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Optimizing Risk Assessment and Management in Nebraska's Road Construction Projects

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Abstract

Transportation infrastructure projects pose significant safety and cost-related challenges. Given the rapid expansion of Nebraska highways to address transportation demands, road construction initiatives hold considerable significance. This study highlights the risks associated with road construction projects in Nebraska. The primary focus of this research is to pinpoint prevalent risks within the roadway infrastructure projects. A thorough literature review identified approximately 40 major risks, and the top 23 were distilled through a questionnaire survey targeting construction professionals. The gathered opinions underwent regression analysis using R programming software. To predict risk levels of road construction projects, an ordered probit model was estimated. The data were assigned weights based on importance and likelihood of occurrence, resulting in a ranked list. This study is anticipated to assist project managers in the transportation industry in evaluating risk priorities and devising effective mitigation strategies at the early stages of the project. This will result in more precise time and cost savings and contribute to ensuring the safety of both workers and road users involved in the construction phase of roadway projects.

Keywords: Risk Management; Transportation Infrastructure; Road Construction; Risk Identification; Road Safety

Introduction

The term "risk" refers to the combination of the probability of an event and its impact on project objectives. Numerous studies suggest that road construction projects entail higher risks compared to other construction projects. This heightened risk is attributed to the extensive geographic coverage of road construction projects and the potential threats posed by underground conditions. The advantages of effective risk management encompass the early identification and analysis of potential risks, enabling the implementation of suitable measures to enhance the construction process. This proactive approach leads to improved project management, as the focus is on recognizing and addressing potential risks associated with the project. The primary goal of risk management is to identify and respond to these potential risks, thereby assisting project participants such as contractors, developers, clients, consultants, and suppliers in fulfilling their commitments. By minimizing the negative impacts on construction costs with respect to time, money, and quality objectives, risk management becomes a crucial element in project success. Risk management is a complex process with multiple dimensions, influenced by several factors that impact the overall project. Inadequate planning and the uncertainty surrounding anticipated outcomes can result in either favorable or unfavorable conditions, collectively referred to as risks. These risks can be classified into diverse types, including external risks, internal risks, curtail risks, political risks, social risks, and safety risks, among others Hanna [1]; Taroun [2].

Risk management encompasses recognizing factors that influence project cost and duration, measuring them, and implementing measures to mitigate potential impacts. The more precarious the activity, the more expensive the potential consequences. If an incorrect decision is made, it aids in determining whether to share the risk with insurance companies. While risk cannot be entirely eliminated, initiative-taking measures can significantly reduce its impact Thomas [3]; Okate & Kakade [4]. Currently, there exist two approaches for identifying risks: qualitative and quantitative. Qualitative analysis relies on statistical methods to assess the occurrence and impact of risks Osama [5]; Smith [6]; Alshehri [7]. In contrast, another technique employs the Monte Carlo simulation to derive values for probability distribution. This involves organizing the project processes in ascending and descending order, subsequently evaluating the associated risks for each process, and compiling a list of potential controls for each identified risk. The primary goal of this study is to identify and examine the diverse risks associated with road construction projects in the context of Nebraska. This involves a thorough analysis of the likelihood of these risks occurring and the potential impact they might have on the overall project. Additionally, the study aims to explore and propose effective strategies for overcoming these identified risks, contributing to a comprehensive understanding and management of risk factors in road construction endeavors in Nebraska.

Data & Methodology

The objective of this research is to comprehensively investigate the risk management aspects of road construction projects in Nebraska. The study involved identifying and categorizing the various risks associated with these projects, with a focus on determining the most significant risks through a thorough evaluation process. The research was structured around three key phases: Phase I involves the identification of 40 risks, which are then categorized into Safety, Technical, Financial, Site, Commercial, Political, Socio-economic, and Environmental risk groups. Phase II entails an evaluation of these risks and filtering 23 most prevalent risks, and Phase III involves analyzing the risks through regression analysis using R, a programming language for statistical computing and data visualization. A pilot survey gathered insights from project managers in Nebraska, specifically those associated with known consultants and contractors. The final sample size was 55 respondents. This survey aimed to gather their perspectives on the risks inherent in construction projects. Additionally, a questionnaire survey was conducted to gain a deeper understanding of the risks and their impacts, with the data being analyzed using R software.

