important psychometric shortcoming namely, the items within each subscale being all framed in the same direction. In the MBI, all items measuring exhaustion and cynicism are phrased negatively, whereas all professional efficacy items are phrased positively. It has been argued that such one-sided scales are inferior to scales that include both positively and negatively worded items in which such subscales might yield an artificial clustering of factors (Lee & Ashforth, 1990; Demerouti & Nachreiner, 1996; Bouman, Brake & Hoogstraten, 2002).

Further, there are arguments against the three-factor model used in the MBI. While emotional exhaustion and depersonalization generally show consistent relationships with burnout (Demerouti & Halbesleben, 2007), personal accomplishment (efficacy) is far less consistent in these relationships (Cordes & Dougherty, 1993). It is suggested that efficacy / personal accomplishment could be less consistent because personal accomplishment is perhaps more appropriately conceptualized as a personality trait rather than as a component of burnout (Cordes & Dougherty, 1993).

In order to overcome these shortcomings of the MBI, an alternative measure of burnout was introduced, The Oldenburg Burnout Inventory (Demerouti, 1999; Demerouti & Nachreiner, 1998). The OLBI, which includes positively and negatively framed items to assess the two core dimensions of burnout: exhaustion and disengagement from work, is based on a model similar to that of the MBI but without the inefficacy dimension. The OLBI also includes questions that assess cognitive and physical components of exhaustion consistent with past suggestions in literature (Pines et al., 1981; Shinn, 1982).

The most current version of the OLBI (Halbesleben & Demerouti, 2005) consists of 16 items measuring burnout in terms of exhaustion and disengagement. The exhaustion dimension is measured using 8 items related to feelings of emptiness, work overload, the need to rest and physical, cognitive and emotional exhaustion (Demerouti et al., 2003). Disengagement dimension is also measured using 8 items which includes distancing oneself from the work, together with negative and cynical behaviors and attitudes in relation to one's job (Demerouti & Bakker, 2008). Initial construct validity evidence for the OLBI was offered by Demerouti, Bakker, Kantas, and Vardakou (2002) while the validity of the OLBI is also proven and demonstrated by numerous studies across multiple occupational groups in different countries (Halbesleben & Demerouti, 2005; Schuster & Dias, 2018; Rosnah et al., 2017). Further, the OLBI is considered the most prominent alternative to the MBI (Demerouti et al., 2000).

3. VALIDITY

The evidence of validity and reliability are prerequisites to assure the integrity and quality of a measurement instrument (Kimberlin & Winterstein, 2008). In a quantitative study, validity refers to the extent to which a concept is measured accurately (Heale, 2015). In quantitative research, validity is the extent to which any measuring instrument measures what it is intended to measure (Thatcher, 2010). According to Ghauri and Gronhaug (2015) validity explains how well the collected data covers the actual area of investigation.

3.1 Face validity

Face validity refers to a subjective judgment on the operationalization of a construct (Drost, 2011). A test / instrument is said to have face validity if its content looks relevant to the person who is taking the test or using the instrument (Taherdoost, 2016). In other words, face validity refers to researchers' subjective assessments of the presentation and relevance of the measuring instrument as to whether the items in the instrument appear to be relevant, reasonable, unambiguous and clear (Oluwatayo, 2012). It is worth noting that some authors believe face validity is not a correct indicator of validity and should not be considered as a way of validating a tool or an instrument (Anastasi, 1988; Bornstein, Rossner, Hill, & Stepanian, 1994).

3.2 Content Validity

Content validity shows the degree to which a measure covers the range of meanings included within a concept (Babbie, 2007). Further, according to Straub et al. (2004) content validity is "the degree to which items in an instrument reflect the content universe to which the instrument will be generalized" (p. 424). Generally, content validation will ensure the tool in question includes all the items that are essential and eliminates any undesirable items representing a particular domain.

The content validation process usually entails the following steps; formulation of the instrument / tool via an exhaustive review of literature, generating the content validity survey, forwarding the survey to experts in the field of the research, calculating the Content Validity Ratio for each item using Lawshe's method (Lawshe, 1975) and finally items that are not significant at the critical level are eliminated. CVR refers to Content Validity Ratio as proposed by Lawshe (1975). It is a linear transformation of a proportional level of agreement on how many "experts" within a panel rate an item as "essential" calculated in the following way:

$$CVR = (ne - (N / 2)) / (N / 2) \quad (1)$$

'CVR' is the content validity ratio, 'ne' is the number of panel members indicating an item as "essential" and 'N' is the total number of panel members. (Lawshe, 1975).

A study conducted on a sample of Portuguese students explored the content validity of the OLBI by way of an experts panel which consisted of 13 psychology professors (Campos et al., 2012). In the opinion of these experts, only 4 items were deemed essential in measuring burnout. However, a different study conducted in Malaysia deemed all items were necessary in assessing burnout (Mahadi et al., 2018).

3.3 Construct Validity

According to Walden (2012), construct validity refers to whether the operational definition of a variable reflects the theoretical meanings of a concept. In other words, construct validity shows the degree to which inferences are legitimately made from the operationalisations in one's study to the theoretical constructs on which those operationalisations are based (Oluwatayo, 2012). There are two types of construct validity; Discriminant validity and Convergent validity.

3.3.1 Discriminant validity

The discriminant validity suggests that using similar methods for researching different constructs should yield relatively low inter-correlations. That is, the construct in question is different from other potentially similar constructs (Oluwatayo, 2012). In simpler terms, discriminant validity is the extent to which latent variable A discriminates from other latent variables (e.g., B, C, D) (Taherdoost, 2016). Further, discriminant validity means that a latent variable is able to account for more variance in the observed variables associated with it than measurement error or similar external, unmeasured influences; or other constructs within the conceptual framework (Farrell, 2010).

3.3.2 Convergent validity

Convergent validity requires that the scores derived from the measuring instrument correlate with the scores derived from similar variables (Campbell & Fiske, 1959; Brock-Utme, 1996; Cooper & Schindler, 2001). Campbell and Fiske (1959) advocate a validation process utilizing a matrix of intercorrelations among tests representing at least two traits, each measured by at least two methods, introduced as the MTMM Matrix. Convergent validity can be achieved by correlating scores obtained between the scale and subscales together. The inter-correlations from the multitrait-multimethod matrix are used to support convergence validity as well as discriminant validity (Campbell & Fiske, 1959). In line with these methods of construct validity, Halbesleben & Demerouti (2005) found convergent and divergent validity of the OLBI by employing the MTMM matrix. Another study conducted across several occupational groups found evidence of both convergent and divergent validity of OLBI (Halbesleben, 2003).

3.4 Criterion validity

Criterion or concrete validity is the extent to which a measure is related to an outcome (Brunner, 2009). It measures how well one measure predicts an outcome for another measure. A test has this type of validity if it is useful for predicting performance or behavior in another situation (past, present, or future) (Taherdoost, 2016).

Thomas and Douglas (1998) explored the contribution of burnout to work performance. They concluded that disengagement, otherwise known as cynicism and emotional exhaustion, are negatively related to job performance. Further, Maslach and Jackson (1985) revealed burnout is associated with decreases in the quality and quantity of job performance. Burnout is also argued to be a significant predictor of hypercholesterolemia and type 2 diabetes (Shirom et al., 2005) along with spells of sickness absence (Schaufeli et al., 2009).

4 METHODS

In order to investigate the content validity, the steps outlined by Taherdoost (2016) were followed and Lawshe's CVR (1975) method was employed to determine the relevance of each item in the OLBI to the measured domain, burnout.

The panel of experts consisted of content experts as well as lay experts. As proposed by Zamanzadeh et al., (2015), lay experts who are potential research subjects were included in the panel of experts as using subjects of the target group as experts ensures that the population for whom the instrument is being developed is represented (Rubio et al., 2003).

The expert opinion of psychology and IT professionals was sought via a content validity questionnaire. This questionnaire included all 16 items of the OLBI and the experts were asked to rate the relevance of each item to the measured domain, "burnout".

In order to measure the construct validity of the OLBI, the Multi-Trait Multi-Method (MTMM) technique was used. Since MBI is considered the gold standard in work related to burnout and since it is a validated tool in the Sri Lankan context (eg. Wickramasinghe et al., 2018) and also due to both MBI and OLBI measuring the same underlying construct (burnout), MBI-GS version was used to measure the convergent validity of OLBI in the MTMM matrix. Figure 1 depicts the instruments and traits of the MTMM matrix.

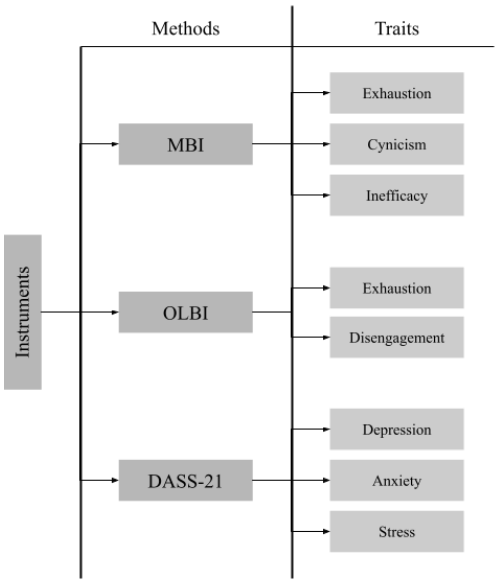

Figure 1: Methods and traits used to determine construct validity

It is argued that the experience of burnout may be nothing more than occupational stress (Maslach, 2018). DASS-21 (Depression, Anxiety and Stress Scale with 21 items) was used to measure the discriminant validity of the OLBI. The DASS-21 is the shortened version of the DASS developed by Lovibond and Lovibond (1995) to assess symptoms of depression, anxiety, and stress among adults. This tool has also been validated in the Sri Lankan context among students at the University of Colombo (Rekha, 2012). In terms of criterion related validity, the respondents' performance, health and absenteeism was measured along with performance by way of self-rated items.

A questionnaire was distributed electronically among 500 randomly selected members of the Computer Society of Sri Lanka (CSSL). The CSSL as mentioned in their website, is the nation's association that represents all IT professionals. This institute was established in 1976 and is the apex body representing Information and Communications Technology professionals in Sri Lanka (The Computer Society of Sri Lanka, n.d.). In order to avoid sensitization to "burnout", this study was introduced as a job attitudes assessment and the anonymity of their response was guaranteed. Each invitee was presented with a choice to opt out of this study if they do not wish to participate.

5 RESULTS ANALYSIS

5.1 Content validity

The expert panel consisted of eight (8) subject matter experts and four (4) lay experts. The subject matter expert panel consisted of a professor in psychology, three senior lecturers in psychology, one psychology lecturer, one clinical psychologist and two psychiatrists. The lay expert panel consisted of a Chief Operating Officer (COO), a Chief Technology Officer (CTO), an associate tech lead and a software architect, all representing the IT profession. The panel consisted of six female and male experts. Based on their responses to the content validity questionnaire, the CVR was calculated. According to Lawshe's (1975) method, a minimum CVR of 0.56 (N = 12 panel members) is required in-order to retain an item. According to Lawshe's method, only 12 items were deemed necessary to measure burnout out of the 16 items in the original OLBI. Therefore, a modified version of the OLBI with only 12 items (OLBI-12) was also tested in the subsequent validity measurements.

5.2 Construct validity

The questionnaire which consisted of all three items (MBI, OLBI and DASS) was distributed among 500 randomly selected IT professionals via email. 161 complete responses were collected. Out of the 161 respondents, 30 were female and 131 were male respondents. The age range of the respondents were between 25 and 64.

The majority of the respondents were senior level IT professionals. In terms of the job category, most of the respondents were software engineers. Among other job categories were system analyst, QA analyst, network engineer, web developer, IT support, hardware engineer, software architect etc.

The average burnout reported by each job category is between 37 and 41. QA analysts reported a slightly lower burnout level (31) compared to the other professions while IT support reported the highest level of burnout (41). In terms of the service line, the respondents well represented the local IT industry in which the majority of the respondents were employed in the software engineering service line followed by software quality assurance (software QA) and IT & Technical Support.

The Multi-Trait Multi-Method matrix proposed by Campbell and Fiske (1959) was used to analyze the construct validity of the OLBI. To ensure validity, correlations between the same trait assessed with different methods must be sufficiently large and larger than those between different traits assessed with either the same or different methods.

The MTMM was applied to both the original 16-item OLBI (OLBI-16) and the 12-item modified version of the OLBI (OLBI-12) based on the opinion of the subject matter experts, as depicted in Table 1 and Table 2 below. MBI exhaustion showed higher positive correlation with the exhaustion dimension of both versions of the OLBI, while the cynicism dimension also showed highly positive correlation with the corresponding disengagement dimension of both versions of the OLBI. These correlations were significant at $p < 0.05$. These values provide evidence of the existence of convergent validity. It is also noteworthy that OLBI-12 showed slightly higher correlations with the MBI compared to the OLBI-16.

Both OLBI-16 and OLBI-12 were tested against DASS-21 to investigate its divergent validity. Both exhaustion and disengagement dimensions showed feeble correlations with depression, anxiety and stress scales in both versions of the OLBI. Depression showed a slight positive correlation to exhaustion and disengagement while the correlations were not significant. At the same time anxiety showed a similar pattern of correlations with the same two scales of both OLBI versions with correlations of 0.048 and 0.068, and these correlations too were not significant. On the other hand, stress showed a minor negative relationship to exhaustion and disengagement but not significant. These correlations suggest even though depression, anxiety and stress are related to burnout, they are not the same phenomena. This consequently provides evidence of the existence of divergent validity.

Traits within each method also demonstrated a similar pattern where exhaustion and cynicism in MBI showed higher positive correlations with each other and exhaustion and disengagement in OLBI (both versions) showed higher positive correlations with each other. Further, depression, anxiety and stress showed higher positive and significant correlations with their own traits as expected. All these correlations were significant.

Table 1: Multi Trait Multi Method Matrix: OLBI-16

Methods		MBI		OLBI-16		DASS		
	Traits	Ex	Cy	Ex	De	Dp	Ax	St
MBI	Ex							
	Cy	.797*						
OLBI-16	Ex	.809*	.778*					
	De	.763*	.780*	.882*				
DASS	Dp	-.004	.064	.065	.041			
	Ax	-.065	.012	.048	.068	.761*		
	St	-.075	-.021	-.042	-.021	.760*	.752*	

Note: * Significant at .05 level; OLBI-16= Original OLBI

Table 2: Multi Trait Multi Method Matrix: OLBI-12

Methods		MBI		OLBI-12		DASS		
	Traits	Ex	Cy	Ex	De	Dp	Ax	St
MBI	Ex							
	Cy	.797*						
OLBI-12	Ex	.817*	.780*					
	De	.782*	.777*	.890*				
DASS	Dp	-.004	.064	.065	.031			
	Ax	-.065	.012	.048	.075	.761*		
	St	-.075	-.021	-.040	-.041	.760*	.752*	

Note: * Significant at .05 level; OLBI-12: Modified OLBI

5.3 Criterion Validity

In order to test concurrent criterion validity, a self-rated item on job performance was added to the same questionnaire along with two other questions to measure the respondents' health. The health-related question was to identify whether the respondent is currently diagnosed with type 2 diabetes and hypercholesterolemia. Followed by another question to determine whether the respondent has been taking time off work more frequently.

A spearman correlation test was performed to determine the correlation between burnout and performance. A negative 0.70 and 0.71 correlation was observed respectively in both OLBI-16 and OLBI-12. This value was also significant at $p < 0.001$.

Independent sample t-tests were carried out to measure the effects of burnout on health and absenteeism. It was revealed that those who were having type 2 diabetes and / or hypercholesterolemia reported slightly higher burnout than those who did not have diabetes or hypercholesterolemia. A similar effect was observed between burnout and absenteeism. Those who reported higher absenteeism rates also reported higher burnout levels. The observations were similar between both OLBI-16 and OLBI-12.

6 DISCUSSION AND CONCLUSION

As stated in the previous section, both versions of OLBI provided reliable and valid results in the Sri Lankan context based on IT professionals. As previously outlined, the first objective of the current study was to determine the content validity of the OLBI. Accordingly, the content validity study revealed that four (4) of the sixteen (16) items were not essential to measure burnout. Out of the four items that were deemed not essential to measure burnout, three items were from the disengagement dimension while only one item was from the exhaustion dimension. The items are as follows;

"Lately, I tend to think less at work and do my job almost mechanically" (disengagement), "Over time, one can become disconnected from this type of work" (disengagement), "This is the only type of work that I can imagine myself doing" (disengagement) and "There are days when I feel tired before I arrive at work" (exhaustion).

The above four items reported CVR values less than 0.56 which was the cut off rate in-order to recognize an item as essential to measure their respective constructs, disengagement and exhaustion. Therefore, according to the content and lay experts, the OLBI is a better fit with only twelve (12) items. Therefore, a new version of the OLBI was introduced with only 12-items as opposed to the original 16-item scale.

The MTMM analysis for construct validity yielded acceptable results in favor of convergent and divergent validity for both versions of the OLBI. According to the MTMM analysis, exhaustion and disengagement constructs showed significant positive relationships with its counterparts of the MBI. This suggested the existence of convergent validity. Accordingly, both MBI and OLBI were found to measure exhaustion and cynicism / disengagement in a similar manner which would result in similar outcomes. A similar result to that of this study has been observed in the initial English translation of the OLBI, where the correlations between factors of MBI and OLBI reported correlations higher than .70 (Halbesleben & Demerouti, 2005).

In terms of the divergent validity of the OLBI, both constructs; exhaustion and disengagement reported insignificant feeble correlations with the constructs of the DASS-21. This finding supports evidence of divergent validity for both versions of the OLBI. As mentioned before, it has been argued that the experience of burnout may be nothing more than occupational stress. Therefore, a relationship among these two constructs could be observed, but it should not be so high as to suggest that burnout and stress are in fact the same phenomenon (Maslach, 2018). Similarly, the findings of the current study support the argument that even though some of the burnout symptoms appear to resemble the ones of depression as it is characterized by anhedonia it has been found that depression and anxiety are in fact different and robust constructs compared to burnout (Koutsimani et al., 2019).

The current study also demonstrated the existence of concurrent criterion validity of both versions of the OLBI. The respondents' health and absenteeism as predictors of burnout were tested. Shirom et al. (2005) revealed that burnout was a significant predictor of hypercholesterolemia and type 2 diabetes. Supporting this statement, the respondents of the current study who were diagnosed as type

2 diabetes patients also reported slightly higher levels of burnout compared to those respondents who did not identify as type 2 diabetes patients. However, the current study did not observe significant evidence between burnout and type 2 diabetes or hypercholesterolemia to suggest an association.

In another study, it has been revealed that burnout was prospectively associated with sickness absence days and absence spells (Schaufeli et al., 2009). The same finding was supported by the current study as well. The analysis revealed a significant difference between the number of absences taken between those who reported higher levels of burnout and those who did not. Those who reported higher burnout also reported a higher level of absence. This finding was similar for both versions of the OLBI.

6.1 Managerial implications

Delgadillo et al. (2018) reported "Therapists are identified as having low, medium or high OLBI-D scores, based on scores above or below 1 standard deviation of the mean (m = 2.15, SD = 0.52; <=1.62 = low, 1.63 to 2.67 = medium, >=2.68 = high)". Looking at the average scores of burnouts within each occupation category, it becomes evident that at present, the local IT industry is experiencing a medium level of burnout and in turn it gives opportunity to undesirable outcomes in the workplace. It is imperative that organizations take necessary measures to address and mitigate occupational burnout. Further, as stated above, Sri Lanka is becoming a global hub in providing IT services and it is only timely that organizations pay more attention towards the mental and physical wellbeing of IT professionals.

Further, organizations can take measures to ensure their employees are of better mental and physical wellbeing. Organizations can provide stress management and interventions by way of offering cognitive behavioral training and mindfulness meditation groups. There is evidence that stress management interventions can help employees adapt to stressful situations, mitigate emotional exhaustion, and develop distress tolerance skills in their work and home lives (Gabriel & Aguinis, 2022). It is also suggested that allowing employees to be active crafters at their work help reduce burnout (Gabriel & Aguinis, 2022). Employers must ensure autonomy and flexibility to negotiate job content, allow employees to choose tasks that play to their strengths but are also challenging, and provide opportunities for development are few methods that employers can implement so that employees can become active crafters at their job (Tims et al., 2012).

As previously stated, employee burnout is pervasive, fosters an unhealthy work culture and creates a toxic working environment which will ultimately lead to adverse effects on firm profits (Gabriel & Aguinis, 2022). Therefore, organizations can implement aforementioned mechanisms to eliminate or mitigate burnout in the workplace.

7 FUTURE RESEARCH

The current study focused on validating the OLBI in the local context based on IT professionals. The field of IT covers a huge spectrum of different professions. It can only be assumed that different professions within the field of IT experience varying levels of burnout without proper evidence. Future research can focus on exploring how different professions within the field of IT and other fields experience burnout. Future research can also replicate the current study with a more generalizable sample over the sample used in the current study. Also, the current study does not go to the extent of exploring the correlates of burnout, therefore future research can focus on exploring the correlates of burnout in the local context. The construct validity of the OLBI was studied in depth, however due to the resource constraints, a significant focus on criterion validity was not placed. Concurrent criterion validity was explored but the predictive and postdictive validity of the tool remains unknown. Future research can also explore these types of validity of the OLBI.

Finally, as pointed out by other authors (Halbesleben & Demerouti, 2005) one of the issues not resolved nor addressed by OLBI is the clinical cut-off scores for burnout. Future research can focus on determining the clinical cut-off scores which will add immense value to knowledge on burnout.

In conclusion, the current study provided successful initial validation evidence of the OLBI in the Sri Lankan context. While further validation is justifiable, the current study provided evidence of content validity, convergent and divergent validity and concurrent criterion validity of the OLBI.

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Smart Health Monitoring System

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ABSTRACT

Due to the high inpatient population in hospitals, regular monitoring of inpatients' vital signs is currently a practical concern. As a solution, our proposed system manages the continuous analysis of the vital signs of every inpatient in the general wards, and informs medical professionals in any location at any time about their inpatients' current states in real-time to improve inpatients' health. The suggested system consists of the following arrangements; arrangement for acquiring health readings, identifying the on-duty reported doctors in charge of wards, arrangement for health data exhibiting unit, fall detection, and ECG acquisition. In addition to these arrangements, a website, and an android mobile application were designed to publish measured inpatient vital signs. This proposed product is both novel and different from the existent products because, it comprises of collective arrangements, and is developed in order to assess hospital wards' inpatients, whereas other systems are designed for remote health monitoring of patients at home. This paper describes the system that was developed and tested successfully.

KEYWORDS: *Real-time database, Temperature, Heart rate, SpO_2, ECG, Fall detection, Website, Mobile application*

1 INTRODUCTION

At present, the inpatient population is significantly larger than the number of healthcare professionals working in the healthcare sector. According to the World Bank collection of development indicators, the nurse to inpatient ratio in Sri Lanka in 2019 was reported to be 1:156 (Trading Economics, n.d.)., Even though the medical resources and facilities are developing on a daily basis, an effective solution has not been proposed to mitigate the issue. Therefore, to address this problem, the proposed system was implemented.

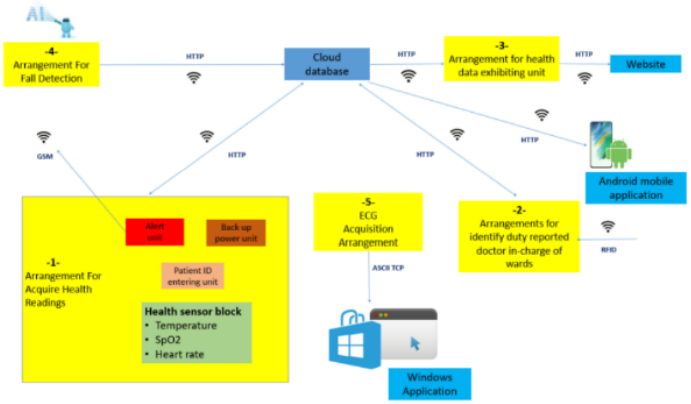

Figure 1. System block diagram

Figure 1 shows five main arrangements and other secondary components required to achieve the intended purpose of the proposed system. The system consists of; arrangement for acquiring health readings, identifying on-duty reported doctors in charge of wards, arrangement for a health data

exhibiting unit, fall detection, and ECG acquisition. The main purpose of the health data acquisition arrangement is to measure the health readings such as temperature, heart rate and SpO_2 level of each inpatient using biosensors attached to the inpatient's body. This arrangement also includes a unit that notifies the responsible doctor in charge of the ward via SMS alert if the inpatient is in a critical condition. Further, it also comprises a back-up power unit to supply power to the health reading acquisition arrangement without any interruption. The arrangement for identifying the duty-reported doctors in charge of wards is a support system for the alert unit in the health data acquisition arrangement. The arrangement for health data exhibiting unit is to display the measured inpatient health data to the hospital staff. Next is the arrangement to detect falls, which is basically to identify falls occurring inside hospital premises. The final arrangement is the ECG acquisition arrangement to measure inpatient electrocardiogram signals and detect elementary arrhythmias. In addition to the above mentioned arrangements, an Android mobile application was developed to provide health status of the inpatient to their relatives.

