Proceedings of 2nd International Conference on Climate Change and Emerging Trends in Civil Engineering CCETC-2025

Integrated Bayesian-Monte Carlo Based Probabilistic Risk Modeling of Cost Overruns in Infrastructure Projects

Hilal Khan [1], Khursheed Ahmed [1,]* and Muhammad Usman Hassan[1]

[1] NUST Institute of Civil Engineering (NICE), School of Civil and Environmental Engineering (SCEE), National University of Sciences and Technology(NUST), Sector H-12, Islamabad 44000, Pakistan; hkhan.ms24nice@student.nust.edu.pk; usman.hassan@nice.nust.edu.pk

* Correspondence: khursheed@nice.nust.edu.pk

Abstract

Cost overruns in road construction projects significantly challenge project efficiency and financial sustainability. This study develops an integrated Bayesian-Monte Carlo framework to identify and quantify critical cost overrun factors in Pakistan's road infrastructure projects. Through literature review and expert consultation, 25 potential causes were systematically reduced to 10 critical factors using expert elicitation and criticality scoring. Bayesian analysis calculated posterior probabilities by combining expert judgment with conditional relationships, while Monte Carlo simulation quantified uncertainties and provided probabilistic ranges for each factor. The framework reveals design error changes as the most critical factor (mean: 61.5%, maximum: 93.3%), followed by variation orders (58.9%) and inaccurate estimates (57.8%). Secondary contributors include land acquisition issues (54.5%) and schedule delays (52.3%). This integrated approach enables evidence-based risk prioritization, replacing arbitrary contingency planning with data-driven decision making. The methodology provides project managers with actionable insights for targeted risk mitigation and optimal resource allocation in resource-constrained environments.

Keywords: Bayesian Analysis; Monte Carlo Simulation; Risk Quantification; Cost Overrun; Road Construction

1. Introduction

The construction industry constitutes a fundamental pillar of economic development and infrastructural advancement across global economies. Nevertheless, cost overruns represent a pervasive and systematic challenge that compromises project delivery efficiency, particularly within large-scale infrastructure developments such as road construction projects [1], [2], [3]. Cost overruns, operationally defined as the variance between initial cost estimates and final project expenditures, manifest through multifaceted uncertainties encompassing planning inadequacies, material procurement volatilities, and exogenous risk factors [4], [5]. These financial deviations precipitate cascading effects that extend beyond immediate project boundaries, generating resource constraints, temporal delays, and impediments to strategic development initiatives [6], [7], [8].

Contemporary risk mitigation methodologies in construction cost management have predominantly employed deterministic and probabilistic analytical frameworks. Traditional approaches encompassing multiple regression analysis and sensitivity assessment techniques have been systematically applied to forecast potential cost escalations and elucidate contributing variables [9], [10], [11]. However, these conventional models demonstrate inherent limitations in capturing the complex interdependencies and stochastic uncertainties characteristic of infrastructure project environments. The emergence of Bayesian network theory and Monte Carlo simulation methodologies has facilitated more sophisticated probabilistic approaches that substantially address these analytical constraints [12], [13]. Bayesian networks enable comprehensive modeling of causal relationships

 https://doi.org/10.64615/fjes.1.Special Issue.2025.29

while accommodating expert knowledge integration in scenarios characterized by limited historical data availability [14], [15]. Monte Carlo simulation methodologies further enhance analytical capabilities by facilitating comprehensive exploration of probabilistic outcome distributions, thereby quantifying cost impact probabilities across diverse scenario configurations [16], [17], [18].

Despite these methodological advancements, substantial research gaps persist within the domain. Existing literature demonstrates a predominant focus on either Bayesian analysis or Monte Carlo simulation approaches in isolation, thereby constraining comprehensive assessment of compounded uncertainties inherent in infrastructure project environments [13]. Furthermore, while the construction industry has progressively adopted probabilistic methodologies, the systematic integration of these techniques within practical risk management frameworks remains inadequately explored. Critical risk factors including material price volatility and land acquisition-induced delays are frequently conceptualized as independent variables, thereby neglecting their inherent interdependencies and systemic interactions [14].

