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Identifying and Prioritizing Critical Risk Factors in the Context of a High-Voltage Power Transmission Line Construction Project: A Case Study from Sri Lanka

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Abstract: This study addresses critical risk factors in high-voltage power transmission line (HVPTL) construction projects, which are vital components of national energy infrastructure. HVPTL projects are essential for meeting energy needs but are often plagued by risks due to their linear construction nature, leading to project underperformance. However, the lack of attention to risk management often leads to project underperformance. This research aims to identify and rank these risks to facilitate effective risk management. Through literature review and preliminary surveys, 63 risk elements were identified under 14 main categories. These risks were ranked using two rounds of Delphi surveys and the analytical hierarchy process (AHP). The study focuses on a Sri Lankan HVPTL project. The most critical risk factors identified include "improper planning by the main contractor", "delays in decision-making by the client/consultant", "errors in initial costing", and "inaccuracies in survey data", with AHP analysis assigning significant weights of 43.9%, 18%, 16%, and 14.9% to these factors, respectively. Comparative analysis with similar studies reveals consistent findings, underscoring the importance of addressing delays in approvals, material unavailability, and construction-quality challenges. These results emphasize the necessity of adopting systematic risk-management techniques in HVPTL projects to mitigate uncertainties and enhance project outcomes.

Keywords: high-voltage power transmission lines; Delphi survey; critical risk factors; risk management; AHP; construction

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1. Introduction

Critical infrastructures (CIs) encompass a diverse array of assets and services that are deeply interconnected, such that disruptions in one component can cascade across others, posing significant risks to both the economy and human welfare [1–3]. CIs can be broadly defined as the assets, physical structures, technical systems, or supply chains that are vital for the social and economic well-being and efficient functioning of communities [1,4]. Their pivotal role in ensuring national security, economic stability, and socio-economic well-being cannot be overstated [5–8]. Examples of CIs include national electricity grids, petroleum manufacturing plants, transportation networks, telecommunications systems, water supply networks, and healthcare systems [1,9]. The interdependence among these systems underscores the potential for widespread impact stemming from even minor failures [1,6,9,10]. With the expanding global population, the demand for robust CIs capable of meeting essential needs continues to grow. Governments worldwide recognize the indispensable role of infrastructure in unlocking economic potential and prioritize investments accordingly [11,12].

Within the spectrum of CI sectors, the electricity and energy supply sector emerge as paramount, playing a central role in numerous essential human activities, including food production, shelter, communication, and healthcare [13,14]. Electricity supply grids constitute a fundamental component of this sector, with deficiencies in power generation and distribution posing a direct threat to these essentials and consequently impeding overall quality of life [13,15–17]. The reliable supply and distribution of electricity are crucial for driving industrial economies and enhancing societal well-being. While research has shown a relationship between increased national electricity consumption and economic growth rates across low-income, middle-income, and high-income countries, it is important to recognize that this relationship may involve mediating variables, such as increased household income and improved infrastructure, which also influence electricity usage patterns [15,18].

The electricity supply system of a nation comprises key components such as generation, transmission, and distribution [19–21]. Among these, electricity grids garner considerable attention owing to their inherent criticality [20–23]. The construction of high-voltage overhead transmission lines serves as a pivotal element in the development of electricity infrastructure in any country [24]. Therefore, the construction of high-voltage power transmission lines (HVPTLs) must be executed promptly to meet the escalating demand for power. Consequently, the timely implementation and completion of HVPTL construction projects have emerged as pivotal factors in addressing this growing need. Analogous to other critical electricity-related infrastructure projects, HVPTL construction projects share common characteristics, including their significance to the national economy, substantial investment costs, the need for specialized technology, and the presence of numerous risk factors during the construction phase [15,16,24]. Past scholars suggested that successful projects are those capable of systematically managing all critical risk elements [15,25–27].

