

**DEVELOPING A RISK ASSESSMENT MODEL FOR
PREFABRICATED BRIDGE CONSTRUCTION
PROJECTS IN DEVELOPING COUNTRIES**

BY

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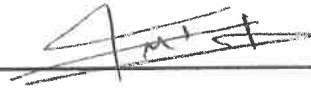


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To my **Late Mother, Ramatu Sesay**

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LIST OF ABBREVIATIONS

AEC - Architecture, Engineering and Construction

AHP - Analytical Hierarchy Process

BIM - Building Information Modeling

CEM - Construction Engineering and Management

CRF – Critical Risk Factor

CRG – Critical Risk Group

ERM - Enterprise Risk Management

FA – Factor Analysis

FMEA - Failure Mode and Effects Analysis

FSE – Fuzzy Synthetic Evaluation

KMO – Kaiser Meyer-Olkin

MF – Membership Function

MS – Mean Score

ORL – Overall Risk Level

PBC – Prefabricated Bridge Construction

PC – Prefabricated Construction

RCA - Root Cause Analysis

RF – Risk Factor

RM – Risk Management

RMF - Risk Management Framework

PMBOK - Project Management Body of Knowledge

PMI - Project Management Institute

SWOT - Strengths, Weaknesses, Opportunities, and Threats

TQM - Total Quality Management

ABSTRACT

Full Name: Francis Sesay

Thesis Title: Developing a Risk Assessment Model for Prefabricated Bridge Projects
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In the current era of rapid infrastructure development in developing countries, the effective management of risks in prefabricated bridge projects poses a significant challenge. Prefabricated bridge initiatives in these regions encounter various complex challenges, necessitating meticulous risk assessment and management. This study presents a comprehensive exploration of the risk landscape surrounding prefabricated bridge projects in developing countries, with a particular focus on Sierra Leone as a case study. The primary aim of this research is to develop a fuzzy risk assessment model tailored to address the unique challenges and dynamics inherent in these regions.

Through an exhaustive literature review and structured interviews with experts, a total of 29 risk factors associated with prefabricated bridge projects in developing countries were identified. These risk factors encompass a wide range of aspects, including but not limited to design risks, manufacturing risks, transportation risks, and construction risks. A total of 21 CRFs were obtained after the computation of their normalized scores. The top five CRFs are poor supply chain integration, inadequate supplier capacity, error in the installation of precast components, complex rectification, and rework, lack of experience of contractor in prefabrication, and poor information sharing between stakeholders, respectively. Subsequently, a questionnaire survey was conducted to gather the opinions of industrial practitioners, enabling the assessment of the probability and severity of these identified risk factors.

Utilizing factor analysis (FA), the identified risk factors were further categorized into four critical factor groups (CRGs) for prefabricated bridge projects including execution risks, materials and logistics risks, stakeholders and suppliers' risks, and economic and financial risks. These CRGs serve as a framework for understanding the key areas of risk. Moreover, the application of fuzzy synthetic evaluation (FSE) revealed that all CRGs exhibited a critical level of risk. Additionally, the overall risk level (ORL) of prefabricated bridge projects, as determined by the FSE model, yielded an overall index of 3.674, indicating a high level of risk in prefabricated bridge projects in developing countries.

This research holds a unique position as the first study to comprehensively explore risks in prefabricated bridge construction projects. Furthermore, it is the first study to specifically investigate risks in bridge construction projects in Sierra Leone. By identifying and categorizing the critical risk factors, the developed risk assessment model facilitates the evaluation of risks and assists in informed decision-making processes during the planning and implementation phases of such projects.

الملخصات

الاسم الكامل: فرانسيس سيساي

عنوان الأطروحة: تطوير نموذج غامض لتقييم المخاطر لمشاريع الجسور الجاهزة في البلدان النامية: دراسة حالة لسيراليون

التخصص الرئيسي: هندسة وإدارة التشييد

تاريخ الدراسة: ديسمبر 2023

في العصر الحالي للتنمية السريعة للبنية التحتية في الدول النامية، تمثل إدارة المخاطر الفعالة في مشاريع الجسور المجهزة تحديًا كبيرًا. تواجه مشاريع الجسور المجهزة في هذه المناطق تحديات معقدة متعددة، مما يستدعي تقييم المخاطر بدقة وإدارتها بعناية فائقة. تقدم هذه الدراسة استكشافًا شاملاً للمناظر الخطرة المحيطة بمشاريع الجسور المجهزة في الدول النامية، مع التركيز بشكل خاص على سيراليون كدراسة حالة. الهدف الرئيسي لهذا البحث هو تطوير نموذج تقييم المخاطر الضبابي يتناسب مع التحديات والديناميات الفريدة المترتبة على هذه المناطق.

من خلال مراجعة شاملة للمصادر الأدبية وإجراء مقابلات مهيكلة مع الخبراء، تم تحديد مجموعة من 29 عامل خطر مرتبط بمشاريع الجسور المجهزة في الدول النامية. تشمل هذه العوامل الخطرية مجموعة واسعة من الجوانب، بما في ذلك ولكن لا تقتصر على مخاطر التصميم ومخاطر التصنيع ومخاطر النقل ومخاطر البناء. تم الحصول على مجموعة من 21 عامل خطر بعد حساب الدرجات الموحدة. فيما بعد، تم إجراء استبيان لجمع آراء الممارسين الصناعيين، مما يمكن من تقييم احتمالية وخطورة هذه العوامل الخطرية المحددة.

لمشاريع (CRGs)، تم تصنيف العوامل الخطرية المحددة إلى أربع مجموعات أساسية (FA) من خلال تحليل العوامل الجسور المجهزة، بما في ذلك مخاطر التنفيذ ومخاطر المواد واللوجستية ومخاطر أصحاب المصلحة والموردين ومخاطر الاقتصاد والمالية. تعمل هذه المجموعات الأساسية على إطار لفهم المناطق الرئيسية للمخاطر. وعلاوة على ذلك، كشف عن أن جميع المجموعات الأساسية تظهر مستوى حرج من المخاطر. بالإضافة (FSE) تطبيق التقييم الاصطناعي الضبابي ، مؤشرًا كليًا FSE لمشاريع الجسور المجهزة، كما تم تحديده من خلال نموذج (ORL) إلى ذلك، أظهر مستوى المخاطر العام ، بلغ 3.674، مما يشير إلى مستوى عالٍ من المخاطر في مشاريع الجسور المجهزة في الدول النامية.

تحتل هذه الدراسة مكانة فريدة كأول دراسة تستكشف بشكل شامل المخاطر في مشاريع الجسور المجهزة. علاوة على ذلك، فإنها أول دراسة تحقق تحديدًا من المخاطر في مشاريع بناء الجسور في سيراليون. من خلال تحديد وتصنيف عوامل المخاطر

الدرجة، يسهم نموذج تقييم المخاطر الذي تم تطويره في تقييم المخاطر ويعزز عمليات اتخاذ القرار المستنيرة خلال مراحل التخطيط والتنفيذ لمثل هذه المشاريع.

CHAPTER 1

INTRODUCTION

1.1. Background of the Research

The construction industry has been instrumental in the progress of society, spanning across both industrialized and rising countries. The relevance of this contribution resides in its ability to provide essential aspects of infrastructure, such as road networks, bridges, railroads and numerous public utilities. These components play a crucial role in enabling efficient transit and facilitating trade [1–3]. The construction and expansion of such infrastructures play a pivotal role in facilitating economic advancement and societal growth through the facilitation of transportation for individuals and commodities, enhancement of productivity, and promotion of investments. The implementation of infrastructure projects is a key necessity in every country, as it not only contributes to the growth of its economic and industrial sectors but also improves the general quality of life for its residents [4].

A bridge is a type of engineering construction that is specifically engineered to traverse a gap or obstacle in the natural landscape, such as a river, deep chasm, or highway [5]. Traditional construction methods, which are commonly employed, entail the implementation of on-site operations utilizing in-situ techniques. These techniques encompass the utilization of formwork, falsework, wet trades, scaffolding, and the generation of significant amounts of construction waste. The project, an organizational structure having a finite lifespan, is used to carry it out [6, 7]. In typical scenarios, the conventional methods of constructing bridges using cast-in-place techniques sometimes require measures such as reducing the width of traffic lanes or diverting vehicular movement onto alternate routes. To maintain continuous traffic flow, the implementation of temporary bridges, access roads, or phased construction schedules is frequently necessary, often spanning extended durations. The implementation of temporary shifts to traffic patterns often leads to an increase in traffic congestion. Moreover, the

implementation of temporary buildings and phased construction plans sometimes results in a substantial expenditure of the designated budget and may not be feasibly sustainable. Furthermore, the prolonged presence of construction operations at the site may give rise to potential distractions for drivers, therefore compromising the safety of both construction workers and individuals commuting through the construction area. Projects that employ the traditional in-situ construction technique frequently fall short of meeting the expected performance objectives for the project, which encompass factors such as cost, schedule, productivity, quality, client satisfaction, and environmental issues [8].

The introduction of off-site production was proposed as a solution to address the deficiencies observed in the construction industry [9]. It is worth mentioning that there has been considerable interest in prefabricated bridge projects in recent years. This is primarily owing to its ability to accelerate construction schedules, reduce costs, minimize traffic disruptions, alleviate construction-related risks, and improve overall quality [10–12]. Prefabricated bridge projects involve the fabrication of bridge components off-site, which are subsequently transported to the construction site for assembly [12, 13]. The utilization of prefabricated components in the construction of bridges offers numerous benefits, with the primary advantages being the mitigation of traffic disruptions and the shortened duration of projects [12]. The implementation of precast components results in significantly reduced durations of bridge closures and the associated disruptions to surrounding roadways. The condensed duration of the construction phase leads to a decrease in the level of exposure that workers and drivers experience with risky conditions. Furthermore, the implementation of factory-based production for bridge components results in a reduction of labor requirements for on-site construction personnel, thus improving their safety [12]. It is noteworthy to acknowledge that the occupational safety and health conditions within the manufacturing setting are somewhat superior due to the lack of vehicular activity in the surrounding area [11].

In the context of developing economies, there is a strong need for infrastructure solutions that are both efficient and cost-effective. This need is particularly significant due to the fast urbanization and economic growth that have contributed to an increased need for expanded transportation networks [14]. As a result, the utilization of prefabricated bridge construction methods is increasingly becoming significant in these particular circumstances. However, the execution of prefabricated construction projects frequently confronts a distinct array of challenges and uncertainties as a result of the transformative characteristics inherent in these procedures. The challenges discussed in the literature encompass a range of factors. These factors include limited technical expertise [15–17], delays in freezing design and specifications [17, 18], issues related to geometric and dimensional tolerances [17, 19–22], as well as errors in component installation that require complex rectifications and rework [17, 23–25]. Furthermore, the lack of proper planning and supervision in the downstream prefabrication supply chain has the potential to compromise the effectiveness of upstream supply chain activities [26]. In addition, it is crucial to provide efficient coordination of component transportation across international boundaries to mitigate significant cost escalation in prefabricated construction projects [27]. The combination of these factors presents a substantial risk to the performance of the project, which could lead to increased costs, project delays, and in extreme cases, structural failures [28]. As a result, the expected benefits of prefabrication may be compromised.

Given the widespread occurrence of risk in prefabricated construction projects, the proficient handling of these inherent risk factors emerges as a pivotal component in determining the success of such projects [29]. However, the implementation of good risk management entails a series of consecutive procedures, which encompass the identification, evaluation, prioritization, mitigation, continuous monitoring, and control of risks [30]. Considering the prevalence of risks in prefabricated construction projects, the initial three phases play a crucial

role in guaranteeing the favorable outcome of such endeavors [31]. Nevertheless, not every risk element is equally crucial. In scenarios characterized by resource constraints, it becomes essential to ascertain, evaluate, and control the most critical risks that can impact the project's likelihood of achieving its objectives.

The existing body of published literature, including the works of Naderpour et al. [32], Mortazavi et al. [33], M. Choudhry [34], and Choudhry et al. [35], has primarily concentrated on the development of risk assessment models exclusively tailored for conventional bridge construction projects.[32–35]. Traditional bridge construction projects typically entail the construction process taking place directly at the bridge site. In contrast, prefabricated bridge construction projects involve the fabrication of bridge components offsite, followed by their transportation and subsequent assembly at the bridge site. The existence of different construction approaches introduces uncertainties and challenges that cannot be adequately addressed by conventional models used for assessing risks. Also, due to the conveyance of large components from manufacturing facilities to the construction site, the supply chain and logistics associated with prefabricated bridge construction projects can be complex [36]. Considering the divergent methodologies employed in prefabricated construction as opposed to traditional construction, it is evident that the existing risk assessment models designed for conventional bridge construction projects may not be applicable or suitable for the context of prefabricated bridge construction projects. The lack of available research calls for the development of a new risk assessment framework specifically designed for prefabricated bridge construction projects. The study aims to contribute to the current body of literature by identifying the primary risks associated with these projects and assessing their potential impact on the overall project.

1.2. Problem Statement

In developing countries, the construction sector faces significant challenges that hinder development goals. A lack of adequate resources, skills shortages, and poor infrastructure have contributed to issues such as project delays and cost overruns, inadequate quality control, as well as a failure to address pressing infrastructure [37, 38]. These challenges have hindered connectivity and economic development. Adopting prefabrication for bridge projects could help address these issues through offsite manufacturing which streamlines processes, improves quality control, saves time and costs [39].

While previous research has identified risk factors and developed risk assessment models for both traditional cast-in-situ bridge construction and prefabricated housing construction respectively, there remains a lack of studies addressing the development of a comprehensive risk assessment model tailored for prefabricated bridge projects. Such a model is needed to provide stakeholders and contractors with vital knowledge about key risks that could undermine project success if left unaddressed. Additionally, its absence exacerbates contractor vulnerability to high-risk projects.

The evaluation of risk factors in bridge projects is largely reliant on the assessment of experts, a process that is inherently uncertain and intricate due to a limited comprehension of the associated risks and uncertainties. Additionally, the management of expert assessments in risk factor evaluation, with its inherent subjectivities and biases, as well as the appropriateness of the selected evaluative models or methods, is of paramount importance. The subjective nature of expert judgment, characterized by ambiguity and a lack of precision resulting from individual biases, disparate understanding levels, and knowledge deficiencies, complicates the risk assessment during project implementation. Consequently, conventional methods such as simple discrete Likert scales or the commonly employed relative importance index are

insufficient to capture the complexities of uncertainty, subjectivity, and bias. The fuzzy synthetic approach, however, quantifies risk assessments linguistically and translates them into definite values. This method, considering the risk attitudes of decision-makers (ranging from risk-seeking to risk-averse) and the specific contexts of the project, coupled with the outcomes of the fuzzy risk assessment, provides a framework for making well-informed decisions regarding risk management.

Therefore, the aim of this study is to develop a reliable and practical risk assessment model for prefabricated bridge construction projects using a FSE.

1.3. Research Questions

The following targeted research questions are worth analyzing for this purpose:

- i. What are the critical risk factors associated with prefabricated bridge construction projects in the context of developing countries?
- ii. How can these critical risk factors be systematically evaluated to determine the overall level of risk inherent in such projects?
- iii. How can such a risk assessment model be validated to ensure its accuracy and dependability?

1.4. Research Aim and Objectives

1.4.1. Research Aim

The main aim of this dissertation is to develop a reliable risk assessment model specifically designed for the unique circumstances of prefabricated bridge construction projects in developing nations. The framework will be constructed by FSE methodology.

1.4.2. Research Objectives

- i. To identify the risks associated with prefabricated bridge projects in developing countries.
- ii. To identify the risk factors that are critical in the implementation of prefabricated bridge construction projects in developing countries.
- iii. To evaluate the CRFs and to develop a risk assessment model for prefabricated bridge construction projects in developing countries.
- iv. To validate the proposed risk assessment model that will ensure its practical applicability and reliability within the context of prefabricated bridge construction projects in developing countries.

1.5. Scope of Study

The primary objective of this study is to provide a risk assessment framework for prefabricated bridge projects in developing areas, utilizing the FSE methodology. The focus of this study will predominantly revolve around prefabricated bridge projects in Sierra Leone, with a purposeful exclusion of traditional bridge construction methods. The study aims to identify and assess the distinct dangers linked to the implementation of prefabricated bridge construction methods in developing nations. It is important to acknowledge that this study does not include an analysis of options for mitigating or controlling risks. The risk factors that will be examined in this study will be determined by conducting a comprehensive investigation of relevant literature and by conducting interviews with experts in the field.

The primary method of data gathering will be the utilization of questionnaire surveys specifically designed for those who have direct involvement in prefabricated bridge construction projects. The validity of the proposed model will be evaluated through a comparative analysis of its predictions and the actual project outcomes, as assessed by experts. This evaluation will be based on a study of completed projects involving prefabricated bridges.

This study is limited in scope as it only focuses on prefabricated bridge projects within the geographical boundaries of Sierra Leone. The applicability of the findings to other global contexts remains uncertain owing to the unique cultural, socioeconomic, geographical, legal and regulatory characteristics prevailing in this region.

1.6. Research value and significance

The evaluation and ranking of risk factors carry substantial practical and managerial implications. This study is a notable accomplishment in the field of risk management as it encompasses the initial three phases: risk planning, identification, and evaluation. By carefully screening and identifying critical risk variables associated with prefabricated bridge projects in developing nations, this study intends to provide project managers with a firm basis. Acquiring this fundamental understanding will enable individuals to effectively distribute resources, including personnel and financial assets, in order to achieve successful project implementation. The process of project planning can be enhanced by adopting a more methodical approach, wherein careful attention is given to detail and thorough consideration is given to potential risks that may impede the successful completion of the project. Additionally, resource allocation can be customized to effectively address and mitigate these unique risks. This technique serves to enhance the overarching project management strategy, so assuring a more robust and resilient approach to the execution of projects.

Furthermore, the establishment of a fuzzy risk assessment model is a multifaceted instrument that possesses significant utility within the context of the peer-review process. From the perspective of contractors, this model will prove to be a highly beneficial resource for evaluating the comparative overall risk levels associated with various ongoing prefabricated bridge projects. This enhances the contractor's decision-making on resource allocation, project selection, and tasks prioritization. Another implication of this study to the contractor is that the model may be utilized during the tender phase to assess the feasibility of submitting a

bid for a project, while considering the potential risks associated with said projects. Additionally, this model can be significantly beneficial on the part of government entities, as it will provide a standardized approach to evaluating the overall risk profile of a portfolio's projects, empowering them to make informed selections in light of limited resources and the level of risk exposures. This approach maximizes the efficiency of the project selection process and guarantees that endeavors are undertaken with an in-depth knowledge of the associated risks.

One notable benefit of the risk assessment approach is its capacity to enable project stakeholders, such as governments, contractors, and financiers, to assess their level of readiness in addressing possible risks. Equipped with this information, stakeholders can undertake risk mitigation measures with an expanded understanding of the unique problems they may encounter. This makes it easier to create a thorough risk management framework, which in turn makes projects more robust. The findings can help stakeholders become more prepared for the complexities of circumstances in emerging countries by sparking proactive risk management.

1.7. Research Organization

Introduction: the introduction sets the stage for the research and provides context for the work to follow. This chapter includes the background of the study, problem statement, research questions to be answered, research aim and objectives, the scope of the study, the value and significance of the study and ends with the conclusion of the introduction.

Literature Review: This chapter undertakes a comprehensive analysis of previous academic literature, focusing on risk assessment models utilized in construction projects and the risk factors associated with offsite construction approaches. Moreover, this chapter critically examines previous research efforts, identifying the gaps in knowledge and providing a clear

justification for the current study. The chapter concludes by outlining the identified risk factors that will form the basis for the questionnaire survey.

Methodology: This chapter provides a comprehensive explanation of the methodological framework and research procedures employed in this study. The academic examination involves a thorough evaluation of the research's design and its underlying philosophical foundations. It outlines the methods used for data collection and sampling, elaborates on the statistical analysis and modeling techniques employed, and describes how the validity of the model is assessed. In each case, a justification is provided to clarify the reasoning behind the use of these specific approaches.

Results and Discussion: This chapter presents the empirical findings derived from the study. The chapter present an in-depth examination and evaluation of these findings, shedding light on their correlations with prior research results.

Conclusion and Recommendation: This chapter provides a succinct summary of the main findings of the study, reevaluates the research questions, deduces implications, presents the study's limitations, and proposes recommendations for future research attempts.

1.8. Chapter Summary

The introductory chapter presents a thorough examination of the research, including its contextual framework, the identification of the research problem, the aims and objectives, the limitations of the study, the value and relevance of the research, and the structural arrangement of the study's content.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

This chapter of the study serves multiple purposes within this study. Firstly, it identifies and establishes the existing gap in the research by highlighting previous studies on risk models on bridge construction projects, hence justifying the necessity of doing the study. Secondly, it provides a historical overview of the practice of prefabrication to contextualize the study within its broader historical framework. Additionally, it offers a comprehensive explanation of important ideas and terms relevant to the investigation including risks in construction and the assessment of risks. Lastly, it identifies and examines the various risk factors that are associated with prefabricated bridge projects.

2.2. Risk Management on Bridge Construction Projects

This literature analysis centers on the selected studies as they provide valuable insights into the discourse on risk assessment and management in bridge construction projects, with a specific emphasis on developing nations. Researchers have employed a range of methodologies and methods, such as the Monte Carlo method, the system dynamics approach, the bootstrap method, and the finite element method, in their investigations.