This investigation addresses these methodological gaps through the development of an integrated Bayesian-Monte Carlo analytical framework specifically calibrated for infrastructure project applications. The proposed methodology synthesizes Bayesian networks' causal modeling capabilities with Monte Carlo simulation's probabilistic assessment strength, thereby enabling enhanced precision in both likelihood estimation and impact quantification of cost overrun determinants. The framework incorporates interdependent risk relationships while generating actionable insights for risk mitigation strategies, facilitating optimized resource allocation decisions for project stakeholders. This comprehensive approach advances theoretical understanding of construction risk analysis while simultaneously providing practical analytical tools for stakeholders pursuing enhanced project efficiency and financial performance optimization.

The application of this integrated methodology to road construction projects within Pakistan's infrastructure development context demonstrates the practical utility of probabilistic risk modeling in enhancing cost estimation accuracy and project delivery outcomes. Pakistan represents a particularly relevant case study given its substantial infrastructural development initiatives and associated implementation challenges. This research contribution addresses a critical lacuna in existing literature by providing a scalable methodological framework for addressing cost overrun uncertainties across diverse construction project contexts globally.

2. Methodology

This study employs an integrated Bayesian-Monte Carlo framework to quantify the uncertainty and impact of cost overrun factors in road construction projects. The methodology is structured in sequential steps including encompassing data collection, Bayesian analysis, and Monte Carlo simulation, to ensure a robust and systematic risk assessment process.

2.1 Data Collection

The data collection process was carried out in two stages, combining qualitative and quantitative approaches to identify and prioritize cost overrun factors. The first stage involved a pilot survey to validate the relevance and significance of potential cost overrun factors. A comprehensive literature review initially identified 25 potential factors commonly associated with cost overruns in road construction projects. This list, as tabulated in **Error! Reference source not found.Error! Reference source not found.**, was then evaluated by 39 industry experts, including clients, contractors, and consultants. The respondents rated each factor's probability and impact on a 5-point Likert scale. The responses were analyzed to compute the criticality of each factor using Equation 1 and Equation 2, based on frequency analysis and a prioritization index. This stage reduced the list to the 10 most significant causes of cost overruns.

$$Academic\ Criticality = \frac{Frequency\ of\ Factor}{Total\ No.of\ Papers} \times 10 \qquad \text{Equation 1}$$

$$Respondents\ \ Criticality = \frac{Avg\ PI\ Score}{25} \times 10 \qquad \text{Equation 2}$$

Table 1: Overall Criticality of Causes

Sr.#	Causes of Cost Overrun	Criticality of Responses	Criticality of Academia	Overall Criticality
1	Variation Orders	4.6	6.0	27.6
2	Material price escalation	4.3	5.3	22.8
3	Inaccurate estimates	3.7	6.0	22.0
4	Schedule delay	4.8	4.0	19.1
5	Design error changes	3.3	5.3	17.5
6	Differing site conditions	3.7	4.7	16.9
7	Land acquisition problem	5.1	3.3	16.8
8	Relocation of services and utilities	4.1	3.3	13.6
9	Market conditions	3.6	3.3	12.0
10	Local government pressures	4.2	2.7	11.3
11	Weather Conditions	2.7	3.3	8.8
12	Improper Planning	4.4	2.0	8.8
13	Constructability and technical complexity	3.1	2.7	8.4
14	Environmental Protection and mitigation cost	2.4	2.0	4.9
15	Corruption	4.2	0.7	2.8
16	Size of project	3.9	1.3	2.6
17	Experience in contracts	3.6	0.7	2.4
18	Inconsistent cash flows	3.5	0.7	2.4
19	Lack of equipment	3.4	0.7	2.3
20	Lack of communication	3.4	2.0	2.3
21	Contract claim settlement	3.0	0.7	2.0
22	Lack of earned value management	2.5	0.7	1.7
23	Owner Project management cost	2.4	0.7	1.6
24	Strikes	2.1	0.7	1.4
25	Change in seismic criteria	2.1	0.7	1.4

The second stage consisted of a detailed survey designed to provide probabilistic inputs for Bayesian analysis. This survey targeted experts from Pakistan's road construction sector and gathered prior probabilities, which represent the likelihood of each cause occurring independently.

Additionally, conditional probabilities were collected, representing the likelihood of each cause given that a cost overrun event had already occurred. The survey design adhered to rigorous sampling size calculations and reliability measures, achieving a Cronbach's alpha value of 0.96, indicating high data reliability.

