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Risk Management in Civil Engineering by FTA, FMEA and Risk Matrix

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Abstract

Infrastructure projects, particularly in civil engineering, are fraught with uncertainties that manifest as both physical and financial risks. The project report, titled Quantifying and Managing Financial and Physical Risks in Infrastructure Projects, aims to bridge the existing gap between managing these two critical categories of risks. By integrating advanced statistical methodologies such as Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Risk Matrix, and Regression Analysis, this study systematically identifies, analyses, and prioritizes risks based on their likelihood and impact. The use of FMEA emphasizes quantifiable risk assessment through Risk Priority Numbers (RPNs), while FTA offers a structured, root-cause analysis framework for understanding failure events. A significant aspect of this study is the innovative utilization of software tools such as Power BI and Microsoft Visio, which enhance data representation, visualization, and collaboration. Power BI excels at creating user-friendly dashboards that provide real-time insights into potential risks, enabling proactive identification and response. Meanwhile, Microsoft Visio facilitates the creation of detailed diagrams that visually depict complex risk interdependencies. These diagrams serve as valuable communication tools, fostering a shared understanding of risk dynamics among all stakeholders. By effectively leveraging these tools, the project significantly improves decision-making processes and empowers stakeholders to formulate and implement actionable risk mitigation strategies. The analysis identifies significant challenges, including delays in obtaining environmental clearances, land acquisition hurdles, and unexpected natural events such as cyclones and heavy rainfall. The results emphasize the need for a comprehensive risk management framework that addresses financial and physical risks in an integrated manner rather than in isolation. This approach provides actionable strategies for optimizing resource allocation, reducing cost overruns, and ensuring the timely completion of projects. This work not only serves as a practical guide for managing risks in road and infrastructure projects but also emphasizes the broader implications for the civil engineering industry. The proposed methodologies and tools can drive more efficient, cost-effective, and resilient infrastructure development. Moreover, the recommendations encourage a culture of risk awareness and proactive planning, which are essential for sustainable growth in the sector.

Keywords: Infrastructure projects, civil engineering, physical risks, financial risks, risk management, failure mode and effects analysis (FMEA), fault tree analysis (FTA), risk matrix, regression analysis, risk priority numbers (RPNS), software tools, Power Bi, Microsoft Visio, risk mitigation strategies, risk awareness, proactive planning

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INTRODUCTION

Projects involving infrastructure, especially road development, are by their very nature complicated and fraught with many unknowns. These uncertainties might show up as financial risks like cost overruns, income shortfalls, or shifts in the economy, or they can show up as physical risks like construction delays, material shortages, or natural disasters. To reduce these risks, increase project profitability, and guarantee successful project delivery, effective risk management is crucial. A thorough methodology for estimating and controlling both material and monetary risks in infrastructure projects is important. This study aims to identify, evaluate, and rank the major risks that may affect project performance by utilizing a variety of strong risk assessment techniques, such as Failure Mode and Effects Analysis (FMEA), risk matrix analysis, fault tree analysis, and regression analysis [1–3].

Physical risks are real dangers that have the potential to immediately interfere with the building of the physical infrastructure and related procedures. These hazards may originate from a number of sources, such as operational, human, and environmental variables. They are especially difficult since, in order to lessen their effects, they frequently call both quick action and a large investment of resources. Economic uncertainties that have the potential to impact infrastructure projects' overall profitability and financial sustainability are referred to as financial risks. They frequently have a domino effect, affecting all parties involved in the supply chain, from end users to contractors. The ability to successfully predict, measure, and manage a wide range of risks is essential to the success of infrastructure projects [4–7].

IDENTIFICATION OF THE PROBLEM

In today's increasingly complex and interconnected world, successful project execution hinges on effective risk management. While various methodologies exist for assessing and mitigating individual risk types (e.g., technical, financial, reputational, environmental), a significant gap persists: the lack of a holistic framework that comprehensively addresses the interplay and interdependencies among these diverse risks [8–10].

Traditional Approaches Often Compartmentalize Risk Assessment, Leading To:

- *Suboptimal decision-making*: Isolated risk assessments may fail to capture the full spectrum of potential consequences and may not identify the most effective mitigation strategies [11–14].
- *Missed opportunities*: The interconnectedness of risks can create cascading effects that are not readily apparent when risks are analysed in isolation.
- *Increased vulnerability*: A fragmented approach may leave organizations exposed to unforeseen risks and their potential impacts.

This research aims to address this critical gap by exploring the development and implementation of an integrated risk management framework. This framework will:

- *Promote a holistic understanding of risk*: By considering the interconnectedness of various risk types, the framework will enable a more comprehensive and nuanced assessment of project vulnerabilities.
- *Enhance decision-making*: By providing a unified view of risk, the framework will support more informed and strategic decision-making throughout the project lifecycle.
- *Improve risk communication*: By fostering a shared understanding of risk across different stakeholders, the framework will facilitate effective communication and collaboration.