2 RELATED WORKS

Lei Ru and Bin Zhang in (Lei Ru, 2021) have proposed a human health monitoring system that uses wearable sensors to gather vital information about the inpatients. It provides reasonably accurate and consistent testability of human vital symptoms. A team of researchers have proposed a health monitoring system for elders (Sumathy, 2021). Sensors measure vital signs such as the pulse rate, respiratory rate, and temperature. If any significant changes are discovered in an inpatient's condition, the system will be communicate the changes to the doctor and the guardian. The system in (El-Nour, 2019) comprises of an application and wearable devices combined with the global positioning system (GPS) to allow inpatients and healthcare providers to track one another. The system provides highly precise inpatient location information to remote health care service providers. It also sends out alarm messages to inpatients and helps them find nearby healthcare providers.

According to (D.Shiva Rama Krishnan, 2018) and (Sudhindra F, 2016) the LM35 contact base thermal sensor arrangement was used to measure human body temperature. This sensor can output sensor readings with a precision of around 0.5 Celsius and it can operate in a range of -55 to +150 Celsius. The MAX30205 which is used in (Bakar, 2020) and (Hasan, 2020) is a contact base thermostat temperature that delivers a clinical-level precise analytic body temperature of 0.1 Celsius in the range of 35 Celsius to 39 Celsius. With a resolution of 16 Bits, the MAX30205 converts measurements into digital readings using an analog to digital converter.

When taking readings of heartbeat, in (Sumathy, 2021) the sensor is attached to the inpatient's finger to monitor his/her heartbeat. These readings are sent to the Cloud where they can be monitored by a doctor and the inpatient’s guardian. If values are below 60 BPM or above 100 BPM, the person needs medical advice. The device designed by (Andika, 2019) was portable so that users can conduct monitoring at any time and from any location. The data obtained from the MAX30102 sensor was displayed on the TFT LCD screen after it entered the I2C pin. The MAX30102 sensor can give both BPM and SpO2 values. The results of ten respondents were taken the same as BPM measured, and compared with standard measuring instruments. This produced an error value of 0.82% which was then used to calibrate the device.

An ECG reading of a healthy person is provided by monitoring their electrical heartbeat (ECG) using sensors attached to their skin. The sensor that was used to measure ECG in (Martin Clinton Tosima Manullang, 2019) is, AD8232 ECG module. The data is sent to the IoT Cloud via an ESP8266 Wi-Fi module for further analysis and visualization on a web interface. A system consisting of an AD8232 sensor and Arduino Uno was proposed by Matin Clinton and two other researchers in (Vaneeta Bhardwaj, 2022) to obtain and classify ECG signals. This system can be connected to a personal computer for ECG plot visualization. This system comprises an algorithm to calculate the duration of the R peak of the ECG signal. As a result, the authors were able to identify abnormalities in the ECG signal. This system was tested on ten people and the results were compared with medical standard 10 leads ECG cardiac device.

In fall detection several approaches were recognized and among them two approaches were mainly considered: threshold-based approach and machine learning-based approach. Threshold-based approaches use a single or many threshold values to classify occurrences. The system compares real-

time sensor data to predefined threshold values, and if these are exceeded, the system signals a fall. In (Rakhman, 2014) accelerometer and gyroscope sensors were used to detect falls. Huynh et al (Huynh, 2015) used three threshold values lower acceleration, upper acceleration, and lower angular velocity to determine whether the person has fallen. Examples for machine learning algorithms are Hidden Markov Model (HMM), Support Vector Machine (SVM), and Decision Tree. A low-cost fall prevention and detection system based on HMM and tri-axial was developed by Tong et al (Bourke, 2008) and the study found that falls could be accurately predicted 200-400ms before an accident and distinguished from other routine activities. Based on an accelerometer sensor inserted into the device, Aguiar et al (Aguiar, 2022) developed a Smartphone-based detection method and tested three algorithms for machine learning: Decision Tree, K-NN, and Naive Bayes. A support vector machine (SVM)-based fall detection method with accelerometer and gyroscope sensors was created by Pierleoni et al (Pierleoni, 2015). The above research findings were referred and analyzed in order to develop a high quality health monitoring system.

3 METHODOLOGY

3.1 Model of the system

The arrangement to collect health sensor readings is the main arrangement in the whole system, and it mainly contributes to achieving the main goal which is to monitor the health readings of each inpatient. Each bed inside hospital wards should consist of a health data acquisition arrangement. As a result of that, vital signs of each inpatient can be obtained, and that data will be transferred to a central Cloud server set up which was designed for the entire hospital. Further, a patient recognizing unit was used to allocate relevant inpatients inside the wards, to develop health data acquisition arrangements. The health data obtained from sensor modules such as temperature, heart rate, and blood oxygen level attached on health data acquisition arrangements will be displayed on a website where the healthcare workers can easily monitor health details on a single display. In addition, this arrangement comprises a unit to send an alert message to the on-duty doctor if an abnormal condition is identified by the nurse. Besides, each ward will comprise an arrangement to identify the duty-reported doctor at a particular time. This helps to identify which doctor is allocated to a particular ward when a nurse manually gives the command to send an SMS during an emergency. The ECG unit is a separate arrangement which transfers results to a desktop application that runs on Windows OS. This arrangement works independently, and it is a portable device that can be carried to any place inside the hospital. Next, the fall detection arrangement in the proposed system is a wireless device attached to the inpatient's body. This is designed considering acceleration and orientation of the inpatient’s body. In addition, the Android mobile application was included in the whole system to assist inpatient’s guardians when they are unable to visit the inpatient at the hospital.

3.2 Anatomy of the system

1. Arrangement to acquire health sensor readings

Acquisition of heart rate and SpO2 readings

The MAX30102 sensor to measure the heart rate and blood oxygen level was connected to the ESP32 controller with serial communication which is I2C. This sensor collects health readings from the respective inpatient and sends those readings to the Cloud database. MAX30102 sensor emits IR light towards the body and measures the amount of light reflected using the photodetector. These IR readings were filtered, and two consecutive beats were discovered. Then the heart rate was calculated by measuring the time gap between the two acquired consecutive heartbeats. Then the SpO2 was measured by measuring the ratio of IR and RED light received by the photodetector. In order to obtain an accurate reading, 100 samples were taken and averaged. This sensor module is proposed to be attached to the finger tip of the inpatient.

Acquisition of Temperature readings

The MAX30205 sensor was utilized to measure the temperature of the inpatients. It was connected to the ESP32 controller via I2C port. This sensor collects health readings from the respective inpatient and sends those readings to the Cloud database. With reference to human body temperature, there are two types which are peripheral, and core body temperature. Peripheral temperature is subjected to greater fluctuations due to its closer proximity to the environment, but core body temperature is not subjected to significant deviations., Even though the core body temperature method gives accurate readings, it is impractical to continuously take measurements from an inpatient using that method. Therefore, the temperature module was designed to be attached between two fingers which provides the peripheral temperature. In addition, to minimize the deviations, a rectifying technique was implemented considering the standard deviation of the errors.

Backup power unit

The introduced backup power system facilitates the health reading acquisition arrangement, by supplying power without any interruption to its operation. Accordingly, the backup power unit was designed in such a way that the backup battery takes control of the power supply automatically when the main power supply is not available. To introduce an automatic power takeover, P-channel MOSFET was utilized for the backup battery in the circuit. Since the circuit should be capable of supplying power uninterruptedly, switching elements need to have a high switching speed. This was the main reason for choosing MOSFET as a switching device to develop this backup power unit. When it comes to the backup battery in the unit, it charges as long as the main power supply is available and, the moment the main power is unavailable, the battery will stop its charging process and act as the power source for the load. Further, BMS (Battery Management System) was used to prevent the backup battery from getting overcharged and, as backup batteries, li-ion rechargeable batteries were utilized.

Inpatient ID entering unit

This unit is mainly comprised of hardware and firmware layers to control the workflow of the unit. The hardware layer, has a 4 by 4 matrix keypad, and a 16 by 2 LCD module. The firmware of this unit expects inpatient registration number prior to proceeding with acquiring biosensor readings from inpatients. Then the entered ID number will be transferred to the Cloud database via HTTP application layer protocol and 802.11 datalink layer protocol. Basically, this unit is for the health data isolation of each inpatient in the Cloud database.

Alert unit

GSM SIM900A module was used to send messages to the on-duty doctor in charge of the wards. The software was developed to construct the message with necessary details which are; ward number, bed number, inpatient ID, temperature, heart rate, and SpO_2. To send messages to the on-duty doctor, AT commands were used. The message will be sent to the number given with the AT+CMGS command while the AT+CMGF command is used to select the operating mode of the GSM modem. Here, 0 is SMS PDU mode while 1 is SMS text mode. In PDU mode, all SMS messages are represented as binary strings encoded in hexadecimal characters and in text mode, SMS messages are represented as readable text. As we need to send a readable text to the doctor, SMS text mode was chosen.

2. Arrangement to identify duty reported doctor in charge of wards

This arrangement was implemented to acquire the telephone number of the duty-reported doctor in charge of the ward. Initially, RFID cards should be issued to every doctor in the hospital after their telephone number is ciphered to the card. This is a separate system that will be fixed at every ward entrance. When a doctor reports for duty, he/she should swipe their card through the relevant RFID reader at a particular ward entrance. Then each doctor's telephone number will be transferred to the Cloud database via HTTP and 802.11 datalink layer protocol. ESP8266 controller was used to accomplish tasks related to this arrangement.

3. Arrangement for health data exhibiting unit

A static website was designed with a single page and this webpage runs on a controller that is attached to a display unit. This arrangement allows hospital staff to examine each inpatient of a particular ward from a single location without checking inpatients' conditions individually. Raspberry Pi was chosen as the controller for this health data exhibiting arrangement as it can connect to the internet via a Wi-Fi connection. It also has a built-in web browser that opens in a browser when the controller is booted up. The hospital webpage has been designed in a way that it will fit into the viewport of a standard screen-sized display which is 22 inches diagonally. These standard-size displays should be placed in every ward of the hospital. Regarding the webpage, the front end of the webpage was implemented utilizing technologies such as HTML, CSS, and JavaScript. Further, to upgrade our project to a next-level health monitoring system, an additional webpage was developed and incorporated into the above-mentioned webpage. This new webpage lists every ward in the hospital and doctors can browse the relevant ward dashboard and examine their inpatients remotely.

4. Cloud database

To implement the Cloud database in the proposed system, Google's firebase was used. The reasons to choose firebase are, that it provides a real-time database that automatically syncs with our frontend application and, it also provides SDKs for almost every platform such as JavaScript, iOS, Android and etc., to manage our front-end application by bypassing the back end. To achieve expected functionality from the proposed system, the database was constructed as we can separate each ward in the hospital and each inpatient bed in the ward.

5. ECG acquisition arrangement

As the main controller for this arrangement, ESP32 was chosen and to acquire ECG signal values, AD8232 3-lead ECG module was utilized. To display the ECG signal, an application was developed in the .net framework and any device which runs on the Windows platform is compatible with this application. When collecting ECG signal data, sampling frequency is a key area that should be considered. The maximum frequency component of the ECG signal can be 150Hz. Therefore, according to the Nyquist theorem, sampling rate should be at least 300Hz (2 X 150Hz). Therefore, as the sampling frequency for this case, 1000Hz was chosen. To send collected data over to the windows device, UART communication was used. Further, to develop the Windows application, Microsoft Visual Studio was used as the development environment with c sharp language and, .net framework was used as the software development kit. The software layout of the desktop application will follow the procedure shown in the figure given below to achieve the output of the arrangement.

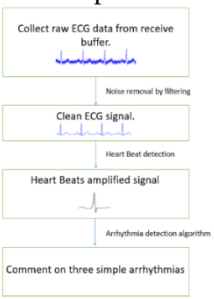

Figure 2. Backend functionalities in desktop application

There are three main types of artifacts that can introduce noise into the ECG signals, which are baseline wander, power line interference, and lead electrode problems. Noise from motion artifacts can be minimized by reducing muscle movements while taking the data. Further, a low pass filter and a high pass filter were implemented to eliminate the baseline wander. Addition to that, a band pass filter was used to remove power-line interference. All these filters were implemented as FIR filters with Kaiser Windowing. In addition to this ECG signal plotting procedure, a method to detect the heart rate and three simple arrhythmias such as sinus bradycardia, sinus tachycardia and, sinus arrhythmia in the heart was designed. In order to do this, a heartbeat detection algorithm was implemented. The goal of the heartbeat detection algorithm is to locate the heartbeats to calculate the heart rate and R peak intervals

of the ECG signal. The key method to locate heartbeats is detecting R peaks of the ECG signal. To detect R peaks, another signal processing technique called teager-kaiser energy operator (TKEO) was utilized and it suppresses the noises contaminating inside a signal and it attenuates signal components that have the value range from zero to one. Therefore, R peaks will be more noticeable.

6. Android mobile application

The android application was developed in Android Studio. In Android Studio, Java was used as the language to develop the code, and as SDK, Android SDK platform 33 was chosen, Firebase real-time database is used at the backend. Here two activities were created in order to enter inpatient registration number and to view health readings of the inpatient. In both activities, the real-time database of firebase was used to acquire details of the inpatient by connecting firebase to the Android Studio project. Android Studio, possesses an inbuilt tool to access firebase functions. With the help of this tool, it can access Firebase data with single functions without hard coding. In this case, it is only required to read data from the database, as we only need to retrieve the health readings and telephone number of the duty-reported doctor in charge of wards to the mobile application. To retrieve this data, a path should be created in our code to access each node in the database. When the functions are called, they will synchronize real-time data without any delay. To test the application, an emulator was utilized. Considering the content of the mobile application, the first layout possesses an inpatient ID entering layout which gives access to the health readings of the inpatient for which the ID is entered. Then in the next layout, it gives the inpatient's ward number, bed number, and the ID. Further, it gives health readings of the relevant inpatient. As an added advantage, the mobile application will also provide the ability for inpatients' relatives to call the duty-reported doctor in charge of wards to acquire additional information about their patients.

7. Fall detection arrangement

The final arrangement in the proposed system is to detect falls, which should turn off manually when the inpatient is resting on a bed, and needs to be turned on manually, when they are using sanitary services. Since changes of body position and sudden change in acceleration are involved in falls, the change of plane of the body is detected by a gyro sensor and for acceleration, an accelerometer was used. Therefore, MPU6050 sensor module is used, as it consists of both gyro and acceleration measuring capability.

Threshold based algorithm

The total sum acceleration vector Acc, which contains both dynamic and static acceleration components, is calculated from sampled data using the following equation.

$$Acc = \sqrt{(Ax)^2 + (Ay)^2 + (Az)^2} \quad (1)$$

where Ax, Ay, Az are the acceleration in the x, y, z axes, respectively.
Similarly, to acceleration, the angular velocity is calculated from sampled data as indicated in the following equation.

$$w = \sqrt{(Wx)^2 + (Wy)^2 + (Wz)^2} \quad (2)$$

where Wx, Wy, Wz are the acceleration in the x, y, z axes, respectively. The acceleration and angular velocity are used to determine the upper and lower fall thresholds. The outcomes of each recorded activity's negative peaks are represented by the lower peak values of the signal. The higher peak values of the signal are the positive peaks for each recorded activity's recorded signals.

Machine learning algorithm

Based on the requirements of the application, data collection is the first step of the ML based fall detection. The ML engine requires two components: a dataset with labeled data containing different movements, each indicating whether it is a fall or an ADL, and a model trained from these data. To train the ML model, a dataset distinguishing between data corresponding to a fall and data corresponding to an ADL must be created. To accomplish this, a set of exercises consisting of falls and ADLs are defined and performed by different subjects in a controlled environment. As the next step in developing the

algorithm for ML, the best training method was chosen. According to the results of the data study, SVM was selected as the best method.

Design architecture

The system design consists of two main parts: a sensor that will track the user's movements and a device that will gather and analyze all the data to determine if a movement is an ADL or a fall. The device will be responsible for notifying that situation when a movement is classified as a fall.

4 RESULTS

4.1 Hardware and software models

1. Arrangement to acquire health sensor readings

As mentioned above, to obtain the heart rate and SpO_2 levels, a sensor was attached to the fingertip, and to obtain temperature readings the sensor was attached in-between the fingers of the inpatient. The figures below show the hardware architecture of the arrangement used to acquire health sensor readings.

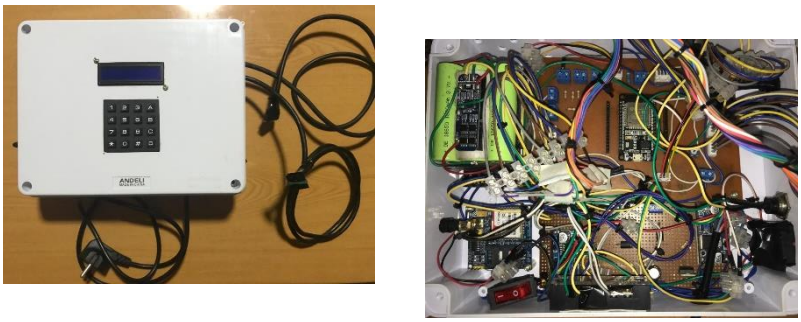

Figure 3. External and internal view of the arrangement used to acquire health sensor readings

Figure 4 shows the inpatient ID entering unit that comprises a 4x4 matrix keypad and an LCD unit. When an ID with 8 characters is entered to the system it will be stored in the database.

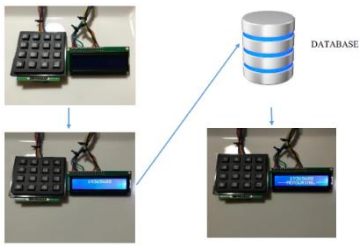

Figure 4. Inpatient registration process

According to the format explained in the methodology section, the message will appear on the doctor's mobile. The figure below shows a snapshot captured after a message was sent to the doctor's mobile from the GSM module.

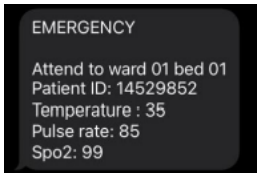

Figure 5. Snapshot of the message that was sent to the mobile from the GSM module

2. Arrangement to identify the duty reported doctor in charge of wards

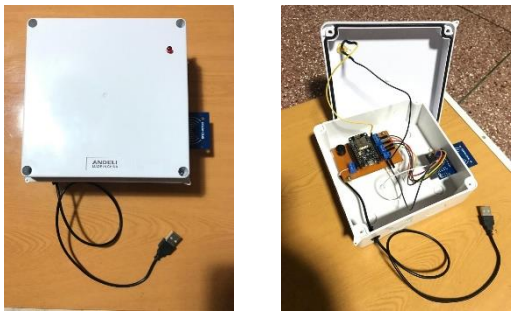

Figure 6. Internal and external view of the arrangement to identify the duty reported doctor in charge of wards

3. Arrangement for health data exhibiting unit

This task was accomplished using a website as mentioned in the methodology section. The designed website is utilized for remote health monitoring, which allows hospital staff to log into the website using various devices.

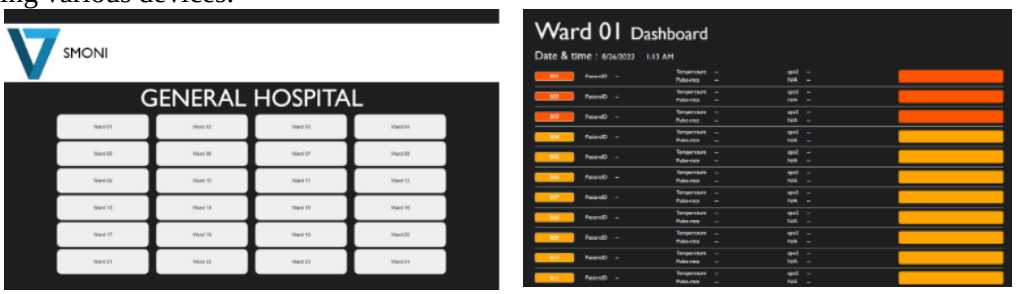

Figure 7. Ward selection web page and ward's health measurement exhibit website

4. ECG acquisition arrangement

When starting the “SMONI ECG-KIT” application, on a Windows device, it will open the start-up interface of the application and it is shown in the figure below.

Figure 8. Start-up interface of the ECG desktop application

5. Android mobile application

The mobile application was tested on a range of devices that are widely accessible. The design is compatible with each device and supports both portrait and landscape data viewing.

Figure 9. First and second layouts of mobile application in portrait mode

6. Fall detection arrangement

Two MPU6050 sensors are used and to achieve better outcomes, data was gathered from each sensor and the average value was taken. Threshold values for both sensors were set, and when compared to one another, the microcontroller receives the information. The microcontroller is programmed to detect the fall and generate immediate outputs. The figure below shows a fall happening when a person walks.

Figure 10. Before and after a fall

Using this threshold-based approach, a dataset distinguishing between data corresponding to a fall and data corresponding to an ADL was created to train the machine learning model. To accomplish this, a set of exercises consisting of falls and ADLs is defined and performed in a controlled environment by various subjects. Separate data sets were collected for each category, such as downSit, freeFall, runFall, runSit, walkFall, and walkSit. As the collected data is noisy, preprocessing was done to eliminate irrelevant and noisy signals from the data. From feature extraction, the result is taken out of the pre-processed data. A machine learning model was created to identify irregular postures, falls, or ADLs using the SVM algorithm. Then, the data was separated into testing and training. The classifier's performance is evaluated using the test data after it has been trained. Consequently, with the help of this machine learning model, it was able to determine whether the movement was a fall or a normal move.

4.2 Analysis of collected data

1. Arrangement to acquire health sensor readings

After connecting the MAX30102 sensor to the inpatient's fingertip, readings of 10 randomly chosen people were taken from different age groups. These readings were taken from the proposed system, as well as from a heart rate measuring device and a SpO_2 level measuring device available in the market to compare both values. After that, those values were compared by calculating the error percentage for each sample using the equation below.

$$Error\ Percentage = \frac{Measured\ value - True\ value}{True\ value} \times 100 \quad (3)$$

Table 1. Comparison of heart rate measurements

Number of samples	Sensor Value (bps)	Device value (bps)	Error percentage (%)
Sample 1	78	81	3.70
Sample 2	76	73	4.11
Sample 3	76	72	5.56
Sample 4	59	59	0.00
Sample 5	61	64	4.69
Sample 6	78	79	1.27
Sample 7	77	79	2.53
Sample 8	72	72	0.00
Sample 9	76	73	4.11
Sample 10	69	69	0.00

Table 2. Comparison of SpO_2 level measurements

Number of samples	Sensor Value (%)	Device value (%)	Error percentage (%)
Sample 1	96	95	1.05
Sample 2	99	96	3.13
Sample 3	97	97	0.00
Sample 4	99	98	1.02
Sample 5	98	97	1.03
Sample 6	98	98	0.00
Sample 7	99	97	2.06
Sample 8	97	97	0.00
Sample 9	97	95	2.11
Sample 10	98	97	1.03

Similarly, temperature measurements of 10 different samples were taken from the developed model and the generic thermometer and the errors were calculated.

Table 3. The comparison of body temperature measurements

Number of samples	Room temperature measured	Body temperature observed by developed model	Actual body temperature observed by generic thermometer	Error
Sample 1	29 °C	35.15	36.27	1.12
Sample 2	29 °C	35.30	36.77	1.47
Sample 3	29 °C	36.57	36.77	1.20
Sample 4	29 °C	34.8	36	1.15
Sample 5	30 °C	35.67	36.61	0.94
Sample 6	30 °C	35.07	36.34	1.27
Sample 7	30 °C	35.22	36.18	0.96
Sample 8	29 °C	35.01	36.59	1.17
Sample 9	29 °C	35.12	36.42	1.3
Sample 10	29 °C	35.84	36.83	0.99

When five attempts were taken from the GSM module, all attempts were successful as the result, which means when the button is pressed the message was delivered to the allocated mobile number. From this we can conclude that the module works accurately.

Table 4. Test attempts of GSM module

Attempt	Result
Attempt 1	Successful
Attempt 2	Successful
Attempt 3	Successful
Attempt 4	Successful
Attempt 5	Successful

2. Cloud database

The performance of database data communication was analyzed by transferring ten sample garbage data to the database from IP-enabled devices utilized in the proposed system. Testing results are depicted in the table below.

Table 5. Performance evaluation of data communication in database

Data samples	operation	Description
Data 1	Post	succeed
Data 2	Post	failed
Data 3	Post	succeed
Data 4	Post	succeed
Data 5	Post	succeed
Data 6	Get	succeed
Data 7	Get	succeed
Data 8	Get	succeed
Data 9	Get	succeed
Data 10	Get	succeed

3. ECG acquisition arrangement

We performed the ECG acquisition on three different people to verify the accuracy of the results. The following figure illustrates an ECG signal of a person who is aged 24. Further, in this presented result, in the comment section, system outputs; "NO ANY ABNORMALITY IS DETECTED". Accordingly, our arrangement looks for abnormal conditions with respect to the sinus bradycardia, sinus tachycardia and, sinus arrhythmia on ECG signals by analyzing the signal and, if any abnormal condition is detected, it will be displayed in the comment section of the interface.

