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**Risk Assessment of Design and Build Bridge Projects Implemented by
Department of Roads in Nepal**

by

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OF
MASTER OF SCIENCE IN CONSTRUCTION MANAGEMENT**

**DEPARTMENT OF CIVIL ENGINEERING
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DECLARATION

I hereby declare that the thesis entitled "**Risk Assessment of Design and Build Bridge Projects Implemented by Department of Roads in Nepal**" submitted to Department of Civil Engineering in partial fulfillment of the requirement for the degree of Master of Science in Engineering in Construction Management, is a record of an original work done under the guidance of Asst. Prof. Santosh Kumar Shrestha and Assoc. Prof. Nagendra Bahadur Amatya, Institute of Engineering, Central Campus, Pulchowk. This thesis contains only work completed by me except for the consulted materials which has been duly referenced and acknowledged.



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CERTIFICATE OF THESIS APPROVAL

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ABSTRACT

Design and build (D&B) contracting has been increasingly used for bridge projects implemented by the Department of Roads (DoR), Nepal, in an effort to integrate design and construction responsibilities within a single contractual framework. However, D&B bridge projects are exposed to multiple risks arising from administrative procedures, technical investigations, execution capacity, contract provisions and external oversight.

This study aims to identify, classify and prioritise the key risks affecting D&B bridge contracts under DoR. A two-round Delphi survey was first conducted to identify and refine a comprehensive list of risk factors, followed by a questionnaire survey of practitioners directly involved in D&B bridge projects. PCA was then applied to derive latent risk components, and the Relative Importance Index (RII) was used to rank individual risk factors. Key Informant Interviews (KII) were carried out to triangulate and validate the quantitative findings.

The analysis extracted four principal components : Administrative and Regulatory Risk, Execution and Supply Chain Risks, Design and Technical Integration Risks, and Contractual and Financial Dispute Risks. RII results showed that payment disputes, unclear payment modalities, foundation redesign due to inadequate soil data, river diversion failures, constructability issues in innovative designs and disputes arising from ambiguous clauses are perceived as the most critical risks. KII findings confirmed the prominence of these domains and provided contextual explanations for how they influence project performance.

The study concludes that improving contractual clarity, strengthening early-stage investigations, enhancing constructability review and adopting structured risk registers aligned with the four components can significantly improve risk management in D&B bridge projects implemented by DoR. The results provide a practical evidence-based framework for prioritising risk mitigation efforts in similar D&B infrastructure projects in Nepal.

Keywords: *Design and Build (D&B), Bridge Construction, Risk Assessment, Principal Component Analysis (PCA), Relative Importance Index (RII), Nepal.*

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
DoR	Department of Roads
D&B	Design and Build
KMO	Kaiser–Meyer–Olkin
KII	Key Informant Interview
PCA	Principal Component Analysis
RII	Relative Importance Index

CHAPTER ONE: INTRODUCTION

This chapter introduces the context and motivation for the study on risk assessment of design and build (D&B) bridge projects implemented by the Department of Roads (DoR) in Nepal. It presents the background of bridge development and D&B contracting, highlights the research gap, states the problem and frames the research questions and objectives. The chapter also explains the significance, scope and limitations of the study and outlines the overall organisation of the thesis.

1.1 Background

Nepal's road network is heavily constrained by rugged topography, deeply incised river valleys and scattered settlements. Bridges therefore act as critical connectors that transform discontinuous road alignments into functional transport corridors. Recent assessments of the national bridge stock indicate that more than 2,400 bridges have been constructed on national, provincial and local roads, with continued investment under DoR and other agencies to close remaining gaps on strategic corridors [1]. These bridges range from short-span culverts and causeways to major river crossings on highways. Bridges have become central to Nepal's connectivity and regional development strategy by reducing travel time and cost, enhancing trade and tourism, and improving access to social services in remote areas [1], [2].

Studies on rural transportation infrastructures in Nepal emphasise that roads and bridges function as lifelines for rural communities by linking them to markets, schools, health facilities and administrative centres [2]. Improved bridge connectivity in rural areas has been shown to enhance livelihoods by increasing access to markets, employment opportunities and essential services [3]. Together, these findings highlight that bridge projects are not simply engineering works but key enablers of socio-economic development in both rural and urban settings.

The importance of bridges in Nepal is magnified by the vulnerability of the transport network to natural hazards. Highway and feeder-road bridges are exposed to complex geo-hazards arising from active tectonics, steep slopes, intense monsoon rainfall and sediment-laden rivers. Past earthquake events, such as the 1988 Udaypur earthquake, have demonstrated the seismic vulnerability of highway bridges and the potential for disruption of strategic routes [4]. More recent research highlights the multi-hazard

fragility of reinforced concrete (RC) bridges in high-seismicity regions, accounting for combined effects of ground shaking, hydrological extremes and other hazards in the Nepali context [5]. Climate change is expected to exacerbate these risks by intensifying rainfall patterns, increasing peak flows and altering sediment dynamics, thereby amplifying flood and scour hazards at bridge sites [6].

At the same time, the transport sector is under pressure to deliver projects faster and at lower cost, within tight public budgets and evolving institutional arrangements. The expansion of the Strategic Road Network (SRN) and Provincial and Local Road Networks (PRN/LRN) has increased the number and complexity of bridge projects being implemented in any given fiscal year [1], [2]. In this environment, conventional design–bid–build contracts have often been criticised for fragmented responsibilities, protracted design–construction interfaces and frequent disputes over variations and claims.

In response, the Department of Roads introduced Design and Build (D&B) contracts for motorable bridges from fiscal year 2012/13 onwards. Under the D&B model, the contractor is responsible for both detailed design and construction based on the employer’s requirements, with the stated intention of accelerating project delivery, improving constructability and reducing interface disputes between designers and builders. The model is aligned with international trends in integrated project delivery, where single-point responsibility is expected to yield better coordination, fewer claims and enhanced innovation in design and construction. However, experience in Nepal indicates that D&B bridge contracts do not automatically resolve the underlying challenges of bridge delivery. Empirical studies on D&B motorable bridges under DoR report frequent schedule delays, cost overruns and disputes related to design approvals, geotechnical and hydrological investigations, land acquisition, utility shifting and payment modalities [9].

Procurement practices further influence project performance. Evidence from bridge and road projects in Nepal highlights the prevalence of aggressive low bidding, where contractors win projects with unrealistically low prices that later translate into cash-flow problems, under-resourcing and attempts to recover losses through claims, variations or compromised quality [10], [11]. Comparative analyses of World Bank–funded and government-funded projects also indicate systemic issues such as collusive bidding, inadequate evaluation of capability and ineffective enforcement of contract conditions

[12]. These procurement-related risks are especially consequential in D&B contracts, where the same entity carries both design and construction responsibilities and where mispricing or misallocation of risk at the tender stage can have significant downstream implications.

Beyond procurement and management issues, the hazard context itself has direct implications for risk allocation in D&B bridge projects. If seismic, flood and climate-related uncertainties are not adequately incorporated into design and contract provisions, they may generate significant cost implications, schedule disruptions and safety concerns during construction and operation [4]–[6]. From a historical perspective, Nepal’s bridge development has evolved from traditional trail suspension bridges, based on indigenous technology and community participation [7], to modern motorable bridges with complex structural and hydraulic designs [1]. Newer work on prioritising trail bridge investments using statistical methods demonstrates that socio-economic benefit, accessibility and risk considerations are increasingly being incorporated into planning frameworks [8].

Within this broader context, risk management has emerged as a critical area of concern for bridge projects. There is a need to move beyond anecdotal accounts of “problems” and towards structured assessment of risk factors, their interrelationships and their relative importance. This thesis focuses on addressing that need by assessing and prioritising risks in D&B bridge projects implemented by DoR, using a combination of Delphi surveys, questionnaire-based ratings, multivariate statistical analysis and validation through Key Informant Interviews (KII).

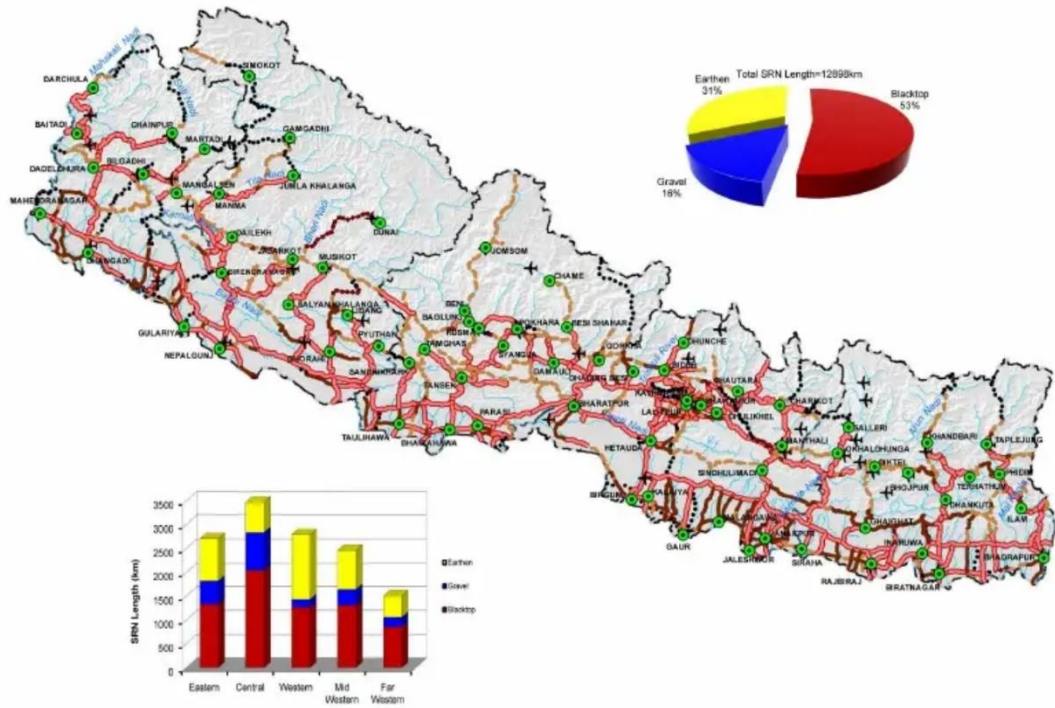


Figure 1.1: Map of Nepal showing the Strategic Road Network

1.2 Research Gap

Internationally, a substantial body of research exists on construction risk management, risk allocation and contract performance for various project delivery systems. Studies have examined risk factors affecting time and cost performance, the impact of procurement strategies, and the role of contractual arrangements in shaping incentives and responsibilities. In the Nepali context, several researchers have explored delays, cost overruns and quality issues in bridge projects, including investigations of specific corridors and case studies of failed or troubled bridges [1], [9]. Other works have focused on low bidding practices and market behaviour in bridge procurement, pointing to systemic issues in public contracting [10]–[12].

For Design and Build bridge projects, Timilsina et al. [9] identify a range of causes of delay, including late site handover, inadequate pre-design investigations, difficulties in obtaining approvals, contractor capacity issues and financial constraints. These studies provide important evidence that D&B bridge projects under DoR are prone to significant implementation challenges. However, they primarily focus on descriptive analysis of

delay causes and do not develop an integrated risk framework or explicitly prioritise risks across different domains.

Several gaps can be identified in the existing literature relevant to this thesis:

(i) Lack of structured risk classification for D&B bridges under DoR. Existing studies list numerous risk factors affecting bridge projects but rarely group them into broader, interpretable components that reflect underlying domains such as design and planning, execution and resource management, contractual and financial mechanisms, or regulatory and environmental processes. For D&B contracts, this classification is particularly important because design and construction responsibilities are integrated, and risks interact across project phases.

(ii) Limited use of multivariate techniques to reveal underlying risk structures. While individual risk factors have been discussed in prior works, there is limited application of exploratory factor analysis or Principal Component Analysis (PCA) to systematically identify latent components that structure risk perceptions in bridge projects. Some studies on other infrastructure sectors employ such techniques to develop risk indices or quality indices, but similar approaches have not been widely applied to D&B bridge projects in Nepal.

(iii) Absence of prioritisation of risks for decision making in D&B bridge contracts. Public agencies and contractors require not only a list of risks but also guidance on which risks are most critical and how they should be prioritised in contract drafting, project planning and site management. Although relative importance techniques and ranking methods are common in construction management studies, there is limited work integrating these techniques with D&B-specific risk structures for DoR bridge projects.

(iv) Limited integration of stakeholder perspectives and expert validation. Previous studies often rely on a single data source and may not adequately capture the diversity of perspectives among stakeholders. Moreover, there is limited use of iterative expert-based methods such as the Delphi technique to identify and refine risk factors, and limited triangulation of quantitative survey findings with qualitative insights from in-depth interviews or KIIs.

(v) Under-explored link between hazard context and contractual risk in D&B bridges. Seismic and climate-related hazards have been analysed for Nepali bridges from a

structural or fragility perspective [4]–[6], but the way these hazards translate into contractual, financial and administrative risks in D&B projects has not been systematically addressed. For example, inadequate consideration of geomorphic dynamics, flood risk or seismic vulnerability in early design stages may lead to significant design revisions, claims and disputes during construction.

Given these gaps, there is a clear need for a comprehensive risk assessment framework tailored to D&B bridge projects under DoR. Such a framework should : identify and consolidate relevant risk factors through expert consultation; use robust statistical tools (such as PCA) to group risks into coherent components; prioritise both components and individual risks using methods such as the Relative Importance Index (RII); and validate and interpret the findings through qualitative triangulation using Key Informant Interviews with experienced practitioners.

1.3 Problem Statement

Despite sustained investment in bridge infrastructure and the adoption of the D&B delivery model, many D&B bridge projects implemented by the Department of Roads continue to experience substantial schedule delays, cost overruns and quality concerns [1], [9]. Empirical evidence suggests that only a minority of D&B contracts are completed within their intended time frames; most require extensions of time and are accompanied by disputes related to site handover, design changes and payment mechanisms [9].

Procurement practices, particularly aggressive low bidding and potential collusive behaviour, further exacerbate these challenges. Contractors may be awarded projects with very low evaluated bids, which increases the likelihood of resource shortages, cash-flow difficulties and attempts to recover losses through claims, variations and compromise of quality [10], [11]. Comparative analyses of World Bank–funded and government-funded projects also indicate systemic issues such as collusive bidding, inadequate evaluation of capability and ineffective enforcement of contract conditions [12]. In a D&B context, where the contractor carries both design and construction responsibilities, inadequate risk allocation for geotechnical, hydrological, environmental and administrative risks at the contract stage can lead to major disputes and, in extreme cases, structural failures or incomplete projects.

At the same time, D&B bridge projects are implemented in a multi-hazard environment characterised by seismic risk, flood and debris-flow hazards and emerging impacts of climate change on hydrological regimes [4]–[6]. If these hazard-related uncertainties are not adequately incorporated into design and contract provisions, they may generate significant cost implications and safety concerns during construction and operation. Yet, despite the importance of D&B bridge projects for Nepal’s transport network and the evident challenges they face, there is limited empirical research that systematically identifies, groups and prioritises risks specific to D&B bridge contracts under DoR.

Consequently, policymakers, designers and contractors lack an evidence-based tool to understand which risk domains and individual risks are most critical in D&B bridge projects, and how these risks should be managed through contract conditions, project planning, design practices and site management. This gap constrains efforts to improve the effectiveness of D&B bridge contracts, to enhance schedule and cost performance and to ensure the long-term safety and resilience of bridge infrastructure.

1.4 Research Questions

In light of the above problem, this study is guided by the following research questions:

RQ1: What are the major risk factors that affect D&B bridge contracts implemented by the Department of Roads in Nepal ?

RQ2: How can these individual risk factors be grouped into broader, interpretable components that reflect underlying patterns in project risk ?

RQ3: Which risk components and individual risk factors are perceived by practitioners as most critical for D&B bridge projects in Nepal ?

1.5 Research Objectives

The overall objective of this study is to assess and prioritise the key risks associated with D&B bridge projects implemented by DoR in Nepal in order to support improved risk allocation and contract management.

This overall objective is broken down into the following specific objectives:

(i) To identify risk factors relevant to D&B bridge contracts under DoR, through an expert consultation using the Delphi technique.

(ii) To classify and structure the identified risk factors into coherent components using Principal Component Analysis (PCA).

(iii) To prioritise risk components and individual risk factors based on practitioners' perceptions using the Relative Importance Index (RII).

1.6 Significance of the Study

The study is expected to provide both theoretical and practical contributions to the field of construction management and to the practice of bridge project delivery in Nepal.

From a theoretical and methodological perspective, the study extends the application of multivariate statistical techniques, particularly PCA, to the context of D&B bridge projects; demonstrates a combined use of Delphi surveys, Likert-scale questionnaires, PCA and RII to move from broad lists of risk factors to empirically derived components and priority rankings; and incorporates triangulation through KIIs, thereby enriching the quantitative analysis with qualitative insights and strengthening the validity of the findings.

From a policy and practice perspective, the study is relevant for public clients and policymakers, particularly the Department of Roads and other government agencies responsible for bridge planning and implementation; consultants and designers, who need to understand how design-related risks interact with contractual and administrative risks in D&B projects; and contractors and construction managers, who must price and manage risks effectively in D&B tenders [1]–[3], [9]–[12]. The findings are also relevant for academia and researchers as an empirical case study of risk assessment in D&B bridge projects in a developing, multi-hazard context.

More broadly, the findings contribute to efforts to enhance the reliability, safety and resilience of Nepal's bridge network. Improved risk management in D&B bridge projects can lead to more timely completion of crossings, better use of public funds and reduced disruption to communities that depend on bridges for access to services and economic opportunities [1]–[3].

1.7 Scope and Limitations of the Study

The scope of this study is delimited as follows:

- (i) The study focuses on D&B bridge projects implemented by the Department of Roads, primarily those executed through the Bridge Sector Office, Dharan, covering the 14 districts of Koshi Province. These projects are considered representative of D&B bridge works implemented under DoR in terms of contractual arrangements, technical complexity and institutional context.
- (ii) The primary unit of analysis is the perception of risk as reported by professionals directly involved in D&B bridge projects, including client-side engineers, consultants, contractors and academics with practical experience. The study does not analyse individual project records or contracts in detail but rather builds an aggregated view of risks based on expert and practitioner judgement.
- (iii) The risk factors considered are those identified and refined through a two-round Delphi process and subsequent questionnaire survey. These factors cover domains such as design and investigations, procurement and bidding, construction execution and resource management, contractual and payment mechanisms, administrative and regulatory processes, and environmental and hazard-related issues.
- (iv) The statistical analysis focuses on Principal Component Analysis (PCA) for dimensionality reduction and Relative Importance Index (RII) for prioritisation. Reliability and suitability tests are applied to ensure the robustness of the PCA results. KIIs are used to validate and interpret the quantitative findings but do not constitute a separate ethnographic or case-study analysis.

The limitations of the study should also be recognised:

- (i) The findings are based on perception data collected through Likert-scale responses and interviews. While the sample size and diversity of respondents are adequate for the chosen methods, the results inherently reflect subjective judgements and may be influenced by individual experiences, organisational roles and recent events.
- (ii) The study is limited to D&B bridge projects under DoR and does not directly cover bridges implemented by provincial or local governments, nor does it address other

delivery models such as design–bid–build or public–private partnerships. Caution should therefore be exercised in generalising the results beyond the studied context.