All projects inherently carry a degree of risk due to their unique nature and varying complexities aimed at delivering favorable outcomes [25,26,28]. Unlike conventional construction projects, HVPTL construction projects entail significant risk during their construction phase, attributed to distinctive features such as right-of-way considerations, utilization of barren lands with challenging ground conditions, deployment of intricate lattice steel structures, global equipment procurement, and extensive public engagement [15,29–31]. However, the lack of emphasis on risk analysis and response planning in HVPTL projects leaves them vulnerable to unforeseen events, leading to detrimental consequences. Delays in HVPTL construction projects are commonplace, exerting adverse impacts on the economic development of nations, despite substantial global investments in power transmission endeavors [30,32–34].

A comparable study conducted by Zhao and Li (2015) focusing on risk assessment in ultra-high-voltage (UHV) power transmission construction underscores the formidable challenges faced by transmission projects in developing countries [35]. These challenges encompass diverse natural environments, multi-stakeholder involvement, elevated construction activities, and intricate community relations. Zhao and Li (2015) emphasize that HVPTL construction entails heightened risks and complexities, emphasizing the critical need for a robust risk analysis framework tailored to such contexts [35]. Efficient construction management and informed decision-making are paramount for project success, necessitating a comprehensive risk assessment at the project's inception to proactively anticipate and address potential challenges [15,16,32,36,37]. While the power sector often prioritizes risk management in power generation, risks associated with HVPT projects are frequently overlooked [15,18,35]. Consequently, the development of an effective risk-evaluation system is imperative to identify and mitigate construction risks in HVPTL projects [15,18,32,35,37].

In many developing countries, conventional construction project risk-management practices suffer from an absence of comprehensive risk-management systems and limited attention to proper risk-management techniques [38,39]. This highlights a critical gap that necessitates the development of a tailored risk-assessment framework specifically designed to address the unique challenges faced by HVPTL construction industries in developing nations [15,35]. Such an initiative holds the potential to not only improve project outcomes but also significantly contribute to the sustainable development of CIs in these regions. Accordingly, this study aims to identify and prioritize critical risk factors within the context of HVPTL construction projects utilizing the Delphi survey technique and AHP analysis. The research focuses on the Sri Lankan HVPTL construction sector as a case study to provide valuable insights and recommendations for enhancing risk-management practices in similar settings. The remainder of this paper is organized as follows. Section 2 presents the methodology adopted in this study, detailing the data-collection process, and analysis techniques. In Section 3, the results of the analysis are discussed, highlighting the key findings and their implications. Section 4 provides a detailed discussion of the results in comparison with existing literature, emphasizing the contributions to the field. Finally, Section 5 concludes the paper by summarizing the key insights, outlining the limitations, and suggesting directions for future research.

2. Materials and Methods

Figure 1 shows the overall methodology of the present study. The methodology employed in this study aligns with interpretivism, utilizing data collection through semi-structured preliminary questionnaires followed by multiple rounds of Delphi questionnaires. Interpretive research inherently captures data influenced by personal perspectives and values, limiting its generalizability [40]. Consequently, this study employs the Delphi survey to synthesize diverse expert opinions into a unified consensus. The Delphi process is a method that is used to achieve convergence in expert opinion on a specific practical issue [41]. The Delphi method is a systematic, interactive forecasting approach that relies on a panel of experts to achieve consensus on complex issues. It is particularly effective in areas characterized by uncertainty or limited empirical data [42]. The method involves multiple rounds of surveys or questionnaires, where experts provide their opinions anonymously. After each round, responses are aggregated and summarized, with feedback provided to participants to refine their judgments in subsequent iterations. This iterative process continues until convergence of opinions is achieved. Key advantages of the Delphi method include the mitigation of bias due to dominant individuals, structured collection of expert input, and the facilitation of consensus-building through controlled feedback [41]. As described by Smith et al. (2009), the Delphi method is a technique developed for reaching consensus expert assessments, and this method can be applied to risk assessment [42].

