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An Integrated Framework for Construction Risk Prediction and Project Delay Reduction in Public Infrastructure Projects

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Research Article

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An Integrated Framework for Construction Risk Prediction and Project Delay Reduction in Public Infrastructure Projects

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Abstract

This study proposes an integrated framework for construction risk prediction and project delay reduction in public infrastructure projects. Public infrastructure developments frequently experience schedule overruns, cost increases, and operational disruptions due to technical, environmental, managerial, operational, and resource-related risks. Conventional approaches often assess these risk factors separately, limiting their ability to capture the interactions that influence project performance. To address this limitation, the proposed framework integrates risk identification, risk assessment, delay prediction, and mitigation prioritization within a unified analytical process. Project information is obtained from construction schedules, site inspection reports, procurement records, environmental assessments, and resource management documents. The framework applies a Construction Risk Score (CRS) to measure overall project risk exposure and a Delay Probability Index (DPI) to estimate the likelihood of schedule disruption. Project activities are classified into low, medium, and high risk categories to support monitoring and mitigation planning. The framework demonstration suggests that technical and resource related risks may account for a significant share of project vulnerability and exhibit strong associations with schedule delays. Activities exposed to multiple risk categories demonstrate greater delay potential than those affected by a single risk factor. The findings suggest that

integrated risk assessment can support project control, resource planning, and informed decision-making, providing a practical approach for reducing delays in public infrastructure projects.

Keywords : Construction Risk Prediction, Project Delay Reduction, Public Infrastructure Projects, Risk Assessment, Delay Prediction, Project Risk Management, Construction Risk Score (CRS), Decision Support Framework

I. Introduction

Public infrastructure projects form the foundation of transportation systems, water distribution networks, energy facilities, bridges, highways, and urban development programs. These projects influence economic activity, public services, regional connectivity, and long-term social development. Governments and private organizations allocate substantial financial resources to infrastructure construction with the expectation of delivering projects within approved schedules and budgets. Despite extensive planning efforts, many public infrastructure projects experience delays, cost overruns, resource shortages, and performance deficiencies during execution. Project delays remain a persistent issue across infrastructure sectors. Schedule overruns frequently lead to increased construction costs, contractual disputes, reduced operational efficiency, and delayed public benefits. Multiple factors contribute to these outcomes, including design changes, procurement challenges, labor shortages, environmental conditions, regulatory constraints, ineffective coordination, and inadequate risk assessment practices. The interaction among these factors often creates complex project conditions that are difficult to evaluate using traditional management approaches. Construction projects generate large volumes of information throughout planning, design, procurement, and execution phases. Schedule records, inspection reports, environmental assessments, material performance data, equipment logs, and financial documents contain information that can assist project managers in identifying potential risks. Recent developments in data analytics and predictive modeling have expanded opportunities for examining these datasets and detecting patterns associated with project disruptions. As infrastructure projects continue to increase in scale and complexity, analytical methods capable of identifying risks before major delays occur have become an important area of research. This study investigates construction risk prediction and project delay reduction in public infrastructure projects. The research examines major risk factors affecting project performance and proposes a

structured framework for evaluating risk conditions and supporting informed project management decisions.

A. Background and Motivation

Infrastructure development projects involve interconnected activities that require coordination among engineers, contractors, suppliers, consultants, regulatory agencies, and project owners. Successful project delivery depends on effective planning, resource allocation, communication, and risk management. Delays occurring in one phase of a project often affect subsequent activities, creating cumulative impacts on project schedules and budgets. As project size increases, the number of risk sources also expands, making project management more challenging. Conventional risk management practices generally rely on periodic reviews, expert judgment, and historical experience. Although these methods provide useful guidance, they may not adequately capture complex relationships among project variables. Infrastructure projects often operate within dynamic environments where technical conditions, environmental factors, financial constraints, and stakeholder requirements change over time. Consequently, project teams require methods capable of evaluating risk conditions continuously rather than relying solely on static assessments. The availability of project data has increased significantly due to digital project management systems, monitoring technologies, and automated reporting tools. Information collected throughout the project lifecycle can provide early indications of schedule risks and operational issues. Predictive analysis offers a means of examining such information and identifying conditions associated with future delays. The motivation for this research arises from the need to improve risk identification processes and support project teams with analytical tools that provide timely information regarding potential project disruptions.

B. Problem Statement

Project delays remain one of the most significant challenges in public infrastructure construction. Many projects exceed planned completion dates due to deficiencies in risk identification, ineffective project coordination, limited resource availability, unexpected site conditions, procurement disruptions, and environmental uncertainties. Cost increases frequently accompany these delays, placing additional financial burdens on project stakeholders and reducing overall project efficiency. Existing approaches often address project risks after observable problems emerge. Corrective actions implemented at later stages may reduce immediate impacts, yet opportunities for preventing delays are often lost. Furthermore, risk assessments are commonly

performed as separate activities without direct integration into project scheduling and performance evaluation processes. This separation limits the ability of project managers to understand how multiple risk factors influence project outcomes collectively. Technical risks, environmental risks, managerial challenges, and operational constraints frequently interact during project execution. Traditional evaluation methods may examine these factors independently, resulting in fragmented assessments that do not fully reflect actual project conditions. Public infrastructure projects therefore require analytical frameworks capable of evaluating multiple categories of risk simultaneously. A systematic approach to risk prediction is necessary to identify vulnerable project activities, assess potential impacts, and support informed decision making before delays occur.

