GUIDELINE TO MINIMISE AND MITIGATE TECHNICAL RISKS IN ROAD PROJECTS: CONTRACTOR'S PERSPECTIVE IN SRI LANKA

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Abstract: This study investigates technical Risk (TR) management strategies for Road Construction Projects (RCP) in Sri Lanka from the Contractor's perspective. A comprehensive literature review was conducted to identify the technical risks in construction projects. A qualitative approach was conducted using two interview stages as the data collection method. Interview Stage I employed five (5) preliminary interview and Interview Stage II employed thirteen (13) semi- structured interview with experts. The collected data were analysed using content analysis, both manually and using NVivo software. The findings showed Eighteen (18) TRs for RCPs in Sri Lanka. Further, the study demonstrates the causes and consequences of TRs in Sri Lankan RCPs. Eventually, the study proposes mitigation strategies for the consequences. Overall, this research determines how to minimise and mitigate the TRs in RCP in Sri Lanka; thus, it is the study's novelty. Future studies can be conducted for the same study in different phases of construction phases, and different perspectives of the stakeholders.

Keywords; *Road Construction Projects; Sri Lanka: Strategies; Technical Risks.*

1. Introduction

Construction is a high-risk industry with a poor risk management track record (Ehsan et al., 2010; Kaur & Singh, 2018). Road construction projects are riskier than other infrastructure projects due to their high capital costs and strong public, municipal, and political participation throughout development (Senić et al., 2024). Nevertheless, the Ministry of Transport and Highways in Sri Lanka is initiating several road improvement programmes in Sri Lanka, including the construction of expressways, highways, rural connectivity roads, and the improvement and rehabilitation of rural roads (Road Development Authority [RDA], 2024).

Several studies have been conducted on risk in road construction projects (Gain et al., 2022; Okate & Kakade, 2019). Further, there are few studies conducted integrating risk, specifically on Sri Lankan road construction (Abhayantha, 2022; Abhayantha et al., 2023; Dhanasinghe & Perera, 2008; Perera, 2014; Perera et al., 2009; Perera et al., 2014; Sugathadasa et al., 2021).There are very few studies conducted on technical risks in construction projects (Mecca & Masera, 1999; Nsobila, 2015). When considering road construction projects, no study addresses the technical risks from a global perspective or in Sri Lanka. This highlights the deficiency of literature in the study area.

Despite that, technical risks are crucial in a construction project. Technical Risk (TR) typically arises from scope definition, requirements definition, estimates, technical processes, technology, design, performance, reliability, safety, security, construction methods, materials, equipment, and test (Nsobila, 2015). In addition, TRs occur during every project phase and are typically the source of the bulk of risk in the construction sector. Further, it severely jeopardizes construction project success (Martin et al., 2018). Investigating the technical risks in a construction project and providing a guideline for minimising and mitigating those risks is crucial because it gives the Client, investors, and other stakeholders confidence that the project is being handled professionally and responsibly. Moreover, this guideline will help the project on course, even if any unexpected issues occur. Eventually, this study will be urgent in providing a proactive approach to ensure smoother project execution. This highlights the industry's need for the study.

Considering the literature deficiency and industry needs, there is a need to investigate the topic further. Hence, this study investigates technical risks in road construction projects in Sri Lanka. Further, risk minimisation and mitigation are crucial for contractors compared to other stakeholders, as they allocate a monetary value for risk in bills of quantities during tender. Thus, this study aims to provide a guideline to allow contractors to minimise and mitigate the technical risks of a road construction project. This study mounted with a research problem, "How to minimise and mitigate the technical risks in road construction projects in Sri Lanka?". Further, three objectives were developed to fulfil the research aim.

Objective 1: Identification of TRs in Road construction projects in Sri Lanka
Objective 2: Investigate the causes of those TRs and their consequences.
Objective 3: Propose strategies to minimise and mitigate the TRs in RCP in Sri Lanka.

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The scope of the research is limited to the technical risks that occur in road construction projects in Sri Lanka. Further, the scope is limited to only one phase: the construction stage of a road construction project. Moreover, technical risks were identified only from the perspective of the Contractor. The paper is structured in six (6) sections: section 1 introduces the research, section 2 discusses the literature on technical risks in construction projects from a global perspective, section 3 explains the research methodology adopted, section 4 gives the findings for three objectives, section 5 discusses the findings, and section 6 concludes the paper with the recommendations and limitations. This study will contribute to ensuring that the TRs in RCP are identified, assessed, and managed in a way that permits the overall goals to be achieved in an RCP in Sri Lanka. Further, the outcomes will be a base study for decision-making related to the risks that are considered technical in the construction industry.