2.2 Bayesian Analysis Framework

The Bayesian analytical framework was implemented to quantify probabilistic relationships and causal interdependencies among identified cost overrun factors. Prior probabilities P(Ai) were systematically derived from expert elicitation responses obtained through the comprehensive survey instrument, representing the baseline likelihood of each factor manifesting under standard project conditions. Conditional probabilities P(Ai|B) were simultaneously extracted from expert assessments, denoting the probability of each causal factor given the occurrence of a cost overrun event.

The fundamental application of Bayes' theorem facilitated the synthesis of prior and conditional probability distributions to generate posterior probabilities P(B|Ai), mathematically expressed as $P(B|Ai) = [P(Ai|B) \times P(B)] / P(Ai)$. These posterior probability estimates provided enhanced probabilistic insights regarding both the likelihood and consequential impact of each identified factor within the cost overrun causation framework. The Bayesian methodology demonstrated particular analytical suitability for this investigation due to the prevalent absence of comprehensive historical datasets within the regional construction context, thereby enabling the systematic integration of expert domain knowledge to model uncertainties and capture dependencies among risk factors.

2.3 Monte Carlo Simulation

Monte Carlo simulation methodology was subsequently employed to comprehensively explore and quantify the uncertainties inherent within the Bayesian analytical outputs. The posterior probabilities derived from Bayesian analysis served as foundational input distributions for the stochastic simulation process, with each critical factor assigned probabilistic parameter ranges based on statistical moments including mean values and standard deviations extracted from survey response distributions.

The simulation protocol was executed utilizing the XLRisk computational add-in platform, implementing iterative probabilistic sampling procedures from the defined probability distributions to generate comprehensive ranges of potential outcome scenarios. The computational outputs encompassed detailed probability density functions and cumulative distribution functions, systematically characterizing both the likelihood and magnitude ranges of cost overruns attributable to each critical causal factor. These probabilistic outputs generated actionable risk intelligence, enabling project stakeholders to implement evidence-based risk prioritization strategies and develop targeted mitigation interventions.

2.4 Integrated Methodological Approach

The systematic integration of Bayesian analysis with Monte Carlo simulation methodology constituted a comprehensive probabilistic framework for infrastructure project risk assessment. The Bayesian component provided sophisticated causal inference capabilities and enabled quantification of conditional dependencies among risk factors, while Monte Carlo simulation facilitated comprehensive exploration of probabilistic outcome distributions and uncertainty propagation mechanisms. This hybrid analytical approach enhanced the precision and robustness of risk quantification procedures while enabling comprehensive understanding of cost overrun dynamics and their underlying causal mechanisms.

The integrated framework addressed fundamental limitations inherent in singular methodological approaches by capturing both deterministic causal relationships and stochastic uncertainty propagation, thereby facilitating enhanced decision-making capabilities for infrastructure project stakeholders. This methodological synthesis provided a theoretically grounded yet practically applicable analytical tool for optimizing risk management strategies and resource allocation decisions within complex project environments.

2.5 Data Quality and Validation Procedures

Comprehensive data quality assurance and validation protocols were systematically implemented to ensure the statistical reliability and methodological validity of collected datasets. Internal consistency assessment was conducted utilizing Cronbach's alpha coefficient analysis, which demonstrated exceptional reliability with an alpha value of 0.96, substantially exceeding the conventional threshold of 0.70 for acceptable internal consistency in survey-based research methodologies.

Statistical normality assessment procedures were implemented to evaluate distributional characteristics of collected data, with appropriate non-parametric transformation techniques applied to address any deviations from normality assumptions where detected. Additional validation measures encompassed outlier detection protocols, response bias assessment, and cross-validation procedures to ensure dataset integrity and analytical robustness. These comprehensive validation protocols ensured that research findings maintained statistical rigor and practical applicability for addressing cost overrun challenges within road construction project contexts.

3. Results and Analysis

3.1 Bayesian Analysis

The Bayesian analysis identified design errors, variation orders, and inadequate cost estimation as the most significant contributors to cost overruns. These factors showed high posterior probabilities, consistent with findings in the literature. For instance, Herrera et al. (2020) [19] identified failures in design and design changes as the most frequent contributors to cost overruns in road infrastructure projects [19]. Table 2 lists the posterior probabilities of the ten critical cost overrun factors.

