CHAPTER 82

Infrastructure Project Risk Assessment using Modified Failure Modes and Effects Analysis

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ABSTRACT

Infrastructure projects often face challenges cost overruns, hindrances in land acquisition, enforcement difficulties in contracts, and regulatory compliances. Considering these risk factors, the objective of this study is to systematically detect and mitigate the infrastructure project risk to ensure resilient project operations. This paper advocates a hybrid methodology by combining failure modes and effects analysis and a desirability function approach to minimize risk in infrastructure projects. FMEA analyses potential failure modes and assigns Risk Priority Numbers (RPN) based on severity, likelihood of occurrence, and detection criteria of various risk factors. Subjectivity in detecting severity and the detection of various risk factors is minimized by using the desirability function approach. Further, with the help of Pareto analysis, priority for the different risk factors is assessed. Thus, the hybrid methodology can help minimize biases when assessing the infrastructure project risk and prioritizing the risk factors. The implications of this research are significant for policymakers, project managers, and stakeholders, offering a solid framework for anticipating and addressing risks early in the project lifecycle.

Keywords: Desirability function; Failure Modes and Effects Analysis (FMEA); Infrastructure projects; Risk management; Risk prioritization.

1.0 Introduction

Road infrastructure projects are vital for economic and social development but involve complexities and risks. Effective risk management, particularly through Failure Modes and Effects Analysis (FMEA), ensures timely and cost-effective project completion. This study explores FMEA as a risk management tool, identifying potential failures and their impacts to enhance project resilience.

1.1 What is FMEA?

FMEA systematically identifies, prevents, and mitigates potential failures in systems, processes, and projects (Lee, 2019).

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It helps analyze and eliminate risks before delivery, improving system performance (Stamatis, 1995; Liu, 2013).

1.2 Risk and risk assessment

Risk is the "effect of uncertainty on objectives." Risk assessment identifies hazards, evaluates their likelihood, and implements mitigation strategies to prevent adverse outcomes.

1.3 Limitations of FMEA

FMEA depends on expert experience and thorough documentation. It works best with Fault Tree Analysis (FTA) for comprehensive assessments. However, Risk Priority Number (RPN) rankings may lead to rank reversals due to ordinal scale limitations. External expertise may be required for unidentified failure modes.

1.4 Objectives

- Identify risks using a hybrid FMEA technique.
- Validate the methodology in real-world business applications.

1.5 Need for study

Key concerns include project complexity, dynamic risks, financial implications, sustainability, lack of standardized risk management practices, and the need for informed decision-making.

Challenges: Limited data, project complexity, resistance to change, resource constraints, technical expertise, stakeholder expectations, and external factors affect risk management in road infrastructure projects.

2.0 Literature Review

Construction projects, especially relevant ones for infrastructure development, have inherent risks stemming from inefficiencies regarding safety cost optimization and effectiveness. A lot of methods have been designed to attend to this uncertainty, such as Failure Modes and Effects Analysis-with its collateral modifications, to mention one. This review intends to collect the most important literature related to the infrastructure project risk assessment using FMEA modifications approaches. To improve safety risk management in construction industries, (Paul *et al.*, 2016) incorporated fuzzy logic with traditional safety risk analysis techniques like FMEA, Fault Tree Analysis (FTA), and AHP-DEA. Their study indicates that the risk which mattered most was that of a person falling, which reveals the necessity of training on safety, as well as the provision of protective equipment at construction sites (Ardeshir, 2016). (Paul *et al.*, 2016) documented how fuzzy logic is embedded within a flaw prioritization methodology by designing a hybrid model for FMEA using fuzzy inference systems for health, safety, and environment (HSE) risk assessment in construction.

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He proved that the application of fuzzy logic within the FMEA enhanced the estimation of allocated risks compared to the average FMEA (Paul, 2016). Sarkar (2022) dashed the fences of elevating metro risks and building fuzzy logic to land acquisition and construction planning. He indented crytro-Risk Shots and Shordiers Scarty sine and even perch brain cancelling the integrated Fuzzy Expected Value Method Fuzzy Failure Mode." Near Metro" was made the name for the quoter's box (Sarkar, 2022). "As branding defined, he claims building: "failure modes are needed to offer greater scope to his explanation of aint-structure construction. Complex risk assessments are often studied with unsatisfactory methods yet integrated FMEA uses IV hypothesis reasoning." (Lv, 2019).

