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Analyzing Construction Risk Factors in Large-Scale Projects: Case Study on the Suramadu Bridge

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ABSTRACT

This study aims to comprehensively examine the risk management practices, challenges, and strategies employed during the construction of the Suramadu Bridge. A structured data collection process began with defining clear objectives to identify risks related to structural integrity, environmental impacts, financial uncertainties, project delays, and safety concerns. Key search terms such as "Suramadu Bridge construction," "risk management in bridge construction," and "construction risk assessment" guided searches across reputable online databases like Google Scholar, IEEE Xplore, ScienceDirect, the ASCE Library, JSTOR, and SpringerLink. Articles were selected based on relevance, credibility, publication date, and analytical depth. Data from these articles were extracted and organized, documenting metadata, key points, risk types, and mitigation strategies. The synthesized data revealed common themes and unique insights into the risk management practices during the Suramadu Bridge construction. The discussion delved into these themes, comparing and contrasting different risk management strategies from the literature. Key findings included effective mitigation strategies for financial and environmental risks, the importance of early risk assessment, and the role of continuous monitoring. Challenges in managing these risks were analyzed, showing how they were overcome or mitigated. The report concluded with recommendations for future infrastructure projects, emphasizing a systematic and proactive approach to risk management. Utilizing tools such as Zotero for reference management, Excel for data organization, and Microsoft Word for report compilation ensured efficiency and accuracy. This approach provided valuable insights into risk management for large infrastructure projects, offering a robust foundation for future research and practice.

1. Introduction

Bridges and other public infrastructure serve as the backbone of civilization. An engineering structure built to preserve the operations of highways, railroads, and waterways is referred to as a bridge. Not to add, bridge structures supply and support the services and necessities of contemporary civilization. A bridge is necessary to promote and improve economic stability and communal living circumstances. As a result, bridge construction across all sectors is swift in every nation, regardless of whether it is supported by a public or private entity [1].

Worldwide, the construction of longer-span bridge projects is on the rise, driven by the demands of a contemporary and expanding civilization. Building a long-span bridge is considered dangerous, complex, and complicated. The project's scope, the expense of the "technical structures," and the involvement of several contractual parties, including suppliers, owners, designers, contractors, and subcontractors, are the leading causes of its complexity. Moreover, the intricacy also arises from the internal project team, comprised of individuals from several nations, corporations, and cultural backgrounds. This results in the realization that the bridge project needs a more extensive and long-term funding plan with several parties involved and impacted by multiple factors [2].

The complications raising the risks undoubtedly impacted the project, especially during the building period. An unpredictable occurrence or circumstance that, if it materializes, impacts one or more project objectives, such as time, cost, scope, or quality, is referred to as a project risk. Construction risks are perceived as unforeseen circumstances that cause a budget overrun or timetable delay. Therefore, poorly handled and unmanaged construction risks have been demonstrated to lead to project inefficiencies and contentious contract interactions. Furthermore, the inherent hazards significantly interrupt operations and harm project performance [3].

Thus, it is true that completing a large-scale bridge project successfully is a difficult challenge. Given this, the best approach to ensure the success of a bridge building is to determine the most critical risks and manage them thoroughly. Therefore, this research seeks to close these knowledge gaps by giving a risk analysis of bridge projects using the case study of Indonesia's first, largest, and longest strait-crossing bridge project. This study is anticipated to help different parties participating in the project, such as the owners, contractors, subcontractors, and other stakeholders, understand the construction risk associated with the large-scale bridge project. By then, it is also anticipated that this study will support the delivery of theoretical frameworks and valuable instruments for decision-makers to gauge critical construction hazards, particularly in significant bridge project [4].

This study aims to identify the most critical risks associated with large-scale bridge construction and propose effective management strategies to mitigate these risks. The research offers valuable insights for stakeholders, including owners, contractors, and subcontractors, by examining the complexities and challenges inherent in such projects. Additionally, the paper intends to enhance the understanding of construction risks and their impact on project performance. It also aims to contribute theoretical frameworks and practical tools for decision-makers to assess and manage significant construction hazards in major bridge projects.