Identifying the Risk

Identifying risks in construction projects on the field is a multifaceted process that incorporates various methods and steps. One approach involves utilizing questionnaires to gather insights from stakeholders involved in the project, including contractors, consultants, and project managers. These questionnaires aim to capture diverse perspectives on potential risks and challenges. Additionally, organizations' records and historical data play a crucial role in identifying risks by offering insights into past projects, their pitfalls, and the lessons learned. Flow charts are employed to visually map out the project processes, aiding in the identification of potential bottlenecks and vulnerabilities Taylan [8]; Sipahi [9] Professional expertise, derived from the knowledge and experience of industry specialists, is instrumental in recognizing nuanced risks that may not be immediately apparent. Onsite investigations further enhance risk identification by providing a firsthand understanding of the project environment, uncovering site-specific challenges, and ensuring that potential risks are thoroughly evaluated in the context of the construction site. This integrated approach, combining questionnaires, records, flow charts, expertise, and onsite investigations, facilitates a comprehensive and nuanced identification of risks in construction projects.

Analyzing the Risk

To effectively analyze risks in construction projects, a systematic process is followed. Initially, potential threats are identified, and their likelihood of occurrence is estimated. The analysis unfolds in several steps. First, an area of operation is selected for a comprehensive risk assessment. Subsequently, the risk exposure is described, drawing upon the detailed facts extracted from records of previous losses Tang [10]; Casanovas [11]. The probability of risk is then assessed, and any existing risk controls are documented. Further steps involve estimating the maximum financial consequences associated with the identified risks and calculating the overall budgetary impact of the risk exposure. Finally, a risk management response is determined, outlining measures to mitigate and address the identified risks. This stepwise approach ensures a thorough examination of potential risks in construction projects, allowing for informed decision-making and pro-active risk management.

Ranking the Risk

Risk ranking, often referred to as Relative Risk Ranking, Risk Indexing, or through tools like Risk Matrix and Filtering, is a strategic approach employed to prioritize risks based on their significance within a complex system loss Tang [10]; Casanovas [11]; Yousri [12]. The primary aim is to bring sharper focus to critical risks from a myriad of potential scenarios. This involves categorizing risks into distinct levels of severity and priority, typically using a risk matrix. The risk matrix is a visual representation that allows project teams to assess and rank risks based on their likelihood and impact. The process of risk ranking integrates a nuanced understanding of the project's risk landscape, considering both the probability of occurrence and the potential consequences. By assigning severity and priority levels to each identified risk, project stakeholders gain a clearer understanding of where to direct their attention and resources. This prioritization aids in effective decision-making, allowing for the implementation of targeted risk mitigation and response strategies Yousri [12]; Assaad [13]. Furthermore, risk ranking facilitates communication among project teams, enabling them to focus on the most critical aspects of risk management. It streamlines the identification of key risk factors and supports the development of initiative-taking measures to address these risks. The systematic evaluation and ranking of risks serve as an essential tool for project managers, ensuring that resources are strategically allocated to minimize the impact of the most significant risks on the overall success of road construction projects Tang [10]; Casanovas [11].

Monitoring and Reviewing the Risk

The monitoring and review of risks in construction road projects are integral components of effective risk management, ensuring a proactive approach to identifying, assessing, and

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addressing potential hazards. The ultimate goal is to either remove or reduce the impact of various risks, and this is achieved through a systematic and regular monitoring process. The monitoring process involves several key steps to comprehensively evaluate and respond to potential risks. Regular monitoring encompasses impact identification, where the consequences and significance of risks are continually assessed. This involves identifying which risks pose a greater threat and understanding how they can adversely affect the project. The decision-making process is then guided by the hazards associated with each risk, determining whether elimination or reduction measures are necessary. Once risks are identified and their severity is assessed, suitable solutions are applied to address and mitigate these risks. The proactive nature of the monitoring process allows for the implementation of preventive measures before incidents occur. This involves applying mitigation measures based on the findings, which not only aids in minimizing the impact of identified risks but also contributes to enhancing overall project safety and success. Figure 1 presents the research framework for this study.