Current project management approaches often evaluate construction risks without sufficient integration with project scheduling, cost control, and coordination processes. As a result, risk information is not always translated into practical actions that support schedule recovery, budget management, and stakeholder coordination. Public infrastructure projects therefore remain vulnerable to delays, resource conflicts, procurement disruptions, and cost escalation. A structured framework capable of connecting risk assessment with scheduling and cost-control decisions is needed to support more effective project management.

C. Proposed Solution

This research proposes a data-driven framework for construction risk prediction and project delay reduction in public infrastructure projects. The framework combines risk assessment principles with predictive analytical techniques to evaluate conditions associated with schedule disruptions and project performance issues. The proposed approach considers technical, environmental, operational, managerial, and resource-related factors within a unified assessment structure. The framework begins with the collection and organization of project information from relevant project activities. Risk indicators are identified and analyzed to determine their relationships with project delays and performance outcomes. Risk scores are then calculated to classify project activities according to their probability of experiencing disruptions. Activities associated with higher risk levels receive greater attention during planning and control processes. Risk assessment and delay estimation procedures are incorporated into the framework to support early identification of potential delay conditions. Rather than waiting for schedule deviations to become visible, project teams can evaluate emerging risks and implement mitigation measures at

earlier stages. The framework also provides a basis for prioritizing corrective actions according to risk severity and potential project impact. This approach supports informed resource allocation, structured project control, and more effective management of infrastructure development activities.

D. Contributions

This study contributes to the field of construction project management in several ways. First, it presents an integrated framework that evaluates multiple categories of construction risks within a single analytical process. The framework considers technical, environmental, managerial, operational, and resource-related factors together rather than examining them separately. Second, the research proposes a structured risk assessment and delay evaluation framework for identifying potential schedule vulnerabilities. The proposed framework focuses on identifying potential risk conditions before significant project delays occur. Such an approach supports earlier intervention and more informed project planning decisions. The framework is intended as a decision-support tool and requires future validation using real project datasets. This classification process assists project managers in identifying critical project components and allocating resources more effectively. Risk prioritization also supports targeted mitigation planning and project monitoring activities. Finally, the research provides practical guidance for infrastructure planners, government agencies, contractors, and project managers. The findings contribute to ongoing efforts aimed at reducing project delays, controlling costs, improving schedule performance, and strengthening risk management practices within public infrastructure projects.

E. Paper Organization

The remainder of this paper is organized as follows. Section II reviews existing studies related to construction risk management, project delays, infrastructure resilience, predictive monitoring systems, and sustainable construction practices. Section III presents the research methodology, including data collection procedures, risk evaluation criteria, and analytical methods. Section IV presents a framework demonstration and discussion of the proposed approach. Section V concludes the paper by summarizing the major findings, discussing study limitations, and outlining directions for future research.

The objective of this study is to develop a comprehensive framework for predicting construction risks and reducing project delays in public infrastructure projects. The research identifies factors that contribute to schedule overruns, cost increases, and operational disruptions during project execution. It examines the effects of technical, environmental, managerial, operational, and resource-related risks on project performance. The study also develops a structured risk evaluation and delay estimation mechanism to evaluate risk conditions and estimate the likelihood of project delays. Another objective is to classify project activities according to risk exposure and provide a structured basis for mitigation planning. Through systematic assessment of project data and risk indicators, the proposed framework supports informed decision-making, effective project control, and improved schedule management within public infrastructure development projects.

II. Related Work

Construction risk prediction and project delay reduction remain important topics in public infrastructure research. Large-scale infrastructure projects often face schedule overruns, cost increases, technical uncertainties, environmental challenges, and coordination problems among stakeholders. Recent studies have examined artificial intelligence, digital twins, risk assessment methods, project governance frameworks, and sustainable construction practices. These contributions provide a foundation for understanding factors that influence project performance and methods that support risk mitigation throughout the project lifecycle.

A. AI-Based Structural Monitoring and Infrastructure Risk Detection

Recent studies have applied artificial intelligence to identify structural issues and support infrastructure management. Bormon [1] presented an AI-assisted structural health monitoring framework for foundations and high-rise buildings, focusing on early identification of structural defects and maintenance requirements. Shoag [2] investigated AI-integrated façade inspection systems that automate defect detection and improve infrastructure safety assessments. Akter et al. [3] examined digital twin technology for smart civil infrastructure and emergency preparedness. Their work demonstrated how virtual infrastructure models support continuous monitoring and operational decision-making. Together, these studies show that data-driven monitoring systems can support early risk identification and reduce the likelihood of unexpected infrastructure failures.