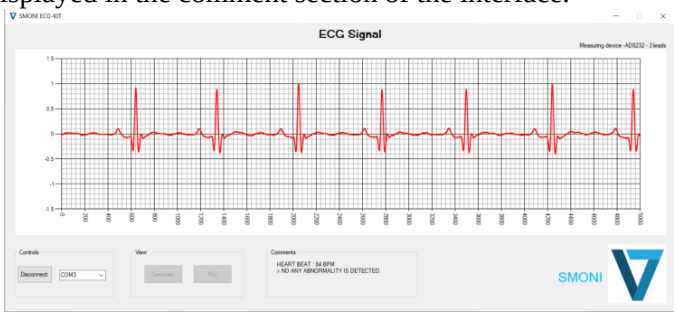

Figure 11. ECG signal of a person

4.3 Performance Evaluation

1. Arrangement to acquire health sensor readings

After the above analysis, error percentages of the heart rate and the blood oxygen level measurements were obtained. The average error percentage of heart rate was calculated utilizing each error percentage calculated from 10 samples.

$$Average\ error\ Percentage = \frac{25.97}{10} = 2.597\% \tag{4}$$

Similarly, the average error percentage of the blood oxygen level was calculated using each error percentage calculated from 10 samples.

$$Average\ error\ percentage = \frac{11.43}{10} = 1.143\% \tag{5}$$

When considering temperature measurements, figures below depict characteristics such as the Mean, Median of the relative errors and, error variation of samples we obtained from the third approach by placing the sensor between two fingers.

Figure 12. Characteristics of error distribution

2. ECG acquisition arrangement

We performed ECG acquisitioning on three different people to verify the accuracy of the results generated from the developed ECG acquisition arrangement. However, since we were unable to compare the output results with a clinical level 12 leads ECG machine, we sought support from a medical practitioner to confirm the accuracy of PQRST point determination. She has approved two output results out of three results.

5 CONCLUSION

When compared to the existing remote health monitoring devices available in the market, we have developed this device to assist healthcare professionals in general hospitals. Considering the large number of inpatient population, and busy work schedules in hospitals, this proposed system aids healthcare workers to perform their day-to-day activities effectively. In addition, it will be time-efficient for doctors as well as nurses and provides extra security to inpatients while they are taking treatments in the hospital. Further research of this proposed product can lead to more developments such as, using machine learning techniques in ECG anomaly detection, making mobile application compatible to both Android and iOS platforms to increase user-friendliness, improving functionalities of the fall detection system, and developing the device in order to acquire other vital signs such as blood glucose levels and blood pressure levels. In conclusion, we can say that research findings are technical, cost effective and user friendly in every aspect where the proposed system manifests the novelty of the product.

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Machine Failure Prediction Using Multilabel Classification Methods

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ABSTRACT

Early detection of machine failure is crucial in every industrial setting as it may prevent unexpected process downtimes as well as system failures. However, machine learning (ML) models are increasingly being utilized to forecast system failures in industrial maintenance, and among them, multilabel classification techniques act as efficient methods. Therefore, this study analyzed machine failure data with five types of machine failures. Initially, a feature selection approach was also carried out in this study to determine the variables which directly cause machine failure. Furthermore, multilabel k-nearest neighbours (MLkNN), multilabel adaptive resonance associative map (MLARAM), and multilabel twin support vector machine classifier (MLTSVM) in adapted algorithms, Binary Relevance, ClassifierChain, and LabelPowerSet in problem transformation approaches, and Random Label Space Partitioning with Label Powerset (RakelD) in ensemble classifiers were employed. To train these models, both the original data set as well as data frame after the feature selection was used, and hamming loss, accuracy, macro, and micro averages were calculated for each of these classifiers. According to the results, MLkNN in adapted algorithms and LabelPowerset in problem transformation approaches performed better than other classifiers used in this study. Therefore, it can be concluded that MLkNN and LabelPowerset could be used to classify multilabel with positive results.

KEYWORDS: *adapted algorithms, ensemble classifiers, feature selection, machine failure, machine learning, multilabel classification, problem transformation.*

1 INTRODUCTION

The loss of production time due to machinery breakdown is a major concern for any business that relies on manufacturing. Failure of a machine occurs when some aspect of an industrial asset does not operate as designed, leading to reduced performance or an outright shutdown. This failure of equipment can have a wide range of consequences, from insignificant to catastrophic, including increased repair costs, unscheduled downtime, lost productivity, and problems for the workers' health and safety, as well as an effect on production and the delivery of services. Machine failure can happen due to many reasons, such as operator mistakes, improper use, inadequate regular and preventative maintenance, unreliable culture, physical damage, and heating up. Therefore, it is important to predict the machine's failure in advance to reduce the unnecessary costs that may incur.

However, in recent years few studies have been done to predict machine failure using different techniques. Traditional approaches to fault diagnosis (Corne, Vervisch, Derammelaere, Knockaert, & Desmet, 2018; Glowacz et al., 2017; Irhoumah et al., 2018; Sapena-Bano et al., 2018) rely on elaborate mathematical models, including supervised diagnosis or processing system dynamic models (AntoninoDaviu & Popaleny, 2018; Bessous, Chemsa, & Sbaa, 2018; Brandt, Gutten, Koltunowicz, & Zukowski, 2018; Ullah, McDonald, Martin, Benarous, & Atkinson, 2019). With the dawn of state-of-the art technologies, industrial settings have started to employ machine learning (ML) techniques to predict the faults in machines. In order to improve the standard approach to compound-fault identification in rotating machinery, Wang, Zhang, Li, and Wu (2020) created a novel ensemble extreme learning machine (EELM) network by merging binary classifiers. They proposed an extreme learning machine (ELM) for clustering and multilabel classification and concluded that the EELM-based fault diagnosis approach provides the best overall performance through their results. Using Motor current

signature analysis (MCSA)- Fourier transforms (FFT), Bessous, Sbaa, and Megherbi (2019) examined the failures in squirrel cage induction motors (SCIMs) caused by rolling element bearings (REBs). In addition, a new indication built on top of the MCSA- discrete wavelet transform (DWT) method was created, and the two methods were compared in depth. In the end, they found that MCSA-DWT provided reliable data on SCIM health.

Kankar, Sharma, and Harsha (2011) concentrated on ball-bearing fault diagnosis utilizing artificial neural networks (ANN) and support vector machines (SVM). The original vibration features were extracted, and their dimensionality was reduced using statistical approaches. From their findings, it was apparent that these ML algorithms can be employed for a fully automated bearing fault diagnosis system. Ferreira and Warzecha (2017) developed a multi-criteria framework for classifying up to ten machine conditions with a focus on experimental processes. They measured the voltages and currents in a synchronous machine. Using a sparse Linear Discriminant Analysis technique, they filtered the signals and extracted the key features they had previously identified. Scatter plots in three dimensions (with a symbol for each machine state) were used to illustrate the findings. After further examination, they determined that this technique can be applied to the diagnosis of a wide variety of machine faults.

Delgado-Arredondo et al. (2017) established a method for fault detection in induction motors in steady-state operation based on the analysis of acoustic sound and vibration signals. The signal was broken down into its component intrinsic mode functions using the complete ensemble empirical mode decomposition. In addition to identifying additional frequencies related to the defects, their proposed approach resulted in improved fault detectability outcomes compared to other published publications.

In their research, Feng, Jones, Chen, and Fang (2018) examined how various multilabel classification techniques performed in the failure classification problem. They tested eight different methods of classification on five different programs containing over eight thousand different bugs. Compared to single-label methods, the experimental results demonstrated that multilabel approaches yield higher accuracy. To determine if a specific code piece is impacted by many scents, Guggulothu and Moiz (2020) proposed and explored the usage of multilabel classification (MLC) techniques. After converting two code smell datasets from the literature into a multilabel dataset (MLD), it was discovered that the two MLC approaches took into account the association between the smells and improved performance for the 10-fold cross-validation with ten iterations.

Tan et al. (2021) analyzed the performance of different cutting-edge multilabel classification algorithms for fault diagnosis of maritime machinery using single-fault data. They used a dataset derived from a Frigate simulator that had been validated against real data to experimentally verify the efficacy of their approach. Their experiments validated the viability of the proposed approach, which can aid in making informed choices regarding the use of multilabel classification for simultaneous fault diagnosis of marine systems. In order to diagnose many defects simultaneously and assess the fault severity in noisy environments, Dineva et al. (2019) used a new method for multilabel classification. Electrical signature analysis and conventional vibration data were utilized for modelling, and the efficacy of different multilabel classification models was examined. They conducted experiments to verify the suggested method's viability under a variety of fault circumstances, including imbalance and misalignment.

The preceding summary of the literature, however, reveals that there have been relatively few studies published on the investigation of the multilabel prediction performance of contemporary classifier algorithms. In addition, there is limited interpretation when it comes to choosing the best classifier for use in the industry. Therefore, this study aims to find suitable multilabel classifiers for machine failure prediction. Section 2 of this paper discusses the materials and methods that have been used, and in section 3, the results obtained are discussed in detail. Section 4 includes the conclusion of this study.

2 MATERIALS AND METHODS

2.1 Data

This study used data related to a machine failure, and data was retrieved from an online data repository (Matzka, 2020). The original dataset is comprised of 10 000 records that describe the following machine features.

1) Product ID - Describes the product quality using the letter notation of L (50% of all products), M (medium value of 30%) and H (high values of 20%), along with a variant-specific serial number.
2) UID - A unique id to identify the products.
3) Air temperature (in Kelvin) - Air temperature was generated using a random walk process that was normalized to a standard deviation of 2 K around 300 K.
4) Process temperature (in Kelvin) - Generated by adding the air temperature plus 10 K to a random walk process with a standard deviation of 1 K.
5) Rotational speed (rotations per minute) - Calculated using a 2860 W power and a normally distributed noise as a background.
6) Torque (Newton Meters) - Torque values were considered without having negative values with a normal distribution around 40 Nm with a stand deviation of 10 Nm.
7) Tool wear (minutes) - The high-quality variations H, M, and L add 5/3, 2 minutes to the process, causing the used tool to deteriorate.

In addition to the above machine features, machine failures have been recorded considering five independent failure types as follows.

1) Tool wear failure (TWF) - The tool wear failure is recorded when a tool fails or is replaced between a time of 200-240 minutes.
2) Heat dissipation failure (HDF) - If the difference in air and process temperatures is less than 8.6 K and the tool's rotational speed is less than 1380 rpm, heat dissipation results in a process failure.
3) Power failure (PWF) - Power failures are recorded if the power is below 3500W or above 9000W. Power is the product of torque and rotational speed (in rads-1).
4) Overstrain failure (OSF) - Overstrain failures are recorded when the product of the tool wear and torque exceeds 11,000 minNm for the L-type products, 12,000 minNm for M-type products and 13,000 for H-type products, respectively.
5) Random failures (RNF) - Each process has a chance of 0.1% to fail despite the process parameters that are defined as random failures.

If at least one of the above failure modes were recorded, the machinery failure label has been recorded as ‘1’, which will indicate the malfunction of the machine. Figure 1 depicts the original form of the data frame.

UDI	Product ID	Type	Air temperature [K]	Process temperature [K]	Rotational speed [rpm]	Torque [Nm]	Tool wear [min]	Machine failure	TWF	HDF	PWF	OSF	RNF
1	M14860	M	298.1	308.6	1551	42.8	0	0	0	0	0	0	0
2	L47181	L	298.2	308.7	1408	46.3	3	0	0	0	0	0	0
3	L47182	L	298.1	308.5	1498	49.4	5	0	0	0	0	0	0
4	L47183	L	298.2	308.6	1433	39.5	7	0	0	0	0	0	0
5	L47184	L	298.2	308.7	1408	40.0	9	0	0	0	0	0	0
...	...	...	...	...	...	...	...	...	...	...	...	...	...
9996	M24855	M	298.8	308.4	1604	29.5	14	0	0	0	0	0	0
9997	H39410	H	298.9	308.4	1632	31.8	17	0	0	0	0	0	0
9998	M24857	M	299.0	308.6	1645	33.4	22	0	0	0	0	0	0
9999	H39412	H	299.0	308.7	1408	48.5	25	0	0	0	0	0	0
10000	M24859	M	299.0	308.7	1500	40.2	30	0	0	0	0	0	0

Figure 1. Original data frame

2.2 Data Preprocessing and Exploration

Firstly, UDI and product Id variables were removed due to the lack of predictive power. The machinery failure variable was also removed, and TWF, HDF, PWF, OSF, and RNF were retrieved as the target columns. After that, data were checked for the availability of null values, and it was found that there were no such records. The type variable, which was originally a categorical variable, was converted to numeric values using one-hot encoding technique. However, the data were scaled using the minmaxscaler from the sklearn library (Pedregosa et al., 2011) since the column values were in different numerical ranges. After scaling, data exploration was performed to understand the data distribution. For

this purpose, a correlation heat map was used, and correlation among the variables was visualized. In addition, highly correlating features that had a score greater than 0.7 were removed from the data. To be more precise about the removing variables, a feature selection was also conducted using the selectKBest method from the sklearn library (Pedregosa et al., 2011).

2.3 Multilabel Classification Techniques

Due to the inclusion of several target columns, this research problem was trained according to multilabel classification techniques. Multilabel classification techniques have the ability to provide multiple outputs compared to traditional classification methods (Herrera, Charte, Rivera, & Jesus, 2016). Firstly, the data were split so that 75% of the data were assigned for the training split while the rest of the data were allocated to the testing set. After using the train-test split approach, methodologies of problem transformation adapted algorithms, and ensemble methods were used to model the data. For this, the scikit-multilearn, which is library developed especially for handling multilabel classification tasks, was used (Szymański & Kajdanowicz, 2017).

1) Adapted algorithms – These algorithms focus on modifying cost/decision functions to adapt single-label classification algorithms to the multilabel case (Szymański & Kajdanowicz, 2017). This study implemented the multilabel k-nearest neighbours (MLkNN), multilabel adaptive resonance associative map (MLARAM), and multilabel twin support vector machine classifier (MLTSVM) for machine failure prediction.

- MLkNN – This algorithm has been developed under adapted algorithms. In MLkNN, the nearest examples to a test class are found using k-Nearest Neighbors, and assigned labels are chosen using Bayesian inference (Zhang & Zhou, 2007).
- MLARAM – This classifier approach focuses on accelerating classification by including an additional Adaptive Resonance Theory (ART) layer for grouping learned prototypes into substantial clusters. In this scenario, activating only a small portion of the prototypes can replace activating all of them, significantly reducing the classification time (Benites & Sapozhnikova, 2015).
- MLTSVM – This is a useful advancement of the twin support vector machine (TWSVM) for multilabel classification. This classifier determines multiple non-parallel hyperplanes to capture the multilabel information embedded in data (Chen, Shao, Li, & Deng, 2016).

2) Problem transformation approaches - Out of the problem transformation approaches, methods of Binary Relevance, ClassifierChain, and LabelPowerSet were utilized for training the data model in this research.

- Binary Relevance - Using the same base classifier from the constructor, the binary relevance technique divides an L-label multilabel classification problem into L separate L-label binary classification problems (Szymański & Kajdanowicz, 2017). The output of the prediction is the union of all classifiers for each label.
- ClassifierChain - This algorithm (Read, Pfahringer, Holmes, & Frank, 2009) treats each label as a link in a conditioned chain of problems involving single-class classification (Szymański & Kajdanowicz, 2017).
- LabelPowerset - In this approach to multilabel classification, a multilabel problem is transformed into a multi-class problem using a single multi-class classifier that has been trained on all unique label combinations found in the training data (Szymański & Kajdanowicz, 2017).

3) Ensemble classifiers - The application of ensemble classification schemes by ensembles of classifiers results in the generation of an array of multilabel base classifiers. In this study, only Random Label Space Partitioning with Label Powerset (RakelD) was applied. Tsoumakas, Katakis, and Vlahavas (2011) introduced RakelD as a library that has been created using an ensemble of classifiers.

However, to observe whether there is an impact of the feature selection on the classification techniques, the models were trained using both the original data frame and the data frame after the feature selection was performed.

2.4 Model Evaluation Metrics

Unlike the traditional approaches of binary classification and multi-class classification, multilabel classification has separate evaluatory metrics (Tsoumakas & Katakis, 2007). In this section, the metrics used to evaluate the results that were obtained are discussed.

1) Hamming loss – Hamming loss that is given in Eq. (1) provides a fraction of labels that are incorrectly classified, which is used to evaluate the multilabel classification methods(Ganda & Buch, 2018).

$$Hamming\ loss = \frac{1}{m}\sum_{i=1}^{m}\left|\frac{Y_i\,\Delta\,Z_i}{M}\right| \quad (1)$$

2) Accuracy - The percentage of predicted correct labels to the total number of labels (predicted and actual) for each instance is known as accuracy, and it can be calculated as in Eq. (2) (Ganda & Buch, 2018).

$$Accuracy = \frac{1}{m}\sum_{i=1}^{m}\left|\frac{Y_i \cap Z_i}{Y_i \cup Z_i}\right| \quad (2)$$

3) Macro average and micro average - Generally, the receiver operating characteristic curve (ROC)-area under the curve (AUC) score is generated by calculating ROC-AUC from the prediction scores. The ROC curve is a graphical method for evaluating a test's ability to distinguish between labels (Akobeng, 2007). The ROC curve can be created by calculating the test's sensitivity and specificity at every possible cut-off point and then plotting those results against 1-specificity (Akobeng, 2007). A ROC curve can also be considered the average of a test's sensitivity over all feasible specificity values or vice versa (Mandrekar, 2010). In macro ROC-AUC, for each label, it computes the metrics and determines the unweighted mean. Label imbalance is not taken into account in this. The micro ROCAUC score considers each label in the label indicator matrix when calculating metrics on a global scale.

In this analysis, both the macro ROC-AUC score and micro ROC-AUC score metrics were tested using the one versus rest method.

3 RESULTS AND DISCUSSION

After training the data models using the methods described in section 2.3, the results were recorded considering the standards of hamming loss, accuracy, macro average, and micro average. The results obtained for the original data model before applying feature selection are depicted in Table 1.

Table 1. Multilabel Evaluation Metric Scores for the Classifiers Before Applying Feature Selection

Approach type	Classifier	Hamming loss	Accuracy	Macro average	Micro average
Adaptation approach	MLkNN	0.0052	0.973	0.8826	0.9700
	MLARAM	0.2020	0.019	0.5620	0.5712
	MLTSVM	0.0078	0.964	0.5620	0.5712
Problem transformation	Binary Relevance	0.0064	0.902	0.8498	0.9630
	LabelPowerset	0.0064	0.970	0.9022	0.9640
	ClassifierChain	0.0064	0.970	0.8826	0.8930
Ensemble of classifiers	RakelD	0.0064	0.970	0.8328	0.9602

Other than the MLARAM model, the rest of the models have scored very low values for the hamming loss. From the adaptation approach, the MLkNN algorithm has the lowest hamming loss and higher scores for accuracy, macro average, and micro average. The LabelPowerset has the maximum

values for evaluation metrics among the problem transformation methods. In addition, RakelD has low scores for macro and micro averages compared to MLkNN and LabelPowerset methods.

However, the multicollinearity among variables could not be overlooked when training these models. Therefore, a correlation heat map was also generated, as in Figure 2, and the features with a correlation which is greater than 0.7 were eliminated. According to the heat map, process temperature and torque variables are highly correlated with air temperature and rotational speed, respectively. To be more accurate about the dropping variables, a feature selection was also conducted using selectKBest method, and the results generated by this method also confirmed that process temperature and torque columns should be dropped from the data frame. Therefore, process temperature and torque columns were eliminated.

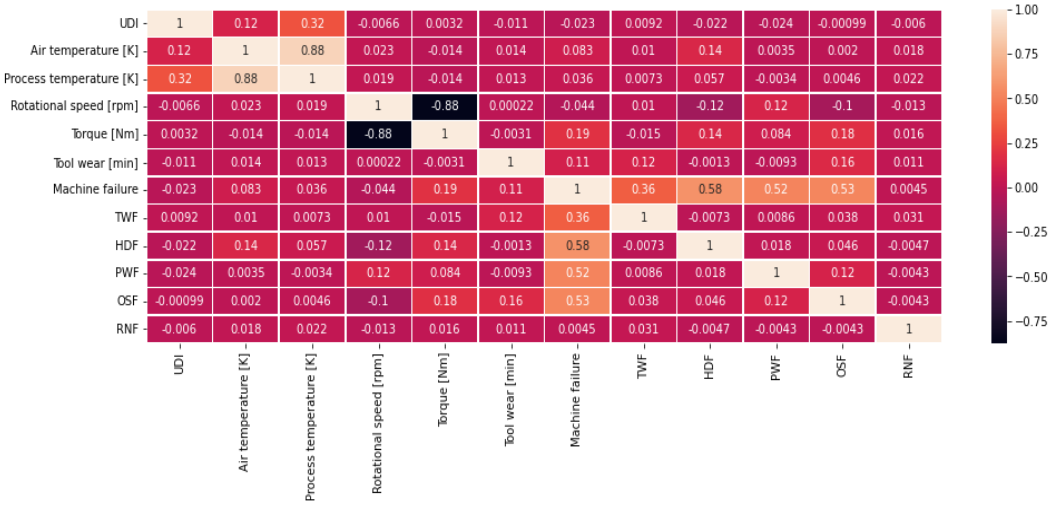

Figure 2. Correlation heatmap describing the relationship among variables

After removing process temperature and torque from the data set, the methods discussed in section 2.3 were reapplied, and the evaluation metrics were also calculated. Table 2 shows the results recorded for the respective metrics for each classification technique.

Table 2. Multilabel Evaluation Metric Scores for the Classifiers After Applying Feature Selection

Approach type	Classifier	Hamming loss	Accuracy	Macro average	Micro average
Adaptation approach	MLkNN	0.0050	0.970	0.8800	0.9700
	MLARAM	0.0190	0.202	0.5620	0.5712
	MLTSVM	0.0078	0.964	0.5620	0.5712
Problem transformation	Binary Relevance	0.0064	0.970	0.8400	0.9670
	LabelPowerset	0.0064	0.970	0.9000	0.9700
	ClassifierChain	0.0064	0.970	0.8800	0.9690
Ensemble of classifiers	RakelD	0.0064	0.970	0.8300	0.9692

According to Table 2, it is clear that the MLARAM has a large hamming loss value and low scores for accuracy, macro average, and micro average. MLkNN method has attained the highest metric scores among the adaption techniques, even after eliminating two variables. Out of the problem transformation methods, the LabelPowerset has gained a low hamming loss score and high values for the other metrics. Even after applying feature selection, the scores for RakelD's macro and micro averages are low in comparison to those of the MLkNN and LabelPowerset methods.

When the models were trained without applying feature selection, the scores recorded for MLkNN and LabelPowerset had optimal values. However, according to the results illustrated in Table 1 and Table 2, it can be seen that the results for both these classifiers that were trained without applying

feature selection and trained after applying feature selection have similar metric values indicating negligible difference in performances.

It was also noted that, during the feature selection phase, the removed torque column could be an essential feature when being considered from the perspective of machinery parts. As power is the product between torque and rotational speed, removing torque might directly affect the predictions, especially regarding power failures. Therefore, considering the features of the machinery, it is recommended to perform feature selection, being mindful of this point.

Matzka (2020) has presented an explainable model and an explanatory interface using the original dataset used in this research work. In this study, the researcher has used explainable decision trees as well as normalized feature deviation as an explanatory interface. However, Matzka (2020) has found that in some circumstances, the decision trees offer no beneficial insights, while the normalized feature deviations offer explanations of low quality. In order to overcome these issues, our study focused on predicting machinery failures using multilabel classification techniques to provide early insights. These techniques are believed to be efficient since they offer users with possible failure type combinations, as opposed to predicting a failure without specifying which failure mode will occur.

4 CONCLUSION

In this research work, a multilabel classification approach was used to predict machinery failures. The original data set has five types of machine failures, and if at least one failure mode was recorded, the machine displayed a tendency to break down. This study performed a feature selection procedure to examine the variables which directly affect machine failure. Furthermore, seven multilabel classifiers were implemented using the original data set as well as the new data frame which was formed after applying feature selection. Hamming loss, accuracy, macro average, and micro average were calculated for each of these models in order to evaluate the performance. From the adapted algorithm approaches, MLkNN, MLARAM, and MLTSVM classifiers were used to train the data, where the MLkNN classifier performed better than the other two methods. The Binary Relevance, LabelPowerset, and ClassifierChain were used respectively from the problem transformation methods, where the LabelPowerset-based model produced substantially better results during the training phase. The RakelD classifier was selected from the ensemble of classifiers since it yielded the best results but performed poorly compared to the MLkNN and LabelPowerset classifiers. However, it is noted that feature selection did not significantly alter the scores obtained from evaluation metrics before and after they were applied. Even though the features of torque and process temperature were removed during the feature selection phase, there is a possibility for this to affect predictions considering the machinery state. Therefore, this study concludes the results with metric scores obtained before applying the feature selection. For future research, the techniques such as multilabel embeddings and label space clusters can be used to observe and compare the results. Alternatively, this study could be conducted by considering only the machinery failure column, which could be converted to a multi-class classification problem rather than a multilabel classification, and disciplines such as deep learning techniques can be utilized.