Table 2: Posterior Probabilities of Critical Factors

Sr. #	Causes of Cost Overrun	Prior Probability $P(A_i)$	Conditional Probability $P(A_i \mid B)$	Posterior Probability $P(B \mid A_i)$
1	Variation Orders	11.9	13.6	56.9
2	Material price escalation	9.6	8.8	45.6
3	Inaccurate estimates	8.4	9.2	54.5
4	Schedule delay	11.7	12	51.1
5	Design error changes	6.6	7.7	58.1
6	Differing site conditions	9.4	8.4	44.5
7	Land acquisition problem	12.1	12.6	51.8
8	Relocation of services and utilities	10.9	9.3	42.5
9	Market conditions	6.9	7	50.5
10	Local government pressures	12.7	11.4	44.7

The results indicate that local government pressures are the most common cause of road project issues, with the highest prior probability of 12.7%. However, land acquisition has a 44.7% chance of causing cost overruns, less than the marginal probability, indicating its relatively lower impact.

Design error changes have the lowest prior probability at 6.6%, but their posterior probability of causing cost overruns is 58%, making them the most influential factor in terms of cost impact. Similarly, inaccurate estimates and market conditions, though occurring less frequently (prior probabilities of 8.6% and 6.9%, respectively), can significantly increase cost overrun risks, with probabilities of 54.5% and 50.5%, respectively.

Variation orders, with a prior probability of 11.9%, rank third among causes. They result in a 56.9% chance of cost overrun if initiated during a project. Land acquisition issues, with a prior probability of 12.1%, rank fourth, as they lead to cost overruns with a probability of 51.8% due to high compensation demands. Schedule delays also rank among the top five impactful factors.

Material price escalation has a lower occurrence and impact, with a posterior probability of 45.6%, as many contracts include price adjustment clauses. Similarly, relocation of services and differing site conditions show low probabilities and impacts compared to other factors.

Using posterior probabilities from Bayesian analysis as input, Monte Carlo simulations were employed to determine the maximum, minimum, and mean probabilities of cost overruns for each cause, offering a more comprehensive risk profile.

3.2 Monte Carlo Simulation

Following the derivation of posterior probabilities through Bayesian analysis, parametric ranges for input variables were systematically established. Each probabilistic input parameter was assigned distributional boundaries defined by upper and lower limits positioned at one standard deviation distance from the respective mean values. The Monte Carlo simulation methodology was subsequently employed to calculate the comprehensive probability distributions for occurrence likelihood of each identified factor. Cumulative density functions were generated through iterative MCS procedures, enabling precise estimation of occurrence probabilities for specific probability values across the defined parameter space. Figure 1 illustrates the Monte Carlo simulation outputs for all critical cost overrun factors.

The analytical results demonstrate that multiple factors constitute significant contributors to cost overrun phenomena in road construction projects. Variation orders, originating from project scope modifications, emerged as the second most critical causative factor, exhibiting cost overrun probability distributions ranging from 33.2% to 87.9% with a mean probability of 58.9%. While variation orders do not universally result in cost escalations, scope augmentation frequently introduces additional risk vectors that precipitate cost increases. Material price escalation, primarily attributable to inflationary pressures, demonstrated probability ranges spanning 24.7% to 78.8% with an average occurrence likelihood of 48.8%. Although contractual price adjustment mechanisms provide partial mitigation of these effects, such provisions typically result in additional financial obligations for project clients.

Inaccurate cost estimation procedures, ranked third in criticality, represent a major causative mechanism with probability distributions ranging from 30.9% to 90.2% and a mean occurrence rate of 57.8%. These estimation inadequacies frequently originate from preliminary design constraints and budgetary limitations, subsequently manifesting as significant discrepancies during project execution phases. Schedule delays, ranked fifth in the hierarchy, occur as consequences of scope modifications and unforeseen project challenges, exhibiting cost overrun probabilities between 30.9% and 77.1% with an average probability of 52.3%.

Design error modifications constitute the most impactful causative factor, demonstrating probability distributions ranging from 34.8% to 93.3% with a mean occurrence likelihood of 61.5%. These errors predominantly result from inadequate field condition assessments and insufficient preliminary investigations. Differing site conditions and land acquisition complications, ranked ninth and fourth respectively, exhibit average occurrence probabilities of 46.4% and 54.5%. Both factors typically arise from inadequate planning procedures or regulatory processing delays. Utility relocation requirements, with an average probability of 44.3%, and adverse market conditions, averaging 52.9% probability, further exacerbate cost escalation issues through resource scarcity and funding delays, particularly during periods of concurrent mega-project implementation. Local government regulatory pressures, ranked eighth in the analysis, contribute additional financial strain with an average probability of 47.4%, highlighting the necessity for enhanced cash flow management and priority optimization strategies.