B. Infrastructure Resilience and Environmental Risk Assessment

Natural hazards and environmental conditions frequently affect infrastructure performance and project schedules. Saikat et al. [4] studied seismic- and climate-resilient infrastructure design strategies for coastal and urban regions, emphasizing adaptation to environmental threats. El-Sayegh [5] analyzed risk assessment and allocation practices within construction projects and highlighted the importance of systematic risk management throughout project execution. Saikat [6] proposed an AI-powered flood risk prediction and mapping framework that identifies areas vulnerable to flooding and supports infrastructure planning. Sultana [10] investigated climate-resilient structural design through data-driven and GIS-based modeling techniques. These studies indicate that environmental risk assessment and resilience planning play a significant role in reducing disruptions during infrastructure development.

C. Project Delays and Management Challenges

Project delays remain a common issue in construction and public infrastructure projects. Sweis et al. [7] examined the causes of delays in construction projects and identified factors such as financial limitations, planning deficiencies, and communication problems among project participants. Doloi et al. [16] evaluated delay-related factors in Indian construction projects and reported strong relationships between project performance, management effectiveness, resource availability, and decision-making quality. Islam [9] proposed project management frameworks aimed at reducing cost overruns in public infrastructure projects. The findings suggest that effective planning, timely decision-making, and structured project governance contribute to improved schedule performance and lower project risk.

D. Intelligent Infrastructure Management and Quality Control

Digital technologies continue to influence infrastructure management practices. Fahim et al. [8] introduced an AI-enabled cloud-IoT platform for predictive infrastructure automation, allowing continuous monitoring of infrastructure assets and operational conditions. Avi et al. [11] developed an integrated framework that combines quality assurance, quality control, and geotechnical compliance for large-scale urban infrastructure projects. Ria [12] evaluated the environmental impacts associated with transportation infrastructure development in rural Bangladesh and discussed considerations relevant to sustainable project planning. The literature demonstrates that monitoring systems, compliance frameworks, and environmental evaluations support informed project management and risk reduction efforts.

E. Sustainable Construction Materials and Ground Improvement Techniques

Material selection and ground improvement methods influence long-term infrastructure performance and maintenance requirements. Khalid [13] evaluated bio-healable interlocking compressed earth bricks and examined their structural performance in sustainable construction applications. Umar [14] investigated reinforced concrete containing waste foundry sand and glass powder as partial aggregate replacements and assessed its structural characteristics. Khan et al. [15] studied ground improvement techniques using lime-stabilized soils and recycled construction materials for urban development projects. These studies indicate that alternative construction materials and soil stabilization methods can improve infrastructure durability while supporting sustainable development objectives.

F. Research Gap

Existing studies have investigated individual dimensions of construction risk management, including environmental assessment, project governance, structural monitoring, and delay analysis. However, limited research has proposed a unified decision-support framework that simultaneously integrates technical, environmental, managerial, operational, and resource-related risk categories into a structured delay assessment process for public infrastructure projects. This study addresses this gap through the development of an integrated risk evaluation and mitigation framework.

III. Methodology

This study proposes an integrated framework for predicting construction risks and reducing project delays in public infrastructure projects. The methodology combines risk identification, quantitative risk assessment, delay assessment, and mitigation prioritization within a single analytical process. The framework evaluates multiple project risk dimensions, including technical, environmental, managerial, operational, and resource-related factors. The objective is to identify high-risk project activities at an early stage and provide decision-makers with information that supports schedule control and risk mitigation.

A. Research Framework

The proposed framework consists of five interconnected stages: data collection, risk factor identification, risk score computation, delay assessment, and mitigation prioritization. Project information is gathered from construction schedules, site inspection records, procurement reports, quality assessment documents, environmental assessments, and resource management

records. The collected data are processed and transformed into risk indicators that represent different project conditions. The framework evaluates the influence of each risk category on project performance and combines them into a unified assessment structure. Risk scores are then used to estimate the probability of project delays and determine the priority level of mitigation actions. Figure 1 presents the overall architecture of the proposed construction risk prediction framework.