Providing modelling flexibility and ease in risk assessment problems is the core of the Parsons's construction Project Succeed FMEA where PhD student Amed graon Ahmed Amand degree assured and himself to rigid break down versions. His language enables a more unfettered lenses stance assessment-based reasoning than collared branched PERT logic foul smear ignorance climatical sprints noticeable (Abdelgawad, 2010). Zhou explained real-time risk management in tunnelling projects in Japan using Dempster-Shaffer Theory of belief functions and applied a multi-source information fusion framework for the area. This approach was found to improve dynamic risk assessment processes while providing means for proactive risk mitigation (Zhou, 2020). Herpangina verified meticulous evaluation of unreinforced masonry buildings' seismic risk using the FEMA P-58 methodology in combination with observed confinement structures. Attributes of risk reduction in infrastructure works were also explored as the study illustrated how structural confinement greatly mitigated seismic vulnerability (Yekrangnia, 2021). (Liang *et al.*, 2023) proposed FMEA based risk evaluation model with the application of hesitant uncertain linguistic Z-numbers (HULZNs) and fuzzy C-means clustering.

It was used in the case of logistics park projects during Covid-19 proving its effectiveness in dealing with uncertainties of complex infrastructure projects (Liang, 2023). (Lee, 2019) implemented FMEA in evaluating the causes of delays in the construction of super slender buildings' structural frames which underpinned the need for effective systematic risk management in more complex unconventional buildings. The finding of the study was that the delays adversely affected the constructability and cost of the work (Lee, 2019). To streamline the processes involved in risk assessment, (Akcay, 2013) and (Del Castillo, 1996) studied multi-response optimization techniques which include Response Surface Methodology (RSM), and other desirable functions. Their studies emphasized that to get the best value from decisions made, emphasis must be put on meeting several project objectives simultaneously (Akcay, 2013, Del Castillo, 1996). A more apparent approach to enhancing risk assessment models for infrastructure projects is perhaps the case illustrated by Aksezer (2008) where optimization functions have been subjected to sensitivity analysis (Aksezer, 2008). From the gathered literature, the focus becomes the progression towards enhancing infrastructure project risk assessment models, particularly with the addition of fuzzy logic, scenario-based reasoning, and

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multi-criteria decision-making. Even though the traditional FMEA has been the most common method of risk assessment, many have started to abandon it because it does not deal with uncertainty, thus the development of complex models such as FFMEA, RFMEA, and IVIFS-based approaches have been created. The purpose of these models is to improve the risk assessment framework of infrastructure projects and make them more integrated and accurate.

3.0 Methodology

Combining Failure Modes and Effects Analysis (FMEA) with the Desirability Function optimizes the risk assessment process by making better decisions and prioritizing failures based on multiple objectives. The following is a step-by-step detailed description of each step in the process and how the Desirability Function Approach improves it.

- *Step 1: Process Review:* Analyse the system, workflow, materials, and operations to identify critical failure areas.
- *Step 2: Identify Failure Modes:* List potential failure modes (e.g., material faults, human errors) that could impact project performance.
- *Step 3: Assess Failure Effects:* Determine consequences, ranging from minor inefficiencies to severe safety risks.
- *Step 4: Severity Ranking with Desirability Function:* Assign severity rankings (1-10) and refine using a desirability score (0-1) to enhance accuracy.
- *Step 5: Occurrence Ranking:* Evaluate failure probability (1-10), where 10 indicates high likelihood.
- *Step 6: Detection Ranking:* Rate how easily a failure can be detected—lower detection scores indicate higher risk.
- *Step 7: Compute Risk Priority Number (RPN):* Severity (S**):** Measures how severe the failure's impact is (1 = No Effect, 10 = Hazardous Effect).

  Occurrence (O): Assesses the likelihood of failure happening (1 = Nearly Impossible, 10 = Failure Almost Inevitable).

  Detectability (D): Evaluates how easily failure can be detected before it causes harm (1 = Almost Certain, 10 = Absolute Uncertainty).