(iii) The risk factors and components identified are constrained by the timeframe and scope of the Delphi and survey processes. Although efforts were made to systematically capture relevant risks, some context-specific or emerging risks may not have been fully captured, particularly those related to rapidly evolving climate and policy conditions [6].

(iv) The study uses PCA, which assumes linear relationships among variables and relies on the structure of the correlation matrix. While PCA is appropriate for exploratory classification and was supported by reliability and suitability tests, different multivariate techniques might yield somewhat different structures, especially in larger datasets.

(v) The study does not link risk perceptions directly to measured project outcomes such as actual cost overruns, delay durations or structural performance. Rather, it provides an indirect assessment based on expert judgement.

Despite these limitations, the study provides a rigorous and practically oriented assessment of risks in D&B bridge projects under DoR, and its findings are expected to offer valuable insights for improving risk management in similar contexts.

1.8 Organisation of the Thesis

This thesis is organised into the following chapters:

Chapter 1 – Introduction: Provides an overview of the study, including background, research gap, problem statement, research questions, objectives, significance, scope and limitations, and organisation of the thesis.

Chapter 2 – Literature Review: Presents a critical review of literature related to bridge development in Nepal, D&B contracting and its application in bridge projects, risk concepts and risk management frameworks in construction, risk allocation and procurement practices, and previous research on risk assessment using methods such as Delphi, PCA and RII. The chapter identifies theoretical and empirical gaps that the present study seeks to address.

Chapter 3 – Research Methodology: Describes the research design, including the mixed-methods approach adopted in the study. It explains the Delphi process for identifying risk factors, the design and administration of the final questionnaire, the sampling strategy

and sample size determination, and the study area. It also details the data analysis procedures, including reliability tests, KMO and Bartlett's tests, PCA, RII calculation and the design and conduct of KIIs for triangulation.

Chapter 4 – Results and Discussion: Presents the empirical findings of the study, including respondent profiles, results of reliability and suitability tests, PCA outputs and interpretation of principal components, RII-based rankings of risk factors and integrated analysis of risk components and their priorities. The chapter also reports the insights from KIIs and uses them to validate and refine the quantitative results, discussing the findings in relation to existing literature and the practical context of D&B bridge projects in Nepal.

Chapter 5 – Conclusions and Recommendations: Summarises the main findings with respect to the research objectives and questions, draws key conclusions, and provides recommendations for DoR, consultants and contractors to improve risk management in D&B bridge projects. The chapter also outlines limitations of the study and suggests areas for future research.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Construction projects are exposed to a broad spectrum of uncertainties related to technical complexity, financial constraints, contractual arrangements, and the external environment. These uncertainties can materialise as risks that affect project time, cost, quality, safety and stakeholder relationships. Systematic risk management has therefore become an essential element of modern project management, particularly in infrastructure projects where failure can have serious socio-economic and environmental consequences.

Early work in the construction field emphasised that risk management in practice was often informal, reactive and fragmented across different project participants, despite the availability of structured methods and tools [2]. Subsequent research has highlighted that risk management should be integrated across the full project life cycle—from project conception, feasibility study and procurement strategy to design, construction and operation [3], [4]. Recent holistic reviews further show a steady growth of research on construction risk management, but also identify gaps in how risks are classified, prioritised and allocated among stakeholders [5].

Within this wider context, bridge projects are particularly exposed to complex risk interactions. They are typically located in riverine and geologically sensitive environments, and their failure or underperformance can severely impact connectivity, economic activity and public safety. In Nepal, where bridges are lifelines for rural and strategic road networks, the implications of inadequate risk management are especially severe. This makes design and build (D&B) bridge projects under the Department of Roads (DoR) a critical domain for structured risk assessment and prioritisation.

To situate the present study, this chapter reviews literature on:

- risk in construction and bridge projects;
- consequences of weak risk management;
- risk allocation in contracts and D&B delivery;
- risk management processes and tools;
- methods for risk identification, analysis and classification; and

- the use of Principal Component Analysis (PCA) and Relative Importance Index (RII) in risk studies.

Based on this, a conceptual foundation is developed for grouping and prioritising risks in D&B bridge projects in Nepal.

2.2 Risk in Construction and Bridge Projects

2.2.1 Generic risk in construction projects

Construction projects involve multiple parties (client, designer, contractor, suppliers), long time horizons and dynamic environments. Akintoye and MacLeod describe construction risk as the exposure of project outcomes to events that can cause deviations from planned cost, time and quality, and argue that contractors often rely on experience and intuition rather than formal risk analysis [2]. Their survey of UK contractors showed that while risk identification was fairly common, quantitative analysis and systematic monitoring were less frequently adopted.

More recent reviews reaffirm that construction risk research spans a wide range of topics, including cost overrun, schedule delay, safety, environmental impact, and organisational issues [5]. The review by Zhao et al. (2000–2021) indicates that risk management has gradually moved from qualitative checklists to more sophisticated multi-criteria and statistical techniques, but that many studies remain sector- or country-specific, which limits generalisation. Studies in developing countries, such as Tessema et al. on Ethiopian construction projects, demonstrate that risk factors often include weak design information, poor contract administration, resource constraints and external political/economic instability [6].

2.2.2 Bridge projects and consequences of inadequate risk management

Bridge projects face general construction risks plus additional hazards related to river morphology, scour, foundation performance, seismicity and hydrological extremes. International experience shows that failure to address these risks can lead not only to project delays and cost overruns, but also to serious structural damage and collapse.

Hussain et al. identify key risks in bridge construction projects in Pakistan and use Monte Carlo simulation on network schedules to show how delays in critical activities propagate

into substantial time overrun [7]. Kumari [8] reports that poor coordination, design changes, inadequate site investigation and resource shortages lead to significant delay and cost escalation in bridge projects. Case-study work on specific bridges, such as the Gayungan Bridge in Indonesia, further illustrates how weak implementation of risk management particularly poor planning of temporary works and construction sequences results in rework, delays and increased cost [9].

From a failure-consequence perspective, Chryssanthopoulos [10] discusses how bridge failures can be classified in terms of human casualties, economic disruption, environmental damage and wider societal impact, arguing that risk management should explicitly consider these consequence dimensions. Studies such as Sharma and Jha's case of the Mahadev Jha Bridge collapse highlight that repeated failures can often be traced to inadequate geotechnical investigation, poor construction supervision and insufficient provision for flood-related scour and river dynamics [11]. These findings underline that bridge risk management must treat geotechnical, hydraulic and structural issues together with contractual and organisational factors.

2.3 Risk Allocation and D&B Bridge Practice

Risk allocation is a core function of construction contracts. The general principle is that each risk should be borne by the party best able to manage or influence it. However, empirical research suggests that public-sector clients often transfer excessive risk to contractors, through incomplete site information, strict timeframes and unbalanced contract clauses [12]. Such practices can increase bid prices, encourage adversarial behaviour and lead to claims.

Shen et al. provide a widely cited classification of risks in construction joint ventures—technical, management, market, legal, financial and political—and discuss how these are commonly allocated between partners [13]. Their findings show that misalignment between perceived and actual control over risks leads to disputes and project underperformance. Similar patterns are observed in other contexts. Iqbal et al. report that contractors in Pakistan perceive certain owner-related risks (delayed payments, scope changes, unclear specifications) as unfairly allocated to them [14]. Yin et al. show that

inappropriate allocation of risks in contracts can trigger opportunistic behaviour by contractors, moderated by the degree of trust and control in the relationship [15].

In the specific context of design and build projects, design and construction responsibilities are combined within the contractor's organisation. International experience suggests that this integration can shorten schedules and improve constructability when risks are clearly defined and properly shared, but can also create disputes if responsibilities for ground conditions, utilities, approvals and late design changes are not clearly addressed [16]. For D&B bridges under DoR, previous research has shown that many contracts require time extensions and face disputes related to site handover, investigations and payment modalities. These findings are consistent with broader concerns about low-bid procurement and aggressive pricing in Nepal's bridge projects [17]–[19].

2.4 Consequences of Bad Risk Management in Bridge Projects

The consequences of inadequate risk management in bridge projects manifest at multiple levels:

- Project-level performance : schedule delays, cost overruns, rework and disputes.
- Asset-level performance : reduced durability, serviceability issues, and in extreme cases, partial or full collapse.
- System-level impacts : disruption of connectivity, economic losses, safety incidents and reputational damage to agencies.

Empirical studies from various countries underline these consequences. The work on Pakistani bridge projects shows that insufficient early-stage risk identification leads to frequent time and cost overruns, especially when combined with inefficient contract administration [7]. Enrichment Journal's case study on the Gayungan Bridge demonstrates how lack of structured risk management (e.g. no formal risk register, limited contingency planning) created vulnerabilities to construction accidents and rework [9].

Sharma and Jha's analysis of the Mahadev Jha Bridge on NH80 links repeated failures to design deficiencies (underestimated scour, inadequate detailing), poor geotechnical investigation and weak supervision [11]. Karim et al. provide broader evidence that

inadequate risk management in construction generally leads to cost overrun, delays and disputes, stressing that reactive risk handling is more expensive than proactive strategies [20]. Chryssanthopoulos [10] argues that, because bridge failures have high societal consequences, risk management should be embedded not only at project level but also in network-level planning and asset management frameworks.

For the Nepali context, where bridges are critical for rural and strategic connectivity, these international findings reinforce the need for robust risk assessment in D&B bridge contracts to prevent costly failures and service disruptions.

2.5 Risk Management Measures and Process Steps

Risk management standards such as ISO 31000 and the Project Management Institute's PMBOK Guide describe risk management as a structured, iterative process comprising: establishing the context, risk identification, risk analysis, risk evaluation, risk treatment, and monitoring and review. The University of Otago's Risk Management Framework similarly outlines phases of context setting, identification, analysis, evaluation, treatment and monitoring, with emphasis on feedback and continuous improvement [4].

Osipova argues that in construction projects, risk management should be aligned with project phases—planning, design, procurement, construction and close-out—and that different actors (client, designer, contractor) should be involved at each stage [3]. Nthase, in a study of Botswana public building projects, presents a process model with risk identification, estimation, evaluation, response and monitoring, illustrating how explicit risk registers, probability impact matrices and mitigation plans can improve outcomes [21]. Other works on risk management strategies in construction organisations highlight strategic responses such as risk avoidance, transfer, mitigation and acceptance, and distinguish between internal (controllable) and external (contextual) risks.

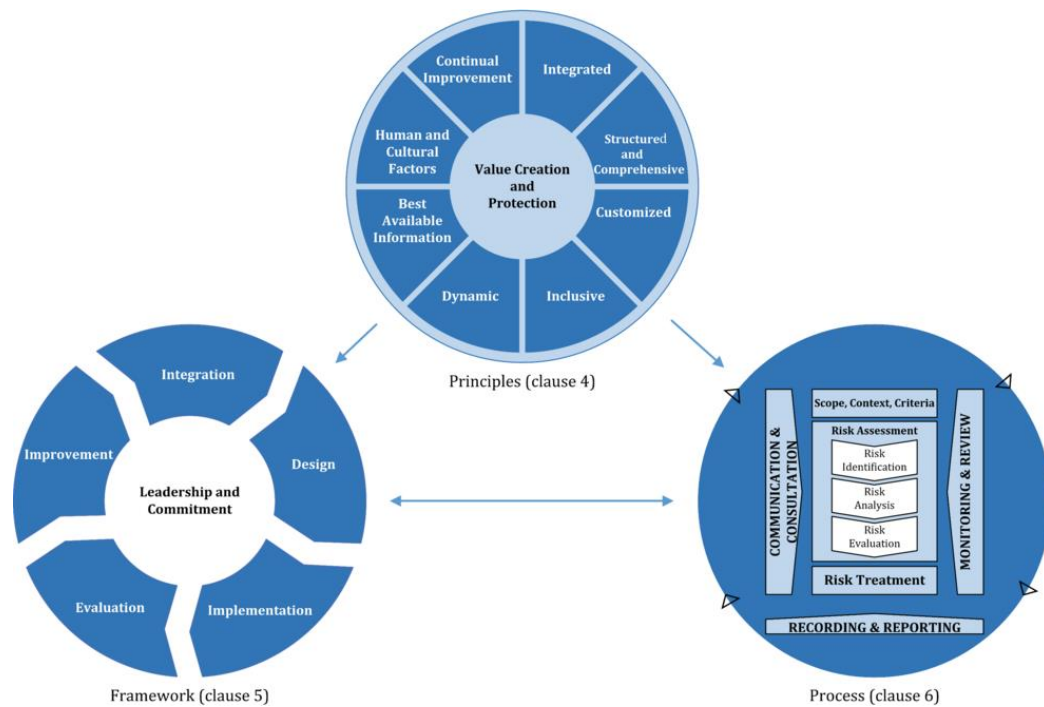


Figure 2.1 – Generic construction project risk management cycle adapted from ISO 31000/PMBOK

2.6 Methods of Risk Identification and Analysis

2.6.1 Risk identification techniques

Risk identification methods in construction range from informal brainstorming and checklists to more structured approaches such as Delphi surveys, expert interviews and taxonomies. Al-Bahar and Crandall emphasise the importance of systematic risk identification using a mix of techniques (brainstorming, checklists, historical data review, and structured interviews), and propose a taxonomy of project risks to ensure that hidden or less obvious factors are not overlooked [23]. Shen et al. also stress that clear classification of risk sources (technical, financial, legal, political, etc.) improves communication and allocation decisions [13].

For bridge projects, risk identification often draws on lessons from past failures, expert judgement, and guidelines. Case-study works that combine field observation with expert interviews—such as on the Mahadev Jha Bridge and other bridge failures—illustrate how

expert insights are essential to capture context-specific risks that may not appear in generic checklists (Sharma & Jha, 2025; Hussain et al., 2011).

2.6.2 Risk analysis techniques

Once identified, risks can be analysed using qualitative, semi-quantitative or quantitative methods. Qualitative methods include risk registers and probability–impact matrices. Semi-quantitative techniques assign scores and weights to derive risk indices. Quantitative methods involve more formal modelling (e.g. Monte Carlo simulation, fault tree analysis, Bayesian networks).

In the context of project risk and delays, a large body of research uses Likert-scale questionnaires with statistical analysis to assess the perceived importance and likelihood of different risk factors. Monte Carlo simulation, as used by Hussain et al., helps quantify schedule risk in bridge construction schedules [7]. More recent work has explored multi-criteria decision-making, fuzzy logic, interpretive structural modelling (ISM/TISM) and MICMAC analysis for complex risk interrelations [24].

For practical application in developing-country infrastructure projects, relatively straightforward yet robust tools—such as PCA and RII—have gained popularity because they can be implemented using survey data and standard statistical software while still providing meaningful structure and prioritisation.

2.7 Broad Classification of Risk Factors into Study Areas

Many authors advocate grouping risks into broad categories or “study areas” to improve clarity and facilitate allocation. Al-Bahar and Crandall propose high-level categories such as construction, design, financial, political and environmental risks [23]. Shen et al. classify risks into technical, management, market, legal, financial and political categories, which have been widely adopted in subsequent research [13].

More recent studies refine these classifications. Abdaljader et al. distinguish between internal and external risks and then further break them down into subcategories such as political/administrative risks, financial risks, safety risks and environmental risks [25]. Work on risk management strategies in construction organisations similarly emphasises internal vs external risk categorisation and discusses how this distinction influences

feasible response strategies. Nthase's framework explicitly separates risk identification from risk mitigation and maps various sub-risks under each domain [21].

These classification schemes provide conceptual support for grouping the 31 risk factors of the present study into broader domains. In the case of D&B bridge projects, the PCA results in later chapters show that empirically derived components such as "Administrative and Regulatory Risk," "Execution and Supply Chain Risks," "Design and Technical Integration Risks" and "Contractual and Financial Dispute Risks" are consistent with the broader classifications proposed in earlier literature, while also being tailored to the specific DoR D&B context.

2.8 Different Risk Areas Prioritised by Different Stakeholders

Several empirical studies highlight that project participants—clients, consultants, and contractors—often prioritise risk factors differently. Assaf and Al-Hejji's classic study on causes of delay in large construction projects reported distinct rankings of delay factors from the perspectives of owners, contractors and consultants [26]. Owners tended to emphasise financial and approval-related issues, while contractors gave higher importance to resource constraints and site conditions.

Gündüz et al. used RII to quantify the importance of delay causes in Turkish construction projects and compared perceptions among different stakeholders [27]. Their results showed that while there is broad agreement on some critical factors (e.g. design changes, payment delays), other risks are weighted differently across parties. Yousri et al. used RII and risk mapping in Egyptian building projects and concluded that stakeholders' roles significantly influence how they perceive and rank risks [28].

Iqbal et al. examined risk importance and allocation in Pakistan's construction industry and found that contractors perceived certain client-related risks as highly important yet inequitably allocated to them [14]. Amarkhil et al., in a meta-analysis of project delay causes, further show that the relative importance of risks varies not only by stakeholder but also by project type and country context [29].

This body of literature reinforces two key points relevant to the present study: (i) Risk prioritisation should be informed by the perspectives of all major stakeholders involved

(ii) When allocating risks in contracts, authorities should consider these differing perceptions to avoid mistrust and disputes.

Because the current research gathers perceptions from DoR engineers, consultants and contractors, the RII-based ranking of risk factors in later chapters inherently reflects this multi-stakeholder viewpoint for D&B bridge projects.

2.9 Use of PCA to Classify / Group Risk Factors in Construction

Principal Component Analysis (PCA) is a multivariate statistical technique for reducing dimensionality by transforming correlated variables into a smaller set of uncorrelated components. In construction research, PCA has been increasingly used to group risk factors and identify underlying dimensions.

Liu et al. applied PCA to construction project risk data in China and obtained several principal components representing clusters such as financial risks, construction management risks and external risks [30]. Tessema et al. used PCA to condense a long list of risk factors in Ethiopian public construction projects into fewer components that explained much of the variance in perceived risk [6]. CIB's report on modular integrated construction projects similarly employed PCA to derive principal risk factors related to stakeholders, supply chain, technology and regulation [31].

In more specialised applications, Alsanabani et al. used PCA to identify latent risk factors associated with pile installation, providing a relevant example for foundation-related risks in bridge projects [32]. Wyke et al. applied PCA to factors influencing cost and time overruns in public construction projects and identified a smaller set of latent variables that capture the main risk drivers [33]. Pang proposed a PCA-based project risk ranking method where PCA is used to reduce the dimensionality before ranking projects based on dominant risk components [34].

Taken together, these studies demonstrate that PCA is useful for simplifying complex risk datasets, revealing underlying structures (e.g. administrative vs technical risks), and providing empirical support for grouping factors into coherent components. The present research follows this tradition by applying PCA with Varimax rotation to a set of 31 D&B bridge risk factors.

2.10 PCA for Risk / Factor Classification in Other Sectors

Beyond construction, PCA is widely used to classify and analyse risk factors in finance, supply chains and other domains. Mavungu et al. applied PCA to financial risk indicators to identify dominant drivers of portfolio risk, illustrating how PCA can simplify highly correlated financial variables into a manageable set of risk factors [35]. Loretan used PCA to generate market risk scenarios, extracting principal factors that explain the variation in financial markets [36].

In supply chain risk, Li et al. combined PCA with genetic algorithms and support vector machines (PCA–GA–SVM) to predict supply chain credit risk, using PCA to reduce input dimensionality and improve model performance [37]. Zhou et al. employed PCA to develop a supply chain risk evaluation model in which PCA-derived scores are used to aggregate indicator information [38]. Celestin provides a recent review on the use of component analysis to simplify multivariate financial data for portfolio risk management, emphasising its role in identifying dominant risk drivers [39].

