An analysis of the risks associated with starting girder operations in high-speed rail projects

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Abstract: The study's findings, which take a comprehensive look at risks during girder operation initiation in high-speed rail projects, are particularly relevant for structural integrity, project schedule, project safety, and the project's economics. The study is a mixed methods research that includes qualitative, descriptive statements from experts and cases and quantitative assessment of frequency, severity scales, and impact indicators. Structural & Engineering risks, Operational & logistical, Safety & Environmental and Financial & Project Management risks were systematically identified and categorized. The results indicate that structural risks, including loading estimates and misalignment, have the greatest severity because they can directly affect the integrity of the infrastructure. Safety measures were also born as critical, having to rely on strict adherence with the safety standards, as well as precautions against risks coming from the workers' accident and equipment failure. Operational risks identified included delays, mainly due to equipment unavailability and logistical issues affecting project timelines, which were more frequent. Commissioning risks, including cost overspending and budget mismanagement, were strongly associated with gaps in other risk areas. A comparison and contrast was also conducted, and it was shown that structural and safety risks are paramount in terms of mitigation strategies. The paper highlights the importance of developing an integrated risk management approach that integrates advanced engineering practices, resource planning efficiency, and proactive decision making.

Keywords: High-speed rail projects, Girder operations, Risk analysis, Operational risks, Safety management, Financial risks, Risk assessment, Infrastructure construction.

INTRODUCTION

The creation of modern transportation infrastructure is now a key demand for many countries aiming for better economic development, regional connectivity and sustainable mobility. High-Speed Rail (HSR) is one of the most advanced and efficient systems to be developed for long-distance passenger transport among different transportation systems (Aven, T., 2016). High-speed rail networks offer a number of benefits over existing transportation infrastructure, such as lower travel time, reliability, higher capacity and lower environmental damage (Baecher, G., et. al. 2005). Cities and nations are rapidly expanding, and governments all over the world are spending significant amounts of money on high-speed rail projects to facilitate economic development and decrease reliance on car and truck transportation that pollutes (Banaitiene, N., et. al. 2012). The world is becoming more urban, and more populated, and governments are investing more in high-speed rail infrastructure for economic development and to provide environmentally sustainable alternatives to car and truck transport (Chen, C., et. al. 2019). This infrastructure is complex to construct and operate, however, encompassing highly advanced technology, engineering and large scale structural systems (Flyvbjerg, B., 2014).

Background of The Study

Dramatic development of transportation infrastructure over the past decade in the world has created a strong need for high-speed rail (HSR) systems to be more efficient, reliable and sustainable. The advantages of HSR of cutting time, improving region connectivity, and impacting the regional economic development along with offering environmentally friendly mobility solutions make it an important mode of transport (Ghosh, S., et. al. 2004). China, Japan, France and Spain have all been able to construct large high-speed rail networks, and show the benefits of cutting-edge rail technology in contemporary transport systems. The growth of these has inspired a number of developing countries to pursue the notion of introducing similar infrastructures in order to boost the transport system's national capacity and address the mobility needs of the future (International Union of Railways, 2018).

Additionally, India is embarking on significant investments to modernize its railways and boost the operational capacity of the railway sector required for long-term growth in its economy (Kerzner, H., 2017). The Mumbai–Ahmedabad High-Speed Rail Corridor is one such project that highlights the integration of cutting-edge engineering and world-class construction practices into India's infrastructure landscape (Li, H., et. al. 1998). Due to the difficulties of obtaining large amounts of land and congestion, elevated rail structures backed by bridge and viaduct systems are an desirable building method being used (Liu, J., et. al. 2020). The process of installing these structures involves the use of girders and other specialized machinery, thereby posing certain operational and safety issues. Hence, it is crucial to carry out systematic risk analysis to identify hazards during the implementation of high-speed railways so as to make them more efficient and safe (PMI, 2021).

LITERATURE REVIEWS

Smith, N., et. al. (2014) investigate the lateral responses of bridge piles under time-sensitive conditions several-case field prototype tests that consisted of a different combinations of the various surcharge distances and loading values were performed along with a numerical model with a soft soil material subroutine. The time varying changes of added lateral load on the piles, the stress of the soil-arching among piles, and the plastic distortion in the soil around piles, were displayed in the nature of the interaction between the piles and soil. The result indicates that the bending moment and deflection of the pile is gradually increasing in proportion to the increase of the length of load duration, and that the former is proportional to the ratio of the thickness of the weak soil layer and the position of the layer. Moreover, the horizontal soil-arching between piles experienced the stabilization, local damage, and plastic flow stages where the passive force exerted on the pile side kept increasing until it stabilized causing a lateral deflection of the pile foundation with time.