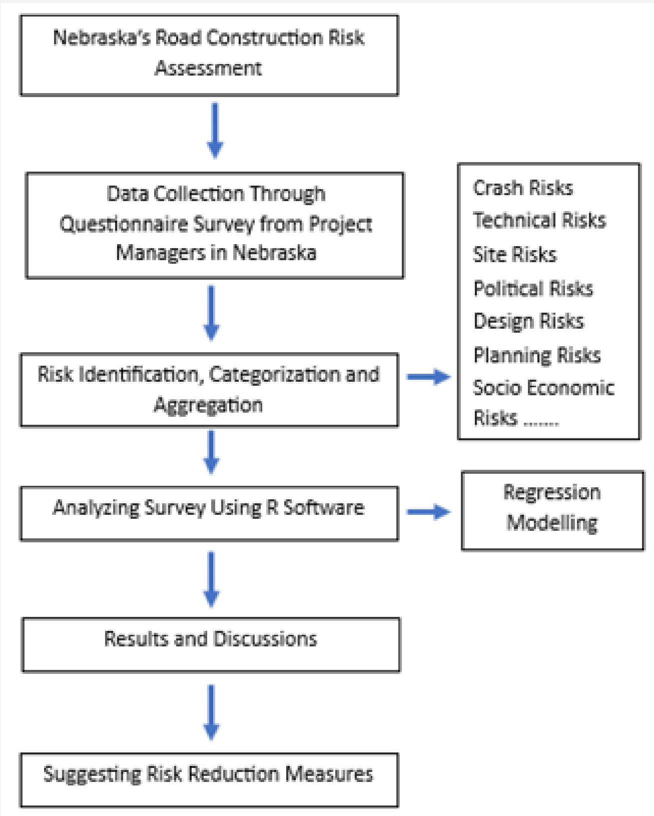

Figure 1: Research Framework.

Questionnaire Survey

In the context of Nebraska's road construction projects, an extensive risk identification and categorization process was undertaken to gather valuable insights from project managers and assistant project managers. The foundation of this research involved the development of a comprehensive questionnaire survey, crafted through a critical review of relevant literature and a preliminary pilot survey. The survey aimed at assessing the diverse risks associated with road construction projects, considering input from construction professionals (mainly project managers and their assistants), consulting companies, contractors, subcontractors, and design firms. The questionnaire itself was designed based on the identification of 40 distinct risk factors drawn from previous studies, and these factors were thoughtfully categorized into five overarching themes: Technical risk, Site risk, Political risk, Environmental risk, and Socio-economic risk. This categorization provided a structured framework for evaluating the various dimensions of risk that project managers and assistant project managers commonly encounter in their roles. Participants in the survey were not only provided with information about the specific project under consideration but also with pre-identified risk factors typically associated with road construction projects. This approach ensured that respondents could provide informed

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and relevant feedback based on their professional experiences. To capture the nuances of the risk assessments, a Likert scale was employed Nemoto & Beglar [14], allowing participants to express the perceived impact of each risk factor on the road construction project. The Likert scale included options ranging from “very low” to “very high,” providing a graded assessment of the risks. Following the survey data collection, the responses were imported into statistical analysis software, specifically R programming (Statistical Programing Software), by further utilizing “Ordinal” Package. This facilitated a rigorous analysis of the collected data, allowing for the identification of patterns, trends, and statistical significance in the reported risk assessments.

Risk Categorization

As discussed previously, identifying and evaluating risks in construction road projects is crucial for ensuring the successful execution and delivery of such complex endeavors. One significant risk lies in client-initiated changes, which can lead to project disruptions, increased costs, and potential conflicts between stakeholders. Effective communication channels and change management protocols must be established to promptly address any alterations to project requirements Siraj & Fayek [15]. Design errors present another critical risk, as they can result in rework, delays, and heightened construction costs. Rigorous design reviews and quality control measures are imperative to minimize errors and ensure a smooth progression through the construction phase. Additionally, the reliance on specific construction technologies and equipment poses inherent risks, as advancements or issues in these areas can significantly impact project timelines and costs. Regular assessments of the technological landscape and equipment reliability are essential to preemptively address potential challenges. Furthermore, traffic management during construction is a paramount concern, with inadequate planning risking safety issues, delays, and negative public perception. A comprehensive traffic management plan is crucial to mitigate challenges and ensure the uninterrupted flow of traffic. Moreover, uncertainties in project planning, including inaccurate scheduling and resource allocation, can lead to delays, resource shortages, and cost overruns. Thorough planning processes are necessary to minimize unforeseen circumstances and ensure project success Alshehri [7]; Lee [16].