These non-construction applications show that PCA is a general-purpose tool for risk grouping and dimensionality reduction in complex systems. They support the methodological choice of the present study by demonstrating that PCA is widely accepted and theoretically sound for extracting latent risk dimensions from correlated indicators.

2.11 Impact of Different Risk Factors and Prioritisation (RII and Similar Methods)

The Relative Importance Index (RII) is a simple yet powerful method frequently used in construction research to prioritise risk and delay factors based on Likert-scale survey responses. Assaf and Al-Hejji used ranking based on frequency and severity scores to identify the most critical delay causes in large construction projects [26]. Gündüz et al. formalised the use of RII to quantify and rank delay factors in Turkey, demonstrating that RII provides a clear hierarchy of causes that can be interpreted by practitioners [27]. Other studies in industrial and infrastructure projects have similarly used RII to identify critical delay or risk factors [40], [41].

In more recent work, Yousri et al. combined RII with risk mapping to classify risks into zones of low, moderate and high priority, helping project stakeholders focus on the most critical risks [28]. Boakye et al. used RII to rank on-site safety hazards in building

construction, showing its applicability to occupational health and safety within the construction sector [42]. Amarkhil et al. used RII as a basis for meta-analysis across multiple delay studies, indicating that RII can also support comparative analysis across different contexts [29]. Alawneh et al. explicitly note that RII is one of the most widely used tools in construction risk management and use it as a building block for a more complex risk assessment method that integrates probability–impact matrices and multi-criteria techniques [43].

The prevalence of RII in these studies justifies its use in the present research to prioritise individual risk factors in D&B bridge projects. Combined with PCA, RII enables a dual view: components capture domains of risk, while RII highlights the most critical individual risks within and across those domains.

2.12 Synthesis of Literature and Identified Research Gaps

The reviewed literature provides a strong conceptual and methodological foundation for assessing risks in D&B bridge projects in Nepal:

- Construction projects are inherently risky, and bridge projects face additional geotechnical, hydraulic and seismic challenges. Weak risk management leads to delays, cost overruns, rework and sometimes catastrophic failures [2], [7], [11], [10].
- Risk allocation in construction contracts is often unbalanced, especially under public procurement regimes that favour low bids, and D&B arrangements can amplify disputes if responsibilities are not clearly defined [13], [12], [14], [15].
- Risk management frameworks emphasise systematic processes, yet in many developing-country contexts, practice remains fragmented and reactive, with limited use of advanced analytical tools [3], [21], [4].
- Numerous studies have identified and ranked risk factors in construction and bridge projects using questionnaires and RII, but relatively few have focused specifically on D&B bridge contracts in South Asian or Nepali settings, and even fewer have combined PCA and RII to both structure and prioritise risks [30], [6], [27], [31].
- Stakeholder perspectives on risk importance and allocation vary; however, there is limited empirical work that systematically captures the perceptions of Department of Roads engineers, consultants and contractors for D&B bridge projects in Nepal [26], [28], [14].

On this basis, the main research gaps addressed by the present thesis are:

- (i) Context-specific focus : There is a lack of structured empirical studies that identify, group and prioritise risks specifically for D&B motorable bridge projects under DoR in Nepal.
- (ii) Integrated use of PCA and RII : Few studies in the bridge sector have used PCA to derive risk components and RII to rank individual risks within these components, especially in a developing-country context.
- (iii) Multi-stakeholder perceptions : Existing research seldom integrates perceptions from client, consultant and contractor sides in a single framework for D&B bridges in Nepal.
- (iv) Link to risk allocation and contract management : There is a need to translate statistically derived risk domains into practical implications for contract conditions, risk allocation, and project management practice under DoR.

The present study responds to these gaps by using a Delphi process to derive a context-relevant list of D&B bridge risks; collecting Likert-scale ratings from practitioners with D&B bridge experience; applying reliability analysis, KMO and Bartlett's test, PCA with Varimax rotation and RII; and integrating these quantitative results with insights on risk allocation and contract management.

CHAPTER THREE : RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the general methodology used by the Department of Roads (DoR), Nepal, to evaluate risks in design and build (D&B) bridge projects. The research design described in the published paper is followed and expanded upon in the final thesis, which also includes a triangulation step that uses Key Informant Interviews (KII) to validate the quantitative results.

The research combines quantitative and qualitative methods. A Delphi-based expert survey was first used to identify and refine a comprehensive list of risk factors related to D&B bridge projects. A structured questionnaire survey was then administered to professionals involved in D&B bridge projects under DoR to obtain numerical ratings of these risks. The quantitative data were analysed using reliability analysis, Principal Component Analysis (PCA) with varimax rotation and the Relative Importance Index (RII). Finally, KII were conducted with experienced experts to triangulate and validate the PCA components and ranked risk factors.

A schematic overview of the research design should be presented as :

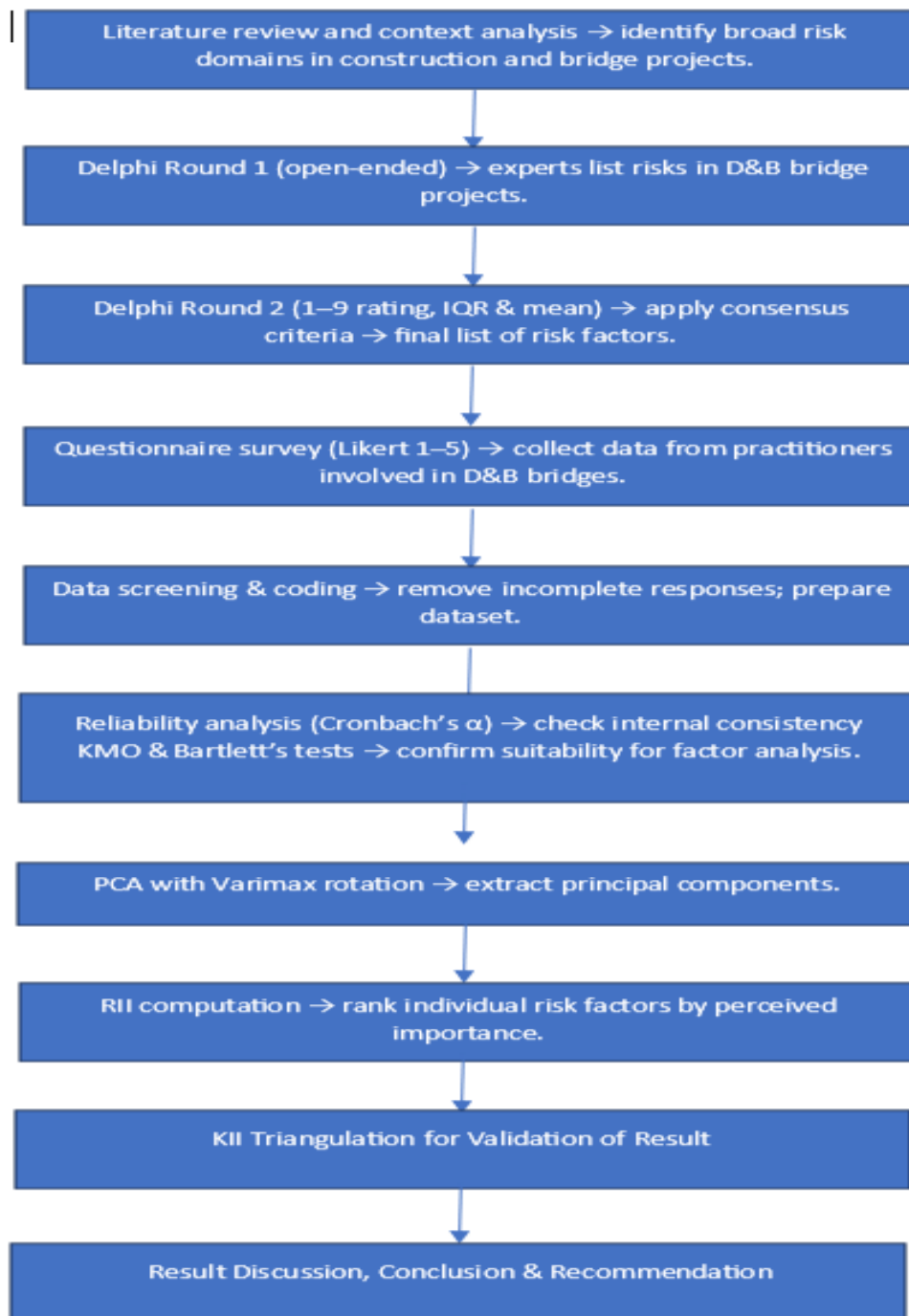


Figure 3.1 – Overall research design of the study

3.2 Research Design

The study adopted a quantitative, cross-sectional survey design complemented by a qualitative validation phase. The quantitative component was used to identify, classify

and prioritise risk factors, while the qualitative KII component strengthened the internal validity of findings through methodological triangulation [70], [71].

The main features of the research design are:

- Approach : Positivist, using structured questionnaires and statistical analysis (PCA, RII).
- Strategy : Expert-based survey targeting professionals with experience in D&B bridge projects under DoR.
- Time horizon : Cross-sectional; data collected at a single point in time.
- Validation : Convergence of evidence from Delphi rounds, questionnaire survey and KII [70], [71].

The design is consistent with established recommendations for survey-based risk research, where an initial broad pool of risk factors is refined and reduced using expert judgment and multivariate analysis [60], [61].

Objective	Data Source / Instrument	Analysis Method	Output
Objective 1: Identify risk factors	Delphi Rounds 1 & 2	Qualitative synthesis, IQR, mean cut-off	List of 31 key risk factors
Objective 2: Group factors	Final questionnaire (92 responses)	Principal Component Analysis (PCA)	4 principal components with 21 retained factors
Objective 3: Rank factors & components	Same questionnaire data	RII, component-wise ranking	Ranked list of risk factors and components

Table 3.1 – Research matrix

3.3 Study Area, Population and Sampling

3.3.1 Study area

The study focuses on design and build bridge projects implemented through the Bridge Sector Office, Dharan, covering 14 districts of Koshi Province. These districts contain a

significant proportion of DoR D&B bridge works and include projects spanning major rivers, varying terrain and different traffic classes. As the number of D&B projects in this cluster has increased, the associated problems, perspectives and risk factors are considered representative of broader D&B bridge projects under DoR in Nepal.



Figure 3.2 – Map of Nepal showing the study area (D&B bridges under DoR in Koshi Province)

3.3.2 Study population

The target population consists of professionals with experience in D&B bridge projects under DoR, including:

- Engineers and managers from DoR (central offices, bridge sector offices, field divisions);
- Consultants involved in design, supervision and review of D&B bridges;
- Contractors involved in D&B bridge execution;
- Academics and experts with substantial experience in bridge construction and procurement.

In the context of Cochran’s framework, this population is large and not precisely known; hence it was treated as an infinite population for sample size determination [44], [45], [46].

3.3.3 Sampling technique

For the Delphi rounds and final questionnaire survey, purposive sampling was adopted to target respondents with direct experience of D&B bridges and familiarity with contractual and technical risks. This is consistent with recommendations for expert-based surveys in construction risk research and Delphi studies [47], [48], [49].

For the KII, a purposive–key informant strategy was used, selecting individuals who hold rich, experience-based knowledge of D&B bridge projects (senior DoR officials, senior consultants and contractors). Such purposive selection is widely recommended for key informant studies in applied research [72], [73].

3.4 Sample Size Determination

Because the exact population of eligible experts was unknown, Cochran’s formula for large (infinite) populations was used to estimate the minimum sample size for the questionnaire survey [44], [45], [46]. The formula for proportions is:

For an infinite or very large population, Cochran’s formula for estimating a proportion is:

$$n_0 = \frac{Z^2 p q}{e^2} \quad (1)$$

where:

- n_0 = required sample size for a large population,
- Z = Z-score corresponding to desired confidence level,
- p = estimated proportion of the attribute in the population (conservatively taken as 0.5 for maximum variance),
- e = desired margin of error.

Following typical practice in construction management surveys [45], [46], the parameters were taken as:

- Confidence level = 90% $\rightarrow Z = 1.645$,
- $p = 0.50$ (maximum variability),
- $e = 0.10$ ($\pm 10\%$ margin of error).

Substituting into Equation (3.1):

$$n_0 = (1.645^2 \times 0.5 \times 0.5) / 0.10^2 \approx 68$$

Thus, a minimum of 68 valid responses was required. The final questionnaire was circulated to around 150 experts (50 each from client, contractors and consultants/academics), and 92 complete and valid responses were obtained, exceeding the minimum and satisfying common recommendations of at least 5–10 respondents per variable for PCA [58], [60], [61].

Category	Description	Count / %
Total questionnaires sent	Experts with D&B bridge experience (50 respondents targeted each from Client, Consultant & Contractors)	≈ 150
Valid responses received	Complete usable responses	92
Response rate		≈ 61.3%

Table 3.2 – Sample Population : Number of questionnaires distributed and number of valid responses obtained

3.5 Data Collection Methods

The research involved three main data collection phases:

1. Delphi Round 1 and Round 2 for identification and refinement of risk factors;
2. Structured questionnaire survey on a 1–5 Likert scale for quantitative risk assessment;
3. Key Informant Interviews (KII) for triangulation and validation of findings.

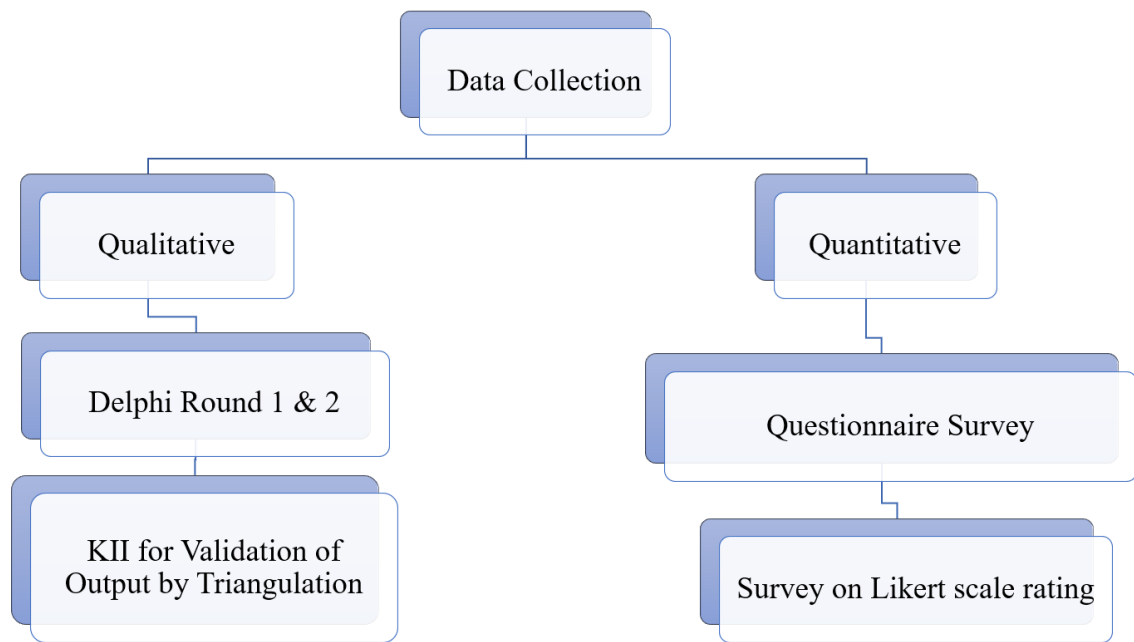


Figure 3.3 – Data Collection Method

3.5.1 Delphi survey

The Delphi method is suitable for synthesising expert judgments on complex issues and building consensus through iterative rounds [47], [48], [49], [50]. In this study:

- Round 1 (open-ended) : Experts were asked to list all risk factors they had experienced or anticipated in D&B bridge projects under DoR. The responses were thematically coded and grouped into preliminary risk categories.
- Round 2 (structured rating) : The consolidated list of risks from Round 1 and literature was presented to experts, who rated the importance of each risk on a 1–9 scale. Interquartile range (IQR) and mean scores were used as consensus criteria to retain or drop risk factors.

This iterative process followed standard Delphi design guidelines on number of rounds, feedback and consensus thresholds [47], [48], [49], [50], resulting in a refined list of 31 risk factors to be included in the final questionnaire.

3.5.2 Questionnaire survey

The final questionnaire comprised two parts:

1. Respondent profile, capturing:

- Organisation type (DoR, consultant, contractor, academic);
- Designation and role (bridge/structural engineer, project manager, site engineer, etc.);
- Years of experience in bridge construction;
- Specific experience with D&B bridge projects under DoR.

2. Risk factor ratings:

- The 31 refined risk factors were presented as statements.
- Respondents indicated their agreement/importance on a 5-point Likert scale (1 = very low importance, 5 = very high importance).

The Likert-type scale is widely used for attitudinal and risk perception surveys due to its simplicity and reliability [51], [52]. While the underlying data are ordinal, many researchers treat such scales as approximately interval for parametric analysis when categories are five or more and items are summed or averaged [53], [54]. This approach is consistent with established practice in construction risk management studies.

Data were collected using Google Forms, allowing faster distribution and automatic data entry. Participation was voluntary and anonymous.

The questionnaire sample is provided in ANNEX.

3.5.3 Key Informant Interviews (KII)

After quantitative analysis, KII were conducted for triangulation. In line with triangulation literature [70], [71], [73], the KII aimed to:

- Validate whether the four principal components and top-ranked risk factors identified through PCA and RII reflected practitioners' experience;
- Explore nuanced explanations behind the statistical results;
- Identify any missing risks or contextual issues specific to D&B bridge projects under DoR.

Key informants were selected using purposive sampling [72], [73]. They included senior DoR officials, experienced bridge designers, and contractors with substantial D&B

bridge portfolios. A semi-structured interview guide summarising the quantitative findings (four components, top 10 risk factors, and overall rankings) was used to elicit detailed feedback.

The KII guide and consent script are included in Appendix C.

3.6 Research Instruments and Measurement Scales

3.6.1 Measurement scale

All 31 risk factors in the questionnaire were measured using a 5-point Likert scale (1–5). Likert's original work described summated ratings as an efficient way to measure attitudes [51]. Subsequent methodological papers have clarified issues related to scale design, response categories, and treatment of Likert data in analysis [52], [53], [54].

In this study:

- The scale points were labelled clearly (Very Low, Low, Moderate, High, Very High) to reduce ambiguity.
- Respondents were instructed to base their judgments on their practical experience with D&B bridge projects.
- Mean and standard deviation were used to summarise responses, consistent with common practice when Likert items are used as composite indicators in PCA and RII [52], [53].

3.6.2 Instrument development and refinement

The risk factor list and wording were developed from:

- Literature on construction and bridge project risks
- Results of Delphi Round 1 and Round 2

The pre-test confirmed that the items were understandable, non-overlapping and relevant to D&B bridge projects. Minor wording adjustments were made to clarify technical terms and align with Nepali DoR practice.

3.7 Data Analysis Methods

The data analysis procedures followed standard guidelines for survey-based scale development and risk assessment [58], [60]–[62].