2. Literature Review

2.1. Large-scale Project

Megaprojects are large-scale, complicated endeavours that usually cost $1 billion or more, take several years to conceive and implement, include numerous public and private players, are transformative, and have an influence on millions of people, according to the Oxford Handbook of Megaprojects Management. However, $1 billion is not a barrier when identifying megaprojects. Because of this, megaprojects are also known as large-scale projects, and they are classified as transient endeavours with a significant financial commitment, great complexity, and long-lasting effects on the environment, the economy, and society [5].

Conversely, traditional large-scale distribution needs a better track record regarding actual costs and benefits and is particularly troublesome. Large-scale initiatives are complex, intricate, and dangerous since they include many people, activities, interfaces, and interdependencies. Large-scale projects are inherently riskier and tend to use resources to the maximum extent possible during development due to the complexity of the construction environment, increased size, resource requirements, long time horizons, and exposure to interconnected and pervasive drivers of risk [6].

Trying to remove all risks in a large-scale undertaking is not feasible. Therefore, it is essential to sound risk management to identify inherent risk events as organizational frameworks and the degree to which risk analysis offers a window to reducing the inherent risk and minimizing its impact. A strange paradox exists in which more megaprojects are being proposed despite their consistently poor performance against initial budget, schedule, and benefits forecasts. For this reason, risk management in the project development process is required to reduce any possible optimism bias and strategic misrepresentation [7].

2.2. Overview of the Suramadu Bridge Project

According to Harsaputra et al. (2009), the Suramadu Bridge, also called the Surabaya-Madura Bridge, is the first strait crossing bridge project and the longest cable-stayed bridge in Southeast Asia. A bridge was constructed across the Madura Strait to connect Java Island with Madura Island. Estimates place the project's overall cost, including connecting roads, at Rp 4.5 trillion (US$445 million) [8]. The 5.4-kilometre Suramadu bridge is considered Indonesia's longest cable-stayed strait-crossing bridge when it opens. Although the Suramadu bridge was constructed for various reasons, the main objective was to improve Madura society's socioeconomic standing since it was comparatively lower than other East Javan regions.

The causeway, approach bridge, and main bridge are the three-span parts that make up the bridge. The length of the Causeway Bridge is 1,458 meters for the Surabaya side and 1,818 meters for the Madura side. The approach bridge is 672 meters long from the Madura and Surabaya sides. With two cable planes attached to two tower pylons and a steel-concrete beam, the main bridge is a cable-stayed structure. Three spans of 192 m, 434 m, and 192 m each make up the main bridge, which has a total length of 818 m. The profile is particular to the Suramadu Bridge [9].

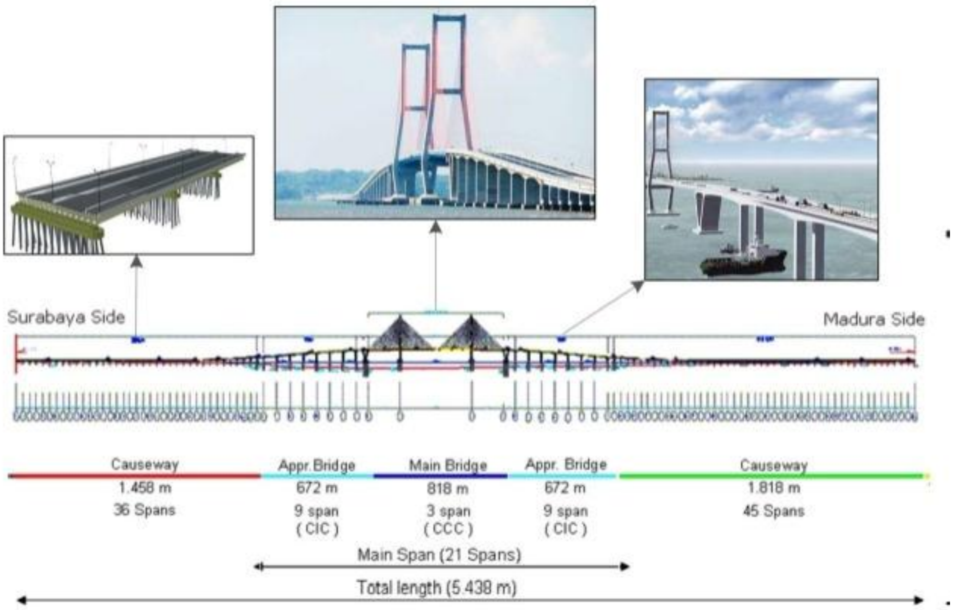

Figure 1. Suramadu Bridge-Specific Profile
Source: https://l1nk.dev/SXtco

The Consortium of China Contractors designed the Suramadu bridge's precise design, with most of the design work completed in China. In addition, Virama Karya Pty Ltd, acting as a consultant, carried out the work design check in Indonesia in collaboration with international partners COWI A/S in Denmark and local partner Pattern General Consulting Pty Ltd. Since the Suramadu Bridge Project was the first large-scale national construction project to use an international joint venture agreement, it is a significant turning point for the Indonesian construction sector [10].