Cultural and archaeological risks may emerge, particularly when construction projects encounter historical artifacts or sites. Early engagement with local authorities and thorough site assessments can help identify and address these risks, preventing project delays and legal complications. Regulatory changes present an ever-present risk that can impact project compliance and approval processes. Staying abreast of regulatory developments and maintaining open communication with relevant authorities are crucial to adapting to evolving requirements. Furthermore, government funding uncertainties and budgetary risks are common in construction projects dependent on public financing. Robust financial planning, continuous monitoring, and contingency provisions are essential to navigate budgetary uncertainties successfully. Additionally, local opposition and public perception risks can lead to delays and reputational damage. Engaging with local communities transparently and addressing concerns effectively are key strategies to gain public support and mitigate these risks Siraj & Fayek [15]. Social equity, inclusion, and climate change are increasingly recognized as essential aspects of construction projects. Ensuring social equity and inclusion in project development is crucial for sustainable and responsible construction, while climate change risks require the incorporation of resilience measures into project planning. Displacement of communities and changes in property values are social and economic risks that necessitate fair and transparent policies to address potential challenges Shuster [17]. Construction projects are not immune to criminal activities, corruption, and bribery, which pose significant threats to project integrity. Implementing robust security measures and maintaining a transparent, ethical approach are critical to mitigating these risks. Finally, changes in community dynamics during and after construction can impact project acceptance. Continuous community engagement and adaptive strategies are necessary to address evolving dynamics and maintain positive relationships throughout the project lifecycle. Table 1 presents key descriptive statistics for these primary 23 road construction project risks. R software was used to estimate these key descriptive statistics.

Risk Weightage and Aggregate Risk

To evaluate and quantify the risks associated with construction road projects in Nebraska, it was essential to employ a comprehensive and well-defined methodology to ensure a systematic and transparent evaluation. The first step involved conducting a severity assessment, which focused on understanding the potential consequences and disruptions posed by each risk factor. Furthermore, probability was evaluated in terms of the likelihood of occurrence, and impact on project objectives assessed the consequences on timelines, costs, and quality. Additionally, stakeholder input played a crucial role in refining the weights assigned to each criterion. The numerical scale facilitated a systematic and objective application of weights, resulting in a comprehensive risk assessment. After applying the methodology to a set of construction road project risks, we obtained individual risk scores based on the severity, probability, and impact assessments. These scores are then aggregated to provide an overall risk ranking for the project. The aggregate ranking categorizes the project’s risk level into distinct tiers such as low, moderate, and high, offering a clear representation of the cumulative risk profile. The methodology followed in this research enhances the traditional risk assessment process by providing a systematic and transparent framework for evaluating and aggregating risks. The inclusion of stakeholder perspectives ensures that the methodology captures a holistic view of the risks involved.

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Table 1: Descriptive Statistics of Questionnaire Survey on Risk Categorization.

Risk Categorization	Sub Categorization of Risk	Risk Levels	Mean	Standard Deviation
Technical Risks	Client Changes Risk	Low	0.49	0.504
		Moderate	0.163	0.373
		High	0.327	0.473
	Design Changes and Error Risk	Low	0.219	0.241
		Moderate	0.163	0.314
		High	0.617	0.314
	Construction Technology and Equipment Risk	Low	0.41	0.388
		Moderate	0.374	0.247
		High	0.216	0.347
	Traffic Management Challenges	Low	0.601	0.328
		Moderate	0.218	0.214
		High	0.18	0.368
	Planning Risks	Low	0.127	0.325
		Moderate	0.345	0.398
		High	0.527	0.324
	Resource Risks	Low	0.636	0.254
		Moderate	0.045	0.258
		High	0.309	0.325
	Traffic Crash Risks	Low	0.124	0.147
		Moderate	0.474	0.421
		High	0.409	0.504
	Unforeseen Soil Conditions/ Geotechnical Risks	Low	0.471	0.373
		Moderate	0.41	0.473
		High	0.69	0.504
	Water and Drainage Risks	Low	0.145	0.373
		Moderate	0.397	0.473
		High	0.458	0.504
Site Risks	Cultural and Archaeological Risks	Low	0.201	0.373
		Moderate	0.727	0.473
		High	0.072	0.504
	Regulatory Changes	Low	0.128	0.373
		Moderate	0.128	0.473
		High	0.745	0.504
	Government Funding and Budgetary Risks	Low	0.472	0.373
		Moderate	0.127	0.473
		High	0.401	0.504
	Local Opposition and Public Risks	Low	0.741	0.373
		Moderate	0.211	0.473
		High	0.048	0.504
	Soil Erosion and Sedimentation Risks	Low	0.514	0.373
		Moderate	0.219	0.473
		High	0.272	0.504