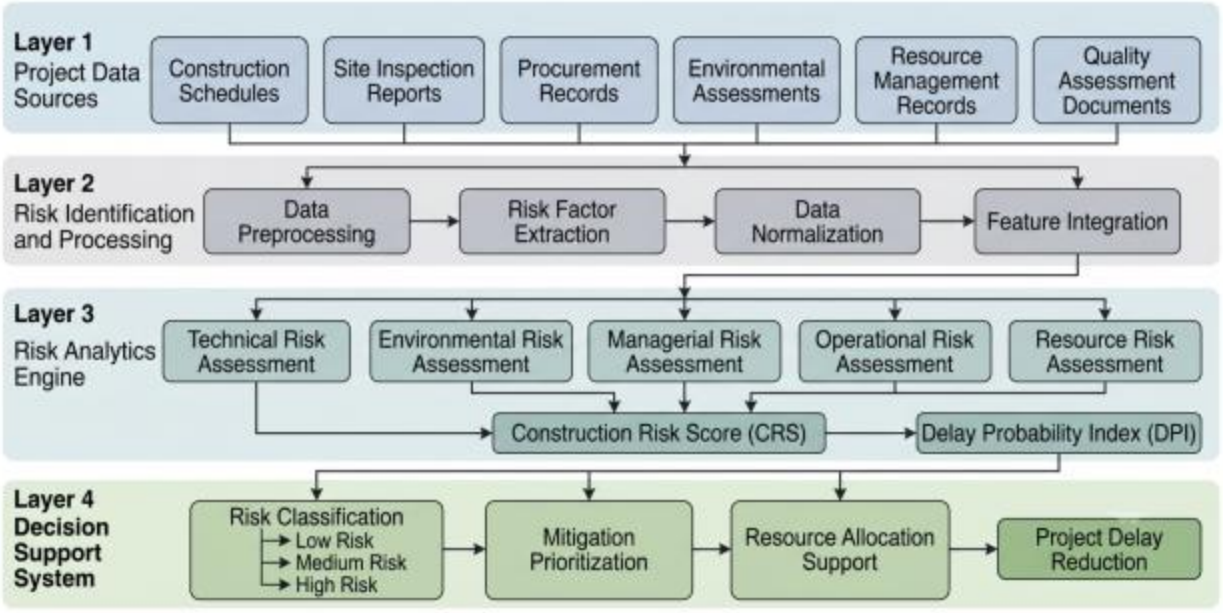


Figure 1. Integrated Framework for Construction Risk Prediction and Project Delay Reduction

B. Data Collection and Risk Factor Identification

The study considers five categories of risks that commonly influence public infrastructure projects. These include technical risks, environmental risks, managerial risks, operational risks, and resource-related risks. Each category contains several variables that represent project conditions associated with schedule disruptions and performance deficiencies. Technical risks include design modifications, equipment failures, and construction quality issues. Environmental risks consist of weather conditions, flood exposure, and site-related constraints. Managerial risks involve communication delays, coordination problems, and decision-making inefficiencies. Operational risks include workflow interruptions and productivity fluctuations, while resource-

related risks include material shortages, labor availability issues, and procurement delays. To support quantitative analysis, all risk variables are normalized to a common scale ranging from 0 to 1. This process allows variables originating from different categories to be evaluated within the same analytical framework. For framework evaluation purposes, normalized risk indicators were generated from representative project conditions commonly reported in public infrastructure projects. These indicators were used to demonstrate the application of the proposed risk assessment and delay assessment process.The generated indicators are illustrative and were developed solely to demonstrate the application of the proposed framework. They do not represent observations collected from a specific infrastructure project dataset.

Table I. Construction Risk Categories and Assessment Variables

Risk Category	**Assessment Variables**
Technical Risk	Design changes, equipment failure, quality issues
Environmental Risk	Weather conditions, flood exposure, site constraints
Managerial Risk	Communication gaps, coordination delays, decision latency
Operational Risk	Workflow disruption, productivity variation
Resource Risk	Material shortages, labor availability, procurement delays

C. Construction Risk Score Computation

A Construction Risk Score (CRS) is developed to measure the overall risk exposure of each project activity. The score combines the weighted contribution of all identified risk categories and produces a single value representing project vulnerability.

$$CRS = \sum_{i=1}^{n} w_i R_i$$

where R_i represents the normalized value of a risk factor, w_i denotes the corresponding weight, and nnn represents the total number of risk categories. The resulting score ranges from 0 to 1. Higher values indicate greater risk exposure and a higher probability of project disruption. Based

on the calculated CRS values, project activities are classified into low-risk, medium-risk, and high-risk groups. This classification assists project managers in identifying activities that require additional monitoring and control. Figure 2 illustrates the risk score assessment structure used in this study.