Wang, S., et. al. (2004) provides detailed discussion to the most important points of superstructure and track construction of the high speed railway (HSR) in Indonesia. It starts with an introduction to the HSR line, the first line of this type in Southeast Asia, and an explanation of the installation of the box girder of the elevated structure with full span prestressed concrete. The main challenges such as complex topography and population density and its implication on the design and construction of the HSR line are highlighted. The paper then discusses the two tracks forms applied in the HSR line (ballasted track and slab track), the construction process, as well as, the merits and demerits of each of the trackform systems when used in various sections of the HSR line. At the end of the paper, a conclusion has been made noting that there is still a need to conduct more research and development to facilitate the operation and maintenance of the current line, and its future extensions.

Zhang, G., et. al. (2013) reviewing the research situation of the damage detection technology of the high-speed trains in the recent years, the authors have summarized the damage detection technology of the high-speed trains and comparatively analyzed the several different technologies and some of their research products on high-speed train track operation and maintenance damage detection. From the analysis results, it can be seen that the research and implementation strategies of high-speed train rail damage detection are mainly related to the non-destructive test technology and method of high-speed train rail, and test platform machinery. Detection platforms like equipment consists of a novel vortex meter, integrated track recording vehicles, laser rangefinders, thermal sensors, laser vision systems, LiDAR, new ultrasonic detectors, rail detection vehicles, rail detection robots, laser on-board rail detection systems, track recorders, self- moving trolleys and others. The focus of research is electromagnetic detection, optical detection, ultrasonic guided wave detection, acoustic emission detection, ray detection, vortex detection, and vibration detection. The research techniques are also applied as methods of detection including optical emission detection and infrared imaging. Rail detection using the LiDAR detection method, ultrasonic detection, eddy current detection, and optical detection have been the most extensively studied and used methods in the last few years.

Zou, P., et. al. (2007) A detailed construction control approach is presented, which is designed and adopted on such type of bridges. The methodology is based on a real-world scenario of a construction project for a bridge in China, which consists of mechanical analysis of the key construction stages, forecasting the bridge's deformation, and taking real-time measurements and corrective action. Moreover, it discusses the use of machine learn ing (ML) in the prediction of camber. The significant results indicate that the vertical displacement in the X Direction (Longitudinal direction) of top chord at the point of upper deck closure is very much responsive to changes in temperature with a difference of about 1012 mm for a change in temperature of 15 ^{o}C. This implies that the closure welding should be carried out close to de sign reference temperature and field measurements taken to make a final adjustment of the fit up. Comparative studies between predictions made by the members elon gation using ML and theoretical approaches revealed the excellent prediction results of the models ET and KNN with errors reported as 2 mm or less, supporting the viability of the camber setting through the ML approach.

Research Objectives

1. To identify the key risk factors associated with launching girder operations in high-speed rail construction projects.
2. To analyze the probability and impact of identified risks using quantitative data collected from construction professionals and project stakeholders.
3. To prioritize the most critical risks affecting launching girder operations through statistical analysis and risk ranking techniques.

To recommend effective risk mitigation strategies to improve safety and operational efficiency in high-speed rail launching girder activities.

Problem Statement

The infrastructure projects of high-speed rail constitute complicated construction processes which demand advanced engineering methodology as well as professional safety control. The operation of launching girder is one of the most essential operations in such projects as the precast bridge segments are installed in elevated rail corridors. Even though the launching of girders enhance the effectiveness of building construction and shorten its time span, construction works also concern the movement of heavy equipment, the work at high altitudes, and the strict coordination of various elements and human resources.

These environments pose a great technical, operational, and safety risk such as equipment breakdown, structural instability, employee accidents and delays in operations. Poor risk management in the launching girder operations may result in some dire accidents, loss of money, as well as derailment of the project. Although high-speed rail projects have increased across the globe, the processes of risk management in the initiation of girder operations tend to focus on past practices of safety through traditionalist approaches and expert opinion instead of systematic processes of analysis. Thus, the quantitative analysis should be designed to assess the likelihood and extent of the various risk factors and facilitate good safety planning in the high-speed rail construction projects.

