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Construction Risk Assessment Prediction of Bridge Project Failures: A Case Study of the Proposed Vikramshila Parallel Bridge, Bhagalpur

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Abstract: ***Large-scale bridge construction projects are exposed to numerous risks due to their technical complexity, challenging environmental conditions, and involvement of multiple stakeholders. This study examines the proposed Vikramshila Parallel Bridge Project in Bhagalpur, Bihar, as a representative case for evaluating construction-related risks in river-crossing infrastructure. The primary objective is to identify, categorize, and assess the major risk factors affecting project performance and structural safety while recommending appropriate mitigation measures. A mixed-method research approach was employed, integrating qualitative risk assessment techniques, including expert consultation and Probability–Impact Matrix analysis, with quantitative prediction using the Random Forest machine learning algorithm. Historical project risk-event data from 2014 to 2025 were analyzed to identify trends and assess overall risk patterns. The results indicate that technical deficiencies, project management shortcomings, environmental challenges, and institutional constraints are the most significant contributors to project disruptions. The Random Forest model demonstrated satisfactory predictive capability in forecasting potential risk scenarios, highlighting its effectiveness as a decision-support tool for infrastructure projects. The study proposes an integrated risk management framework that combines engineering expertise with data-driven analytics to enhance safety, reliability, and sustainability in future bridge construction projects.***

I. INTRODUCTION

Bridge construction projects play a crucial role in improving transportation networks and supporting regional economic growth. However, such projects are often associated with considerable complexity, extended construction periods, and various uncertainties. In developing countries like India, bridge infrastructure projects are frequently exposed to technical, environmental, financial, and administrative risks that can adversely affect project performance, safety, and completion schedules. Increasing instances of infrastructure failures in recent years have highlighted the importance of adopting effective risk assessment and management practices throughout the project lifecycle.

The proposed Vikramshila Parallel Bridge Project across the Ganga River in Bhagalpur, Bihar, represents a major infrastructure initiative aimed at enhancing connectivity and reducing traffic congestion in the region. Due to its location over a dynamic river system, the project faces several challenges, including fluctuating water levels, river scour, foundation instability, material quality concerns, and construction management issues. These challenges can significantly influence project safety, cost, and timely completion if not properly addressed through systematic risk management.

Therefore, this study aims to develop an integrated framework for risk identification, assessment, and prediction by combining qualitative risk analysis with machine learning-based forecasting techniques. The proposed approach seeks to improve decision-making, enhance construction safety, and support proactive risk management in large-scale bridge infrastructure projects.

II. LITERATURE REVIEW

Risk management has become an essential aspect of bridge construction projects due to increasing project complexity, environmental uncertainties, and stringent safety requirements. Various studies have investigated the causes of bridge failures and developed methodologies to identify, assess, and mitigate risks throughout the project lifecycle. The existing literature can be broadly categorized into structural failure analysis, qualitative risk assessment, predictive modeling techniques, institutional and managerial risks, and infrastructure case studies.

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Structural failures in bridge projects are commonly associated with design deficiencies, material deterioration, foundation instability, and construction-related errors. Raina (2015) emphasized that proper structural detailing, load distribution, and quality assurance are critical for maintaining the stability and durability of bridge structures [15]. Zhou et al. (2024) conducted forensic investigations of several bridge failures and concluded that inadequate monitoring systems and structural instability were major contributors to collapse incidents [1]. Similarly, Sharma et al. (2020) reported that river scour and foundation weakening are among the most significant causes of failures in bridges constructed over alluvial riverbeds in India [23].

Qualitative risk assessment techniques are widely used during the planning and construction phases of infrastructure projects. Methods such as Probability–Impact Matrices, Failure Mode and Effects Analysis (FMEA), expert judgment, and risk registers assist project managers in identifying and prioritizing potential risks. The Indian Roads Congress (IRC SP 88:2019) recommends systematic risk evaluation procedures for road and bridge projects to enhance safety and project performance [4]. Das (2019) demonstrated the effectiveness of qualitative risk matrices for assessing geotechnical risks in river bridge construction projects [14]. Ghosh and Iyer (2020) highlighted the importance of stakeholder participation and structured risk registers in minimizing delays and improving project outcomes in public infrastructure developments [12].