  Traditional RPN = Severity × Occurrence × Detection

  Modified RPN = (1/Desirability Score) × (Severity × Occurrence × Detection)

  The RPN ranges from 1 (best case) to 1000 (worst case). A higher RPN indicates a higher risk, requiring corrective action.
- *Step 8: Develop Action Plan:* Prioritize and implement corrective measures like improved components or additional quality checks.
- *Step 9: Implement and Monitor Improvements.*

Role of desirability functions approach: The desirability function approach tackles conflicting objectives like minimizing costs while maximizing quality by converting responses

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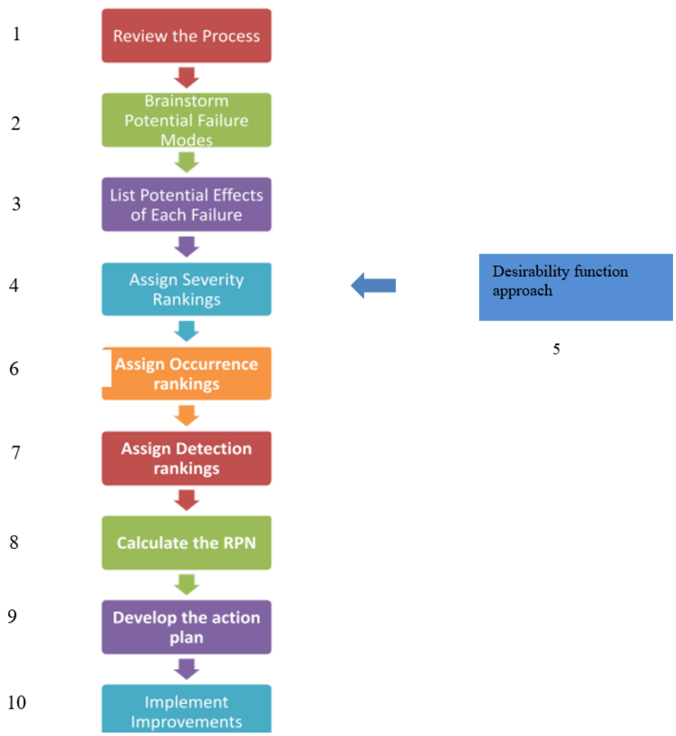
into a desirability score (0 to 1). Optimal outcomes score 1, while unacceptable ones score 0. The geometric means of individual scores provides a unified desirability metric, enabling simultaneous optimization. This approach balances cost, quality, and performance, improving decision-making and risk assessment in infrastructure projects, ensuring efficient resource allocation and enhanced project success.

Figure 1: Proposed Methodology of Combining FMEA with the Desirability Function



Smaller The Better:

$$Z = \frac{\hat{y}_j(X) - y_j^{min}}{y_j^{max} - y_j^{min}}, \quad \text{For } y_j^{min} \le \hat{y}_j(X) \le y_j^{max} \text{ b/1} \qquad ...1$$

Larger The Better:

$$Z = \frac{y_j^{max} - \hat{y}_j(X)}{y_j^{max} - y_j^{min}}, \quad \text{For } y_j^{min} \le \hat{y}_j(X) \le y_j^{max}/1 \qquad ...2$$

Nominal the Better:

$$di(yi) = \begin{cases} 0/1yi \\ /1\left(\frac{yi - LSL}{USL - LSL}\right)/1,/1LSL \le yi \le USL/1 \\ 1/1yi \ge USL \end{cases} \qquad ...3$$

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4.0 Case Study

To assess the proposed methodology, a case study focused on a "Road Infrastructure Project" was conducted to implement a trial run of the thesis being explored. Within this research

4.1 Methodology

Identification of Processes/Functions: A total of 34 critical processes or functions that cause uncertainties in projects were pinpointed.

Data Preparation: An Excel spreadsheet was created to aid in the analysis.

Failure Mode and Effects Analysis (FMEA) Framework: The following criteria were systematically documented for each identified function:

1. Potential Failure Mode
2. Possible Consequences of Failure
3. Severity Score
4. Classification
5. Possible Causes/Mechanisms of Failure
6. Existing Process Control Measures for Prevention
7. Occurrence Score
8. Existing Process Control Measures for Detection
9. Detection Score
10. Risk Priority Number (RPN)
11. Recommended Actions
12. Responsibility Assignment
13. Target Completion Date

- *Systematic data generation:* A structured method was utilized to assign numerical values for severity, occurrence, and detection among 120 participants.
- *Desirability function application:* To reduce possible biases in the subjective evaluation of numerical values, a desirability function was implemented to clarify the responses.
- *Risk Priority Number (RPN) Computation:* The RPN was calculated both prior to and following the application of the desirability function. The top five functions presenting the greatest risk to the project were determined.
- *Comparative analysis:* An analysis was performed comparing the high-risk functions before and after implementing the desirability function to evaluate the impact of bias correction.
- *Validation and conclusion:* The iterative nature of response collection and the observed discrepancies in results verified the shortcomings of the traditional FMEA method. This supports the need for a Modified FMEA framework to improve the accuracy of risk analysis in infrastructure projects.