2. Literature Review

The word "technical" in the construction sector refers to the specialized knowledge, abilities, and processes needed for planning, constructing, and maintaining infrastructure and buildings. Architecture, engineering, construction management, materials science, project planning and scheduling, cost estimation, quality assurance and control, adherence to safety requirements, and environmental protection measures are just a few of the many fields that fall within the broad category of technical expertise (Construo, 2024). "Technical risks" are any elements that could prevent a project from being completed successfully as per the requirements of the Client (Procore, 2024). Nsobila (2015) highlighted that technical risks are due to technical causes, where a technical cause is the cause that is related to project initiation, execution, and operation. Technical risks were identified as being caused by various factors such as design, technical complexity, the expenses associated with technical measures, advanced technical processes, the use of new and advanced technology, the necessity for data correctness, equipment failure, inefficient transportation facilities, and higher site overhead (Martin et al., 2018; Siang & Ali, 2012).

2.1 TECHNICAL RISKS EXPERIENCED IN CONSTRUCTION

The comprehensive literature review identified twenty (20) technical risks for construction projects. It includes failures in design (Ahmed et al., 2018; Dhivya et al., 2019; El-Sayegh & Mansour, 2015; Martin et al., 2018), design variations or design changes by clients (Ahmed et al., 2018; Aslam et al., 2019, Dhivya et al., 2019; El-Sayegh & Mansour, 2015; Martin et al., 2018), insufficient technological skills, failures in new technology, delays in expropriations, delays in the preparation of submittals, delays in approvals of submittals (El-Sayegh & Mansour, 2015), errors in estimation (Ahmed et al., 2018), inefficient planning (El-Sayegh & Mansour, 2015; Nsobila, 2015); inadequate programme scheduling (Nsobila, 2015); poor quality of materials (Martin et al., 2018; Nsobila, 2015), poor coordination, delay in obtaining approval from authorities, insufficient right of way (El-Sayegh & Mansour, 2015; Martin et al., 2018), system or equipment failure (Dhivya et al., 2019; Martin et al., 2018; Nsobila, 2015), low quality of purchased accessory facilities, shortage in accessory facilities (Dhivya et al., 2019), shortage in material (Ahmed et al., 2018; Martin et al., 2018), shortage in skillful workers (Ahmed et al., 2018; Martin et al., 2018; Nsobila, 2015), shortage in supply of water, gas, and electricity (Martin et al., 2018).

2.2 TECHNICAL RISKS EXPERIENCED IN ROAD CONSTRUCTION IN SRI LANKA

As a developing country seeking to accelerate economic growth, Sri Lanka offers more significant opportunities for infrastructure development investments (Perera, 2014). A comprehensive literature review was conducted. Previous studies were conducted on the synergy between only two or three of the following key aspects: risk identification, investigation on the causes and consequences of risk, proposal of strategies for risk consequences, road construction projects, risk specifically on technical risk, and Sri Lankan context. However, no study has been carried out that synergizes all the aspects mentioned above. This study synergizes the (a) identification of technical risks in RCP in Sri Lanka, (b) investigation of its causes and consequences, and (c) proposing strategies to minimise and mitigate the consequences. Thus, this is the novelty of the study.

This study investigates the technical risks in Sri Lankan road construcntion projects to identify the existing technical risks, industry practitioners' perceptions about such risks, and their causes and consequences for project goals. Further, there is a need for the study to assess the TRs' repercussions and uncertainties for Contractors. Contractors must possess the skills to identify, assess, and manage risks and ensure that risk information has effectively been disseminated (Ali & Taylor, 2014). Therefore, this study identifies TRs from the Contractor's perspective. Addressing the aforementioned literature gap will lead to the success of the road construction projects in Sri Lanka within the agreed budget and agreed time for completion without jeopardising the quality. It provides a thorough awareness of known risks and taking necessary actions to mitigate the effect and possibility of such risks occurring, decrease problems, and enhance the probability of success (Goh & Abdul-Rahman, 2013). As a result, this study will be beneficial to the construction sector in Sri Lanka.

3. Methodology

A qualitative approach in observing developing concepts through incredible insight by vigorously exploring the concept for a limited sample (Yin, 2011). Thus, a qualitative approach was used in this study as the topic is novel within the context of the study. The survey enables the collection of the data from diverse samples, and this broad participation helps generalize

findings and provides insights applicable to the entire sector, rather than being limited to specific cases (Islam & Aldaihani, 2022). Hence, the case study would not capture the diversity of risks or allow for sector- wide generalizations. However, the diversity ensures that all perspectives on TRS are considered, providing a comprehensive understanding of RCP in SL. In addition, it allows to collect data from a wide range of project including urban and rural roads. Thus, the survey strategy was selected for this study, and the interview with the experts was used as the data collection technique.. Considering the selection of the sample, Nyimbili & Nyimbili (2024) outlined that the purposive sample allows the researcher to deliberately select the participants who can provide rich, relevant, and detailed insights. Thus, the purposive sampling technique was adopted to select the experts for two interview stages since there are very few professionals with knowledge and experience on road construction and technical risks.