3. Method

Data Collection

A structured data collection process was established to comprehensively understand the risk management practices, challenges, and strategies utilized during the construction of the Suramadu Bridge. This process began with defining clear objectives and compiling detailed data on various risks such as structural integrity, environmental impacts, financial uncertainties, project delays, and safety concerns. The scope of the study was extensive, encompassing all significant aspects of risk management in large infrastructure projects [11].

Keywords such as "Suramadu Bridge construction," "risk management in bridge construction," and "construction risk assessment" guided the search across reputable online journal databases like Google Scholar, ScienceDirect, the ASCE Library, SpringerLink, and other sources. Targeted search queries were conducted to extract the most relevant studies, ensuring no crucial information was overlooked. Articles were selected based on their relevance, credibility, publication date, and depth of analysis, ensuring the inclusion of high-quality information [12].

Once the relevant articles were selected, data extraction and organization followed. Metadata such as author names, titles, journal names, publication dates, and abstracts were documented, alongside summaries of critical points, identification of risk types (e.g., financial, environmental, safety), and noted mitigation strategies. This information was systematically organized into a database using spreadsheet software, facilitating easy management and analysis. The data was then synthesized to identify common themes, strategies, and unique insights, providing a comprehensive understanding of the risk management practices employed during the Suramadu Bridge construction [13].

The findings were reported in a structured format, including an introduction, methodology, findings categorized by type of risk, discussion, conclusion, and recommendations for future projects. Various tools and resources were utilized to ensure efficiency and accuracy, such as reference management software Zotero for managing citations, Excel for organizing data, and Microsoft Word for compiling the report. This systematic approach ensured the collection of comprehensive and high-quality information, offering valuable insights into managing risks in large infrastructure projects.

4. Result and Discussion

4.1. Risks Overview

There are many risk factors affecting the safety of bridge construction; through the analysis of accident cases and literature, based on the four primary risk factors of artificial, equipment, management, and environment, 25 secondary risk factors are organized and obtained

NO	PRIMARY RISK FACTOR	SECONDARY RISK FACTOR
R1	Human Factors	Fatigue operation
R2		Non-compliant operation
R3		Weak safety awareness
R4		Insufficient technical ability
R5		Operational error
R6		Poor management competence
R7		Equipment aging
R8	Equipment Factors	Equipment failure
R9		Inadequate equipment maintenance
R10		Inappropriate equipment selection
R11		Defects in equipment and material quality
R12		Improper material storage
R13		Improper material usage methods
R14	Management Factors	Loopholes in regulations and rules
R15		Ineffective implementation of management systems
R16		Lack of supervision and management
R17		Insufficient safety training
R18		Inadequate safety inspections
R19		Unreasonable construction plans
R20	Environmental Factors	Severe weather conditions
R21		Poor geological and hydrological conditions
R22		Unfavorable working environment in the construction area
R23		Complex traffic conditions along the perimeter
R24		Risk of natural disasters
R25		Complex underground pipeline conditions

Most researchers concurred and affirmed that the "risk of natural disasters" is the most significant risk based on the Risk Factors. They agree that the complexity of the aggregate, dimension, and environment, particularly in the Suramadu bridge project, has increased the workload for construction workers and presented several difficulties. For example, the building cannot start in the event of a rainstorm or if the sea wind reaches 60 km/h and the room temperature is unstable enough to allow the cable erection for the main bridge section to be delayed [14].

Significantly, this risk effect results in rework, safety concerns, and project delays, all of which influence the budget and timeline. While researchers acknowledge that the risk of natural disasters is the most severe, claim risk number two is "Ineffective implementation of management systems", about which the consultant party stressed that they agree. However, the contractor side identified a second significant risk as "Loopholes in regulations and rules" (R14). Different duties, responsibilities, and expectations between the two parties led to this discrepancy [15]. For instance, the contractor party was primarily involved in the building activity, but the consultant party was part of the project owner and connected with government agencies. To address the R14 problem and the intricacy of the project, It has been determined that the contractor must develop proactive plans to plan and organize the project timeline by cash availability.