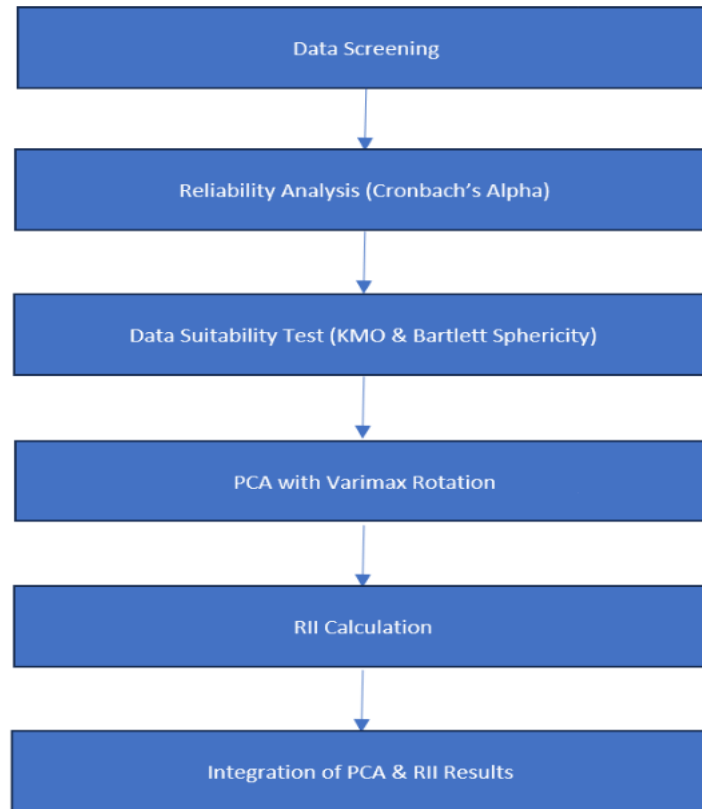


Figure 3.4 – Data analysis framework

3.7.1 Data screening and preparation

Raw data from Google Forms were exported to Microsoft Excel and IBM SPSS Statistics. The following steps were undertaken :

- Checking for missing responses : Incomplete questionnaires (missing large portions of the risk rating section) were removed.
- Coding : Likert responses were coded from 1 to 5.

3.7.2 Reliability analysis (Cronbach's alpha)

To assess internal consistency of the 31-item risk scale, Cronbach's alpha (α) was computed. Cronbach's alpha is the most widely used reliability coefficient for multi-item scales [55], though its interpretation requires caution [56], [57].

$$\alpha = \frac{k}{k-1} \left(1 - \frac{\sum \sigma_i^2}{\sigma_T^2} \right) \quad (2)$$

where k is the number of items, σ_i^2 is the variance of item i and σ_T^2 is the variance of the sum of all items [28,29].

Table 1: Interpretation of Cronbach's Alpha

α range	Interpretation
$\alpha \geq 0.90$	Excellent
0.80–0.89	Good
0.70–0.79	Acceptable
0.60–0.69	Questionable
0.50–0.59	Poor
< 0.50	Unacceptable

Table 3.3 – Interpretation of Cronbach Alpha

Guidelines from multivariate texts suggest that:

- $\alpha \geq 0.70$ indicates acceptable reliability,
- $\alpha \geq 0.80$ indicates good reliability,
- $\alpha \geq 0.90$ indicates excellent reliability [58], [59].

In this study, the overall Cronbach's alpha for the 31 risk items was greater than 0.90 ($\alpha \approx 0.91$), indicating excellent internal consistency of the scale. This supports the use of the data for further factor analysis and component extraction.

3.7.3 Suitability of data for PCA (KMO and Bartlett's test)

Before applying PCA, the suitability of the correlation matrix was examined using:

- Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy;
- Bartlett's test of sphericity.

The KMO statistic assesses whether partial correlations among variables are small and ranges from 0 to 1 [64], [65]. Common rule-of-thumb thresholds suggest that $\text{KMO} \geq 0.80$ is "meritorious", ≥ 0.70 "middling", and ≥ 0.60 "mediocre", with values below 0.50

considered inadequate for factor analysis [66]–[68]. Bartlett’s test checks whether the correlation matrix significantly differs from an identity matrix; a p-value < 0.05 (typically < 0.001) indicates that the matrix is suitable for factor extraction [65], [67], [68].

Table 2: Interpretation of KMO values

KMO range	Interpretation
0.90–1.00	Marvelous
0.80–0.89	Meritorious
0.70–0.79	Middling
0.60–0.69	Mediocre
0.50–0.59	Miserable
< 0.50	Unacceptable

Table 3.4 – Interpretation of KMO Values

For this study:

- Overall KMO \approx 0.854, indicating meritorious sampling adequacy;
- Bartlett’s test was highly significant (χ^2 with appropriate degrees of freedom, $p < 0.001$), justifying the use of PCA.

These results confirmed that the dataset was appropriate for extracting underlying components from the 31 risk factors.

3.7.4 Principal Component Analysis (PCA) with varimax rotation

Principal Component Analysis was conducted to reduce the 31 correlated risk variables into a smaller set of latent components. PCA is widely used in construction risk studies to identify groups of related risks and construct higher-level constructs [60], [61].

The procedure followed recommendations from methodological literature [60]–[62], [64], [65]:

- Extraction method : PCA on the correlation matrix.
- Component retention : Kaiser’s eigenvalue > 1 criterion supported by visual inspection of the scree plot [60], [61], [62].
- Rotation : Varimax orthogonal rotation, which aims to maximise variance of loadings on each component and achieve a simpler, more interpretable structure [64], [65].

- Factor loading threshold : Items with loadings ≥ 0.70 on a single component and minimal cross-loadings on others were retained for interpretation, consistent with strict loading criteria suggested in scale development literature [58], [60], [61].

The analysis resulted in four principal components, jointly explaining a substantial proportion of total variance (above the commonly suggested 50% threshold [58], [60], [61]). Each component represented a coherent risk domain in D&B bridge projects (e.g., design and cost planning risk; project execution and resource management risk; contractual and payment dispute risk; administrative and regulatory risk).

The rotated component matrix and reliability of each component are in Chapter 4.

3.7.5 Relative Importance Index (RII) for ranking risk factors

To rank the individual risk factors and the components in terms of perceived importance, the Relative Importance Index (RII) method was used. RII has been widely applied to rank delay and risk factors in construction projects [27]–[77].

For a 5-point Likert scale, the RII for each factor was calculated as:

To prioritise individual risk factors, the Relative Importance Index (RII) was calculated from the Likert ratings using:

$$RII = \frac{\sum W}{A \times N} \quad (3)$$

- W = weight given to each response (1–5),
- A = highest weight (5 in this study),
- N = total number of respondents.

The RII values range from 0 to 1, with higher values indicating more critical risk factors. In this study:

- RII was computed for all 31 factors;
- Factors retained through PCA (based on loading threshold) were then ranked according to their RII values;
- The top 21 risk factors and the four principal components were reported and discussed in Chapter 4.

This combination of PCA (for grouping) and RII (for ranking) is consistent with contemporary risk assessment practice, where dimensionality reduction and priority setting are integrated [27], [76], [77].

3.7.6 Software used

The analyses were performed using:

- IBM SPSS Statistics for reliability analysis, KMO and Bartlett's tests, PCA and descriptive statistics;
- Microsoft Excel for RII computation and preparation of tables and charts.

3.8 Triangulation and Validation through Key Informant Interviews

Triangulation involves using multiple methods or data sources to examine the same phenomenon, thereby enhancing the credibility and robustness of findings [70], [71]. In this study, triangulation was implemented by integrating quantitative survey results with qualitative KII insights.

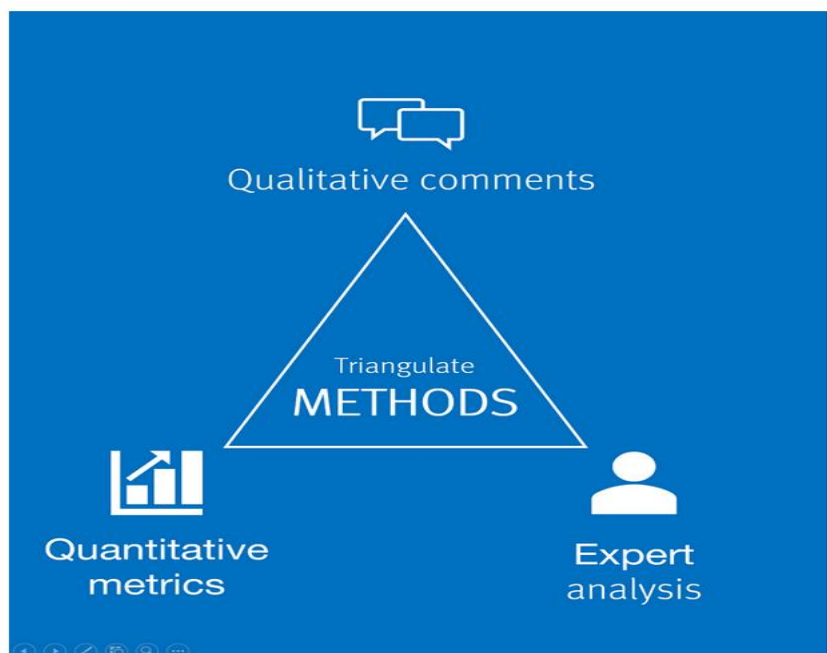


Figure 3.5 – Triangulation Method in Research

3.8.1 Triangulation rationale

Following Jick's classic argument for mixing quantitative and qualitative methods [70], and later elaborations on triangulation in applied research [71], the KII were designed to:

- Confirm whether the statistically derived components and rankings aligned with practitioners' lived experience;
- Identify any important risks that might not have been strongly highlighted in the quantitative results;
- Provide contextual explanations for why certain risk domains emerged as more critical in D&B bridge projects under DoR.

3.8.2 Selection of key informants

Key informants were chosen using purposive sampling [72]. Selection criteria included:

- At least more than 15 years of experience in bridge design, construction or contract management;
- Direct involvement in D&B bridge projects under DoR;
- Representation from different stakeholder groups (DoR, consultants, contractors).

This approach aligns with recommendations that key informants should be information-rich cases possessing specific and in-depth knowledge relevant to the research questions [72], [73].

3.8.3 KII procedure and analysis

A semi-structured KII guide was developed based on the PCA and RII results. Each interview included:

- A brief explanation of the research objectives and methods;
- Presentation of the four principal components and their indicative risk factors;
- Presentation of the top 10–15 risk factors according to RII;
- Open-ended questions asking informants to comment on:
 - Whether these components and rankings matched their experience;
 - Which risks they considered underestimated or overestimated;
 - Additional risks or contextual issues in D&B bridge projects.

Interviews were conducted either in person or online, with notes taken during each session. Responses were analysed through thematic coding, focusing on convergence or

divergence with the quantitative findings. Where informants consistently agreed with the PCA components and top RII factors, this was taken as confirmatory evidence. Any systematic disagreements or newly identified issues were documented and are discussed in Chapter 5 as implications and recommendations.

CHAPTER FOUR: DATA ANALYSIS, RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the detailed analysis and interpretation of the empirical data collected from practitioners involved in design and build (D&B) bridge projects implemented by the Department of Roads (DoR), Nepal. The chapter elaborates the results that were briefly reported in the research paper and provides additional explanations suitable for a full thesis.

The profile of the 92 respondents is first shown, along with some basic descriptive statistics about their risk assessments. Second, Cronbach's alpha, the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy, and Bartlett's test of sphericity are used to assess the 31-item risk scale's suitability and reliability and make sure the data satisfy the requirements for Principal Component Analysis (PCA) [78]–[80]. Third, the underlying components of risk are extracted using PCA with Varimax rotation and the Kaiser eigenvalue greater than one criterion. Four coherent risk domains are defined by interpreting the rotated component matrix [78], [61]–[6]. The rationale for the 0.70 factor loading cut-off is given special consideration, based on methodological literature that considers such loadings to be practically and substantively significant [82]–[56].

Fourth, individual risk factors are ranked using the Relative Importance Index (RII), which enhances the component structure by emphasizing the most important risks at the item level [27]–[43]. Fifth, risk domains for D&B bridge projects are prioritized by integrating PCA and RII results, and the results are interpreted in light of earlier studies on construction and bridge risks. In order to strengthen the validity of the conclusions, the chapter concludes with a brief summary of how these quantitative findings were triangulated with insights from Key Informant Interviews (KII) [70]–[73].

4.2 Respondent Profile and Descriptive Statistics

Professionals working on D&B bridge projects were given a total of 150 questionnaires; 92 complete answers were collected and kept for analysis after clear D&B experience and missing data were eliminated. This translates to a roughly 61% effective response

rate. The obtained sample size complies with widely used guidelines for factor analysis and multivariate analysis, which generally consider samples with more than five cases per item to be sufficient, especially when communalities are moderate and factor loadings are reasonably high [78], [79]. These guidelines suggest at least three to ten observations per variable. Thus, the current dataset satisfies recognized criteria for PCA and reliability analysis with 31 risk variables and 92 observations.

4.2.1 Organisational affiliation of respondents

Key stakeholder groups involved in D&B bridge projects under DoR, such as DoR engineers and project managers, bridge design consultants, D&B contractors, and a few academics or experts in policy or advisory roles, were represented among the respondents. Table 4.1: Organizational affiliation of respondents summarizes the distribution across these organizational categories.

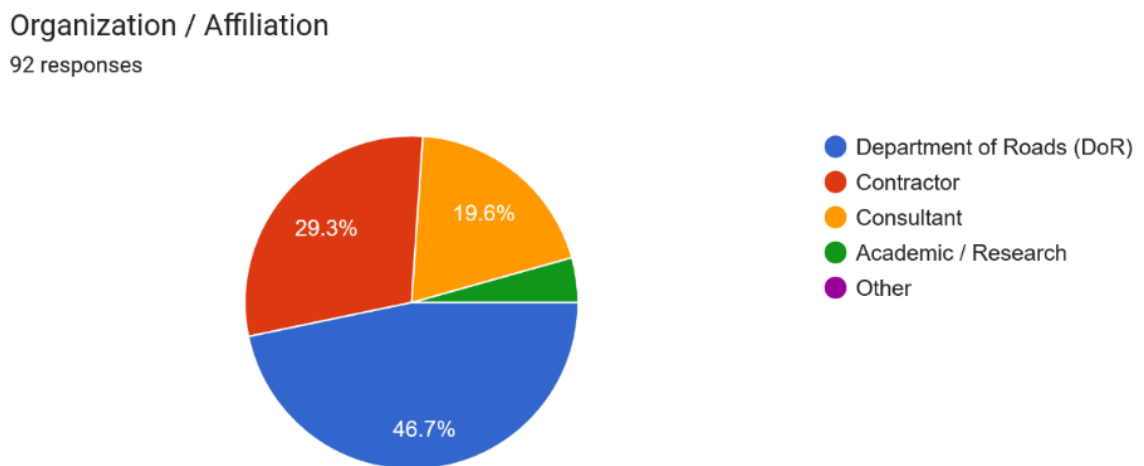


Figure 4.1 – Organizational Affiliation of Respondents

Table 3: Distribution of respondents by organisational affiliation (Table 4.1)

Organisation	<i>N</i>	%
Department of Roads (DoR)	43	46.74
Contractor	27	29.35
Consultant	18	19.57
Academia / Others	4	4.35
Total	92	100

Table 4.1 Organizational Affiliation of Respondents

A relatively balanced representation between client (DoR), consultant and contractor organisations helps to capture a wide range of perspectives on D&B bridge risks, which is important given that different parties typically emphasise different risk areas and consequences [87]–[26].

4.2.2 Designation and role in projects

Respondents held a range of designations, from junior engineers and site supervisors to senior divisional engineers, project managers and firm owners. Their primary roles in D&B bridge projects included design, contract administration, site supervision, construction management and overall project coordination.

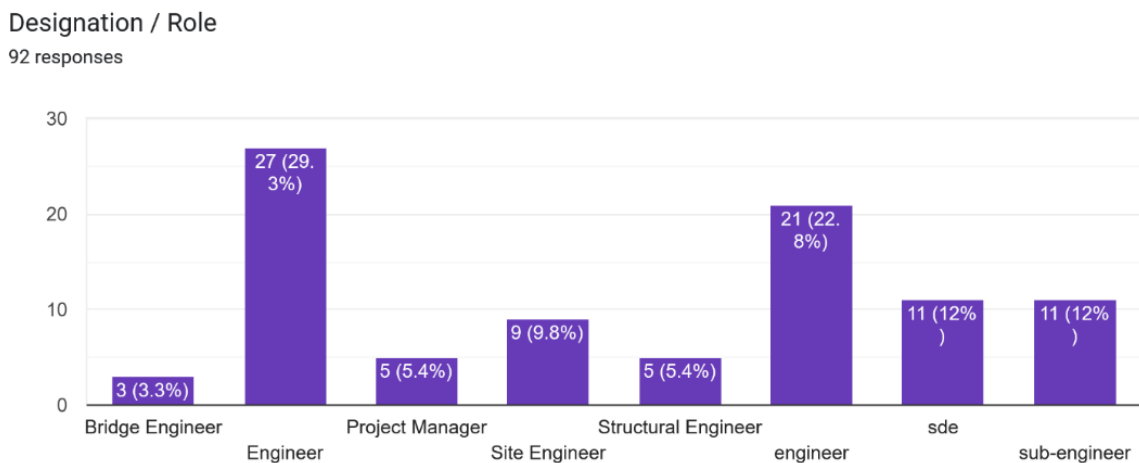


Figure 4.2 – Designation/Roles of Respondents

The presence of both technical and managerial roles aligns with findings in construction risk research that perceptions of risk and priorities for mitigation often differ between those primarily responsible for design, those managing construction on site and those overseeing contracts from the client side [87]–[26]. Including diverse roles therefore enhances the richness of the dataset and the resulting component structure.

4.2.3 Experience in bridge construction and D&B projects

Years of experience in bridge construction

92 responses

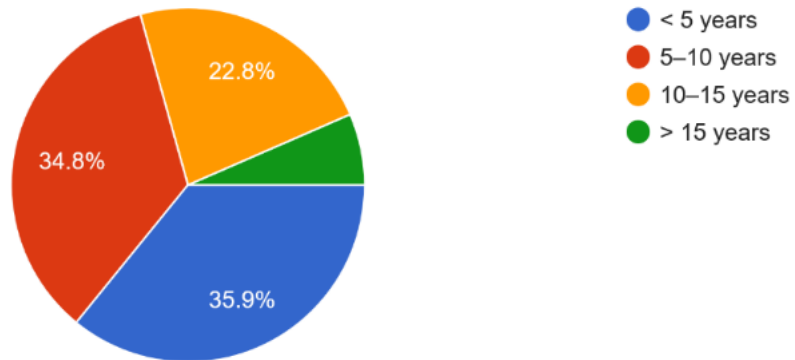


Figure 4.3 – Experience of Respondents in Bridge Construction

Years of experience	<i>N</i>	<i>%</i>
< 5 years	33	35.87
5-10 years	32	34.78
10-15 years	21	22.83
> 15 years	6	6.52
Total	92	100

Table 4.2 Experience of Respondents in Bridge Construction

The majority of respondents had more than five years of overall bridge construction experience, and a substantial share had direct experience in D&B bridge contracts. This experienced sample is desirable because risk assessment in D&B procurement requires familiarity with both design-related challenges (investigations, design changes, integration of disciplines) and construction-related execution risks (constructability, supply chain, supervision). Experienced respondents are also more likely to have encountered contractual disputes, claims and payment issues in practice, which improves the reliability of their risk ratings.