Naderpour et al. [32] conducted a thorough risk assessment of bridge construction projects in Iran, utilizing the Monte Carlo simulation technique. To identify and evaluate risk indicators, the researchers utilized a comprehensive methodology, integrating site visits, interviews, and questionnaires. Following this, the risks that were identified underwent a thorough prioritizing process involving statistical testing. To have a more thorough comprehension of the potential ramifications, the researchers utilized the Monte Carlo simulation method to objectively examine the effects of cost and schedule risks on project execution and budget allocation. The

findings of the study revealed that, among all of the factors investigated, financial risk emerged as the most significant challenge to the successful implementation of bridge construction projects in Iran. The significant insight not only illuminates the primary issue in this particular setting but also emphasizes the importance of implementing efficient risk management measures. Given the aforementioned circumstances, the study additionally offers significant suggestions targeted at reducing and controlling this prominent risk, presenting a constructive approach to improving the overall effectiveness and long-term viability of bridge construction projects in the Iranian context.

Choudhry et al. [35] conducted an extensive study aimed at establishing risk factors specifically relevant to the field of bridge construction in Pakistan. The primary objective of their research was to examine the potential financial and temporal risks associated with such ventures. In order to accomplish this objective, a comprehensive strategy incorporating both quantitative and qualitative approaches was utilized. The objective of this comprehensive strategy was to determine the comparative relevance of various risk factors in relation to the project's financial resources and its specified duration. The findings of the study highlight the prominent influence of inadequate funds on both the financial elements and adherence to the specified schedule of the project. Consequently, lack of sufficient financial resources was determined to be one of the key challenges that leads to cost and schedule overrun. The key challenge that hindered the project's cost-effectiveness and adherence to its estimated timetable was the lack of sufficient financial resources. The study yielded significant findings about the importance of financial issues and their influence on the outcomes of bridge construction endeavors. A noteworthy aspect of the research was the inclusion of a comprehensive set of recommendations that delineate the intricate procedural challenges entailed in performing rigorous risk assessments. The objective of these recommendations is to furnish a pragmatic resource for project professionals and stakeholders alike. The purpose of the guidelines is to provide assistance to

individuals in recognizing and resolving any risks that might impede the effective culmination of the project. The purpose of these recommendations is to serve as a comprehensive tool for the efficient management of risk factors in the context of bridge construction projects, with a special emphasis on the challenges faced in developing countries, where limitations in resources are more pronounced. In conclusion, this study highlights the critical importance of risk assessment and effective management in the context of bridge construction projects. The significance of this emphasis is particularly pertinent within the framework of developing nations, where constraints on resources inject heightened complexities into the already intricate domain of construction endeavors. This study highlights the need of doing proactive risk assessment and implementing ways to reduce these risks, with the ultimate goal of assuring the successful achievement of such undertakings.

Mortazavi et al. [33] conducted a study which entailed a comprehensive analysis with the objective of evaluating the relative importance of several factors that influence risk in the domain of bridge construction projects. This research involved a comprehensive investigation of the inherent risks associated with such endeavors, utilizing a multidimensional methodology that comprised the collecting of data through surveys, in-depth interviews, and the employment of statistical analytic tools, namely SPSS and VENSIM 7. The acquired data served as the foundation for an advanced undertaking centered on the modeling of risk behavior, employing the concepts of system dynamics analysis. The study enabled the investigation of complex interconnections among different risk variables in bridge construction projects. In order to facilitate the dissemination of their results, the researchers developed a series of 10 graphic representations that accurately portray the intricate network of interconnections comprising the fundamental framework of the risk landscape. In addition, the researchers utilized a relevant case study completed in Iran to enhance the advancement of their risk model. The existing model functions as a potent tool for the identification and full understanding of the primary

risk factors and their complex interactions within the distinct field of bridge construction initiatives.

Zou et al. [40] put forward a novel approach for managing risk factors in bridge building projects. They suggested the utilization of a tailored Risk Breakdown Structure (RBS) that is closely associated with Building Information Modeling (BIM). The integration of these two frameworks aims to improve the efficiency and effectiveness of risk management in the context of bridge construction initiatives. The investigation was carried out in three discrete phases. The team started by breaking down BIM into its constituent elements. Following that, they created an extensive database including information pertaining to possible risks associated with BIM. Finally, a theoretical framework to demonstrate a correlation between the RBS and BIM was formulated. The study's findings unequivocally showcased the efficacy of the suggested technique in accurately detecting and effectively mitigating the inherent risks associated with the construction of bridges.

Choudhry [34] conducted an extensive analysis of various factors that may contribute to the occurrence of cost and schedule overruns within the specific context of a bridge construction project in Pakistan. The research conducted in this study involved the systematic identification of possible risks related to the project. This was achieved by implementing a rigorous approach that relied on the administration of a complete questionnaire survey. Furthermore, a thorough examination was carried out through the utilization of Monte Carlo simulation methods to assess the possible consequences of the identified risks on the project's financial resources and schedule. The results of this comprehensive inquiry emphasize the critical need of doing risk analysis to facilitate effective cost and schedule management, offering valuable insights into the methodologies applied in conducting such assessments.

Dang et al. [41] undertook a study to investigate the intricate nature of risk patterns from the perspective of contractors, with particular focus on road and bridge construction projects in Vietnam. The research study employed a questionnaire survey as its major research methodology with the objective of identifying the most frequent hazards and examining their impact on project outcomes. The study effectively identified and classified four unique risk categories, which include risks associated with the contractor, the project itself, the project owner, and the surrounding environmental conditions. The study provided significant insights into the varied risk profiles of different project types in the context of construction projects in Vietnam, highlighting the intricate nature of risk in this domain. Significantly, the aforementioned findings provide a crucial asset for multinational construction corporations engaged in operations within Vietnam. They furnish these firms with a complete comprehension of the inherent hazards linked to the nation's infrastructure development endeavors.

Hashemi et al. [42] put forth the suggestion to employ the bootstrap approach as a means of conducting interval-based risk assessments. The work presented in this paper introduces a novel methodology that combines nonparametric resampling approaches with interval estimations to thoroughly examine the risks associated with these projects. The study suggests that utilizing interval values can be an effective approach for representing both partial and complete judgments in complex decision-making situations that are intrinsically ambiguous. In addition to mitigating risks, this novel approach is hypothesized to have a significant impact on the variability of outcomes within the project framework. To ascertain the feasibility of their proposed approach for identifying and ranking risk factors, the authors provided empirical substantiation employing a persuasive case study carried out in Iran.

Ahn et al. [43] conducted a comprehensive study to evaluate the sustainability risks associated with third-party damages to bridges. The researchers developed an advanced risk model

specifically designed to assess potential financial losses and environmental consequences. The researchers conducted a thorough analysis using multiple regression to examine payout data from a famous insurance company in Korea. This rigorous approach resulted in the development of a reliable model for estimating losses. Four key characteristics that have a considerable impact on financial losses resulting from third-party damages were discovered among the nine independent variables analyzed. These factors include superstructure type, foundation type, susceptibility to floods, and the ranking of contractors based on contract value. The process of quantifying different risk factors and creating a model to assess potential losses is a valuable contribution to achieving sustainability goals and effectively managing risks in the field of bridge construction management.

Cho and Kim [44] employed finite element analysis methods to do a probabilistic risk assessment of constructing bridges at different phases. The primary aim of their research was to determine the significance of various risks and clarify how these risks impact the project, ultimately influencing its final results.

The existing corpus of literature provides a comprehensive survey of studies examining the complexities of risk assessment and management in the field of bridge construction. Nevertheless, it is evident that there is a lack of studies on risk identification and assessment related to projects involving prefabricated bridges. Prefabricated bridge construction projects include a range of risk considerations, which encompass transportation challenges, lack of skilled labor, etc. These considerations bear noteworthy consequences on project cost, schedule, and the quality of labor force. Considering the lack of academic research given to this particular knowledge gap, the present study endeavors to address this lacuna by conducting a study into the identification and assessment of risk factors associated with projects centered around prefabricated bridge construction.

2.3. Prefabricated Construction

The extant research pertaining to the field of management has mostly concentrated on four key categories, including vertical interactions, benefits, impediments, and promotional techniques [45]. Prior studies have thoroughly investigated the characteristics of prefabricated construction management and its influence on interactions between buyers and suppliers, recognizing the significant role that suppliers play in ensuring a dependable and uninterrupted supply chain [46–48]. Furthermore, scholarly investigations have delved into the intricacies of customer-contractor interactions, recognizing their substantial role in facilitating the efficient administration of prefabricated construction endeavors through the reduction of on-site modifications. Notably, these studies have placed particular emphasis on vertical relationships [47]. It is crucial to recognize that the acquisition of prefabricated components is primarily facilitated through two primary approaches, namely make-to-order and engineer-to-order [45]. The utilization of a make-to-order strategy in manufacturing operations allows for the production of both standardized and customizable components [49]. This approach has been proven to effectively improve supply chain management [50]. On the other hand, the engineer-to-order approach aims to provide consumers with a diverse range of products that are customized to meet their requirements and specifications [51]. However, this approach presents growing difficulties in the management process as a result of the intricate nature of communication between the various parties involved [52]. Previous research has extensively examined the advantages linked to the adept utilization of prefabricated construction techniques, including enhanced productivity [53, 54], enhanced quality management [55], and decreased waste [56]. However, it is important to note that prefabricated construction is not without its own unique set of challenges. The fragmented supply chain is characterized by various challenges, including a shortage of competent personnel and restricted material capacity [57]. Additionally, inexperienced stakeholders contribute to the complexities of the

supply chain [58]. Previous scholarly literature has put forth a range of strategies aimed at enhancing the adoption of prefabricated construction methods. These strategies encompass the incorporation of information technology [59], the implementation of planning systems, the promotion of technological innovation, [60], and the establishment of coordination mechanisms[61].

Despite the existence of prior research that has produced favorable results, the current corpus of scholarly work has not fully established and prioritized the risk factors associated to the implementation of prefabricated bridge construction projects. The primary aim of this study is to address the existing gap in knowledge by systematically identifying and assessing the potential risks associated with the implementation of prefabricated bridge construction projects in developing nations. Moreover, the objective of this study is to employ fuzzy synthetic evaluation techniques to model the probable consequences of these risks.

2.4. Prefabricated Construction and Performance

Scholars have utilized many terminologies, such as industrialized construction, offsite construction, and modular integrated construction, to synonymously describe the notion of prefabrication [62–64]. Scholars have utilized many terminologies, such as industrialized construction, offsite construction, and modular integrated construction, to synonymously describe the notion of prefabrication [35, 60, 61]. These terminologies are utilized to differentiate prefabricated construction from the traditional cast-in-place construction approach. Within the domain of prefabricated construction, the constituent elements or modules of structures are originally manufactured within a controlled factory environment, located away from the eventual site of construction. Once these components or modules have reached completion, they are transported to the physical building site for the purpose of assembly and installation [65]. Arashpour et al. [66] have classified prefabrication as a "hybrid

construction" technique, as it combines off-site and on-site procedures, in contrast to the exclusively on-site methodology of traditional cast in-situ construction.

Several studies have provided evidence supporting the advantages of prefabricated construction compared to cast-in-place construction, which has led to a growing preference for the former over the latter [67, 68]. The advantageous performance of prefabricated structures provides developers with the benefit of faster returns on investment and accelerated recoupment times. Moreover, it promotes the timely provision of government-funded housing to metropolitan populations with limited financial resources [26]. The utilization of prefabricated construction methods, which involve the combination of off-site manufacture and on-site assembly, has the potential to greatly improve the effectiveness of traditional on-site construction [62]. Research has demonstrated that the decrease in on-site operations within the context of prefabricated construction has resulted in a notable enhancement of project time performance, estimated to be around 12% [69]. Significantly, a study conducted by Shahzad et al. [70] demonstrated that the utilization of prefabrication as opposed to the conventional cast in-situ building approach resulted in a noteworthy increase in marginal productivity, with time savings of up to 34%. The correlation between the escalation of off-site production of components and enhancements in construction project performance has been established [71]. The research undertaken Tsz et al. [72] demonstrates that a range of twenty to twenty-five percent of time savings were observed in seven out of ten structures examined, which aligns with the conclusions drawn by Bertram et al. [73].

Nevertheless, it is imperative to acknowledge that the benefits of prefabricated construction are not universally experienced. O'Connor et al. [74] and Wuni et al. [31] have observed cases in which modular integrated construction projects did not fully capitalize on these advantages, leading to significant delays and project failures. There is a growing body of evidence on the poor performance of prefabricated construction projects. Undoubtedly, a growing collection of

information underscores the inadequate performance of prefabricated construction projects. Chen et al. [75] conducted a study to identify various elements that influence the duration of construction for prefabricated homes. Among these aspects, the project technology system and project delivery system were found to be of utmost significance. Similarly, Li et al. [76] documented a significant postponement of two months in a construction timeline. According to Li et al. [45] noted that schedule disruptions were evident in prefabricated projects conducted in Hong Kong, as referenced by their previous work. In addition, the implementation of prefabricated construction methods in Australia, as observed by, Arashpour et al. [66] resulted in an extended duration for completing projects. Korea has also had several unsuccessful prefabricated construction initiatives [77]. Zhang et al. [78] have emphasized that insufficient project performance is a notable barrier to the extensive implementation of prefabricated construction systems. As a result of inadequate project performance and delays in adhering to schedules, prefabricated building projects have frequently failed to meet anticipated outcomes.

2.5. Previous Work on Construction Project Assessment

Risk management plays a crucial role in the construction sector, where the process of risk assessment is widely acknowledged as the principal means of managing potential risks and uncertainties that may affect project outcomes [79]. In the past, the focus of risk assessment has primarily been around quantitative analysis, which poses inherent difficulties in determining objective probability for unique construction projects [80]. Given the aforementioned constraints, it is not uncommon for project managers to rely on subjective probability as a means of incorporating their personal knowledge, expertise, and intuitive judgment into the risk assessment procedure [81].

Several risk assessment models have been developed to address the complexities associated with estimating hazards in building projects. An instance of notable research conducted by Mustafa and Al-Bahar [82] was the utilization of the Analytic Hierarchy Process (AHP) to

assess the risks associated with construction projects. The Analytic Hierarchy Process (AHP) was utilized to determine the probability and impacts of different outcomes in construction projects. The study also examined the constraints of the Analytic Hierarchy Process (AHP), critically evaluating its suitability for conducting risk assessments within the domain of construction projects. In a different context, Kangari [83] performed an extensive survey of prominent construction entities inside the United States. The objective of this study was to acquire a deeper understanding of their perspective on risk and the strategies employed by their contractors to mitigate it at building sites. Kartam et al. [84] proposed a categorization of risk management methods, specifically distinguishing between preventative and mitigative approaches. Their study involved the administration of a questionnaire to assess the utilization of these methods within the construction industry in Kuwait.

Numerous alternative models have been proposed to assess the level of risk associated with building projects and prioritize key risks based on the perspectives of different project stakeholders. Baccarini and Archer [85] employed the P-I model to evaluate the risk score of construction projects with respect to cost, schedule, and quality. The determination of the risk score employs a mechanism that has resemblance to previous approaches. The process entails the computation of the mean likelihood and impact of a risk on many facets of the project, including cost, time, and quality. The obtained average is subsequently multiplied by a pre-established threshold in order to derive the risk score. Hence, the final risk assessment of the project is determined. Hillson [86] introduced a P-I model that completely examines both risks and opportunities within the construction risk management area, attempting to remedy the deficiencies noted in prior methodologies. Jannadi and Almishari [87] provide a definition of risk as the likelihood of adverse outcomes affecting persons or assets. The researchers evaluated and quantified the inherent risks associated with various operations in building projects. The software tool built by the researchers possesses the capability to evaluate the

likelihood, severity, and susceptibility level associated to various risks that may arise during a certain project. Nevertheless, there is a deficiency in the comprehensive definition of the methodology employed to acquire risk evaluations. Oztas and Okmen [88] presented an approach for examining schedule and cost risks in fixed-price design-build construction projects using a case study. This methodology may be employed to facilitate efficient planning and precise cost estimation. Zou et al [89] conducted a study to determine the priority of critical risks in Chinese construction projects. The researchers assessed the potential impact of these risks on many aspects such as cost, schedule, quality, safety, and environmental sustainability. Additionally, the study provided recommendations for effectively managing these risks. Furthermore, researchers have integrated fuzzy risk assessment with the TOPSIS approach to determine the most appropriate model for each selection criterion. Additionally, some scholars have developed a multi-attribute decision-making framework specifically tailored for risk assessment in construction projects [90]. Zavadskas et al. [91] have developed a framework for the assessment of construction project risks using multi-attribute decision-making methodologies. The attributes for risk assessments are carefully chosen, with consideration given to their impact on both the efficiency of the construction process and the overall cost of the final product. Jaskowski and Biruk [92] have suggested a risk analysis and evaluation framework based on the Analytic Hierarchy Process (AHP) intending to improve project planning and evaluate risk mitigation measures. Risk assessment is conducted by evaluating project characteristics and anticipated conditions. This involves assigning weights to risks and establishing distribution guidelines for activity duration.

Therefore, the enhancement of risk management in construction projects in developing countries requires a systematic and comprehensive review methodology that is specifically designed to address the unique hazards associated with these endeavors.

2.6. Risk Factors in Cast In-Situ Bridge Construction Projects

Many risk factors can influence the success of cast-in-situ bridge construction projects. Azis [93] conducted an empirical investigation into the construction processes of the Kutai Kartanegara Bridge in East Kalimantan, Indonesia, and determined that the delay in the delivery of materials, schedule changes, and discrepancies in material quantities constituted significant risks within the project framework. The study suggests that these identified risks require effective mitigation strategies to enhance the likelihood of successful project execution and to reduce the potential for negative consequences in construction endeavors. In their analytical review, Tri Nugroho et al. [94] explored the diverse internal and external factors that affect risk levels in bridge construction. The investigation revealed that both categories, encompassing political dynamics and social instability, significantly contribute to the spectrum of risks associated with the construction of bridges. Also, Chang et al. [95], in their empirical research, observed that political risk is a prominent challenge for Chinese international contractors engaged in global high-speed railway initiatives. The study highlights that the disposition of host governments, the level of social endorsement, and the prevailing economic conditions are pivotal factors shaping the investment landscape for such projects. In an investigative study, Wang [96] underscored the significance of material quality as a risk factor in the management of bridge construction. This factor, alongside human resources, machinery, equipment, and environmental conditions, was identified as integral to the efficacy of construction processes.

Natural conditions such as weather and soil properties present risks that must be considered [97]. Formwork design and construction is critical, as any issues can compromise the quality and strength of concrete [98]. Inaccurate reinforcing bars can lead to inadequate structural strength [99]. Concrete mixing, placement and curing must be carefully controlled, as defects negatively impact concrete strength and durability [98]. Construction joints between segments

are prone to deficiencies if not properly designed and constructed [99]. Personnel-related factors like accidents can cause delays [91], and uncertainties around structural integrity and unforeseen field conditions increase risks over the design life [91]. Previous research has shown that foundations alone account for over 60% of construction emissions in low-energy buildings due to the huge material requirements [100]. Therefore, mitigation strategies must be implemented during all project phases to manage these risk factors and complete construction safely, economically, and to structural performance requirements [97]. Further research into cast-in-situ bridge design could help optimize environmental impacts through reduced material usage [93].

2.7. Risk Factors in Offsite Construction

Prefabrication, offsite construction, pre-assembly, and modularization encompass a wide range of contemporary and innovative methods that provide clients, developers, and project managers with several novel opportunities to achieve enhanced cost-effectiveness within the construction industry. According to Goodier et al. [101] prefabrication is a manufacturing process that predominantly occurs in specialized facilities. It involves the assembly of multiple parts to form a component, which is subsequently brought to the construction site for installation. The adoption of prefabrication has been extensively supported by a plethora of advantages, as documented in various scientific and industrial research publications [102, 103]. However, prior studies from different contexts have also recognized that the utilization of prefabricated construction methods is associated with a range of risk concerns that might potentially undercut the intended benefits of this method for a construction project. Zhang et al. [78] conducted a study and identified several significant barriers hindering the widespread adoption of prefabrication in Hong Kong. These barriers include extended lead times, limited on-site storage space, long design time, inflexibility for design change, high total cost, and high initial cost. Notably, this study, although useful, its scope was limited to the identification of the

barriers to the adoption of prefabrication in Hong Kong rather than the risk factors associated with the implementation of prefabricated construction. Jaillon et al. [104] utilized a mixed-methods approach, including both questionnaire surveys and case studies, to identify the design issues related to the adoption of prefabrication techniques in construction projects in Hong Kong. The results of their study unveiled various design-related issues, such as the lack of uniqueness or customization in prefabricated building designs and insufficient consideration of geological factors. Nevertheless, it is crucial to acknowledge that the scope of their research was limited, as it largely centered on the design aspects of prefabricated components, rather than encompassing a comprehensive analysis of the entire implementation process of prefabrication. Moreover, it should be noted that the study's generalizability would be somewhat constrained due to its primary focus on housing projects, which exhibit notable variations in prefabrication procedures compared to those employed in bridge construction. Several significant studies have also been undertaken to evaluate schedule risks in different geographical locations within the domain of residential modular integrated construction projects. Li et al. [65] analyzed schedule risks in Hong Kong, employing a social network methodology. In addition, Li et al. [45] conducted a study in Hong Kong, utilizing a system dynamics model to analyze scheduling risks in the context of residential modular integrated construction. Also, in a study conducted by Li et al. [25], an in-depth analysis was conducted on modular integrated construction projects in Hong Kong. The study utilized a hybrid approach that merged system dynamics and discrete event simulation techniques to predict several schedule risk factors associated with these projects effectively. In a similar vein, Lee et al. [105] undertook the endeavor of assessing the risk factors that contribute to cost overrun in modular integrated building projects in Korea. Moreover, Wang et al. [20] utilized the importance-performance analysis approach to identify the critical risk factors associated with prefabricated housing projects in the Chinese context. The study highlighted the various risk

factors associated with housing projects across their full lifecycle, including stages such as feasibility assessment, design, production and transportation, building, and operational phases. It is important to highlight that these studies, though useful, are of lesser scope as they primarily focused on housing projects. As a result, the extent to which they can be directly applied to bridge construction projects may be limited. Hence, the existing corpus of scholarly works on risks associated with prefabrication in construction lacks a thorough analysis of risk factors that are directly relevant to bridge construction projects. Hence, the main aim of this research is to contribute a unique and relevant perspective to the current scholarly literature through the quantitative assessment of the critical risk factors associated with the implementation of prefabricated bridge projects in developing countries. **Table 1** provides a detailed list of 43 potential risks that can impact off-site construction projects. Due to the scarcity of existing literature on prefabricated bridge projects, the risk register was formulated based on risk factors commonly associated with prefabrication in general, modular construction, and traditional bridge construction projects.