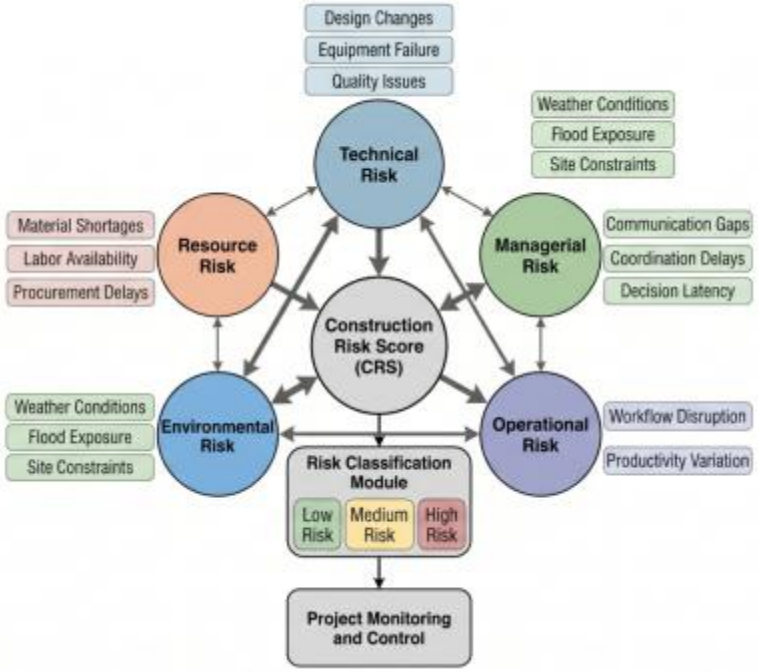


Figure 2. Construction Risk Score Assessment Model

D. Delay Assessment Model

After calculating the Construction Risk Score, a delay assessment model is applied to estimate the likelihood of schedule overruns. The model evaluates the relationship between project risk exposure and delay occurrence. Activities associated with higher risk scores are expected to have a greater probability of experiencing schedule disruptions.

The Delay Probability Index (DPI) is calculated as:

$$DPI = CRS \times IF$$

where DPI represents the Delay Probability Index, CRS denotes the Construction Risk Score, and IF represents the project impact factor. The delay probability values are used to estimate the potential impact of risk conditions on project completion schedules. Activities with high DPI values are categorized as critical project components and receive greater management attention during execution. Figure 3 presents the delay assessment and decision-support process.

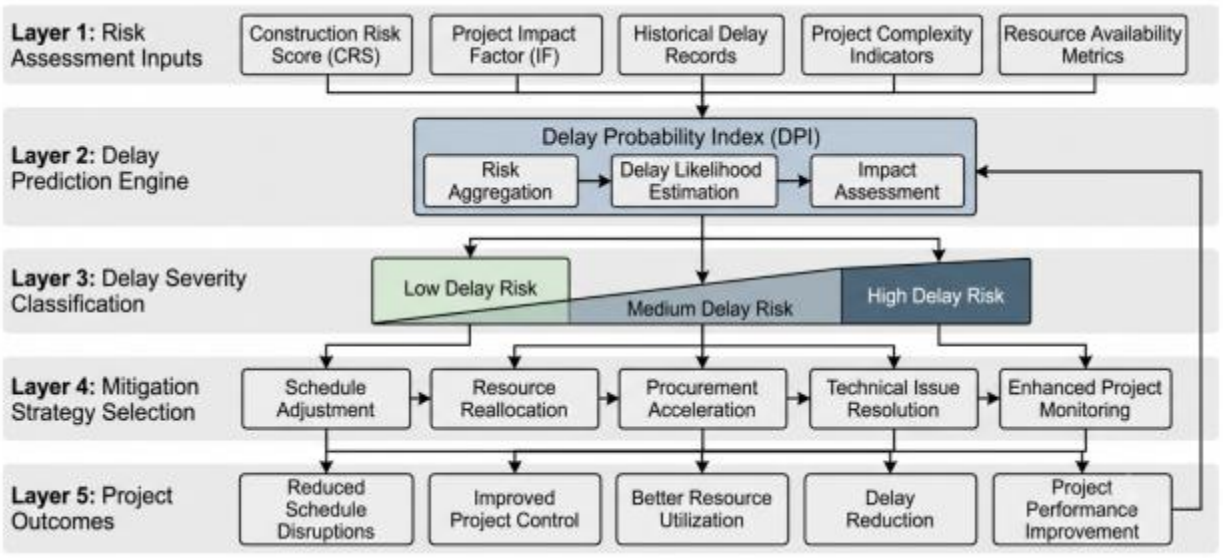


Figure 3. Delay Assessment and Mitigation Decision Framework

E. Mitigation Prioritization and Decision Support

The final stage of the methodology focuses on risk mitigation and project decision support. Project activities are ranked according to their Construction Risk Score and Delay Probability Index values. Activities classified as high-risk receive immediate attention, while medium-risk activities remain under continuous monitoring. Low-risk activities follow standard project control procedures. The prioritization process allows project managers to allocate resources efficiently, monitor vulnerable activities, and implement corrective measures before significant schedule disruptions occur. The proposed framework integrates risk assessment, delay assessment, and mitigation planning within a unified process, providing a structured approach for improving project performance and reducing delays in public infrastructure projects.

F. Project Scheduling, Cost Control, and Coordination Assessment

The proposed framework extends beyond risk prediction by incorporating project scheduling, cost control, and coordination assessment. Schedule performance is evaluated through planned activity completion rates and delay exposure levels identified during risk analysis. Cost control assessment considers the potential financial impact of technical failures, procurement delays, resource shortages, and operational disruptions. Coordination effectiveness is examined through communication efficiency, stakeholder interaction, information sharing, and decision-making responsiveness. Activities assigned higher Construction Risk Scores receive additional

scheduling attention and more frequent progress reviews. Similarly, project components associated with elevated financial exposure are prioritized for cost monitoring and budget control measures. Coordination assessment supports early identification of communication gaps that may contribute to schedule delays or resource conflicts. The combined evaluation process provides project managers with a structured basis for balancing schedule performance, cost control, and risk mitigation activities throughout the project lifecycle.