By addressing these challenges, this research seeks to contribute to more robust and resilient project outcomes across a wide range of domains [15–17].

METHODS FOR RISK ASSESSMENT

Risk Matrix

Verification began with a simple technique that included both quantitative and qualitative characteristics. The technique aims to identify and assess risk. It is a description of the project's existing control of risk variables, which is relatively simple to analyse and evaluate, as well as to execute. The contractual scale represents the range of measurements for a specific criterion (Figure 1) [18–21].

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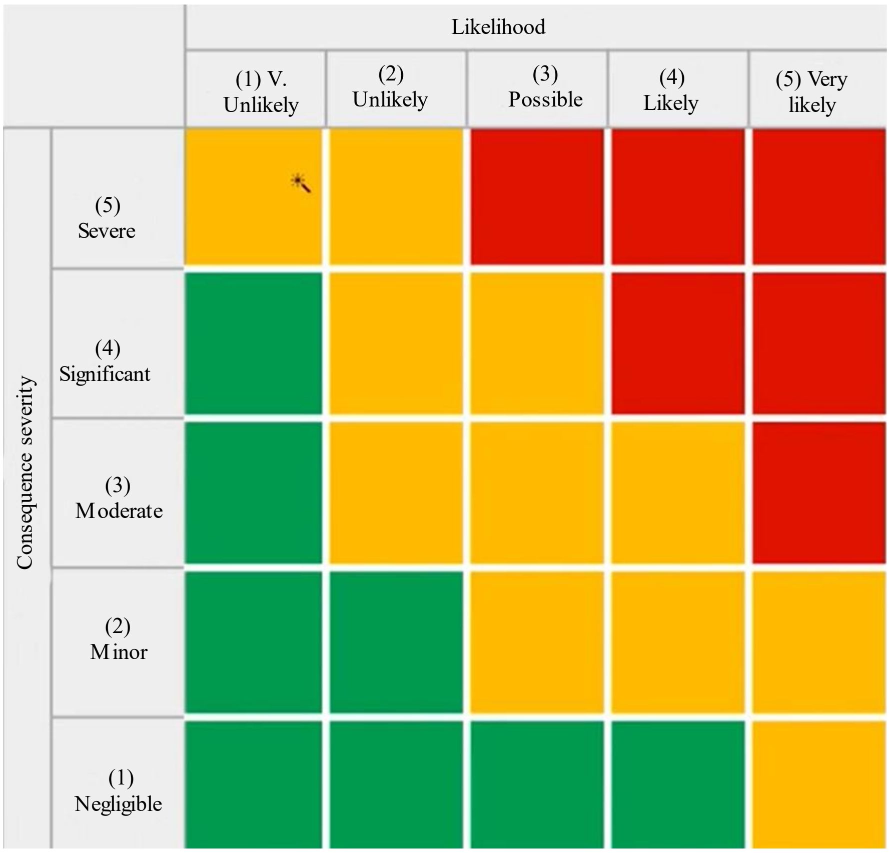

Figure 1. Risk matrix.

Advantages of risk matrix

- *Simplified risk assessment*: It provides a straightforward framework for evaluating risks based on their likelihood and impact.
- *Prioritization*: The matrix helps prioritize risks, enabling project teams to focus on the most critical ones.
- *Communication*: The visual nature of the matrix facilitates clear communication of risks among team members and stakeholders.
- *Resource allocation:* The matrix helps allocate resources efficiently by focusing on risks with the highest potential impact [22–25].
- *Risk mitigation planning*: The matrix helps identify potential mitigation strategies for each risk based on its severity.

Disadvantages of risk matrix

- *Subjectivity*: The assessment of likelihood and impact can be subjective and vary among individuals.
- *Limited scope:* The method focuses on individual risks without considering interdependencies or cumulative effects.
- *Lack of detail:* The matrix may not provide enough detail about the nature and causes of risks.
- *Qualitative assessment*: The matrix primarily relies on qualitative assessments, which can be less precise than quantitative methods.

FMEA

It is a risk management method of identifying and preventing system product and process problems before they occur. Failures are prioritized according the severity of event, frequency of their occurrence and how easily they can be detected.

Involves Generation of a Risk Index (RPN: Risk Priority Number) on basis of three criteria: Severity (S): Damages caused by the event on the project, Occurrence; (O): The likeliness of the event to occur; and Detection (D): Detecting the failure and taking proactive measures to reduce the severity (Table 1).

RPN=S×O×D

Minimum RPN=1
Maximum RPN=1000

Advantages of FMEA

- It helps create better designs for processes and goods.
- Higher dependability.
- Better quality.
- Enhanced security.
- Enhanced customer satisfaction.
- It helps to reduce expenses.
- Reduces re-design expenses and development time.
- Lowers warranty expenses.
- Reduces non-value-added processes and waste.
- Participates in the creation of control plans, requirements for testing, plans for optimal maintenance, reliability, growth analysis, and associated tasks.