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Whole Life Costing Awareness and Implementation Challenges in the Sri Lankan Construction Industry

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ABSTRACT

Construction industry is highly demanding, especially with regard to the project cost as a significant aspect. However, more informed cost advice can be produced considering the project's life cycle that begins with the conception and ends with its disposal instead of using a conventional initial capital cost basis. Thus, Whole Life Costing (WLC) and Life Cycle Costing (LCC) concepts are essential. Though many LCC research studies exist, WLC studies are minimal in the Sri Lankan construction industry context. Therefore, this study aims to explore WLC awareness and implementation challenges in the Sri Lankan construction industry. A literature review was conducted to search for the concepts. Empirical data were gathered using questionnaires by implementing a quantitative survey strategy. Findings depict that the awareness of WLC in the Sri Lankan construction industry is poor, preventing its benefits. Moreover, this research identified difficulty in identifying includes and excludes for calculating WLC, lack of details at early stages, lack of awareness of WLC benefits, lack of understanding of WLC tools, lack of reliable data and lack of expertise/knowledge on WLC as the primary challenges in implementing WLC in the Sri Lankan construction industry. Therefore, these challenges must be mitigated for the beneficial WLC implementation in the Sri Lankan construction industry while enhancing awareness and knowledge of the WLC concept among professionals, especially quantity surveyors, to facilitate responsible initiation of WLC practices in the Sri Lankan construction industry.

KEYWORDS: *Awareness, Benefits, Challenges, Construction industry, Life Cycle Costing, Sri Lanka, Whole Life Costing*

1 INTRODUCTION

1.1. Background

Construction industry is one of the world's most significant industries, contributing a considerable proportion of most countries' GDP (Horta et al., 2013) and 5%-6% of the nation's employment (Ruddock et al., 2011). However, construction cost is affected by several variables, namely labour, material, overheads and revenue-related variables, including taxation, repatriation restrictions and foreign exchange rates (Baloi & Price, 2003). Therefore, it is evident that cost performs a leading role in the growth of the construction industry. However, as per Higham et al. (2015), providing more knowledgeable cost advice is critical considering the project's whole life cycle rather than solely on a standard initial capital cost basis.

Whole Life Costing (WLC) is a tool supporting decision-making on construction projects considering the long-term view of costs and benefits involved (Manege and Kennedy, 2020). The primary purpose of WLC is to assess and optimize a building's whole life cost and help decision-making throughout the life of the structure (Opoku, 2013). However, a lack of uniform methodology is one of the main challenges in WLC deployment. In contrast, the absence of regular and trustworthy data on cost and performance, a general lack of demand and interest on the part of clients, and a shortage of knowledge of WLC are identified as other barriers (Opoku, 2013).

British Standards Institute (2008), defines Life Cycle Costs as the 'costs of an asset or its parts throughout its life cycle while fulfilling the performance requirements and Whole Life Costs as 'all

significant and relevant initial and future costs and benefits of an asset, throughout its life cycle, while fulfilling the performance requirements'. Accordingly, the Life Cycle Cost is a subset of the Whole Life Costs (Manege & Kennedy, 2020), even though Life Cycle Costs and Whole Life Costs are believed and treated as synonymous concepts by most construction industry practitioners.

Even though building construction consultants in Sri Lanka do not use the Life Cycle Costing (LCC) concept to its full potential as per Sandaruwan and Chandanie (2021), there are LCC research studies concerning the Sri Lankan Construction industry, e.g. barriers in practicing life cycle costing techniques experienced by Sri Lankan quantity surveyors (Sandaruwan and Chandanie, 2021), On-site renewable energy for industrial buildings in Sri Lanka: a life cycle cost analysis (Nanayakkara et al., 2021), Comparative life-cycle cost (LCC) study of green and traditional industrial buildings in Sri Lanka (Shanika et al., 2021), the impact of sustainable features on life cycle cost (LCC) of green buildings in Sri Lanka (Weerasinghe, 2018). However, the research studies examining WLC proceedings beyond LCC are seldom found in the Sri Lankan construction industry, showing that the awareness of WLC and its implementation are scarce is in the Sri Lankan construction industry. WLC is an all-inclusive exercise considering not only life cycle costs but also non-construction costs, income, and externalities (Manege and Kennedy, 2020). Hence, WLC implementation will help consultants make well-informed decisions with more benefits compared to LCC. Therefore, this study explores Whole Life Costing (WLC) awareness and implementation challenges in the Sri Lankan Construction industry.

2 LITERATURE REVIEW

2.1. Importance of WLC and LCC

A building project's life cycle starts with the conceptual idea and concludes with its disposal. When making decisions, investors or owners are used to focusing solely on the initial cost, overlooking future maintenance and operating costs (Davies,2004). However, a complete evaluation of building costs is needed due to the increased knowledge among stakeholders ranging from building owners and suppliers to building occupants and facility managers in modern construction projects (Opawole, 2020). Whole Life Costing (WLC) and Life Cycle Costing (LCC) are tools to support decision-making considering long-term costs and benefits involved in construction projects (Manege and Kennedy, 2020). In addition, these tools provide more informed cost advice at an early stage of projects rather than advising on cost using an initial capital cost basis (Higham et al. 2015).

2.2. Definitions of WLC and LCC

The literature provides several definitions for LCC and WLC to gain a better understanding of both concepts. Tables 1 and 2 provide some of the definitions/descriptions for LCC and WLC given by different authors.

Table 1: Definitions /descriptions for Life Cycle Costing

Ref.	Definitions/descriptions for LCC
[1]	LCC is a tool for calculating the total cost performance of a facility over time, which includes acquisition, operating, maintenance and disposal costs.
[2]	LCC has been defined as a technique which can measure all costs related to the construction, operation, and maintenance of a construction project over a particular timeframe.
[3]	LCC, as an asset management technique, allows the operating costs of premises to be evaluated at frequent intervals, which can also be recognized as its unique advantage.
[4]	LCC is an economic assessment considering all agreed projected significant and relevant cost flows over a period of analysis expressed in monetary value.
[5]	LCC is constrained by a poor projection of future building operation and maintenance expenses and a lack of measurable risk assessment measures.
[6]	LCC is a technique used to estimate the total cost of ownership. It allows comparative cost assessments over a specific period, considering relevant economic factors regarding initial capital costs and future operational and asset replacement cost.

[1]Langdon (2007), [2]Heralova (2017), [3]Ashworth et al. (2013), [4]International Organization of Standardization ISO 12006-2 (2001), [5]Hunter et al. (2006), [6]Zakaria et al. (2020)

Table.2: Definitions /descriptions for Whole Life Costing

As depicted in Tables 1 and 2, literature includes definitions for WLC and LCC, where differences can be identified. Therefore, distinguishing between WLC and LCC is essential.

Ref	Definitions/descriptions for WLC
[1]	WLC it is a tool to assist in assessing the cost performance of construction work, aimed at facilitating choices where there are alternative means of achieving the client's objectives and where alternatives differ, not only in their initial cost but also in their subsequent operational costs
[2]	WLC consists of non-construction costs, income, externalities and life cycle costs (construction, operation, maintenance and end of life)
[3]	WLC is Rethinking Construction, Best Value and procurement routes, such as Public Private Partnerships and the Private Finance Initiative, which have led to clients and designers putting more emphasis on considering whole life costs.
[4]	WLC is value for money and is the optimum combination of whole-life cost and quality to meet the user's requirements.
[5]	WLC is a technique for examining and determining all the costs – in money terms – direct and indirect, of designing, building and facility management (operating, maintenance, support and replacement) of a building throughout its entire service life, including the disposal cost.
[1]Kishk et al. (2006), [2]Manege and Kennedy (2020), [3]Kirkham et al. (2004), [4]Office of Government Commerce (2003), [5]Horner (2002)	

2.3. WLC vs LCC

Even though LCC and WLC are used interchangeably in practice, they are not similar. WLC consists of non-construction costs, income, externalities and life cycle costs (construction, operation, maintenance and end of life) (Manege and Kennedy, 2020). Figure 1 illustrates the elements of WLC and LCC, showing the relationship between WLC and LCC.

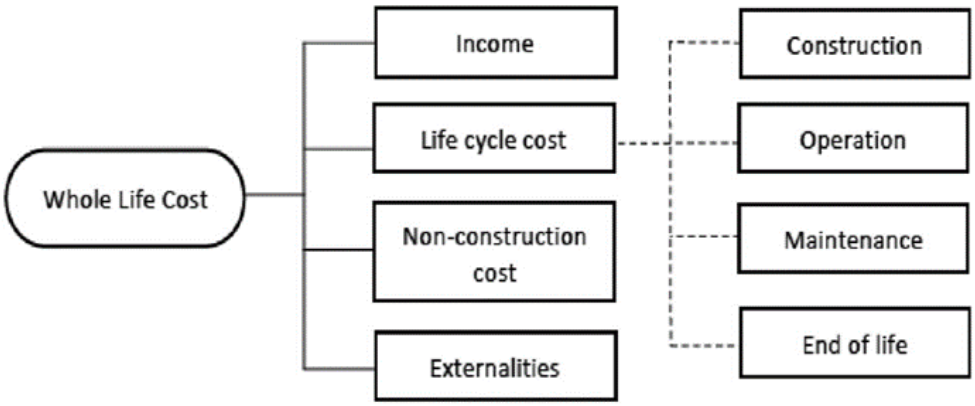

Figure 1: Elements of WLC and LCC

Source: Manege and Kennedy (2020)

As per Figure 1, LCC is one element of WLC. WLC is associated with several building-related costs and benefits for producing, operating, maintaining, and disposing of an asset, e.g. initial costs, fuel costs, operational, maintenance and repair costs, replacement costs, residual amounts, finance expenses

and non-monetary benefits (Fuller 2007). In addition, as per BSI (2008), WLC also includes non-construction costs, income, and externalities other than LCC, as shown in Figure 1. Therefore, implementing WLC provides benefits related to both WLC and LCC. Hence, stakeholders involved in construction projects must realize the advantages of using WLC, which also includes LCC.

2.4. Benefits of WLC

LCC may be used to foresee the cash flow of an asset for budgeting, cost planning, tendering, and cost reconciliation in a project (Sandaruwan et al., 2021). This is not restricted to the expense of inception and construction but extends during the building's entire duration. (Opawole, 2020). Since the LCC is a subset of WLC, all the benefits of LCC are also related to the WLC. Table 3 gives the benefits of LCC and WLC found in the literature.

Table 3: Benefits of WLC and LCC

Benefits of WLC and LCC	Ref
Analyse and optimise a building's whole life costs	[1]
Give a tool to guide decision-making throughout the building's life	[1], [2]
Involved in delivering early-stage project cost advice for a Project	[3]
The facility's total cost commitment can be effectively used to; reduce building ownership costs, evaluate economic aspects of a project, improve the risk management process, monitor project cost performance, control design development, identify project costs, increase cost transparency, recognize the various cost drivers	[4]
Clients can have a long-term connection with their built environment asset benefits Combined with a clear desire on the client's behalf to optimize ownership costs over the asset's entire life.	[5], [6]
Help in evaluating the environmental/economic aspects of a proposed building project at an early stage to design in a more sustainable manner	[7]
[1]Al-Hajj and Aouad (1999), [2] Kirkham (2005), [3]Higham et al. (2015), [4]Knauer et al. (2005), [5]Higham et al. (2015), [6]Opoku (2013), [7]Caplehorn et al. (2012)	

2.5. Barriers to implementing WLC

Hunter et al. (2005) considered the barriers to practice in the industry caused by a lack of past data on building elements and services.(., . Employers' and practitioners' shortage of understanding of LCC tools, inaccuracy of data, employers' desire to maintain budgets within short-term horizons, and a lack of shared techniques are all barriers to adopting LCC as an initial stage project in the UK as an evaluation tool according to Higham et al.(2015). Heralova (2017) reported that LCC deployment was hampered by a shortage of industrial requirements for reporting LCCs and past cost data Zakaria et al. (2020) identified that the absence of a standard method for calculating LCC and clients' reluctance to pay for LCC are significant barriers in Malaysian construction projects. The technological obstacles were recognized as software tools, laws and standards, data and information, strategy and technique. Chiurugwi et al (2000) identified a lack of procurement award incentives as a barrier when implementing LCC in the construction industry. Moreover, Horner (2002) recognized "the lack of trustworthy and reliable data on aspects of whole life cost (capital, facilities management, and disposal) and building element performance and services" as one of the significant barriers in WLC implementation . Sandaruwan et al. (2021), Kishk (2004), and Kishk et al. (2003) identified the critical issue that impacts the use of LCC in practice, is determining the quality of the data available to carry out an analysis of the initial costs, future running and maintenance costs, life cycles, and discount and inflation rates of a potential construction project.

Due to many obstacles, Sri Lankan quantity surveyors hesitate to use LCC procedures. The most common barriers preventing the usage of LCC practices in the local building construction industry are; a shortage of awareness of the LCC tool among employers and practitioners, nonexistence of knowledge about LCC, a lack of previous data, a lack of interest from employers and experts, a lack of a standard calculation method for LCC, a lack of recognized guidelines, and a lack of an industry standard for

reporting LCC (Sandaruwan and Chandanie, 2021). Sandaruwan and Chandanie (2021) further mentioned how recognized professional bodies (e.g. Construction Industry Development Authority (CIDA), Institute of Quantity Surveyors Sri Lanka (IQSSL), Sri Lanka Institute of Architects (SLIA), and the Institute of Engineers Sri Lanka (IES L)) could encourage the use of the LCC concept in the Sri Lankan construction industry. Accordingly, they suggest launching a new awareness campaign focusing on the advantages and applications of the LCC concept, enhancing LCC training, introducing user-friendly systems and applications, and including LCC as a module of education courses. In addition, government's involvement in regulations, standards, and guidelines will also help eliminate the obstacles mentioned above (Sandaruwan and Chandanie, 2021). Therefore, identifying the importance of WLC awareness in the Sri Lankan construction industry and barriers that hamper the usage of WLC is beneficial in ensuring value for money by considering not only LCC but also non-construction costs, income, and externalities.

3 RESEARCH METHOD

Quantitative research findings are representative of a population through a large data set and can be generalized (Saunders et al. 2009). Therefore, since this research aims to find Whole-Life Costing (WLC) awareness and implementation challenges in the Sri Lankan construction industry, this research was required to collect quantitative data to achieve its research aim. A quantitative survey strategy was implemented with a questionnaire developed based on findings from a comprehensive literature review. A sample of 60 Sri Lankan construction industry professionals was selected using a non-probability convenient sampling method due to the time restrictions of the study and the difficulty of finding a complete list of Sri Lankan construction industry professionals. The questionnaire prepared using "Google forms" was circulated among the sample.

Descriptive statistical approaches such as percentages and Relative Important Index (RII) were used to analyze the collected quantitative data.

The equation to calculate RII is shown in Eq (1).

$$RII = \frac{\sum W}{A \times N} \quad (1)$$

Where 'W' is the rank given to each factor by the respondents (ranging from 1 to 5), 'A' is the highest rank (here, A=5), and 'N' is the total number of respondents. RII value has a range from 0 to 1. The higher value of RII gives higher significance to the usefulness of WLC implementation, benefits of WLC implementation, and barriers to WLC implementation.

4 DATA ANALYSIS AND DISCUSSION

Out of distributed questionnaires among 60 professionals, only 40 were returned, resulting in a response rate of 67%.

4.1. Demographic information about the respondents

Initially, the demographical data, including profession, experience and highest academic qualifications were analyzed. Respondents' profession, experience in the industry and educational background vary, resulting in different points of view related to the subject matter, as shown in Figures 2, 3 and 4.

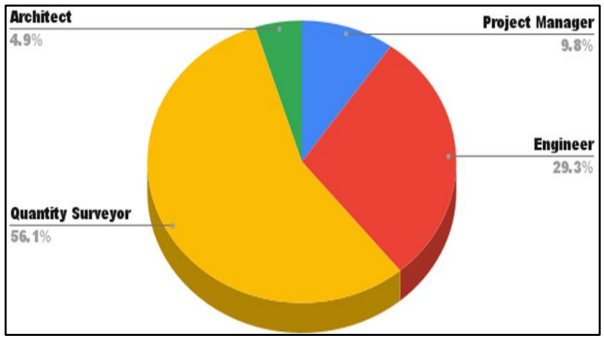

Figure 2: Respondents' Profession

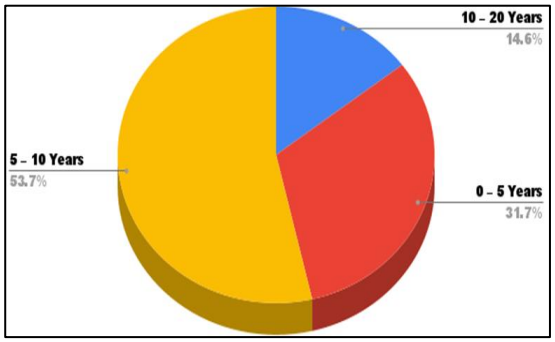

Figure 3: Respondents' work experience

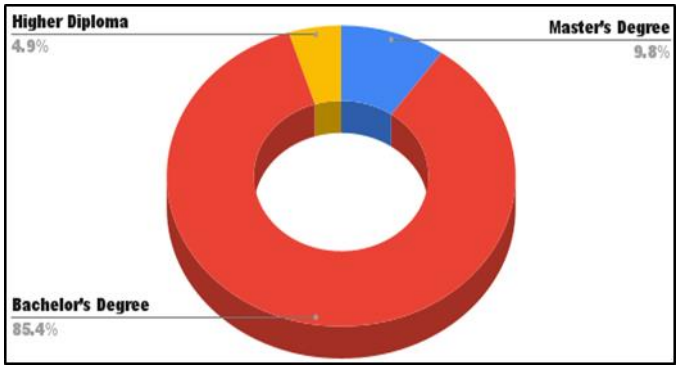

Figure 4: Highest Educational qualifications

As per Figure 2, 56.1% of quantity surveyors, 29.3% of engineers, 9.8% of project managers and 4.9% of architects responded to the questionnaires. In addition, as per Figure 3, 53.7% of respondents have 5 – 10 years of experience in the industry, while Figure 4 shows that 85.4% of respondents have a bachelor's degree as their highest academic qualification at the time of the survey.

4.2. Respondents' knowledge and awareness of the Whole Life Costing (WLC) and Life Cycle Costing

The contextual data was analyzed in quantitative forms, which directly affected the aim of the research. The first concern is whether the responders know WLC and LCC concepts. Accordingly, findings show that 92.7% of respondents know what LCC is, and 85.4% know what Whole Life Costing is. In addition, the research found that 85.4% of respondents have not been involved in the execution of WLC or LCC in construction projects. In contrast, only 14.6% of respondents mentioned that they had been involved in the LCC practices in building construction projects.

Furthermore, respondents were asked to select the best suit description related to WLC and LCC to identify their understanding of both concepts.

1. Opinion 1 - Whole Life costing (WLC) and Life cycle costing (LCC) are synonyms
2. Opinion 2 - Life cycle costing (LCC) is a subset of Whole life costing (WLC)
3. Opinion 3 - WLC is an investment appraisal and management tool that assesses an asset's total cost over its whole life. On the other hand, LCC is a tool to determine the most cost-effective option among competing alternatives to purchase, own, operate, maintain and, finally, dispose of an object or process when each is equally appropriate to be implemented on technical grounds.
4. Opinion 4 - Whole Life costing (WLC) and Life cycle costing (LCC) are two different concepts.

Accordingly, the majority (37.5%) of respondents think that WLC and LCC are synonyms, while 12.5% selected Option 3, which indicates the roles of WLC and LCC. Unfortunately, only 20% mentioned that LCC is a subset of WLC. Therefore, it is apparent that Sri Lankan construction industry professionals are not adequately aware of the roles and differences between LCC and WLC concepts.

Further, results show that most Sri Lankan construction industry professionals misunderstand the two concepts, i.e., they think WLC and LCC are synonyms.

Moreover, the awareness of the WLC elements among Sri Lankan construction industry professionals was found and presented in Figure 5.

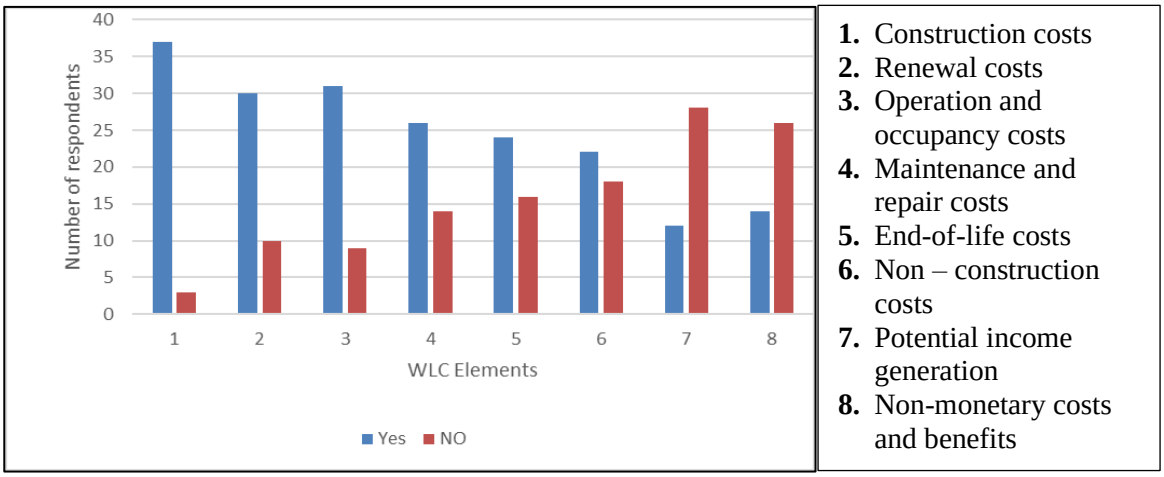

Figure 5: Awareness of the elements of WLC

Figure 5 demonstrates that most respondents know construction costs are a WLC element. In addition, renewal costs, maintenance and repair costs, operation and occupancy costs, end-of-the-life costs and non-construction costs are also elements of WLC, as mentioned by more than 50% of the respondents. Since these elements are related to LCC, a subset of WLC, it indicates the professionals' awareness of LCC rather than WLC. On the other hand, only a few respondents identified that potential income generation and non-monetary costs and benefits, e.g., social benefits and environmental damages, are elements of WLC. This result indicates some respondents' lack of knowledge and misunderstanding of the WLC concept.

4.3. Whole life Costing implementation in the construction industry

Party to initiate WLC practices

Figure 6 illustrates the respondents' answers to the question, "which party should initiate the Whole life costing practices in the construction industry?".

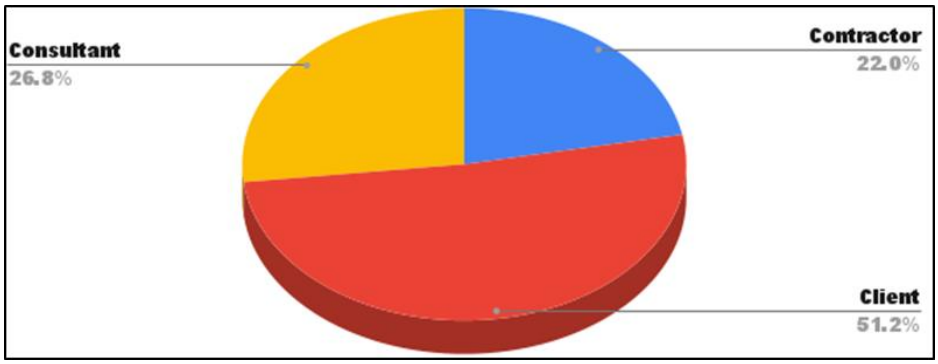

Figure 6: Respondents' opinion about which party should initiate WLC

According to Figure 6, 51.2% of respondents believe clients should initiate WLC practices in the industry, while 26.8% of respondents think consultants should do it. However, only 22% of respondents think the responsibility for initiating WLC practices rests with the contractors.

Responsible profession for initiating WLC practices

Further, respondents were asked which profession should take responsibility for initiating WLC practices, and the responses are illustrated in Figure 7.