4.2.4 Descriptive statistics of risk ratings

A descriptive summary of the Likert-scale ratings (means and standard deviations) for the 31 risk factors is included in an appendix. Overall, the distribution of means suggests that most risks were perceived as at least moderately significant, with only a few items receiving very low average ratings. This is consistent with the subsequent RII analysis, which shows that nearly all identified risks fall within a relatively narrow band of medium-to-high importance, although several stand out as particularly critical for D&B bridges.

Descriptive Statistics			
Risk Factors	Mean	Std. Deviation	N
Inaccurate Initial Cost Estimate	2.64	1.095	92
Unreliable supply chain for specialized bridge materials	2.60	1.038	92
Material Specifications not complying with design	2.66	1.122	92
Inexperience in pricing tenders for Design and Build Works	2.64	1.085	92
Delay in Site Possession and Right of Way	2.67	1.091	92
Poor Site Management and Supervision	2.70	1.136	92
Delay in Environmental Permit and Clearance	2.67	1.101	92
Increased frequency of flash floods and non-seasonal rain	2.67	1.140	92
Disputes in Delay Claims and Liquidated Damages	2.71	1.163	92
Disputes regarding utilization of mobilization amount	2.59	1.050	92
Delays due to Design Errors and Omissions	2.66	1.132	92
Slow Information Flow and Approval	2.63	1.097	92
Shortage of Specialized Manpower	2.64	1.115	92
Multiple design changes during execution	2.66	1.112	92
Disputes due to Ambiguous Contract Clauses	2.68	1.128	92
Falsework Formwork Collapse	2.62	1.078	92
Poor Construction Quality Control by Sub-contractor	2.63	1.087	92
Design changes in protection works due to Scouring and Change in River	2.68	1.167	92
Initial Delays due to incomplete design integration	2.64	1.075	92

Conflicts due to overlapping designer contractor responsibilities	2.64	1.075	92
Scope modifications by client causing Late stage changes	2.72	1.151	92
Client Payment Delays	2.63	1.087	92
Volatile Material Price Escalation	2.65	1.084	92
Variations and Change Order Delays	2.47	0.931	92
Value Engineering Conflicts during Design Approval and Variation Order	2.74	1.212	92
Disputes due to unclear modality of payment	2.74	1.248	92
Constructability Issues in Innovative design practices	2.75	1.210	92
Discrepancies in predicted river hydrodynamics during flood	2.68	1.195	92
Foundation Redesign due to faulty soil test data	2.77	1.232	92
River Diversion Failures	2.77	1.276	92
Payment disputes arising from financial audit by constitutinal bodies	2.78	1.291	92

Table 4.3 Mean & Standard Deviation of Likert Scale Responses

4.3 Reliability of Risk Scale and Data Suitability for PCA

Before conducting PCA, the internal consistency of the 31-item risk scale and the suitability of the data for factor analysis were assessed. This step is standard in exploratory factor analysis and PCA applied to multi-item questionnaires [78], [61], [60].

4.3.1 Cronbach's alpha reliability

Cronbach's alpha (α) for the 31 risk items was calculated as 0.909, indicating excellent internal consistency of the scale. In general, values of α above 0.70 are considered acceptable, values above 0.80 good and values above 0.90 excellent in social science and management research [78], [61], [60]. Hair et al. [78] and Tabachnick and Fidell [79] note that such high values suggest that the items measure a coherent underlying construct, although very high alpha can also reflect a large number of items and some redundancy.

In this study, the items were deliberately generated and refined through a Delphi process and literature review, and they cover related but distinct risk aspects (administrative, technical, contractual and execution-related). The alpha value of 0.909 therefore indicates

that, taken as a whole, the scale reliably captures the overall construct of risk in D&B bridge contracts, while still allowing differentiation between more specific risk domains.

Statistic	Value
Cronbach's Alpha	0.909
Cronbach's Alpha (Standardised Items)	0.910
Number of Items	31

Table 4.4: Reliability statistics for the 31-item risk scale showing the value of Cronbach's alpha and the number of items in the scale.

4.3.2 KMO measure and Bartlett's test of sphericity

The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity were computed to assess whether the correlation matrix of the 31 items was suitable for factor analysis. The KMO value obtained was 0.854, which falls within the meritorious range according to Kaiser's classification (0.80–0.89) [65]. Dziuban and Shirkey [80] and other authors recommend KMO values of at least 0.60, with values above 0.80 indicating that the patterns of correlation are sufficiently compact and that factor analysis is likely to yield distinct and reliable components [65], [80].

Bartlett's test of sphericity was highly significant ($p < 0.001$), rejecting the null hypothesis that the correlation matrix is an identity matrix. This indicates that the items are sufficiently intercorrelated to justify the application of PCA.

Measure	Value
Kaiser–Meyer–Olkin Measure of Sampling Adequacy	0.854
Bartlett's Test of Sphericity (Approx. Chi-square)	2144.445
Degrees of Freedom (df)	465
Significance (Sig.)	$p < 0.001$

Table 4.5: KMO and Bartlett's test for the 31-item risk scale.

Together, the high KMO value and significant Bartlett's test confirm that the dataset is well suited for PCA, consistent with widely accepted decision rules for factor analysis [65], [80].

4.4 Principal Component Analysis Results

PCA was conducted on the 31 risk items using Varimax rotation and the Kaiser eigenvalue-greater-than-one criterion to identify latent components underlying the observed correlations. Varimax is an orthogonal rotation method introduced by Kaiser [64], designed to achieve a simple structure where each item loads highly on only one component and weakly on others, facilitating interpretation [64]–[6]. The Kaiser criterion and scree plot were used jointly to select a set of components [81], [6].

4.4.1 Component extraction, eigenvalues and scree plot

The initial, unrotated PCA solution produced a set of eigenvalues associated with each component. Applying the Kaiser criterion (eigenvalues > 1) resulted in the extraction of four principal components. Together, these four components explained approximately 67.75% of the total variance in the 31 risk variables, which is above the often-cited threshold of 60% for social science applications and is considered satisfactory for complex, multi-dimensional constructs like construction risk [78], [79], [81].

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.713	28.108	28.108	8.713	28.108	28.108	5.881	18.970	18.970
2	4.882	15.749	43.856	4.882	15.749	43.856	5.644	18.206	37.176
3	4.356	14.053	57.909	4.356	14.053	57.909	5.056	16.311	53.487
4	3.050	9.840	67.749	3.050	9.840	67.749	4.421	14.262	67.749
5	0.942	3.040	70.789						
6	0.853	2.751	73.540						
7	0.816	2.633	76.173						
8	0.691	2.230	78.404						
9	0.660	2.128	80.532						
10	0.557	1.797	82.329						
11	0.535	1.724	84.053						
12	0.500	1.613	85.666						

13	0.45 2	1.459	87.125						
14	0.39 3	1.266	88.391						
15	0.38 3	1.234	89.626						
16	0.35 8	1.156	90.782						
17	0.34 8	1.124	91.906						
18	0.31 3	1.009	92.915						
19	0.28 1	0.908	93.822						
20	0.25 9	0.835	94.657						
21	0.22 9	0.738	95.395						
22	0.21 5	0.694	96.089						
23	0.19 7	0.634	96.723						
24	0.18 0	0.580	97.303						
25	0.16 6	0.535	97.838						
26	0.15 8	0.509	98.348						
27	0.13 0	0.418	98.766						
28	0.12 4	0.400	99.166						
29	0.10 5	0.340	99.506						
30	0.08 8	0.283	99.789						
31	0.06 6	0.211	100.000						
Extraction Method: Principal Component Analysis.									

Table 4.6 : Total variance explained by extracted components

The detailed eigenvalues, percentage of variance explained by each component and cumulative variance are presented in Table 4.6 : Total variance explained by extracted components.

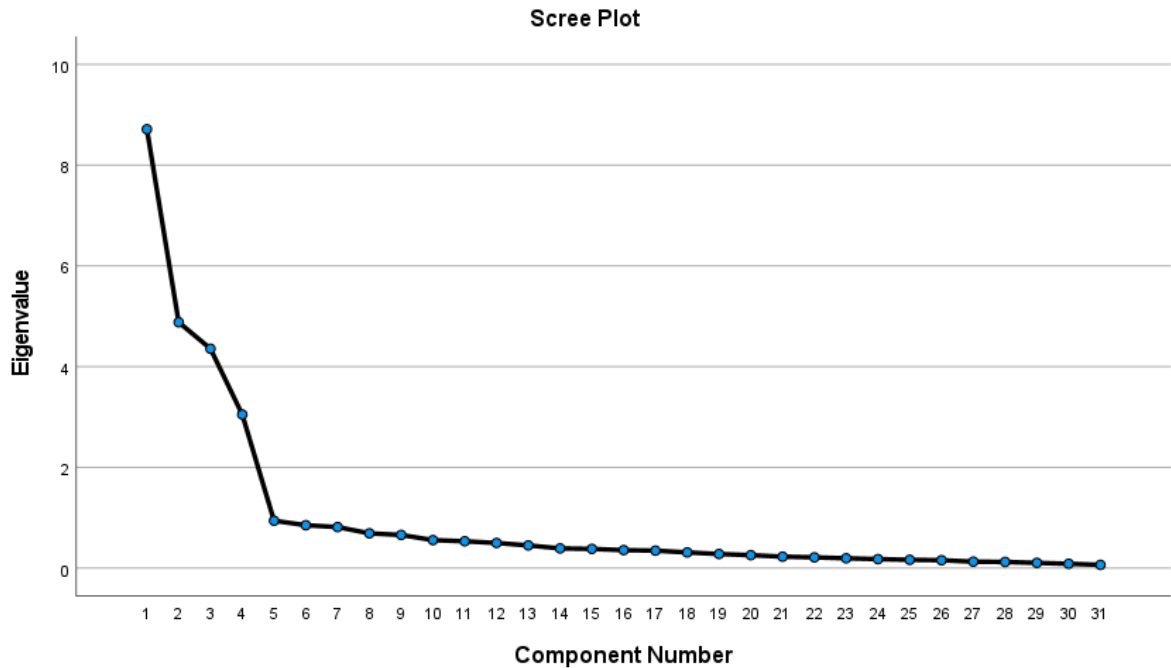


Figure 4.4 : Scree plot of eigenvalues for the 31 risk items

Figure 4.1 : Scree plot of eigenvalues for the 31 risk items shows a clear elbow after the fourth component, supporting the retention of four components, consistent with standard practice in PCA and EFA [61], [81], [6].

4.4.2 Rotated component matrix and factor loadings

After extraction, Varimax rotation was applied to obtain a rotated component matrix with more interpretable loadings. The rotated solution showed that each component had several items with high positive loadings, while loadings on other components were small in magnitude. To focus on substantively important associations and reduce noise, a factor loading cut-off of 0.70 was adopted when interpreting the components.

Literature on exploratory factor analysis and PCA indicates that loadings of around 0.30–0.40 are the minimum threshold for inclusion, 0.50 or above are typically considered practically significant, and loadings of 0.70 and above indicate a strong, practically important association between the item and the underlying factor [82]–[56]. Maskey et al. [82] explicitly note that factor loadings greater than 0.70 are considered practically significant in applied research. Kim et al. [83] argue that loadings of approximately 0.707 correspond to good convergent validity in factor-analytic models, and Ahmed et al. [56] describe loadings of 0.70 and above as a perfect factor loading in the context of

technology acceptance measurement. Given these guidelines, adopting a 0.70 cut-off in this thesis provides a conservative and robust basis for identifying the core items that strongly define each component.

Using this cut-off, 21 of the 31 risk factors exhibited loadings ≥ 0.70 on one of the four components and low cross-loadings on others.

Rotated Component Matrix					
Variable	Label	Component			
		1	2	3	4
Q1	Inaccurate Initial Cost Estimate	0.406	0.217	0.680	0.145
Q2	Unreliable supply chain for specialized bridge materials	0.053	0.731	0.113	0.157
Q3	Material Specifications not complying with design	0.672	0.192	0.041	0.195
Q4	Inexperience in pricing tenders for Design and Build Works	0.090	0.902	0.054	-0.052
Q5	Delay in Site Possession and Right of Way	0.878	0.044	-0.012	0.026
Q6	Poor Site Management and Supervision	-0.064	0.201	0.541	0.601
Q7	Delay in Environmental Permit and Clearance	0.828	0.100	-0.032	0.056
Q8	Increased frequency of flash floods and non-seasonal rain	0.010	0.117	0.685	0.192
Q9	Disputes in Delay Claims and Liquidated Damages	0.048	-0.012	0.040	0.852
Q10	Disputes regarding utilization of mobilization amount	0.530	0.116	-0.055	0.092
Q11	Delays due to Design Errors and Omissions	-0.002	0.136	0.885	-0.032
Q12	Slow Information Flow and Approval	0.860	0.055	-0.047	0.066
Q13	Shortage of Specialized Manpower	0.039	0.881	0.152	0.180
Q14	Multiple design changes during execution	0.006	0.062	0.899	0.129
Q15	Disputes due to Ambiguous Contract Clauses	0.068	-0.010	0.170	0.878

Q16	Falsework Formwork Collapse	0.472	0.640	0.069	0.063
Q17	Poor Construction Quality Control by Sub-contractor	0.106	0.854	0.103	0.117
Q18	Design changes in protection works due to Scouring and Change in River	0.147	0.572	0.602	0.000
Q19	Initial Delays due to incomplete design integration	0.701	-0.001	0.075	0.067
Q20	Conflicts due to overlapping designer contractor responsibilities	0.115	0.866	0.166	0.029
Q21	Scope modifications by client causing Late stage changes	-0.093	0.140	0.872	0.045
Q22	Client Payment Delays	0.716	0.071	0.056	-0.120
Q23	Volatile Material Price Escalation	0.080	0.722	0.147	-0.072
Q24	Variations and Change Order Delays	0.835	0.132	-0.028	0.120
Q25	Value Engineering Conflicts during Design Approval and Variation Order	-0.053	-0.003	0.829	0.045
Q26	Disputes due to unclear modality of payment	0.106	0.108	0.083	0.859
Q27	Constructability Issues in Innovative design practices	0.062	0.723	-0.023	-0.154
Q28	Discrepancies in predicted river hydrodynamics during flood	0.085	0.062	0.006	0.695
Q29	Foundation Redesign due to faulty soil test data	0.658	0.077	0.512	0.066
Q30	River Diversion Failures	0.557	-0.010	0.043	0.593
Q31	Payment disputes arising from financial audit by constitutinal bodies	0.100	-0.072	0.094	0.844

Table 4.7 : Rotated Component Matrix Showing Factor Loadings

Component	Variables with high loadings
Component 1 – Administrative and Regulatory Risk	– Q5 Delay in site possession and right of way (0.878); Q7 Delay in environmental permit and clearance (0.828); Q19 Initial delays due to incomplete design integration (0.701); Q12 Slow information flow and approval (0.860); Q22 Client payment delays (0.716); Q24 Variations and change order delays (0.835)
Component 2 – Execution and Supply Chain Risks	Q27 Constructability issues in innovative design practices (0.723); Q23 Volatile material price escalation (0.722); Q4 Inexperience in pricing tenders for D&B works (0.902); Q13 Shortage of specialised manpower (0.881); Q20 Conflicts due to overlapping designer–contractor responsibilities (0.866); Q17 Poor construction quality control by sub-contractor (0.854); Q2 Unreliable supply chain for specialised bridge materials (0.731)
Component 3 – Design and Technical Integration Risks	Q25 Value engineering conflicts during design approval and variation order (0.829); Q21 Scope modifications by client causing late-stage changes (0.872); Q11 Delays due to design errors and omissions (0.885); Q14 Multiple design changes during execution (0.899)
Component 4 – Contractual and Financial Dispute Risks	Q31 Payment disputes arising from financial audit by constitutional bodies (0.844); Q26 Disputes due to unclear modality of payment (0.859); Q9 Disputes in delay claims and liquidated damages (0.852); Q15 Disputes due to ambiguous contract clauses (0.878)

Table 4.8 : Summary of Rotated Component Matrix

The rotated loadings (≥ 0.70) are summarised in Table 4.8 : Summary of rotated component loadings. Items with loadings below 0.70 are still used in the RII analysis and contribute to the overall scale reliability, but they are not treated as core defining variables for naming the components.

4.4.3 Naming and interpretation of components

Based on the pattern of high loadings, the four components were interpreted and named as follows:

Component 1 – Administrative and Regulatory Risk

This component includes items such as:

- Delay in site possession and right of way;
- Delay in environmental permit and clearance;
- Initial delays due to incomplete design integration;
- Slow information flow and approval;
- Client payment delays;
- Variations and change order delays.

These risks relate primarily to client-side administrative processes, regulatory approvals, internal decision-making and variations. The component captures bottlenecks in land acquisition, environmental permitting, design integration and approval procedures that can delay project start and progress. Such administrative and regulatory risks have been highlighted as important drivers of delay and cost escalation in public-sector projects in many countries [78], [87], [88].

Component 2 – Execution and Supply Chain Risks

High-loading items include:

- Constructability issues in innovative design practices;
- Volatile material price escalation;
- Inexperience in pricing tenders for D&B works;
- Shortage of specialised manpower;
- Conflicts due to overlapping designer–contractor responsibilities.

This component reflects contractor-side and supply-chain challenges, such as correct pricing of integrated design–build work, shortages of specialised skills, material price volatility and constructability issues when implementing innovative designs. Similar clusters of execution and supply-chain risks have been reported in PCA-based studies of construction risk and project delays [74], [85], [87], [89].

Component 3 – Design and Technical Integration Risks

Key items include:

- Foundation redesign due to faulty soil test data;
- River diversion failures;
- Design errors and omissions;
- Scope modifications by client causing late-stage changes.

These risks relate to deficiencies in geotechnical and hydrological investigations, design errors and late changes in scope. The component underscores the importance of robust upstream investigations and properly coordinated design in riverine bridge projects, echoing wider literature that emphasises geotechnical and hydraulic uncertainties as critical risk drivers in bridge and infrastructure projects [87], [88], [89], [90].

Component 4 – Contractual and Financial Dispute Risks

High-loading items include:

- Payment disputes arising from financial audit by constitutional bodies;
- Disputes in delay claims and liquidated damages;
- Poor site management and supervision;
- Disputes due to ambiguous contract clauses.