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	Water Pollution Risks	Low	0.471	0.373
		Moderate	0.41	0.473
		High	0.69	0.504
	Air Pollution Risks	Low	0.471	0.373
		Moderate	0.41	0.424
		High	0.69	0.584
Environmental Risks	Climate Change Risks	Low	0.291	0.311
		Moderate	0.272	0.454
		High	0.437	0.511
	Displacement of Communities	Low	0.254	0.613
		Moderate	0.473	0.253
		High	0.273	0.522
	Changes in Property Values	Low	0.145	0.273
		Moderate	0.397	0.477
		High	0.458	0.404
	Social Equity and Inclusion	Low	0.201	0.573
		Moderate	0.727	0.673
		High	0.072	0.204
Socio-Economic Risk	Criminal Activities	Low	0.672	0.573
		Moderate	0.2	0.453
		High	0.128	0.554
	Corruption/Bribes	Low	0.127	0.333
		Moderate	0.4	0.413
		High	0.473	0.514
	Changes in Community Dynamics	Low	0.272	0.353
		Moderate	0.091	0.323
		High	0.637	0.404

Regression Modelling

In order to understand what factors were collectively causing higher risks in road construction projects in Nebraska, a probit modelling approach was utilized. For the ordered probit model with three ordered categories of aggregated risks in construction projects, the probabilities for each risk category are presented below. In the ordered probit model, it is assumed that the cumulative distribution function (CDF) follows a normal distribution, and the model estimates the parameters of this distribution to estimate the probabilities of the observed outcomes. The probabilities of estimating a low, moderate and high road construction project aggregated risk are given as follows.

Probabilities to estimate – High Aggregated Risk

$$P(Risk\ type = High\ Aggregated\ Risk \mid A) \quad \text{eq (1)}$$

Probabilities to estimate - Moderate Aggregated Risk

$$P(Risk\ type = Moderate\ Aggregated\ Risk \mid A) \quad \text{eq (2)}$$

Probabilities to estimate-Low Aggregated Risk

$$P(Risk\ type = Low\ Aggregated\ Risk \mid A) \quad \text{eq (3)}$$

Risk severity probabilities Sum to 1

$$P(High\ Agg.Risk \mid A) + P(Moderate\ Agg.Risk \mid A) + P(Low\ Agg.Risk \mid A) = 1 \quad \text{eq (4)}$$

The dependent variable of the model is an observed ordinal variable X (in this study, risk level in road construction projects). The model assumes that there is a continuous, unmeasured latent variable, X*, whose values determine the value of the observed ordinal variable X. The variable X* has two threshold points represented by κ (the lowercase Greek letter kappa). The value of the observed variable X depends on whether X* has crossed a threshold, as shown below: The relationship between X and X^* is presented in equation 5.

$$X_i = \begin{cases} Low\ Risk & \text{if } X_i^* \le K_1 \\ Moderate\ Risk & \text{if } K_1 \le X_i^* \le K_2 \\ High\ Risk & \text{if } X_i^* \ge K_2 \end{cases} \quad \text{eq(5)}$$

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The aggregated risk categories in road construction projects are a function of the latent variable X. As a result, the following gives the ordered probit model to estimate for a given specification (i.e., for a chosen set of explanatory variables from the questionnaire survey data):

$$P(X_i = \text{ Low Risk Level}) = \frac{1}{1+\exp(Z_i - K_1)} \quad \text{eq(6)}$$

$$P(X_i = \text{ Moderate Risk Level}) = \frac{1}{1+\exp(Z_i - K_2)} - \frac{1}{1+\exp(Z_i - K_1)} \quad \text{eq(7)}$$

$$P(X_i = \text{ High Risk Level}) = 1 - \frac{1}{1+\exp(Z_i - K_2)} \quad \text{eq(8)}$$

Where, the subscript i indicates an index of a recorded risk level, X_i is the variable indicating risk type (high, moderate or low). And κ_1 is a coefficient of the threshold separating low risk from moderate risk, and κ_2 is a coefficient of the threshold separating moderate risk from high risk Kockelman & Kweon [18]; Farooq [19].