Table 1. Preliminary List of Risk Factors

	Risk Factors	References
RF1	Inadequate supplier capacity	[19, 20, 58, 104, 106–111]
RF2	Supplier financial instability	[109, 110, 112, 113]
RF3	Poor supply chain integration	[25, 65, 108, 114–116]
RF4	Delay in delivery of materials and components	[25, 45, 76, 114, 117–119]
RF5	Limited capacity/height of the crane	[120, 121]
RF6	Limited site storage space	[69, 78, 104, 106, 122–124]
RF7	Poor information sharing between stakeholders	[22–24, 101, 111, 113, 124–130]
RF8	Complexity of design	[131–133]
RF9	Error in the design and installation of precast components, complex rectification, and rework	[23, 24, 65, 76, 105, 134]
RF10	Defective design and change order	[16, 65, 76, 78, 105, 131, 132]
RF11	Crane breakdown and malfunctioning	[19, 131, 135]
RF12	Slow quality inspection procedure	[41, 108, 110, 136]
RF13	Misplacement of components during storage	[76]

	Risk Factors	References
RF14	Limited expertise and experience in prefabrication	[15, 16, 19, 104–108, 110, 113, 119, 129]
RF15	Lack of experience of contractor in prefabrication	[16, 19, 20, 23, 24, 104, 111, 115, 121, 126, 127, 131, 135, 137, 138]
RF16	Failure of Production system and equipment	[17, 105, 129, 132]
RF17	Weather disruptions and force majeure	[24, 114, 118, 119, 132, 139]
RF18	Transportation restriction	[16, 68, 131, 140, 141]
RF19	Inaccurate cost estimation	[17, 24, 105, 142]
RF20	Late freezing of design and specification	[109, 111]
RF21	Long distance of site from factory	[108, 116]
RF22	Poor control of working flows	[140, 141, 143]
RF23	Lack of compatibility of prefabricated components	[136, 144]
RF24	Lack of specialized equipment	[58, 127]
RF25	Poor planning of resources and schedule	[133, 145–147]
RF26	Political and social instability	[24]
RF27	Stakeholder fragmentation	[65, 108, 116, 117, 135, 142]
RF28	Unavailability of raw materials and components	[18, 131]
RF29	Poor quality of materials	[45, 108]
RF30	Limited capacity and capability of the facility	[131, 135]
RF31	Lack of coordination of deliveries and installation	[19, 133, 135]
RF32	Damage to prefabricated components	[65, 116, 135]
RF33	Disputes and contractual problems	[24, 148]
RF34	Poor road condition	[149]
RF35	Poor management practices	[17, 23, 25, 104, 107, 108, 122, 123, 133, 147, 150]
RF36	Delay in obtaining permits and approval	[24, 76]
RF37	Lack of skilled labor	[17, 20, 67, 111, 115, 149]
RF38	Lack of relevant codes, or compliance with standards, and construction regulations	[15, 18, 24, 57, 58, 101, 107, 108, 110, 113, 115, 116, 120, 126–128, 131–133, 142, 147]
RF39	Fall from height	[20]
RF40	Geometric and dimensional intolerances	[17, 19–22, 135]
RF41	Constructability issues	[115, 128, 151]
RF42	Shortage of precast/prefabricated components	[17, 109, 114, 118, 132, 138]
RF43	Manual handling of heavy precast/prefabricated components	[21, 152, 153]

2.8. Chapter Summary

This chapter conducts a thorough analysis of the current body of research pertaining to risk assessment models within the domain of bridge construction projects. The study identifies a significant gap in previous research and offers a justification for the current work. Moreover, it outlines the precise risk factors that will form the foundation for the formulation of the study's questionnaire.

CHAPTER 3

RESEARCH METHODOLOGY

3.1. Introduction

The establishment of a thorough risk evaluation model for prefabricated bridge construction projects in Sierra Leone holds notable value, given the distinct challenges and contextual factors prevalent in the region. This study aims to fulfill this requirement by utilizing a systematic approach to enhance current understanding and provide a framework that considers specific contextual factors and intricacies. The main objective of this work is to create a specialized fuzzy risk assessment model for prefabricated bridge projects in Sierra Leone. This model aims to effectively quantify risks and improve project management practices. The methodology employed in this study involves a comprehensive literature review, expert interviews, and a structured questionnaire survey. These methods are complemented by data analytic techniques such as mean score analysis and factor analysis. The risk elements are modeled by the utilization of fuzzy synthetic evaluation. This research aims to enhance the infrastructure development efforts in the Democratic Republic of Sierra Leone by contributing to safer, more efficient, and successful prefabricated bridge construction projects. This will be achieved by aligning with international best practices and incorporating views from industry professionals.

3.2. Research Strategy

Figure 1. offers an in-depth summary of the study's aims and the procedures that were employed to achieve them. The methods used to accomplish these aims are grouped into two categories. The first category is the data collection technique, which includes a comprehensive literature search, in-depth interviews with key figures in the industry, and the distribution of questionnaires to obtain representative data. The second group is data analysis methods, which cover the numerous processes used to examine the data collected which includes the factor

analysis method that grouped the risk factors into principal risk factors, and mean score ranking for the determination of the critical risk factors. The development of the risk assessment model also makes use of FSE, a technique for assessing data sets with ambiguous or imprecise information.

The study's goals were met, and useful inferences were drawn from the collected data because of the wide variety of methods used to collect and analyze the information. The study's findings will aid in decision-making and further the body of knowledge in their respective fields.

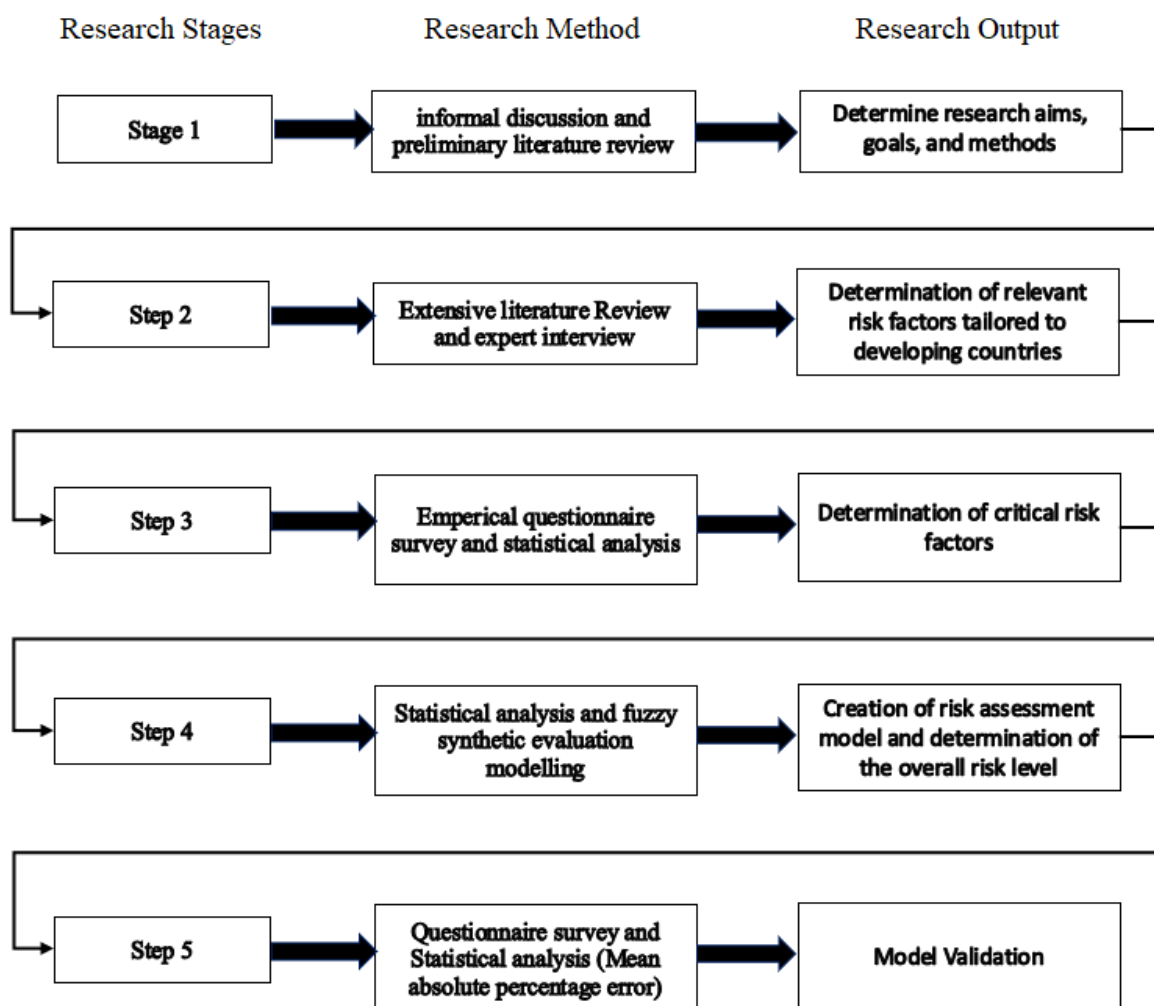


Figure 1. Research workflow

3.3. Data Collection Techniques

According to Fellows and Liu [154], when selecting research methods, one must consider the desired extent and profundity of the study. Questionnaire surveys offer a comprehensive investigation, while interviews grant distinct perspectives from practitioners. Additionally, literature studies can provide valuable insights into established knowledge and practices, as well as identify gaps that need to be addressed. The study has opted for a combined approach as it concentrates on the risks related to prefabricated bridge construction projects.

3.3.1. Literature review studies

Risk management plays a crucial role in the successful execution of prefabricated bridge construction projects, serving as a fundamental component within the broader framework of project management. To commence a thorough risk management initiative, the first step is the identification of potential risks. To establish a comprehensive list of risk factors pertinent to developing countries, a two-step identification procedure was undertaken. The preliminary step of the study involved conducting an extensive examination of pertinent scholarly literature. This was subsequently supplemented by a series of interviews conducted with industry professionals who have had substantial expertise and extensive experience in the domain of prefabricated bridge construction. The examination of literary works was undertaken through a comprehensive evaluation of scholarly publications accessible in the Scopus database. Previous studies, such as [28, 31, 155], have largely utilized Elsevier Scopus as the primary source for article retrieval. Therefore, Scopus database will be utilized for this research. Given the absence of prior research on prefabricated bridge construction, the analysis encompassed the potential risks associated with cast in-situ bridge projects, modular buildings and other off-site construction methods. Following the selection of a suitable database for accessing articles, previous scholarly literature was read to aid in the identification of alternative phrases that

possess synonymous meanings with the terms 'risk' cast in-situ, and 'prefabrication'. The Title-Abs-Key search employed consist of a variety of keywords such as (“risks” OR “barriers” OR “uncertainties”) AND (“Prefabrication” OR “offsite construction” OR “off-site construction” OR “offsite manufacturing” OR “off-site manufacturing” OR “precast” OR “pre-cast” OR “prefabricated” OR “prefab” OR “pre-fab” OR “modular construction” OR “modular integrated construction”) OR “MIC” OR “industrial construction” OR “precast construction” OR “pre-fabricated construction” OR "cast in-situ" OR "in-situ concrete" OR bridge construction”). The search was restricted to scientific journals and papers that were exclusively published in the English language. Subsequently, a meticulous screening process was undertaken on the titles and abstracts of the acquired papers, which was subsequently followed by a comprehensive examination of the full texts. The aim was to identify and analyze research that has documented any potential risks or uncertainties associated with off-site construction. Following a comprehensive evaluation, a collective of 30 scholarly articles were deemed suitable for inclusion in the study. Following this, the acquired articles were evaluated, resulting in the development of a comprehensive list of 43 risk factors as shown in **Table 1**.

3.3.2. Experts interviews

In the second phase of the risk factor identification process, a series of interviews was conducted with professionals from the industry who possess substantial experience and expertise in prefabricated bridge projects within the Sierra Leone context. These interviews were conducted individually with ten experts, scheduled at different times, utilizing the Zoom platform. The primary aim of these interviews was to solicit the expert opinion regarding the relevance of the previously identified risk factors in the specific context of Sierra Leone. Furthermore, the interview sought to capture any risk factors that might not have been captured during the literature review process but were deemed pertinent by these industry experts. The experts were selected based on the following criteria:

- i. The experts must have a substantial record of working experience in prefabricated bridge construction projects
- ii. The experts must have Participated in at least one prefabricated bridge project, and
- iii. The experts must be familiar with the risk factors associated with prefabricated bridge projects.

To ensure that these experts had ample time to familiarize themselves with the identified risk factors, the list of these risk factors was dispatched to them seven days before their respective interview sessions. Table 2 shows the profile of the interviewees. In contrast to previous research conducted by Ameyaw et al. [156], where only five experts were contacted for the initial screening of the risk factors, a total of ten participants were considered appropriate to gather insights on the relevant risk factors in prefabricated bridge projects in Sierra Leone. Furthermore, the participants' extensive years of experience demonstrate their competence and expertise, making them well-equipped to provide informed perspectives on the identified risk factors.

Table 2. Profile of Interviewees

Profile	Category	Frequency
Organization	Government	3
	Contractor	5
	Consultant	2
Years of experience	5-10 years	6
	11-15 years	3
	15 & above years	1
Job role	Project Manager	3
	Engineer	5
	Designer	2

During the interviews, the experts were tasked with evaluating the relevance of these risk factors to the Sierra Leonean context, employing a five-point grading scale. This scale ranged from 1 (indicating not relevant) to 5 (signifying extremely relevant), with intermediate points designating varying degrees of relevance. As a result, two additional risk factors, namely 'inflation' and 'delayed payment' were incorporated into the list of risk factors. Mean score analysis in SPSS was employed to analyze the responses provided by the experts. Risk factors that received scores below the average threshold of 2.50 as in Wuni et al. [31] were considered irrelevant and subsequently eliminated from the risk register. **Table 3** shows the mean score ranking of the identified risk factors.

Table 3. Mean Score Ranking of the Preliminary Risk Factors

S/N	Risk Factors	References	Mean Score	Standard deviation
RF1	Inadequate supplier capacity	[19, 20, 58, 104, 106–111]	4.40	0.894
RF2	Supplier financial instability	[109, 110, 112, 113]	4.40	0.548
RF3	Poor supply chain integration	[25, 65, 108, 114–116]	4.20	0.447
RF4	Delay in delivery of materials and components	[25, 45, 76, 114, 117–119]	3.40	1.517
RF5	Limited capacity/height of the crane	[120, 121]	1.80	0.554
RF6	Limited site storage space	[69, 78, 104, 106, 122–124]	3.80	0.447
RF7	Poor information sharing between stakeholders	[22–24, 101, 111, 113, 124–130]	3.40	0.894
RF8	Complexity of design	[131–133]	1.80	0.837
RF9	Error in the design and installation of precast components, complex rectification, and rework	[23, 24, 65, 76, 105, 134]	3.60	0.548
RF10	Defective design and change order	[16, 65, 76, 78, 105, 131, 132]	3.80	0.837
RF11	Crane breakdown and malfunctioning	[19, 131, 135]	1.60	0.894
RF12	Slow quality inspection procedure	[41, 108, 110, 136]	1.80	0.548
RF13	Misplacement of components during storage	[76]	3.60	1.140
RF14	Limited expertise and experience in prefabrication	[15, 16, 19, 104–108, 110, 113, 119, 129]	3.80	0.447
RF15	Lack of experience of contractor in prefabrication	[16, 19, 20, 23, 24, 104, 111, 115, 121, 126, 127, 131, 135, 137, 138]	3.40	1.342
RF16	Failure of Production system and equipment	[17, 105, 129, 132]	3.20	0.837

S/N	Risk Factors	References	Mean Score	Standard deviation
RF17	Weather disruptions and force majeure	[24, 114, 118, 119, 132, 139]	3.60	1.342
RF18	Transportation restriction	[16, 68, 131, 140, 141]		
RF19	Inaccurate cost estimation	[17, 24, 105, 142]	3.60	0.894
RF20	Late freezing of design and specification	[109, 111]	1.00	0.707
RF21	Long distance of site from factory	[108, 116]	1.60	0.548
RF22	Poor control of working flows	[140, 141, 143]	1.60	0.894
RF23	Lack of compatibility of prefabricated components	[136, 144]	2.00	0.707
RF24	Lack of specialized equipment	[58, 127]	1.80	0.837
RF25	Poor planning of resources and schedule	[133, 145–147]	3.20	1.304
RF26	Political and social instability	[24]	3.40	0.548
RF27	Stakeholder fragmentation	[65, 108, 116, 117, 135, 142]	1.40	0.894
RF28	Unavailability of raw materials and components	[18, 131]	3.00	1.00
RF29	Poor quality of materials	[45, 108]	1.80	1.304
RF30	Limited capacity and capability of the facility	[131, 135]	1.60	1.140
RF31	Lack of coordination of deliveries and installation	[19, 133, 135]	1.80	0.548
RF32	Damage to prefabricated components	[65, 116, 135]	2.00	0.837
RF33	Disputes and contractual problems	[24, 148]	3.20	0.837
RF34	Poor road condition	[149]	1.40	0.548
RF35	Poor management practices	[17, 23, 25, 104, 107, 108, 122, 123, 133, 147, 150]	3.60	0.548
RF36	Delay in obtaining permits and approval	[24, 76]	4.00	0.707
RF37	Lack of skilled labor	[17, 20, 67, 111, 115, 149]	3.20	0.447
RF38	Lack of relevant codes, or compliance with standards, and construction regulations	[15, 18, 24, 57, 58, 101, 107, 108, 110, 113, 115, 116, 120, 126–128, 131–133, 142, 147]	4.20	0.837
RF39	Fall from height	[20]	4.20	0.837
RF40	Geometric and dimensional intolerances	[17, 19–22, 135]	3.20	0.894
RF41	Constructability issues	[115, 128, 151]	4.20	0.548
RF42	Shortage of precast/prefabricated components	[17, 109, 114, 118, 132, 138]	3.20	0.894
RF43	Manual handling of heavy precast/prefabricated components	[21, 152, 153]	3.80	
R44	Inflation	Suggested	3.80	0.707
R45	Delayed payment	Suggested	3.60	0.548

As a result, 16 of the initially identified risk factors were deemed irrelevant by the experts and consequently removed from further consideration. Therefore, a 29-risk factor register was developed to be incorporated into the questionnaire survey. **Table 4** shows the finalized 29-risk factor register.

Table 4. Finalized Risk factor Register

S/N	Risk Factor	References
RF1	Inadequate supplier capacity	[19, 20, 58, 104, 106–111]
RF2	Supplier financial instability	[109, 110, 112, 113]
RF3	Poor supply chain integration	[25, 65, 108, 114–116]
RF4	Delays in the delivery of materials and components	[25, 45, 76, 114, 117–119]
RF5	Poor information sharing between stakeholders	[22–24, 101, 111, 113, 124–130]
RF6	Error in the installation of precast component, complex rectification, and rework	[23, 24, 65, 76, 105, 134]
RF7	Defective design and change order	[16, 65, 76, 78, 105, 131, 132]
RF8	Fall from height	[20]
RF9	Lack of experience of contractor in prefabrication	[16, 19, 20, 23, 24, 104, 111, 115, 121, 126, 127, 131, 135, 137, 138]
RF10	Unavailability of raw materials	[18, 131]
RF11	Inaccurate cost estimation	[17, 24, 105, 142]
RF12	Geometric and dimensional intolerances	[17, 19–22, 135]
RF13	Shortage of precast/prefabricated components	[17, 109, 114, 118, 132, 138]
RF14	Disputes and contractual problems	[24, 148]
RF15	Failure of Production component system and equipment	[17, 105, 129, 132]
RF16	Constructability issues	[115, 128, 151]
RF17	Manual handling of heavy precast/prefabricated components	[21, 152, 153]
RF18	Inflation	Suggested
RF19	Political and social instability	[24]
RF20	Delayed payment	Suggested
RF21	Poor management practices	[17, 23, 25, 104, 107, 108, 122, 123, 133, 147, 150]
RF22	Delay in permits and approval	[24, 76]
RF23	Weather disruptions and force majeure	[24, 114, 118, 119, 132, 139]
RF24	Lack of Skilled labor	[17, 20, 67, 111, 115, 149]

S/N	Risk Factor	References
RF25	Lack of relevant codes, or compliance to standards, and construction regulations	[15, 18, 24, 57, 58, 101, 107, 108, 110, 113, 115, 116, 120, 126–128, 131–133, 142, 147]
RF26	Poor planning of resources and schedule	[133, 145–147]
RF27	Limited site storage space	[69, 78, 104, 106, 122–124]
RF28	Limited expertise and experience in prefabrication construction	[15, 16, 19, 104–108, 110, 113, 119, 129]
RF29	Misplacement of components during storage	[76]

3.4. Pilot Study

A pilot study was conducted with three industry experts and two academics prior to the full-scale study [156]. The pilot study aimed to assess the suitability and reliability of the survey instrument in answering the research questions. It also helped determine the time required for participants to complete the survey and guided the rephrasing of questions to elicit richer responses. Based on feedback from both industry experts and academics, the survey instrument was refined and structured to obtain richer responses and prevent respondent fatigue.