However, in light of the remarks made by both sides, R24 is significantly impacted by the altered design as well as Indonesia's uncertain geopolitical structure and environment. The contractor party created a cost contingency plan to address the financial effects of project uncertainty. In this instance, one of the risk mitigation strategies is the creation of a cost contingency plan. Here, a contingency cost is an estimated sum added to a project's basic estimate to account for project risk. The researchers noted that these results indicate that this technique causes the contract price to increase [16].

According to contractors' assessments, " Ineffective implementation of management systems " (R15) is the third globally substantial risk. Due to their complexity and significant financial commitment by the management, the public sector owns most bridge construction projects. The East Java State Government provided development financing for The Suramadu Bridge Project through loans from China Exim Bank and East Java Bank. In addition, the funds came from both the national and municipal governments of Surabaya and the four cities of Madura. Given that the funding came from a multi-level, multi-nation government with several parties engaged, the bureaucracy and process for allocating the funds were intricate and time-consuming, such as the loop effect and risk causation R15, which caused a delay in the project timeline [17].

Moreover, in line with the parties' statements, it is discovered that a significant source of R14 and R15 in Indonesia comes from both the country's fragile political environment and its dearth of robust economic activity. However, R15 is seen as quite important by the consultant party since it is determined that the structural design's "Loopholes in regulations and rules" and "Unreasonable construction plans" both activate and impact this risk, which has a detrimental impact on the budget and timeline for building. Because cable-stayed structures are distinct, separate standards must be created for each project. Therefore, modifications to the design and construction of cable-stayed bridges are required. From the contractor's perspective, R19 often happened in any addition, deletion, or modification to the structural design, necessitating extensive building work to replace [18].

Additionally, it is admitted by the consultant and contractor parties that the reason for R19 was a designer's fault (the specific design was incorrect and out of date) and that the specific issues of the general requirements were improperly addressed. It resulted in an appalling influence on creative design and a lack of collaboration with other relevant groups. The earlier research by Choudhry et al. (2014), which found that R19 yields on project cost escalation and payment delay, supports this conclusion. In the event of a modification order in the Suramadu Bridge Project, the constructor must pay the extra costs. Constructors have brought a constructability claim to recover extra damages from modifying the original design and building techniques. In light of this, the contractor included a contingency cost in their working contract [19].

Building cable-stayed bridges necessitates significant modifications to the structure's design, including installing and removing structural elements of the half-built building. It is essential to have adequate knowledge of the current partial structure built at every stage of the construction process and to look into the potential impacts of changing the methods used. For example, the final constructions heavily rely on the order in which things happened during construction and the kind of erection employed [20].

Several journal article found that the consultant party also confirms that R24 and R19, which came in third, are close. It was the most dangerous event that happened throughout the cable-stayed bridge-building process. Jergeas and Ruwanpura (2010) support the previously described conclusions. It has been established that a typical error by stakeholders in large-scale projects underestimates the duration and expense of delays [21].

It also reveals that the Unreasonable construction plans indicate a need to comprehend the project scope specification more. Crucially, Flyvbjerg et al. (2003) confirmed that this problem is acknowledged as one of the primary reasons for the megaproject cost overrun. Further engineering support duties are necessary in this respect. For example, working with the construction engineer to create, coordinate, and document the erection sequence creation of all shop drawings, including those for stay-cable systems and post-tensioning needs, as well as the owner-mandated documentation of all other duties.

Furthermore, failing to take into account the cumulative effect of R19 is another one of the misaligned megaproject tactics that leads to further cost overruns.The three most significant risks in the Suramadu bridge project are the "risk of natural disasters" (R24), "Loopholes in regulations and rules" (R14), and "Ineffective implementation of management systems" (R15). This is even though the risk significance were different. The " Poor management competence " is the fourth significant risk on a global scale (R6). The contractor side rated it sixth; however, the consultant party agreed upon this outcome [22].