A comprehensive literature review was conducted to identify the technical risks associated with road construction projects. The findings from the literature survey were validated in the Sri Lankan context using preliminary interviews in Interview Stage I. Five preliminary interviews were conducted at interview Stage-I to enhance, contextualise, and tailor the literature review findings to the Sri Lankan construction industry. The technical risks for construction projects identified for the global context were validated in the Sri Lankan road construction sector using Interview stage I. Accordingly, a few TRs were added, removed, and modified for RCP in SL.

Then, the findings of the stage I interview were aggregated to construct the technical risks in road construction projects in Sri Lanka. At stage II of the Interview, causes for the technical risks, consequences of those, and strategies to mitigate and minimise consequences were identified for the technical risks specifically for Sri Lankan road projects with the help of experts by having a semi-structured interview guideline. Considering the data saturation and time constraints, the sample size was limited to thirteen (13). Though choosing the best relevant sample for the study is a complicated task (Taheerdoost, 2016), the reliability of the data is more crucial (Polonsky & Waller, 2011). The selection of experts followed a mix of criteria, as depicted in the last row of Table 1. Further, Table 1 provides the profile of the experts who participated in Interview Stage II, where participants of Interview Stage I were deemed included. All the experts were selected from contractor organisations, as the study focused on TRs in RCP in Sri Lanka from the Contractor's perspective.

Table 1, Profile of Respondents

Expert Code	Designation	Selection Criteria					
		(a)	(b)	(c)	(d)	(e)	(f)
E1	Project Director	✓	✓	✓	✓	✓	✓
E2	Project Engineer	✓	✓	✓	✓	✓	✓
E3	Chief Engineer	✓	✓	✓	✓	✓	✓
E4	Geotechnical Engineer	✓	✓	✓	✓	✓	✓
E5	Project Quantity Surveyor	✓	✓	✓	✓	✓	✓
E6	Project Manager	✓	✓	✓	✓	✓	✓
E7	Senior Engineer	✓	✓	✓	✓	✓	✓
E8	Civil Engineer	✓	✓	✓	✓	✓	✓
E9	Project Engineer	✓	✓	✓	✓	✓	✓
E10	Senior Quantity Surveyor	✓	✓	✓	✓	✓	✓
E11	Chief Engineer	✓	✓	✓	✓	✓	✓
E12	Senior Quantity Surveyor	✓	✓	✓	✓	✓	✓
E13	Chief Quantity Surveyor	✓	✓	✓	✓	✓	✓

Columns (a) to (f) represent the selection criteria for experts or in-depth interviews. It refers as follows.

a. Experience in road construction projects in Sri Lanka more than or equal to ten (10) years
b. Experience in either managing risk, project management, or technical design in road construction projects
c. Experience in working in a contractor organization.
d. Playing a role of decision-making or leadership or advisory in their organizations
e. Having a solid academic background in construction-related degree
f. Having Professional Qualifications in an in-built environment

The interviews with experts range from 30 to 50 minutes. With the consent of the interview respondents, it was voice-recorded and transcribed using digital tools. Analysing the collected data is significant as it draws the answers from the textual data collected into something meaningful. Without analysis, qualitative data would be just a mass of texts collected from the data collection process (Saunder et al., 2015). Content analysis is a tool or method to extract significant desired raw information from texts or images and organize it into systematic concepts before making valid inferences and interpretations (Foy, 2019). Dealing with a large amount of data, such as eighteen (18) technical risks, their causes, their consequences, and strategies to mitigate the consequences, content analysis was considered appropriate since it is a systematic approach to limit the subjectivity in the interview transcription. Thus, this study utilized the content analysis method to analyse the bulk of qualitative data. The use of specialized software was considered handling worthy for handling large amounts of code. Therefore, the study utilized Nvivo-11 software. In a few instances, manual content analysis was also

carried out. The results of the analysis correspond well to the purpose of the study. The results were then used to develop guidelines to enhance the technical risk mitigation and minimisation process for road construction projects in Sri Lanka.

4. Findings

4.1. IDENTIFICATION OF TECHNICAL RISKS ON THE RCP IN SRI LANKA

The comprehensive literature review identified twenty (20) TRs on construction projects from a global perspective as per section 2.1. Afterward, the interview stage I was conducted to validate the findings of the literature on the Sri Lankan road construction sector. Here, few TRs were removed, merged, renamed, and added for RCP in Sri Lanka. Accordingly, five (5) TRs were removed as not suitable for Sri Lankan road construction projects, such as, insufficient right of way, shortage in supply of water, gas and electricity, insufficient technological skills, failures in new technologies, delay in obtaining no objection certificate (NOC) from authorities. Here, Delay in NOC from au.thorities were disregarded due to occurrence is negligibly low. Similarly, the two risks related to technology was eliminated, as E5 outlined "*Failures in technology may be seen as operational or implementation risks, rather than intrinsic technical risks tied to the project*". Adding on to that, E3 manifested "*there are well recognized technical risks in Sri Lanka such as geotechnical challenges, design flaws, and material quality issues. This traditional focus excludes risk related to technology*". In addition, the shortage of supply of utilities were removed to SL as it is related to logistics and operational activities and E2 pointed out "*its likelihood of occurrence is low due to availability of water tanks, and portable generator".*