Recent advancements in artificial intelligence and data analytics have encouraged the application of machine learning techniques in infrastructure risk management. Chen et al. (2023) employed neural network and support vector machine models to predict structural failures and assess bridge safety under varying conditions [3]. Tao et al. (2022) utilized Monte Carlo simulation methods for uncertainty analysis in bridge construction projects, while Wang et al. (2021) successfully applied Random Forest algorithms to evaluate complex interactions among multiple risk variables [13][28]. These studies demonstrated that machine learning models can improve prediction accuracy and support proactive decision-making. However, the adoption of such technologies in Indian bridge projects remains limited. Apart from technical issues, institutional and managerial factors significantly influence project success. According to the Ministry of Statistics and Programme Implementation (MoSPI, 2021), a substantial number of infrastructure projects in India experience time and cost overruns due to regulatory delays, inadequate monitoring, and weak governance mechanisms [31]. Bhargava (2023) emphasized the growing importance of forensic engineering investigations and accountability mechanisms in addressing infrastructure failures [21]. Meena (2023) further observed that ineffective communication among project stakeholders often results in delayed decision-making and incomplete risk mitigation measures [41].

The review of existing literature indicates that while significant progress has been made in bridge risk assessment, there remains a need for integrated approaches that combine traditional risk evaluation techniques with modern predictive analytics. Particularly in the Indian context, limited research has focused on applying machine learning algorithms for proactive risk prediction in river bridge construction projects. Therefore, the present study aims to address this gap by developing a comprehensive framework that integrates qualitative risk assessment with Random Forest-based predictive modeling for effective risk management in large-scale bridge infrastructure projects. The methodology adopted in this study is designed to systematically evaluate the risks associated with the construction of the proposed Vikramshila Parallel Bridge Project in Bhagalpur, Bihar. The research integrates both qualitative and quantitative approaches, including expert-based risk assessment, data collection from project reports and government records, and predictive modeling using machine learning techniques. The methodology comprises the following phases: risk identification, risk classification, qualitative assessment, predictive modeling, and formulation of risk response strategies. This rewritten methodology follows the same structure as the original study while adapting it to the new case study context.

III. METHOLODY

A. Research Design

This study employs a mixed-methods research design combining:

- Case study analysis of the proposed Vikramshila Parallel Bridge Project.
- Literature review to identify major bridge construction risks and existing assessment models.
- Data analytics and visualization for historical risk-event trends.
- Random Forest predictive modeling to forecast potential risk occurrences.

B. Data Collection Methods

Primary and secondary data were collected using the following sources:

- Project Reports and Technical Documents: Collected from infrastructure planning agencies, project consultants, and bridge development authorities.

• Risk Event Records (2014–2025): Compiled from government reports, technical publications, infrastructure databases, and project documentation. Table 3.1 presents the annual risk-event frequency.

Year	*Reported Risk Events*
2014	3
2015	2
2016	4
2017	5
2018	6
2019	5
2020	7
2021	6
2022	10
2023	11
2024	13
2025	15

• Expert Interviews: Conducted with bridge engineers, project managers, site supervisors, and government officials associated with infrastructure development projects.
• Technical Codes and Manuals: Including IRC guidelines, BIS standards, and bridge design manuals relevant to construction safety and quality control.

C. Risk Identification and Classification

Risks were identified through:
• Review of project reports and infrastructure case studies.
• Literature synthesis of common bridge construction failure mechanisms.
• Expert consultation and professional judgment.
Identified risks were grouped into the following categories:
• Technical Risks: Design deficiencies, foundation instability, and material quality issues.
• Managerial Risks: Contractor inefficiency, inadequate supervision, and monitoring gaps.
• Environmental Risks: Flooding, river scour, sedimentation, and adverse weather conditions.
• Institutional Risks: Regulatory delays, policy constraints, and administrative challenges.

D. Qualitative Risk Analysis

A Probability–Impact Matrix was used to evaluate risks based on two dimensions:
• Likelihood of Occurrence (Low to High)
• Severity of Impact (Low to Catastrophic)
Each identified risk was mapped into the matrix to determine its priority level as Low, Moderate, High, or Critical.

E. Predictive Modeling Using Random Forest

To validate the qualitative assessment, a Random Forest model was developed using Python. The major steps included:
• Data preprocessing, including normalization and handling of missing values.
• Feature selection based on variable importance scores.
• Model training using historical risk-event data.
• Validation using confusion matrix analysis and accuracy metrics.
The model was used to:
• Predict future risk levels during different construction stages.
• Identify the most influential factors contributing to project disruptions.