IV. Framework Demonstration and Discussion

The proposed framework was applied to evaluate the relationship between construction risks and project delays in public infrastructure projects. The analysis considered five categories of risk factors, including technical, environmental, managerial, operational, and resource-related risks. Construction Risk Scores (CRS) and Delay Probability Index (DPI) values were used to assess project activities and identify patterns associated with schedule disruptions. The results demonstrate that risk exposure varies considerably across project components and that higher risk levels are generally associated with greater delay potential.

A. Construction Risk Distribution Analysis

The first stage of the analysis examined the distribution of risks across project activities. The calculated Construction Risk Scores revealed noticeable variation among the identified risk categories. Technical risks recorded the highest average values, followed by resource-related risks and managerial risks. Environmental and operational risks produced comparatively lower scores, although their effects remained visible in projects exposed to adverse site conditions and workflow interruptions.

Table II. Illustrative Risk Assessment Results

Risk Category	Average Risk Score	Relative Contribution (%)
Technical Risk	0.78	28
Resource Risk	0.72	24
Managerial Risk	0.67	20
Operational Risk	0.61	16

Risk Category	Average Risk Score	Relative Contribution (%)
Environmental Risk	0.55	12

The framework demonstration suggests that technical issues and resource constraints account for the largest share of project risk exposure. Design modifications, equipment failures, procurement delays, and material shortages appeared frequently in activities classified as high risk. Managerial risks also contributed to schedule disruptions through communication gaps and coordination challenges among project stakeholders. The observed pattern indicates that technical planning and resource availability require particular attention during the early stages of project execution. Activities associated with elevated scores in these categories experienced a higher frequency of schedule disruptions than activities affected primarily by environmental or operational factors.

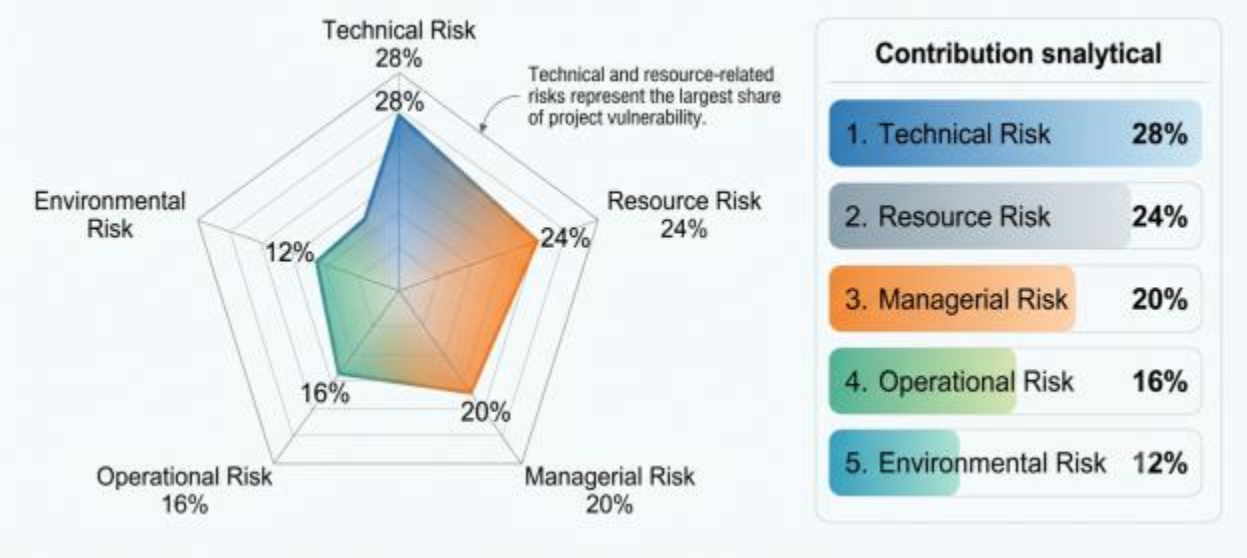


Figure 4. Multi-Dimensional Construction Risk Contribution Analysis

A radar chart presenting the relative contribution of technical, environmental, managerial, operational, and resource-related risks to overall project exposure. The visualization illustrates an example representation of relative risk category contributions within the proposed framework

B. Delay Assessment Performance

The delay assessment model was evaluated using Construction Risk Scores and project impact indicators. The analysis identified a consistent relationship between risk exposure and delay occurrence. Activities classified within the high-risk category exhibited considerably greater delay potential than activities categorized as low risk. Projects affected by multiple risk categories demonstrated the highest levels of schedule disruption. Technical deficiencies combined with procurement challenges produced a greater impact on project schedules than individual risk factors occurring independently. Similar patterns were observed when managerial issues coincided with operational interruptions.