Disadvantages of FMEA

FMEA only identifies the primary failure modes in a system by using the top-down approach, which eliminates operator error.

If two failure events have the same RPN number than the ranking is based on the RPN number so a less severe event may be ranked higher than the event which is more severe.

FTA

It is a methodical technique to problem-solving, troubleshooting, and utilizing a diagram to determine the underlying reason of a failure. It is a flexible tool for a root cause analysis since it may be used to investigate a single failure or methodically look at a collection of components.

FTA is a top-down, deductive reasoning failure analysis that combines a sequence of lower-level occurrences to analyse an undesirable state of a system using Boolean logic. The primary purpose of this analytical technique is to comprehend how systems can malfunction and to determine the most effective means of risk mitigation.

Typically, the Tree is expressed using standard logic gate symbols. A Cut Set is the path across a tree that connects an event to an initiator. A Minimal Cut Set is the shortest plausible path from the fault to the initiating event in the tree. There are two ways to evaluate a fault tree:

1. Qualitative approach; and
2. Quantitative approach.

Table 1. FMEA model.

	Severity(S)	**Occurrence(O)**	**Detection(D)**	**RPN=S×O×D**
Potential Failure 1	5	2	10	100
Potential Failure 2	2	10	5	100
Potential Failure 3	2	5	10	100
Potential Failure 4	10	5	2	100

Advantages of FTA

FTA encourages a proactive approach to risk management by identifying potential failures before they occur, allowing for corrective actions and mitigation strategies to be implemented in advance. This helps prevent catastrophic incidents and ensures the safety of construction workers and the public. By pinpointing potential weak points within a system, FTA helps engineers design and build more robust and reliable structures. This is crucial for ensuring the long-term functionality and performance of civil engineering projects.

Addressing potential failures during the design and construction phases is significantly more cost-effective than dealing with failures after a project is completed. FTA helps identify potential issues early on, reducing costly repairs and rework later in the project lifecycle.

The comprehensive analysis provided by FTA allows engineers to make more informed decisions about design choices, construction procedures, and maintenance plans. This data-driven approach leads to better overall project outcomes.

Disadvantages of FTA

Conducting a thorough FTA requires gathering vast amounts of data about the components, failure modes, and potential interactions within a complex system. Collecting this data can be a time-consuming and resource-intensive process. Some aspects of FTA involve subjective judgments and assumptions. Different engineers may have varying interpretations of the data or potential failure modes, leading to potential discrepancies in the analysis.

FTA focuses on identifying potential failures within the system itself. It does not account for external factors, such as environmental hazards or human errors, which could significantly impact the safety and performance of a project.

MODELING

In order for any mathematical model to be more accurate, we must first create our own models. Since data is the most important component of our project, we must be extra cautious that the information we collect matches our objective.

The data of national highway construction in state of Tamil Nadu by using both flexible and rigid pavement construction method was taken for further study.

Data analysis: By using all those three methods the actual models were made using the obtained data from the industry.

FTA

FTA is the deductive technique and it is used to classify the relationship between failure system and event. From obtained data we create the various models of FTA (Figure 2).

Cost model

Cost is now considered the primary study criterion based on the data collected, and the number of events that can affect the project's overall cost is then determined.

In this model, cost is a base event, where labour cost, material cost fluctuation and heavy demand of materials are major failure events. Likewise, increase in labour wages, number of labours, water demand, asphalt shortage, cost of land, cost of aggregate, rate of interest, material extraction, utility cost and cost due to natural calamities are the basic failure events which lead to major failures events and eventually increase in cost.

The cost model is as per shown in Figure 3:

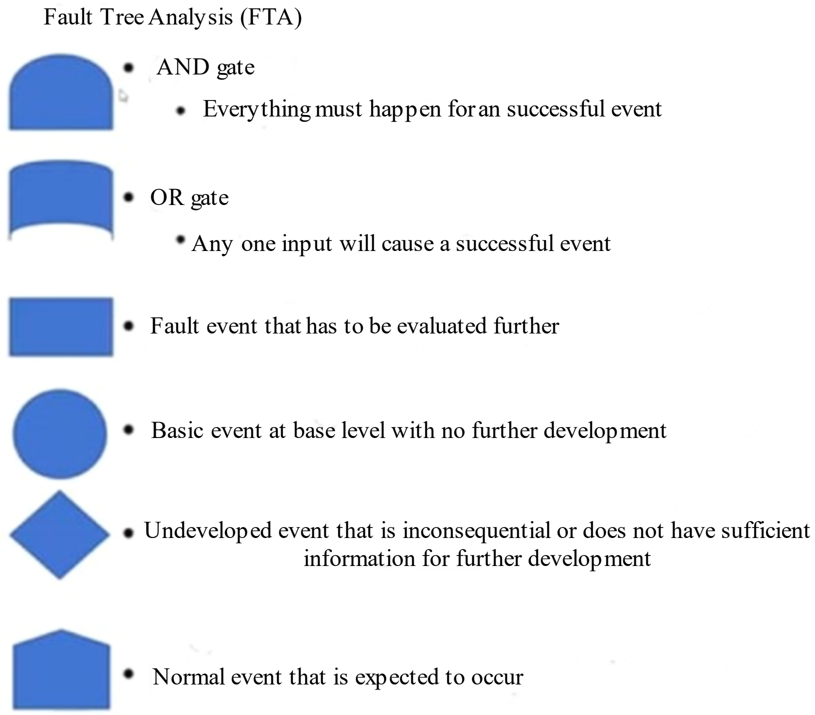

Figure 2. FTA.