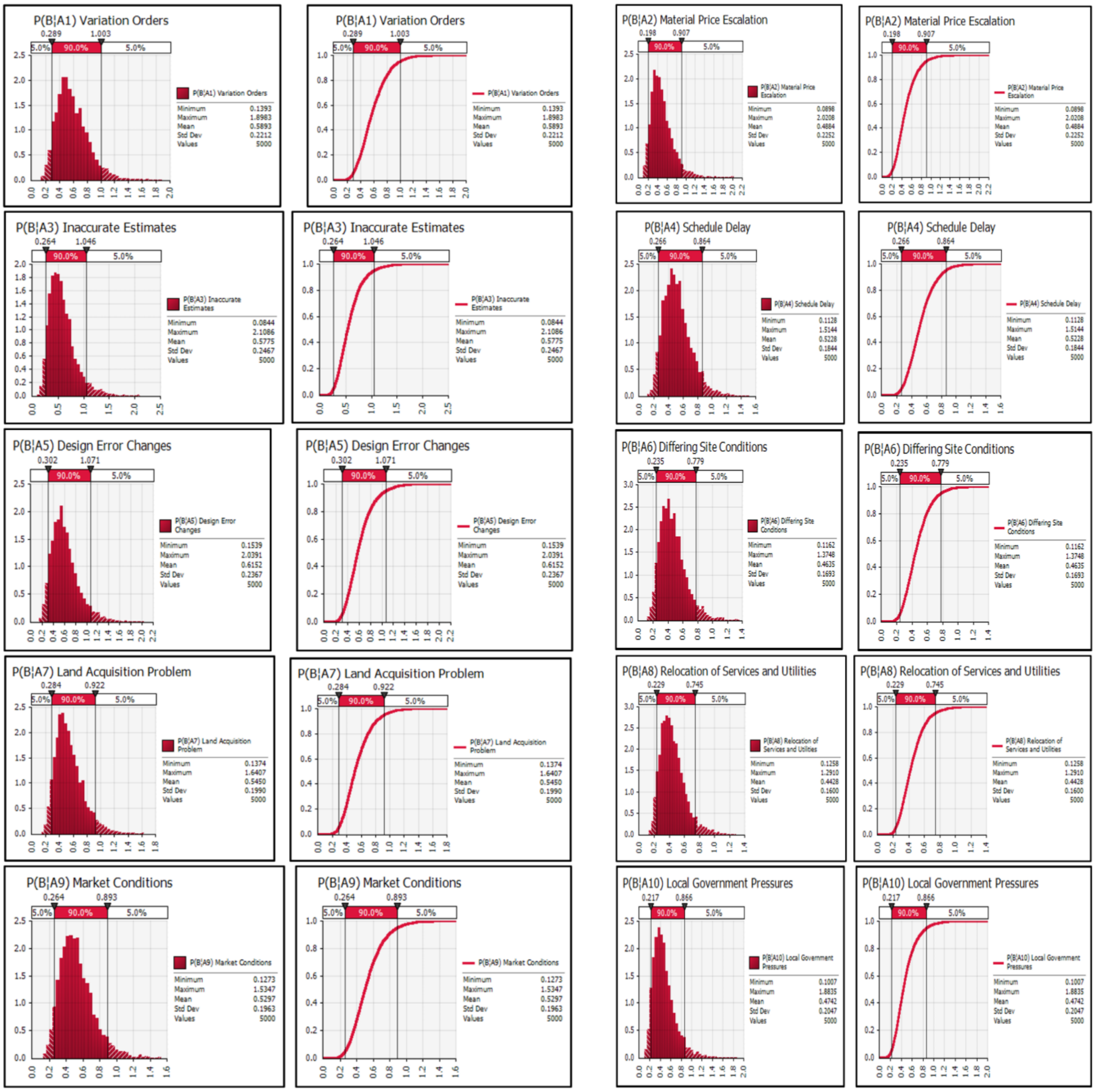

Figure 1: Monte Carlo Simulations of Critical Factors

The comprehensive ranking of critical cost overrun causes has been reorganized according to maximum probability values to facilitate decision-maker recognition of the most significant cost escalation factors and quantify their respective impact magnitudes. Table 3 presents the final factor rankings derived from Monte Carlo simulation analyses, providing stakeholders with evidence-based prioritization frameworks for risk management interventions.