Further, few TRs identified in the literature were merged and renamed during the validation of literature findings to SL RCP. One is delays in the preparation and approval of submittals. Similarly, the TRs, such as those with inefficient planning and inadequate program scheduling, are merged. Moreover, delay in approval of submittals, delay in preparation of submittals, and delays in expropriation are included in the delay in approval of submittals. Afterward, the low quality of the purchased accessory facilities was included in the shortage of accessory facilities. Moreover, seven (7) new technical risks were added during contextualization of th literature findings to RCP in Sri Lanka, such as (a) Incompetence of transportation facilities, (b) Increase in Site overheads, (c) Unusual Weather and Force Majeure, (d) Accident, (e) Industrial Disputes, (f) Sub-contractors Low Credibility, and (g) Unknown physical conditions. Eventually, the findings of Interview Stage I provide eighteen (18) technical risks that impact road construction projects in Sri Lanka.

4.2. INVESTIGATION ON THE CAUSES OF TRS IN THE RCP IN SRI LANKA

The eighteen (18) technical risks for road construction projects in Sri Lanka, identified in Interview Stage I, were given to Interview Stage II to investigate the causes of those technical risks to RCP in Sri Lanka. The results are presented in Table 2. Column 2 of Table 2 provides the causes for the respective TRs. Accordingly, most respondents highlighted that estimation error is the most experienced technical risk during road construction projects in Sri Lanka. Though the estimation process is related to the finance of a construction project, the cost estimation of the bills for quantity items is technical work. E12 asserted, "*the cause of estimating errors using the incorrect unit of measurement, for example, square feet instead of square yards*." The subsequent common risk is the Client's design change. E10 highlighted, "*the Client, whose opinion may undergo some financial problems leading to some budget constraints or may simply seek to make some savings, and this problem may lead to a change in schedule, specifications, and the quality of construction*." Besides, subcontractors' low credibility, industrial disputes, and shortage of skilled workers are the other most experienced TRs in RCP in SL. Accordingly, E11 pinpointed the cause for the subcontractor's low credibility as *"less experience of contractors in the construction domain is one of the major causes of this particular risk*." Concerning the shortage of skilful workers, E3 highlighted that "*without adequate manpower to perform the work, the project can suffer from longer construction schedules and potential delays in delivering the project on time to the owner*." The findings showed few common causes for few TRs, such as insufficient design information, lack of cooperation between the professional staff from different disciplines, discrepancies among the contract documents, poor documentation, lack of proper planning, financial constraints, lack of required technical expertise among the staff, poor supervision, lack of progress monitoring, ambiguity in the scope of work, and lack of expertise and experience of the Contractor. On the other hand, lack of quality material and shortage of material were identified as Technical risks as well as a cause for other technical risks. Similarly, the unknown physical condition is a cause for many TRs.

4.3. INVESTIGATING THE CONSEQUENCES OF THE TRS IN RCP IN SRI LANKA

The eighteen (18) technical risks for road construction projects in Sri Lanka, identified in Interview Stage I, were given to Interview Stage II to investigate the consequences of those technical risks to RCP in Sri Lanka. Table 2 Column 3 provides the consequences with respect to the TRs in RCP in Sri Lanka. The findings show few repeated consequences due to many TRs, such as cost overrun, project delay, redesign, inability to achieve the expected lifetime of the project, additional requirement for material, labour, and equipment, loss of profit to the Contractor, inability to achieve the success of the project, productivity decreases, less quality of output, negative feedback from the public, and reputational damage to the contractor organization and other professionals. E11 revealed that redesign is one of the considerable effects of design failure. Similarly, E1, E4, and E10 highlighted that *" reputational damages are significant issues of poor quality of procured materials*". Further, E13 manifests that the reputational damage is a consequence of the accident.

4.4. STRATEGIES TO MINIMISE AND MITIGATE THE CONSEQUENCES OF TRS ON RCP IN SRI LANKA

The strategies for the consequences of TRs were identified in the Interview stage II. The last column of Table 2 presents the strategies for corresponding TRs and their consequences. As per Table 2, the typical strategies identified were taking time to design the project, proper site investigation, proper supervision, carrying out site visits in regular intervals, proper communication with project participants, pre-plan the projects, pre-plan the facilities needed, employing well- experienced site staff, proper quality assurance procedures in the contractor organization, give priority to cost significant items, and use of highly sophisticated software.