3.5. Questionnaire Survey and Participant Selection

The research is firmly rooted in the positivist paradigm and utilizes quantitative research methodology to identify and assess the risk factors associated with prefabricated bridge projects in developing countries. To achieve this aim, a questionnaire-based survey methodology was selected as the principal means of data gathering, with data collection operations commencing in February 2023. The use of questionnaire surveys has become a prominent and reliable method in the field of Construction Engineering and Management (CEM) research. This is evident from the studies of Ameyaw et al. [156]; Ameyaw and Chan [157]; Osei-Kyei et al. [155]; Wuni et al. [31]; Zafar et al. [28], etc. Questionnaire surveys are valued for their ability to effectively capture the perceptions of a diverse range of industry experts and facilitate the assessment of relationships among these perceptions [156]. Also,

questionnaire facilitates respondents to provide their input at their own convenience, while also enabling the collection of a substantial number of responses in a relatively efficient and cost-effective manner [158]. Additionally, the collection of quantitative data can be achieved by the utilization of closed-ended questions using a structured questionnaire. The utilization of this methodology is imperative for this study, since it requires a systematic evaluation of risk factors, which in turn requires the collection of numerical data. In this study, respondents were tasked with evaluating individual risk factors on a five-point Likert scale, rating both the probability and severity of the risk factors (1 = very low, 2 = low, 3 = moderate, 4 = high, 5 = very high). Previous research studies such as Ameyaw and Chan [156] and Osei-Kyei et al. [155] have suggested the adoption of a seven-point Likert scale as a means to address concerns regarding leniency and central tendency that are often associated with other ordinal scales. However, this study is based on the premise that a five-point Likert scale is suitable for evaluating risk factors using fuzzy logic (Wuni et al. 2022a). Furthermore, study such as Zafar et al. [28] found the five-point scale to be more straightforward to interpret compared to the seven-point variant. Also, the adoption of the five-point Likert scale aligns with prior research in the field of CEM e.g., Wuni et al. [31]; Xu et al. [159]; Zafar et al. [28]. The questionnaire was structured into three distinct sections. Section 1 aimed to gather background information from the respondents. sections 2 and 3 focused on obtaining the respondents' perceptions of the probability and severity of the identified risk factors, respectively. These perceptions were based on the respondents' personal experiences.

The evaluation of risk factors in this study required the participation of industry professionals who possess the necessary expertise and practical experience in the field of prefabricated bridge construction projects in Sierra Leone. The absence of a centralized database hindered the implementation of a random sampling technique, as it prevented the derivation of a representative sample frame. Following the methodology adopted by Wuni et al. [31] and Zafar

et al. [28], this research utilized a purposive sample method that involved selecting participants based on preset criteria. Additionally, a snowballing technique was employed to locate additional appropriate respondents. The purposive sampling strategy facilitated the inclusion of industry practitioners with substantial experience in prefabricated bridge projects, while the snowballing technique allowed initial practitioners to respond and recommend additional experienced industry professionals who have been engaged in prefabricated bridge construction projects. The pre-defined criteria for the industry experts were as follows:

- i. A substantial record of working experience in prefabricated bridge construction projects [28],
- ii. Participation in at least one prefabricated bridge project [31], and
- iii. Familiarity with the risk factors associated with prefabricated bridge projects.

The ten professionals who were initially invited for the interview during the initial vetting of the risk factors were contacted to respond to the questionnaire, and subsequently, they recommended other suitable respondents for participation in the study.

3.6. Data Analysis Techniques

The questionnaire survey data was analyzed statistically with SPSS 27.0 (Statistic Package for the Social Sciences). Cronbach's Alpha, mean score ranking, risk impact score, and factor analysis are the employed statistical methods in this study. In this regard, a brief discussion on each of the statistical methods utilized is provided below.

3.6.1. Cronbach's alpha reliability test

One of the most common ways to test whether the risk factors in a questionnaire statistically measure the constructs they are supposed to represent is using Cronbach's alpha [156]. Through this analysis, the validity and generalizability of the factors can be determined, as evidenced by previous literature [160]. By averaging the correlations between test variables, Cronbach's

alpha reliability coefficient can be determined, which can take on values between 0 and 1 [156]. A dataset with an alpha of 0.7 or higher is considered reliable, as suggested by Tavakol and Dennick [161]. Cronbach's Alpha can be calculated with the aid of the following formula [161].

$$\alpha = \left(\frac{K}{K-1} \right) * \left(1 - \frac{\sum_i \sigma_i^2}{\sigma_x^2} \right)$$

where:

- α is Cronbach's alpha coefficient;
- k is the number of items in the test;
- σ_i^2 is the variance of the i th item;
- σ_x^2 is the variance of the total score.

3.6.2. Mean score analysis

The mean score ranking method has been used by CEM researchers to evaluate the importance of risk factors. It has been used by researchers like Wuni et al. [31] to model critical risk variables in MIC projects and rank the risks, by Ameyaw et al. [156] to analyze and rank risk factors in PPP water projects in developing countries, and by Zafar et al. [28] to assess time and cost risk factors in highway projects in terrorism-affected areas. The study utilized the mean score statistical technique to analyze the questionnaire data and establish the sequence of priority for the risk factors. The mean score ranking method is a quantitative technique that aids in identifying the significant risk factors in a research investigation. It is computed using the subsequent formula:

$$MS = \frac{\sum x_i}{n}$$

where:

- MS is the mean score,
- $\sum X_i$ is the sum of all scores on the risk factors,
- n is the number of risk factors

3.6.3. Risk impact score

Researchers in the field of risk management frequently examine various aspects of the idea of risk. Researchers frequently describe risk as the product of two dimensions: the likelihood that a risk factor (such as cost and time overruns or poor-quality delivery) takes place, and the severity of the influence that its occurrence has on the project's outcome [156]. They believed that risk associated with projects may be calculated by measuring the probability with which a risk occurs and the degree of degree when it does. Simply said, the probability-severity relationship is considered an essential part of assessing risk in project management. As evidenced by Tweeds [162] demonstration of an average risk estimate, this approach to risk estimation has been extensively adopted in the field of decision theory. Numerous research studies, including those by Chan et al. [163], Ameyaw et al. [164], and Shen et al. [164], have utilized this approach in estimating the risk impact score. Ameyaw et al. [156], for instance, used this technique to evaluate the significance of risk factors. Therefore, this approach to risk estimation is deemed appropriate for this study. The following equation can be utilized to calculate the estimated risk [156, 162–164].

$$\text{Risk Impact Score} = \sqrt{(\text{probability} * \text{severity})}$$

3.6.4. Factor analysis

Factor analysis (FA) is a statistical method employed to reduce the dimensions of multivariate data [165]. The primary objective of FA is to minimize the loss of information while condensing a large number of variables and uncovering the interrelationships among them Hair et al. (1998), as referenced by Chan et al. [166]. The determination of the optimal number of

factors required to obtain a precise depiction of the dataset relies on the cumulative proportion of variance accounted for by each factor [166]. Principal Components Analysis (PCA) methodology is employed to understand the latent clustered variables using the Varimax rotation approach. This technique has been extensively employed in studies such as in Wuni et al. [31], Mazher et al. [158], Zafar et al. [28], etc. Consistent with the existing precedents in previous research, this study uses FA to streamline and categorize the risk factors into critical risk groups (CRGs).

The Kaiser-Meyer-Olken (KMO) and Bartlett's test of sphericity are two essential measurements that must be performed first to determine whether factor analysis is appropriate [28, 31, 156].

3.6.4.1. Kaiser–Meyer–Olken (KMO)

A factor analysis may be deemed appropriate or not for a particular study by performing the KMO test, which looks at the degree of partial correlation between variables and the distribution of their values [156]. According to Chan et al. [163], the KMO statistic can take on numbers between 0 and 1, with numbers less than 0.50 indicating a high degree of a partial relationship across variables, which makes the factor analysis not ideal [167]. Norusis [167] recommends a KMO value of at least 0.50 to assure the technique's validity in construction management research.

3.6.4.2. Bartlett's test of sphericity

The presence or absence of a unity matrix is tested using Bartlett's sphericity at a significance level of 0.05 or less [160]. Given that 1s represents variables on the diagonal and 0s represent those off the diagonal, this test is suggestive of the existence of a correlation between the variables in question. The sample size is a critical factor in the success of this experiment. As

Lingard and Rowlinson [168] pointed out, because of this, researchers in the field of CEM have given special attention to the data and sample size of their studies.

3.7. Fuzzy Synthetic Evaluation Modelling

The FSE is a component of fuzzy set theory that utilizes membership degrees in sets to handle imprecise or linguistic terms, rather than binary evaluations of true or false [169]. The fuzzy sets membership grades are denoted by real numbers that fall within a closed interval of zero to one. A value of zero indicates no membership, while a value of one represents complete membership. Fuzzy logic proved effective in decision-making processes, given its ability to represent human behavior and nonlinearity, enhance expert knowledge models, handle uncertainty, model human and government behavior, facilitate flexible modeling and enable simplified representations [170]. The FSE methodology employs linguistic variables and terms to represent the inherent vagueness in human cognitive processes [31], rendering it appropriate for solving problems involving multiple attributes and decision-making. FSE has been widely utilized within the CEM research field to perform quantitative assessments and develop models of risk factors. Xu et al. [159] utilized FSE to develop a model for public-private partnership projects in China. Wuni et al. [31] employed FSE to assess and rank risk factors in modular integrated construction. Similarly, Chan et al. [166] applied FSE to determine the overall risk index associated with target cost contracts and guaranteed maximum contracts. This research employs FSE to assess and prioritize risks, and to determine the overall risk index of prefabricated bridge projects in developing nations. The technique is particularly suited for this purpose, as it enables a meaningful quantitative assessment of fuzzy linguistic variables, such as very low, low, moderate, high, and very high, which are employed in this research. The study utilized the procedure highlighted in [156] for the application of FSE model and it comprises the following sequential steps:

- i. Defining the basic set of risk factors $\Pi = \{f_1, f_2, \dots, f_m\}$, where “m” is the number of risk factors.
- ii. Establish a set of grade alternatives $E = \{e_1, e_2, e_3, \dots, e_n\}$ The variable "e" represents the linguistic grading scale for both probability and severity, ranging from very low to very high.
- iii. Computing the weightage (W_i) for each of the risk factor acquired from the mean score analysis using the equation: $W_i = \{w_1, w_2, \dots, w_m\}$, where $0 \leq w_i \leq 1$.
- iv. Computing the FSE matrix for each risk factor. The matrix is given by: $R_i = |r_{ij}|_{m \times n}$, where r_{ij} is the degree to which the alternative "e" satisfies f_m
- v. Computing the final fuzzy synthetic evaluation matrix $D_i = W_i \circ R_i$, where D_i is the overall assessment matrix and $\circ$ is the fuzzy synthetic operator.
- vi. The resulting FSE matrix is then normalized to produce the factor groupings and criticality indices.

3.8. Model Validation

Model testing is an essential part of the modeling process that guarantees the model will function as intended. Validation and verification of models are cornerstones of the model testing process [171]. The model's accuracy and reliability may be confirmed, and compliance with standards can be ensured, by these two factors. As a result, before integrating a model into a project, it is crucial to undertake model testing to determine the model's efficacy. The absence of a standardized approach for selecting the most suitable validation methods and statistical tests can make the process of validation challenging, despite its importance [172]. In this regard, Law [173] stressed that validation relies on the unique aim of the research study.

Research validity assessment techniques can be divided into two types, namely qualitative and quantitative [174, 175]. Quantitative techniques embrace research strategies that use statistical or numerical information and objective data to investigate presumptive relationships among variables, while qualitative procedures are appropriate when dealing with subjective data expressed through concepts and language rather than numbers [176]. Due to the subjective

nature of the identified risk factors and proposed models, this research employed a qualitative validation strategy.

To evaluate the reliability of the proposed prefabricated bridge risk assessment model, a questionnaire will be used to conduct in-depth interviews with five specialists from five different organizations in Sierra Leone. Each of the professionals should have participated in at least one project and have worked for more than five years on prefab bridge construction. For each of the five projects, the proposed fuzzy synthetic evaluation model will determine their overall risk level. Mean absolute percentage error was proposed as a criterion for reporting the extent of the model's accuracy [177]. In this research, the suggested model's accuracy and dependability were evaluated using the mean absolute percentage error. The number of experts is considered sufficient to validate the established model in comparison to past studies in construction management. For instance, Liu and Ling [177] validated a fuzzy system for markup estimations using a single expert and three cases. Arain and Low [178] used four experts and a single case to validate a knowledge-based decision support system for handling variation orders. Five experts were used by Imriyas [179] in a single-case verification of an expert system for insurance premium ranking. In addition, Liao et al. (2019) used five experts across five separate projects to verify the accuracy of the established fuzzy synthetic evaluation model for gauging the readiness of building projects in Singapore to use building information modeling. It has been established in the literature that the defuzzified value and the actual value should differ by no more than 33.00 percent for a fuzzy expert system to be deemed reliable and accurate [180, 181]. For instance, to predict a company's competitiveness, Ling et al. [182] created mathematical models with mean absolute percentage error values of 14.40 and 22.20 percent. To evaluate the total enterprise risk management maturity of Chinese construction enterprises with an international presence, Zhao et al. [183] created a knowledge-based decision support system with a mean absolute percentage error of 10.40%. Therefore, from the

precedence of [183], the study evaluates the model's validity and reliability by computing its error, percentage error (PE), mean percentage error (MPE), and mean absolute percentage error (MAPE).

$$Error (E) = ORL_{SP} - ORL_M$$

Where ORL_{SP} and ORL_M are the overall risk level based on the specific projects and overall risk level based on the proposed model respectively [177].

$$Percentage Error (PE) = \left(\frac{ORL_{SP} - ORL_M}{ORL_M} \right) * 100\%$$

$$Mean Percentage Error (MPE) = \sum_{i=1}^n \frac{(Percentage Error)_i}{n}$$

Where i is the i^{th} number of projects considered and n is the number of projects considered in the case study.

$$\text{Therefore, Mean Absolute Percentage Error (MAPE)} = \sum_{i=1}^n \frac{|(Percentage Error)_i|}{n}$$

3.9. Chapter Summary

This chapter provides a comprehensive explanation of the methodical strategy employed in the research study to achieve its main purpose. The approaches adopted in this study include a thorough literature review, interviews, a well-designed questionnaire survey, rigorous statistical analysis, and the utilization of FSE as the modeling tool. Figure 3.7 provides a concise visual depiction that effectively captures the many procedural processes. The main objective of this chapter is to present a comprehensive and precise description of the methods and instruments employed in this research endeavor, clarifying the reasoning behind their choice and their crucial contribution to enhancing our comprehension of the study issue.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Results

4.1.1. Data collection analysis

A total of 113 respondents were initially contacted via email, to solicit their participation in the questionnaire survey. From this sample of 113 respondents who were administered the survey, it became evident that 13 individuals did not satisfy the pre-defined criteria for inclusion in the study. Furthermore, notwithstanding the conscientious endeavors in sending multiple follow-up and reminder emails, it was observed that 22 participants failed to provide any responses to the survey. Consequently, a total of 78 valid responses were ultimately obtained, resulting in a commendable response rate of 69.03%. Significantly, the response rate observed in this study compares favorably to the response rates documented in previous research, specifically the 59% reported by Zafar et al. [28] and the 47% stated by Xu et al. [184]. This response rate is especially commendable when considering the specific circumstances of Sierra Leone, a nation classified as a developing country with an estimated population of around 7.1 million, as reported by the 2021 mid-term population census conducted by Statistics Sierra Leone in 2022 [185]. In addition, considering the significant involvement of the respondents in prefabricated bridge projects, the sample size can be confidently considered as both representative and sufficient for subsequent data analysis. **Table 3** provides a concise summary of the demography of the survey respondents.

Table 5. Background Information of the Respondents

Profile	Category	Frequency	Percent	Cumulative percent
Industry experience	Below 5 Years	10	12.8	12.8
	5 to 10 Years	21	26.9	39.7
	11 to 15 Years	27	34.6	74.3

Profile	Category	Frequency	Percent	Cumulative percent
	16 to 20 Years	12	15.4	89.7
	21 Years and Above	8	10.3	100.0
	Total	78	100.0	
Prefabricated bridge experience	Below 5 Years	15	19.2	19.2
	5 to 10 Years	36	46.2	65.4
	11 to 15 Years	19	24.4	89.7
	16 to 20 Years	5	6.4	96.2
	21 Years and Above	3	3.8	100.0
	Total	78	100.0	
Education level	Diploma	11	14.1	14.1
	Bachelor's degree	42	53.8	67.9
	Master's degree	25	32.1	100.0
	Total	78	100.0	
Organization/Company	Government	17	21.8	21.8
	construction company	40	51.3	73.1
	Engineering consultancy company	21	26.9	100.0
	Total	78	100.0	
Job role	Project manager	19	24.4	24.4
	Supervisor	16	20.5	44.9
	Engineer/Architect	31	39.7	84.6
	QA/QC officer	5	6.4	91.0
	HSEQ officer	7	9.0	100.0
	Total	78	100.0	

From **Table 5**, it can be observed that a significant majority of the industry experts surveyed, specifically 87.2%, possessed a minimum of five years of practical experience in the construction sector. Furthermore, a substantial proportion of these professionals, specifically 80.8%, reported a similar degree of engagement in prefabricated bridge projects. Furthermore, it is noteworthy that a significant proportion of the participants, specifically 85.9%, had achieved the successful completion of a minimum of a bachelor's degree in their respective areas of expertise. The amalgamation of practical expertise and academic qualifications endows these industry professionals with a blend of practical abilities and theoretical insight, making them highly suitable for assessing the inherent risk factors associated with prefabricated bridge projects in Sierra Leone. **Table 5** also provides significant insights into the variety of organizations with which the respondents have been affiliated, encompassing government bodies, construction companies, and consultant establishments. The diverse range of positions these individuals have occupied within these organizations highlights the extensive and varied nature of their professional backgrounds. As a result, the combined viewpoints and insights of the individuals involved in this study provide a distinct and comprehensive viewpoint, so augmenting the significance of their contributions.

4.1.2. Identification of the CRFs

The mean score analysis was utilized to assess the relative significance of the 29 identified risk factors. This approach aligns with similar approaches utilized in previous research studies to determine the relative impacts of risk factors [156, 186]. Following the computation of the average scores for both the probability and severity associated with each risk factor, the corresponding impact scores is calculated by applying the formula: [*Impact* = (*mean probability* × *mean severity*)^{1/2}] [186]. The utilization of this analytical framework, in accordance with established academic precedent, enabled the prioritization of these risk factors by evaluating their computed impact values. Based on the previous research

conducted by Chan et al [186], the risk factors that have normalized values 0.5 or greater are categorized as critical. As shown in **Table 6**, a comprehensive summary of the evaluation underscores the identification of 21 risk factors that emerged as critical through the judgment of the experts. It is paramount that these Critical Risk Factors (CRFs) receive heightened attention from policymakers, contractors, and investors, given their potential to significantly influence project outcomes. To offer more specificity, the top five CRFs, along with their corresponding impact values, are outlined below: Poor supply chain integration (3.82), Inadequate supply chain (3.57), Errors in the installation of precast components, complex rectification, and rework (3.55), Lack of experienced contractors (3.47), and Poor information sharing between stakeholders (3.43). Of noteworthy significance is the fact that these CRFs denoted as RF1, RF3, RF4, RF5, RF7, RF9, RF12, RF13, RF15, RF21, RF25, and RF28, were previously recognized as CRFs in a review study on the risk factors associated with modular integrated construction [31]. This implies that the impact of these risk variables extends beyond a particular setting and holds wider significance. This finding provides more support for the need to prioritize interventions and policies that target these risk factors, as they are expected to provide long-lasting effects.

Table 6. Ranking of Risk Factors in Prefabricated Bridge in Sierra Leone

S/N	Risk factors	Risk probability	Risk severity	Risk significance	Risk impact	Rank	Normalized values
RF1	Inadequate supplier capacity	3.53	4.60	16.25	4.03	2	0.86
RF2	Supplier financial instability	3.28	4.25	13.95	3.74	10	0.70
RF3	Poor supply chain integration	3.83	4.80	18.40	4.29	1	1.00
RF4	Delays in the delivery of materials and components	3.07	4.40	13.49	3.67	12	0.66
RF5	Poor information sharing between stakeholders	3.82	3.95	15.08	3.88	5	0.78
RF6	Error in the installation of precast components,	3.40	4.72	16.05	4.01	3	0.84

S/N	Risk factors	Risk probability	Risk severity	Risk significance	Risk impact	Rank	Normalized values
	complex rectification, and rework						
RF7	Defective design and change order	2.97	4.25	12.61	3.55	14	0.59
RF8	Fall from height	1.97	3.10	6.10	2.47	29	0.00
RF9	Lack of experience of contractor in prefabrication	3.43	4.50	15.45	3.93	4	0.80
RF10	Unavailability of raw materials	2.08	3.92	8.17	2.86	27	0.21
RF11	Inaccurate cost estimation	3.05	4.10	12.51	3.54	16	0.59
RF12	Geometric and dimensional intolerances	3.12	4.35	13.56	3.68	11	0.67
RF13	Shortage of precast/prefabricated components	3.22	4.55	14.64	3.83	7	0.75
RF14	Disputes and contractual problems	2.75	4.12	11.33	3.37	21	0.49
RF15	Failure of Production component system and equipment	3.18	4.50	14.32	3.78	9	0.72
RF16	Constructability issues	2.60	3.87	10.06	3.17	23	0.39
RF17	Manual handling of heavy precast/prefabricated components	2.42	3.48	8.41	2.90	26	0.24
RF18	Inflation	3.07	4.20	12.88	3.59	13	0.62
RF19	Political and social instability	2.82	3.80	10.70	3.27	22	0.44
RF20	Delayed payment	2.98	4.13	12.32	3.51	18	0.57
RF21	Poor management practices	2.93	4.25	12.47	3.53	17	0.58
RF22	Delay in permits and approval	3.05	3.87	11.80	3.44	20	0.53
RF23	Weather disruptions and force majeure	2.20	4.23	9.31	3.05	24	0.32
RF24	Lack of Skilled labor	3.23	4.55	14.71	3.84	6	0.75
RF25	Lack of relevant codes, or compliance to standards, and construction regulations	3.18	3.87	12.32	3.51	19	0.57
RF26	Poor planning of resources and schedule	2.50	3.70	9.25	3.04	25	0.31

S/N	Risk factors	Risk probability	Risk severity	Risk significance	Risk impact	Rank	Normalized values
RF27	Limited site storage space	3.13	4.02	12.60	3.55	15	0.59
RF28	Limited expertise and experience in prefabrication construction	3.20	4.50	14.40	3.79	8	0.73
RF29	Misplacement of components during storage	2.17	3.03	6.57	2.56	28	0.05

Normalized value = (average actual value – average minimum value)/(average maximum value – average minimum value)

A total of eight risk factors were identified, all of which have values below the critical threshold of 0.5. Consequently, these risk factors were classified as noncritical. The noncritical risk factors encompass different factors such as political and social stability, constructability issues, weather disruptions and force majeure events, inadequate planning of resources and schedules, manual handling of heavy precast components, shortages of raw materials, misplacement of prefabricated components during storage, and falls from heights.