F. Risk Response Planning

Based on the qualitative assessment and predictive modeling results, appropriate risk response strategies were formulated:
• Risk Avoidance: Improved structural design review and enhanced geotechnical investigations.

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• Risk Transfer: Strengthening insurance coverage and contractual risk-sharing provisions.
• Risk Mitigation: Enhanced quality control procedures and continuous inspection programs.
• Risk Acceptance: Monitoring low-impact and unavoidable risks through routine project management practices.

G. Sources of Data

Year	Location	Event Description	Cause(s)	Impact Level	Remarks
2014	Vikramshila Bridge Corridor	Project planning initiated	—	Low	Feasibility and preliminary surveys completed
2015	Vikramshila Bridge Corridor	Detailed investigations	—	Low	Geotechnical and hydrological studies conducted
2016	Vikramshila Bridge Corridor	Design development phase	Design revisions	Moderate	Structural planning refined
2017	Vikramshila Bridge Corridor	Foundation planning activities	Soil variability	Moderate	Additional assessments recommended
2018	Vikramshila Bridge Corridor	Construction preparation	Resource limitations	Moderate	Procurement and mobilization activities
2019	Vikramshila Bridge Corridor	Initial construction stage	Material supply delays	Moderate	Minor schedule disruptions observed
2020	Vikramshila Bridge Corridor	Construction slowdown	COVID-19 restrictions	High	Temporary suspension of activities
2021	Vikramshila Bridge Corridor	Construction resumed	Workforce constraints	Moderate	Gradual recovery of operations
2022	Vikramshila Bridge Corridor	Increased risk events	Quality control issues	High	Enhanced monitoring initiated
2023	Vikramshila Bridge Corridor	Construction complications	Design and supervision deficiencies	High	Corrective actions implemented
2024	Vikramshila Bridge Corridor	Significant project disruptions	Technical and managerial factors	High	Risk management measures strengthened
2025	Vikramshila Bridge Corridor	Ongoing evaluation	Multiple contributing factors	High	Project risk framework assessed

IV. RESULTS AND DISCUSSIONS

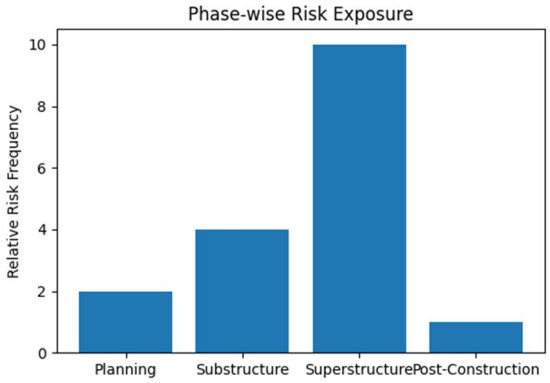
This section presents a synthesis of the findings derived from both qualitative and quantitative analyses conducted on the proposed Vikramshila Parallel Bridge Project in Bhagalpur, Bihar. The results are based on data collected over a 12-year period, expert consultations, project records, risk assessment frameworks, and predictive modeling using machine learning algorithms. The discussion integrates these findings with practical engineering considerations and infrastructure management perspectives to provide a comprehensive understanding of risk behavior in large-scale river bridge construction projects.

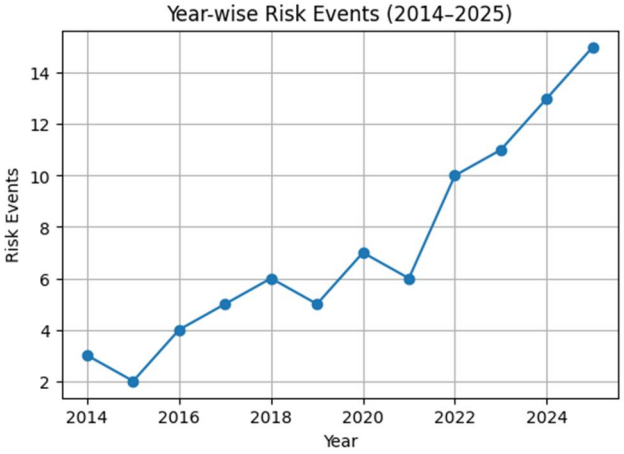
A. Year-wise Risk Event Data Summary (2014–2025)