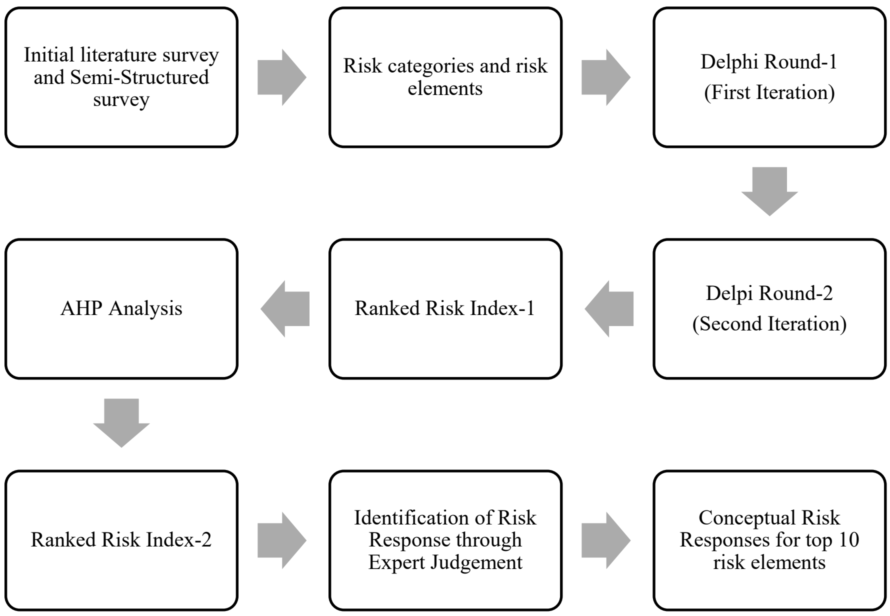

Figure 1. Summarized research methodology.

Initially, an in-depth literature review was conducted to identify the different risk elements and risk categories in relation to the HVPTL construction projects. After an initial literature review, a semi-structured interview was conducted among the professionals who were involved in the HVPTL construction projects to get an insight into anticipated risk elements in the Sri Lankan context. The findings from the initial literature review and the semi-structured interview were used to prepare the questionnaire for the Delphi survey. Subsequently, the Delphi survey was employed to prioritize risk factors based on their impact on the project and likelihood of occurrence. The Delphi survey involved multiple iterative rounds to achieve consensus until responses converged and stability was reached, indicating that there were no significant changes in expert opinions for the rank of the risk elements. In this study, two rounds of questionnaires were administered. The results of the Delphi survey identified the risk factor with the highest probability of occurrence and impact as the most critical. Following two rounds of the Delphi survey, the top-ranked risk factors were further analyzed using the analytical hierarchical process (AHP) to refine their ranking. Subsequently, a questionnaire was distributed to five selected experts who participated in the initial questionnaire, soliciting their insights to determine risk responses for the 10 top-ranked risk factors identified through the Delphi and AHP analyses.

2.1. Introduction to Case Study Area

The current study focuses on assessing critical risk factors associated with HVPTL projects, with Sri Lanka serving as the primary case study area. Situated at the southern tip of the Indian subcontinent, Sri Lanka faces significant energy and economic challenges, including electricity shortages and high inflation rates [13]. These crises are attributed to various factors such as prolonged droughts, low hydroelectric power generation, and delayed investments in the electricity sector, underscoring the criticality of infrastructure sectors in the country. Further, the management of the electricity supply in Sri Lanka is overseen by the Ceylon Electricity Board (CEB), which acts as the sole island-wide power transmitter. According to the CEB (2020), demand for electricity in the country during the last 15 years has been growing at an average rate of about 6.0% per annum, while peak demand has been growing at a rate of 4.0% per annum [43]. However, the peak demand has grown at a rate of 4.7% during the last 5 years [44,45]. The worldpopulationreview.com (2022) website states that the current annual population growth rate in Sri Lanka is 0.37% [46]. According to the global prediction given earlier, the population in Sri Lanka over the next 8 years would go up to 21,474,701 from the current value of 21,323,471. Consequently, there is a pressing need for infrastructure expansion to meet the escalating energy requirements of the country. The CEB's Long-Term Generation Expansion Plan forecasts a 4.7% average annual growth rate in net electricity demand over the next 25 years [44,45]. To meet this growing demand, an increase in the number of HVPTL projects is inevitable, regardless of whether energy-generation targets are achieved through renewable or non-renewable sources. The projected expansion plan indicates a substantial investment requirement of USD 15,924 million (LKR 2980.63 billion) by 2039 to accommodate the evolving energy landscape.