Some unique strategies for specific TRs are as follows. To mitigate or minimise the accidents, E9 indicated that signs and instructions are vital to ensure areas of construction sites where vehicles will be traveling in and out are well signposted so that pedestrians are aware. The respondent also added that anyone entering the site needs to be provided with induction before their visit. Similarly, E11 pinpointed a strategy for mitigating the consequences of TR unknown physical conditions in the site as carrying out persistent ground investigations for obtaining physical samples to determine the thicknesses and properties of the road structure, subgrade, and peat layers are vital to eradicate this risk. Further, E8 depicted a strategy for inadequate program scheduling as developing a plan beyond just creating a schedule. The proposal included conducting a risk assessment and management strategy, developing site-specific safety plans, establishing contingency plans and site logistics, and lining up the delivery of materials and equipment. Moreover, E4 stated that providing opportunities for training, mentoring, and continuing education courses available to both new and existing employees, establishing advancement opportunities, and facilitating career paths for workers to move up are vital factors for enhancing the competency of workers. Besides, E6 pinpointed the development of a standard and repeatable estimating process that allows for the leverage of unit cost assemblies. In addition, E2 manifested the importance of using quality materials for road construction projects as "*using low-quality materials for road guarantees zero durability*". E7 pinpointed that a site investigation helps to determine the most suitable materials to use in construction. Hence, there is a need to check the soil and decide what materials will be best for construction. Also, they will determine how suitable it is to continue with the project since reputation loss is a severe, dire consequence for a contractor.

Table 2, Guideline for minimising and mitigating the TRs in RCP in SL: The identification of TRs in RCP in SL, along with its causes, consequences, and strategies to mitigate the consequences.

Technical Risk	Causes of Technical Risks	Consequences of Technical Risks	Strategies to mitigate the consequences of Technical Risks
Design Failures	• Inadequate project objectives • Lack of management • Unforeseeable physical conditions • Lack of clarity in the Client Brief • Lack of cooperation among design team members	• Redesign • Considerable defects • Negative feedback from the public • Uncomfortable during transport • Staff salary expenses • Delay from the planned schedule • Collapse of structure • Unable to achieve the expected lifetime	• Take sufficient time to design • Proper site investigation • Alteration of programme • Prepare checklist • Develop a comprehensive client brief
Design variation by Client	• Changes in the scope of the work and specification • Balance the natural eco-system • Ambiguity in requirements • Financial constraints • Safeguard the public interest • Unforeseeable physical conditions • Material shortage and lack of availability of materials • Lack of adequate investigation by consultants	• Cost Overrun • Delay to the project • Increase in the project cost • Redesign • Additional claims for prolongation cost • Additional requirements for material, labour, and equipment • Disagreement and dispute	• Draft clear client requirements • Proper site investigation • Obtain neighbour's consent concerning the construction • Carryout the site visit in proper intervals • Verify whether the design is practical to construct
Estimation Errors	• Failure to use an estimating checklist • Misunderstanding the quality • Entering costs incorrectly • Lack of audit and review processes • Math errors • Measurement errors	• Fault pretender estimate • Improper tender evaluation • Incapable contractor selection • Cause of dispute among parties • Unexpected variations • A significant change in project value • Loss of profit to the Contractor • Loss of reputation of cost consultancy firm	• Checklist for taking down all the necessary items • Prepare the BOQ in computerized formats • Possess knowledge of current market prices • Be aware of tax changes in Sri Lanka

	• Using incorrect units of measure • Forgetting to include costs • Failure to adhere to the method of measurement • Lack of knowledge of the current market prices • Discrepancy among drawings • Drawing scale errors • Lack of senior staff to supervise • Arithmetical errors during BOQ preparation • Lack of technical knowledge • Failure to include all necessary items		• Provide priority for cost-significant items • Appoint experienced QS to prepare BOQ • Rechecking the BOQ
Unknown physical conditions at the site	• Lack of proper site investigation • Improper/ accurate report formation • Lack of conversation with neighbors • Lack of pre-tender site visit • Unsatisfied number of tests due to financial constraints • Incapable site investigation staff	• Failure to use machinery and equipment • The cost of the project increases • Delay for additional site investigation • New material necessity • New method of construction	• Site visit regularly • Obtain the necessary report at the right time • Employ well-experienced site staff
Inadequate Program Scheduling	• Lack of understanding • Lack of planning • Lack of highly sophisticated software • Unclear about the scope of work • Unexpected events, force majeure, adverse climatic conditions, variations	• Delays in project • Loss of profit to Contractor • Liquidated damages	• Consider all the critical milestones. • Fully concentrate on the scope of work • Utilize highly sophisticated software • Employ qualified professionals
Poor Quality of Procured Materials	• Zero Project Auditing • Poor supervision of materials • Lack of procurement team • Lack of BS standards in specification • Limitation on finances on a material purchase • Lack of availability of specified materials • Improper Quality Assurance procedures by the Contractor • Unethical behaviours of staff and top management • Bribery from Client	• Less-quality construction project • A considerable number of defects • Unable to achieve the success of a project • Reputation damage of the main Contractor • Less durability • Frequent repair and replacement • Collapse of structure	• Proper quality assurance procedures in the contractor company • Proper supervision • Specify the BS and ISO standards for materials during the pre-tender period. • Appoint a procurement committee in the organization led by the highly experienced QS
System and Equipment Failure	• Inadequate supply of professionals • Lack of skilled labour force • Incapable operator • Long-time equipment usage • Lack of proper maintenance • Lack of sufficient lubrication and repair	• Cannot achieve the expected lifetime • Additional material, labour, and equipment are necessary • Productivity decreases	• Proper maintenance • Allow skilled labours to handle the system and equipment • Proper lubrication and repair
Material Shortage	• Delay in ordering materials • Availability of construction materials • Incorrect Design • Errors in BOQ preparation	• Unable to achieve the expected lifetime • Failure in the quality of service • Productivity decreases • Unable to achieve the success of the project	• Proper BOQ preparation • Proper in transportation • Proper material usage • Correct design