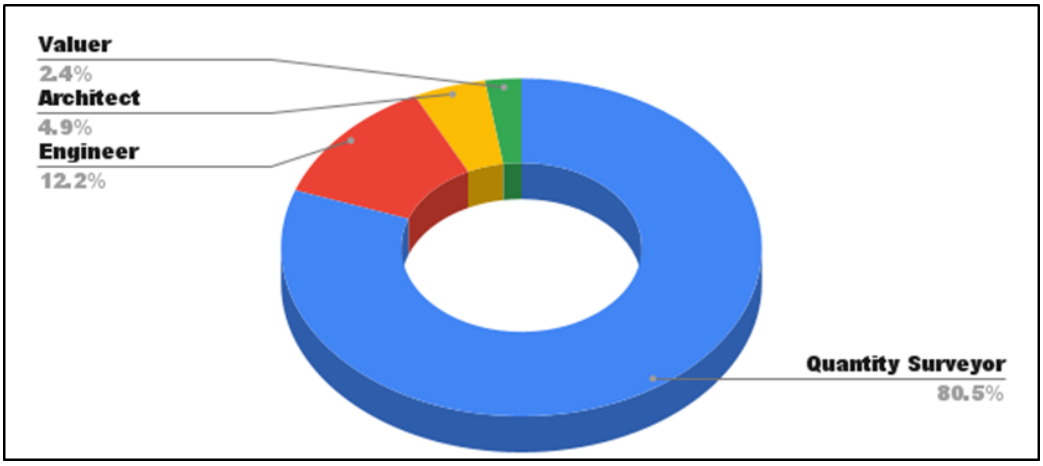

Figure 7: Respondents' opinion about Responsible profession for initiating WLC

Most respondents, 80.5%, selected quantity surveyors as the responsible profession for initiating WLC. On the other hand, 12.2% of the respondents said engineers should take responsibility for initiating WLC, while 4.9% and 2.4% of respondents selected architects and valuers, respectively, as responsible professions for initiating WLC.

Usefulness of implementing WLC in different sectors of projects

The usefulness of implementing WLC in the projects of different sectors in the Sri Lankan construction industry was found using a scale of 1-5, indicating; 1-not useful, 2-slightly useful, 3-moderately useful, 4-useful, 5-very useful. Data were analyzed by calculating RII and ranking from the most useful sector to the least useful sector to implement WLC. Accordingly, Table 4 depicts RII and the ranking of the sectors to implement WLC.

Table 4: RII values and ranks for Sectors to implement WLC

Sector	Usefulness RII	Rank
Private Sector Projects	0.795	1
Other, e.g., projects of NGOs	0.745	2
Public Sector Projects	0.710	3

Table 4 shows that WLC implementation is more useful for private sector projects with the first rank. Secondly, it is useful for other sector projects like projects of NGOs and, thirdly, for public sector projects. However, there is only a slight difference in the RII of all three sectors, with an RII of more than 0.7, indicating that WLC implementation is useful for projects in all sectors in Sri Lanka.

4.4. Benefits and Challenges for Whole Life Costing implementation in the construction industry

The significance of benefits the Si Lankan construction industry could gain from implementing WLC was found by analyzing data. Table 5 illustrates the RII and the ranking of those benefits.

Table 5: Significance of benefits from WLC implementation

Benefit	RII (Relative Importance Index)	Rank
Increasing long-term value	0.690	1
Developing the total cost of ownership	0.685	2

Forecasting the future operating cost of the building	0.680	3
Optimizing the selection of materials, equipment and components	0.681	4
Getting a better understanding of the risks in the early stage of the building	0.665	5
Providing increased certainty and transparency	0.660	6
Appraising the cost performance of design alternatives	0.655	7
Identifying non-construction costs, e.g., site costs, finance costs, and rental costs	0.645	8
Identifying the durability standards	0.640	9
Getting an idea about potential income generations	0.630	10
Increasing economic sustainability	0.620	11
Getting an idea about non-monetary costs and benefits, e.g., social benefits, environmental damages	0.610	12

As per Table 5, the Sri Lankan building construction industry can gain by increasing the long-term value of construction products, which is the most important benefit of WLC implementation. In addition, developing the total cost of ownership, forecasting the future operating cost of the building, optimizing the selection of materials, equipment and components, getting a better understanding of the risks in the early stage of the building, providing increased certainty and transparency and appraising the cost performance of design alternatives can be identified as other significant benefits of WLC implementation having more than 0.65 RII. On the other hand, getting an idea about non-monetary costs and benefits (e.g., social benefits, environmental damages) is considered the least significant benefit of WLC implementation, owing RII of 0,61. However, Table 5 indicates the importance of all the benefits, giving more than 0.6 RII for all the benefits.

In contrast, Table 6 presents the significance of challenges /barriers to implementing and using WLC in the Sri Lankan Construction industry.

Table 6: Significance of challenges for WLC implementation

Challenge/ Barrier	RII (Relative Importance Index)	Rank
Difficulty in identifying includes and excludes calculating WLC	0.675	1
Lack of details at early stages	0.665	2
Lack of awareness of WLC benefits	0.656	3
Lack of understanding of WLC tools	0.655	4
Lack of reliable data	0.654	5
Lack of expertise/knowledge on WLC	0.653	6
Unavailability of a standardized approach	0.630	7
Maintaining databases to obtain data for WLC elements is difficult and expensive	0.620	8
Difficulty in calculations	0.570	9
Lack of client interest	0.535	10

The ranking shows the most impactful challenge to the least impactful challenge. Challenges with more than 0.65 RII can be considered as significantly impactful challenges when implementing WLC in the Sri Lankan construction industry. They are difficulty in identifying includes and excludes calculating WLC, lack of details at early stages, lack of awareness of WLC benefits, lack of understanding of WLC tools, shortage of reliable data and lack of capability/knowledge on WLC. Since all the challenges have an RII of more than 0.5, all challenges can be considered to be impacting the Sri Lankan construction industry when implementing WLC.

5 CONCLUSION

A comprehensive literature review was conducted to understand WLC and LCC concepts clearly. As per literature findings, the WLC concept is used in many countries like the UK, proving the gain of many benefits via WLC implementation. However, even though research studies related to LCC are available in the literature related to the Sri Lankan construction industry, there is a scarcity of research studies about WLC. Therefore, this research study aimed to explore Whole Life Costing awareness and implementation challenges in the Sri Lankan construction industry. Accordingly, a quantitative survey strategy was followed, and data were collected using questionnaires. Due to the time restrictions, the sample was selected using a non-probability convenient sampling method. From the sample of 60 Sri Lankan construction industry professionals, 40 responded to the survey. Findings revealed that Sri Lankan construction industry professionals are unaware of the difference between the WLC and LCC concepts. In addition, they have disregarded the potential income generation and non-monetary costs and benefits are elements of WLC. Further, as per findings, when implementing WLC practices, the client party initiates, and the quantity surveying profession must take the responsibility for initiating as a construction industry professional.

The construction industry of Sri Lanka could mostly get benefits such as increasing the long-term value of construction products, developing the total cost of ownership, forecasting the future operating cost of the building, optimizing the selection of materials, equipment and components, getting a better understanding of the risks in the early stage of the building, providing increased certainty and transparency and appraising the cost performance of design alternatives through WLC implementation.

In order to gain the above advantages through WLC implementation, the identification of challenges is critical. Difficulty in identifying includes and excludes calculating WLC, lack of details at early stages, lack of awareness of WLC benefits, lack of understanding of WLC tools, lack of reliable data and lack of expertise/knowledge on WLC are the main challenges that prevent the implementation of WLC in the Sri Lankan construction industry. These challenges have to be mitigated for the effective implementation of the WLC concept in the Sri Lankan construction industry.

The study can be recommended to enhance awareness of the WLC concept among Sri Lankan construction industry professionals, especially quantity surveyors, via CPDs, seminars, workshops…etc., to take responsibility for practicing WLC in the Sri Lankan construction industry. On the other hand, the identified challenges of WLC implementation must be mitigated as much as possible. Therefore, future research can be conducted to identify strategies to mitigate such challenges.

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Characteristics of Travel Mode Choice of Families with Children Below Five Years Old

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ABSTRACT

Travel mode choices for children under five years old have not been fully explored in past research studies The main objectives of this study were to identify travel characteristics of children aged below five years, travel mode choices for them, and investigate the factors affecting their selection. A survey using a questionnaire was conducted with parents in the Western Province of Sri Lanka to collect data. It revealed that private cars as the most frequent vehicle choice followed by public buses. The Multinomial Logistic Regression analysis identified the age of the child, distance, income, type of vehicle owned, and walking time to the nearest public transport station as the main factors that affect the travel mode choice of children under five years old. Also, the habit of securing the child and the child's familiarity with the use of a car seat when traveling in a private car were identified as factors that affect travel safety. The recommendations were provided to policy makers, parents, and the public in order for children to make safer, comfortable, economical, and sustainable trips.

KEYWORDS: *Travel Mode Choice, Multinomial Logistic Regression Analysis, child travel safety, child travel behavior*

1 INTRODUCTION

Transportation has existed since ancient times and with time, it has evolved in many ways. In the current world, transportation plays a major role in safety, health, economy, and sustainability. Transportation is required for all people regardless of age. This study focuses on children aged 0-5 category. With the increasing population in the world, a large cohort is in the 0-5 age category (McCarthy et al, 2017).

Annually about 1.3 million fatalities are reported because of road traffic crashes and car crashes were identified as the primary cause of death among 4 - to 7-year-old children in the world (Dissanayake and Amarasingha, 2016). World Health Organization (WHO) also points out that road traffic accidents are a leading cause of deaths among children. (WHO, 2022). As shown in Table 1, a higher number of deaths are caused by accidents in Sri Lanka annually and 37% of these victims are between ages 0 to 14 years. (Sri Lanka Police, 2022). According to Census of Population and Housing (2012), Sri Lanka has a 10.28% of the population aged below five years. In Sri Lanka, the mortality rate is 6.93 per 1,000 live births for children below five years (WHO, 2022). Therefore, it is important to investigate this issue and make safer and sustainable transportation systems to fulfill their needs.

Table 1. Accident statistics in Sri Lanka (Source: Sri Lanka Police, 2022).

Year	2013	2014	2015	2016	2017	2018	2019
Total number of accidents	37,877	35,966	38,107	37,591	36,599	35,158	30,433
Number of fatalities	2,362	2,439	2,818	3,017	3,147	3,151	2,839
Number of Injuries	30,023	29,406	32,964	34,574	33,452	32,007	24,611

As children aged 0-5 travel mostly with their parents, accordingly, the travel mode will depend on their parents' opinions and decisions. They mostly travel for their medical needs, education needs, leisure needs, etc. The choice of travel mode of children can be dependent on several factors. At present, one of the most influencing factors for travel mode choice may be the transportation cost. When parents travel with their children, the selection of their vehicles does not depend only on economic factors but also other factors like comfort, safety, travel time, trip distance, etc. At the same time, Cheng et al. (2019) argued families with children under 6 years old have limited the mode choice behavior. Also, travel information of children in the world is not available for reference.

Therefore, it is important to find out the travel characteristics of the children below five years old, the mode choices for them, the factors that affect the travel modes choices for those children, and to investigate the ways to reduce traffic accidents and travel issues. If the countermeasures are identified, the relevant authorities would be able to implement them. This would be helpful to improve the safety, comfort, and sustainability of the transport system of families with children under five years old.

2 LITERATURE REVIEW

Chakrabarti and Joh (2019) discovered that families with young children are associated with a relatively higher selection of cars, and lower use of public transport and active travel such as walking and bicycling. It is important to keep children physically active because active transport is associated with a wide range of health benefits. Dessing, et al. (2014) have done research on active transport between home and school by collecting the data of seventy-nine children of Dutch elementary schools with the help of GPS. The students were required to wear Global Position System receivers for one week to get the distance between home and school; to determine the average and maximum speeds. The results of the study revealed that nearly 80% of the students use active transport that can influence the healthy behavior of children. It has also been identified that with increased distance between home and school, cycling and motorized trips have too been increased. The results suggested guidelines for locating schools related to residences.

By recognizing the factors affecting the travel mode choice among families with young children it may be possible to encourage sustainable travel practices (McCarthy, et al, 2017). The secondary data was used to identify the crucial factors such as structural factors, psychosocial factors, and household characteristics. It has been identified that private cars are an important travel mode when families travel with young children. Parental preferences also affect the travel mode choice of young children. Policy makers can address the issues and encourage other travel modes by developing related infrastructure facilities.

The factors on traffic crashes and the characteristics of child safety restraint, and the effective countermeasures to increase the safety of children on highways were investigated by Dissanayake and Amarasingha (2016). This investigation was done using the crash data from Kansas, USA and the frequencies and percentages of restraint used among children aged 4-13 were tabulated. The connection between the use of restraints with the severity of injuries and the characteristics of children were analyzed by estimating odd ratios. The results of this research revealed that severe injuries can happen when children are seated in front, travelling with drunk drivers, travelling on rural roads, or travelling during nighttime. Also, cases reckless driving, speeding and disturbances on the road may affect the severity of injuries of children. To avoid these incidents in future, the researchers suggested children travelling in the rear seats using size appropriate and age-appropriate child seats. Educating parents and children about safety measures that can be used will also improve the highway safety of children.

Amarasingha and Balasayanthan (2018) studied the travel mode share of people in Jaffna district, Sri Lanka through a questionnaire survey and identified cars as the predominant mode among the urban residents while the motorcycle is the most frequent travel mode among the rural residents. Gunathilaka et al. (2021) investigated mode choices of three provinces in Sri Lanka and found that the most predominant travel mode in the Southern province as the van while in Northern and Eastern provinces, it was the motorcycle. Overall, the highest modal share was from public buses and trains accounting for 44.1%. It was found that personal characteristics and the travel- based characteristics were the most influential characteristics for transport mode selection. However, these studies are focused on adult population do not represent children under five years of age.

Madhuwanthi, et al. (2016) conducted a questionnaire survey to identify the aspects of personal characteristic and the travel-based characteristic for the travel mode choice in Colombo Metropolitan area in Sri Lanka. Income, vehicle ownership, safety and comfort have been identified as the main factors that influence the travel mode choice of individuals over 15 years old. Pathirana and Sirisoma (2022) developed a mode choice model considering commuter trips for the Western province of Sri Lanka using the travel details collected through a travel diary survey from all household members except children aged below five. Amarasingha and Piantanakulchai (2009) developed a mode choice model considering the shopping trips for Palinda Nuwara of Sri Lanka using a household travel survey excluding the children.

The studies on the mode choices of the school students could also be found in the literature. Damsara et al. (2021) did an analysis for mode selection of school students in Colombo, Sri Lanka focusing on children above five years old. Nevelsteen et al. (2012) conducted a questionnaire survey among children aged six to twelve years old in northern Belgium to identify the parental factors for the travel mode choice. The safety of the child is affected by factors such as gender, age, and traffic infrastructure at the child's home or destinations. Shokoohi et al. (2012) investigated the association of parental perception in traffic safety in the neighborhood considering walking to and from school using the data from a cross sectional survey of parents. The survey was conducted in the Netherlands for school children between ages 7 to 12 across 15 different schools to investigate the factors influencing travel satisfaction and travel mood among the children traveling to school. Van den Berg et al. (2020) investigated the factors influencing travel satisfaction and travel mode among the primary school children traveling to school. The data for the research was gathered via a survey from both students and their parents. The survey was conducted in the Netherlands for school children between ages 7 to 12 across 15 different schools. Then the results were characterized, and path analysis was used to estimate the effects of descriptive variables on the dependent variables and their relationships. It was identified that the age of the child, income, perceptions of neighborhood infrastructure and social cohesion are the factors that affect parental safety perceptions on children travelling to school the most. Also, the findings show that factors like sunny days, travelling with a friend, or with the favorite mode of transport will increase the travel satisfaction of the children.

Attitudes and beliefs will contribute considerably to a travel behavior when considering children, as they have less self-regulation skills and lack control over their behaviors (Stark and Hössinger, 2018). Therefore, this study expects to evaluate a travel awareness campaign for the aged. Without relying on earlier methods and to gain more specific details on children, a multi-methodological design is used. The study will test out three different formulations. They are value-based concepts, theory of planned behavior related concept: that is a measuring mode on a one-dimensional scale and content related concept. The data for the survey has been collected via a questionnaire survey. A descriptive analysis was done to several items that were taken from the survey such as Universalism – which focused on environmental aspects, social status and autonomy. Also, a factor analysis and a regression analysis have been done to evaluate the results. It was found that the theory of planned behavior related attitudes triggers intentional travel behaviors but not evidence based and emotional attitudes. The results from all the analyses showed that the one-dimensional theory of planned behavior related attitudes is the most suitable/appropriate predictors for the travel mode choice behavior.

According to the literature review, no research has been done on the travel mode choice of children between age 0 to 5 years in Sri Lanka though similar studies have been done for occupants aged more than 15 years old. Also, a very limited number of studies have been conducted to investigate the issue globally. By conducting a travel mode choice study among the families with children aged 0 to 5, their travel pattern can be identified and that can be used for improvement of safety, health, and sustainability in transportation.

3 METHODOLOGY

3.1 Study Area

The study area for the research was selected as the Western Province, Sri Lanka which is the densest province, in Sri Lanka. Both the commercial capital Colombo and the legislative capital Sri Jayawardenepura Kotte are in this province. The province is divided into three administrative districts which are Colombo, Gampaha, and Kalutara. The province also includes 40 Divisional Secretary's Divisions. Western province has a population of 5,821,710 according to the Census of Population and Housing (2012). The population of children aged 0-5 is identified as 530,477 with data from the survey done in 2011.

3.2 Questionnaire

Data collection for the study was done using a questionnaire survey. The questionnaire consisted of several questions, mainly considering three aspects; the factors affecting the travel mode choice; use

of safety related equipment for children; and the behavior of the child while travelling. The questionnaires were prepared in both Sinhala and English languages.

3.3 Pilot Study

A pilot study was done before the main survey was done for the study. The pilot study is a small-scale trial study that is useful to validate the questionnaire, to identify any mistakes and to ensure the validity of the research process. This also helps to do the main study in a similar manner in a wider scale. About 100 data samples were collected for the pilot study. From those data samples, it was identified that the majority travel in their private car with 33 samples and the motorcycle was the second highest mode used for traveling with 20 samples. Other modes that were used were walking, three-wheeler, bus, taxi car and train. Also, 80% of those who travelled with motorcycle used a helmet for their child and 54.5% who travel with their private car used a child safety car seat for their child. With the data collected for the pilot survey some minor changes were made to the questionnaire survey to collect more reliable, and accurate data.

3.4 Data Collection

The sample size for the study was decided to take from the Solvin's Formula as shown in equation (1) (Madhuwanthi et al., 2016);

$$n = \frac{N}{(1+NE^2)} \quad (1)$$

where: n = sample size, N = population size, and E = error tolerance. The error tolerance was taken as 5% considering a confident interval of 95%. N is taken as the population of children between 0 to 5 years in Western Province which is 530,477. Therefore, for this case, the sample size would be 400 and in this study the sample size was decided through random sampling techniques.

Data on characteristics of the traveler (age, gender, monthly family income, vehicle ownership, etc.); characteristics of the trip (purpose of the trip, travel mode, approximate distance, accessibility public transport); characteristics of the mode (travel time, safety, comfort, cost, flexibility, environmentally friendly); safety measure usage (helmet usage, car seat usage, etc.); and behavior of the child during the travel were collected and tabulated for analysis.

3.5 Multinomial Logistic Regression Analysis

After the data collection, the analysis for the study was done using the Multinomial Logistic Regression Analysis. Logistic regression analysis can be used to explain the relationship between a dependent and an independent variable based on the probabilities, odd ratios etc. This can only be applied when the dependent variable is categorical. In this study the dependent variable is 'travel mode choice' consisting of 8 categories.

There are several assumptions on Multinomial Logistic Regression analysis, and they are verified before conducting the analysis (Peng et al., 2002). The assumptions are:

- The dependent variable is measured at the nominal level
- One or more independent variables exist which are continuous, ordinal or nominal (including dichotomous variables)
- Observations should be independent, and the dependent variable is mutually exclusive and exhaustive categories
- Multicollinearity should be avoided
- The logit transformation of the dependent variable and any continuous independent variables should have a linear relationship
- Outliers should not exist.

In the multinominal logistic regression model, the utility maximization assumes that the means an individual traveler selects the mode which has the maximum utility. The utility that an individual traveler n associates with the alternative mode i in the alternative available mode choice set C_n is given by U_{in} (Including both deterministic V_{in} and uncertainty ε_{in}; $U_{in} = V_{in} + \varepsilon_{in}$). Then an alternative with

the maximum utility is chosen. Therefore, the probability that the alternative mode i is chosen by the traveler n from the choice set C_n is presented in Equation 2 (Ben-Akiva. and Bierlaire, 1999).

$$P_{in} = Porb\,(U_{in} \geq U_{jn} \;\forall\; j \in C_n) \tag{2}$$

The probability of using mode $i\,(P_i)$ based on multinomial logistic model can be expressed as in Equation 3.

$$P_{in} = \frac{e^{U_{in}}}{\sum_{k=1}^{j} e^{u_{ik}}} \tag{3}$$

Equation 4 shows the utility function of mode (i) for a number of independent variables (Ben-Akiva, and Bierlaire, 1999).

$$U_i = C + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_{31} + \cdots + \alpha_a x_a \tag{4}$$

where,
U_i= Utility function of mode i,
C= Constant,
α= coefficient of the attribute, and
x = independent variable.

The coefficient estimation is done using maximum likelihood estimation methods.

4 RESULTS

Table 2 shows descriptive data of the study. A majority of children in the sample were transported by private cars which accounted for 29% ,followed by buses (22%).

Table 2. Descriptive data collected targeting families with children age below five years

Variable	Variable category	Number of responses	Variable	Variable category	Number of responses
Age of the child	Younger than 1	42	Travel Mode	Walking	15
	1 year	50		Motorcycle	65
	2 years	50		Three-wheeler	49
	3 years	70		Bus	88
	4 years	88		Private car	116
	5 years	100		Taxi car	45
Household Monthly Income	Less than Rs 50,000	41		Train	11
	Rs 50,000 - Rs 100,000	143		Other	11
	Rs 100,000 - Rs 150,000	135	Travel purpose Travel purpose	Educational needs	138
	Rs 150,000 - Rs 200,000	49		Healthcare needs	124
Private Car ownership	Yes	242		Leisure needs	101
	No	158		Other	37

4.1 Likelihood Ratio Test

Table 3 represents the likelihood ratio values indicating how the independent variables are significant with the dependent variable. Initially, there were 27 variables for the analysis with child behavioral data. After checking the correlations of the variables, 21 independent variables were used for the analysis. The dependent variable was “Travel Mode”. Several independent variables as shown in Table 3 were significant at 95% significant level. The significant variables were the age of the child, approximate distance to the location, household monthly income, type of vehicle owned, walking time for the nearest public transport station, habit of securing the child in a car seat if travelling in a private

car, and whether the child is familiar with the use of car seat if travelling in a private car. The latter two variables were subcategories of the use of child safety car seat in a private car that signify the safety of the child while travelling. The variables related to travel behavior of children were not significant in the analysis.

Table 3. Likelihood ratio test results

Variables	Chi-Square	P value
Age	295.987	0.000
Purpose of the trip	10.296	.999
Distance	368.315	0.000
Time of travelling	31.818	.061
Safety	21.183	.818
Comfort	12.360	.995
Time consumption	14.840	.980
Easy and flexible	9.909	.999
Environmentally friendly	28.208	.453
Monthly income	652.926	0.000
Vehicle ownership	1.317	.988
Type of vehicle owned	375.382	0.000
Walking time to the nearest public transport station	85.513	0.000
Helmet usage	1.183	.991
Helmets keep your child safer	27.105	.513
Parent has a habit of providing a helmet for the child	8.516	.286
Child is familiar and likes to wear a helmet	9.963	.999
Car seat usage	12.059	.996
Car seat keeps your child safer	32.260	.055
Parent has a habit of securing the child in a car seat	207.891	0.000
Child is familiar and likes to use a car seat	439.912	0.000

4.2 Parameter Estimates

Parameter estimates can be further used to understand the significant factors' effect as it is more descriptive. Here a reference category of the dependent is compared with the other categories of the dependent variable. Also, each of those dependent categories is compared with all the independent variable categories. These results can be used to understand how the factors differ with the reference category. For this study, the reference category has been taken as the "Private Car". As it is the most frequent category available, it will be more effective to compare it with other categories.

Table 4. shows the parameter values only for the significant factors obtained from this study. The coefficients in the table represent the unstandardized regression coefficient of each variable. A coefficient can be of a positive or negative value and can be used to compare the independent categories with the reference category. If it is a positive value, then the dependent variable category has a more choice/significance than the same variable in the reference category whereas if the "B" coefficient is negative the dependent variable category will have a less choice/significance than the same variable in the reference category. This will be more clear from the example described below. Also, the coefficient gives the measure as to how stronger or weaker the choosing of a travel mode is. Some independent variables have been measured on an ordinal scale. Safety and comfortability etc. have been measured on a scale of a five-point scale system as strongly disagree, disagree, neutral, agree and strongly disagree.