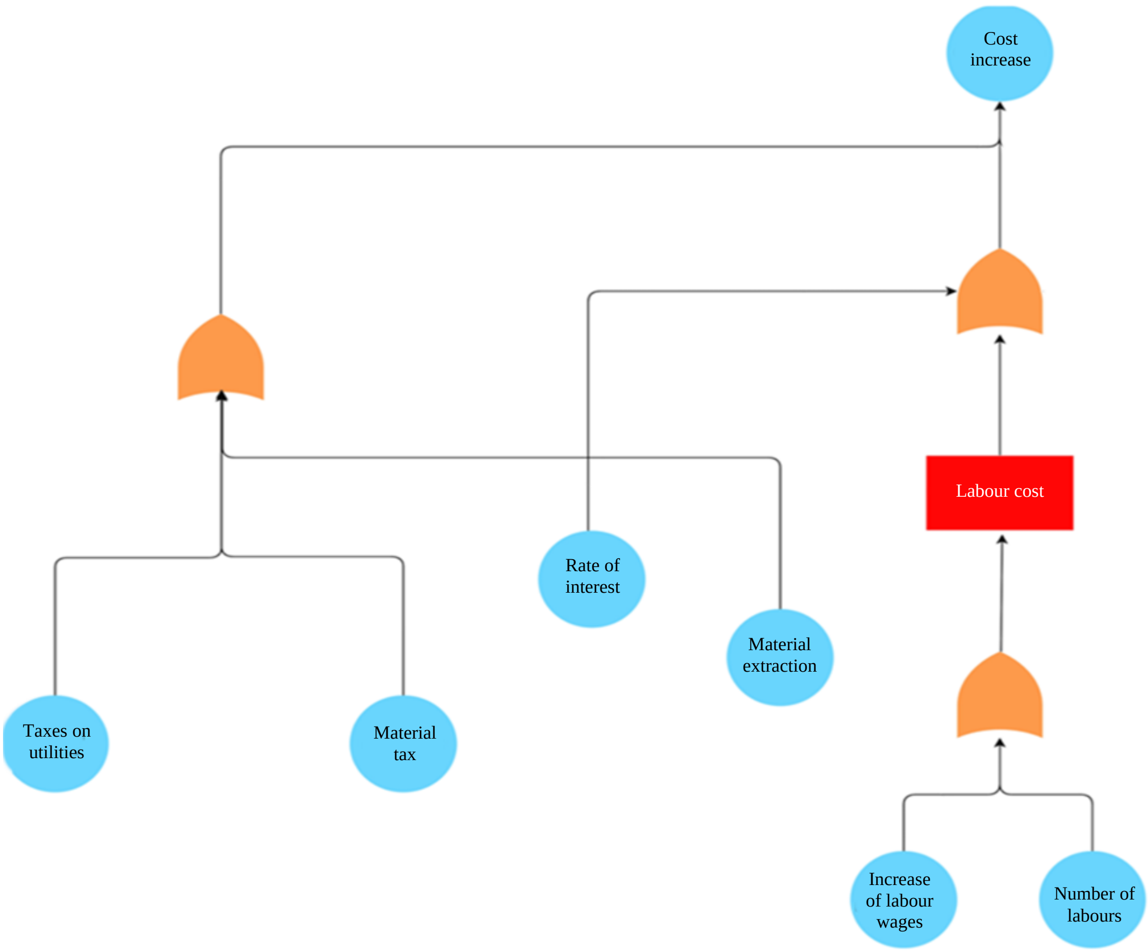

Figure 3. Cost model.

Time Model

The primary focus of this model is on how different factors contribute to an increase in project time. This model's main focus is on the various elements that lead to an increase in project time. According to this model, the main failure events for the time delay model are delays in the procurement of materials, delays in the storage of materials, transportation problems, natural causes, improper planning, improper designing, delays in the design and procurement process, challenges obtaining permission for soil extraction, and unforeseen purchases of public land. Likewise, transportation delay, insufficient space, flood, Covid-19, protest of land owners, water supply and electricity transmission line are basic failure events.

The time model is as per shown in Figure 4:

FMEA

Following the assignment of numerical values, a Risk Priority Number (RPN) is produced, which provides insight into the likelihood that the occurrence would result in a delay or raise project costs.