	• High wastages • Loss in transportation	• Delay in the commencement of construction activities	
Shortage in accessory facilities	• Poor supervision and increased wastage	• Productivity decreases • Unable to achieve the expected lifetime	• Proper planning of the facilities need • Appoint qualified resource persons
Shortage in skillful workers	• Lack of training and experience to know all the rules • Inadequate skill development programmes • Unavailability of skillful workers in the surrounding area	• Considerable number of defects • Delay to the project • Material shortage • Loss of profit to the Contractor • Less-quality construction project	• Conduct skill development programme for workers • Allocate labours to the specialization work • Hire skills workers to an outside place
Incompetence of transportation facilities	• Difficult to access heavy vehicle	• Difficult to access to the site • Difficult to transport the materials and machinery	• Site visit to the site before construction • Arrange alternative transport facilities • Plan with the site location area
Increase in Site overheads	• Delayed payment • Cost inflation	• Professional reputational damage • Reputational damage to the company	• Pre-plan the project • Proper investigation of site expenditure • Proper allocation overhead cost estimate
Unusual Weather and Force Majeure	• Unusual Weather • Force Majeure	• Unexpected labour shortage • Massive loss to the project • Material shortage • Lack of machine operators • Failure of operation of plant and material • Congestion to passengers • Hardening of cement cannot be used further • It is impossible to dewater from neighboring lands	• Allow contingency percentage in BOQ • Analyse geological reports for the past 10 years • Develop mitigation measures as a pre-plan • Appoint geological specialists to the construction projects
Accident	• Lack of proper signs and instructions • Lack of safety procedures	• Negative feedback from the public • Reputational damage to the company • Loss of profit to the Contractor	• Proper site safety procedure • Appoint a qualified safety officer • Provide sufficient signboards
Poor Coordination	• Poor documentation process • Lack of progress monitoring	• Unable to achieve the success of the project • The cost of the project increases • Loss of profit to the Contractor • Unable to achieve the expected lifetime • Cause dispute among parties	• Monthly meeting • Proper supervision • Daily progress update • Allow friendly communication with the top management
Delay in approval of submittals	• Lack of proper preparation of submittals • Delay in preparing the documents for approvals • Lack of attention by authorities and regulatory bodies • Lack of necessary signatures • Insufficient affidavit by the attorney-at-law	• Delay in purchasing material • Delay in the commencement of construction activities • Amendments to existing water supply and electricity	• Prepare accurately without errors. • Push the staff in the governmental authorities to obtain approvals quickly.
Industrial Disputes	• Contract errors or omissions • Differencing site conditions • Claims error • Error in design, drawings, and specification	• Process of awarding that is longer or more complicated • Extra administrative and managerial costs • Cost overrun and time delays • Relationship deterioration and cooperation breakdown	• Proper communication with participants • Monthly meetings • Appoint Dispute Avoidance Board (DAB) • Proper contract agreement

	• Act of God, Uncertainty Protest by labours • Unrealistic expectations • Delay in Payment • Underpricing to win the tender • Vague contract terms • Having several meanings for one contractual term • Shortage of adequate design details	• Tension and a deteriorating team spirit • Productivity decreases • Communication breakdown and professional relationship • Reputational damage to the company • Professional reputational damage • Profitability and corporate viability are at risk	• Give proper meaning to the contract terms
Subcontractor's Low Credibility.	• Absence of prequalification of sub-contractors • Unavailability of materials and labor • Early disclosure of working hours • Lack of support from the main Contractor • Ambiguity in the scope of work • Limitations of usage of main contractors' preliminaries and overheads • Less experience in the field of construction • Less productive machines and equipment • Lack of financial capability • Lack of professional expertise • Insufficient design information	• Failure in the quality of service • Unable to achieve the expected lifetime of the project. • A considerable number of defects • Reputation damage of the main Contractor • Rework • Increase in liquidity damages • Unable to complete the main contractors scope of work as per schedule	• Proper evaluation and selection of sub-contractors • Check whether you are financially fit or not • The requirement for a concise and accurate sub-contractor agreement • Need to check the availability of equipment and machinery to hire • Obtain data related to experience past similar projects • Draft clear terms and conditions • Carryout proper site visits to ensure the construction as per the shop drawings • Monitoring