This component groups risks related to contract interpretation, dispute over delay claims and liquidated damages, ambiguous clauses and payment disputes, especially those triggered by external financial audits. While poor site management is also operational, in this dataset it loads with dispute-related items, reflecting how management shortcomings often become contentious issues in claims. Similar contractual and dispute-related risk clusters have been identified in studies of construction contracts and risk allocation [87]–[26]. Each component exhibits excellent internal consistency when reliability is computed for the subset of items associated with that component, with Cronbach’s alpha values above 0.80 for all four components (see **Table 4.9**)

Administrative & Regulatory Risk				Design & Technical Integration Risks			
Component 1		RII Rank	Cronbach's α	Component 3		RII Rank	Cronbach's α
Q5	Delay in Site Possession and Right of Way	8.000	0.904	Q25	Value Engineering Conflicts during Design Approval and	3.000	0.923
Q7	Delay in Environmental Permit and Clearance	9.000		Q21	Scope modifications by client causing Late	5.000	
Q19	Initial Delays due to incomplete design integration	15.000		Q11	Delays due to Design Errors and Omissions	10.000	
Q12	Slow Information Flow and Approval	17.000		Q14	Multiple design changes during	11.000	
Q22	Client Payment Delays Variations and Change	19.000					
Q24	Order Delays	21.000					
Execution & Supply Chain Risks				Contractual & Financial Dispute Risks			
Component 2		RII Rank	Cronbach's α	Component 4		RII Rank	Cronbach's α
Q27	Constructability Issues in Innovative design practices	2.000	0.922	Q31	Payment disputes arising from financial audit by constitutional bodies	1.000	0.907
Q23	Volatile Material Price Escalation	12.000		Q26	Disputes due to unclear modality of payment	4.000	
Q4	Inexperience in pricing tenders for Design and Build Works	13.000		Q9	Disputes in Delay Claims and Liquidated Damages	6.000	
Q13	Shortage of Specialized Manpower	14.000		Q15	Disputes due to Ambiguous Contract Clauses	7.000	
Q20	Conflicts due to overlapping designer contractor responsibilities	16.000					
Q17	Poor Construction Quality Control by Sub-contractor	18.000					
Q2	Unreliable supply chain for specialized bridge materials	20.000					

Figure 4.5 : Component-wise RII Rank Loading and Cronbach Alpha

Component	Cronbach's α
Administrative and Regulatory Risk	0.904
Execution and Supply Chain Risks	0.922
Design and Technical Integration Risks	0.923
Contractual and Financial Dispute Risks	0.907

Table 4.9 : Component-wise reliability statistics

Overall, the PCA results provide a compact and interpretable structure of four latent risk domains—Administrative and Regulatory Risk, Execution and Supply Chain Risks, Design and Technical Integration Risks, and Contractual and Financial Dispute Risks—explaining a substantial proportion of the variance in practitioners' risk ratings.

4.5 Relative Importance Index (RII) Results and Ranking of Risk Factors

While PCA groups correlated risk factors into components, project decision-makers also need to know which specific risks are perceived as most critical. To address this, the Relative Importance Index (RII) was used to rank the 31 risk factors.

4.5.1 RII computation

For each risk factor, the RII was calculated using the standard formula:

To prioritise individual risk factors, the Relative Importance Index (RII) was calculated from the Likert ratings using:

$$RII = \frac{\sum W}{A \times N} \quad (3)$$

where $\sum W$ is the sum of the weights assigned to a given factor by all respondents (with weights corresponding to Likert ratings from 1 to 5), A is the highest possible rating (5 in this study) and N is the total number of respondents (92). This index ranges from 0 to 1, with higher values indicating higher perceived importance. The RII method is widely used in construction research to rank delay causes, risk factors and performance indicators [27]–[43].

4.5.2 Top ten risk factors by RII

In this study, RII values for the 31 risk factors ranged from approximately 0.49 to 0.56. Below is the list of the ten highest-ranked risks along with their RII values and ranks. The top ten are :

Code	Factor description	RII	Rank
Q31	Payment disputes arising from financial audit by constitutional bodies	0.5565	1
Q29	Foundation redesign due to faulty soil test data	0.5543	2
Q30	River diversion failures	0.5543	3
Q27	Constructability issues in innovative design practices	0.5500	4
Q25	Value engineering conflicts during design approval and variation order	0.5478	5
Q26	Disputes due to unclear modality of payment	0.5478	6
Q21	Scope modifications by client causing late-stage changes	0.5435	7
Q9	Disputes in delay claims and liquidated damages	0.5413	8
Q6	Poor site management and supervision	0.5391	9
Q15	Disputes due to ambiguous contract clauses	0.5370	10

Table 4.10 : Top Ten Ranked Risk Factors in RII Ranking

These results highlight several important patterns:

- Contractual and financial disputes feature prominently, with payment disputes, unclear payment modalities, disputes in delay claims and liquidated damages and disputes due to ambiguous contract clauses among the top ten. This aligns with international literature showing that unclear risk allocation, ambiguous clauses and weak claim mechanisms are major sources of conflict and project underperformance [87]–[26].
- Geotechnical and hydraulic uncertainties (foundation redesign and river diversion failures) rank very highly, reflecting the challenges posed by foundation design, soil investigations and river diversion in Nepal’s complex riverine environments. Studies on bridge risks in other contexts likewise emphasise geotechnical and hydraulic issues as critical [89], [90].
- Constructability and design–execution interface issues (constructability of innovative designs, value engineering conflicts, late scope modifications and poor site management) are also among the top risks. Innovative designs without adequate constructability review, value engineering conflicts during design approval and late-stage scope changes

can undermine the theoretical advantages of D&B procurement by increasing rework, delays and cost overruns [74]–[43], [87].

Taken together, the RII results confirm that, although many risks are perceived as important, contractual/financial dispute risks, design and investigation-related uncertainties and constructability problems stand out as particularly critical for D&B bridge performance under DoR.

4.6 Integrated Interpretation and Validation of Findings

4.6.1 Priority ranking of risk components

To synthesise the PCA and RII results, the RII values of items within each component were examined, and the components were ranked according to the concentration of high-RII items. This integrated analysis showed that the most severe risks in D&B bridge projects are concentrated in:

1. Contractual and Financial Dispute Risks (Component 4) – highest proportion of top-ranked RII items;
2. Execution and Supply Chain Risks (Component 2) – includes high-ranked constructability and pricing-related risks;
3. Design and Technical Integration Risks (Component 3) – includes foundation redesign, river diversion failures and late scope changes;
4. Administrative and Regulatory Risk (Component 1) – important, but relatively fewer items in the absolute top of the RII ranking.

Rank based on RII Loading	Component No.	Label
1	4	Contractual & Financial Dispute Risks
2	2	Execution & Supply Chain Risks
3	3	Design & Technical Integration Risks
4	1	Administrative & Regulatory Risk

Table 4.11 : Component-wise ranking of risk using RII loading

This ordering (C4 > C2 > C3 > C1) provides a hierarchy of risk domains that can guide DoR and other stakeholders in prioritising risk management efforts.

4.6.2 Comparison with previous studies

The structure and ranking of components are consistent with findings from international construction risk literature. Many studies have reported contractual and financial risks—such as payment delays, claims, disputes and ambiguous clauses—as primary drivers of delay and cost overrun in public works [27]–[43], [87]–[26]. Execution and supply-chain risks, including material price escalation, labour shortages and inadequate contractor capacity, are likewise frequently cited as critical [74], [85], [87]. Design and technical risks related to geotechnical investigations, hydrology and scope changes have been linked to serious performance issues in bridge and heavy civil projects [89], [90].

The present results therefore confirm that D&B bridges under DoR face a similar constellation of risks as reported in other countries, but with specific manifestations related to Nepal’s institutional and geomorphic context—particularly the influence of external audits by constitutional bodies on payment disputes, and the challenges of designing and constructing bridges over dynamic rivers.

4.6.3 Triangulation with Key Informant Interviews (KII)

To strengthen the validity of the quantitative findings, Key Informant Interviews (KII) were conducted with a purposive sample of senior engineers, consultants and contractors who have extensive experience with D&B bridge projects under DoR. Purposive expert sampling is widely recommended for key informant studies, as it selects respondents based on their knowledge and involvement in the phenomenon of interest [72]. Triangulating survey-based statistical results with in-depth qualitative insights is a recognised strategy for enhancing credibility and contextual understanding [70], [86], [73].

The KII responses broadly confirmed the priority areas identified by PCA and RII:

- Contractual and financial disputes : Key informants highlighted frequent disputes arising from unclear payment procedures, delayed payments during and after audits, and differing interpretations of clauses related to extensions of time, liquidated damages and variation orders. These narratives reinforce the prominence of Component 4 and the high RII ranking of payment and dispute-related items.
- Execution and supply-chain challenges : Several informants emphasised difficulties in accurately pricing D&B tenders due to uncertain investigations and fluctuating material

prices, as well as shortages of specialised bridge construction skills and coordination issues between design and site teams. These insights align with Component 2 and the elevated RII of constructability-related risks and pricing/inexperience risks.

- Design and technical integration issues : Informants also reported cases where inadequate or rushed geotechnical and hydrological studies led to foundation redesign, river diversion challenges and late design changes after construction had already commenced. This corroborates the high ranking of foundation redesign and river diversion risks and the importance of Component 3.

- Administrative and regulatory bottlenecks : Although ranked fourth in the integrated analysis, key informants still described land acquisition, environmental clearance and slow decision-making as significant sources of early delay and uncertainty. This supports the inclusion of Component 1 as a distinct risk domain that, while not in the very top tier, remains important for overall project performance.

Overall, the KII triangulation suggests a high degree of convergence between practitioners' quantitative ratings and their qualitative accounts of risk experiences in D&B bridges. This convergence increases confidence that the four-component structure and the prioritised risk list are not artefacts of the statistical method alone, but reflect real-world patterns observed by experienced professionals [70]–[73].

4.7 Summary of the Chapter

This chapter has presented an in-depth analysis and discussion of the empirical results of the study. The main findings can be summarised as follows:

- The 31-item risk scale exhibited excellent internal consistency, with Cronbach's alpha of 0.909, and the dataset showed meritorious sampling adequacy ($KMO = 0.854$) and a highly significant Bartlett's test, confirming suitability for PCA [78]–[80].

- PCA with Varimax rotation and the Kaiser eigenvalue > 1 criterion extracted four coherent components, explaining approximately 67.75% of the total variance. These components were interpreted as Administrative and Regulatory Risk, Execution and Supply Chain Risks, Design and Technical Integration Risks, and Contractual and Financial Dispute Risks. Using a conservative loading threshold of 0.70, 21 risk items

were strongly associated with these components, each component demonstrating excellent internal consistency [78], [61]–[56].

- RII analysis revealed that the most critical individual risks relate to payment disputes and unclear payment modalities, foundation redesign due to inadequate soil data, river diversion failures, constructability issues in innovative designs, late scope modifications and disputes arising from ambiguous contract clauses. The RII values were tightly clustered, indicating that practitioners perceived most of the identified risks as at least moderately important, but with a clear subset standing out as especially critical [27]–[43].

- Integrating PCA and RII showed that Contractual and Financial Dispute Risks (Component 4) and Execution and Supply Chain Risks (Component 2) form the top priority risk domains, followed by Design and Technical Integration Risks (Component 3) and Administrative and Regulatory Risk (Component 1). This hierarchy offers a structured basis for prioritising risk mitigation strategies in D&B bridge projects.

- Triangulation through Key Informant Interviews confirmed and contextualised these findings: senior practitioners described experiences that closely mirrored the statistically identified risk patterns, particularly around contract/payment disputes, geotechnical and hydraulic uncertainties and constructability challenges, thereby enhancing the credibility and practical relevance of the results [70]–[73].

These findings provide the empirical foundation for the conclusions and recommendations presented in the next chapter, where specific risk management measures are proposed for DoR and other stakeholders in D&B bridge delivery.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Overview

This chapter presents the overall conclusion and recommendations of the study on risk assessment of design and build (D&B) bridge projects implemented by the Department of Roads (DoR), Nepal.

5.2 Summary of the Study

5.2.1 Overall aim and research questions

The aim of the study was to assess, structure and prioritise risks in D&B bridge projects implemented by DoR, with a view to supporting better risk allocation and contract management. In line with this aim, three research questions were posed:

- RQ1 : What are the major risk factors that affect D&B bridge contracts implemented by DoR in Nepal?
- RQ2 : How can these individual risk factors be grouped into broader, interpretable components that reflect underlying patterns in project delivery?
- RQ3 : Which risk components and individual risks are perceived by practitioners as most critical for D&B bridge projects in Nepal?

These questions guided both the design of the empirical work and the subsequent analysis using Principal Component Analysis (PCA) and Relative Importance Index (RII), later validated through KII.

5.2.2 Research design and methodology

To address the above questions, the study adopted a mixed-methods, cross-sectional design:

1. Delphi-based risk identification and refinement

- A two-round Delphi survey with experienced DoR engineers, consultants and contractors was conducted.
- Round 1 used open-ended questions to elicit risk factors affecting time, cost, quality and safety in D&B bridge projects.
- Round 2 asked experts to rate the importance of the consolidated risk list on a 1–9

scale, using mean and interquartile range (IQR) criteria to reach consensus and refine the list to 31 risk factors.

2. Questionnaire survey and quantitative analysis

- The 31 risk factors were incorporated into a structured questionnaire, where 92 practitioners with direct D&B bridge experience rated each factor on a five-point Likert scale (1–5).

- Data were screened for completeness and coded, then analysed using :
 - Reliability analysis (Cronbach’s alpha);
 - Kaiser–Meyer–Olkin (KMO) measure and Bartlett’s test of sphericity for data suitability;
 - PCA with Varimax rotation and the Kaiser eigenvalue > 1 criterion;
 - RII to rank the importance of individual risk factors.

3. Key Informant Interviews (KII) for triangulation

- After quantitative analysis, semi-structured KII were conducted with a purposive set of senior DoR officials, consultants and contractors, selected as key informants based on their deep experience with D&B bridge contracts.

- The KII guide presented the four PCA components and the top-ranked RII risks and asked informants to comment on their validity, relative importance and contextual explanations.

- The resulting qualitative insights were thematically analysed to confirm, nuance or challenge the statistical findings.

The study area focused mainly on D&B bridges within the jurisdiction of the Bridge Sector Office Dharan (Koshi Province), but the risk categories and findings are relevant to DoR D&B practice more generally.

5.3 Summary of Key Findings

This section summarises the main findings in relation to the specific objectives of the study.

5.3.1 Objective 1 – Identification of risk factors

Objective 1 (O1) was to identify and compile a comprehensive list of risk factors relevant to D&B bridge contracts under DoR.

- The Delphi rounds, informed by literature and expert judgement, produced a refined list of 31 distinct risk factors covering:
 - Administrative and regulatory issues (e.g. site possession, environmental clearances, approvals and variations);
 - Execution and supply-chain issues (e.g. material price volatility, unreliable suppliers, shortages of specialised manpower, sub-contractor quality control);
 - Design and technical integration issues (e.g. inadequate investigations, design errors, design changes during execution, scope modifications);
 - Contractual and financial disputes (e.g. payment procedures, audit-related disputes, ambiguous clauses, delay claims and liquidated damages).

These risks collectively address the full project lifecycle under D&B delivery, from investigations and design to construction, contract administration and external oversight.

5.3.2 Objective 2 – Classification of risks into components (PCA)

Objective 2 (O2) was to apply quantitative techniques to classify the identified risks into coherent components that reflect broader areas of study of those risks.

Key findings:

- The 31-item scale showed excellent reliability, with Cronbach’s alpha of 0.909, indicating a strong internal consistency of the overall risk construct.
- The KMO value of 0.854 (“meritorious”) and a highly significant Bartlett’s test ($p < 0.001$) confirmed that the correlation matrix was suitable for factor analysis.
- PCA with Varimax rotation and the eigenvalue > 1 criterion extracted four principal components, jointly explaining 67.75% of the total variance.
- Applying a conservative factor loading cut-off of 0.70, justified by methodological literature as reflecting strong practical and convergent validity, 21 out of 31 risk factors were retained as core defining items for the components.

The four components were interpreted as:

1. Administrative and Regulatory Risk;
2. Execution and Supply Chain Risks;
3. Design and Technical Integration Risks;
4. Contractual and Financial Dispute Risks.

Each component displayed excellent internal consistency (component-wise Cronbach's alpha > 0.90), confirming that the grouped risks form coherent domains.

5.3.3 Objective 3 – Prioritisation of critical risks and components (RII + KII)

Objective 3 (O3) was to find the risk factors and areas which are most critical to the D&B bridge projects as perceived by practitioners.

From the RII analysis:

- RII values for the 31 risks ranged from about 0.49 to 0.56, indicating that most identified risks are perceived as at least moderately important.
- The top 10 risks by RII were dominated by:
 - Contractual and financial dispute risks:
 - Payment disputes arising from financial audit by constitutional bodies;
 - Disputes due to unclear modality of payment;
 - Disputes in delay claims and liquidated damages;
 - Disputes due to ambiguous contract clauses.
 - Technical and constructability risks:
 - Foundation redesign due to faulty soil test data;
 - River diversion failures;
 - Constructability issues in innovative design practices;
 - Value engineering conflicts during design approval and variation order;
 - Scope modifications by client causing late-stage changes.
 - Management risk:
 - Poor site management and supervision.

By examining the concentration of high-RII items within each PCA component, the components were prioritised as:

1. Contractual and Financial Dispute Risks (Component 4);
2. Execution and Supply Chain Risks (Component 2);
3. Design and Technical Integration Risks (Component 3);
4. Administrative and Regulatory Risk (Component 1).

The KII findings strongly supported this ordering. Key informants consistently emphasised:

- The central role of contract interpretation, payment mechanisms and audit-related disputes in creating uncertainty and delay;
- The importance of execution capacity, pricing accuracy and supply-chain reliability;
- Persistent geotechnical and hydrological uncertainties and late design changes;
- The impact of land acquisition and regulatory processes, especially at early stages.

5.4 Conclusions

Based on the empirical findings and triangulation with expert interviews, several major conclusions can be drawn.

5.4.1 D&B bridge projects face a multi-dimensional but structured risk landscape

D&B bridge projects under DoR are exposed to a broad set of risks spanning administration, design, execution, supply chain and contractual domains. However, these risks are not random or unstructured; they can be meaningfully grouped into four latent components:

1. Administrative and Regulatory Risk;
2. Execution and Supply Chain Risks;
3. Design and Technical Integration Risks;
4. Contractual and Financial Dispute Risks.

This structure confirms that practitioners perceive risk in interrelated domains, rather than as isolated factors, supporting the use of multivariate tools like PCA for risk classification.

5.4.2 Contractual and financial dispute risks are the top priority domain

Despite the presence of significant technical and administrative risks, the domain of Contractual and Financial Dispute Risks emerged as the highest-priority component, with the highest concentration of top-ranked RII items. Payment disputes, unclear payment modalities, ambiguous contract clauses and disagreements over delay claims and liquidated damages are perceived as especially critical for D&B bridge performance.

Combined with KII evidence, this indicates that contractual clarity and financial risk allocation are currently weak points in D&B bridge contracts under DoR. Even when

physical construction progresses satisfactorily, disputes over interpretation of provisions, audit findings and payment processes can cause severe disruptions.

5.4.3 Execution and supply-chain constraints significantly affect D&B performance

The second highest-priority component, Execution and Supply Chain Risks, reflects persistent challenges in correctly pricing D&B tenders, managing material price escalation, ensuring reliable supply of specialised materials and securing qualified technical staff. Constructability issues in innovative designs and quality problems with sub-contractors further complicate execution.

The findings suggest that the theoretical advantages of D&B—such as improved constructability and integrated design–construction—are not fully realised when contractor capacity and supply-chain reliability are constrained or when risk is not realistically priced and managed.

5.4.4 Design and technical integration remain critical in riverine bridge context

The third component, Design and Technical Integration Risks, highlights that D&B bridge projects remain vulnerable to inadequate investigations, design errors, frequent design changes and late scope modifications. Foundation redesign due to faulty soil data, river diversion failures and repeated design revisions indicate that pre-tender investigations and design coordination still require strengthening.

In a country with complex geomorphology and active river systems, managing these technical risks is essential for both structural safety and whole-life performance of bridges.

5.4.5 Administrative and regulatory delays compound other risks

Although Administrative and Regulatory Risk ranks fourth in the integrated priority order, it still plays a substantial role in initiating delays and uncertainties, particularly in early project stages. Delays in site possession, right-of-way, environmental clearances and internal approvals can compound technical and contractual risks by compressing schedules, forcing rushed decisions and increasing the likelihood of claims and variations.