If the RPN numbers of two events are same, then their ranking is determined on the basis of which event has higher severity and if severity is also same then the criteria of occurrence is taken into account and ranking of failure events is obtained accordingly. After obtaining the RPN numbers, the probability of each event is determined and a discrete graph is plotted between probability and time delay, which is obtained from the industry data.

The FMEA model is shown in Table 2. Based on the above model, it can be concluded that Cyclone has the highest RPN hence it has the highest potential to cause harm to them project and shortage of labours has the least audacity.

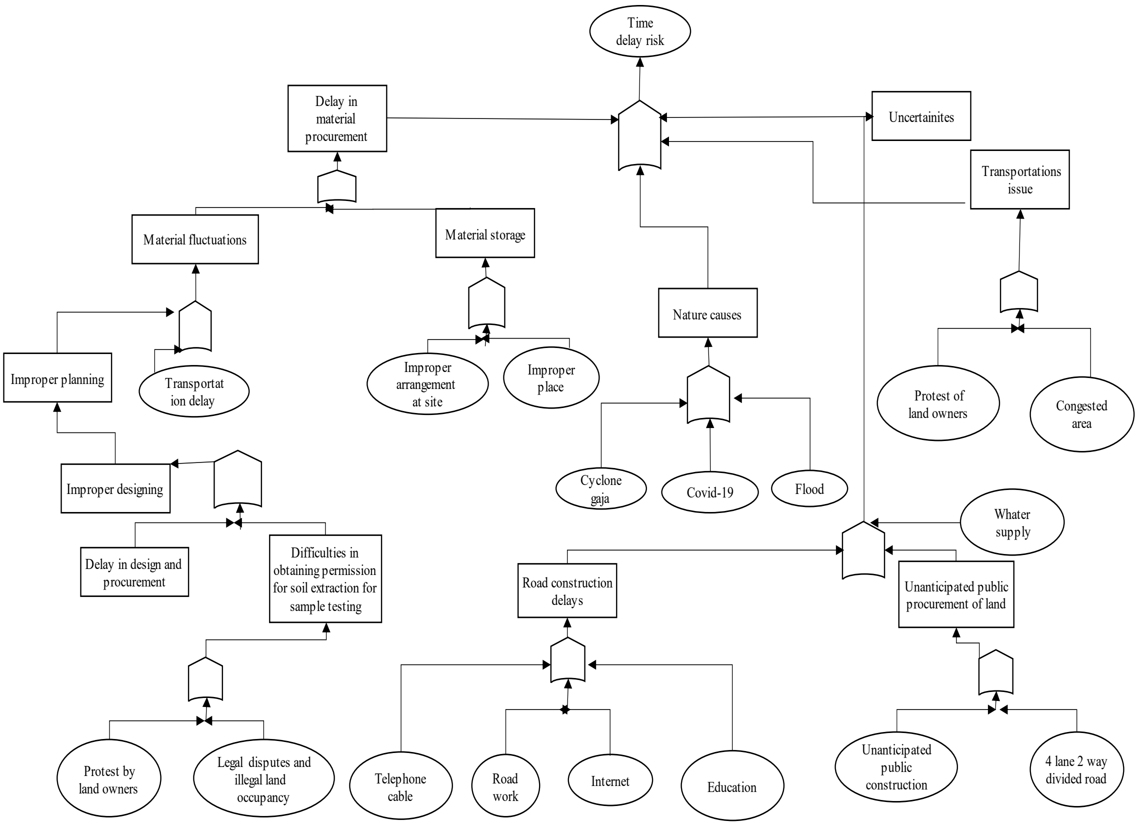

Figure 4. Time model.

Table 2. FMEA.

Construction of rigid /flexible payment							
S.N.	**Potential failure**	**Severity (s) (1–10)**	**Occurrence (O) (1–10)**	**Detection (D) (1–10)**	**RPN No. (S×O×D)**	**Impact of factor**	**Time delay**
1	Environmental clearance	9	9	3	243	0.243	39
2	Cracks due to stress variation	4	8	6	192	0.192	0
3	Delay in legal approvals	9	7	3	189	0.189	137
4	Covid 19	9	2	10	180	0.18	270
5	Borrow are permission	8	6	3	144	0.144	94
6	Quality of water (salty water)	6	4	6	144	0.144	4
7	Unseasonal heavy rainfall	7	4	5	140	0.14	10
8	Cyclone GAZA	9	5	3	135	0.135	46
9	Additional structure due to public demand	5	8	3	120	0.12	25
10	Pot holes	5	7	3	105	0.105	0
11	Outflow of water from dam	7	7	2	98	0.098	15
12	Imposed ban quarrying	8	2	6	96	0.096	48
13	Quality of material	6	4	4	96	0.096	5
14	Alligator cracks	4	10	2	80	0.08	0
15	Construction material for embankment	6	2	6	72	0.072	12
16	Water logging	4	6	3	72	0.072	30
17	Existing structure house	7	9	1	63	0.063	38
18	Formation of ruts	2	10	3	60	0.06	0
19	Vertical displacement of pavement slab	7	3	2	42	0.042	0
20	Unevenness of pavement	2	7	3	42	0.042	10
21	Existing religious structure	10	3	1	30	0.03	60
22	Land availability	6	5	1	30	0.03	394
23	Shortage of labours	6	5	1	30	0.03	128

Risk Matrix

On X-Axis the Probability pertains to the extent of how likely it is for the risk to occur.