METHODOLOGY

Research Design and Approach

Descriptive and analytical research design is used in the present study to explore the risks encountered in girder operations of high speed train projects. These usually address the describing aspect, which targets the identification and classification of different kinds of risk factors, and the analysing aspect, which targets the frequency, seriousness and effect of these risks on overall project performance. Both qualitative and quantitative methods of research have been used, and a mixed-method approach is employed. The qualitative component involves the interpretation of risk factors based on the expert insights and case based understanding and the quantitative component involves measuring risk factors with numeric indicators like frequency percentage, severity scale, delay impacts, cost impacts etc

Data Collection Methods

The data collection methods used were structured questionnaire and expert consultation. The survey included civil engineers, project managers, site supervisors, etc., involved in high-speed railroad and bridge construction works in the field. The research questionnaire was designed to come up with respondents' perceptions of the various risk factors in terms of the occurrence, severity and the effect they were creating on project timetables and costs. The respondents were selected by purposive sampling of those who are experienced in girder operation. The number of respondents in the sample was around 40-50, which provides a good balance of technical skills.Second hand data were obtained from published research articles, project reports, technical documents and case studies of various construction of high speed rail. They offered key insights that informed the prior risks, best practices and challenges identified during girder launching operations.

Identification and Classification of Risk Factors

The identification of risk factors was done using literature reviews and analysing the primary and secondary data collected. A detailed Risk List was first created by involving experts from acoustic and noise control fields and following up on documented cases based on girder operations in high-speed train projects. These risks were then further narrowed and sorted by characteristics and potential effects. A thematic classification approach was used to categorize the risks based on their nature and consider them under four broad categories – structural and engineering risks, operational and logistic, safety and environmental, and financial and project management risks. This classification is based on a Risk Breakdown Structure (RBS) and allows systematic organization, maintains a consistent evaluation and facilitates comparisons.

Risk Assessment and Measurement Techniques

A structured risk assessment framework was created, along with indicators for key assessment. The three key parameters measured for each risk factor were the frequency (the percentage of occurrence of the risk), a risk level (a rating from 1 to 5), and impact measures (project time, cost and safety effects). The frequency is a measure based on the results of the survey and the evidence on cases that shows how often a given risk is occurring. The severity level was based on the impact, and when a Likert scale was used, this ranged from very low severity (Likert 1) to very high severity (Likert 5). The participants indicated on each risk and the average was obtained to obtain overall risk severity. Depending on the factor, an impact measure was assessed through delay (days) or cost increase (%). Also, the risk of impacts was evaluated based on safety risks associated with the impacts. To ensure a complete and reliable evaluation, the frequencies of the listed risks in percent of respondents were determined; the impacts on the delay and costs were estimated using the expert judgment and secondary data sources.

Data Analysis and Comparative Evaluation

The collected data were analyzed descriptively which aimed to give clarity and consistency in data interpretation and interpretation. The responses to the survey were systematically recorded, summarized, and mean values for each risk factor were calculated as values or percentages, as well as severity scores. These results are presented in structured tables, making it easy to visualise and compare the results by risk category. The relative importance of risks was determined by comparing them by calculating the average severity extent of each risk within each category, to determine the overall severity level of that category. These summed values were then used for ranking the risk categories, with higher values representing higher risk. The ranking was done by computing severity scores for each category, comparing severity of them, fixing rank (Rank 1 for most severe), and categorizing the risks as Critical, High and Moderate. This systematic assessment enables comprehensive understanding of the relative importance of the various risks and to identify the risks that need prompt attention and those that can be managed as part of routine risk mitigation.