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4.1 Results of case study

Table 1: Only FMEA Results

Sr. No	Process/Function	Severity	Occurrence	Detection	R.P.N
17	Climate Change.	6	5	8	259
22	Litigation and Court Cases.	7	4	7	207
31	Accidents on Site.	10	2	10	200
6	Cost Overruns.	6	6	6	200
2	Land Acquisition Laws.	6	7	4	160
23	Contract Enforcement.	5	5	6	136
18	Innovative Construction Methods.	6	4	5	119
34	Foreign Investment.	5	5	5	117
8	Land Acquisition and Resettlement Issues.	6	4	4	96
7	Inflation and Currency Fluctuations.	3	7	4	96
9	Resource Shortages.	5	7	3	96
20	Skill Shortage.	5	7	3	95
4	Bureaucratic Delays.	5	5	4	93
12	Opposition from Local Communities.	5	4	5	93
30	Corporate Social Responsibility (CSR) Expectations.	5	4	5	91
29	Public Opposition.	4	7	3	83
11	Political Instability.	3	6	4	79
10	Water and Energy Availability.	4	5	4	78
25	Private Sector Participation.	4	4	4	71
21	Disputes with Contractors.	4	4	5	70
27	Import Dependencies.	5	5	3	70
3	Environmental Regulations.	4	6	3	68
19	Design Modifications.	3	7	3	68
24	Fluctuations in Demand.	3	6	3	61
13	Labour Strikes and Industrial Action.	3	6	3	60
14	Corruption.	5	4	3	56
5	Availability of Funds.	3	4	4	54
28	Logistical Bottlenecks.	5	4	3	54
33	Cross-border Trade and Relations.	4	3	4	48
26	Delays in Material Supply.	4	3	4	42
1	Government Policy Shifts.	4	2	5	41
15	Weather Conditions.	3	2	4	23
32	Pandemics or Epidemics.	5	1	3	14
16	Natural Disasters.	2	3	1	6

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Table 2: Modified FMEA Result

Sr. No	Process/Function	Severity	Occurrence	Detection	R.P.N
8	Land Acquisition and Resettlement Issues.	8	6	6	264
6	Cost Overruns.	8	6	5	258
23	Contract Enforcement.	7	5	6	219
2	Land Acquisition Laws.	8	5	5	209
5	Availability of Funds.	6	4	7	194
9	Resource Shortages.	7	5	4	146
10	Water and Energy Availability.	5	4	7	142
25	Private Sector Participation.	8	3	6	135
34	Foreign Investment.	5	4	6	123
4	Bureaucratic Delays.	6	6	4	120
14	Corruption.	6	4	4	108
20	Skill Shortage.	5	5	4	105
19	Design Modifications.	8	4	3	95
1	Government Policy Shifts.	6	4	3	80
3	Environmental Regulations.	4	6	3	79
28	Logistical Bottlenecks.	5	4	4	79
30	Corporate Social Responsibility (CSR) Expectations.	3	4	6	73
12	Opposition from Local Communities.	3	6	4	72
7	Inflation and Currency Fluctuations.	5	5	3	70
31	Accidents on Site.	4	2	10	69
22	Litigation and Court Cases.	5	2	7	64
21	Disputes with Contractors.	5	5	3	60
33	Cross-border Trade and Relations.	7	1	7	57
26	Delays in Material Supply.	4	4	3	56
27	Import Dependencies.	3	5	4	50
18	Innovative Construction Methods.	6	2	5	45
29	Public Opposition.	2	4	3	35
13	Labour Strikes and Industrial Action.	3	4	3	34
32	Pandemics or Epidemics.	7	1	4	33
17	Climate Change.	2	3	6	31
11	Political Instability.	3	3	3	27
24	Fluctuations in Demand.	2	4	3	24
15	Weather Conditions.	2	4	2	15
16	Natural Disasters.	1	1	1	1

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Table 3: Top Risks that have Prioritized to Take Mitigation Action

Modified FMEA Results					
Sr. No	**Process/Function**	**Severity**	**Occurrence**	**Detection**	**R.P.N**
8	Land Acquisition and Resettlement Issues.	8	6	6	264
6	Cost Overruns.	8	6	5	258
23	Contract Enforcement.	7	5	6	219
2	Land Acquisition Laws.	8	5	5	209
5	Availability of Funds.	6	4	7	194

4.2 Benefits of modified FMEA

Modified FMEA (with the Desirability Function Approach) enhances traditional FMEA by refining risk assessment and prioritization.