Risk Rating Levels (Probability of Occurrence)

1. *Rare*: unlikely to happen
2. *Unlikely*: possible to happen
3. *Moderate*: likely to happen
4. *Likely*: almost sure to happen
5. *Almost certain*: sure to happen

On Y-Axis the Impact aims to determine the level of effects that the hazard can cause to the project.
Impacts:

1. Insignificant
2. Minor
3. Significant
4. Major
5. Severe

The Risk Level is generated by the relation Risk Level = Probability × Impact

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Analysis Based on Risk Levels

- *1–4:* Acceptable: no further action may be needed and maintaining control measures is encouraged.
- *5–9:* Adequate: may be considered for further analysis.
- *10–16*: Tolerable: must be reviewed in a timely manner to carry out improvement strategies.
- *17–25*: Unacceptable: must implement cease in activities and endorse for immediate action.

The Risk Matrix is as per shown in Figure 5:

OPPORTUNITIES AND CHALLENGES

Opportunities

The adoption of advanced tools and methodologies presents significant opportunities to enhance risk management in infrastructure projects. Techniques like Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA), and Regression Analysis enable proactive identification and prioritization of risks, while tools such as Power BI and Microsoft Visio improve data visualization and stakeholder collaboration. These innovations shift risk management from reactive to strategic, enhancing decision-making and project outcomes.

Integrating financial and physical risk management creates opportunities for holistic project planning. Treating these risks as interconnected rather than separate challenges help optimize resources, reduce costs, and prevent delays. This approach equips project managers with actionable strategies to handle uncertainties effectively, ensuring greater resilience and sustainability in infrastructure development.

Risk matrix

Likelihood

Severity	Rare	Unlikely	Possible	Likely	Almost certain
Catastrophic	Covid 19	Cyclone GAZA	Existing religious structures	Environmental clearance	Delay in legal approvals
Severe	Imposed ban on quarrying	Vertical displacement of pavement slab	Outflow of water from dam	Borrow area permission	Existing private establishments
Major	Saline water	Unseasonal heavy rain fall	Quality of material	Shortage of labours	Land availability
Moderate		Construction material for embankment	Water logging	Cracks due to stress variation	Pot holes
Minor		Unevenness of pavement	Formation of ruts	Alligator cracks	Additional structures due to public demand

Figure 5. Risk matrix showing reduced risk of hazards.

This study highlights opportunities to standardize risk management practices and promote awareness within the civil engineering industry. Applying these strategies to areas like environmental clearances, supply chain disruptions, and natural hazard preparedness can significantly improve project efficiency and sustainability, setting a new benchmark for success in infrastructure projects.

Challenges

Environmental and Land Acquisition Challenges

Delays in environmental clearances and land acquisition processes represent significant hurdles in infrastructure projects. These challenges often arise due to bureaucratic inefficiencies, legal disputes, and resistance from local communities. For instance, projects frequently face opposition from landowners who refuse to vacate their property, even after compensation agreements, leading to legal battles and prolonged delays. Furthermore, the requirement for environmental approvals, such as relocation of irrigation systems or obtaining clearances for construction in ecologically sensitive zones, adds to the complexity and timeline of project execution. Addressing these issues requires streamlined processes, community engagement, and proactive legal frameworks to minimize disruptions.

Unpredictable Natural Events

Unforeseen natural events, including cyclones, heavy rainfall, and floods, pose substantial risks to infrastructure projects. These events can lead to halted construction activities, damage to ongoing work, and additional costs for restoration. For example, projects impacted by cyclones like Cyclone GAZA have experienced extended delays due to incessant rains, damaged infrastructure, and subsequent recovery work. Additionally, events like waterlogging and unexpected dam water releases exacerbate delays in construction. To mitigate these risks, projects must incorporate robust contingency plans, invest in resilient designs, and employ predictive weather analysis tools.

Supply Chain and Workforce Disruptions

Delays in the procurement of essential materials, labour shortages, and supply chain interruptions further compound the challenges. Global supply chain crises, local transportation issues, and scarcity of resources such as soil or construction materials can significantly impede progress. Additionally, events like the COVID-19 pandemic have highlighted vulnerabilities in workforce availability and resource distribution, causing cascading delays. To counteract these challenges, effective risk management strategies should include flexible procurement plans, stockpiling critical resources, and ensuring alternative supply chains. Investments in workforce training and deployment of automated systems can also reduce dependency on manual labour and improve overall project resilience.