Table 4. Parameter Estimates

Travel Mode	Independent variable	Category	coefficient	Sig.
Walking	Distance	Within 1km	2.326	0.049
	Safety	Strongly disagree	-0.582	0.000
	Time consumption	Strongly disagree	0.724	0.000
	Monthly Income	Less than Rs.50,000	2.414	0.033
	Car seat keeps the child safer	Neutral	-1.375	0.020

	Parent has a habit of securing the child in a car seat	Strongly disagree	0.413	0.027
Motorcycle	Purpose of the trip	Educational needs	-1.384	0.021
		Medical/healthcare needs	-.0.861	0.004
	Safety	Strongly Disagree	-0.011	0.000
Three-wheeler	Distance	Between 5-10km	0.784	0.016
	Comfort	Neutral	-1.679	0.040
	Monthly Income	Between Rs.50,000-100,000	1.765	0.060
Bus	Easy and flexible	Strongly disagree	2.641	0.023
	Monthly Income	Less than Rs.50,000	1.726	0.043
	Vehicle Ownership	No	1.857	0.009
Taxi Car	Comfort	Disagree	-1.088	0.015
	Environmentally friendly	Agree	0.799	0.021
	Monthly Income	Between Rs.150,000-200,000	2.476	0.022
	Parent has a habit of securing the child in a car seat	Strongly disagree	1.468	0.008
Train	Distance	Within 1-5km	-0.666	0.018
	Time of travelling	Afternoon	1.290	0.016
	Comfort	Disagree	0.323	0.033
Other	Distance	Within 1-5km	0.331	0.014
	Vehicle Ownership	Yes	-1.843	0.016

Considering the travel mode of "Walking" as shown in Table 2, there have been six sub-categories that have been significant against the reference category. In the first sub-category, if the distance of the journey is within 1km, there is a 2.326 odd chance of choosing the travel mode walking than the private car. If a user does "Strongly disagree" on safety at all when choosing a travel mode, it has 0.582 odd times less chance of choosing walking than the private car. But there is a 0.724 odd chance of choosing walking if a user does "Strongly disagree" on the time consumed when choosing the travel mode. Also, if the monthly income of the family is less than Rs 50,000 it is 2.414 odd chance of more users choosing walking as the travel mode over the private car. If a parent has a "Neutral" status on the "Car seat keeps the child safer" variable there is 1.375 times lesser chance that the user will choose walking over the private car. And if the user has a "Strongly disagree" opinion on the "Parent has a habit of securing the child in a car seat" there is a 0.413 times more chance of choosing walking as a travel mode than the private car. For the other categories in the travel mode choice, the variables can be compared with the reference category as same as the first category. This will give a more descriptive analysis of how each category of the independent variables would affect the travel mode choice.

4.3 Usage of Safety Equipment

In this study, the usage of safety gear for children under five was also identified. Specifically, the usage of safety helmets while travelling on motorcycles and the usage of child safety car seat in private vehicles are identified with the aid of the questionnaire survey. Some factors for using the safety gear from both the child's and the parent's perspective were obtained. The usage of safety equipment and factors used to determine them would affect traffic safety.

In Figure 1 and Figure 2, the percentages of usage of safety helmets and child safety car seat are shown. About 16.25% of participants were motorcycle users. Among them, 76% of motorcyclists used a safety helmet while travelling with a child aged below five. However, 24% of motorcyclists did not use a helmet for their child while travelling. Out of the 29% of private car users of the participants of this study, only 52% users placed their child in a safety car seat while travelling with a child aged below five while 48% of users did not place their child in a safety car seat while travelling.

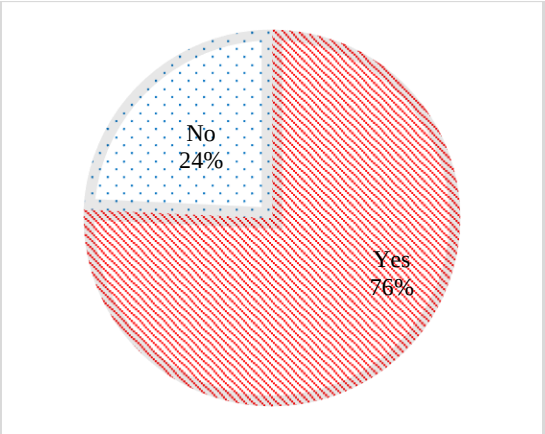

Figure 1. Safety helmet usage of motorcyclists

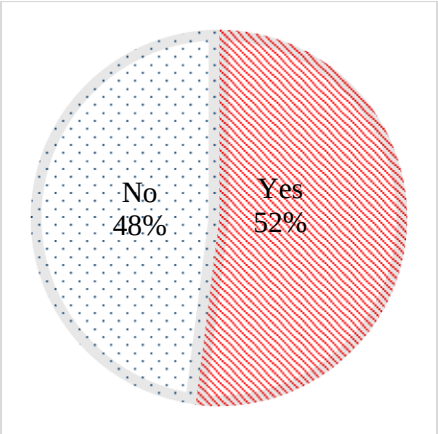

Figure 2. Car seat usage of private car users

4.4 Child Behavior While Travelling

One of the objectives of the study was to identify the travel behavior of children while travelling. For this purpose, there were several questions included in the questionnaire related to travel behavior.. Figure 3 shows the results obtained through the questionnaire.

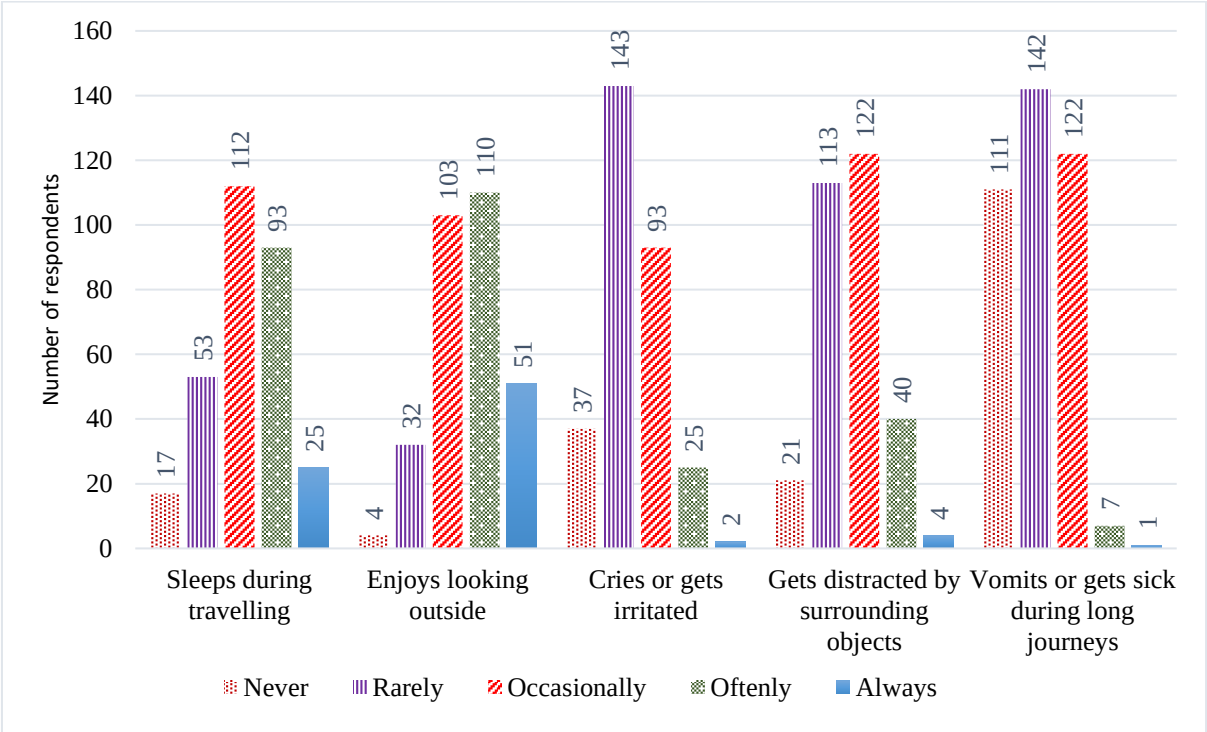

Figure 3. Child behaviour frequency while travelling

5 DISCUSSION

The main objective of this research is to identify the factors that would affect the travel mode choice of families with children aged 0 to 5 years. The most significant factors as per the Likelihood ratio test in Table 2 for the travel mode choice were obtained. They were the age of the child, approximate distance to the location, household monthly income, type of vehicle owned, walking time to the nearest public transport station, habit of securing the child in a car seat if travelling in a private car and the child's familiarity with the use of a car seat if travelling in a private car.

When considering the variable "age," there were six categories representing the ages below five. This can be significant due to several reasons. When the child is very young, such as younger than 1 or within 1-year, parents care more about the child's safety and health. Therefore, parents tend to take

safer, secure, comfortable and less time-consuming travel modes. For example, parents who usually travel by bus may tend to travel in three-wheelers or taxis. Parents with motorcycles also tend to take a different travel mode that is safer and more comfortable. But when the children grow older, parents may travel in their usual travel mode. Parents with private vehicles except motorcycles may travel in the same mode as the safety and comfort is higher.

Another significant factor in the travel mode choice is the approximate distance to the location. This factor can affect the choice of travel mode in several ways. Especially, when considering current economic conditions and fuel crisis, people tend to travel in public transport modes for long distances even though they own a private vehicle. People who do not own vehicles can take different modes depending on the distance. For example, for destinations within 5 km they could take a three-wheeler or a taxi and for destinations more than 10km, they could take a bus or trains as the cost of a three-wheeler/taxi prices are way higher than the bus or trains. The comfort of the travel modes can also be a factor in this as some parents consider higher comfort when travelling longer distances with children, especially parents with motorcycles.

Household monthly income is another factor that is significant in travel mode choice with children under five years. Income was divided into five categories in the model. Income will be directly proportional to the cost of travelling, which most people consider. It is significant as parents consider the cost of travelling if there are no other factors to be considered by the parents whereas the low-income parents will tend to travel in travel modes with low costs and higher income parents would not consider cost a significant factor when choosing a travel mode when travelling with children.

The type of vehicle owned has also been significant on the model. This variable could also affect in different ways when travelling with a child aged below five years. There were five categories such as motorcycle, three-wheeler, car, van, and others in the model. Some parents may have a vehicle that is not appropriate for family travelling. Also, the vehicle type could also affect the choice. When travelling with a young child, parents may consider taking more comfortable and safe travel modes. These reasons could affect the parents when choosing a travel mode. Families with cars and vans will mostly go in their own vehicles with children. However, it could also depend on the availability of the vehicle.

Walking time to the nearest public transport station is also another significant factor in the model. This factor will not be very applicable to parents with private vehicles as they mostly travel in their own vehicle. But it could also vary as in the previous vehicle ownership factor. When a family lives near a public transport station such as a bus or railway station they tend to travel using that mode. But if the distance is too far to walk, parents will choose another method such as three-wheelers or taxis. They could even split the trip into two different modes. For example, one transport mode from home to the nearest public transport station and from there another transport mode. Therefore, it is clear that the walking time to the nearest public transport station is another significant factor when choosing a travel mode for children.

The other two remaining factors that the model represents are the habit of securing the child in a car seat and the child's familiarity and likelihood of using a car seat that concerns the safety while travelling with children. These factors only affect families with private cars as child safety car seats are only possible to be used with private cars. With the samples, a majority of 29% car users placed their child in a car seat. Even though there is a car seat in their vehicle, the usage of it depends on factors, such asparents' habit, and child's familiarity/likelihood/preference?. This is a safety concern while travelling with children aged 0-5 years.

Compared with other studies, with an analysis carried out with data from several databases (McCarthy, et al, 2017), identified that structural factors such as quality of cycling, pedestrian and public transport infrastructure have had an impact on the travel mode. But this will not be much applicable to the Sri Lankan scenario because these infrastructures are not available, or they are not in good condition. Therefore, these factors were not tested in this analysis. Increasing travel distance has also been determined as a factor that impacts the travel mode choice mainly with taxis and private cars. Similarly, this study also identified distance to the location as a significant factor. Also, household income, characteristics related to children such as age, child related safety equipment such as car seat usage are several other factors that are similar to the results in this study. In addition, the number of dependent children, cost of transport, child's physical capabilities are some other factors (McCarthy, et al, 2017) that have not been identified as significant in this study.

A study done in Netherlands (Van den Berg et al, 2020) with children between 7 to 12 years identified age of the child, income, perceptions of neighborhood infrastructure and social cohesion as the most influential factors in children's travelling mode choices. The survey was done with both parents and children there. There are similar factors in this study such as age and income of the child's family. However, neighborhood infrastructure does not apply to the Sri Lankan context and social cohesion is not valid for children aged 0 to 5 years.

When considering studies done in Sri Lanka by Gunathilake et al. (2021), Pathirana and Sirisoma (2022), Amarasingha and Piantanakulchai (2009), Damsara et al. (2021), Madduwanthi, et al, (2016), they were done for persons more than five years old. Therefore, it is not realistic to compare this study with the above mentioned studies.. Nevertheless, , income, vehicle ownership, safety and comfort have been identified as the main considerable factors that influence the travel mode choice from the previous studies as well. Therefore, all the factors here are almost identical to the findings of this study. Vehicle ownership can be paralleled with the types of vehicles owned and safety can be considered as the use of car seat even though there is an age limit in the study, the factors are nearly the same.

There are some other studies that have identified that parents will determine their travel mode choice based on the traffic infrastructure and accidents (Nevelsteen, et al, 2012). The traffic infrastructure condition will not be considered in the Sri Lankan context and many Sri Lankan parents do not pay much attention to accidents when the travel mode choice is made. .

When looking at the safety equipment used for children, most of the motorcycle users use helmets for their children. But when compared with age, there is a higher percentage of children under one year who are not wearing helmets. When considering the usage of child safety car seats, it is very low. Only 52% use helmets for their children. In this case, the rate of casualty will be high if there is an accident. Using size appropriate and age-appropriate seat belts, children travelling in the rear seats, and educating parents and children with safety measures will be more effective measures to increase child safety (Dissanayake and Amarasingha, 2016). Also, with infrastructure developments (Nevelsteen, et al, 2012) safety of travelling can be improved.

Child behavior is also a factor that parents would consider. Common behaviors of children were also identified in the study. Theory of planned behavior related attitudes trigger intentional travel behaviors but not evidence based and emotional attitudes of children (Stark and Hössinger, 2018). Also, travel satisfaction is one of the indicators (Van den Berg, et al, 2020) of the trip's contribution to the subjective wellbeing of the traveler. Therefore, a child's behavior is also an important factor in travelling mode choice.

6 CONCLUSIONS

This study was done with the main objective of finding the factors affecting the travel mode choices of families with children aged below five years. Also, the study was focused on the safety and travel behavior of children while travelling. The data for the study was collected via questionnaire surveys for 400 samples from the Western Province of Sri Lanka. The study covered all the travel modes used to travel within the country. Before conducting the main survey, a pilot survey was conducted with 100 samples to validate the questionnaire. The analysis of the study was done using the Multinomial Logistical regression analysis. Before the analysis the assumptions for the model were checked and verified. The dependent variable for the study was taken as the "travel mode choice" and initially 27 independent variables were used for the analysis. Using the Likelihood ratio test in the outputs, the significant factors of the model were identified. They were age of the child, approximate distance to the location, household monthly income, type of vehicle owned, walking time to the nearest public transport station, habit of securing the child in a car seat if travelling in a private car and the child's familiarity with the use of car seats if travelling in a private car. The parameter estimates how each category of independent variable is affected on the reference category that was observed. Also, a comparison on child safety equipment and child travel behavior was made.

The obtained results were justified with similar research identifying the major concerns. Finally, the recommendations were provided to policy makers, relevant authorities, and parents for making the transportation sector safer, comfortable, economical, and sustainable.

6.1 Recommendations

Findings of this study can be used by the policy makers to make informed decisions on the transportation sector that will enhance the safety, comfort, economics , sustainability and the overall quality of transportation including travelling. Also, the legal terms can be updated in support of these conditions. Relevant authorities such as vehicle manufacturers, accessory providers etc. should also consider these aspects. Also, if any changes can be made to the safety gear such as making age-appropriate seat belts and helmets. Parents should consider the above factors while travelling with children. Parents can be advised/educated with some information regarding these concerns by experts in this field.

In addition, these findings can be used for future studies. This research was conducted to get an initial understanding of the factors that could affect the travel mode choices of parents with children aged 0-5 years. Subsequently, this research can be improved with wide categories such as how the transportation system can be improved to make the children travel safer and more comfortably, specially school children. Also, the research could be improved with larger samples sizes, collecting more detailed information etc.

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A Case Study of Assessing the Accuracy of Secondary Consolidation Prediction Using Qualitative Approach

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ABSTRACT

Infrastructure constructed, especially over soft organic soil layers, can be subjected to excessive settlement within its life cycle due to the complex behaviour of the soft soil with time. However, with necessary actions prior to construction, the impacts from such soil layers can be mitigated to some extent. The case under consideration is a leisure resort in Matara, a 15-storey hotel resting on a raft foundation near the southern coastal line of Sri Lanka. With time, some cracks have formed within the building, and an investigation was done to identify the cause for the crack formation. It has been determined that cracks have appeared due to the excessive settlement of the subsurface. Furthermore, ground investigation results suggest that a peat layer is beneath the building within a depth of 15-24m. As per the survey report on the settlement of the building, secondary consolidation of the soft soil significantly impacts the excessive settlement. Therefore, three methods were used to predict the secondary consolidation settlement of the peat layer beneath the building. The methods are prediction using empirical correlations, laboratory experiment results that will follow the constant coefficient of secondary consolidation throughout time and the qualitative method, which assumes that the secondary consolidation coefficient varies with time. Based on the above techniques, predictions were made, and results suggest that the qualitative method has a significant accuracy compared to the actual settlements of the building. These observations provide some proof that the coefficient of secondary consolidation varies with time according to the qualitative approach and does not remain constant throughout the lifespan of the building as suggested by conventional methods.

KEYWORDS: *Coefficient of secondary consolidation, Crack formation, Settlement, Soft soil, Time-dependent settlement*

1 INTRODUCTION

Organic soil is an important soil type formed by the accumulation of partially or fully decomposed organic matter, such as animal and plant residues. Generally, organic soils have a high amount of moisture contents, high compressibility, and a high rate of creep behaviour properties that result in catastrophic settlements due to increased stresses compared to the other types of soils.

The secondary consolidation settlement is defined as the increase of the settlement due to the reorientation of soil particles under constant effective stress. The primary and secondary consolidation settlements could take place at the same time, but for convenience, it is assumed that only after the completion of the primary consolidation settlement the secondary consolidation settlement begins. Even though the secondary settlement is approximately negligible for sandy and gravel soils, according to Mesri et al. (1997), secondary consolidation settlement is significant for organic soils.

The building under consideration is a 15-storey building constructed on a raft foundation near Weligama in 2012. The building was built with a beach frontage of 115m and a frontage of 100m to Galle Road. The construction is located closer to the coastal area and surrounded by the Polwatta river, as shown in Figure 1.

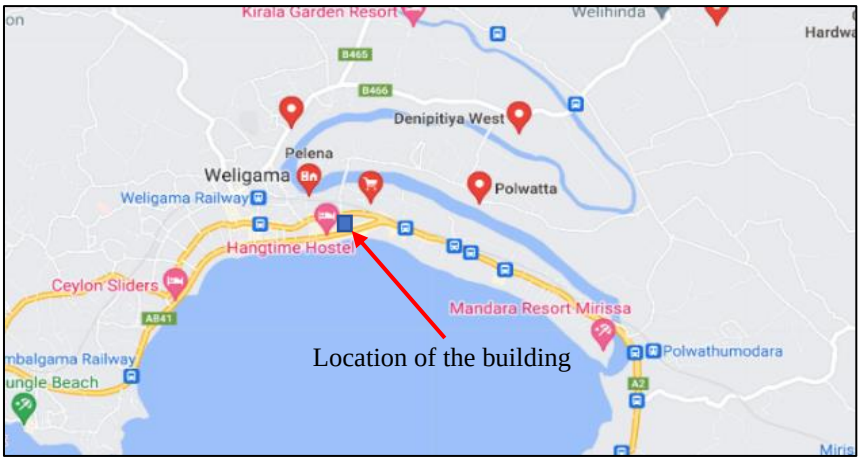

Figure 1. Location of the Leisure Resort

In 2020, significant cracks appeared on the building, eight years after the commenced date. An investigation was conducted to determine why the cracks appeared, and it has been identified that cracks have appeared due to the excessive settlements of the subsurface. During the investigation, the settlement and crack propagation magnitude was measured by establishing serval survey points along each level of the building, as shown in Figure 2.

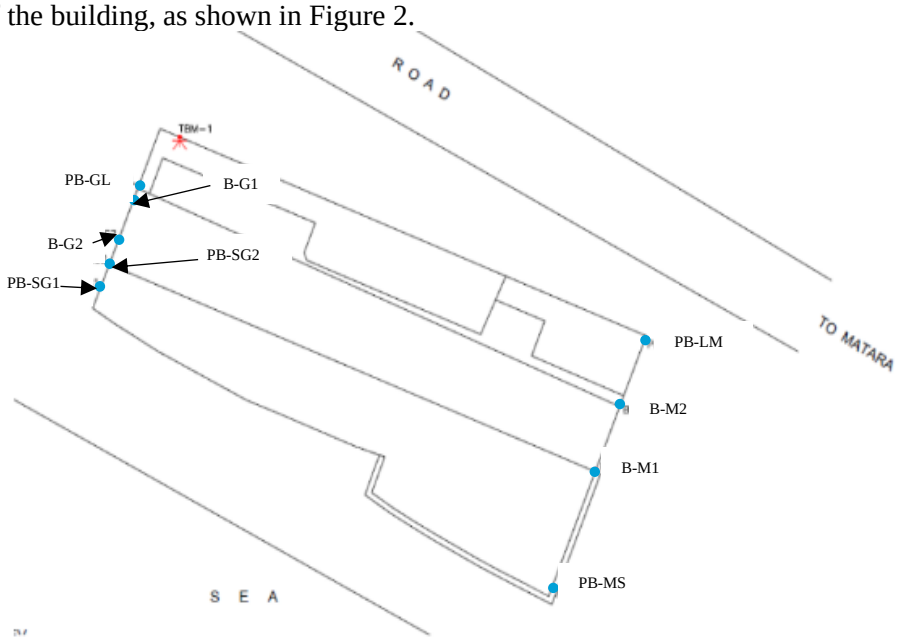

Figure 2. Survey points located at the Ground/Basement level

The survey results show that the building has settled differentially from the sides of the building within a 2-year time. Observed results suggest that the excessive settlement of the building may be due to the secondary consolidation of the cohesive organic soil at its normally consolidated stage underneath the foundation at 15-24m depth below the foundation. Therefore, it tends to settle under the secondary consolidation of soft soil. Even though the conventional method assumed that the coefficient of secondary consolidation under the normally consolidated stage remains constant and does not vary with time, the actual settlements show a progressive increase, and it suggests that C_α varies with time.

The Time-dependent secondary consolidation under the over-consolidate stage was analyzed by Mesri et al. (1997) with the help of special consolidation laboratory test results on a peat sample of Middleton. Observations from the laboratory tests suggest that soft soil (Organic soils) tends to undergo secondary consolidation under the over-consolidated stage with time due to the presence of organic matter. The obtained results of Mesri et al. (1997) were further verified by Ajlouni et al. (2001) on a

peat sample of James Bay peat and inorganic clay samples. In both cases, the C''_α / C_α ratio increases with the time ratio; however, the pattern is different for Middleton and James Bay peat. In Middleton peat, the C''_α / C_α ratio increased with time and slowly reduced. However, in James Bay peat, a gradually increasing trend over time is shown in Figure 3.

Colombo Katunayake Expressway is an example of construction built over an organic soil layer under the soil's over-consolidate state. The consolidation tests done on the organic soil of the CKE project suggest that time-dependent secondary consolidation will occur under the over-consolidated stage. It means with time, organic soil will settle according to the variation of the secondary compression index under the over-consolidate stage.

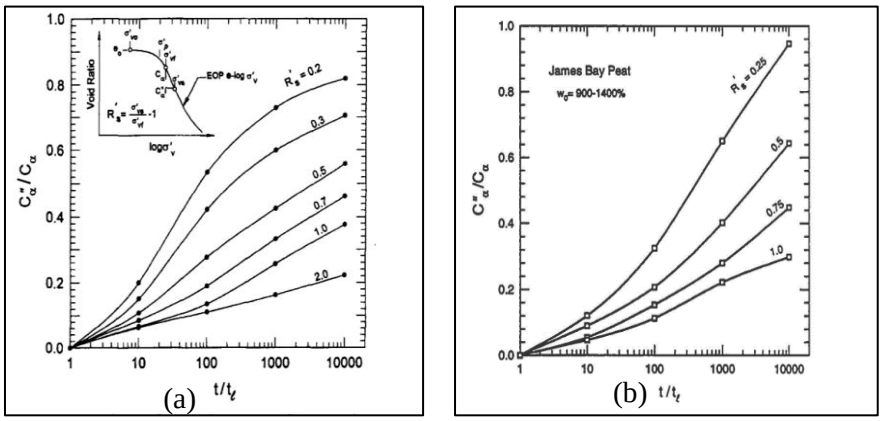

Figure 3. C''_α / C_α variation with t/t_l (a) Middleton Peat and (b) James Bay Peat

However, the progressive settlement of the leisure resort in Matara suggests that the normally consolidated organic soil underneath might also be experiencing a similar type of variation in the coefficient of secondary consolidation. Therefore, it is speculated that the above behaviour of over-consolidated soft soil is also applicable to the normally consolidated soil. Parallel to the survey on settlement monitoring of the building, a ground investigation work was done on 6 boreholes near the corners of the existing building as shown in Figure 4, to investigate the soil profile beneath the building and to identify the root cause for the excessive settlement.