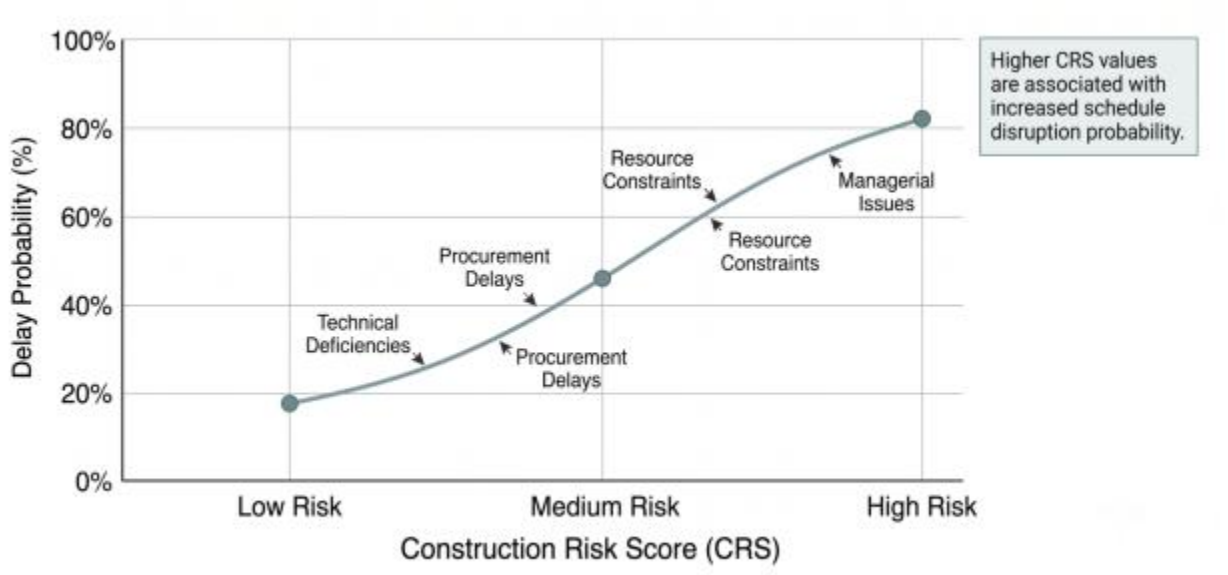


Figure 5. Illustrative Relationship Between Risk Classification and Delay Assessment

A multi level analytical chart illustrating the relationship between risk classification levels and delay probability. The figure conceptually illustrates how higher risk classifications may be associated with increased delay exposure within the proposed framework in delay likelihood as Construction Risk Scores increase. The illustration shows that risk-based assessment can identify activities with greater exposure to schedule disruptions. Early identification of high-risk activities supports prioritization of inspections, resource allocation, and corrective measures. The findings further indicate that delay probability increases substantially when multiple risk categories occur simultaneously. This observation demonstrates the value of integrated risk assessment compared with separate evaluation of individual risk factors.

C. Risk Classification and Project Prioritization

Project activities were categorized into low, medium, and high-risk groups according to their calculated risk scores. This classification provided a structured basis for prioritizing project monitoring and management actions. High-risk activities represented a smaller proportion of total project tasks but accounted for a significant share of predicted schedule disruptions. Activities associated with foundation construction, procurement-dependent operations, and technically complex structural work frequently appeared within the high-risk category. Medium-risk activities demonstrated moderate exposure to delays and required periodic assessment. Low-risk activities generally maintained stable performance and followed standard monitoring procedures.