4.1.3. Identification of the CRGs in prefabricated bridge projects

This study utilized the principal component extraction methodology, using Varimax rotation and Kaiser Normalization as the selected rotation method, for analyzing the 21 Critical Risk Factors (CRFs) derived from data normalization. The iterative rotation process successfully reached convergence after a total of eight iterations. This convergence resulted in a four-factor solution, which was distinguished by eigenvalues that exceeded the value of 1. The four-factor solution accounted for a total of 58.326% of the variance observed in the dataset. The associations between the CRFs and CRGs are depicted in Table 4, which presents the factor loadings. The factor loadings provide a measure of the extent to which the CRFs influence the outcome of the CRGs. It is important to highlight that individual CRFs contained within each factor group make a substantial contribution to the nomenclature allocated to these factor groups. It is worth mentioning that Xu et al. [187] postulated that the nomenclature of factor groupings is subjective, and alternative designations may be proposed by other researchers.

Table 7 presents a summary of the categorization of CRFs into four distinct CRGs, namely execution risks, material and logistics risks, supplier and stakeholder risks, and economic and financial risks. Notably, the initial three aggregated components combined explain 28.525%, 11.708%, and 9.963% of the overall variance, correspondingly. Significantly, all factor loadings exceed or roughly approximate the criterion of 0.5. Overall, the loadings and interpretations of the retrieved components exhibited a reasonable level of consistency. Therefore, it can be surmised that these four highlighted groups play a critical part in the effective implementation of prefabricated bridge projects in developing nations. According to Ameyaw and Chan (2015), factor grouping serves two main purposes: firstly, it utilizes CRFs as input variables to comprehensively evaluate project risk levels. Secondly, it helps to reduce the complexity of managing a large number of risk factors, thereby enhancing the effectiveness of risk management practices.

Table 7. CRF Extraction and Loadings

S/N	Principal risk groups (PRGs)/Critical risk factors (CRFs)	Factor loading	Eigen value	% of variance explained	Cumulative % of variance explained
CRG1:	Execution risks		5.99	28.525	28.525
RF9	Lack of experience of contractor in prefabrication	0.834			
RF21	Poor management practices	0.807			
RF28	Limited expertise and experience in prefabrication construction	0.759			
RF24	Lack of Skilled labor	0.751			
RF12	Geometric and dimensional intolerances	0.61			
RF25	Lack of relevant codes, or compliance to standards, and construction regulations	0.604			

S/N	Principal risk groups (PRGs)/Critical risk factors (CRFs)	Factor loading	Eigen value	% of variance explained	Cumulative % of variance explained
RF7	Defective design and change order	0.535			
RF6	Error in the installation of precast component, complex rectification, and rework	0.46			
CRG2	Material and logistics risks		2.459	11.708	40.233
RF15	Failure of production components and equipment	0.848			
RF13	Shortage of precast/prefabricated components	0.82			
RF4	Delays in the delivery of materials and components	0.716			
RF27	Limited site storage space	0.691			
RF22	Delay in permits and approval	0.321			
CRG3	Stakeholder and supplier risks		2.092	9.963	50.196
RF14	Disputes and contractual problems	0.729			
RF2	Supplier financial instability	0.724			
RF5	Poor information sharing between stakeholders	0.671			
RF3	Poor supply chain integration	0.585			
RF1	Inadequate supplier capacity	0.472			
CRG4	Economic and financial risks		1.707	8.13	58.326
RF18	Inflation	0.838			
RF20	Delayed payment	0.669			
RF11	Inaccurate cost estimation	0.567			

4.1.4. Developing weightings for the CRFs and CRGs

The next stage in the development of the fuzzy risk assessment model for prefabricated bridge construction projects within Sierra Leone involves the determination of suitable weightings for both CRFS and CRGs. Following the precedence of Wuni et al. (2022a), the weightings for the 21 distinct CRFs and the 4 CRGs are calculated using the following formula:

$$W_i = \frac{M_i}{\sum_{i=1}^5 M_i}, \quad 0 < w_i < 1, \text{ and } \sum_{i=1}^n = 1 \quad (1)$$

Wherein:

W_i is the weighting assigned to an individual CRF or CRG with respect to the probability and severity.

M_i denotes the mean score attributed to a particular CRF or CRG, with i representing values on the five-point Likert scale, ranging from 1 to 5.; and

$\sum M_i$ corresponds to the summation of the average scores for all CRFs or CRGs in consideration.

The weighting function given by W_i comprises of set of weights denoted by:

$$\{w_1, w_2, \dots, w_n\} \quad (2)$$

As an illustration, consider the risk probability associated with RF9. According to Table 5, RF9 has a mean probability score of 3.43. Additionally, the cumulative mean probability scores for the CRG1 amount to 25.46. Therefore, by utilizing equation (1), the probability weighting for RF9 can be calculated in the following manner:

$$w_{RF9(p)} = \frac{3.43}{3.43 + 2.93 + 3.20 + 3.23 + 3.12 + 3.18 + 2.97 + 3.40} = \frac{3.43}{25.46} = 0.135$$

The process of calculating the weighting functions for the remaining CRFs within each group, CRG1 to CRG4, for both probability and severity, is carried out using the same procedure as described above. Additionally, the computation of the normalized weighting function sets for each CRG adheres to the requirement specified in equation (1). The weighting function set for CRG1 is calculated as follows:

$$\sum_{i=1}^8 w_{CRG1(p)} = 0.135 + 0.115 + 0.126 + 0.127 + 0.123 + 0.125 + 0.117 + 0.134$$

$$= 1.000$$

The probability means scores for each of the CRGs (CRG1=25.46, CRG2=15.65, CRG3=17.11, and CRG4=9.10) are normalized using the total probability mean score of 67.32. The normalizing step entailed the utilization of equation (1) to derive the weighting function for each CRG as shown below:

$$W_{CRG1(p)} = \frac{25.46}{25.46 + 15.65 + 17.11 + 9.10} = \frac{25.46}{67.32} = 0.378$$

$$W_{CRG2(p)} = \frac{15.65}{25.46 + 15.65 + 17.11 + 9.10} = \frac{15.65}{67.32} = 0.233$$

$$W_{CRG3(p)} = \frac{17.11}{25.46 + 15.65 + 17.11 + 9.10} = \frac{17.11}{67.32} = 0.254$$

$$W_{CRG4(p)} = \frac{9.10}{25.46 + 15.65 + 17.11 + 9.10} = \frac{9.10}{67.32} = 0.135$$

$$\sum_{i=1}^4 W_{CRG(p)} = 0.378 + 0.232 + 0.254 + 0.135 = 1.000$$

The requirement stated in equation (1) is satisfied, as the sum of the normalized weightings for all the CRGs equals 1. Similarly, the computation of the weighting function for the CRG (severity) follows the same procedure, ensuring that the sum of its normalized weightings

equals 1. As a result, the determination of membership functions will be based on the weightings assigned to the CRFs and the CRGs. **Table 8** summarizes the weighting functions for each CRF and CRG for both probability and severity.

Table 8. Weightings of CRFs and CRGs for Prefabricated Bridge Projects

S/N	CRFs/CRGs	Risk probability (p)				Risk severity (s)			
		Mean probability	Weighting of CRF	Total mean of CRG	weighting of CRG	Mean severity	Weighting of CRF	Total mean of CRG	weighting of CRG
CRG1	Execution risks			25.46	0.378			34.99	0.387
RF9	Lack of experience of contractor in prefabrication	3.43	0.135			4.50	0.129		
RF21	Poor management practices	2.93	0.115			4.25	0.121		
RF28	Limited expertise and experience in prefabrication construction	3.20	0.126			4.50	0.129		
RF24	Lack of Skilled labor	3.23	0.127			4.55	0.130		
RF12	Geometric and dimensional intolerances	3.12	0.123			4.35	0.124		
RF25	Lack of relevant codes, or compliance to standards, and construction regulations	3.18	0.125			3.87	0.111		
RF7	Defective design and change order	2.97	0.117			4.25	0.121		
RF6	Error in the installation of precast component, complex rectification, and rework	3.40	0.134			4.72	0.135		
CRG2	Material and logistics risks			15.65	0.233			21.34	0.236

S/N	CRFs/CRGs	Risk probability (p)				Risk severity (s)			
		Mean probability	Weighting of CRF	Total mean of CRG	weighting of CRG	Mean severity	Weighting of CRF	Total mean of CRG	weighting of CRG
RF15	Failure of production components and equipment	3.18	0.203			4.50	0.211		
RF13	Shortage of precast/prefabricated components	3.22	0.206			4.55	0.213		
RF4	Delays in the delivery of materials and components	3.07	0.196			4.40	0.206		
RF27	Limited site storage space	3.13	0.200			4.02	0.188		
RF22	Delay in permits and approval	3.05	0.195			3.87	0.181		
CRG3	Stakeholder and supplier risks			17.11	0.254			21.72	0.240
RF14	Disputes and contractual problems	2.75	0.161			4.12	0.190		
RF2	Supplier financial instability	3.28	0.192			4.25	0.196		
RF5	Poor information sharing between stakeholders	3.72	0.217			3.95	0.182		
RF3	Poor supply chain integration	3.83	0.224			4.80	0.221		
RF1	Inadequate supplier capacity	3.53	0.206			4.60	0.212		
CRG4	Economic and financial risks			9.10	0.135			12.43	0.137

S/N	CRFs/CRGs	Risk probability (p)				Risk severity (s)			
		Mean probability	Weighting of CRF	Total mean of CRG	weighting of CRG	Mean severity	Weighting of CRF	Total mean of CRG	weighting of CRG
RF18	Inflation	3.07	0.337			4.20	0.338		
RF20	Delayed payment	2.98	0.327			4.13	0.332		
RF11	Inaccurate cost estimation	3.05	0.335			4.10	0.330		
	Total CRG			67.32				90.48	

4.1.5. Computing the membership function (MF) for each CRF and CRG

From the normalization process of the combined mean scores of the factors, a total of 21 risk factors were determined to be critical for computing the overall level of risk in prefabricated bridge construction projects in developing countries. Suppose that the set of basic criteria used in the fuzzy risk assessment model to be $\pi = \{f_1, f_2, f_3, \dots, f_{21}\}$, and the grades for selection are defined as $E = \{1, 2, 3, 4, 5\}$ where 1 = very low, 2 = low, 3 = moderate, 4 = high, and 5 = very high for both the risk probability and severity, the MF for each of the CRF is then computed from the percentage of responses from the respondents. The MF for the CRG is then computed from the MF of the CRFs within each factor grouping. For example, the survey results on the probability of RF9 “lack of experience of contractor in prefabrication” shows that 8.3% assessed it as very low, 8.3% as low, 16.7% as moderate, 26.7% as high, and 40.0% as very high. Therefore, the membership function for the probability of RF9 can be computed as:

$$MF_{RF9(p)} = \frac{0.083}{\text{Very Low (1)}} + \frac{0.083}{\text{Low (2)}} + \frac{0.167}{\text{Moderate (3)}} + \frac{0.267}{\text{High (4)}} + \frac{0.400}{\text{Very high (5)}} \quad (3)$$

The MFs can also alternatively be expressed as (0.083, 0.083, 0.167, 0.267, 0.400).

Similarly, the MF for severity of RF9 is given as:

$$MF_{RF9(s)} = \frac{0.08}{\text{Very low}} + \frac{0.13}{\text{Low}} + \frac{0.17}{\text{Moderate}} + \frac{0.42}{\text{High}} + \frac{0.20}{\text{Very high}}$$

The MF is expressed alternatively as (0.08, 0.13, 0.17, 0.42, 0.20).

Using the same approach, the MF for both probability and severity for the remaining CRFs are computed. The MFs of the CRGs are then computed using the MF of the CRFs. However, a fuzzy evaluation matrix is required for computing the MF of the CRGs. The fuzzy evaluation

matrix for the MFs for the CRFs for both probability and severity within their CRGs is given by:

$$R_i = \begin{bmatrix} MF_{CRGi1} \\ MF_{CRGi2} \\ MF_{CRGi3} \\ \dots \\ MF_{CRGin} \end{bmatrix} = \begin{bmatrix} V_{1CRGi1} & V_{2CRGi1} & V_{3CRGi1} & V_{4CRGi1} & V_{5CRGi1} \\ V_{1CRGi2} & V_{2CRGi2} & V_{3CRGi2} & V_{4CRGi2} & V_{5CRGi2} \\ V_{1CRGi3} & V_{2CRGi3} & V_{3CRGi3} & V_{4CRGi3} & V_{5CRGi3} \\ \dots & \dots & \dots & \dots & \dots \\ V_{1CRGin} & V_{2CRGin} & V_{3CRGin} & V_{4CRGin} & V_{5CRGin} \end{bmatrix} \quad (4)$$

Where R_i represents the fuzzy MFs for the CRFs within a given CRG (called fuzzy matrix) with elements expressed as V_{jCRGi1} and MF_{CRGi1} to MF_{CRGin} represents the MFs of n CRFs in each CRG. The values for V_1 to V_5 in equation (4) are the level 3 MFs shown in **Table 8**. The fuzzy evaluation matrix (D_i) can then be computed from the weightings (W_i) and the fuzzy matrix (R_i) using the equation:

$$D_i = W_i \bullet R_i = (w_{i1}, w_{i2}, \dots, w_{in}) \times \begin{bmatrix} V_{1CRGi1} & V_{2CRGi1} & V_{3CRGi1} & V_{4CRGi1} & V_{5CRGi1} \\ V_{1CRGi2} & V_{2CRGi2} & V_{3CRGi2} & V_{4CRGi2} & V_{5CRGi2} \\ V_{1CRGi3} & V_{2CRGi3} & V_{3CRGi3} & V_{4CRGi3} & V_{5CRGi3} \\ \dots & \dots & \dots & \dots & \dots \\ V_{1CRGin} & V_{2CRGin} & V_{3CRGin} & V_{4CRGin} & V_{5CRGin} \end{bmatrix} \\ = (d_{i1}, d_{i2}, \dots, d_{in}) \quad (5)$$

Where d_{in} represents the degree of membership of the grade alternative for a given CRF_i and “•” is the fuzzy composite operator. For example, the CRG2 consists of five CRFs which includes RF15, RF13, RF4, RF27, and RF22. The probability weightings for these CRFs are 0.203, 0.206, 0.196, 0.200, and 0.195 respectively. The weighting function (probability) for CRG2 is given by:

$$W_{CRG2(p)} = \{0.203, 0.206, 0.196, 0.200, 0.195\}$$

Also, the MF (probability) for the CRFs within CRG2 can be express as:

$$R_{CRG2(p)} = \begin{bmatrix} MF_{CRG2_{RF15}} \\ MF_{CRG2_{RF13}} \\ MF_{CRG2_{RF4}} \\ MF_{CRG2_{RF27}} \\ MF_{CRG2_{RF22}} \end{bmatrix} = \begin{bmatrix} 0.07 & 0.08 & 0.12 & 0.40 & 0.33 \\ 0.08 & 0.10 & 0.33 & 0.23 & 0.25 \\ 0.17 & 0.12 & 0.05 & 0.43 & 0.23 \\ 0.03 & 0.08 & 0.20 & 0.23 & 0.45 \\ 0.23 & 0.38 & 0.18 & 0.15 & 0.05 \end{bmatrix}$$

Thus, using equation (5), the fuzzy evaluation matrix for CRG2 is computed as follows:

$$\begin{aligned} D_{CRG2(p)} &= W_{CRG2(p)} \bullet R_{CRG2(p)} \\ &= (0.203, 0.206, 0.196, 0.200, 0.195) \times \begin{bmatrix} 0.07 & 0.08 & 0.12 & 0.40 & 0.33 \\ 0.08 & 0.10 & 0.33 & 0.23 & 0.25 \\ 0.17 & 0.12 & 0.05 & 0.43 & 0.23 \\ 0.03 & 0.08 & 0.20 & 0.23 & 0.45 \\ 0.23 & 0.38 & 0.18 & 0.15 & 0.05 \end{bmatrix} \\ &= (0.08, 0.10, 0.18, 0.34, 0.31) \end{aligned}$$

Similarly, the fuzzy evaluation matrix of severity for CRG2 is computed using the same approach.

The weighting function (severity) for CRG2 is given by:

$$W_{CRG2(s)} = \{0.211, 0.213, 0.206, 0.188, 0.181\}$$

Also, the MF (severity) for the CRFs within CRG2 is expressed as:

$$R_{CRG2(s)} = \begin{bmatrix} MF_{CRG2_{RF15}} \\ MF_{CRG2_{RF13}} \\ MF_{CRG2_{RF4}} \\ MF_{CRG2_{RF27}} \\ MF_{CRG2_{RF22}} \end{bmatrix} = \begin{bmatrix} 0.02 & 0.10 & 0.17 & 0.40 & 0.32 \\ 0.03 & 0.13 & 0.17 & 0.30 & 0.37 \\ 0.07 & 0.13 & 0.15 & 0.37 & 0.28 \\ 0.07 & 0.12 & 0.33 & 0.32 & 0.17 \\ 0.03 & 0.13 & 0.28 & 0.43 & 0.12 \end{bmatrix}$$

Therefore, the fuzzy evaluation matrix for CRG2 (severity) is computed as follows:

$$D_{CRG2(s)} = W_{CRG2(s)} \bullet R_{CRG2(s)}$$

$$= (0.211, 0.213, 0.206, 0.188, 0.181) \times \begin{bmatrix} 0.02 & 0.10 & 0.17 & 0.40 & 0.32 \\ 0.03 & 0.13 & 0.17 & 0.30 & 0.37 \\ 0.07 & 0.13 & 0.15 & 0.37 & 0.28 \\ 0.07 & 0.12 & 0.33 & 0.32 & 0.17 \\ 0.03 & 0.13 & 0.28 & 0.43 & 0.12 \end{bmatrix}$$

$$= (0.04, 0.12, 0.22, 0.36, 0.26)$$

Using a similar approach, the probability and severity fuzzy evaluation matrix is computed for the remaining CRGs as shown in **Table 7**.