Table 3: Final Ranking of Causes of Cost Overrun

Sr. #	Causes of Cost Overrun	Posterior Probability	Mean	Standard Deviation	Minimum at 10%	Maximum at 90%
1	Design Error Changes	P(B│A5)	0.6152	0.2367	0.3484	0.9330
2	Variation Order	P(B│A1)	0.5893	0.2212	0.3324	0.8799
3	Inaccurate Estimates	P(B│A3)	0.5775	0.2467	0.3093	0.9025
4	Land Acquisition problem	P(B│A7)	0.5450	0.1990	0.3213	0.8128
5	Market Conditions	P(B│A9)	0.5297	0.1963	0.3077	0.7836
6	Schedule Delay	P(B│A4)	0.5228	0.1844	0.3090	0.7717
7	Material Price escalation	P(B│A2)	0.4884	0.2252	0.2471	0.7881
8	Local government pressures	P(B│A10)	0.4742	0.2047	0.2520	0.7550
9	Differing site condition	P(B│A6)	0.4635	0.1693	0.2942	0.6328
10	Relocation of services and utilities	P(B│A8)	0.4428	0.1600	0.2623	0.6498

5. Conclusions

This study comprehensively identified, analyzed, and quantified the critical factors contributing to cost overruns in road construction projects. Using a systematic methodology combining Bayesian analysis and Monte Carlo simulation (MCS), the research provides a probabilistic framework for understanding the uncertainties associated with each factor. The findings serve as a practical tool for decision-makers to manage risks effectively and enhance project performance.

- A detailed literature review identified 25 cost overrun factors, narrowed down to 10 significant causes, including variation orders, inaccurate estimates, and design error changes.
- Design error changes (61.5%), inaccurate estimates (57.8%), and variation orders (58.9%) were found to be the top contributors, with maximum probabilities of up to 93.3%, 90.2%, and 87.9%, respectively.
- Bayesian analysis and MCS quantified uncertainties, providing a probability distribution for each factor. Key risks like land acquisition (54.5%), schedule delays (52.3%), and market conditions (52.9%) also exceeded the marginal probability of 49.5%.
- Material price escalation (48.8%), differing site conditions (46.3%), and relocation of utilities (44.3%) ranked lower but remain relevant. The probabilistic framework enables targeted mitigation and resource optimization.
- This approach allows project managers to focus on high-impact risks, avoiding arbitrary contingencies and improving cost controls. The methodology is particularly valuable for resource-constrained environments like Pakistan..

Funding: This research received no external funding.

Data Availability Statement: Dara will be made available upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

[1] D. D. Ahiaga-Dagbui, P. E. D. Love, S. D. Smith, and F. Ackermann, "Toward a Systemic View to Cost Overrun Causation in Infrastructure Projects: A Review and Implications for Research," *Project Management Journal*, vol. 48, no. 2, pp. 88–98, Apr. 2017, doi: 10.1177/875697281704800207.

[2] S. Narayanan, A. M. Kure, and S. Palaniappan, "Study on Time and Cost Overruns in Mega Infrastructure Projects in India," *Journal of The Institution of Engineers (India): Series A*, vol. 100, no. 1, pp. 139–145, Mar. 2019, doi: 10.1007/s40030-018-0328-1.

[3] J.-E. Nilsson, "The Weak Spot of Infrastructure BCA: Cost Overruns in Seven Road and Railway Construction Projects," *J Benefit Cost Anal*, vol. 13, no. 2, pp. 224–246, Aug. 2022, doi: 10.1017/bca.2022.10.

[4] P. E. D. Love, C.-P. Sing, X. Wang, Z. Irani, and D. W. Thwala, "Overruns in transportation infrastructure projects," *Structure and Infrastructure Engineering*, vol. 10, no. 2, pp. 141–159, Feb. 2014, doi: 10.1080/15732479.2012.715173.

[5] C. C. Cantarelli, B. Flyvbjerg, E. J. E. Molin, and B. Van Wee, "Cost Overruns in Large-scale Transportation Infrastructure Projects: Explanations and Their Theoretical Embeddedness," *European Journal of Transport and Infrastructure Research*, 2010, doi: 10.18757/EJTIR.2010.10.1.2864.