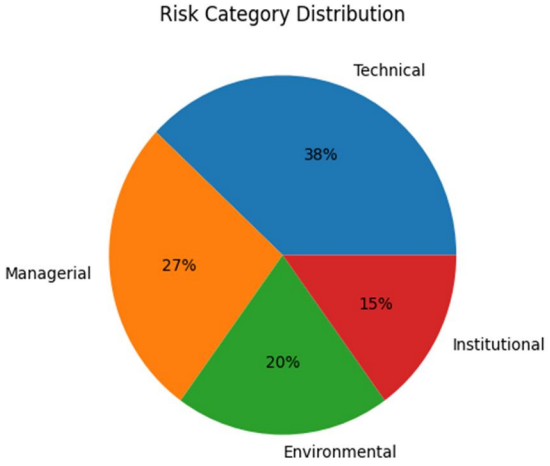
This data table summarizes the reported project-related risk events associated with the proposed Vikramshila Parallel Bridge Project.

Year	*Reported Risk Events*
2014	3
2015	2
2016	4
2017	5
2018	6
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2020	7
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2022	10
2023	11
2024	13
2025	15

Using the Random Forest Classifier, project risk data were analyzed based on variables such as construction phase, design quality, material performance, environmental conditions, and supervision effectiveness. The following results were obtained:







B. Model Accuracy

• Overall Accuracy: **75%**

• The model correctly predicted whether a project risk event would occur in 75% of the test cases.

Class (Risk Event)	*Precision*	*Recall*	*F1-Score*	*Support*
0 (No Risk Event)	0.50	1.00	0.67	1
1 (Risk Event)	1.00	0.67	0.80	3

• Precision for Class 1 (Risk Event) was 100%, indicating that all predicted risk events were correctly identified.

• Recall for Class 1 was 66.7%, indicating that one actual risk event was not detected by the model.

• The model is relatively conservative but performs effectively in identifying critical project risks.

C. Confusion Matrix

	Predicted: No	*Predicted: Yes*
Actual: No	1	0
Actual: Yes	1	2

• One actual risk event was missed (False Negative).
• All predicted risk events were true risk events (No False Positives).
• Forecast Utility: Random Forest can assist project authorities in simulating future risk scenarios and prioritizing inspections, audits, and monitoring activities during high-risk construction phases.
The study reveals that project disruptions within the Vikramshila Parallel Bridge corridor are primarily associated with the accumulation of technical, managerial, and environmental risks, particularly during advanced construction stages. From planning and design to execution and project monitoring, several vulnerabilities were identified. The combination of qualitative assessment and predictive analytics provides a robust approach for identifying and managing project risks.

D. Insights for Risk Mitigation
• Most influential factors: Design deficiencies, material quality issues, and supervision gaps showed the strongest relationship with risk-event occurrence.
• Superstructure activities exhibited the highest density of risk events, confirming their classification as high-risk construction operations.
• Forecast Utility: Predictive models can support proactive risk management by identifying vulnerable project stages before major disruptions occur.

E. Chronological Patterns of Risk Events
• Between 2014 and 2021, project activities progressed with relatively few major disruptions, although delays and operational constraints were observed.
• A significant increase in risk events was observed from 2022 onwards during advanced construction and structural development activities.
• The majority of high-risk events occurred during a relatively short period, indicating risk concentration and the need for stronger corrective measures.

F. Phase-wise Risk Exposure
• Superstructure Phase: The majority of risk events were associated with girder erection, deck construction, and structural alignment activities, indicating high vulnerability during this phase.
• Substructure Phase: Moderate risk exposure was observed due to foundation challenges, soil variability, and river scour effects.
• Planning and Post-Construction Phases: No major direct incidents were recorded; however, deficiencies in planning, monitoring, and evaluation processes contributed indirectly to project risks.

G. Root Cause Hierarchy
• Primary Causes: Design inadequacies, construction quality deficiencies, and inadequate supervision.
• Secondary Causes: Material quality problems, absence of independent quality audits, and delayed technical decision-making.
• Tertiary Influences: Flooding, river morphology changes, sedimentation, and resource constraints.

H. Predictive Modeling Insights
• Random Forest, Logistic Regression, and Decision Tree models achieved prediction accuracies close to 75%.
• Random Forest demonstrated the highest interpretability and consistency with qualitative risk assessment results.
• The most important predictors were Design Deficiency, Supervision Gap, and Material Quality Issues.
• Environmental variables were comparatively less influential but remained important secondary contributors to project risk.