4.1.6. Determining the Criticality of the CRGs

Following the computation of fuzzy evaluation matrices for the probability and severity associated to each CRG, the identification of these CRGs is subsequently conducted using the formula outlined in the research conducted by [156]

$$CRG_{index} = \sqrt{\left\{ \sum_{i=1}^5 D_p \times E_i \right\} \times \left\{ \sum_{l=1}^5 D_s \times E_l \right\}} \quad (6)$$

Where D_p and D_s represents the fuzzy evaluation matrix for a specific CRG probability and severity respectively, while E_i corresponds to the five points grading scale adopted in the study. Using equation (6), the criticality index for each CRG can be determine as follows:

CRG1

$$= \sqrt{\{(0.09, 0.12, 0.17, 0.25, 0.37) \times (1, 2, 3, 4, 5)\} \times \{(0.06, 0.12, 0.22, 0.33, 0.27) \times (1, 2, 3, 4, 5)\}}$$

$$= \sqrt{(3.697 \times 3.636)} = 3.67$$

CRG2

$$= \sqrt{\{(0.08, 0.10, 0.18, 0.34, 0.31) \times (1, 2, 3, 4, 5)\} \times \{(0.04, 0.12, 0.22, 0.36, 0.26) \times (1, 2, 3, 4, 5)\}}$$

$$= \sqrt{(3.690 \times 3.665)} = 3.68$$

Table 9. Membership Functions (Probability and Severity) for CRFs and CRGs for Prefabricated Bridge Construction Projects in Developing Countries

S/N	Risk Factors	MF for all CRFs and CRGs for prefabricated bridge projects in developing countries (risk probability)			MF for all CRFs and CRGs for prefabricated bridge projects in developing countries (risk severity)		
		weightings	MF for each CRF	MF for each CRG (0.09, 0.12, 0.17, 0.25, 0.37)	weightings	MF for each CRF	MF for each CRG (0.06, 0.12, 0.22, 0.33, 0.27)
CRG1	Execution risks						
RF9	Lack of experience of contractor in prefabrication	0.135	(0.08, 0.18, 0.27, 0.35, 0.12)		0.130	(0.08, 0.13, 0.17, 0.42, 0.20)	
RF21	Poor management practices	0.115	(0.10, 0.25, 0.42, 0.18, 0.05)		0.120	(0.05, 0.20, 0.23, 0.23, 0.28)	
RF28	Limited expertise and experience in prefabrication construction	0.126	(0.07, 0.18, 0.30, 0.37, 0.08)		0.130	(0.05, 0.10, 0.23, 0.30, 0.32)	
RF24	Lack of Skilled labor	0.127	(0.08, 0.18, 0.33, 0.32, 0.08)		0.132	(0.03, 0.13, 0.18, 0.37, 0.28)	
RF12	Geometric and dimensional intolerances	0.123	(0.17, 0.20, 0.32, 0.28, 0.03)		0.124	(0.03, 0.15, 0.08, 0.40, 0.33)	
RF25	Lack of relevant codes, or compliance to standards, and construction regulations	0.125	(0.17, 0.20, 0.40, 0.17, 0.07)		0.106	(0.08, 0.07, 0.30, 0.23, 0.32)	
RF7	Defective design and change order	0.117	(0.18, 0.40, 0.28, 0.08, 0.05)		0.120	(0.07, 0.10, 0.32, 0.27, 0.25)	
RF6	Error in the installation of precast component, complex rectification, and rework	0.134	(0.10, 0.17, 0.35, 0.28, 0.10)		0.138	(0.05, 0.10, 0.27, 0.38, 0.20)	
CRG2	Material and logistics risks			(0.08, 0.10, 0.18, 0.34, 0.31)			(0.04, 0.12, 0.22, 0.36, 0.26)

		MF for all CRFs and CRGs for prefabricated bridge projects in developing countries (risk probability)			MF for all CRFs and CRGs for prefabricated bridge projects in developing countries (risk severity)		
S/N	Risk Factors	weightings	MF for each CRF	MF for each CRG	weightings	MF for each CRF	MF for each CRG
RF15	Failure of production components and equipment	0.203	(0.13, 0.17, 0.30, 0.33, 0.07)		0.214	(0.02, 0.10, 0.17, 0.40, 0.32)	
RF13	Shortage of precast/prefabricated components	0.206	(0.12, 0.22, 0.35, 0.23, 0.08)		0.217	(0.03, 0.13, 0.17, 0.30, 0.37)	
RF4	Delays in the delivery of materials and components	0.196	(0.17, 0.27, 0.23, 0.28, 0.05)		0.208	(0.07, 0.13, 0.15, 0.37, 0.28)	
RF27	Limited site storage space	0.200	(0.17, 0.35, 0.20, 0.23, 0.05)		0.185	(0.07, 0.12, 0.35, 0.32, 0.17)	
RF22	Delay in permits and approval	0.195	(0.23, 0.38, 0.18, 0.15, 0.05)		0.176	(0.03, 0.13, 0.28, 0.43, 0.12)	
CRG3	Stakeholder and supplier risks			(0.08, 0.12, 0.18, 0.28, 0.34)			(0.06, 0.09, 0.26, 0.36, 0.22)
RF14	Disputes and contractual problems	0.161	(0.23, 0.35, 0.23, 0.10, 0.08)		0.187	(0.12, 0.17, 0.20, 0.28, 0.23)	
RF2	Supplier financial instability	0.192	(0.17, 0.32, 0.25, 0.23, 0.03)		0.194	(0.10, 0.05, 0.20, 0.35, 0.30)	
RF5	Poor information sharing between stakeholders	0.217	(0.33, 0.33, 0.23, 0.10, 0.00)		0.176	(0.03, 0.05, 0.30, 0.45, 0.17)	
RF3	Poor supply chain integration	0.224	(0.07, 0.07, 0.37, 0.28, 0.22)		0.227	(0.03, 0.07, 0.25, 0.35, 0.30)	
RF1	Inadequate supplier capacity	0.206	(0.10, 0.20, 0.28, 0.37, 0.05)		0.215	(0.03, 0.12, 0.37, 0.38, 0.10)	
CRG4	Economic and financial risks			(0.06, 0.11, 0.14, 0.32, 0.37)			((0.07, 0.06, 0.30, 0.28, 0.30)

		MF for all CRFs and CRGs for prefabricated bridge projects in developing countries (risk probability)			MF for all CRFs and CRGs for prefabricated bridge projects in developing countries (risk severity)		
S/N	Risk Factors	weightings	MF for each CRF	MF for each CRG	weightings	MF for each CRF	MF for each CRG
RF18	Inflation	0.337	(0.17, 0.28, 0.28, 0.22, 0.05)		0.339	(0.03, 0.07, 0.25, 0.35, 0.30)	
RF20	Delayed payment	0.327	(0.17, 0.28, 0.28, 0.22, 0.05)		0.332	(0.05, 0.03, 0.40, 0.30, 0.22)	
RF11	Inaccurate cost estimation	0.335	(0.15, 0.38, 0.32, 0.13, 0.02)		0.329	(0.12, 0.07, 0.25, 0.18, 0.38)	

CRG3

$$= \sqrt{\{(0.08, 0.12, 0.18, 0.28, 0.34) \times (1, 2, 3, 4, 5)\} \times \{(0.06, 0.09, 0.26, 0.36, 0.22) \times (1, 2, 3, 4, 5)\}}$$

$$= \sqrt{(3.691 \times 3.590)} = 3.64$$

CRG4

$$= \sqrt{\{(0.06, 0.11, 0.14, 0.32, 0.37) \times (1, 2, 3, 4, 5)\} \times \{(0.07, 0.06, 0.30, 0.28, 0.30) \times (1, 2, 3, 4, 5)\}}$$

$$= \sqrt{(3.843 \times 3.690)} = 3.77$$

4.1.7. Computing the overall risk level (ORL) of prefabricated bridge projects

The weightings for each of the CRGs with their respective fuzzy evaluation matrix are then used for computing the final fuzzy evaluation matrix of the overall risk level index for prefabricated bridge construction projects in developing countries. The fuzzy evaluation matrices of the CRGs and their respective weightings for both probability and severity are shown in **Table 9**. The overall probability and severity matrices and weightings for the CRGs are given by:

$$R_{overall (p)} = \begin{bmatrix} MF_{CRF1} \\ MF_{CRF2} \\ MF_{CRF3} \\ MF_{CRF4} \end{bmatrix} = \begin{bmatrix} 0.09 & 0.12 & 0.17 & 0.25 & 0.37 \\ 0.08 & 0.10 & 0.18 & 0.34 & 0.31 \\ 0.08 & 0.12 & 0.18 & 0.28 & 0.34 \\ 0.06 & 0.11 & 0.14 & 0.32 & 0.37 \end{bmatrix}$$

$$R_{overall (s)} = \begin{bmatrix} MF_{CRF1} \\ MF_{CRF2} \\ MF_{CRF3} \\ MF_{CRF4} \end{bmatrix} = \begin{bmatrix} 0.06 & 0.12 & 0.22 & 0.33 & 0.27 \\ 0.04 & 0.12 & 0.22 & 0.36 & 0.26 \\ 0.06 & 0.09 & 0.26 & 0.36 & 0.26 \\ 0.07 & 0.06 & 0.30 & 0.28 & 0.30 \end{bmatrix}$$

$$W_{overall (p)} = (0.378, 0.233, 0.254, 0.135)$$

$$W_{overall (s)} = (0.387, 0.236, 0.240, 0.137)$$

The final overall fuzzy evaluation matrix for probability (D_p) for the overall risk level for prefabricated bridge projects in developing countries is determined by using equation (5) as follows:

$$D_{overall(p)} = \begin{bmatrix} 0.378 \\ 0.233 \\ 0.254 \\ 0.135 \end{bmatrix} \times \begin{bmatrix} 0.09 & 0.12 & 0.17 & 0.25 & 0.37 \\ 0.08 & 0.10 & 0.18 & 0.34 & 0.31 \\ 0.08 & 0.12 & 0.18 & 0.28 & 0.34 \\ 0.06 & 0.11 & 0.14 & 0.32 & 0.37 \end{bmatrix} = (0.08, 0.11, 0.17, 0.29, 0.35)$$

$$D_{overall(s)} = \begin{bmatrix} 0.387 \\ 0.236 \\ 0.240 \\ 0.137 \end{bmatrix} \times \begin{bmatrix} 0.06 & 0.12 & 0.22 & 0.33 & 0.27 \\ 0.04 & 0.12 & 0.22 & 0.36 & 0.26 \\ 0.06 & 0.09 & 0.26 & 0.36 & 0.22 \\ 0.07 & 0.06 & 0.30 & 0.28 & 0.30 \end{bmatrix} = (0.06, 0.20, 0.31, 0.28, 0.14)$$

Now, the overall risk index for prefabricated bridge projects in developing countries is computed using equation (6):

Overall risk level

$$\begin{aligned} &= \sqrt{\{(0.08, 0.11, 0.17, 0.29, 0.35) \times (1, 2, 3, 4, 5)\} \times (0.06, 0.20, 0.31, 0.28, 0.14) \times (1, 2, 3, 4, 5)} \\ &= \sqrt{(3.710 \times 3.639)} = 3.674 \text{ (High)} \end{aligned}$$

This value represents the overall risk level of prefabricated bridge projects in Sierra Leone. This finding indicates that prefabricated bridge projects in developing countries exhibit a high overall risk level, as evidenced by a numerical value of 3.674.

4.1.8. Developing a risk assessment model for prefabricated bridge projects

A risk assessment model has been developed for prefabricated bridge projects, incorporating risk indices obtained from the assessment of the four distinct CRGs. The primary goal for developing this model is to enhance the facilitation of a comprehensive risk assessment [31]. Chen et al. (2019) proposed the utilization of a linear additive equation as a suitable approach for developing a risk assessment model. This decision is based on its inherent simplicity and comprehensibility [31]. Notably, previous research efforts, as shown in Wuni et al. 2022a) and

Chen et al. [188], have effectively utilized the linear additive methodology in the development of risk index models. Hence, taking into account the proven efficacy shown in prior investigations, this study likewise adopts the utilization of a linear additive equation for the development of the risk assessment model. According to [155], the risk index for each CRG is standardized to ensure that their total sum is equal to one.

Hence, the risk indices associated with the four CRGs are subjected to a normalization process, as defined by equation (1). The risk indices for each CRG are as follows: CRG1 (3.67), CRG2 (3.68), CRG3 (3.64), and CRG4 (3.77). To illustrate, let us consider the computation of the normalized weighting for the risk index of CRG1:

$$W_{CRG1} = \frac{3.67}{3.67 + 3.68 + 3.64 + 3.77} = \frac{3.67}{14.75} = 0.249$$

In a similar manner, the computation of risk indices for CRG2, CRG3, and CRG4 involves the utilization of this approach, resulting in normalized weights of 0.249, 0.247, and 0.255 accordingly. The requirement stated in equation (1) is satisfied when the sum of the normalized weightings of the risk index for the four CRGs equals 1. Hence, the risk assessment index for prefabricated bridge constructions is denoted as:

$$\begin{aligned} RAI = & 0.249 \times (\textit{execution risks}) + 0.249 \times (\textit{material and logistics risks}) \\ & + 0.247 \times (\textit{stakeholders and supplier risk}) \\ & + 0.255 \times (\textit{economic and financial risks}) \end{aligned}$$

4.2. Discussion

4.2.1. Critical risk Groups

The summary findings, as depicted in **Table 10**, demonstrate the criticality of the four critical risk groups (CRGs) in terms of their probability and severity, risk levels and ranks, and the

overall risk level associated with prefabricated bridge projects in developing countries. The utilization of the FSE yields an overall risk score of 3.67, exhibiting a notable probability (3.710) and severity (3.639). Moreover, the findings indicate that both CRG4 and CRG2 exceed the determined overall risk level of 3.67 in relation to their individual risk scores. In contrast, CRG1 and CRG3 demonstrate risk indices that are lower than the overall risk score. The aforementioned findings indicate an increased level of risk associated with the execution of prefabricated bridge projects in developing countries. The implication is that there is a need for policymakers, investors, and other project stakeholders to adopt effective risk management techniques in the implementation of prefabricated bridge projects.

Table 10. Risk Index for CRGs and ORL of Prefabricated Bridge Projects

Critical risk groups (CRGs)	Probability		Severity		Overall risk level (ORL)		
	Index	Linguistic	Index	Linguistic	Index	Linguistic	Rank
Execution risk (CRG1)	3.697	High	3.636	High	3.667	High	3
Material and logistics risks (CRG2)	3.690	High	3.665	High	3.677	High	2
Stakeholders and suppliers' risks (CRG3)	3.691	High	3.590	High	3.640	High	4
Economic and financial risks (CRG4)	3.843	High	3.690	High	3.766	High	1
Overall risk level (ORL)	3.710	High	3.639	High	3.674	High	-

4.2.2. CRG1 – Execution risks

The Eigenvalue for this risk category is 5.99, accounting for approximately 28.525% of the overall variance in the risk factors associated with prefabricated bridge constructions (refer to **Table 8**). The aforementioned category comprises five out of the twenty-one CRFs, yielding an average probability score of 25.46 and an average severity score of 26.99 (refer to **Table 9**). Additionally, the normalized weighted score for the probability is 0.378, whereas the normalized weighting for severity is 0.388. This group is ranked 3rd among the CRGs, with an overall risk level of 3.667. It has a risk index value of 3.697 for the probability and 3.636 for severity, as indicated in **Table 10**. The term “Execution risks” encompasses the essential nature and characteristics of the specific risk factors that fall under this category, as they are inherently linked to the execution stage of prefabricated bridge projects. Luo et al. [147] identified some critical risk factors (CRF) in offsite construction in China, including limited expertise and experience (RF28) as well as the contractors' lack of experience (RF9). Zhang et al. [78] emphasized that the lack of experienced contractors may lead to increased prices and reduced product quality in the context of prefabricated products. Offsite construction procedures possess unique methodologies, which encompass complex installation needs. These methodologies have the potential to challenge conventional paradigms of knowledge and skill within the contractor sector [133]. In order to achieve successful execution of prefabricated bridge projects, it is important to possess a comprehensive understanding and expertise in technical manufacturing abilities. Nevertheless, within the specific context of developing nations, the progress of prefabricated bridge initiatives is still at a nascent phase, leading to a dearth of crucial expertise and proficiency among construction contractors. Hence, the lack of knowledge among contractors poses a substantial risk element in this particular construction method. Pan et al. [189] highlighted the significant influence of cumulative expertise and specialized knowledge on achieving cost reductions in offsite building projects. Hence, it is

crucial to appropriately recognize and give priority to the collected experience and competence held by individuals engaged in prefabricated bridge projects, as this element plays a substantial role in the overall achievement of the project. Shahtaheri et al. [21] conducted a study in the field of offsite construction, wherein they identified dimensions and geometric intolerances (RF12) as a critical risk factor (CRF). The researchers emphasized that exceeding allowed limits of these tolerances can result in expensive rework, hence exacerbating the issues faced by the project. Furthermore, Wuni et al. [17] emphasized that the lack of relevant codes and adherence to existing standards and regulations (RF25) is a critical risk factor in modular integrated construction. The lack of codes presents a significant obstacle as it impedes the conformity to prescribed standards and guidelines, thus putting at risk the successful implementation of prefabricated bridge projects. The consequences of these risk factors have extensive implications, as they hinder the capacity of prefabricated bridge projects to conform to regional requirements for such construction endeavors. In order to effectively address these risks, it is crucial for governments and investors to have a thorough comprehension of the potential risks associated with the implementation of prefabricated bridge projects before commencing them. The adoption of a proactive strategy will empower stakeholders to make well-informed decisions and implement strategies that increase the probability of project success while mitigating potential setbacks.

4.2.3. CRG2 – Materials and logistics risks

The Eigenvalue for this risk group 2.459, which accounts for approximately 11.708 percent of the overall variance in the risk factors related to prefabricated bridge projects (**Table 8**). The aforementioned group is comprised of five out of the twenty-one CRFs, with an overall average score of 15.65 for probability and 21.34 for severity, as seen in **Table 9**. Additionally, the normalized weighting for its probability is 0.378, while the normalized weighting for its severity is 0.388. The category is ranked 2nd among the CRGs, with an overall risk level of

3.667. This risk level is determined by a risk index value of 3.690 for the probability and 3.665 for severity, as indicated in **Table 10**. The phrase “materials and logistics risks” encompasses the collective impact of the risk factors associated with both materials and logistics, contributing to the total risk profile. Blismas et al. [109] posited that the application of offsite construction methods in construction projects has the potential to decrease construction time and mitigate delays. However, Hsu et al. [118] have emphasized that delays in the transportation of components to the construction site (RF4) are among the factors that could undermine this advantageous outcome. According to Wuni et al. [17], one of the primary risk factors in the implementation of modular integrated construction is the occurrence of delays in the transportation of components to the designated jobsite. Delays in the delivery of components occurs from transportation congestion [118], severe weather conditions [114], inadequate scheduling and planning [139], prefabrication manufacturing failure [132]. Moreover, the presence of restricted storage capacity can result in potential delays in the implementation of prefabricated construction methods. For example, in the event that prefabricated components are delivered to the construction site but are unable to be adequately kept, there is a potential for disruption to the construction timetable. According to Zhang et al. [78] insufficiency of storage space at a construction site can lead to delays caused by congestion and inefficient material flow. According to a study conducted by Jaillon and Poon [104], it was found that in highly populated urban areas, the average proportion of space allocated for storing prefabricated components was around 22% of the standard floor area. The employment of precast parts, namely precast columns, might be severely impeded in situations when projects are constrained by limited site area [104]. Given the aforementioned issues, the utilization of Building Information Modeling (BIM) in conjunction with just-in-time management presents itself as a practical approach to effectively tackle these logistical limitations [78].

4.2.4. CRG3 – Stakeholders and suppliers risks

This critical risk group has an Eigenvalue of 2.092, accounting for approximately 9.963% of the overall variance in the risk factors associated with prefabricated bridge projects (refer to **Table 7**). This group comprises five out of the 21 CRFs, with probability score of 17.11 and a severity score of 21.72, as shown in **Table 8**. Additionally, the normalized weighting for both probability and severity are 0.254 and 0.240 respectively. This category is ranked 4th among the CRGs, exhibiting an overall risk level of 3.640. It has risk index values of 3.691 and 3.590 for probability and severity respectively (refer to **Table 9**). Based on the attributes of the five CRFs under this CRG, the nomenclature “Stakeholders and Suppliers Risks” is deemed appropriate for the risk factors in relation to stakeholders and suppliers. Wuni et al. [17] conducted an extensive review of the critical risk factors (CRFs) associated with modular integrated construction and identified inadequate supply chain integration and poor collaboration and communication among project stakeholders as prominent CRFs within the realm of modular integrated construction projects. Poor supply chain integration can give rise to notable risks in prefabricated bridge projects. Inadequate coordination or integration among various entities within the supply chain, including material suppliers, manufacturers, and transportation providers, can lead to a range of negative consequences such as delays, escalated expenses, and compromised product quality. Wang et al. [114] observed that inadequate supply chain integration within the context of prefabricated construction can result in several negative consequences, including communication gaps, disruptions in material delivery, and the potential for project schedule and cost performance to be compromised. According to Luo et al. [130] inadequate collaboration and communication among project stakeholders pose a substantial risk factor. Hence, this particular issue gains significant relevance as it has the potential to undermine the overall viability and attainment of the project's objectives. In instances where project stakeholders, encompassing designers, contractors, suppliers, and

subcontractors, exhibit inadequate collaboration and fail to efficiently exchange vital information, a multitude of issues may arise. Inadequate cooperation and communication have been identified by Ahmed et al. [190] as factors that can lead to misaligned goals, misunderstandings, and a delay in timely decision-making. The absence of communication might potentially lead to design inaccuracies, project approval delays, and disruptions in the manufacturing and delivery of prefabricated components. It can also hinder problem-solving and decision-making processes, leading to cost overruns and schedule delays [191]. Additionally, inadequate communication might hinder the effective coordination of tasks within the construction site, hence elevating the probability of accidents and safety problems.

In order to mitigate this potential risk, it is imperative for project stakeholders to develop unambiguous lines of communication, cultivate a collaborative culture, and employ project management tools and technology that enhance the exchange of information and promote effective decision-making among all project participants [30]. Enhancing cooperation and communication among project teams can effectively facilitate the rapid resolution of difficulties and ultimately assure the successful execution of prefabricated bridge projects.

4.2.5. CRG4 – Economic and financial risks

This risk category has an Eigenvalue of 1.707, which accounts for approximately 8.130 percent of the overall variance in the risk variables related to prefabricated bridge projects (refer to **Table 7**). This group comprises three out of the twenty-one CRFs, with a total mean score of 9.10 for probability and 12.43 for severity (refer to **Table 8**). Additionally, the normalized weightings for both probability and severity are 0.135 and 0.137 respectively. The analysis indicates that CRG4 "Economic and financial risks" is deemed to be the most critical among the other CRGs. It possesses an overall risk level of 3.766, with a risk index value of 3.843 for probability and 3.690 for severity, as presented in **Table 10**. The ranking of this CRG was not anticipated due to it having the fewest CRFs. Nevertheless, it does demonstrate that experts

recognize its significant influence on prefabricated bridge projects in developing countries. The category exhibiting the highest CRF is inflation, with a weight of 0.337. It is closely followed by inaccurate estimation, which has a weight of 0.335. Lastly, delayed payments have a weight of 0.327 (refer to **Table 7**). According to Musarat et al. [192], the escalation of inflationary pressures might result in amplified expenditures related to materials, labor, and equipment, hence exerting an influence on project budgets and timelines. Musarat et al. [193] asserted that the presence of inflationary pressures has the potential to diminish the purchasing power of project budgets, which may consequently lead to cost overruns and financial difficulties. During periods of high inflation, the overall cost of bridge construction can be impacted by the increased prices of vital components such as steel and concrete. Moreover, it is possible for labor expenses to escalate due to the upward pressure on wages resulting from the need to align with the rising cost of living. The escalation of costs associated with inflation can impose financial burdens on projects and potentially result in delays, should revisions to the budget and negotiations in procurement become necessary. Additionally, the presence of inaccurate cost estimation poses a significant risk in the context of prefabricated bridge construction. Inaccurate early cost estimates may result in budgetary deficits, financial burdens, and interruptions in the implementation of a project. According to a study conducted by Lee and Kim [105] it has been emphasized that the presence of faulty cost estimates might give rise to unanticipated financial difficulties, which may subsequently lead to project delays or necessitate the acquisition of supplementary funds. Consequently, the underestimation of project expenses might result in exceeding the allocated budget, so compelling project teams to pursue supplementary funding or make concessions in terms of project quality or scope. On the contrary, if costs are overestimated, it can result in the failure to identify potential cost-saving options, thereby impacting the project's overall competitiveness. The utilization of comprehensive cost estimation techniques by project stakeholders, taking into account

pertinent elements, and consistently revising estimates over the duration of the project lifecycle, holds significant importance.