[6] R. F. Herrera, O. Sánchez, K. Castañeda, and H. Porras, "Cost Overrun Causative Factors in Road Infrastructure Projects: A Frequency and Importance Analysis," *Applied Sciences*, vol. 10, no. 16, p. 5506, Aug. 2020, doi: 10.3390/app10165506.

[7] J. E. Park, "Curbing cost overruns in infrastructure investment," *European Journal of Transport and Infrastructure Research*, vol. 21, no. 2, 2021, doi: 10.18757/ejtir.2021.21.2.5504.

[8] J. M. Andrić, A.-M. Mahamadu, J. Wang, P. X. W. Zou, and R. Zhong, "THE COST PERFORMANCE AND CAUSES OF OVERRUNS IN INFRASTRUCTURE DEVELOPMENT PROJECTS IN ASIA," *JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT*, vol. 25, no. 3, pp. 203–214, Mar. 2019, doi: 10.3846/jcem.2019.8646.

[9] P. E. D. Love, D. D. Ahiaga-Dagbui, and Z. Irani, "Cost overruns in transportation infrastructure projects: Sowing the seeds for a probabilistic theory of causation," *Transp Res Part A Policy Pract*, vol. 92, pp. 184–194, Oct. 2016, doi: 10.1016/j.tra.2016.08.007.

[10] Y. Alhammadi, M. S. Al-Mohammad, and R. A. Rahman, "Modeling the Causes and Mitigation Measures for Cost Overruns in Building Construction: The Case of Higher Education Projects," *Buildings*, vol. 14, no. 2, p. 487, Feb. 2024, doi: 10.3390/buildings14020487.

[11] C. D. Annamalaisami and A. Kuppuswamy, "Reckoning construction cost overruns in building projects through methodological consequences," *International Journal of Construction Management*, vol. 22, no. 6, pp. 1079–1089, Apr. 2022, doi: 10.1080/15623599.2019.1683689.

[12] M. Rajabalinejad, "Bayesian Monte Carlo method," *Reliab Eng Syst Saf*, vol. 95, no. 10, pp. 1050–1060, Oct. 2010, doi: 10.1016/j.ress.2010.04.014.

[13] A. Namazian, S. H. Yakhchali, V. Yousefi, and J. Tamošaitienė, "Combining Monte Carlo Simulation and Bayesian Networks Methods for Assessing Completion Time of Projects under Risk," *Int J Environ Res Public Health*, vol. 16, no. 24, p. 5024, Dec. 2019, doi: 10.3390/ijerph16245024.

[14] M. A. Ashtari, R. Ansari, E. Hassannayebi, and J. Jeong, "Cost Overrun Risk Assessment and Prediction in Construction Projects: A Bayesian Network Classifier Approach," *Buildings*, vol. 12, no. 10, p. 1660, Oct. 2022, doi: 10.3390/buildings12101660.

[15] P. Gehl, F. Cavalieri, and P. Franchin, "Approximate Bayesian network formulation for the rapid loss assessment of real-world infrastructure systems," *Reliab Eng Syst Saf*, vol. 177, pp. 80–93, Sep. 2018, doi: 10.1016/j.ress.2018.04.022.

[16] A. Touran and R. Lopez, "Modeling Cost Escalation in Large Infrastructure Projects," *J Constr Eng Manag*, vol. 132, no. 8, pp. 853–860, Aug. 2006, doi: 10.1061/(ASCE)0733-9364(2006)132:8(853).

[17] A. Moghayedi and A. Windapo, "Modelling the uncertainty of cost and time in highway projects," *Infrastructure Asset Management*, vol. 9, no. 2, pp. 73–88, Jun. 2022, doi: 10.1680/jinam.21.00004.

[18] J. R. van Dorp and M. R. Duffey, "Statistical dependence in risk analysis for project networks using Monte Carlo methods," *Int J Prod Econ*, vol. 58, no. 1, pp. 17–29, Jan. 1999, doi: 10.1016/S0925-5273(98)00081-4.

[19] R. F. Herrera, O. Sánchez, K. Castañeda, and H. Porras, "Cost Overrun Causative Factors in Road Infrastructure Projects: A Frequency and Importance Analysis," *Applied Sciences*, vol. 10, no. 16, p. 5506, Aug. 2020, doi: 10.3390/app10165506.