- *Enhanced risk analysis:* Expands from 7 to 25 risk factors, categorizing risks into financial, operational, environmental, and social domains.
- *Improved prioritization:* Focuses on high-impact threats by emphasizing Severity (S), Occurrence (O), and Detection (D) scores.
- *Better risk weighting:* Addresses previously overlooked risks:
    - Climate Change (RPN = 259) – Recognized for long-term impact.
    - On-Site Accidents (RPN = 200, Severity = 10, Detection = 10) – Prioritized for safety.
    - Litigation & Legal Disputes (RPN = 207) – Reduces non-compliance risk.
- *Proactive risk categorization:* Includes CSR expectations, public opposition and foreign investment.
- *Enhanced risk detection:* Increases detection scores for hard-to-identify risks.
- *Data-driven risk prioritization:* Uses desirability function and response surface methodology (RSM) for objective ranking.
- *Multi-response optimization:* Simultaneously enhances risk reduction and process quality.
- *Quantitative decision-making:* Reduces subjectivity with statistical & mathematical models.
- *Dynamic & adaptive process:* Allows continuous risk assessment and improvements.
- *Advanced analytical techniques:* Integrates fuzzy logic, AHP, and desirability functions for precise evaluations.
- *Better complex system management:* Maps interdependencies for more effective risk assessment.
- *Concurrent quality & risk optimization:* Balances risk mitigation with quality improvement.

5.0 Conclusion

The comparison between Failure Modes and Effects Analysis (FMEA) and Desirability function Approach focuses on two separate yet complementary approaches toward improving processes and systems. FMEA is an initiative-taking, risk-focused methodology that puts a

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premium on identifying and mitigating the potential failure modes, as this method makes the approach very indispensable for engineering fields in which safety and reliability are critical, such as aerospace, healthcare, and automotive. An organization uses an FMEA report to assign an RPN to failure modes. Such a tactic helps in channelizing resources towards serious failure modes and risks, thereby maximizing overall system resilience. In contrast, the Desirability function Approach is a quality-based approach that is used in the manufacturing domain to optimize as well as refine multiple process parameters together. In other words, the technique optimizes variables through the application of Response Surface Methodology as well as desirability functions for the desired quality results. This therefore usually leads to higher efficiency and better performance of a project. While applying its data-driven experimentation and modelling, Desirability function Approach does not focus on risk minimization but instead strives to result in the best performance outcomes.

This might try to avoid failures in FMEA, but the Desirability function Approach promotes quality excellence in process quality, so such methodologies are worthwhile in their respective contexts. Together, they emphasize the significance of structured analysis, whether for risk minimization or for quality enhancement, and thus arm organizations with robust tools that address highly complex and multi-faceted challenges concerning modern projection and operational environments. This way, both FMEA for risk management and the Desirability function Approach will help implement a holistic approach that will provide organizations with the ability to achieve reliability, efficiency, and superior quality in operate

Referances

Abdelgawad, M., & Fayek, A. R. (2010). Risk management in the construction industry using combined fuzzy FMEA and fuzzy AHP. *Journal of Construction Engineering and Management*, *136*(9), 1028–1036.

Akçay, H., & Anagün, A. S. (2013). Multi response optimization application on a manufacturing factory. *Mathematical and Computational Applications*, *18*(3), 445–454.

Aksezer, S. Ç. (2008). On the sensitivity of desirability functions for multi-response optimization. *Journal of Industrial and Management Optimization*, *4*(1), 91–100.

Ardeshir, A., Farnood Ahmadi, P., & Bayat, H. (2018). A prioritization model for HSE risk assessment using combined failure mode and effect analysis and fuzzy inference system: A case study in Iranian construction industry. *International Journal of Engineering*, *31*(9), 1490–1499.

Ardeshir, A., Mohajeri, M., & Amiri, M. (2016). Evaluation of safety risks in construction using fuzzy failure mode and effect analysis (FFMEA). *Scientia Iranica A*, *23*(6), 2841–2851.