Results

The estimated Probit model for risk prediction in roadway construction projects in Nebraska is presented in Table 2. The coefficients reveal the impact of various factors on the likelihood of higher risk severity. Adverse weather conditions (β = 0.8247, p = 0.0244), unforeseen soil conditions (β = 0.5330, p = 0.0459), delays in obtaining necessary permits (β = 0.9872, p = 0.0131), accidents/crashes (β = 0.1291, p = 0.035), and changes in project specifications (β = 0.2760, p = 0.077) are all positively associated with increased risk severity. Conversely, political and economic stability (β = -0.0199, p = 0.022) and positive community and stakeholder relations (β = -0.2031, p = 0.001) are linked to a decreased likelihood of higher risk severity. The threshold coefficients indicate significant changes in the transition between different risk severity categories, with a notable increase at the threshold between low and moderate risk (β = 0.5125) and a substantial rise at the threshold between moderate and high risk (β = 1.7145). The model, evaluated with 55 observations (total respondents of questionnaire survey), exhibits a log-likelihood of -417.33, and the goodness of fit is assessed through the AIC (1474.74) and BIC (1987.14), with lower values indicative of a better fit. These findings contribute valuable insights into the factors influencing risk severity in road construction projects, offering implications for project planning and management strategies. It should be noted that multiple trials of the ordered probit model were conducted, and the model with the lowest values of AIC and BIC was selected for enhanced convergence [20,21].

Table 2: Estimated Risk Severity Model Based on Questionnaire Survey.

Variable (code name)	Estimate	Std. Error	Z-Value	P-value
Adverse weather indicator (1 if there is adverse weather during road construction, 0 otherwise)	0.8247	0.3833	2.227	0.0244
Unforeseen soil conditions indicator (1 if there are unforeseen soil conditions, 0 otherwise)	0.533	0.2939	1.996	0.0459
Change is project specification indicator (1 if there are changes in project specification, 0 otherwise)	0.276	0.1566	1.77	0.077
Delays in obtaining necessary permits indicator (1 if there are delays due to permits, 0 otherwise)	0.9872	0.34	2.529	0.0131
Accidents/Crashes indicator (1 if there are crashes on roads during construction)	0.1291	0.0607	2.13	0.035
Political and economic stability (1 if there is political and economic stability, 0 otherwise)	-0.0199	0.0086	-2.32	0.022
Contractual issues (1 if there are contractual issues, 0 otherwise)				
Community and stakeholder relations (1 if the relationship is good, 0 otherwise)	-0.2031	0.0074	-2.51	0.001
Threshold Coefficients				
Low Risk | Moderate Risk	0.5125	0.2511	2.067	-
Moderate Risk |High Risk	1.7145	0.2989	5.689	-
Summary Statistics				
Number of observations = 55				
Log-likelihood = -417.33				
Ordered model = Probit				
AIC = 1474.74				
BIC = 1987.14				

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Conclusion

In this study, the risks associated with road construction projects in Nebraska were assessed through a questionnaire survey targeting construction industry professionals, specifically those involved in roadway projects. The survey results were then visualized and subjected to descriptive statistical analysis. An ordered probit modeling approach was employed to predict the severity of identified risks, revealing that adverse weather conditions, unforeseen soil issues, permit delays, and changes in project specifications were significant factors contributing to higher risks in terms of project delays, safety, and costs. Conversely, stability in political and economic environments, as well as positive community and stakeholder relationships, were found to mitigate these risks. The recommendations arising from these findings emphasize two primary strategies. Firstly, the importance of developing robust weather contingency plans is highlighted, incorporating flexible schedules, weather forecasting tools, and weather-resistant construction methods to address the impact of adverse weather conditions on construction timelines.

Secondly, the need for thorough site investigations and soil analysis before project initiation is underscored to uncover unforeseen soil conditions, enabling better project planning and implementation of effective risk mitigation strategies. Additionally, efficient permitting processes, detailed feasibility studies, early engagement with regulatory authorities, and involving stakeholders in the initial planning stages are recommended to minimize delays and changes in project specifications. Advocating for political and economic stability is crucial, and fostering positive community and stakeholder relationships throughout the project lifecycle is emphasized to reduce the risk of disputes and disruptions. Implementing a proactive risk management plan, investing in team training and skill development, building flexibility into contracts, and encouraging collaboration among stakeholders are all suggested measures to navigate and mitigate risks effectively, thereby enhancing the overall success of road construction projects in Nebraska.

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