5.4.6 KII triangulation confirms and contextualises quantitative findings

The KII triangulation provides strong confirmation of the PCA and RII results. Senior practitioners' narratives align closely with the identified priority domains and top risks, particularly regarding audit-related payment disputes, uncertain ground conditions, constructability challenges and administrative bottlenecks.

At the same time, the KII add nuance by highlighting:

- The importance of institutional culture (e.g. risk aversion around audits);
- The influence of political and local pressures on land acquisition and scope changes;
- Practical constraints on early investigations and design coordination within existing budgeting and scheduling frameworks.

This convergence between quantitative and qualitative evidence increases the credibility and practical relevance of the conclusions drawn.

5.5 Recommendations

Based on the above conclusions, the following recommendations are proposed for key stakeholder groups.

5.5.1 Recommendations for DoR and policymakers

1. Refine D&B contract provisions on payment and claims

- Clarify the payment modality, including interim payments, retention, price adjustment and final settlement.
- Specify clear procedures for handling audit queries and post-audit payment holds, to minimise prolonged disputes and cash-flow disruptions.
- Define transparent and realistic extension-of-time (EoT) and delay claim procedures, with clear documentation requirements and decision timelines.

2. Strengthen early-stage investigations and employer's requirements

- Allocate adequate budget and time for geotechnical, hydrological and geomorphic investigations before tender, particularly for riverine bridges.
- Prepare stable and well-defined employer's requirements, reducing the need for major scope changes and foundation redesign during construction.

- Encourage use of independent review of key investigation results and preliminary designs for complex sites.

3. Streamline land acquisition, environmental and approval processes

- Establish clear timelines and responsibilities for site possession, right-of-way clearance and environmental approvals.
- Improve inter-agency coordination (e.g. between DoR, local governments and environmental authorities) through formal protocols and monitoring dashboards.
- Consider phased or conditional notices to proceed only where critical clearances are realistically achievable, to avoid latent administrative risks.

4. Promote risk-informed procurement and realistic tender pricing

- Review evaluation criteria to discourage purely lowest-price bidding for complex D&B bridges; incorporate quality, experience and risk management capacity.
- Require bidders to submit outline risk management plans and preliminary constructability assessments as part of technical proposals.
- Explore the use of two-envelope or quality–cost-based selection methods for high-risk crossings.

5.5.2 Recommendations for contractors and consultants

1. Improve risk-informed pricing and bid preparation

- Enhance internal capacity in cost estimation and risk pricing under D&B, taking into account uncertainties in investigations, design changes and regulatory processes.
- Collaborate early with specialists (e.g. geotechnical and hydraulic experts) during bid preparation to better understand potential technical risks.

2. Strengthen constructability review and design–site coordination

- Implement systematic constructability reviews before finalising designs, focusing on river diversion arrangements, foundation constructability and staging.
- Establish robust communication protocols between design teams and site teams, with regular technical coordination meetings and joint reviews of design changes.

3. Enhance quality management and supply-chain resilience

- Develop and implement quality management systems tailored to D&B bridge projects, especially for sub-contracted works.

- Diversify and strengthen relationships with suppliers of specialised bridge materials, and establish contingency plans for price escalation and lead-time variations.

5.5.3 Recommendations for integrated risk management practice

1. Adopt structured risk registers aligned with the four components

- Develop standard risk registers that explicitly reflect the four principal components (Administrative & Regulatory, Execution & Supply Chain, Design & Technical Integration, Contractual & Financial Disputes).

- Use these registers as living documents throughout the project lifecycle, updated at key milestones (tender evaluation, contract award, design completion, construction stages).

2. Institutionalise joint risk workshops and KII-style reviews

- Conduct joint risk workshops at project inception, bringing together DoR, consultants and contractors to discuss likely risks and mitigation strategies.

- Apply a KII-style review at mid-project and post-completion stages to reflect on realised risks and lessons learned, formally feeding back into future D&B contracts.

3. Integrate PCA/RII-based prioritisation into decision-making

- Use the PCA and RII structure developed in this study as a reference framework for future DoR risk assessments of D&B bridges.

- Periodically update the component structure and RII rankings as more data from additional projects becomes available, ensuring that risk prioritisation remains evidence-based and up to date.

5.6 Limitations and Scope for Future Research

While the study provides a structured and empirically validated view of D&B bridge risks under DoR, several limitations should be acknowledged.

1. Sample size and geographical focus

- The questionnaire responses (N = 92) were limited to practitioners with experience in D&B bridges primarily in the Koshi Province cluster and selected DoR projects.

- Although sufficient for PCA, the sample does not cover all provinces or agencies; risk patterns in provincial/local government bridges or other regions may differ.

2. Cross-sectional design

- The study is cross-sectional, capturing perceptions at one point in time.
- It does not directly track how risks evolve across project phases or how specific risk occurrences affect actual cost, time and quality outcomes.

3. Perception-based measures

- Both the questionnaire and KII rely on perceptions and recollections of practitioners.
- Although respondents were experienced and triangulation improves validity, perception-based measures may differ from strictly measured performance data.

4. Number and diversity of key informants

- The KII sample, while purposive and expert-based, included a limited number of high-level informants.
- Additional perspectives, for example from local communities or oversight institutions, could further enrich understanding of certain risks, particularly social and environmental ones.

Given these limitations, the following areas are suggested for future research:

- Extension to other regions and agencies, including provincial and local bridges and non-DoR projects, to compare risk structures and adjust the component model accordingly.
- Longitudinal studies linking initial risk assessments to actual project performance data (time, cost, quality, disputes) to quantify the realised impact of the identified risk domains.
- Scenario-based and probabilistic risk analysis, integrating PCA/RII results with simulation or reliability models to estimate potential cost and time overruns under different risk scenarios.
- Comparative analyses of different procurement models, such as D&B vs traditional design-bid-build or public-private partnership (PPP), focusing on how risk allocation and component prioritisation change with procurement type.

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APPENDIX A: QUESTIONNAIRE FOR DELPHI ROUND – 1

Delphi Round 1 – Identification of Risk Factors in Design and Build Bridge Projects (DoR Nepal)

I am a masters level student at Pulchowk Campus currently pursuing my degree in Msc. Construction Management under Department of Civil Engineering. I would like to request your involvement in the following Delphi survey as a part of my Masters thesis on "Risk Analysis of Design and Build Contracts for Bridge Construction Implemented by the Department of Roads, Nepal". Your input is highly appreciated. Thank You.

- **Aditya Pandey**

email : 078mscom001.aditya@pcampus.edu.np

* Indicates required question

Dear Expert,

This form is the first round of a Delphi study for my master's degree thesis research :

"Risk Analysis of Design and Build Contracts for Bridge Construction Implemented by the Department of Roads, Nepal."

Purpose : To identify potential risk factors in D&B bridge projects under DoR.

Your responses will remain anonymous and confidential.

Thank you for your valuable time and contribution.

By continuing, you agree to participate voluntarily in this academic study.

Untitled Section

Respondent Information

1. **Name (Optional) :**

2. **Organization / Affiliation : ***

Mark only one oval.

- Department of Roads (DoR)
- Contractor
- Consultant
- Academic / Research
- Other: _____

3. **Designation / Position :**

4. **Years of experience in bridge construction : ***

Mark only one oval.

- <5
- 5-10 years
- 10-15 years
- >15 years

5. **Have you worked in Design & Build (D&B) projects ? ***

Mark only one oval.

- Yes
- No

6. **Approximate number of D&B bridge projects you have been involved in ***

Mark only one oval.

- 1-2
- 3-5
- >5

Risk Identification

Please list the major risk factors that you believe affect Design and Build (D&B) bridge projects implemented by the Department of Roads (DoR), Nepal.

Please provide the specific risk factors under the following classifications :

7. Design Risks :

8. Geological / Hydrological Risks :

9. Construction / Execution Risks :

10. Financial / Economic Risks :

11. **Contractual / Legal Risks :**

12. **Management (Planning, Performance, Coordination) Risks :**

13. **Environmental / Social Risks :**

14. **External / Force Majeure Risks :**

15. **Other Risks :**

APPENDIX B: QUESTIONNAIRE FOR DELPHI ROUND – 2

Delphi Round 2 – 1–9 Scale Ratings of Risk Factors (D&B Bridges, DoR Nepal)

Please rate each risk factor on a 1–9 scale within its category.

Use 1 = Least critical / minimal concern, and 9 = Most critical / extreme concern.

Do NOT rank items; simply give each item its own 1–9 rating. This data will be used for KII analysis.

* Indicates required question

Instructions

Rate each item independently from 1 (least critical) to 9 (most critical). Do NOT rank. No ties restrictions.

Respondent Information

For classification only; no identifying information will be reported.

1. Name (optional)

2. Organization / Affiliation *

Mark only one oval.

Department of Roads (DoR)

Contractor

Consultant

Academic / Research

Other

3. Designation / Role *

4. Years of experience in bridge construction *

Mark only one oval.

- < 5 years
- 5–10 years
- 10–15 years
- > 15 years

5. Have you been directly involved in Design & Build (D&B) bridge projects? *

Mark only one oval.

- Yes
- No

Rating Scale

Scale meaning: 1–3 = Low concern; 4–6 = Moderate; 7–9 = High. Use your expert judgment.

Technical / Design Risks

Please rate each risk on a 1–9 scale. Do NOT rank across items.

6. Scale 1–9 – Technical / Design Risks (1 = least critical ... 9 = most critical) *

Select a value from 1 (least critical) to 9 (most critical) for EACH row. This is NOT a ranking.

Mark only one oval per row.

	1	2	3	4	5	6	7	8	9
Inadequate Initial Site Data	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Seismic Design Complexity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Hydrological & Hydraulic Miscalculations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Foundation Design Errors	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Constructability Issues in Design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Material Specification Issues	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Design Errors and Omissions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Value Engineering Conflicts	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Interface Design Risks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Geological / Hydrological Risks

Please rate each risk on a 1–9 scale. Do NOT rank across items.

7. Scale 1–9 – Geological / Hydrological Risks (1 = least critical ... 9 = most critical) *

Select a value from 1 (least critical) to 9 (most critical) for EACH row. This is NOT a ranking.

Mark only one oval per row.

	1	2	3	4	5	6	7	8	9
Adverse Geotechnical Conditions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Landslides and Slope Instability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
High Water Table and Water Ingress	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Scour and River Morphology	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Liquefaction Potential	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Rockfall Hazards	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Construction / Execution Risks

Please rate each risk on a 1–9 scale. Do NOT rank across items.

8. Scale 1–9 – Construction / Execution Risks (1 = least critical ... 9 = most critical) *
 Select a value from 1 (least critical) to 9 (most critical) for EACH row. This is NOT a ranking.

Mark only one oval per row.

	1	2	3	4	5	6	7	8	9
Challenging Terrain and Site Access	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Foundation Construction Failures	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
River Diversion Failures	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Falsework/Formwork Collapse	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Precast Element Handling & Erection Risks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Poor Construction Quality Control	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Shortage of Skilled Labour and Supervisors	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Critical Equipment Breakdown	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
On-site Safety Accidents	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Financial / Economic Risks

Please rate each risk on a 1–9 scale. Do NOT rank across items.

9. Scale 1–9 – Financial / Economic Risks (1 = least critical ... 9 = most critical) *

Select a value from 1 (least critical) to 9 (most critical) for EACH row. This is NOT a ranking.

Mark only one oval per row.

	1	2	3	4	5	6	7	8	9
Volatile Material Price Escalation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Currency Exchange Fluctuation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Inaccurate Initial Cost Estimation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Client Payment Delays	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increased Financing Costs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Cost of Rework and Rectification	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Unforeseen Costs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Contractual / Legal Risks

Please rate each risk on a 1–9 scale. Do NOT rank across items.

10. Scale 1–9 – Contractual / Legal Risks (1 = least critical ... 9 = most critical) *
 Select a value from 1 (least critical) to 9 (most critical) for EACH row. This is NOT a ranking.

Mark only one oval per row.

	1	2	3	4	5	6	7	8	9
Ambiguous Contract Clauses	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Variations and Change Order Disputes	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Delay Claims and Liquidated Damages	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Delay in Site Possession and Right-of-Way	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Permit and Approval Delays	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Liability for Latent Defects	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Performance Security Encashment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Management / Coordination / Planning Risks

Please rate each risk on a 1–9 scale. Do NOT rank across items.

11. Scale 1–9 – Management / Coordination / Planning Risks (1 = least critical ... 9 = most critical) *

Select a value from 1 (least critical) to 9 (most critical) for EACH row. This is NOT a ranking.

Mark only one oval per row.

	1	2	3	4	5	6	7	8	9
Poor Designer-Contractor Integration	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ineffective Project Planning and Scheduling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Slow Information Flow and Approval	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Inadequate Risk Management	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Poor Site Management and Supervision	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stakeholder Misalignment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Environmental / Social Risks

Please rate each risk on a 1–9 scale. Do NOT rank across items.

12. Scale 1–9 – Environmental / Social Risks (1 = least critical ... 9 = most critical) *
Select a value from 1 (least critical) to 9 (most critical) for EACH row. This is NOT a ranking.

Mark only one oval per row.

	1	2	3	4	5	6	7	8	9
Ecological and Regulatory Compliance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Public Protest and Community Opposition	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Site Pollution and Environmental Damage	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Discovery of Archaeological Artifacts	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Impact on Local Livelihoods	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

External / Force Majeure Risks

Please rate each risk on a 1–9 scale. Do NOT rank across items.

13. Scale 1–9 – External / Force Majeure Risks (1 = least critical ... 9 = most critical) *
Select a value from 1 (least critical) to 9 (most critical) for EACH row. This is NOT a ranking.

Mark only one oval per row.

	1	2	3	4	5	6	7	8	9
Major Natural Disasters	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Adverse Monsoon Conditions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Political Instability and Bandhs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supply Chain Disruptions and Blockades	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Pandemics and Epidemics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Additional Comments

Optional

14. Any additional risk factors or comments on wording/categorization?

Consent

15. I understand the purpose of this Delphi study and voluntarily agree to participate. *

Mark only one oval.

Yes, I agree

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APPENDIX C : CONCENSUS CRITERIA CHECK BY IQR

IQR Calculation for Consensus Check for Responses from Experts for Delphi Round 2														
Question No.								mean	Standard Deviation	Quartile 1	Quartile 3	Inter-quartile Range		Ranking
1	9	9	9	9	9	8	1	7.714286	0.699854212	7	8	1		8
2	7	1	1	1	1	1	1	1.857143	0.832993128	1	2.5	1.5		53
3	9	9	9	9	9	9	2	8	0.755928946	7.5	8.5	1		2
4	9	9	9	9	9	9	1	7.857143	0.638876565	7.5	8	0.5		4
5	9	9	9	5	1	1	1	5	0.534522484	5	5	0		23
6	9	9	5	1	1	1	1	3.857143	0.638876565	3.5	4	0.5		34
7	9	9	9	9	9	1	1	6.714286	1.27775313	6	7.5	1.5		15
8	9	9	9	9	9	7	1	7.571429	0.728431359	7	8	1		9
9	6	1	1	1	1	1	1	1.714286	0.638876565	1.5	2	0.5		53
10	9	9	9	9	9	4	1	7.142857	0.832993128	6.5	8	1.5		14
11	9	9	9	9	1	1	1	5.571429	0.494871659	5	6	1		19
12	9	9	9	9	5	1	1	6.142857	0.989743319	5.5	6.5	1		18
13	9	9	9	9	9	9	3	8.142857	0.832993128	7	8.5	1.5		4
14	9	7	1	1	1	1	1	3	0.755928946	2.5	3.5	1		38
15	9	3	1	1	1	1	1	2.428571	0.728431359	2	3	1		46
16	9	9	7	1	1	1	1	4.142857	0.832993128	3.5	5	1.5		29
17	9	9	9	8	1	1	1	5.428571	1.178030179	4.5	6.5	2		19
18	9	9	9	6	1	1	1	5.142857	0.989743319	5	6	1		21
19	9	9	9	9	9	5	1	7.285714	1.030157507	7	8	1		12
20	9	9	2	1	1	1	1	3.428571	0.728431359	3	4	1		37
21	9	9	9	9	9	6	1	7.428571	0.903507903	7	8	1		9
22	9	9	9	4	1	1	1	4.857143	0.638876565	4.5	5	0.5		25
23	9	9	9	1	1	1	1	4.428571	1.293626448	4	5.5	1.5		27
24	9	5	1	1	1	1	1	2.714286	1.030157507	2	3.5	1.5		42
25	9	9	9	9	7	1	1	6.428571	1.178030179	6	7	1		17
26	9	6	1	1	1	1	1	2.857143	0.638876565	2.5	3	0.5		41
27	9	9	9	9	8	1	1	6.571429	0.699854212	6	7	1		15
28	9	9	9	9	9	3	1	7	1.049781318	7	8.5	1.5		9
29	9	2	1	1	1	1	1	2.285714	0.699854212	2	3	1		48
30	9	1	1	1	1	1	1	2.142857	0.638876565	2	2.5	0.5		50
31	9	8	1	1	1	1	1	3.142857	0.534522484	3	3	0		38
32	9	9	6	1	1	1	1	4	1.309307341	3	5	2		31
33	9	9	9	9	9	9	4	8.285714	0.699854212	8	9	1		1
34	9	9	9	9	9	2	1	6.857143	1.160576915	7	8	1		12
35	9	9	8	1	1	1	1	4.285714	1.27775313	3.5	5	1.5		28
36	9	9	3	1	1	1	1	3.571429	1.178030179	3.5	4	0.5		36
37	9	4	1	1	1	1	1	2.571429	0.699854212	2	3	1		42
38	8	1	1	1	1	1	1	2	1.030157507	1.5	3	1.5		48

39	9	9	9	9	9	9	5	8.428571	0.638876565	7.5	8	0.5		4
40	9	9	9	3	1	1	1	4.714286	0.755928946	4.5	5.5	1		23
41	9	9	4	1	1	1	1	3.714286	0.755928946	3.5	4.5	1		31
42	9	9	9	2	1	1	1	4.571429	1.678191446	4	5	1		26
43	9	9	9	7	1	1	1	5.285714	0.989743319	4.5	5.5	1		21
44	9	9	1	1	1	1	1	3.285714	2.099562637	3	4	1		29
45	9	9	9	9	2	1	1	5.714286	1.069044968	3.5	5	1.5		31
46	5	1	1	1	1	1	1	1.571429	0.903507903	2	3	1		45
47	4	1	1	1	1	1	1	1.428571	1.195228609	2.5	3.5	1		38
48	3	1	1	1	1	1	1	1.285714	1.178030179	1.5	3.5	2		46
49	2	1	1	1	1	1	1	1.142857	0.699854212	2	3	1		42
50	9	9	9	9	9	9	6	8.571429	0.832993128	7	8.5	1.5		4
51	9	9	9	9	9	9	7	8.714286	0.534522484	8	8	0		2
52	1	1	1	1	1	1	1	1	0.755928946	1.5	2.5	1		51
53	9	9	9	9	3	1	1	5.857143	1.245399698	3	4.5	1.5		34
54	9	9	9	9	4	1	1	6	0.9258201	1.5	2	0.5		51

APPENDIX D : QUESTIONNAIRE FOR FINAL SURVEY

Impact Rating of Risk Factors in D&B Bridge Projects under Department of Roads, Nepal

Risk Analysis of Design and Build Contracts for Bridge Construction Implemented by the Department of Roads, Nepal

Dear Respondent,

Thank you for taking the time to support this research. Please rate the IMPACT of each factor on Design & Build (D&B) bridge projects under the Department of Roads (DoR), Nepal.