4.5. IMPACT OF TR ON THE TIME, COST AND QUALITYOF A RCP IN SRI LANKA

Roads in Sri Lanka constructed in geographically diverse such as mountainous terrain, weak soil, and flood- prone areas make projects susceptible to technical risks. Understanding how technical risks influence the time, cost, and quality provides insights into the severity of the risk to implement the mitigation strategies quickly. Time, cost, and quality are the three elementsa client of the construction project has to demand the project on the market. Addressing these impacts ensures that stakeholders understand the consequences of risks and apply timely strategies to manage or mitigate them, which fulfils the aim of the study.

The understanding on the impact on time would help to implement buffer periods, and introduce risk aware timeliness. Similarly, the understanding of the impact of TRs on the cost would help to plan contingency budget, and the cost- saving opportunities. Besides, the understanding of the impact of TRs on quality would help implement rigorous quality control and quality assurance measures. Eventually, the understanding of the impact of time, cost, and quality on the TRs is vital for implement proactive measures, ensure successful project outcomes with durable infrastructure on RCP in SL. On the other hand, the time, cost, and quality are interconnected; delay in time leads to higher cost, cutting cost can compromise the quality, and prioritizing the high- quality outputs may require additional time, and cost. Achieving the balance between these three aspects would lead to the success of the road project. Considering this importance, the impact of the above three elements on the technical risks of a road construction project in Sri Lanka was explored. Table 3 shows the technical risks and their respective impact on the time, cost, and quality of the road construction projects in Sri Lanka.

Table 3,, Impact of TRs on time, cost, and quality of a RCP in SL

Technical Risks	Time	Cost	Quality
Design Failures	✓	✓	✓
Design variation by Client	✓	✓	
Estimation Errors	✓	✓	✓
Unknown physical conditions at the site	✓	✓	✓
Inadequate Program Scheduling	✓		
Poor Quality of Procured Materials			✓
System and Equipment Failure	✓	✓	
Material Shortage	✓		✓

Shortage in accessory facilities	✓		
Shortage of skillful workers			✓
Incompetence of transportation facilities	✓	✓	
Increase in Site overheads		✓	
Unusual Weather and Force Majeure	✓	✓	
Accident		✓	
Poor Coordination	✓		
Delay in approval of submittals	✓		
Industrial Disputes	✓	✓	
Subcontractor's low credibility.		✓	✓

Accordingly, the TRs, such as design failures, estimation errors, and unknown physical conditions at the site, impact all aspects of a road project's time, cost, and quality. On the other hand, the design variations by the client, system, and equipment failures, incompetence of transportation facilities, unusual weather and force majeure, and industrial disputes impact the time and cost of the RCP in SL. In addition, the material shortage impact on the time and quality. Further, contractors' low credibility impacts on cost and quality. Moreover, eight (8) TRs impact only one element. Therefore, the minimisation and mitigation of TRs in an optimum way considering the impact on the three elements are crucial for the Contractor, project success, and reputation of the Contractor.

5. Discussion

5.1. CONTEXTUALIZATION OF FINDINGS

No previous study has identified the technical risks for RCP in Sri Lanka. This study mounted with a research question "How to minimise and mitigate the technical risks in road construction projects in Sri Lanka"?. This study identifies all the technical risks in road construction projects in Sri Lanka. Having considered the causes for TRs, consequences of TRs, and strategies to mitigate the consequences, the study aims to prepare guidelines. Table 2 acts as self-explanatory, and it will be a guideline for minimising and mitigating the technical risks in road construction projects in Sri Lanka. Nsobila (2015) identified TR in Ghanaian construction projects, and their findings show similarities to the results of this study. The shortage of material was considered a financial and economic risk by Perera et al. (2021), which was considered a technical risk in this study.

The study found that there were some contrasting findings in terms of TRs considered for Sri Lankan road construction projects. Perera et al. (2009) categorised the act of god, adverse weather conditions, and unforeseen site ground conditions as the external and site condition risk categories. However, this study considered the aforementioned risks under technical risks as well. Similarly, this study regarded the increase in site overheads under technical risks, which was categorised under the contractual risk in Perera et al. (2009). In addition, the subcontractors' low credibility was identified as a technical risk because their reliability directly impacts the quality, timeline, and overall success of the project. In addition, the incompetence of transportation facilities was regarded as a technical risk as it directly affected the logistics, safety, and continuity of project execution, potentially impacting the technical success and stability of the project. Further, the accident was considered TR in RCP as it halted the project, causing cascading delays for subsequent phases of the RCP. Accidents expose the projects to regulatory consequences, requiring additional compliance checks and impacting technical credibility. Moreover, industrial disputes reduce productivity and impact dependent technical activities in the project workflow. According to many past studies (Ahmed et al., 2018; Aslam et al., 2019; El-Sayegh & Mansour, 2015), delay in obtaining No-objection-certificate (NOC) from authority was considered a risk, where it was disregarded for Sri Lankan road projects, as its probabilityof occurrence is negligibly low.