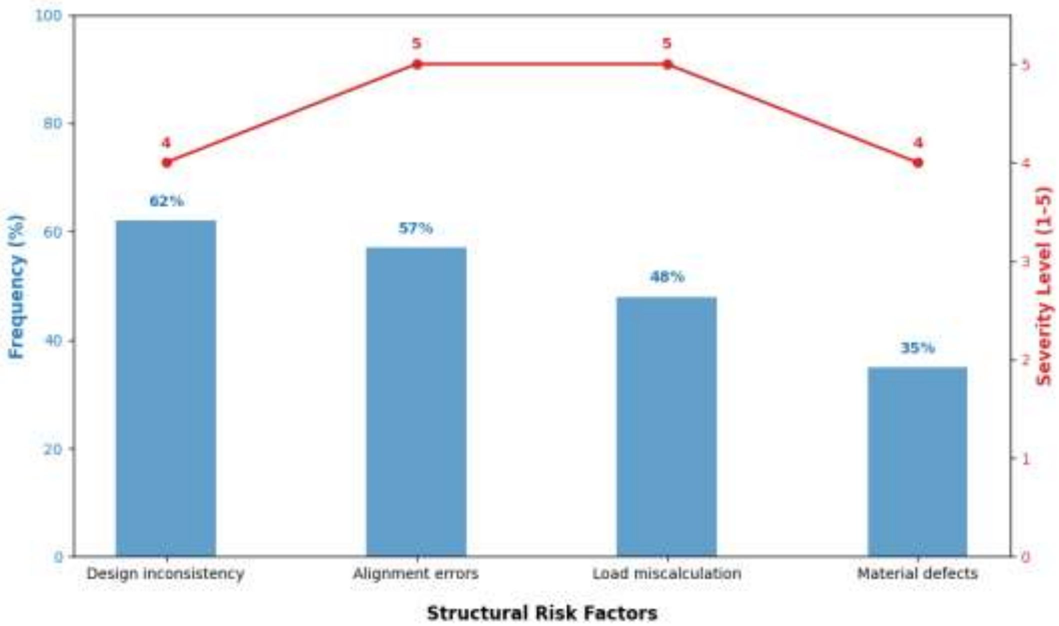
RESULTS

Structural and Engineering Risks in Girder Operations

Girder operations begin while in its initiation stage, making structural and engineering precision very critical. The results show that structural risk is one of the most crucial factors affecting the success of girder launching in High-speed rail (HSR) construction projects. The potential hazards are most often due to non-matching designs, rough load estimation, material and/or alignment deviance during installation. The results show that the most significant structural risks are load miscalculations, and alignment errors. Miscalculation of loads is frequently made because the dynamic loads are too much or too little accounted for when designing the load causing structure. Dynamic loads often cause more vibration and stress distribution in high speed rail systems than in conventional rail systems, which better exemplifies why dynamic loads must be considered. In addition, alignment problems when installing the girders can cause the structures to become unstable over time, which can result in higher maintenance costs and safety risks. While not as common, material defects can still be a significant factor because of the risk of compromising the structural integrity. Another area observed as a common problem element was design inconsistencies in achieving the designs from one stage to another in their design process, for example, design to production stage inconsistencies which resulted in rework and delays.

Table 1: Structural Risk Factors and Their Impact

S. No.	Risk Factor	Frequency (%)	Severity Level (1–5)	Impact on Project
1	Design inconsistency	62%	4	Rework and structural mismatch
2	Load miscalculation	48%	5	Structural failure risk
3	Material defects	35%	4	Reduced durability
4	Alignment errors	57%	5	Operational instability



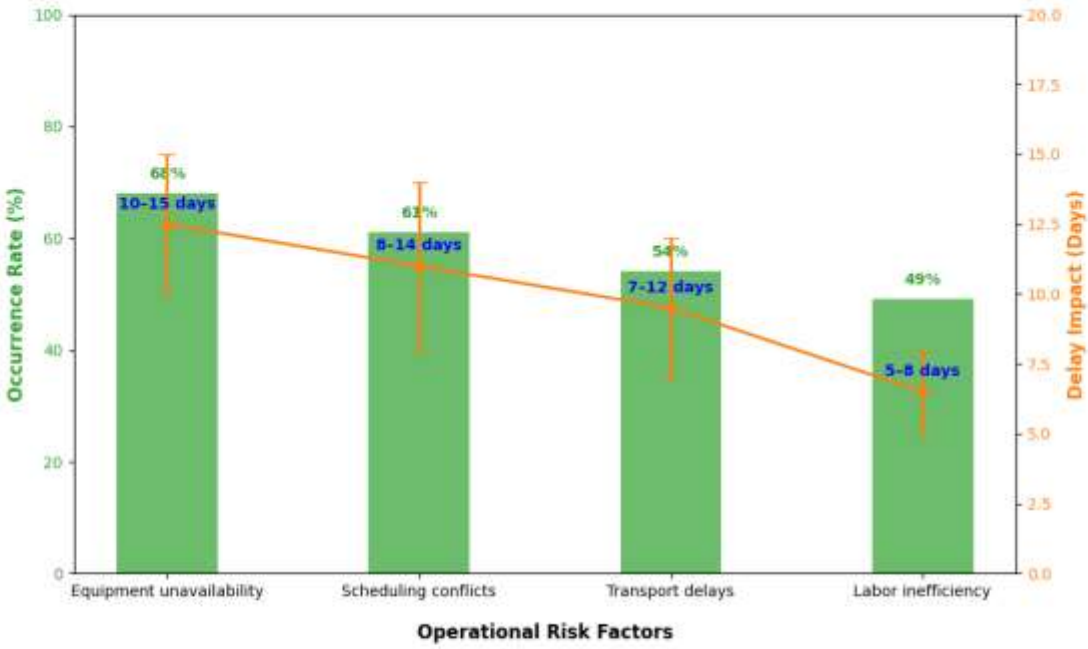
Graph 4. Analysis of Structural Risk Factors: Frequency and Severity Level