- Use a 1–5 Likert scale for IMPACT: 1 = Very Low, 5 = Very High

Your responses will remain confidential and used for academic purposes only.

Regards :

Aditya Pandey

MSc. Construction Management, Pulchowk Campus

078mscom001.aditya@pcampus.edu.np

* Indicates required question

Respondent Information

For classification only; no identifying information will be reported.

1. Name (optional)

2. Organization / Affiliation *

Mark only one oval.

- Department of Roads (DoR)
- Contractor
- Consultant
- Academic / Research
- Other

3. Designation / Role *

4. Years of experience in bridge construction *

Mark only one oval.

- < 5 years
- 5–10 years
- 10–15 years
- > 15 years

5. Have you been directly involved in Design & Build (D&B) bridge projects? *

Mark only one oval.

- Yes
- No

Please Rate following Risk Factors based on their Impact on the Project.

1 = Very Low impact, 5 = Very High impact.

6. 1. Shortage of Specialized Manpower *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

7. 2. Initial Delays due to incomplete design integration *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

8. 3. Poor Site Management and Supervision *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

9. 4. Design changes in protection works due to Scouring and Change in River Morphology *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

10. 5. Client Payment Delays *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

11. 6. Delays due to Design Errors and Omissions *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

12. 7. Delay in Site Possession and Right-of-Way *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

13. 8. Disputes due to Ambiguous Contract Clauses *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

14. 9. Increasing frequency of flash floods and non-seasonal rain *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

15. 10. Variations and Change Order Disputes *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

16. 11. Volatile Material Price Escalation *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

17. 12. Conflicts due to overlapping designer - contractor responsibilities and unclear roles *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

18. 13. Disputes regarding utilization of mobilization amount *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

19. 14. Poor Construction Quality Control *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

20. 15. Material Specifications not complying with design *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

21. 16. Falsework/Formwork Collapse *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

22. 17. Unreliable supply chain for specialized bridge materials *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

23. 18. Inaccurate Initial Cost Estimate *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

24. 19. Constructability Issues in Innovative design practices *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

25. 20. Value Engineering Conflicts during Design Approval and Variation Orders *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

26. 21. Multiple design changes during execution *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

27. 22. Slow Information Flow and Approval *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

28. 23. Delay in Environmental Permit and Design Approval *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

29. 24. Disputes in Delay Claims and Liquidated Damages *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

30. 25. Disputes due to unclear modality of payment *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

31. 26. Payment disputes arising from financial audit by constitutional bodies *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

32. 27. scope modifications by client causing late-stage changes *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

33. 28. Discrepancies in predicted river hydrodynamics during floods *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

34. 29. Foundation Redesign due to faulty soil test data *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

35. 30. Inexperience in pricing tenders for Design and Build Works *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

36. 31. River Diversion Failures *

Mark only one oval.

1 2 3 4 5

Very Very High (5)

Consent

37. I understand the purpose of this survey and voluntarily agree to participate. *

Mark only one oval.

Yes, I agree

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APPENDIX E : INTERVIEW QUESTIONNAIRE FOR KII

Validations of Findings in Research on Risk Assessment of Design and Build Bridge Projects Implemented by Department of Roads, Nepal

Key Informant Interview (KII) Questionnaire

Researcher: Aditya Pandey

Affiliation: MSc. In Construction Management, Department of Civil Engineering, Pulchowk Campus, IoE, Tribhuvan University

Section 1: Respondent Information

Name of Respondent:

Designation:

Organization:

Years of Experience in Bridge Projects:

Experience in Design & Build (D&B) Bridge Projects (No. of projects):

Contact (optional):

Date:

Section 2: Brief Overview of the Study

This Key Informant Interview (KII) aims to support **validation of the quantitative findings** from the research titled:

“Risk assessment of design and build bridge projects implemented by department of roads in Nepal”

The study focused on **Design and Build (D&B) contracts for motorable bridges** implemented by the Department of Roads (DoR), Nepal. A total of **31 risk factors** related to planning,

design, contract administration, construction, and external conditions were identified and rated by practitioners with experience in D&B bridge projects.

Using responses from **92 practitioners**, the data were analyzed using:

- Reliability analysis (Cronbach's alpha)
- KMO and Bartlett's test
- Principal Component Analysis (PCA) with Varimax rotation
- Relative Importance Index (RII)

PCA grouped the 31 risk factors into **four principal components**:

1. **Administrative and Regulatory Risk**
2. **Execution and Supply Chain Risks**
3. **Design and Technical Integration Risks**
4. **Contractual and Financial Dispute Risks**

The **top ten risk factors** by RII (highest perceived importance) were:

1. **Q31** – Payment disputes arising from financial audit by constitutional bodies
2. **Q29** – Foundation redesign due to faulty soil test data
3. **Q30** – River diversion failures
4. **Q27** – Constructability issues in innovative design practices
5. **Q25** – Value engineering conflicts during design approval and variation order
6. **Q26** – Disputes due to unclear modality of payment
7. **Q21** – Scope modifications by client causing late-stage changes
8. **Q9** – Disputes in delay claims and liquidated damages
9. **Q6** – Poor site management and supervision
10. **Q15** – Disputes due to ambiguous contract clauses

Your views are requested to **confirm, refine or challenge these findings** based on your professional experience with D&B bridge projects under DoR.

Section 3: Component-wise Questions

Component 1 – Administrative and Regulatory Risk

This component includes the following risk factors:

- **Q5** – Delay in site possession and right of way
- **Q7** – Delay in environmental permit and clearance
- **Q19** – Initial delays due to incomplete design integration
- **Q12** – Slow information flow and approval
- **Q22** – Client payment delays
- **Q24** – Variations and change order delays

C1-Q1. Based on your experience, how significant are the above administrative and regulatory risks for D&B bridge projects under DoR?

Which issues do you consider most critical, and why?

C1-Q2. Do you agree that these risks can be grouped together under the heading “Administrative and Regulatory Risk”?

If not, how would you group or reclassify them?

C1-Q3. Are there any other important **administrative or regulatory risks** in D&B bridge projects that you feel are missing from this list?

Please specify.

C1-Q4. In your opinion, what **practical measures** (procedures, coordination mechanisms, contract provisions, etc.) could help reduce the impact of these administrative and regulatory risks?

Component 2 – Execution and Supply Chain Risks

This component includes the following risk factors:

- **Q27** – Constructability issues in innovative design practices
- **Q23** – Volatile material price escalation
- **Q4** – Inexperience in pricing tenders for D&B works
- **Q13** – Shortage of specialised manpower
- **Q20** – Conflicts due to overlapping designer–contractor responsibilities
- **Q17** – Poor construction quality control by sub-contractor
- **Q2** – Unreliable supply chain for specialised bridge materials

C2-Q1. How frequently do the above **execution and supply chain risks** affect D&B bridge projects you have been involved in?

Please describe your observations.

C2-Q2. Among these execution and supply chain risks, which two or three do you consider the **most dangerous** for time, cost or quality performance, and why?

C2-Q3. Do you feel that current **contractor pre-qualification, design capability, and supply-chain arrangements** under DoR D&B contracts are adequate to manage these risks?

Please explain.

C2-Q4. What **improvements** (e.g. in tender evaluation, constructability review, resource planning, supply-chain strategy) would you suggest to better manage execution and supply chain risks in D&B bridge projects?

Component 3 – Design and Technical Integration Risks

This component includes the following risk factors:

- **Q25** – Value engineering conflicts during design approval and variation order
- **Q21** – Scope modifications by client causing late-stage changes
- **Q11** – Delays due to design errors and omissions
- **Q14** – Multiple design changes during execution

C3-Q1. In your experience, how common are **design and technical integration issues** such as those listed above in D&B bridge projects?

Please comment with examples if possible (without naming specific projects).

C3-Q2. Do you think these four risks appropriately represent the **main design and technical integration issues** in D&B bridges, or are there other important aspects that should be added?

C3-Q3. How effectively do current procedures (employer's requirements, design review and approval processes, coordination between design and site teams) address these design and technical integration risks?

C3-Q4. What changes in practice or contract provisions would you recommend to reduce **design errors, late design changes and value engineering conflicts** in D&B bridge projects?

Component 4 – Contractual and Financial Dispute Risks

This component includes the following risk factors:

- **Q31** – Payment disputes arising from financial audit by constitutional bodies
- **Q26** – Disputes due to unclear modality of payment
- **Q9** – Disputes in delay claims and liquidated damages
- **Q15** – Disputes due to ambiguous contract clauses

C4-Q1. How frequently do **contractual and financial dispute issues** such as those listed above arise in D&B bridge projects under DoR?

Please describe typical situations.

C4-Q2. In your view, which of these four risks create the **most serious obstacles** to smooth contract administration and project delivery, and why?

C4-Q3. Do you find the current D&B contract documents (including clauses on **payment, audits, extensions of time and liquidated damages**) clear enough to avoid disputes, or do they contribute to ambiguity?

Please explain.

C4-Q4. What specific improvements in **contract wording, payment procedures or dispute-resolution mechanisms** would you suggest to minimise contractual and financial dispute risks in future D&B bridge projects?

Closing Note

Thank you for your time and valuable insights. Your responses will be used solely for academic research to **validate and refine the risk assessment framework** for Design and Build bridge projects implemented by the Department of Roads in Nepal.

APPENDIX F : RII CALCULATION

Respondent_ID	Q2	Q4	Q5	Q7	Q9	Q11	Q12	Q13	Q14	Q15	Q17	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Q31
R1	4	4	3	3	3	3	4	3	3	3	4	3	4	3	4	4	3	3	3	3	3
R2	2	1	1	1	2	2	1	2	3	3	2	2	1	4	1	3	1	3	2	1	2
R3	1	1	4	4	3	1	4	1	1	2	1	2	1	1	1	1	3	1	2	1	2
R4	3	3	1	1	5	5	1	3	4	5	3	1	2	5	1	3	1	3	3	1	3
R5	4	3	2	2	3	3	1	3	3	4	2	2	2	3	1	3	1	5	3	2	4
R6	4	3	2	1	3	2	1	3	3	3	3	1	3	3	2	4	2	3	4	5	3
R7	3	2	2	4	3	1	2	1	1	3	1	4	2	1	2	2	3	1	3	1	3
R8	2	4	3	4	4	1	3	4	2	3	3	4	3	2	3	2	3	2	3	3	3
R9	3	3	1	3	3	2	1	3	2	1	3	2	3	3	1	3	1	2	2	3	3
R10	3	2	2	2	3	3	2	2	3	3	2	2	2	3	2	4	1	3	4	2	3
R11	1	1	1	1	5	3	1	1	3	2	1	1	2	4	2	4	1	4	2	1	3
R12	3	2	3	3	3	4	3	2	4	3	3	3	3	3	3	2	3	3	3	2	5
R13	2	4	4	4	3	1	4	2	1	3	1	3	2	1	3	2	3	1	4	3	4
R14	4	3	3	4	3	3	3	4	4	3	4	2	4	4	3	3	3	3	5	5	5
R15	2	3	2	2	4	1	2	3	2	4	3	2	4	2	2	2	3	1	3	3	4
R16	3	2	2	2	3	4	2	2	3	3	2	4	1	2	1	1	2	3	5	1	5
R17	4	3	4	3	3	3	3	3	2	2	3	3	3	2	3	3	4	3	3	3	2
R18	2	3	3	3	3	3	3	3	4	3	4	4	3	4	3	4	4	4	5	2	3
R19	3	4	3	3	1	4	2	3	4	1	3	2	3	4	4	2	2	3	2	5	1
R20	3	3	4	4	3	3	3	2	3	4	3	2	4	3	4	4	4	5	4	3	3
R21	2	3	1	1	1	4	1	2	4	1	2	2	3	4	1	1	1	5	1	1	1
R22	1	2	3	3	1	1	3	2	1	3	2	3	2	3	3	2	3	2	2	2	1
R23	4	4	2	1	4	3	3	4	2	4	4	1	4	2	1	4	2	3	4	3	4
R24	3	3	3	3	4	1	4	3	1	3	4	2	3	1	4	3	3	2	3	4	2
R25	3	4	3	3	2	2	3	4	1	3	3	3	4	1	3	3	3	1	3	5	3
R26	3	3	2	3	4	2	3	3	2	2	3	3	3	2	3	2	2	3	3	3	3
R27	3	3	1	1	2	3	1	3	3	2	4	1	4	4	2	3	1	3	2	5	2
R28	3	3	2	2	4	3	3	3	4	4	3	1	3	3	3	3	2	3	4	3	4
R29	3	3	4	3	3	4	3	3	3	3	3	4	4	4	4	3	3	4	4	3	3
R30	1	1	1	1	2	3	2	1	2	2	1	1	1	3	1	1	1	2	1	1	2
R31	3	3	4	3	3	1	3	4	1	4	3	3	3	1	3	3	3	1	4	3	3
R32	1	2	3	3	2	2	2	1	2	3	1	4	1	2	3	1	3	2	1	3	2
R33	1	2	3	3	3	3	3	2	3	2	1	3	2	3	3	2	3	3	2	3	2
R34	3	4	3	4	1	3	3	4	2	1	3	3	4	2	2	3	3	2	1	3	1
R35	2	2	3	2	2	4	4	1	4	3	2	3	2	3	3	1	3	3	1	2	3
R36	3	3	4	2	3	3	3	3	3	4	3	4	3	3	3	4	4	2	5	5	4
R37	3	4	3	3	3	4	3	4	4	3	4	3	3	4	3	3	3	3	3	5	5
R38	3	3	2	2	1	4	2	3	3	2	3	2	3	3	1	3	1	5	2	3	2
R39	3	4	3	3	1	4	3	4	3	2	3	2	4	4	3	4	2	3	2	3	2
R40	3	3	1	1	2	1	1	3	1	1	3	2	3	2	2	3	2	1	2	4	2
R41	2	3	3	4	3	2	4	4	3	3	4	3	3	4	4	3	3	2	3	2	4
R42	2	2	2	1	3	2	3	3	4	4	3	2	2	2	2	1	3	3	3	2	4
R43	3	4	3	3	3	1	3	3	1	2	4	3	3	1	3	3	3	1	1	3	2
R44	1	1	1	1	1	1	1	1	3	1	2	1	1	2	1	1	1	1	1	3	1
R45	2	1	3	2	4	3	2	2	3	4	2	4	2	3	2	1	3	5	3	1	3
R46	3	4	3	4	1	2	4	3	1	1	3	3	3	2	4	3	3	1	1	5	1

R47	3	4	3	3	2	3	4	3	3	2	4	4	4	2	3	4	3	3	2	3	2
R48	3	3	3	3	4	3	2	4	4	4	4	4	3	4	3	3	3	3	3	3	3
R49	1	4	3	3	4	3	3	4	3	4	3	3	3	3	3	4	3	5	5	2	5
R50	2	3	1	1	1	3	2	3	3	2	2	1	1	3	2	1	1	3	1	2	1
R51	4	3	3	2	2	4	3	4	3	3	4	3	3	3	3	4	3	5	3	4	2
R52	1	1	4	3	4	2	4	1	2	3	1	3	1	2	3	2	3	3	3	1	3
R53	3	3	2	2	1	2	1	2	2	1	2	3	2	2	2	4	2	2	1	2	1
R54	4	3	3	4	4	3	4	4	3	4	4	3	4	4	3	3	3	3	3	3	4
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R56	3	3	2	1	1	2	2	3	2	1	3	2	3	2	4	2	2	2	1	3	1
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R59	3	3	2	4	4	3	3	3	3	4	3	4	4	3	2	3	2	3	5	3	3
R60	3	3	3	4	4	1	4	3	3	3	1	3	4	3	4	4	3	3	4	1	2
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R66	1	1	1	1	4	1	1	1	1	4	1	1	1	1	1	1	1	4	1	5	
R67	2	3	4	3	4	3	3	3	4	4	4	3	3	3	3	3	4	4	3	2	4
R68	2	2	3	4	2	3	3	1	3	2	1	3	1	3	4	2	3	3	1	4	2
R69	1	2	3	3	1	2	4	1	2	1	1	3	2	1	3	3	3	1	1	2	1
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R88	4	2	3	2	2	3	4	2	3	1	3	1	3	3	4	3	4	2	1	2	1
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R90	3	4	2	2	5	5	2	5	5	5	5	4	5	5	1	4	3	3	5	3	3
R91	4	3	4	4	2	4	3	3	5	3	2	4	4	5	2	3	3	5	3	3	4
R92	3	2	1	3	5	1	1	2	1	5	2	1	3	1	3	1	2	1	5	1	5

Factor ID	Responses with Weight = 1	Responses with Weight = 2	Responses with Weight = 3	Responses with Weight = 4	Responses with Weight = 5	Total Respondents (N)	Weighted Sum (ΣW)	RII = $\Sigma W / (5*N)$
Q2	19	18	36	19	0	92	239	0.519565217
Q4	19	17	36	18	2	92	243	0.52826087
Q5	17	20	34	18	3	92	246	0.534782609
Q7	18	18	35	18	3	92	246	0.534782609
Q9	19	17	33	18	5	92	249	0.541304348
Q11	19	18	34	17	4	92	245	0.532608696
Q12	19	19	33	19	2	92	242	0.526086957
Q13	19	19	33	18	3	92	243	0.52826087
Q14	19	17	35	18	3	92	245	0.532608696
Q15	18	19	33	18	4	92	247	0.536956522
Q17	19	18	35	18	2	92	242	0.526086957
Q19	18	19	35	18	2	92	243	0.52826087
Q20	18	19	35	18	2	92	243	0.52826087
Q21	18	18	33	18	5	92	250	0.543478261
Q22	19	18	35	18	2	92	242	0.526086957
Q23	18	19	34	19	2	92	244	0.530434783
Q24	19	19	47	6	1	92	227	0.493478261
Q25	18	17	39	7	11	92	252	0.547826087
Q26	19	18	34	10	11	92	252	0.547826087
Q27	17	19	37	8	11	92	253	0.55
Q31	19	19	29	13	12	92	256	0.556521739

Factor ID	RII
Q31	0.556522
Q27	0.55
Q25	0.547826
Q26	0.547826
Q21	0.543478
Q9	0.541304
Q15	0.536957
Q5	0.534783
Q7	0.534783
Q11	0.532609
Q14	0.532609
Q23	0.530435
Q4	0.528261
Q13	0.528261
Q19	0.528261
Q20	0.528261
Q12	0.526087
Q17	0.526087
Q22	0.526087
Q2	0.519565
Q24	0.493478

ANNEX I : SUBMISSION ACKNOWLEDGEMENT FROM IOE GRADUATE CONFERENCE - 17 TEAM

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ADITYA PANDEY

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Date: Sat, 29 Nov 2025, 11:00 pm

Subject: [IOEGC17] Submission Acknowledgement

To: Aditya Pandey <078mscom001.aditya@pcampus.edu.np>

Aditya Pandey:

Thank you for submitting the manuscript, "Risk Assessment of Design and Build Bridge Projects Implemented by Department of Roads in Nepal" to 17th IOE Graduate Conference. With the online conference paper management system that we are using, you will be able to track its progress through the editorial process by logging in to the conference portal:

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ANNEX II : ORIGINALITY REPORT

PAPER NAME

Risk Assessment of Design and Build Bridge Projects Implemented by Department of Roads in Nepal

AUTHOR

Aditya Pandey

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