In Sri Lanka, the construction of HVPTL lines holds particular significance due to its pivotal role in addressing the nation's energy needs and supporting economic development. The transmission network comprises a mix of 220 kV and 132 kV overhead HV lines (see Figure 2), along with grid substations distributed across the island [43,45]. Despite the pivotal role of risk management in project execution, Sri Lankan industrial practices often neglect formal risk-management techniques. Decision-making processes rely heavily on experiential knowledge, leading to limited adoption of structured risk-management frameworks. Consequently, risk-retention techniques are underutilized, with contractors bearing the brunt of unforeseen project risks. The absence of dedicated risk-analysis frameworks further exacerbates project risks, highlighting the urgent need for comprehensive risk-management strategies tailored to the Sri Lankan HVPTL construction context.

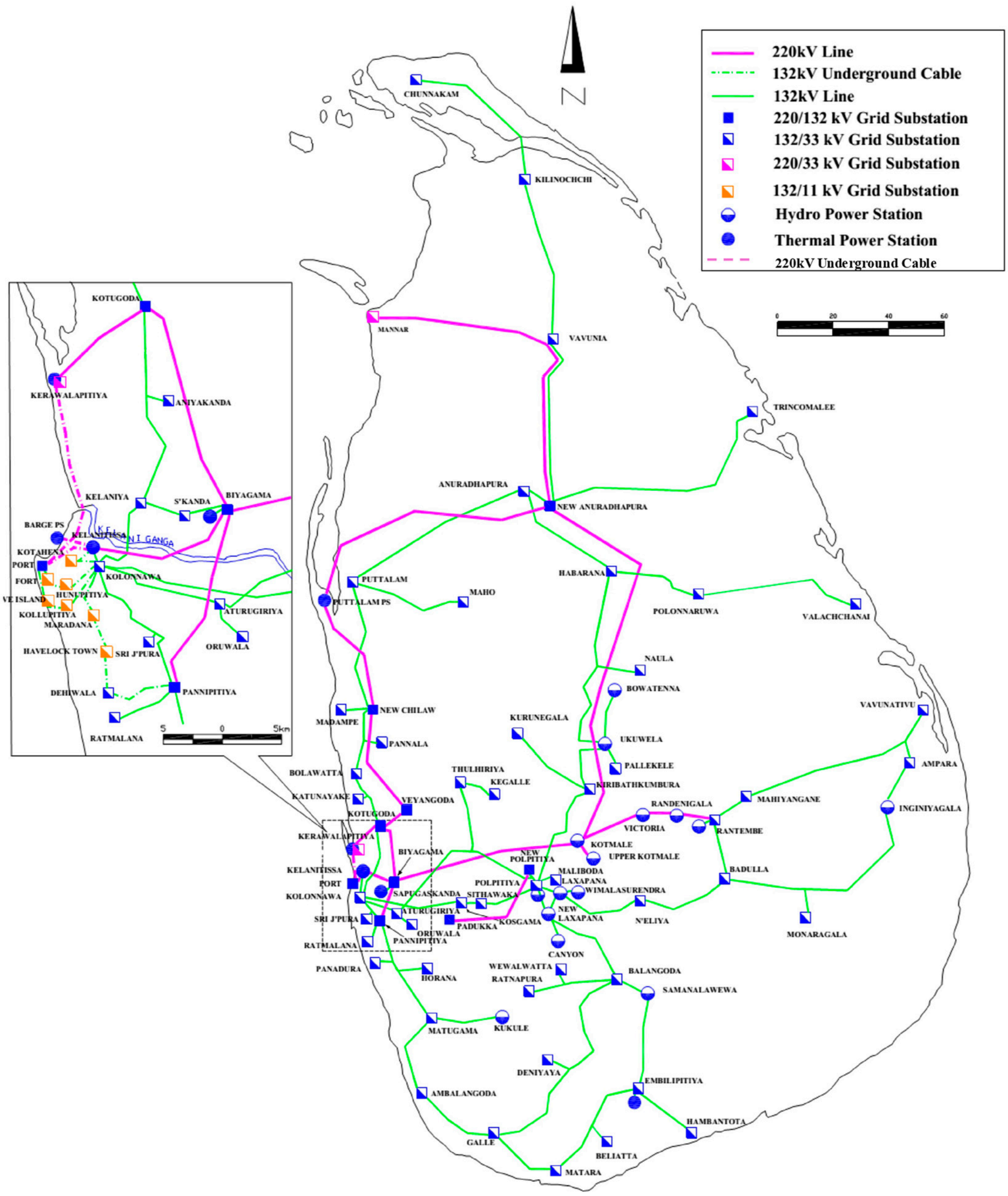

Figure 2. Map of the Sri Lankan transmission system in 2020.

2.2. Selection of Expert Panel for Delphi Survey

The population of the present study consists of professionals who were involved in HVPTL construction in Sri Lanka. Since this study employs the Delphi technique, the selection of participants is inherently limited to nonprobability sampling methods [47,48]. The Delphi method relies on the expertise of a panel rather than a statistically representative sample, which necessitates purposive, rather than random, selection. As explained by Keeney et al. (2001), the sampling process for the Delphi method often involves heterogeneous or purposive sampling [47,49,50]. This approach ensures that a pertinent range of perspectives is represented by deliberately selecting individuals with relevant knowledge and expertise in the subject matter. Such targeted sampling is crucial to achieving the depth and quality of expert input required for meaningful consensus within the Delphi process.