Operational and Logistical Risks

The running and logistics factors have a big impact on the effectiveness and speed of running girders. The findings show that the equipment availability, transportation delays, labour inefficiencies and scheduling conflicts are significant causes of operational risk. The most common problem observed was equipment unavailability (more than two-thirds), among these. The availability of specialized equipment for girder launching may be limited, causing a delay in the project. Schedule changes also result from delayed travel times, especially during traffic-heavy time periods or geographic regions. Challenges with the efficiency of the work people perform compound the issues associated with operations and can also be caused by a lack of training and coordination. Idle time and wastage of resources, as a result of scheduling conflicts among different construction activities, were also identified as a key issue.

Table 4. Operational Risk Assessment

S. No.	Risk Factor	Occurrence Rate (%)	Severity (1–5)	Delay Impact (Days)
1	Equipment unavailability	68%	4	10–15
2	Transport delays	54%	4	7–12
3	Labor inefficiency	49%	3	5–8
4	Scheduling conflicts	61%	4	8–14



Graph 4. Operational Risk Assessment: Occurrence Rate and Delay Impact

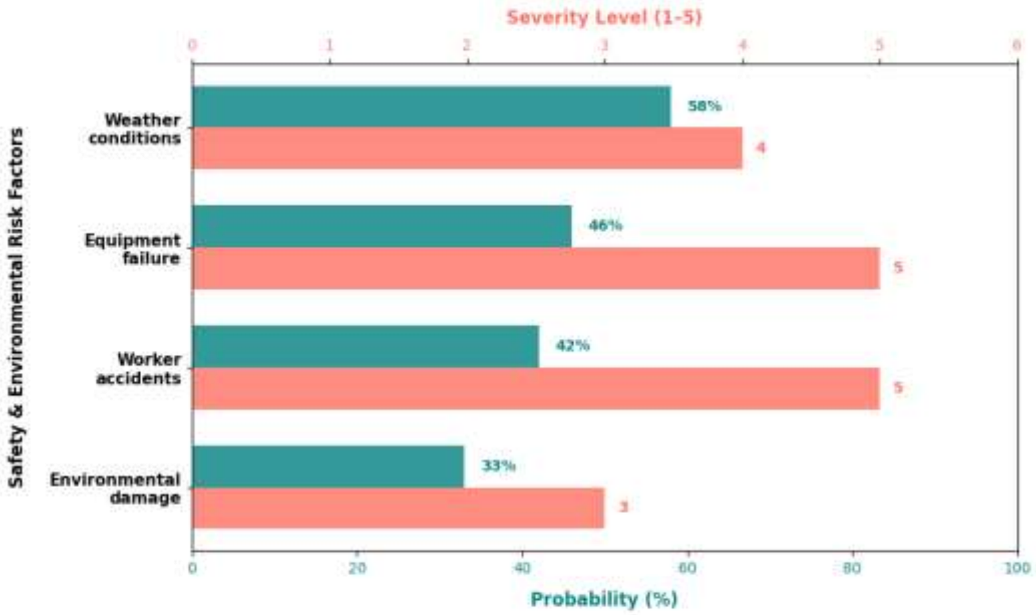
Safety and Environmental Risks

Among the considerations of girder operation are issues related to safety and environment, especially considering the large expanses and complexity of the high-speed rail facilities. The results highlight that incidents involving workers, failures of equipment, unfavorable weather and environmental disturbances are important risk factors. The frequency of workers' accidents is low, and the severity is high because their consequences can be severe, such as a person injured or even killed. Equipment failure is another major risk that can occur from mechanical issues or poor equipment maintenance. Rainfall, wind, hot or cold temperature were observed to have a significant impact on girder launching activities. Other environmental hazard factors, such as noise and disruption of the environment, were also noted, especially in urban and environmentally-sensitive areas.