Despite a slight disparity in the order of importance, researchers concurred that the management competence significantly impacted the project's advancement. In actuality, being unprepared especially against the national economic crisis was the reason behind the temporary suspension of the Suramadu bridge project. Several significant infrastructure projects, including the Suramadu bridge, have been put on hold due to the national financial crisis.

Fortunately, the project was rediscovered in 2002 thanks to a Presidential Decree (No.15/2002, issued March 22, 2002). Franck (2005) In August 2003, the bridge's construction began. Unfortunately, a lack of funding forced the suspension of bridge construction at the end of 2004. Following the attainment of solutions from domestic and global players about the fund, the project was recommenced in November 2005 [23]. " Poor geological and hydrological conditions " is the fifth significant risk (R21). The consultant party ranked R2 is considered one of the most serious risk, where as the contractor party evaluated it as approximately as the fifth most critical risk compared from the previous four. As was said in the preceding discussion, it was discovered that the reasons for this dissimilarity result were that each party had distinct jobs, responsibilities, and expectations. From the perspective of the contractor, both engineers and technicians may produce a less trustworthy study if they do not fully comprehend the offshore geotechnical [24]

Because of the characteristics of the Madura Strait, it was discovered in the Suramadu bridge project that the seabed and soil conditions were complex and challenging to evaluate. In addition to the strait's geological conditions, which made it difficult for the contractor to oversee construction, it was discovered that the strait had many sea mines, especially in the vicinity of the Suramadu bridge project's tract area. Ninety per cent of those mines were known to be inoperable, but the explosives utilized there posed a risk to human safety and the environment [25].

While acknowledging that the patterns in the RII graphs from the contractor and consultant parties are comparable, it presents five distinct risks that, when computed using the Mann-Whitney U test technique, are statistically different at the 95% confidence level. [26] " Poor management competence " (R6), "Loopholes in regulations and rules" (R14), " Inadequate safety inspections " (R18), "Fatigue Operaiton" (R1), and "Risk of Natural Disaster" (R24) are these five dangers. This discrepancy arises from various roles and responsibilities, cultural differences, and differing perspectives on organizing contractor and consultant parties [27].

The researchers arrived at roughly similar conclusions on the relevance of the other 25 risk occurrences. Therefore, it can be viewed the bulk of severe hazards as identical [28]. This study showed that the contractor often ranks substantial hazards associated with the building phase higher than the consultant party. For example, "Equipment Failure" (R8), "Fatigue Operation" (R1), "Defects in equipment and material quality" (R11), and "Risk on Natural Disaster" (R24) all had a significant impact on the project's advancement.

6. Conclusion

This study contributes to the current corpus of knowledge by examining the construction risk of megaprojects to close knowledge gaps. It does this by identifying, evaluating, and analyzing the Suramadu bridge project and by talking about the similarities and differences in the results obtained by contractor and consultant parties. The main conclusions show that the technical, financial, and physical categories accounted for the severe risks, which substantially impacted schedule, cost, and safety goals. "Unexpected nature behaviour" was shown to be the risk factor most impactful after a worldwide RII study. The outcome shows that building projects over or close to the water has a significant risk and directly affects the project timeline in terms of overall performance and cost. Regarding project performance, technical activity, and physical advancement, the research also reveals that the contractor party identified high risk within the technical category.

On the other hand, compared to conventional construction projects, one of the most common issues encountered while building cable-stayed bridges was the need for more experienced workers for the constructor's organization. According to Chan et al. (2018), cable-stayed bridges are an example of inventive construction instead of standard construction. As a result, project staff members need to be engineering-focused and capable of handling complex bridge technology. The present study's limitations necessitate evaluating the findings within the framework of many constraints.

In light of the potential limitations on the findings' generalizability and the relatively small number of participants in the current study, more research is required to identify additional construction risks, specifically in the large-scale bridge project, and to provide a more comprehensive picture of the perspectives of stakeholders directly involved in the construction environment. In addition, more research is required to create a model or framework to help the expert accept and manage the risk and lessen its effects during the massive bridge-building project.

As one of the first studies to analyze risk in large-scale cable-stayed bridge projects, this research adds to the knowledge of construction safety and can assist stakeholders in developing better plans and strategies. Both before and during the building phase, to lower the likelihood and effect of a threat, raise the likelihood and effect of an opportunity, and stop the recurrence of deaths that might endanger the project's capacity to function in terms of budget, schedule, quality, and safety.

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