5.2. IMPLICATION OF THE STUDY

Eighteen (18) technical risks are identified for the road construction sector in Sri Lanka. This study identified separate causes for every technical risk. Accordingly, eradicating these causes in road construction projects will significantly reduce the TR in RCP in Sri Lanka. Similarly, the study provided consequences for every technical risk. If the causes of the technical risks are not controlled well, the emergence of TRs cannot be eliminated; thus, consequences will be experienced by the parties involved in the project. Thus, minimising the consequences of the technical risks can be minimised by eliminating the causes of the TRs. Similarly, the mitigation of the consequences can be carried out by imposing strategies for the consequences. This would be the foremost implication of this study.

By implementing the study's findings through eradicating the causes of TRs and utilizing the strategies to mitigate the consequences of TRs, the road construction sector would experience several benefits such as enhanced project planning and execution, improved cost management, reduced cost overruns, reduction of project delays, increased safety for workers, initiatives for innovation in road construction, and better decision making for stakeholders. In addition, this study has the potential to reduce the added cost caused by repairs, redesigns, and extra resources. Further, understanding the study will lead to optimizing resource allocation. Besides, the project team can incorporate risk mitigation and minimisation strategies into their road construction project plan.

5.3. LIMITATIONS IN THE STUDY

Out of thirteen (13) interviews, four (4) were QSs, seven (7) were Engineers, one (1) was Project Manager and one (1) was Project Director. If the composition of technical roles were interviewed, the outcomes might differ. This is one limitation of the study. The applicability of the findings can vary from country to country, given the nature of the road construction sector. In addition, the data collected is from Contractor's perspective. Thus, the findings of the study and their implications are more towards the Contractor.

6. Conclusions

In Sri Lanka, building roads is essential to economic growth since it connects rural and urban areas and improves trade, tourist, and service accessibility. Technical risk minimisation and mitigation in road construction projects in Sri Lanka are the unspoken areas in the extant literature. Risk and risk response strategies were identified for several risks in Sri Lankan construction projects, and none have focused on technical risk identification and ways to minimise and mitigate it on RCP in Sri Lanka. Thus, in fulfilment of the existing gap, this study investigated the technical risks in road construction projects in Sri Lanka. Among the identified eighteen (18) TRs in Sri Lanka, estimation errors are considered the most critical risks the contractors face. The study provides ways to minimise and mitigate the consequences of risk. If the TRs are minimised and mitigated, it may save time and money, eventually adding value to the project. This study impacts the design and construction phases of road construction projects toward risk-free construction.

The study recommends a few immediate actions such as (a) integration of new technologies for early detection of risks, (b) create risk minimization and mitigation culture among road construction organizations, (c) taking wise decisions at the design stages to minimise the technical risks, (d) impose government regulations regarding risk management to the projects, (e) develop communication and coordination among the stakeholders, and (f) conduct training and seminars to risk minimisation.

This study contributes to the industry practitioners by uniquely adding guidelines to the body of knowledge on ways to minimise and mitigate the technical risks in road construction projects in Sri Lanka. Further, this study will contribute to the industry stakeholders' creation of a structured environment for decision-making and project adaptability. Moreover, the study provides novel insights for the project team to create contingency plans, minimising potential downtime, and keep the project on schedule. The guidelines contribute to the investors by providing confidence in their investment security in road infrastructure development. Regarding the contribution to the theory, the study fills the gap by providing a guideline. As the literature on the minimisation and mitigation of the technical risks in RCP in Sri Lanka is scarce, this study can be referred to when conducting studies related to risk and road construction in Sri Lanka.

This study proposes future research on the same topic as this study; however, they can be conducted from a client or consultant perspective. Similarly, the same study can be conducted on other phases of the construction projects. The investigation of technical risks in road construction projects in Sri Lanka from different perspectives of the stakeholders and different phases of the construction phase would give a whole picture of TRs in RCP in Sri Lanka. Besides, similar studies can be carried out in other types of infrastructure and building projects. Further, the study proposes the integration of emerging technologies such as artificial intelligence (AI) and big data for future TR management. Similarly, the study proposes incorporating software tools for TR management in construction. Thus, the study proposes further research to investigate the software tools applicable to TR management in RCP and the applicability of emerging technology, such as AI and big data, for TR management in RCP.

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