Table 4. Safety and Environmental Risk Indicators

S. No.	Risk Factor	Probability (%)	Severity Level (1–5)	Safety Impact
1	Worker accidents	42%	5	Injury/fatality risk

2	Weather conditions	58%	4	Work stoppage
3	Equipment failure	46%	5	Operational hazards
4	Environmental damage	33%	3	Regulatory/legal impact



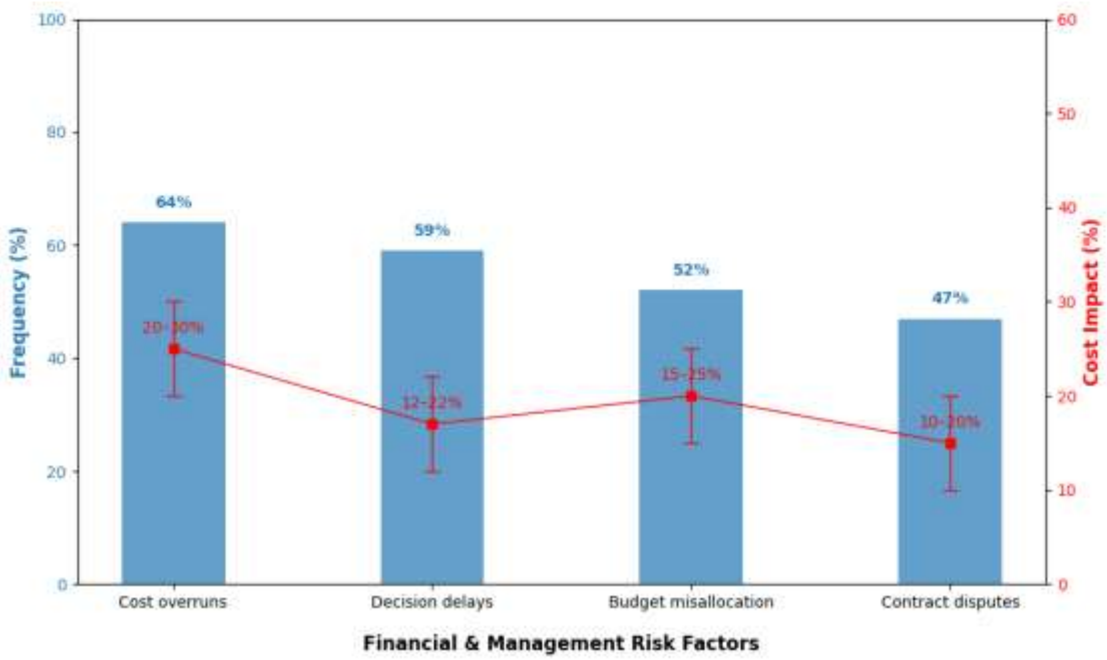
Graph 4. Safety and Environmental Risk Profile: Probability and Severity Level

Financial and Project Management Risks

Financial and managerial aspects play a crucial role in determining the feasibility and sustainability of girder operations. According to the results, the main financial risk factors are cost overruns, the misallocation of the budget, dispute over contracts, and delays in decision-making. Financial risk was recognized as the primary risk, commonly associated with cost overrun, which could arise from work rework, lack of resources and delays. Because of budget misallocation, especially in early project stages, funding shortages occur during critical time periods like the time to install girders. There were also some clashes among stakeholders resulting from lack of clarity in terms of responsibilities and performance expectations. However, ongoing delays in decision making processes are also common (due to bureaucratic processes or lack of coordination) and contribute to the delay of project progress.