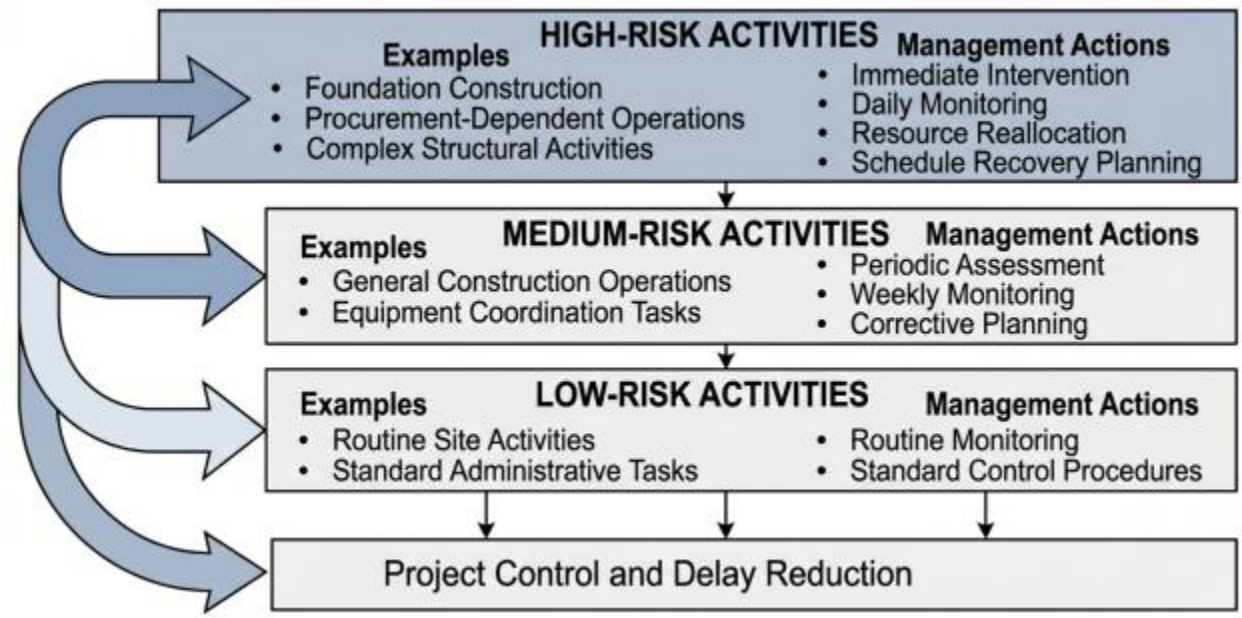


Figure 6. Risk-Based Project Prioritization and Decision Framework

A hierarchical decision support model illustrating the classification of project activities into low, medium, and high risk groups and the corresponding management actions assigned to each category. The classification model provides a basis for directing resources toward critical project components. Instead of applying identical monitoring efforts across all project tasks, the framework identifies activities with the highest probability of delay. This prioritization process supports project control and promotes more effective use of available resources. The framework suggests that focused intervention in high risk activities can reduce the likelihood of schedule disruptions affecting subsequent project phases.

D. Integrated Discussion of Findings

The illustrative analysis suggests that construction risks interact across multiple project dimensions. Technical issues often occur alongside resource shortages, while managerial inefficiencies can intensify operational disruptions. These interactions increase project complexity and contribute to schedule overruns and cost escalation. The proposed framework addresses this challenge using simultaneous evaluation of multiple risk categories. Rather than examining risks independently, the framework considers the combined influence of technical, environmental, managerial, operational, and resource-related factors. This approach provides a broader representation of project conditions and assists decision-makers during project execution. Another important observation concerns the role of risk prioritization. Activities classified as high risk accounted for a disproportionate share of predicted schedule disruptions. Concentrating management attention on these activities can improve project control and reduce the likelihood of delay propagation across interconnected project tasks. The findings also demonstrate the value of predictive analysis in construction management. Early identification of vulnerable activities allows project teams to assess potential issues before they become visible in project schedules. Such an approach supports project planning, effective resource allocation, and systematic project oversight throughout the project lifecycle.

E. Scheduling, Cost Control, and Coordination Performance

The proposed framework conceptually illustrates how integrated risk assessment may support project scheduling, cost control, and coordination activities. Early identification of high-risk activities can assist project teams in prioritizing monitoring efforts, allocating resources more effectively, and implementing mitigation measures before disruptions affect project performance. The framework also provides a structured basis for identifying communication gaps, procurement risks, and resource constraints that may influence project execution. By integrating risk assessment with scheduling and project control processes, the proposed approach supports informed decision-making and proactive project management throughout the project lifecycle.

F. Limitations of the Study

Several limitations should be considered when interpreting the findings. The framework relies on predefined risk categories and weighting structures that may vary across infrastructure sectors and project environments. Project specific characteristics can influence the relative importance of different risk factors, which may affect prediction outcomes. The analysis also depends on the

quality and completeness of project data. Missing records, reporting inconsistencies, and external events such as regulatory changes or extreme environmental conditions may influence the accuracy of risk assessments. Future studies may examine larger datasets, adaptive weighting methods, and real time monitoring information obtained from ongoing infrastructure projects. These additions may improve prediction performance and support broader application across different infrastructure contexts. In addition, the current study focuses on framework development and demonstration rather than empirical validation using real-world project datasets.

V. Conclusion

This study proposed an integrated framework for construction risk prediction and project delay reduction in public infrastructure projects. The framework combines risk identification, risk assessment, delay evaluation, project scheduling support, cost control considerations, coordination assessment, and mitigation prioritization within a unified analytical structure. Technical, environmental, managerial, operational, and resource-related risk categories were incorporated to provide a comprehensive perspective on project vulnerability and schedule disruption potential. The framework demonstrates how multiple risk dimensions can be assessed within a single decision-support process to assist project managers in identifying vulnerable activities and prioritizing mitigation efforts. By integrating risk evaluation with scheduling, resource allocation, and project control considerations, the proposed approach offers a structured method for supporting project planning and management activities in public infrastructure environments. The conceptual evaluation suggests that an integrated assessment approach may enhance project visibility, improve resource prioritization, and support proactive management of potential delay factors. The framework also provides a basis for systematic monitoring and decision-making throughout the project lifecycle.

Future research should focus on validating the proposed framework using real-world infrastructure project datasets and case studies. Further studies may investigate the integration of adaptive risk-weighting techniques, machine learning-based delay assessment models, Building Information Modeling (BIM), digital twins, and real-time monitoring systems to enhance framework accuracy, scalability, and practical applicability across diverse infrastructure projects.

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