4.3. Validation of Risk Assessment Model

The stage of the study entails an assessment of the reliability and robustness of the proposed prefabricated risk assessment model. To evaluate the reliability and consistency of the fuzzy risk assessment model for prefabricated bridge projects in developing countries, a carefully designed questionnaire was created. The questionnaire was based on the 21 critical risk factors (CRFs) and was then distributed to five experts who are associated with a construction company that has successfully completed multiple prefabricated bridge projects. Notably, the five experts have extensive experience of over ten years in the field of prefabricated bridge projects. Together, they have collectively applied their knowledge and skills to three shared prefabricated bridge projects. In order to ensure both clarity and confidentiality, these experts have been designated as A, B, C, D, and E, while the three specific projects under investigation are identified as X, Y, and Z. Within the group of specialists, Expert A occupied the role of Project Manager, experts B, C, and D occupied the positions of Engineers, and Expert E occupied the role of an Architect. Project X consists of a bridge span measuring 163 meters, while Projects Y and Z have lengths of 100 meters and 73 meters, respectively.

In contrast to previous research, the number of experts that participated was considered adequate to validate the proposed model. For example, the study conducted by Liu and Ling [177] uses one expert to validate a fuzzy system for mark-up estimations across three cases. In a similar vein, the study conducted by Arain and Pheng [178] involved the participation of four experts who were tasked with validating a knowledge-based decision support system specifically designed for the effective administration of variation orders in the context of institutional building projects. In addition, Liao et al. [194] engaged the participation of five experts in their research, who collectively provided their expertise in five separate situations,

in order to validate a model that specifically evaluates the readiness of Building Information Modeling (BIM) implementation.

In order to initiate the evaluation process, the experts were initially assigned the responsibility of assessing the overall level of risk for each of the three projects, employing a five-point scale (ranging from 1, denoting a very low risk, to 5, indicating a very high risk). It is imperative to emphasize that the assessments were carried out independently by each expert, and their individual evaluations for Projects X, Y, and Z were duly documented. The resulting mean ratings for these projects were found to be 3.60, 4.00, and 4.20, corresponding to Projects X, Y, and Z, respectively.

Subsequently, each of the experts was provided with three questionnaires, each comprising the 21 CRFs, and were tasked with assessing the probability and severity of each risk factor. This assessment was executed using a five-point grading system (where 1 signifies very low, 2 represents low, 3 denotes moderate, 4 implies high, and 5 corresponds to very high), with specific regard to Projects X, Y, and Z.

Table 8 provides a concise presentation of the summative outcomes regarding the overall risk levels for Projects X, Y, and Z. These results have been obtained through the utilization of the proposed model. The evaluation of the model's precision and dependability is conducted by calculating error percentages (PE), mean error percentages (MPE), and absolute mean error percentages (MAPE). The utilization of this particular methodology has been previously adopted within the field of construction management in order to validate the precision of constructed models, as demonstrated by prior research conducted [177, 178, 194]. Thus, following the precedents of previous studies, the MAPE is very appropriate for this study. The formulas are shown below.

$$Error = E_e - E_m \quad (6)$$

$$PE = (E_e - E_m) \times 100 \quad (7)$$

$$MPE = \sum_{i=1}^n PE/n \quad (8)$$

$$MAPE = \sum_{i=1}^n |PE_i|/n$$

Where:

E_e is the expert estimate of the overall risk level, E_m is the model estimate of the overall risk level, PE is the percentage error, and MAPE is the absolute percentage error.

To illustrate the computational process, consider project X. The weightings for each of the CRFs and CRGs are derived from the overall risk assessment of prefabricated bridge projects by the experts from the general survey. The membership functions for the CRFs and CRGs are computed based on the responses of the five experts for project X.

For example, the findings from the survey regarding the likelihood of RF9, which pertains to the "lack of experience of the contractor in prefabrication," indicate that 3% of respondents evaluated it as very low, 10.0% as low, 17% as moderate, 33% as high, and 37% as very high. Consequently, the membership function for the probability of RF9 is calculated using eq. (3) and is given by (0.03, 0.10, 0.17, 0.33, 0.37). Similarly, the same approach is used in computing the MFs for the remaining CRFs for both probability and severity as shown in Table 11.

The MFs for project X for the CRGs are computed using equation (4) and (5). For example, consider CRG2. The probability MF is computed as:

$$R_{CRG2(px)} = \begin{bmatrix} MF_{CRG2_{RF15}} \\ MF_{CRG2_{RF13}} \\ MF_{CRG2_{RF4}} \\ MF_{CRG2_{RF27}} \\ MF_{CRG2_{RF22}} \end{bmatrix} = \begin{bmatrix} 0.01 & 0.13 & 0.16 & 0.33 & 0.37 \\ 0.05 & 0.12 & 0.15 & 0.25 & 0.44 \\ 0.06 & 0.13 & 0.15 & 0.35 & 0.32 \\ 0.04 & 0.13 & 0.16 & 0.30 & 0.38 \\ 0.12 & 0.12 & 0.17 & 0.32 & 0.28 \end{bmatrix}$$

Thus, using equation (5), the fuzzy evaluation matrix for CRG2 is computed as follows:

$$D_{CRG2(p)} = W_{CRG2(p)} \bullet R_{CRG2(p)} = (0.203, 0.206, 0.196, 0.200, 0.195) \times \begin{bmatrix} 0.01 & 0.13 & 0.16 & 0.33 & 0.37 \\ 0.05 & 0.12 & 0.15 & 0.25 & 0.44 \\ 0.06 & 0.13 & 0.15 & 0.35 & 0.32 \\ 0.04 & 0.13 & 0.16 & 0.30 & 0.38 \\ 0.12 & 0.12 & 0.17 & 0.32 & 0.28 \end{bmatrix}$$

$$= (0.03, 0.13, 0.17, 0.32, 0.36)$$

Using similar approach, the MFs for project X for the remaining CRGs for both probability and severity are computed as shown in Table 11.

The final overall fuzzy evaluation matrix for both probability (D_p) and severity D_s for project X is determined by using equation (5) as follows:

$$D_{overall(p)} = \begin{bmatrix} 0.378 \\ 0.233 \\ 0.254 \\ 0.135 \end{bmatrix} \times \begin{bmatrix} 0.03 & 0.13 & 0.17 & 0.32 & 0.36 \\ 0.03 & 0.12 & 0.16 & 0.32 & 0.37 \\ 0.05 & 0.12 & 0.15 & 0.30 & 0.35 \\ 0.07 & 0.14 & 0.18 & 0.31 & 0.37 \end{bmatrix} = (0.04, 0.13, 0.16, 0.31, 0.37)$$

$$D_{overall(s)} = \begin{bmatrix} 0.387 \\ 0.236 \\ 0.240 \\ 0.137 \end{bmatrix} \times \begin{bmatrix} 0.04 & 0.08 & 0.12 & 0.38 & 0.42 \\ 0.03 & 0.07 & 0.09 & 0.36 & 0.40 \\ 0.05 & 0.06 & 0.11 & 0.37 & 0.41 \\ 0.03 & 0.07 & 0.10 & 0.36 & 0.40 \end{bmatrix} = (0.04, 0.07, 0.11, 0.37, 0.41)$$

Table 11. Membership Functions for CRFs and CRGs for Project X

MF for all CRFs and CRGs for prefabricated bridge projects in developing countries (risk severity)							
S/N	Risk Factors	weights	MF for each CRF	MF for each CRG	weights	MF for each CRF	MF for each CRG
CRG1	Execution risks	0.378		(0.03, 0.13, 0.17, 0.32, 0.36)		0.387	(0.04, 0.08, 0.12, 0.38, 0.42)
RF9	Lack of experience of contractor in prefabrication	0.135	(0.03, 0.10, 0.17, 0.33, 0.38)		0.130	(0.04, 0.08, 0.13, 0.38, 0.38)	
RF21	Poor management practices	0.115	(0.03, 0.12, 0.17, 0.33, 0.35)		0.120	(0.03, 0.08, 0.12, 0.38, 0.43)	
RF28	Limited expertise and experience in prefabrication construction	0.126	(0.02, 0.13, 0.20, 0.29, 0.36)		0.130	(0.04, 0.08, 0.13, 0.38, 0.42)	
RF24	Lack of Skilled labor	0.127	(0.03, 0.14, 0.12, 0.32, 0.40)		0.132	(0.04, 0.09, 0.12, 0.38, 0.42)	
RF12	Geometric and dimensional intolerances	0.123	(0.03, 0.14, 0.18, 0.28, 0.37)		0.124	(0.04, 0.08, 0.12, 0.38, 0.41)	
RF25	Lack of relevant codes, or compliance to standards, and construction regulations	0.125	(0.02, 0.14, 0.22, 0.31, 0.32)		0.106	(0.04, 0.07, 0.09, 0.38, 0.42)	
RF7	Defective design and change order	0.117	(0.02, 0.14, 0.13, 0.34, 0.37)		0.120	(0.04, 0.06, 0.10, 0.38, 0.42)	
RF6	Error in the installation of precast component, complex rectification, and rework	0.134	(0.03, 0.13, 0.18, 0.33, 0.33)		0.138	(0.01, 0.07, 0.13, 0.36, 0.43)	
CRG2	Material and logistics risks	0.233		(0.03, 0.12, 0.16, 0.32, 0.37)		0.236	(0.03, 0.07, 0.09, 0.36, 0.40)

MF for all CRFs and CRGs for prefabricated bridge projects in developing countries (risk severity)							
S/N	Risk Factors	weights	MF for each CRF	MF for each CRG	weights	MF for each CRF	MF for each CRG
RF15	Failure of production components and equipment	0.203	(0.03, 0.13, 0.17, 0.33, 0.36)		0.214	(0.03, 0.08, 0.09, 0.36, 0.45)	
RF13	Shortage of precast/prefabricated components	0.206	(0.03, 0.13, 0.16, 0.32, 0.37)		0.217	(0.03, 0.08, 0.09, 0.36, 0.44)	
RF4	Delays in the delivery of materials and components	0.196	(0.03, 0.12, 0.16, 0.32, 0.38)		0.208	(0.03, 0.07, 0.10, 0.36, 0.45)	
RF27	Limited site storage space	0.200	(0.03, 0.13, 0.16, 0.32, 0.36)		0.185	(0.03, 0.07, 0.08, 0.36, 0.48)	
RF22	Delay in permits and approval	0.195	(0.03, 0.12, 0.16, 0.32, 0.38)		0.176	(0.06, 0.07, 0.11, 0.37, 0.40)	
CRG3	Stakeholder and supplier risks	0.254		(0.05, 0.12, 0.15, 0.30, 0.35)	0.240		(0.05, 0.06, 0.11, 0.37, 0.41)
RF14	Disputes and contractual problems	0.161	(0.01, 0.13, 0.16, 0.33, 0.37)		0.187	(0.12, 0.17, 0.20, 0.28, 0.23)	
RF2	Supplier financial instability	0.192	(0.05, 0.12, 0.15, 0.25, 0.44)		0.194	(0.10, 0.05, 0.20, 0.35, 0.30)	
RF5	Poor information sharing between stakeholders	0.217	(0.06, 0.13, 0.15, 0.35, 0.32)		0.176	(0.03, 0.05, 0.30, 0.45, 0.17)	
RF3	Poor supply chain integration	0.224	(0.04, 0.13, 0.16, 0.30, 0.38)		0.227	(0.03, 0.07, 0.25, 0.35, 0.30)	
RF1	Inadequate supplier capacity	0.206	(0.12, 0.12, 0.17, 0.32, 0.28)		0.215	(0.03, 0.12, 0.37, 0.38, 0.10)	
CRG4	Economic and financial risks	0.135		(0.07, 0.14, 0.18, 0.31, 0.37)	0.137		(0.03, 0.07, 0.10, 0.36, 0.40)

MF for all CRFs and CRGs for prefabricated bridge projects in developing countries (risk severity)							
S/N	Risk Factors	weights	MF for each CRF	MF for each CRG	weights	MF for each CRF	MF for each CRG
RF18	Inflation	0.337	(0.06, 0.14, 0.16, 0.30, 0.35)		0.339	(0.03, 0.07, 0.10, 0.38, 0.42)	
RF20	Delayed payment	0.327	(0.07, 0.14, 0.18, 0.30, 0.42)		0.332	(0.03, 0.07, 0.10, 0.35, 0.45)	
RF11	Inaccurate cost estimation	0.335	(0.08, 0.14, 0.20, 0.32, 0.33)		0.329	(0.03, 0.08, 0.10, 0.36, 0.44)	

Now, the overall risk index for project X is computed using equation (6):

Overall risk level

$$= \sqrt{\{(0.04, 0.13, 0.16, 0.31, 0.37) \times (1, 2, 3, 4, 5)\} \times (0.04, 0.07, 0.11, 0.37, 0.41) \times (1, 2, 3, 4, 5)}$$

$$= \sqrt{(3.819 \times 4.044)} = 3.930$$

Using the approach illustrated above, the overall risk level for project Y and Project Z are computed as shown in Table 12.

Table 12. Results of the Case study Projects by the FSE Model

	Average overall risk level	Overall risk level		Percentage
Projects	estimated by the experts (Ee)	of the model (Em)	Error	error (PE)
X	3.600	3.930	-0.327	-9.083
Y	4.000	3.559	0.441	11.025
Z	4.200	3.563	0.637	15.167
MPE	-	-		5.703
MAPE	-	-		11.758

The results for the comprehensive risk evaluation of three prefabricated bridge projects, obtained using the fuzzy risk model, are outlined as follows: 3.930, 3.559, and 3.563, respectively (refer to **Table 12**). In comparison to the mean overall risk levels established by domain experts, it is noteworthy that the percentage error (PE) are as follows: -9.083%, 11.025%, and 15.167%. It is imperative to emphasize that Li et al. [177] have suggested the adoption of the Mean Absolute Percentage Error (MAPE) as a metric for assessing the magnitude of model inaccuracies. In the context of our ongoing study, the Mean Absolute

Percentage Error (MAPE) figures for the three projects yielded an average of 11.758%. This outcome indicates a noteworthy degree of precision in the assessment process. Previous research endeavors, such as the work conducted by Ling et al. [182], wherein mathematical models were devised for the prediction of corporate competitiveness. These models resulted in mean absolute percentage error (MAPE) values of 14.40% and 22.20%. In addition, it is important to mention that [180] and Fayek and Sun [181] have asserted that a fuzzy expert system can be considered dependable if the difference between the defuzzified value and the true value is 33% or less. Furthermore, the scholarly work conducted by [183] made a significant contribution to the existing literature by presenting a knowledge-based decision support system designed to assess the overall risk management maturity of Chinese construction firms engaged in international operations. The study yielded a Mean Absolute Percentage Error (MAPE) value of 10.40%. Based on the comparison analysis conducted, it becomes apparent that the fuzzy risk assessment model utilized in our study involving prefabricated bridge constructions demonstrates qualities of comprehensives, reliability, and validity. As a result, the model presents itself as a reliable and valid tool for assessing the risk variables associated with prefabricated bridge projects in developing countries.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

In recent decades, a considerable amount of research has been carried out with the aim of identifying risk factors and developing risk assessment models that are relevant to offsite construction methods, including prefabrication and modular integrated construction. The central emphasis of these studies has primarily centered on housing projects. Similarly, scholarly investigations have been undertaken to develop risk assessment models for cast in-situ bridge construction projects. However, there is a clear lack of study in the field of developing a comprehensive, reliable, and practical risk assessment model that is specifically designed for prefabricated bridge construction projects. The aforementioned lacuna is further intensified by the inherent distinct risks and processes associated with this method of construction. Therefore, the lack of a risk assessment methodology has significant ramifications for projects, since stakeholders and contractors may lack essential knowledge about the key risk factors that could possibly undermine the successful implementation of these projects. Moreover, the absence of such a model increases the vulnerability of contractors to engaging in high-risk projects.

The primary aim of this research project is to develop a comprehensive, reliable, and practically feasible risk assessment model for prefabricated bridge construction projects specifically tailored for implementation in developing nations. The proposed model will be constructed using a fuzzy synthetic evaluation technique. In order to achieve this goal, a set of four research objectives were outlined:

- i. To identify the risks associated with prefabricated bridge projects in developing countries.

- ii. To identify the risk factors that are critical in the implementation of prefabricated bridge construction projects in developing countries.
- iii. To evaluate the Critical Risk Factors and to Develop a Risk Assessment Model for Prefabricated Bridge Construction Projects in Developing Countries.
- iv. To validate the proposed risk assessment model that will ensure its practical applicability and reliability within the context of prefabricated bridge construction projects in developing countries.

5.2. Review of Research Objectives

5.2.1. Objective 1: Identification of risk factors

To determine the risk factors associated with prefabricated bridge construction projects in developing countries, a two-step approach was undertaken for risk identification. The first stage of the risk identification process involved a thorough examination of relevant literature and content analysis. The Scopus database was utilized as the primary source for accessing academic papers relevant to this research. A Title-Abs-Key search strategy was implemented, using set of specified keywords: such as "risks," "barriers," and "uncertainties," as well as terms related to various construction methods such as "Prefabrication," "offsite construction," "off-site construction," "offsite manufacturing," "off-site manufacturing," "precast," "pre-cast," "prefabricated," "prefab," "pre-fab," "modular construction," "modular integrated construction," "MIC," "industrial construction," and "precast construction," among others. In order to effectively handle the quantity of retrieved publications, specific exclusion criteria were implemented. Subsequently, an evaluation was conducted using content analysis techniques, resulting in the identification of a total of 43 risk factors.

The next step in the process of identifying risk factors entailed conducting semi-structured interviews with 10 industry professionals who have significant experience and expertise in the field of prefabricated bridge construction projects in Sierra Leone. The experts were tasked with assessing the applicability of the 43 identified risk factors in the specific context of Sierra Leone. Furthermore, participants were prompted to include any relevant risk factors that they believed were relevant but had not been included in the initial stage. As a result, two additional risk factors were integrated, whereas sixteen pre-existing risk factors were considered irrelevant in the specific context of Sierra Leone and thus eliminated from the list of identified risk factors.

The experts confirmed a total of 29 risk factors associated with prefabricated bridge construction projects in Sierra Leone, as depicted in Table 4, as a consequence of this two-step procedure.

5.2.2. Objective 2: Identification of the CRFs in prefabricated bridge Projects.

After identifying relevant risk factors specific to the Sierra Leone setting, a questionnaire survey was designed and subsequently distributed to experts in prefabricated bridge construction projects. The aforementioned method followed pre-established criteria for the inclusion of participants. Following that, the mean scores obtained from participants' evaluations of the probability and severity of these potential risks were computed using SPSS version 27.

As a result, a risk impact score was calculated for each risk factor by taking the square root of the mean scores for both probability and severity. The impact scores of these derived risk factors were subsequently submitted to a normalizing technique. Risk factors that have a normalized value of 0.5 or above were categorized as critical. The results of the normalization procedure indicated that out of the 29 risk factors evaluated, 21 were classified as critical which

requires further assessment. Hence, it is crucial for decision-makers and contractors to allocate considerable attention to these critical risk factors in order to guarantee the successful and streamlined execution of their projects.

5.2.3. Objective 3: Evaluation of CRFs

After the identification of the critical risk factors, the next step involved the theoretical categorization of these 21 critical risk factors into four critical risk groups. These groups were labeled as CRG1 -Execution Risks, CRG2 - Materials and Logistics Risks, CRG3 - Stakeholders and Suppliers' Risks, and CRG4 - Economic and Financial Risks through the use of factor analysis. The aforementioned risk categories were utilized as the principal input variables within the framework of a fuzzy risk assessment model. The fuzzy synthetic evaluation technique was then utilized to determine the overall level of risk associated with prefabricated bridge construction projects in developing countries. The objective of this procedure was also to assess the degree of criticality associated with each of the aforementioned risk groupings.

The results of the fuzzy synthetic evaluation revealed a significant degree of risk associated with prefabricated bridge constructions in Sierra Leone, with a quantified risk level of 3.674. This value represents a high degree of risk exposure, which has ramifications for both governmental entities and contractors involved in such projects. Furthermore, the study revealed the relative criticality of the various risk groups. CRG4 - Economic and Financial Risks, emerged as the foremost concern, occupying the highest position with a criticality score of 3.766. CRG2 - Materials and Logistics Risks, secured the second position as indicated by its criticality score of 3.677. Notably, CRG1- Execution Risks, obtained the third position with a criticality score of 3.667, while CRG3 - Stakeholders and Suppliers' Risks, took the fourth position with a criticality value of 3.640. The present compilation of findings highlights the

significant influence exerted by each of the critical risk groups on prefabricated bridge projects in developing nations.