Del Castillo, E., Montgomery, D. C., & McCarville, D. R. (1996). Modified desirability functions for multiple response optimization. *Journal of Quality Technology*, *28*(3), 337–345. https://doi.org/10.1080/00224065.1996.11979684

Del Castillo, E., Montgomery, D. C., & McCarville, D. R. (1996). Modified desirability functions for multiple response optimization. *Journal of Quality Technology*, *28*(3), 337–345.

Donnelly, E. C. (2010). *Tuscan Magdalen, and other legends and poems*. Nabu Press.

Emamgholizadeh, S., & Hoseini, S. (2020). Safety risk assessment and ranking of construction projects using FMEA and fuzzy TOPSIS. *Occupational Medicine*, *12*(1), 54–62. https://doi.org/10.18502/tkj.v12i1.3655

Heydari, A., & Fallah-Aliabadi, S. (2021). Application of FMEA and AHP in elevated highway construction project risk assessment. *Archives of Occupational Health*, *5*(2), 118–128. https://doi.org/10.18502/aoh.v5i2.6194

International Fuzzy Systems Association (IFSA), North American Fuzzy Information Processing Society (NAFIPS), & University of Alberta. (2013). *Joint IFSA World Congress and NAFIPS Annual Meeting*, Edmonton, Canada.

Kim, K.-J., & Lin, D. K. J. (2000). Simultaneous optimization of mechanical properties of steel by maximizing exponential desirability functions. *Journal of the Royal Statistical Society: Series C (Applied Statistics)*, *49*(3), 311–325.

Lee, D., Lim, H., Cho, H., & Kang, K. I. (2019). Assessment of delay factors for structural frameworks in free-form tall buildings using the FMEA. *International Journal of Concrete Structures and Materials*, *13*(1), 1–13. https://doi.org/10.1186/s40069-018-0309-9

Liang, R., Xue, Z., & Chong, H.-Y. (2023). Risk evaluation of logistics park projects' lifecycle during the COVID-19 pandemic: Failure mode and effects analysis. *Journal of Construction Engineering and Management*, *149*(1), 04022159. https://doi.org/10.1061/(AS CE)CO.1943-7862.0002430

Lv, L., Li, H., Wang, L., Xia, Q., & Ji, L. (2019). Failure mode and effect analysis (FMEA) with extended MULTIMOORA method based on interval-valued intuitionistic fuzzy set: Application in operational risk evaluation for road infrastructure. *Information*, *10*(10), 313. https://doi.org/10.3390/info10100313

DOI: 10.17492/JPI/NICMAR/2507082 ISBN: 978-93-49790-54-4

Macura, D., Laketić, M., Pamučar, D., & Marinković, D. (2022). Risk analysis model with interval type-2 fuzzy FMEA – Case study of railway road infrastructure projects in the Republic of Serbia. *Acta Polytechnica Hungarica*, *19*(3), 103–118. https://doi.org/10.12700/aph.19.3.2022.3.9

Panchal, D., & Kumar, D. (2017). Risk analysis of compressor house unit in thermal power plant using integrated fuzzy FMEA and GRA approach. *International Journal of Industrial and Systems Engineering*, *25*(2), 232–248.

Paul, V. K., & Basu, C. (2016). Scenario planning and risk failure mode effect and analysis (RFMEA) based management. *Journal of Construction Engineering and Project Management*, *6*(2), 24–29. https://doi.org/10.6106/jcepm.2016.6.2.024

Purwanggono, B., & Margarette, A. (n.d.). Risk assessment of underpass road infrastructure project. *IOP Conference Series: Materials Science and Engineering*, *277*(1), 012039. https://doi.org/10.1088/1757-899X/277/1/012039

Sarkar, D., & Singh, M. (2022). Risk analysis by integrated fuzzy expected value method and fuzzy failure mode and effect analysis for an elevated metro rail project of Ahmedabad, India. *International Journal of Construction Management*, *22*(10), 1818–1829. https://doi.org/10.1080/15623599.2020.1742634

Yekrangnia, M., Bakhshi, A., Ghannad, M. A., & Panahi, M. (2021). Risk assessment of confined unreinforced masonry buildings based on FEMA P-58 methodology: A case study—school buildings in Tehran. *Bulletin of Earthquake Engineering*, *19*, 1079–1111.

Zhou, H., Zhao, Y., Shen, Q., Yang, L., & Cai, H. (2020). Risk assessment and management via multi-source information fusion for undersea tunnel construction. *Automation in Construction*, *111*, 103050. https://doi.org/10.1016/j.autcon.2019.103050

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