Strategies to Address Challenges in Infrastructure Projects

Environmental and Land Acquisition Challenges

Delays in environmental clearances and land acquisition are major obstacles. Streamlined regulatory frameworks and digital platforms for submitting and tracking clearances can speed up approvals. Early stakeholder engagement, transparent compensation packages, and relocation assistance help mitigate resistance. Fast-track courts and dedicated legal teams can resolve land disputes quickly, while identifying potential hurdles during the planning phase allows for effective contingency strategies.

Unpredictable Natural Events

Extreme weather events require resilient infrastructure designs that incorporate flood-resistant and adaptive construction techniques. Predictive analytics and advanced forecasting tools help anticipate adverse conditions. Disaster recovery plans with emergency funds, resources, and workforce safety protocols minimize downtime, while insurance coverage ensures financial protection and quicker recovery.

Supply Chain and Workforce Disruptions

Supply chain disruptions and workforce shortages can be mitigated by diversifying procurement channels and establishing buffer stock for critical materials. Regular training programs and crossskilling initiatives create a flexible workforce, while automation technologies like robotics and prefabrication reduce reliance on manual labour. A crisis management framework ensures resource allocation during disruptions like pandemics.

These strategies enhance operational efficiency, reduce risks, and contribute to the timely delivery of resilient and sustainable infrastructure projects.

IMPACT OF PROJECT

Increased Efficiency

Reduced failure cycles: By implementing robust risk management strategies and proactive hazard identification, this project aims to minimize costly delays, rework, and project failures. This translates to smoother project execution with fewer disruptions, ultimately enhancing overall efficiency.

Improved stakeholder collaboration: Effective communication and collaboration are essential for successful project delivery. This project emphasizes open and transparent communication channels among all stakeholders, including engineers, contractors, clients, and regulatory bodies. This fosters better coordination, reduces misunderstandings, and facilitates timely decision-making, thereby improving project efficiency.

Cost-Effectiveness

Reduced risk of hazards: By proactively identifying and mitigating potential hazards, the project minimizes the likelihood of costly accidents, injuries, and environmental damage. This not only reduces direct costs associated with such incidents but also avoids potential legal liabilities and reputational damage.

Optimized resource utilization: Improved efficiency, as discussed earlier, directly translates to optimized resource utilization. By minimizing delays, rework, and wastage, the project can achieve cost savings while maintaining or even exceeding performance expectations.

Time Savings

Accelerated project completion: By streamlining project workflows, minimizing disruptions, and optimizing resource allocation, the project can be completed more quickly than traditional approaches. This accelerated delivery can provide significant benefits to the client, including earlier occupancy of the facility, faster return on investment, and reduced financing costs.

Broader Impacts on Civil Engineering

Advancements in project management: The successful implementation of this project can contribute to the development of innovative project management methodologies and best practices within the civil engineering field. These advancements can be adopted by other projects, leading to widespread improvements in efficiency, cost-effectiveness, and safety.

Technological Innovation: The project may involve the adoption of cutting-edge technologies, such as Building Information Modelling (BIM), drones, and robotics, which can revolutionize the way civil engineering projects are designed, constructed, and maintained.

Enhanced professional development: The project can provide valuable learning opportunities for engineers and other professionals involved, fostering professional growth and advancing the overall knowledge base within the civil engineering field.

CONCLUSION

This project has successfully leveraged a range of statistical techniques, including Risk Matrix, Failure Mode and Effects Analysis (FMEA), and Fault Tree Analysis (FTA), to conduct a comprehensive data analysis. Our evaluation has identified Microsoft Visio as the most suitable tool for

FTA modelling, while Power BI has proven invaluable for effectively visualizing and presenting the analysed data.

FMEA emerges as the most effective method for road management risk analysis due to its comprehensive and proactive approach. Unlike FTA, which is limited to single-event failure analysis, FMEA systematically identifies all potential failure modes and their effects. Additionally, it outperforms the Risk Matrix by offering precise risk prioritization through Risk Priority Numbers (RPN) based on severity, occurrence, and detection. This makes FMEA a more reliable tool for prioritizing and mitigating risks, ultimately enhancing safety and system reliability.

The insights gleaned from these analyses underscore the critical importance of land availability and securing environmental approvals as pivotal factors in successfully managing road infrastructure projects. These findings emphasize the need for proactive planning and engagement with stakeholders to navigate these complex challenges and ensure project success.

Future Scope

The current research represents a valuable initial step in exploring the application of regression analysis for project prediction in civil engineering. To further enhance the model's effectiveness and broaden its applicability, the following steps are crucial:

Data Expansion

The current study utilized data from a single project. Expanding the analysis to encompass a larger dataset from multiple projects will significantly improve the model's robustness and generalizability. A broader dataset will allow for more accurate identification of patterns, trends, and correlations, leading to more reliable predictions.

Risk Mitigation Strategies

Developing and integrating specific risk mitigation strategies for each identified project type will enhance the practical value of the predictive model. This will empower project managers with actionable insights and concrete steps to address potential challenges proactively.