Table 4: Financial and Management Risk Analysis

S. No.	Risk Factor	Cost Impact (%)	Frequency (%)	Overall Risk Level
1	Cost overruns	20–30%	64%	High
2	Budget misallocation	15–25%	52%	Medium-High
3	Contract disputes	10–20%	47%	Medium
4	Decision delays	12–22%	59%	High



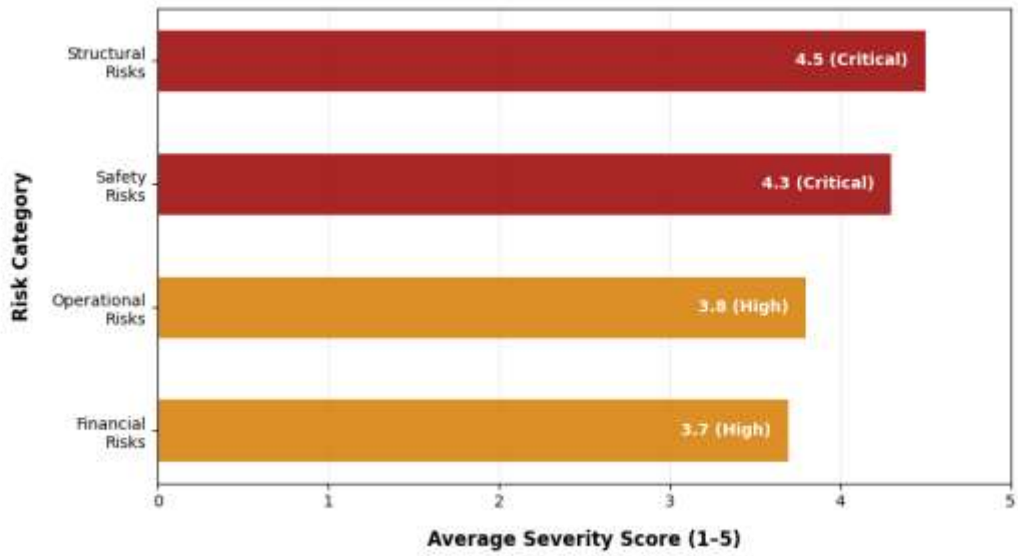
Graph 4: Financial and Management Risk Analysis: Frequency and Cost Impact Range

Comparative Risk Severity Analysis

A comparison of the relative severity of various risk categories was performed. The results showed that structural and safety risks receives the highest severity scores, which are followed by operational and financial risks. Structural risks were the primary risks as concerns directly affected the integrity and function of the infrastructure. The risks were also considered to be very high in terms of safety because of the human and legal outcomes that could result. Operational risks were commonly reported but had an average level of risk severity, mostly related to timelines. Financial risks, reached a significant level, but were mainly secondary influences of other categories of risk.

Table 5: Comparative Risk Severity Index

Risk Category	Average Severity Score	Rank	Priority Level
Structural Risks	4.5	1	Critical
Safety Risks	4.3	2	Critical
Operational Risks	3.8	3	High
Financial Risks	3.7	4	High



Graph 5: Comparative Risk Severity Index by Category

Discussion

This study indicates that the issue of risks on girder operations for high speed rail projects is multidimensional and interdependent. Structural and engineering risks were found to be the most dominant risk among the others, because risks that impact the integrity and longevity of infrastructure directly. Errors in loading, alignment, and other issues can lead to structural issues that have repercussions on safety and operational efficiency. Safety and environmental risks also had high severity, highlighting the need for adherence to safety measures and proactive environmental management. While operational and logistical risks were more likely to occur, they tended to be felt mainly as a result of project delays and inefficiencies rather than posing any imminent threats to the structures. Financial and project management risks were less significant, but were highly correlated with the inefficiencies in other areas, suggesting that problems in other technical and operational fronts commonly contribute to financial overruns or delays. The comparative analysis further emphasizes the importance of having a coordinated risk management solution that emphasizes structural accuracy and safety along with coordinating operations and financial planning.

CONCLUSION

The present study provides comprehensive analysis of the risks involved in starting the operations of the girders in high-speed rail project and emphasizes the complexity and interrelatedness of these risks. It is evident from the findings that the structural risk and the engineering risk are the most significant, since they have a direct impact on the stability and safety of the structure and on its long-term performance. Load miscalculations, inconsistencies in designs, and alignment problems can manifest in many ways, and have a widespread impact, from safety concerns and operational stoppages, to higher maintenance needs. Moreover, safety and environmental hazards were highlighted as leading risks because they could have adverse effects on human beings and on regulations, indicating the need to have strict safety measures and environmental protection. While not as severe as operational or logistical risks, they still have an impact on the project's delivery time. Equipment availability, transportation issues and scheduling problems can compound the expense and stress on project management due to delays. Financial and managerial risks were also identified to be closely associated with the other risk categories, as there is a high possibility that cost overruns/budget inefficiencies arise when technical and operational issues are not addressed.

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