The composition of the panel constitutes a critical determinant of the study's success, as the information analyzed to arrive at a consensus-based decision relies on the expert insights provided by the panel of specialists [49–52]. The selection of experts is primarily based on their qualifications, accessibility, and commitment to contributing to the study. As can be noted from Figure 3, prior research indicates that there is no fixed number of panel members required; rather, the optimal size varies across studies [53]. For homogeneous groups, a sample size of 10 to 15 is generally considered sufficient [53,54]. In contrast, heterogeneous panels necessitate a larger number of members, suggesting that a broader representation is acceptable for a study [49,52,54,55]. Therefore, this study has leveraged the expertise of 16 panelists to obtain the data needed for the analysis in Delphi rounds 1 and 2. The selected panelists comprised professionals from the power-transmission construction industry, including design engineers, construction/site engineers, project managers, contractors, and client engineers. To ensure heterogeneity, the Delphi panel encompassed experts occupying roles in funding organizations, clients, consultants, and contractors, representing the three primary stakeholder groups. In the Sri Lankan context, both the client and consultant roles are typically fulfilled by the CEB, while funding organizations may be local banks or international financial institutions. When selecting the panel members, their experience in HVPTL projects, education level, and ability to understand the research's objectives were considered, and each panel member had a minimum of 6 years of experience in Sri Lankan HVPTL projects. All panel members had bachelor's degrees in engineering, and 9 out of the 16 members had post-graduate degrees.