Figure 4. Boreholes for the Ground investigation

In this study, the actual settlement of the building will be compared with the predicted settlement of the underlying soft soil layer in two main approaches; (1) considering the coefficient of secondary consolidation (C_α) is constant throughout the time and (2) considering C_α varies with the time by utilizing the laboratory test results and previous literature. Under the two approaches, three methods have been used; (1) Prediction using empirical correlations, (2) Prediction using laboratory experiments (3) Qualitative method.

2 METHODOLOGY

The coefficient of secondary consolidation should be determined prior to the prediction of secondary consolidation settlement of soft soil. The following sections explain the different methods followed in determining the coefficient of secondary consolidation.

2.1 Coefficient of secondary consolidation is constant throughout the time

- C_α predicted using empirical correlation,

  Under this method, the empirical correlation proposed by Vidurapriya et al. (2021) on C_α/C_c for Sri Lankan peats in the southern part was used to obtain the C_α parameter to predict the secondary consolidation settlement using the following equation 1.

$$S_S = \frac{C_\alpha}{1+e_0} HxLog(\frac{t}{t_p}) \quad (1)$$

$$C_\alpha = 0.0331C_c \quad (2)$$

  Where S_s – Secondary consolidation settlement, H – Thickness of the peat layer, C_α – Coefficient of secondary consolidation under the normally consolidated stage, t – time considered after completion of primary consolidation, t_p – time of completion of primary consolidation, e_0 – Initial void ratio and C_c – Compression index.

- Constant C_α obtained using laboratory experiments,

  Laboratory experiments were conducted on undisturbed organic soil samples that have low organic content extracted from the ground investigation beneath the building. Special consolidation tests were carried out on these samples to investigate secondary consolidation behaviour. The obtained C_α is shown in Table 3 under section 3.1.

2.2 Coefficient of secondary consolidation varies with the Time

According to the observed settlement variation of the building, the actual settlement is increasing rapidly with time, as shown in Figure 5. It suggests that the coefficient of the secondary consolidation does not remain constant with the elapsed time, and it should vary with the time to obtain a rapidly increasing settlement. According to the obtained results from the laboratory tests conducted on undisturbed samples beneath the building, under the over-consolidated state of organic soil, the coefficient of modified secondary consolidation (C'_α) varies with time, as shown in Figure 6. Modified secondary consolidation of organic soil refers to the secondary consolidation that occurs at a reduced rate due to over-consolidation. Therefore, to compare the actual settlement with the predicted settlement, it was assumed that C_α under the normally consolidated state also varies with the time analogues to the over-consolidated state. This method is further explained in section 2.4 and graphically shown in Figure 9.

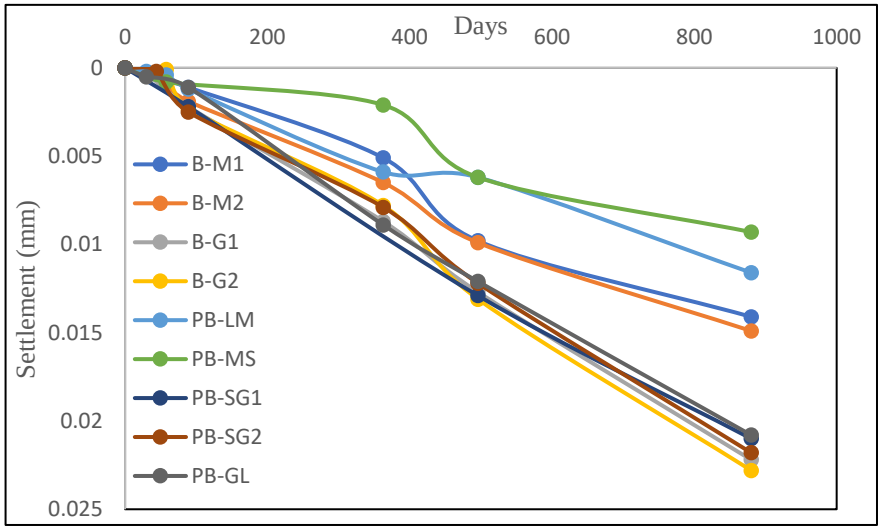

Figure 5. Settlement variation at the ground level of the building

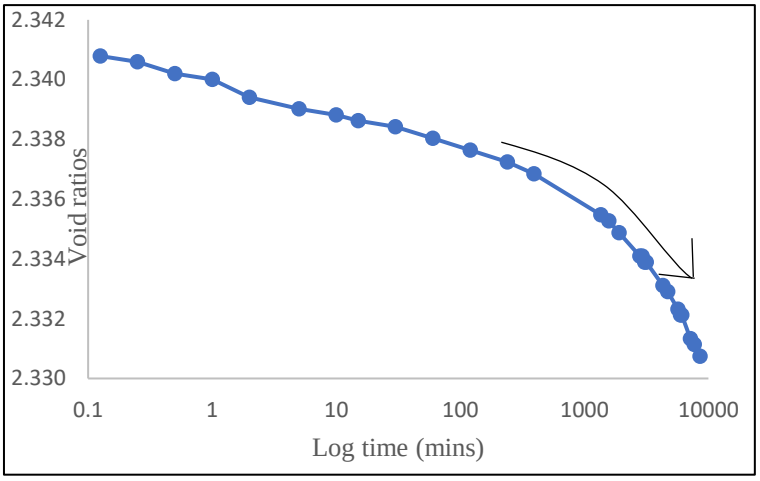

Figure 6. C'_{α} variation with time under the over-consolidated stage

2.3 Available data

According to the survey conducted on the investigation of cracks appearing in the building, following data was obtained.

- Settlement readings of survey points established along the sides of the building
- Ground investigation data (Subsurface profile) and laboratory test results

Based on the above data, settlement readings of the ground floor level of the building were considered for the convenience of comparison with the predicted settlement readings. The selected ground-floor survey points of the building are shown in Figure 7.

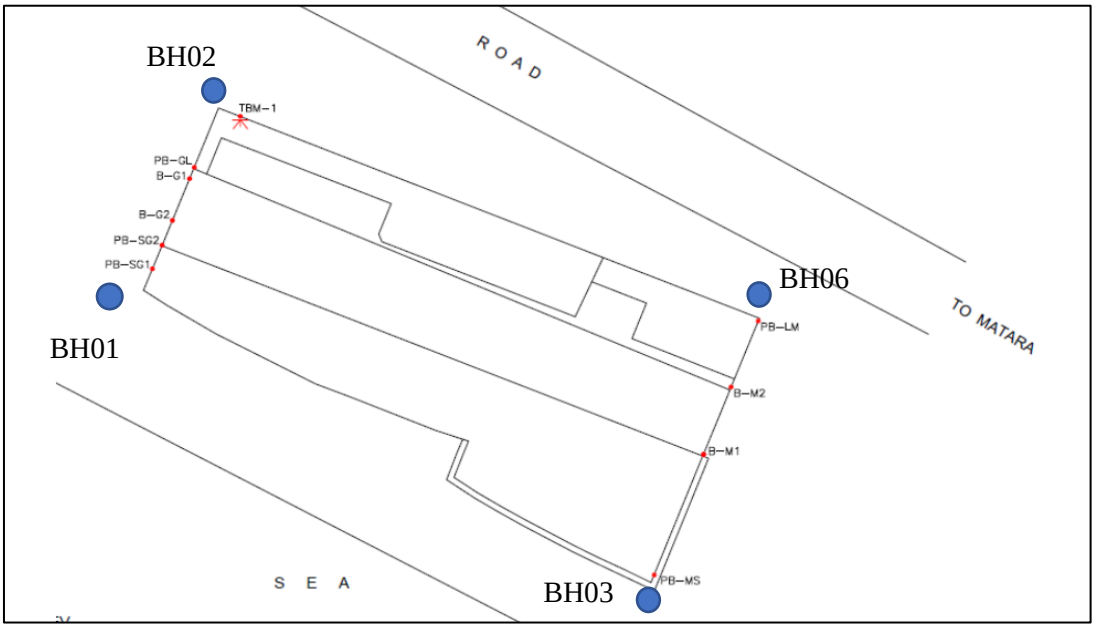

Figure 7. Survey points at the ground level of the building and subsequent boreholes

As the settlement monitoring was done along the edge of the left and right sides of the building, a cross-sectional soil profile was drawn, as shown in Figure 8, using the borehole data to get an approximate layer thickness at the settlement monitoring points, as shown in Table 2. Due to the spread-out survey points of the building, borehole data was assigned to the survey points based on the distance to the borehole location to obtain the average void ratios and C_c values.

- PB-GL, B-G1, B-G2, PB-SG2, PB-SG1 = BH01 & BH02 (Left side of the building from seaside view)

- PB-LM, B-M2, B-M1, PB-MS = BH03 & BH06 (Right side of the building from seaside view)

Obtained void ratios and C_c values for each borehole above mentioned as follows in Table 1,

Table 1. Void ratios and C_c values for the respective boreholes

Borehole	e_0	C_c
BH01	1.996	0.585
BH02	2.237	0.970
BH03	1.713	0.564
BH06	1.674	0.686

Table 2. Layer thickness, average void ratios and C_c values for the survey points

Settlement location	Thickness of the peat layer (m)	Average Void ratios	Average C_c
PB-SG1	6.5	2.117	0.778
PB-SG2	6	2.117	0.778
B-G2	6	2.117	0.778
B-G1	6.5	2.117	0.778
PB-GL	7	2.117	0.778
PB-MS	4	1.694	0.625
B-M1	3.5	1.694	0.625
B-M2	3.5	1.694	0.625
PB-LM	3	1.694	0.625

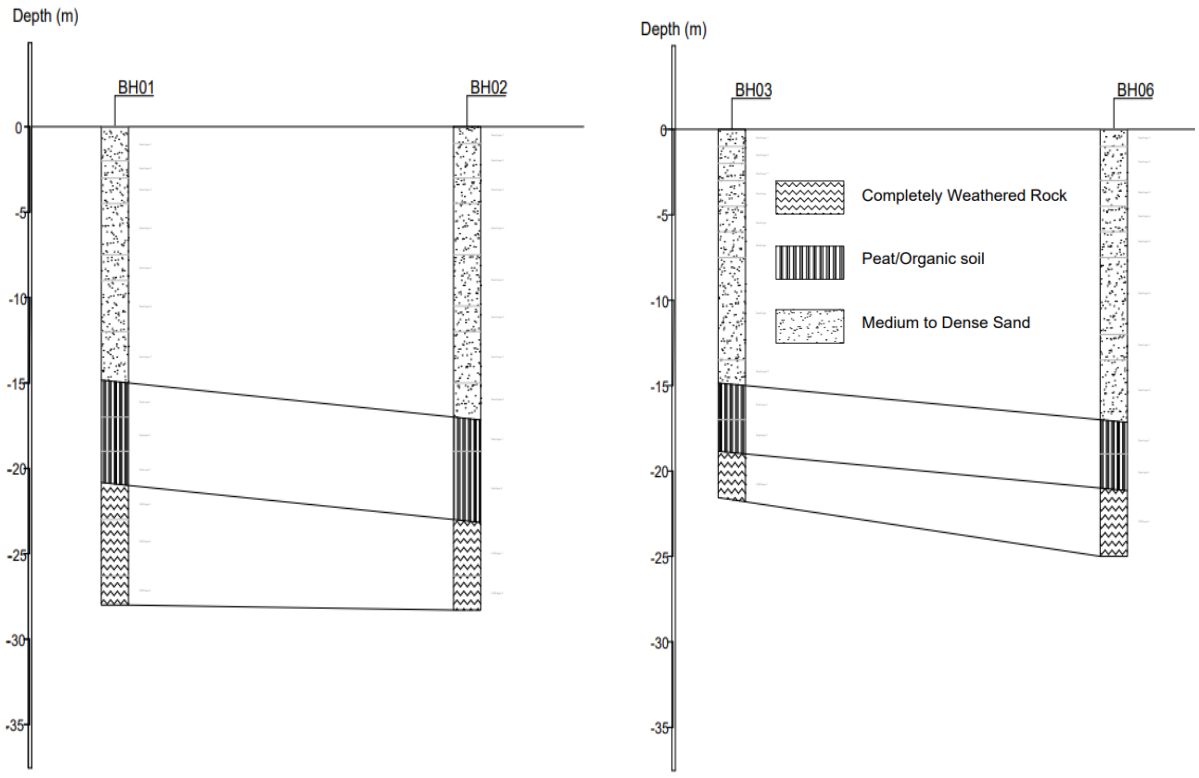

Figure 8. Cross-section profile of the subsurface beneath the Leisure Resort

2.4 Prediction of Secondary Consolidation

Prediction of the settlement at the survey points was carried out as follows,

- C_α constant,
  - Based on laboratory experiments

According to the results obtained through the laboratory experiments mentioned in Table 2. average void ratios and C_α values were considered, and based on equation 1, secondary consolidation was predicted. The following assumptions were made in the prediction of the secondary consolidation settlement.

- Leisure resort construction was commenced in 2012
- Leisure resort construction completion in 2014/06/24
- Assumed that secondary consolidation was appearing in 2014
- Therefore, the End of primary consolidation is 730 days (t_p)

  - Based on the findings of Vidurapriya et al. (2021) on C_α/C_c for Sri Lankan peats

According to the average C_c values mentioned in Table 2 C_α values were obtained with respect to the relationship of C_α/C_c = 0.0331. Based on the data mentioned in Table 2, secondary consolidation was predicted using Equation 1.

- C_α varies with the time,
  - Based on qualitative measures of the laboratory results

As discussed in section 2.2, a graph was plotted considering the time ratios and $C_{\alpha m}$ ratios as shown in Figure 9, based on the settlement observations from the special consolidation test results on undisturbed peat samples under the over-consolidated stage.

- Time ratios = $\frac{t_{(n+1)}}{t_n}, \frac{t_{(n+2)}}{t_n}, \frac{t_{(n+3)}}{t_n} \ldots\ldots$
- $C_{\alpha m}$ ratios = $\frac{C_{\alpha m(n+1)}}{C_{\alpha m(n)}}, \frac{C_{\alpha m(n+2)}}{C_{\alpha m(n)}}, \frac{C_{\alpha m(n+3)}}{C_{\alpha m(n)}} \ldots\ldots$

Where t_n = Time considered as a reference value after EOP, t_{n+1},t_{n+2} = time considered after t_n, $C_{\alpha m(n)}$ = Secondary compression index under over-consolidate stage at Time t_n and $C_{\alpha m(n+1)}$, $C_{\alpha m(n+2)}$ = Secondary compression index under over-consolidate stage at time t_{n+1}, t_{n+2}

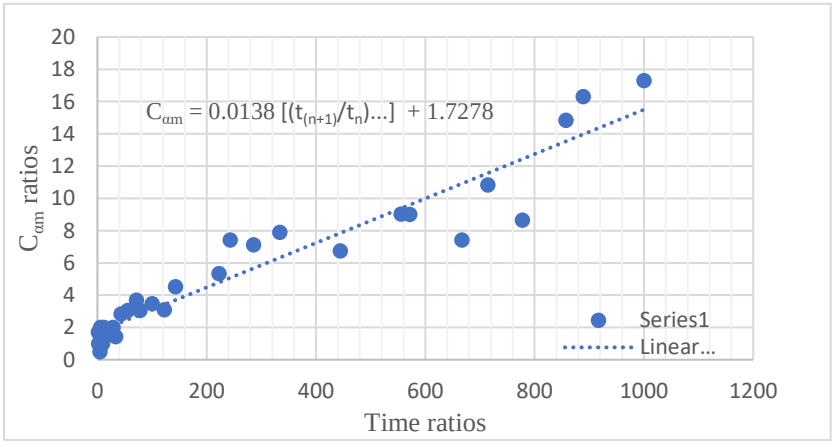

Figure 9. $C_{\alpha m}$ ratio versus time ratio

Based on the above-obtained equation for the plotted graph, C_α values were obtained and by using Equation 1 and data from Table 2. secondary consolidation was predicted.

3 RESULTS AND DISCUSSION

3.1 Organic content of the soil samples and estimated Cα

The following table represents the organic contents and estimated C_α with the help of laboratory experiments under the constant C_α throughout the time.

Table 3. Void ratios and C_α for the tests conducted on undisturbed samples of the leisure resort

Sample No	Organic Content (%)	e_0	C_α
A	27.2	3.927	0.055
B	27.2	3.925	0.056
C	7.2	2.661	0.051
D	5.3	2.36	-
F	8.0	2.316	0.052
Average C_α			0.0535

3.2 Comparison of prediction of secondary consolidation with actual settlement

The comparison of secondary consolidation settlement for the settlement monitoring period is given in a graphical format in figures 10-14.

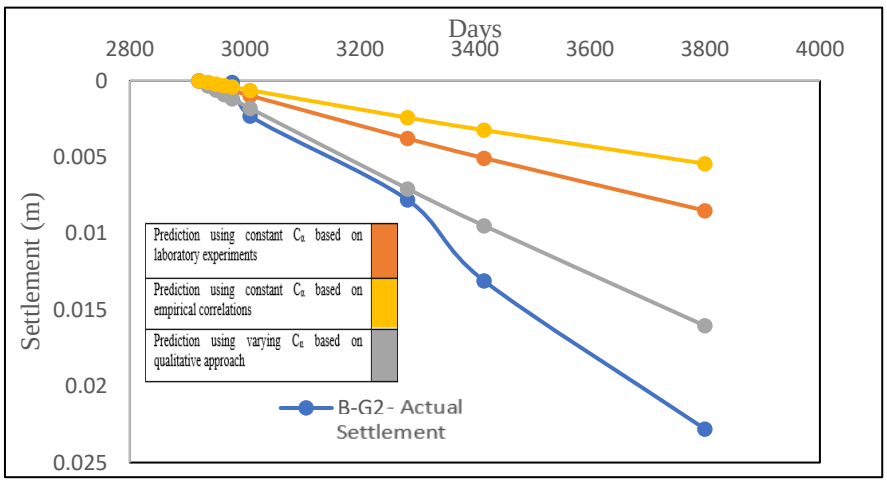

Figure 10. Settlement Compariosn at B-G2

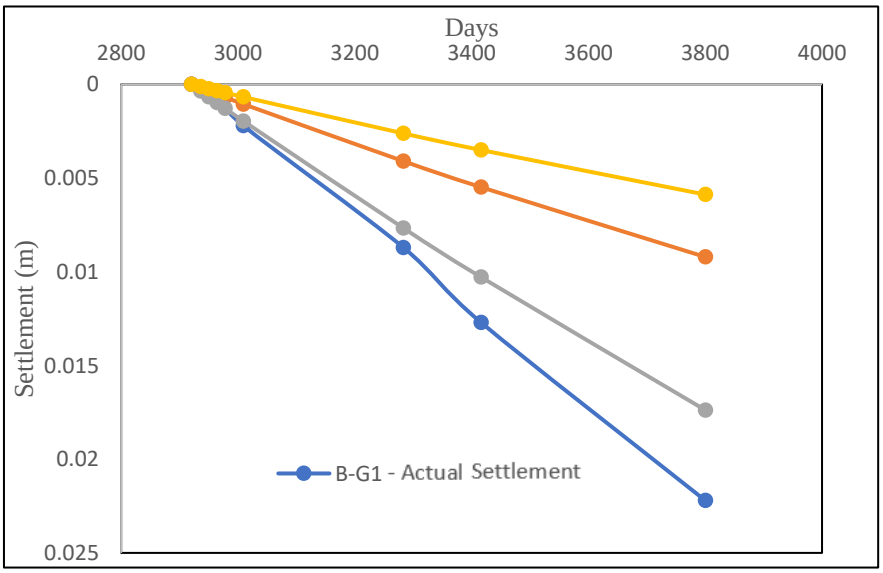

Figure 11. Settlment Comparison at B-G1

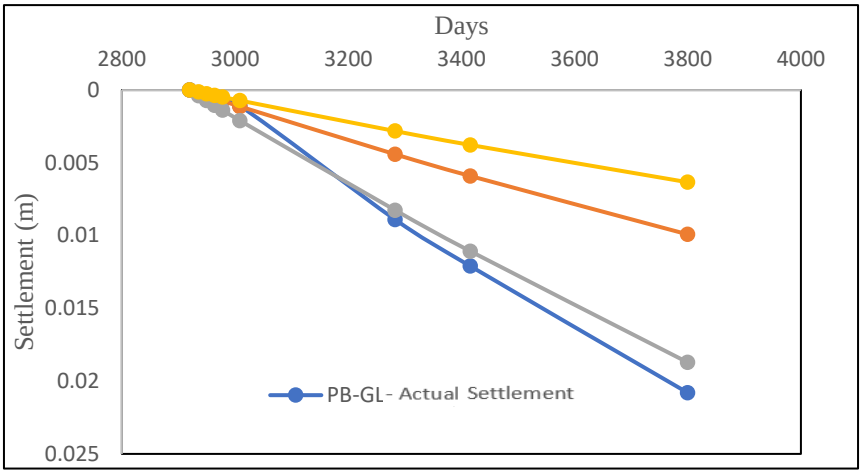

Figure 12. Settlement Comparison at PB-GL

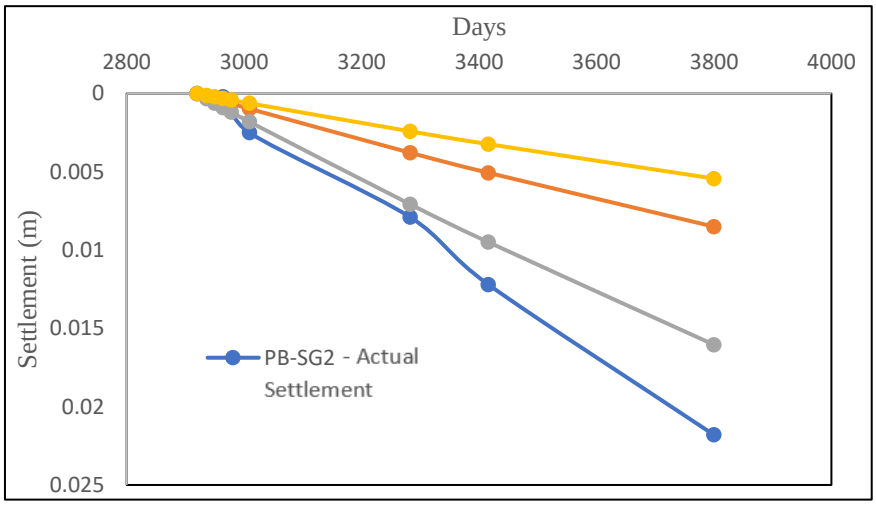

Figure 13. Settlement Comparison at PB-SG2

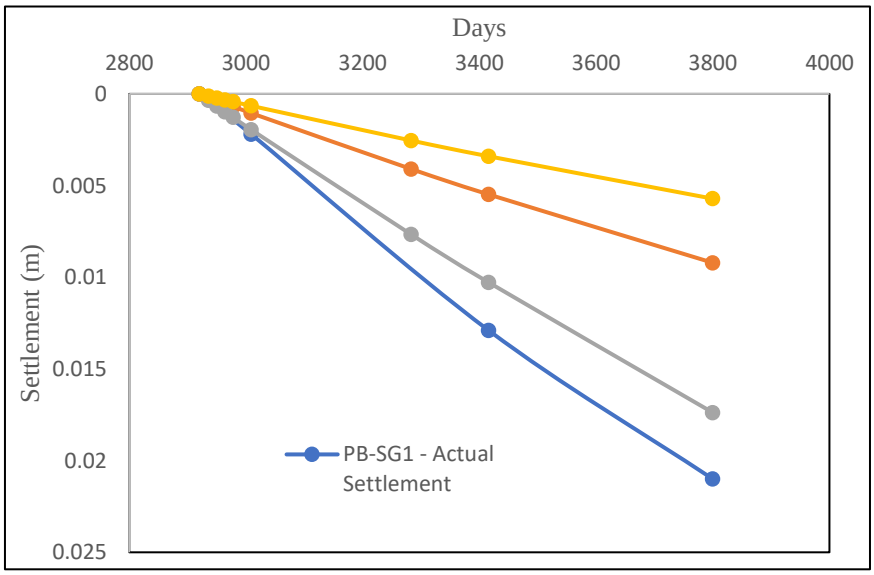

Figure 14. Settlement Comparison at PB-SG1

The graphs suggest that the settlement prediction using C_α obtained from empirical correlation underpredicts the secondary consolidation settlement. The C_α obtained from the empirical correlation slightly varies from the actual C_α values obtained for the soft soil deposit under the building. According to O'Kelly and Pichan (2013), a soil's microstructure significantly affects its physical and mechanical properties. The factors affecting microstructure properties also vary from one deposit to another (Hobbs, 1986; Vasander, 2014). Therefore, the observed underprediction when using empirical correlations can be due to changes in the organic soil's microstructure under consideration. This is further confirmed by the low organic content values as shown in Table 3. under section 3.1, which are typically below the average compared to the other Sri Lankan deposits.