Regression Analysis Refinement

Continuous refinement of the regression analysis model is essential to improve its accuracy and predictive power. This may involve exploring different regression techniques, incorporating additional relevant variables, and optimizing model parameters. By pursuing these future directions, this research can contribute significantly to advancing project management practices in civil engineering, leading to more efficient, cost-effective, and successful projects that benefit both the industry and society as a whole.

REFERENCES

1. Wahbi Albasyouni, Ibrahim Abotaleb, Khaled Nassar. Proposing the Use of Failure Mode and Effect Analysis (FMEA) as Risk Assessment Tool in Construction. International Journal of Innovative Technology and Exploring Engineering (IJITEE). 2023; 12(12): 6–14.
2. Siu MF, Ekyalimpa R, Lu M, Abourizk S. (University of Alberta, Edmonton, Alberta, Canada). Applying Regression Analysis to Predict and Classify Construction Cycle Time. ASCE International Workshop on Computing in Civil Engineering. 2013; 669–676.
3. Wessiani NA, Yoshio F. Failure mode effect analysis and fault tree analysis as a combined methodology in risk management. IOP Conf Ser: Mater Sci Eng; IOP Publishing. 2017; 337: 012033.
4. Angeline Swarna M, Venkatakrishnaiah R. Fault Tree Analysis in Construction Industry for Risk Management. IJCSEIERD; ISRJournals and Publications. 2014; 2(1): 15–21.
5. Rifat Sonmez. (Middle East Technical University, Ankara 06531, Turkey). Conceptual cost estimation of building projects with regression analysis and neural networks. Can J Civ Eng. 2004; 31(4): 677–683.

6. Agnieszka Dziadosza, Mariusz Rejmentb. Risk analysis in construction project - chosen methods. Elsevier Ltd.; Procedia Eng. 2015; 122: 258–265.
7. Bagus Wickra Dytha, Tatang Akhmad Taufik. Risk analysis using risk failure mode and effect in implementation of integrated digital reporting with power bi dashboard, The 7th International Conference on Management of Technology. 2023.
8. Lefayet Sultan Lipol, Jahirul Haq. Risk analysis method: FMEA/FMECA in the organizations. International Journal of Basic & Applied Sciences (IJBAS-IJENS). 2011; 11(05): 49–57.
9. Infrastructure Risk Group. Managing Cost Risk & Uncertainty in Infrastructure Projects Leading Practice and Improvement: Report from the Infrastructure Risk Group. 2013.
10. Victor Andre Ariza Flores, Victor Andre Ariza Flores, Victor Andre Ariza Flores. Enhancing Risk Management in Road Infrastructure Facing Flash Floods through Epistemological Approaches. Buildings. 2024; 14(7): 1931.
11. Nolberto Munier. Risk Management for Engineering Projects. Cham: Springer; 2014.
12. Erica Caetano Roos, Joana Siqueira de Souza, Francisco Jos´e Kliemann Neto. Project risks and regulation in transport infrastructure: A study in Brazilian agencies concessions planning process. Transportation Research Interdisciplinary Perspectives (TRIP). 2024; 23: 101031.
13. Akoh Sani Reuben. Risk management framework for highway construction projects in Nigeria. Thesis. Heriot-Watt University; 2018.
14. Ashley David B, Diekmann James E, Molenaar Keith R. Guide to Risk Assessment and Allocation for Highway Construction Management. US Department of Transportation; 2006 Oct
15. Zhang G, Zou PXW. Fuzzy Analytical Hierarchy Process Risk Assessment Approach for Joint Venture Construction Projects in China. J Constr Eng Manag. 2007; 133(10): 771–779.
16. Office of Government Commerce. Managing Successful Projects with PRINCE2. The Stationery Office; 2009.
17. Mohamed M, Janaka R, George J. CTAN for Risk Assessments Using Multilevel Stochastic Networks. J Constr Eng Manag. 2007; 133(1): 96–101.
18. Paslawski J. Flexibility as risk management option implemented in the bridge repair. Balt J Road Bridge Eng. 2011; (4): 258–266.
19. Raftery J. Risk analysis in project management. London: E. and F. N. Spon, Routledge; 1994.
20. Gupta S, Prasad S. Impact of digital transformation on organizational performance: A conceptual framework. Int J Bus Manag. 2020;15(5):12–25.
21. Westerman G, Bonnet D, McAfee A. Leading digital: Turning technology into business transformation. Boston: Harvard Business Review Press; 2014.
22. Matt C, Hess T. Digital Transformation Strategies. Bus Inf Syst Eng. 2015; 57(5): 339−343.
23. Stamatis DH. Risk Management Using Failure Mode and Effects Analysis. 2nd ed. Milwaukee (WI): American Society for Quality; 2019. p. 45–67.
24. Kerzner Harold. Project Management: A Systems Approach to Planning, Scheduling, and Controlling. 8th Edn. John Wiley & Sons; 2002.
25. Project Management Institute. A Guide to the Project Management Body of Knowledge (PMBOK Guide). Project Management Institute; 2000.