A linear additive risk assessment model was developed in response to the aforementioned findings. This model incorporated the criticality index of each corresponding CRG as the coefficient for that specific group. It is crucial to highlight that this model not only enables the assessment of critical risk factors associated with prefabricated bridge projects, but also functions as a significant instrument for contractors aiming to evaluate and perhaps avoid high-risk projects with comparable attributes.

5.2.4. Objective 4: Validation of the proposed risk assessment model

In order to ascertain the effectiveness of the risk assessment model under consideration, a carefully constructed questionnaire survey was developed, with a specific emphasis on the 21 critical risk factors. The survey was subsequently distributed to a panel of five experts who collectively have extensive experience in three comparable prefabricated bridge projects conducted in Sierra Leone. The experts were assigned the responsibility of conducting two primary evaluations. The first evaluation involved assessing the overall levels of risk associated with three specific projects, namely A, B, and C. The second evaluation focused on evaluating the probability and severity of 21 major risk variables, utilizing a five-point Likert scale.

After being assessed by professionals, it was concluded that projects A, B, and C exhibited corresponding overall risk ratings of 3.60, 4.00, and 4.20. Following this, the suggested model utilized the expert evaluations of risk probability and severity for the 21 critical risk factors associated with the three projects. The model was then deployed to calculate the overall risk levels, resulting in values of 3.930, 3.559, and 3.563 for projects A, B, and C, respectively.

In order to assess the reliability of the model, the Mean Percentage Error (MPE) and the Mean Absolute Percentage Error were computed, yielding values of 5.703% and 11.758%

correspondingly. When compared to other research that have utilized the Mean Absolute Percentage Error (MAPE), these results demonstrated a significant level of accuracy. Therefore, it can be inferred that the model exhibits reliability and practical utility in evaluating risk factors associated with prefabricated bridge projects within the framework of developing countries.

5.3. Value and Significance of the Research

The present study represents a substantial scholarly contribution to the existing body of knowledge in the domain of construction management, specifically emphasizing the evaluation of risks in infrastructure projects in developing countries. This research holds a unique position as the first study to comprehensively explore risks in prefabricated bridge construction projects. Furthermore, it is the first study to specifically investigate risks in bridge construction projects in Sierra Leone. The findings of this study hold significant implications for decision-makers and contractors, not only within Sierra Leone but also in comparable settings. The study highlights significant implications for practical and managerial issues in the field of risk management, specifically focusing on the key phases of risk planning, risk identification, and risk assessment.

This study is notable for its comprehensive analysis and identification of critical risk factors associated with prefabricated bridge projects in developing nations. This study not only identifies and emphasizes the critical risk factors associated with these initiatives, but also provides a detailed risk checklist specifically designed for such endeavors. This checklist can be efficiently utilized for risk management purposes in future projects. Equipped with this foundational knowledge, project stakeholders can be more adept at allocating resources, such as personnel and financial assets, in a manner that maximizes the likelihood of achieving effective project execution. This methodology facilitates a systematic and rigorous project

planning procedure, tailored resource allocation, and improved project management tactics, ultimately guaranteeing a more resilient approach to project implementation.

The integration of a fuzzy risk assessment model into the study's framework functions as a flexible tool that has significant value in the peer-review process. Contractors, specifically, have the potential to gain substantial advantages from this model. It allows them to evaluate the overall levels of risk associated with various prefabricated bridge projects, hence simplifying informed decision-making in terms of resource allocation, task prioritization, and project selection. During the tender phase, the utilization of the model assists contractors in assessing the viability of submitting a bid for a project, while considering the numerous risk factors that are associated with it. Government institutions have the opportunity to utilize this framework in a similar manner, allowing them to methodically evaluate the overall risk levels of projects in their portfolios. This will enable them to make well-informed decisions, taking into account the availability of resources and the level of risk involved. The main objective of this model is to enhance project selection by offering a thorough comprehension of inherent uncertainties, hence strengthening the overall risk management framework and fortifying project resilience.

Moreover, the study enhances the capacity of project stakeholders, such as governmental entities, contractors, and financiers, by equipping them with the tools to assess their capacity in efficiently handling these risks. With this understanding, stakeholders are able to formulate risk mitigation plans that are more informed about the particular challenges that they may face. This contributes to the development of a stronger risk management framework and enhances the overall resilience of the project. This study fundamentally facilitates proactive risk management, enhancing the capacities of stakeholders to effectively negotiate the intricacies associated with developing nation environments.

One noteworthy characteristic of this study is its recognition as the initial empirical examination of multi-attribute objective risk assessment with a specific emphasis on prefabricated bridge constructions. Although its origins lie within the specific setting of Sierra Leone, the ramifications of this phenomenon have far-reaching effects that encompass a wider range of developing nations. The development of a comprehensive register consisting of 29 risk factors, along with the identification of 21 Critical Risk Factors (CRFs) based on input from industry professionals, establishes a universally applicable framework. This framework can be utilized as a dependable and practical list of factors for the formulation of risk management guidelines in various developing country settings. This highlights the significance of embracing a comprehensive approach to risk management, recognizing that issues considered less serious in Sierra Leone may possess critical importance in other developing countries. This highlights the need of adaptation in the process of evaluating risks and the need for customized risk management approaches in different contexts.

In conclusion, this study not only contributes to the knowledge of risk management in infrastructure projects in developing nations but also provides practical methodologies and frameworks that can be implemented in various comparable settings. This facilitates the adoption of more efficient risk management strategies, leading to improved project resilience and overall success.

5.4. Limitations

Similar to any research undertaking, it is important to acknowledge that the present study is not exempt from some limitations that should be considered by both decision-makers and readers. The questionnaire survey was limited by the availability of a restricted pool of industry experts who had experience in prefabricated bridge projects specifically within the setting of Sierra Leone. The primary cause of this limitation can be attributed to the scarcity of similar

initiatives inside the nation. As a result, the study opted to forgo the use of random sample methods and instead employed purposive sampling and semi-snowballing techniques.

The second and last constraint related to the study's exclusive concentration on prefabricated bridge projects within the geographical context of Sierra Leone. The generalizability of the study's findings to other worldwide contexts is unproven due to the distinct cultural, socio-economic, geographical, legal, and regulatory factors present in this specific region. When executing prefabricated bridge projects, it is important to consider the unique risk factors associated with each country. These risk factors should be incorporated into the existing risk assessment framework to ensure a comprehensive evaluation.

5.5. Recommendation for Future Research

The primary focus of this research work has been on the identification and assessment of risk factors that are associated with prefabricated bridge projects in Sierra Leone. The projected implications of the current study are expected to have practical and scholarly benefits. However, there remain opportunities for additional research within this field. It is recommended that researchers do more investigations to evaluate the long-lasting usefulness and dependability of prefabricated bridge initiatives, not just in Sierra Leone but also in other poor countries where this methodology is employed. It is imperative for such research to thoroughly investigate the extent to which the risk assessments put out by the model correspond with real project outcomes over a prolonged duration. Additionally, it is imperative to continue conducting research endeavors in order to enhance the compilation of risk variables that are unique to prefabricated bridge projects. It is vital to regularly examine and update the roster of risk factors in order to adapt to the evolving practices within the sector and the changing contextual situations. In conclusion, it is highly recommended that researchers further extend the utilization of the fuzzy risk assessment model to other emerging nations that share

comparable construction environments. The purpose of this expansion is to evaluate the model's capacity to adapt and perform effectively in a variety of different contexts.

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APPENDIX A: PRELIMINARY STUDY



23rd February 2023.

Dear Sir/Madam,

Request to Participate in a Preliminary MSc. Research Titled “Developing a Risk Assessment Model for Prefabricated Bridge Projects in Developing Countries

I am writing to invite you to participate in a preliminary study for a research project titled "Developing a cost and schedule risk assessment model for prefabricated bridge construction projects in developing countries", which aims to identify relevant risk factors associated with prefabricated bridge construction projects in Sierra Leone.

As an industry expert, your input is invaluable in this research project, and we would greatly appreciate your participation. We believe that your experience and knowledge will provide us with valuable insights into the challenges and risks associated with prefabricated bridge construction projects in developing countries, particularly in Sierra Leone.

During the preliminary study, we will be shortlisting relevant risk factors that are associated with prefabricated bridge construction projects in the context of Sierra Leone. We also welcome your suggestions and additions to the list of factors that we have identified. Your input will help us develop a comprehensive risk assessment model that will be useful for stakeholders involved in prefabricated bridge construction projects in developing countries.

Your contribution to this research project is crucial to its success, and we believe that your expertise and insights will be beneficial in developing a comprehensive risk assessment model. We are confident that with your input, we can develop a model that accurately reflects the risks associated with prefabricated bridge construction projects in Sierra Leone.

Thank you for your time and consideration, and we look forward to your participation in this project.

Sincerely,

Francis Sesay

MSc Student

Department of Construction Engineering & Management

King Fahd University of Petroleum & Minerals

Guidelines

1. Please complete the survey and save.
2. Submit the completed questionnaire via email to gxxx1xxxxx@kfupm.edu.sa or WhatsApp to +966-xxx-xxxx.

Questionnaire Outline

Section A: Background Information

This section solicits background information on you (All fields are not mandatory).

Section B requests you to assess the relevance of each risk factor on a scale of 1 to 5 (1= not relevant at all, 5= extremely relevant).

Section C: Additional risk factors

This section solicits you to add any other risk factor that is applicable to prefabricated bridge construction projects in S/L that is not initially captured.

Section A: General Background Information on the Respondent Expert

1. Which role(s) best applies to your current in the implementation of prefabricated bridge projects:

Client ☐ Consultant ☐ Contractor ☐ Supplier ☐
2. What is your highest level of education? Choose from the dropdown. If it is not listed, please specify. Choose an item.
3. 3. Which position do you hold with your company or institution? Choose from the dropdown. If it is not listed, please specify. Choose an item.
4. Have you participated in the Prefabricated bridge construction Project? Choose an item. If yes, how many? Choose from the dropdown. If it is not listed, please specify. Choose an item.
5. How many years of practice have you had on prefabricated bridge construction projects? Choose an item.
6. Name of the most recent prefabrication project you have worked on: Click or tap here to enter text.

Section B: Risk Factor Relevance in Prefabricated Bridge Projects in S/L

Please rate the relevance of each checked risk factor in the implementation of prefabricated bridge construction projects on a scale of 1 to 5. The numerical scale used is as follows: **1 represents not relevant, 2 represents slightly relevant, 3 represents moderately relevant, 4 represents highly relevant, and 5 represents extremely relevant.**

ID	Risk Factors	Degree of relevance				
		1	2	3	4	5
RF1	Inadequate supplier capacity	☐	☐	☐	☐	☐
RF2	Supplier financial instability	☐	☐	☐	☐	☐
RF3	Poor supply chain integration	☐	☐	☐	☐	☐
RF4	Delay in delivery of materials and components	☐	☐	☐	☐	☐
RF5	Limited capacity/height of crane	☐	☐	☐	☐	☐
RF6	Limited site storage space	☐	☐	☐	☐	☐
RF7	Poor information sharing between stakeholders	☐	☐	☐	☐	☐
RF8	Complexity of design	☐	☐	☐	☐	☐
RF9	Error in the design and installation of precast component, complex rectification, and rework	☐	☐	☐	☐	☐
RF10	Defective design and change order	☐	☐	☐	☐	☐
RF11	Crane breakdown and malfunctioning	☐	☐	☐	☐	☐
RF12	Slow quality inspection procedure	☐	☐	☐	☐	☐
RF13	Misplacement of components during storage	☐	☐	☐	☐	☐
RF14	Limited expertise and experience in prefabrication	☐	☐	☐	☐	☐
RF15	Lack of experience of contractor in prefabrication	☐	☐	☐	☐	☐

RF16	Failure of Production system and equipment	☐	☐	☐	☐	☐
RF17	Weather disruptions and force majeure	☐	☐	☐	☐	☐
RF18	Transportation restriction	☐	☐	☐	☐	☐
RF19	Inaccurate cost estimation	☐	☐	☐	☐	☐
RF20	Late freezing of design and specification	☐	☐	☐	☐	☐
RF21	Long distance of site from factory	☐	☐	☐	☐	☐
RF22	Poor control of working flows	☐	☐	☐	☐	☐
RF23	Lack of compatibility of prefabricated components	☐	☐	☐	☐	☐
RF24	Lack of specialized equipment	☐	☐	☐	☐	☐
RF25	Poor planning of resources and schedule	☐	☐	☐	☐	☐
RF26	Political and social instability	☐	☐	☐	☐	☐
RF27	Stakeholder fragmentation	☐	☐	☐	☐	☐
RF28	Unavailability of raw materials and components	☐	☐	☐	☐	☐
RF29	Poor quality of materials	☐	☐	☐	☐	☐
RF30	Limited capacity and capability of the facility	☐	☐	☐	☐	☐
RF31	Lack of coordination of deliveries and installation	☐	☐	☐	☐	☐
RF32	Damage of prefabricated components	☐	☐	☐	☐	☐
RF33	Disputes and contractual problems	☐	☐	☐	☐	☐
RF34	Delayed payment	☐	☐	☐	☐	☐
RF35	Poor road condition	☐	☐	☐	☐	☐
RF36	Poor management practices	☐	☐	☐	☐	☐
RF37	Delay in obtaining permits and approval	☐	☐	☐	☐	☐
RF38	Lack of skilled labor	☐	☐	☐	☐	☐

RF39	Lack of relevant codes, or compliance to standards, and construction regulations	☐	☐	☐	☐	☐
RF40	Fall from height	☐	☐	☐	☐	☐
RF41	Geometric and dimensional intolerances	☐	☐	☐	☐	☐
RF42	Inflation	☐	☐	☐	☐	☐
RF43	Constructability issues	☐	☐	☐	☐	☐

APPENDIX B: QUESTIONNAIRE SURVEY

Questionnaire Guidelines

1. Kindly Provide responses that reflect your true thoughts and experiences.
2. Kindly submit the filled questionnaire at your earliest convenient time by the 30th of April 2023.
3. Kindly Send the filled questionnaire to the email g202113010@kfupm.edu.sa or via WhatsApp to the number +966-57-163-1621
4. Kindly provide a response for every question in the questionnaire if your response in Q1 in Part 1 is yes.

Questionnaire Outline

1. Part 1: Background Information

This section will ask for some basic information about the respondents. All questions in this section are **MANDATORY**.

2. Part 2: Risk Factors

The second part of the questionnaire will focus on the risk factors. Respondents will be asked to evaluate each risk factor on two dimensions: probability and severity. Probability refers to the likelihood that a risk event will occur, and severity refers to the extent of damage of the risk event on the project objectives. Respondents will be asked to rate each risk factor on a 5-point Likert scale, with **1 indicating "Very Low" 2 is "low", 3 is "moderate" 4 is "high", and 5 indicating "Very High"**.

PART 1: BACKGROUND INFORMATION

1. Have you worked on prefabricated bridge construction projects before? Choose an item.
2. If your answer to Q1 is Yes, how many years of experience do you have in prefabricated bridge construction projects? Choose an item. Click or tap here to enter text.

3. How many years of experience do you have in the construction industry? Choose an item. Click or tap here to enter text.
4. Which role(s) best applies to your company/organization in the implementation of prefabricated bridge projects? If it is not listed in the dropdown, please specify. Choose an item. Click or tap here to enter text.
5. What is your role in the prefabricated bridge construction project? If it is not listed in the dropdown, please specify. Choose an item. Click or tap here to enter text.
6. 6. What is the average size range of prefabricated bridge construction projects you have worked on, for e.g., spans of 200 meters, etc.? Click or tap here to enter text.
7. Which part (s) of the bridge do you construct using precast method? Multiple choice is permitted). (a). Girders ☐, (b). Deck panels ☐, (c). Piers and Abutment ☐, (d). Parapet and barriers ☐, (e). Others (Please indicate) Click or tap here to enter text.

PART 2: RISK FACTORS

Kindly assess the likelihood and severity of the following risk factors on prefabricated bridge projects, using a rating scale of 1 to 5, where 1 denotes a very low probability or severity, 2 denotes a low probability or severity, 3 denotes a moderate probability or severity, 4 denotes a high probability or severity, and 5 denotes a very high probability or severity.

ID	Risk Factor	Grading Scale									
		Probability					Severity				
RF1	Inadequate supplier capacity	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF2	Supplier financial instability	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF3	Poor supply chain integration	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF4	Delays in the delivery of materials and components	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF5	Poor information sharing between stakeholders	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF6	Error in the installation of precast component, complex rectification, and rework	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF7	Defective design and change order	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF8	Fall from height	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF9	Lack of experience of contractor in prefabrication	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF10	Unavailability of raw materials	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF11	Inaccurate cost estimation	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF12	Geometric and dimensional intolerances	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□

ID	Risk Factor	Grading Scale									
		Probability					Severity				
RF13	Shortage of precast/prefabricated components	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF14	Disputes and contractual problems	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF15	Failure of Production component system and equipment	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF16	Constructability issues	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF17	Manual handling of heavy precast/prefabricated components	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF18	Inflation	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF19	Political and social instability	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF20	Delayed payment	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF21	Poor management practices	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF22	Delay in permits and approval	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF23	Weather disruptions and force majeure	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF24	Lack of Skilled labor	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□

ID	Risk Factor	Grading Scale									
		Probability					Severity				
RF25	Lack of relevant codes, or compliance to standards, and construction regulations	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF26	Poor planning of resources and schedule	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF27	Limited site storage space	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF28	Limited expertise and experience in prefabrication construction	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF29	Misplacement of components during storage	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□

APPENDIX C: VALIDATION QUESTIONNAIRE

Questionnaire Guidelines

- i. Kindly Provide responses that reflect your true thoughts and experiences on a specific project.
- ii. Kindly submit the filled questionnaire at your earliest convenient time by the 10th of May 2023.
- iii. Kindly Send the filled questionnaire to the email g202113010@kfupm.edu.sa or via WhatsApp to the number +966-57-163-1621

Questionnaire Outline

Part 1: Background Information

This section will ask for some basic information about the respondents. All questions in this section are **MANDATORY**.

Part 2: Risk Factors

The second part of the questionnaire will focus on the risk factors. Respondents will be asked to evaluate each risk factor on two dimensions: probability and severity. Probability refers to the likelihood that a risk event will occur, and severity refers to the extent of damage of the risk event on the project objectives. Respondents will be asked to rate each risk factor on a 5-point Likert scale, with **1 indicating "Very Low" 2 is "low", 3 is "moderate" 4 is "high", and 5 indicating "Very High"**.

Part 3: Evaluation of the Overall Level of Risk in the Project

The section will request you to evaluate the overall level of risk associated with the specific projects for which you have considered in part 2.

PART 1: BACKGROUND INFORMATION

1. What is your highest level of education (High school/Diploma, bachelor's degree, master's degree, Doctorate degree)? Click or tap here to enter text.
2. Type of organization/Company (Government, Private construction company, Engineering consultancy)? Click or tap here to enter text.
3. Position/Title: What is your position/title in the prefabricated bridge projects, for e.g., Project Manager, Supervisor, Engineer/Designer, Contractor, etc.) Click or tap here to enter text.
4. How many years of experience do you have in prefabricated/precast bridge construction projects: Click or tap here to enter text.
5. What is the name of the prefabricated bridge project? Click or tap here to enter text.
6. What is the average size range of prefabricated bridge construction projects you have worked on, for e.g., spans of 200 meters, etc.? Click or tap here to enter text.

PART 2: RISK FACTORS

Kindly assess the likelihood and severity of the following risk factors on prefabricated bridge projects, using a rating scale of 1 to 5, where 1 denotes a very low probability or severity, 2 denotes a low probability or severity, 3 denotes a moderate probability or severity, 4 denotes a high probability or severity, and 5 denotes a very high probability or severity.

ID	Risk Factor	Grading Scale									
		Probability					Severity				
RF1	Inadequate supplier capacity	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF2	Supplier financial instability	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF3	Poor supply chain integration	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF4	Delays in the delivery of materials and components	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF5	Poor information sharing between stakeholders	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF6	Error in the installation of precast component, complex rectification, and rework	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF7	Defective design and change order	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF8	Fall from height	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF9	Lack of experience of contractor in prefabrication	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF10	Unavailability of raw materials	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF11	Inaccurate cost estimation	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□

ID	Risk Factor	Grading Scale									
		Probability					Severity				
RF12	Geometric and dimensional intolerances	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF13	Shortage of precast/prefabricated components	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF14	Disputes and contractual problems	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF15	Failure of Production component system and equipment	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF16	Constructability issues	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF17	Manual handling of heavy precast/prefabricated components	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF18	Inflation	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF19	Political and social instability	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF20	Delayed payment	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF21	Poor management practices	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF22	Delay in permits and approval	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□

ID	Risk Factor	Grading Scale									
		Probability					Severity				
RF23	Weather disruptions and force majeure	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF24	Lack of Skilled labor	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF25	Lack of relevant codes, or compliance to standards, and construction regulations	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF26	Poor planning of resources and schedule	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF27	Limited site storage space	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF28	Limited expertise and experience in prefabrication construction	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□
RF29	Misplacement of components during storage	1□	2□	3□	4□	5□	1□	2□	3□	4□	5□

Part 3: Evaluation of Overall Project Risk

Based on your experience with this specific PBC project, assess the overall risk level on a scale of 1 to 5:

Vitae

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Referred Journal	• Sesay, F., Khwaja, M., Wuni, I. Y., Alshibani, A.,
Papers Under Review	Ghaithan, A. M. H. (2023) Developing a fuzzy Risk Assessment Model for Prefabricated Bridge Projects in Developing Countries: Engineering Construction and Architectural Engineering.