However, as evident from the comparisons above, the prediction of settlement using the actual C_α also does not give accurate results. In most cases presented above, the difference between the measured and predicted settlements gradually increases at a higher rate with the elapsed time. This behaviour suggests that the rate of actual secondary consolidation settlement is not constant, as proposed by the conventional theories used in the industry.

To obtain a better prediction that matches well with the measured settlement, the C_α should be considered a time-dependent variable. Although accurate laboratory experiments should be carried out to determine the variation of C_α with time, only qualitative analysis was conducted in this study due to the lack of appropriate undisturbed samples. The C_α ratio vs time ratio relationship obtained from special consolidation tests on over-consolidated samples extracted from the soft soil deposits under the resort building was used to obtain time-dependent C_α values for the normally consolidated soil. The comparison suggests that the prediction using this varying C_α generates the most accurate settlement compared to the other methods followed in this study. The slight variation observed between the actual and above-predicted settlement could be because these C_α values were obtained qualitatively based on results for overconsolidated soil. To get an accurate settlement prediction, laboratory tests should be conducted to obtain the actual C_α variation with time for these organic soil deposits.

4 CONCLUSION

The secondary consolidation settlement of organic soil deposits is considered more significant than the primary consolidation settlement as it prevails for prolonged periods. Such long-term settlements often cause problems for the long-term performance of infrastructure built on these organic deposits. The resort building considered in this study is an ideal example of such a situation. The excessive differential settlement of underlying organic soil layers, even after eight years since completion, has caused the formation of cracks in the building. The secondary consolidation settlement of the building was analysed using three methods; empirical correlations to predict C_α, C_α determined by a laboratory test and qualitative analysis of time-dependent C_α. Upon successful comparison of settlements predicted using the above methods, it was found that the settlement predicted assuming that the C_α varies with time was the more accurate among the three. This suggests that the C_α of organic soil layers varies with the elapsed time. This study determined the time-dependent C_α by qualitative measures as the data permitted. A systematic quantitative analysis should be carried out to assess the time-dependency of the C_α of organic soil deposits in Sri Lanka to arrive at solid conclusions and more accurate predictions.

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Conflict Handling Styles used by Design Team Leaders During Post Contract Stage of Building Construction Projects in Sri Lanka

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ABSTRACT

In comparison to other industries, construction sector encompasses a distinct, complex, and a competitive environment. It enriches the community with improvements when individuals with diverse perspectives, abilities, and degrees of construction expertise collaborate with each other. In this highly competitive multiparty context, conflicts have been labeled as one of the key constraints that prevent the `success of construction projects. Conflict is a fact that everyone must deal with on a regular basis. Construction projects are therefore not an exception. It entails different types of conflicts. To handle these different types of conflicts, construction professionals use different conflict handling styles. Therefore, the aim of this study is to investigate design team leaders' preference of conflict handling styles and its impact on team spirit of the members of the design team during the post contract stage of building construction projects in Sri Lanka.

To collect data, an e-based, closed-ended questionnaire was used incorporating the conflict handling styles introduced in Rahim's Dual Concern theory. The questionnaire was answered by 56 professionals who have the experience of working in the design team during the post contract stage. The study was limited to the building construction projects in Sri Lanka. To analyze the gathered data, descriptive statistics such as mean, percentage, count correlation co-efficient etc. were used.

The study has revealed that during the post contract stage, the design team leaders use all five conflict handling styles of Rahim's Dual concern theory: integrating style, obliging style, dominating style, avoiding style, and compromising style in different frequencies to handle conflicts among design team professionals. The design team professionals often use compromising style and rarely use integrating style, obliging style, dominating style, and avoiding style to handle conflicts among the design team professionals during the post contract stage respectively.

Furthermore, the study indicates that these styles bring different levels of impact to the team spirit of design team professionals during the post contract stage of building construction projects in Sri Lanka. The team spirit of design team members is shown to be strongly affected by the compromising style. In contrast, the other four conflict handling styles, integrating style, obligating style, dominating style, and avoiding style, were identified to moderately impact team spirit. Moreover, findings revealed that all these five conflicts handling styles show a strong relationship with the team spirit of design team members during the post-contract stage of building construction projects in Sri Lanka.

The research findings may assist construction industry design team leaders and other stakeholders to manage conflicts in a more efficient way and provide an insight to the way to handle conflicts to improve the team spirit of the design team during the post-contract stage of building construction projects in Sri Lanka.

KEYWORDS: *Conflicts, Conflict Handling Styles, Building Projects, Design team, Construction industry, Post contract stage.*

1 INTRODUCTION

Conflicts are an inevitable aspect of every organization, but how the organization defines and controls the underlying causes of the conflicts is crucial (Choi, 2021). In highly competitive multiparty construction contexts, conflict is one of the key constraints that prevents the success of the construction projects (Yousefi, Hipel, & Hegazy , 2010). Complexity, high working pressure and for many other

reasons, construction sector has become vulnerable to conflicts (Lingard & Francis , 2005) and it has been influenced by the associated negativity (Simon Tolson, 2013 July).

Conflicts may occur at every stage of the construction process. Failure to offer possession of sites, changes in legislations, frequent design changes in the designs, ambiguities in the contracts, delays and scope changes are major factors that cause conflicts and disputes in the construction industry (Weerasooriya, 2020). Construction design changes may lead the project to impracticability, design flaws, and changes in the client's needs, the conflicts that may be noticed in the pre-contract phase are likely to be seen in the post-contract stage (Skitmore & Ng, 2000). Therefore, it is crucial to have a clear understanding of effective handling of conflicts throughout the post-contract stage, as it has a direct negative impact on the project's performance (Ogunlana & Awakul, 2002).

Building design is no longer a one-person job as the complexity of large-scale design and construction exceeds the capabilities of any individual (Serag-Eldin, 2010). The design team leader is an important stakeholder, whose services are required from the inception to the completion of the construction project as his or her decisions may directly affect the performance and the success of the building construction projects (Tham, 2007). In construction projects, there are different types of conflicts, and these conflicts must be handled with due care (Bendersky, 2003). Based on the responsible party, Acharya and his team (2006), classified conflicts in a project into five basic conflict categories. They are consultant evoked conflicts, owner evoked conflicts, contractor evoked conflicts, third party evoked conflicts, and other project evoked conflicts. (Acharya, Lee, & Im, 2006). Conferring to the levels at which the conflict occurs, Rahim (2011), categorized organizational conflict as intrapersonal, interpersonal, intragroup, and intergroup conflict (Rahim, 2011). Another classification used to classify construction conflicts is task conflicts, relationship conflicts, and process conflicts (De Church, Hamilton, & Hans , 2007; Desivilya , Somech, & Lidgoster, 2010).

Resolution of conflicts strongly depends on the conduct of the parties involved, it is preferable to utilize a behavior-based approach instead of a standard method (Giritli, Balci, & Sertyesilisik, 2009). However, stress and anxiety level in reaching an agreement, power imbalances, work complexity, team culture, and leadership models used by team leaders have an impact on how conflicts should be managed (Ludin & Soderholm, 1995). Thus, to solve a conflict effectively, one must select the most appropriate conflict managing style (De Silva & Sandanayake, 2022). In consideration of different impacts of ways of handling conflicts, many researchers have introduced different theories of conflict management. Some of these theories are Mary Parker Follett Model (1940), Hall’s Win-Lose Approach (1969), Thomas Kilmann, Conflict Mode Instrument (1977) and Devito Model (1995) (Giritli, Balci, & Sertyesilisik, 2009). In addition, various studies have identified different conflict handling styles and models to manage conflicts with their construction organizations. (Vigil- King , 1999).

Moreover, considering the uniqueness and associated risks of each construction project, the researchers have examined the factors and causes of different types of construction conflicts (Mannix & Jehn., 2001). Conflicts can affect the success of a building project either negatively or positively, depending on how they are being managed (De Silva & Sandanayake, 2022). Conflicts can impact in many ways which will eventually impact overall project progress. Conflicts could also weaken the alliance and cooperation required for the efficacy of teamwork. Team spirit is an essential factor in the success of a construction project (Chan, Scott, & Chan, 2004). Taking it into account, in the global context, different researchers have examined the impact of conflicts on team coordination and performance of project teams. The study revealed that the multicultural project team effectiveness can be enhanced by using the avoiding style (Thabassi, Abdullah , & Bryde, 2018; Ayoko, 2016; Banks, Pollack , & Seers, 2016).

While there is a substantial corpus of literature on the broad topic of conflicts and different conflict handling styles, related to construction projects, a gap is observed in examining the conflict handling styles used by Design Team Leaders during post contract stage of building construction projects and its impact on team spirit of design teams in Sri Lanka. Thus, this study is undertaken to investigate the conflict handling styles used by Design Team Leaders and its impact on team spirit of the members of the design team during the post contract stage of building construction projects in Sri Lanka.

2 LITERATURE REVIEW

2.1 The conflict

Conflict is a natural occurrence in human life whilst some may claim that conflict is both essential and unavoidable (Zhai, Anita, Liu1, & Xiaofeng, 2011). It is a common occurrence in group of activities and fundamental to a wide spectrum of team members' interactions (Mannix & Jehn., 2001). Conflicts arise when there is a deformation of ideas or goals to be accomplished by individuals or the parties concerned. (Anita Rauzana, 2016).

In the early days of management research and theory, conflict was often seen as a negative and undesirable component of organizational life. However, presently it is widely understood that conflict is unavoidable and that it is not always or necessarily negative for an organization (Lazarus, 2014). If properly managed, conflicts may contribute to the creation of innovative ideas as well as group internal cohesion. Therefore, recognizing and successfully managing conflict for the benefit of the organization is critical to its success (Lazarus, 2014). Organizations may benefit from conflict in both positive and negative directions, which is why a robust conflict management strategy is required. Conflict can lead to the success of construction building projects by developing team spirit and mutual understanding among construction organization participants. (Serag-Eldin, 2010).

2.2 Conflicts among design team members

Conflicts inevitably occur in large-scale building projects due to the presence of a diverse range of stakeholders with multiple objectives (Abdul-Raman,, Berawi, Berawi, & Moh, 2006). In a building construction project, multidisciplinary teams may cause conflicts among the design team members. Conflict and disputes appear to be an inherent aspect of the construction business, especially since the majority of construction projects are complicated and unpredictable. (Jaffar, Tharim, & Shuib, 2011).

The rate of occurrence of conflict situations among design team members in the building construction projects has significantly grown as a result of the massive development of the construction sector of Sri Lanka. (Heenkenda & Chandanie, 2012). Construction project conflicts and disagreements will obstruct timely completion, reduce productivity, and hinder achieving value for money (Yan, Kuphal, & Bode, 2000). Construction industry of Sri Lanka, on the other hand, is structured in such a way that it approaches ADR (Alternative Dispute Resolution) directly rather than avoiding it through good conflict management. Moreover, Conflict management receives more attention today in order to save money and time later in the project's life cycle (Heenkenda & Chandanie, 2012).

2.3 Conflicts at post contract stage

Conflicts develop throughout the post contract stage, as project members enter and leave at different times. Teams working on construction projects are made up of a variety of experts and parties, including contractors, suppliers, engineers, architects, and quantity surveyors (Leung, Liu, & Ng, 2005). On the other hand, every construction project management team might evaluate the project's progress and current conditions differently (Gudiene, Banaitis, & Banaitiene, 2013). Based on the conflict initiator, Acharya and Lee (2006) categorized the causes of conflicts into five types. Acharya and his team found out six main reasons for the occurrence of conflicts in the construction sites (Acharya, Lee, & Im, 2006). They are, different site conditions, local people obstructions, change order and evaluation differences, design errors and omissions, exclusive number of works, and double meaning in specifications (DeChurch, Hamilton, & Haas, 2007).

2.4 Conflict Handling Styles

Conflict handling approaches have been referred to in a variety of ways by different researchers. Different conflict handling approaches have been proposed by researchers such as Conflict Model Instrument by Thomas and Kilmann (1974), Devito model by Devito (1995), and Marry Parker Follett model by Mary parker (1940) (Jandt, 2016)

2.4.1 Dual Concern Theory by M. Afzalur Rahim

Dual Concern theory is widely accepted among conflict management research due to its inherent characteristics such as ease of use, easy interpretation, and effective prediction ability. (Vu & Carmichael , 2009). The dual concern theory (DCT) is a theoretical framework that explains how people's behavioral inclinations influence their approach to conflict resolution. It is based on Blake and Mouton's theoretical foundation and managerial grid. Integrating (problem solving), obliging, dominating (forcing), avoiding, and compromise are the five conflict management styles (Chou & Yeh, 2007).

Integrating Style: Conflict is considered as an issue that demands a solution in this strategy, thus both parties make an effort to find a solution while enhancing their creativity and talents Chou & Yeh, 2007; Verma, 1998), ***Obliging style***: Low concern for self and strong concern for the other person are the two dimensions evaluated in this method (Chou & Yeh, 2007), ***Dominating style*** - Chou and Yeh (2007) define this style as having a high concern for oneself and a low regard for the other person (Chou & Yeh, 2007), ***Avoiding style:*** This technique was defined by Cheung and Chuah (1999) and Akiner (2014) as denying or disregarding the existing or impending conflict between the parties (Cheung and Chuah, 1999; Akiner , 2014), ***Compromising style*** - Moderate care for self and others at the same time by presenting a mutually acceptable conclusion are the two characteristics examined for conflict management in this technique (Cheung and Chuah, 1999; Akiner , 2014)

2.5 Impact of conflict handling styles on the team spirit of construction industry professionals

Construction industry participants will need to employ conflict handling styles in the near future. Conflict resolution has the ability to improve a construction company's performance, team, spirit and efficiency (Simons & Peterson, 2000). As the construction industry is a temporary multi-organization, team spirit directly affects the performance of the team (Abuja , 2018).

2.5.1 Team Sprit

"The Team" can be defined as a collection of individuals who are complimentary, cohesive, and harmonic. The team achieves collective achievements through the collective contributions of all members. As a result, "team spirit" refers to the collaborative approach in which team members work together to achieve the team's goals and objectives. Obligation is the treatment for team spirit; thus it becomes the work force to encourage team members and inject vitality into the task (Gao , 2014). Project success is determined by impacting factors such as timeframes, pricing, quality, requirements, and process satisfaction (Barki & Hartwick, 2001). The impact on the team would be enhanced or reduced creativity, efficiency, and performance (Thomas, 2009).

2.5.2 Conflict handling styles and team spirit

Construction industry's rapid global development of complex projects has resulted in several inter-organizational disputes (Hu, Chen, Gu, Huang, & Liu, 2017). Depending on the factors including the leader's conflict management style, the nature of the disagreement may have a beneficial or an unfavorable influence on project performance (Wu, Zhao, & Zuo, 2017). According to the literature, the success or failure of dealing with conflict has a direct influence on the execution of temporary organization’s projects and the team spirit (Muller, Turner, Andersen, & Shao, 2016).

Project managers and managers in the construction sector use a conflict handling style that is more open to coping with disagreement. Mutual dependence allows cooperative conflict settlement, which might lead to better project collaboration (Chen, & Tjosvold, 2002). As a result, differing approaches to handling conflict in team environments may have an impact on how teams collaborate (Thabassi, Abdullah , & Bryde, 2018).

Therefore, considering the conflict handling styles used by the design team leaders of the design team during the post contract stage of building construction projects in Sri Lanka, to increase the team spirit of the design team, following hypothesis can be developed.

H1 -Integrating conflict handling style used by the design team leaders during the post contract stage of building construction projects in Sri Lanka will create a strong relationship between the conflict handling style and the team spirit of the design team.

H2 -Obliging conflict handling style used by the design team leaders during the post contract stage of building construction projects in Sri Lanka will create a strong relationship between the conflict handling style and the team spirit of the design team.

H3 - Dominating conflict handling style used by the design team leaders during the post contract stage of building construction projects in Sri Lanka will increase the team spirit of the design team.

H4 -Avoiding conflict handling style used by the design team leaders during the post contract stage of building construction projects in Sri Lanka will create a strong relationship between the conflict handling style and the team spirit of the design team.

H5- Compromising conflict handling style used by the design team leaders during the post contract stage of building construction industry in Sri Lanka will create a strong relationship between the conflict handling style and the team spirit of the design team.

3 RESEARCH METHODOLOGY

The background study was carried out to identify the exact research gap. Subsequently, a comprehensive literature review was carried out using books, journals, research articles, etc., identifying different conflict handling styles that can be used by the design Team Leaders in construction projects. Conflict is a global phenomenon, unique to every individual (De Silva & Sandanayake, 2022). The study was focused on the conflict handling styles used by the design team professionals during the post contract stage of building construction projects in Sri Lanka, and to collect data, a quantitative approach has been adopted. Statistical data was collected through a questionnaire survey since the findings of the research were focused on observing the conflict-handling styles used by the design team leaders (affected people) in the construction industry. A purposive sampling technique was used, hence by using a selected sample of professionals, this study can be assessed more accurately and thereafter a sample of 100 professionals was chosen, especially design team leaders and members engaged in the building construction projects in Sri Lanka were chosen for this questionnaire survey. Consequently, 56 completed responses were gathered. The data collected through the questionnaire survey was analyzed using the Mean-weighted rating formula and the following Table 1 shows the Likert scales and ranges.

Table 1: Likert scale for identifying the Frequency and impact of using conflict handling styles by the design team leaders to handle the conflicts within the design team during the post contract stage of building construction projects in Sri Lanka

Value	Range	Likert scale for	
		Frequency of using conflict handling styles	**impact of using conflict handling styles**
1	1.00-1.08	Very low	Very low
2	1.81-2.60	Low	Low
3	2.61-3.40	Rare	Moderate
4	3.41-4.20	Often	High
5	4.21-5.00	Very Often	Very High

Finally in order to establish a relationship between the conflict handling styles and the team spirit of the design team during the post contract stage of building construction projects in Sri Lanka, data was analyzed using the Spearman's Correlation analysis.

Table 2: Correlation coefficient interpretation

Spearman's coefficient	Correlation relationship
≥ 0.70	Very strong
0.40 – 0.63	Strong
0.30 – 0.39	Moderate
0.20 – 0.29	Weak
0.01 – 0.19	Negligible

4 DATA ANALYSIS AND DISCUSSION

The questionnaire survey was carried out according to the purposive sampling technique while distributing the survey among the selected professionals such as architects, engineers (civil, tructural, MEP), quantity surveyors, project managers and draft men who have experience in working in the design team during the post contract stage of building construction projects in Sri Lanka via Google Forms.

4.1 Demographic Information of Respondents

Table 3 shows the summary of the professions of the people who were participants in the survey.

Table 3: Classification of professions

Profession	Percentage
Architects	36%
Civil Engineers	16%
Draft Men	2%
MEP Engineers	4%
Project Managers	12%
Quantity Surveyors	26%
Structural Engineers	4%

The most common profession among the survey participants was architects, with 36% as a percentage. Civil engineers accounted for 16% of the total respondents, while project managers were 12%. The least number of participants were draft men, and it shows 2% as a percentage of the total number of respondents in this survey.

4.2 Frequency of usage of conflict handling styles by the design team leaders to handle conflicts within the design team during the post contract stage of building construction projects in Sri Lanka

In this study, data was collected on a Likert scale related to the 5 conflict handling styles in the dual concern theory on the frequency of usage of conflict-handling styles by the design team leaders to handle conflicts within the design team during the post contract stage of building construction projects in Sri Lanka.

Table 4 demonstrates the weighted mean values of conflict handling styles used by design team leaders during the post contract stage of building construction projects in Sri Lanka.

Table 4: Frequency of Usage of Conflict Handling styles by the design team leaders to handle conflicts within the design team during the post contract stage of Building Construction Projects in Sri Lanka.

Conflict Handling style	Mean	Likert Scale Vale
Integrating style	3.08	Rare
Obliging style	2.86	Rare
Dominating style	2.62	Rare
Avoiding style	2.62	Rare
Compromising style	3.64	often

According to the collected data, the design team leaders often use compromising style to handle conflicts within the design team members. Further, integrating style, obliging style, dominating style and avoiding style are rarely used by the design team leaders to handle conflicts within the design team during the post contract stage of building construction projects in Sri Lanka.

4.3 Impact of conflict handling styles of design team leaders on the team spirit of the design team during the post contract stage of building construction projects in Sri Lanka

Table 5 shows the analyzed statistical data collected from the respondents to identify the impact of conflict handling styles of design team leaders on the team spirit of the design team during the post contract stage of building construction projects in Sri Lanka.

Table 5: Impact of conflict handling styles of Design team leaders on the team spirit of the design team during the post contract stage of building projects in Sri Lanka.

Conflict Handling style	$\bar{x}$	Likert scale Value
Integrating style	3.30	Moderate
Obliging style	2.96	Moderate
Dominating style	2.76	Moderate
Avoiding style	2.76	Moderate
Compromising style	3.74	High

From the collected data, the compromising style has a high impact on the team spirit of the design team during the post contract stage. However, except for compromising style, all the other four conflict handling styles, integrating style, obliging style, dominating style and avoiding style show a moderate impact on the team spirit of the design team during the post contract stage of building construction projects in Sri Lanka.

4.4 The relationship between conflict handling styles and the team spirit of design teams during post contract stage of building construction projects in Sri Lanka

To establish a relationship between the conflict handling style and the team spirit of the design team during the post contract stage of building construction projects in Sri Lanka, few hypotheses were formulated. By rendering to the following correlation coefficient interpretations, the relationship of the above hypothesis can be analyzed. Correlation coefficient interpretations are shown in the following tables: Table 2 and Table 6 (Hauke & Kossowski, 2011).

Table 6: Correlation coefficient of conflict handling styles

Conflict handling style	Correlation coefficient	Rank
Integrating style	0.55876	2
Obliging style	0.57674	1
Dominating style	0.49633	4
Avoiding style	0.42298	5
Compromising style	0.50058	3

According to Table 6, all the conflict-handling styles in the dual concern theory create a strong relationship between the team spirit of the team members in the design teams during the post-contract stage of building construction projects in Sri Lanka. Further, according to the above table, among these 5 conflicts handling styles, obliging conflict handling style creates the strongest relationship whilst avoiding style creates the weakest relationship with the team spirit of the design team members during the post contract stage of building construction projects in Sri Lanka. Hence, for all the conflict handling styles, Spearman's correlation coefficient shows a stronger relationship which proves that due to the strong relationship between the conflict handling style and the team spirit, these conflict handling styles increase the team spirit of the design teams' members. Therefore, hypotheses H1, H2, H3, H4 and H5 created a positive result.

5 CONCLUSION AND RECOMMENDATIONS

Conflict is a common phenomenon to human beings. In terms of the construction industry, conflicts are a frequent experience for all the stakeholders. These conflicts can be classified into different classifications in terms of the parties responsible, sources, organizational levels etc. To handle such

conflicts, many researchers have established different theories; few of them are Mary Parker Follett Model (1940), Hall's Win-Lose Approach (1969), Thomas Kilmann Conflict Mode Instrument (1977) and the Devito Model (1995). In terms of the construction industry, among these conflict handling theories, Rahim's dual concern theory is widely used to define handling construction conflicts.

Conflicts have become an inherent element of the daily routine of the design teams during the post contract stage of building projects in Sri Lanka (Abeynayake & Weddikkara, 2012). This fact was proved by the findings of this research as the majority of the design team members experienced conflicts within the design team during the post-contract of building construction projects in Sri Lanka. In order to manage those issues, different conflict handling styles have been used by the design team leaders in the construction industry.

Findings in the research revealed that all the five conflict handling styles in the dual concern theory were used by the design team leaders to manage the conflicts during the post-contact stage of building construction projects in Sri Lanka with different frequencies. Design team professionals often use the compromising style and rarely use the integrating style, obliging style, dominating style, and avoiding style to handle conflicts among the design team professionals during the post contract stage.

In view of the impact on team spirit, compromising style shows a high impact whilst, all the other four conflict handling styles, integrating style, obliging style, dominating style and avoiding style were found to have moderate impact on the team spirit of the design team during the post contract stage of building projects in Sri Lanka.

Moreover, when analyzing the findings of this research, conflict handling styles, and their impacts on the design teams during the post-contract stage of building construction projects in Sri Lanka were identified. . To develop a relationship between the conflict handling style and the team spirit, a correlation analysis was used between these two variables. The test has proven a strong relationship between the conflict handling style and team spirit as the correlation coefficient for all the conflict handling styles was between 0.40 and 0.63. Therefore, it can be stated that all the conflict handling styles in the Dual Concern Theory exhibit a strong relationship between the team spirit and enhanced the team spirit and prove all the hypotheses were positive.

Based on the research findings, the following recommendation can be made: According to the design team members' perspective, the analysis of conflict handling styles and the team spirit of the design team during the post-contract stage may be used to evaluate the team leaders in the design team and their ability to handle conflicts among the design team members in order to foster team spirit and enhance performance of the construction projects. Furthermore, as further research directions dictate, the same research could be undertaken for other construction industry professionals, team leaders, and at other stages of the building process.

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