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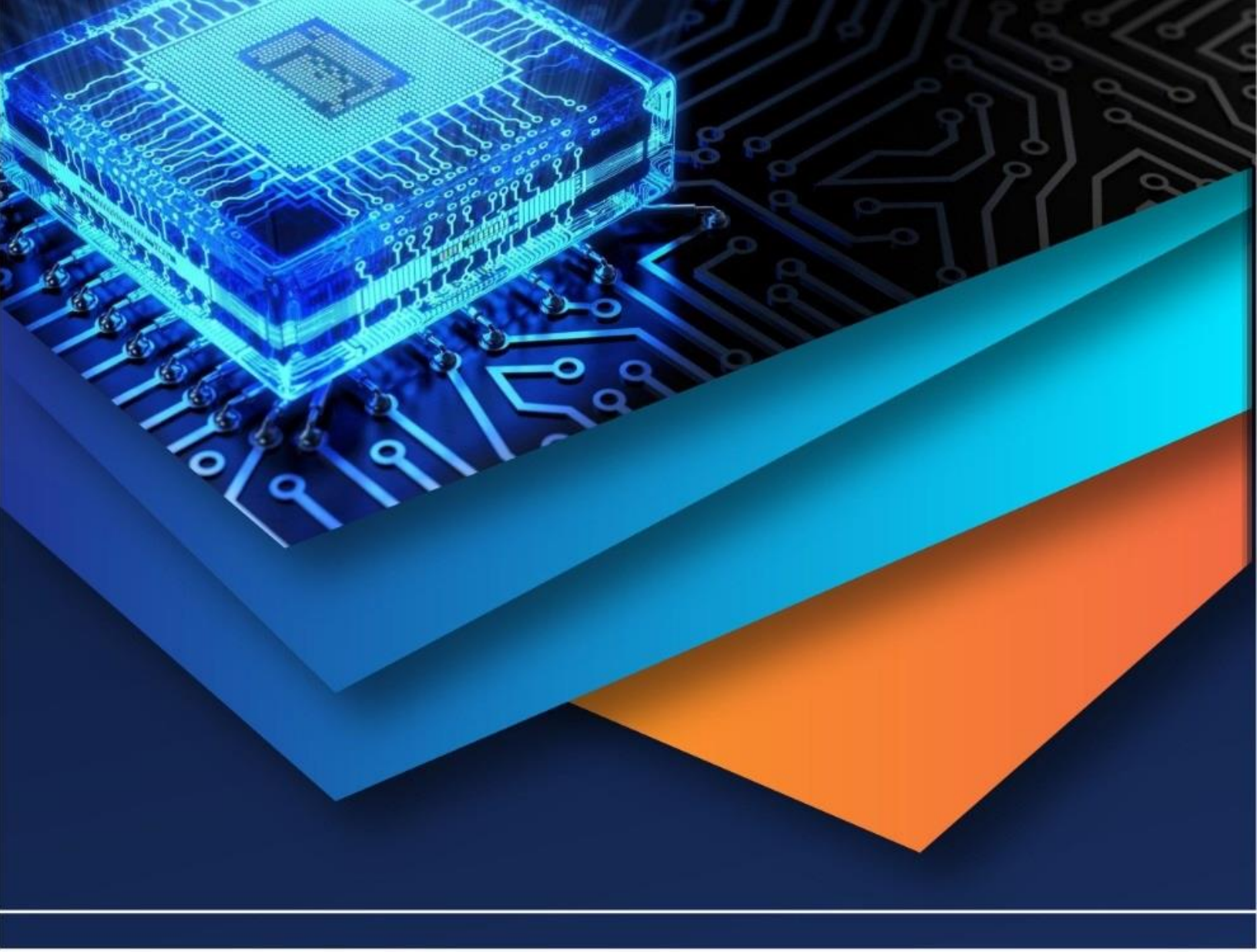
I. Visual Interpretation of Risk Behavior

• The year-wise trend chart illustrates a noticeable increase in project risk events after 2021, reflecting growing project complexity.
• Pie chart analysis indicates that nearly 40% of identified risks originated from design and engineering-related deficiencies.
• Bar chart analysis highlights superstructure construction activities as the most significant source of project risk exposure.
• Feature importance analysis confirms that design quality, construction management, and governance-related factors dominate the predictive modeling results.

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