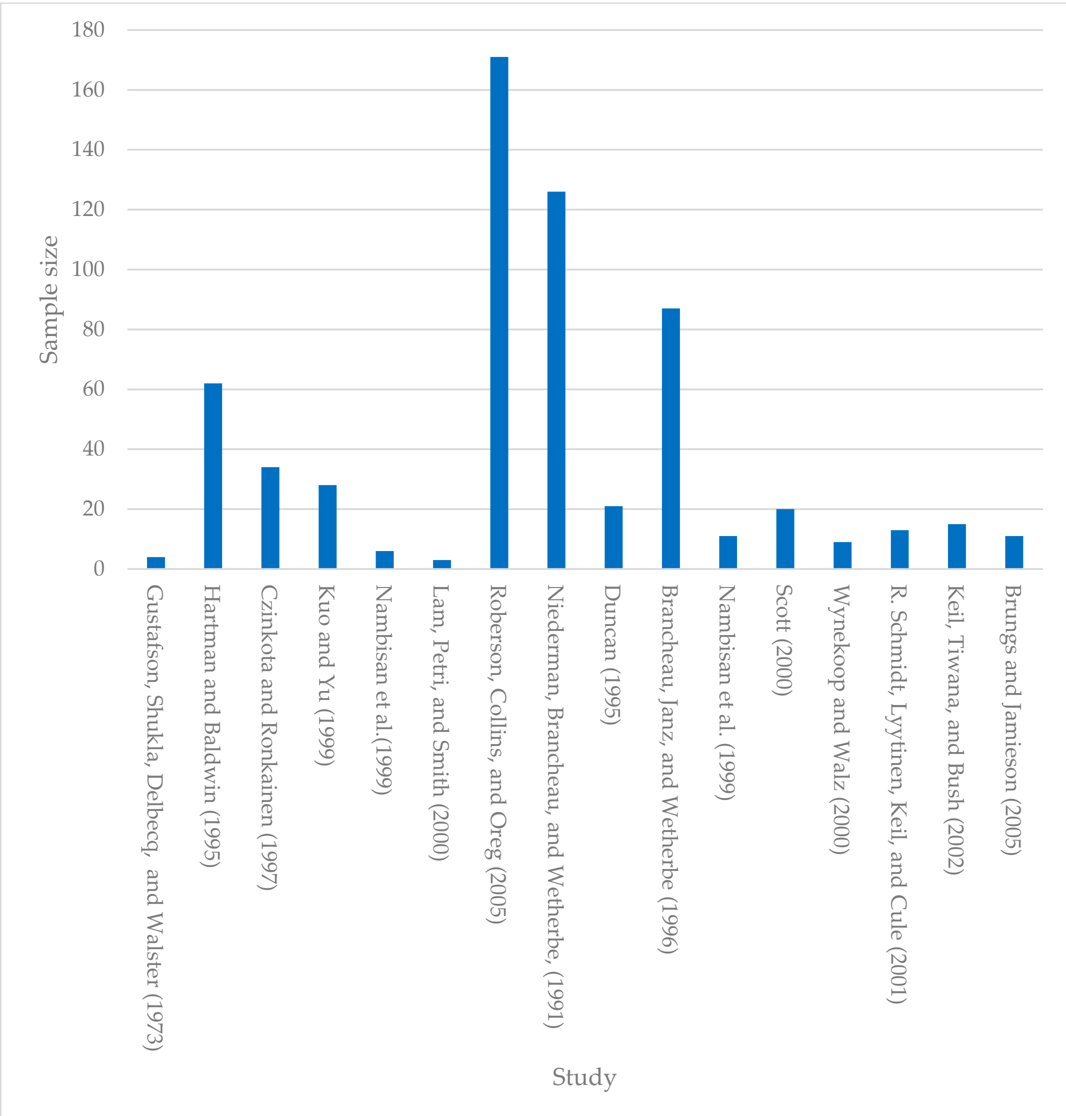

Figure 3. Number of Delphi rounds and sample sizes used in the published literature (adopted from [53]).

In the initial round of the Delphi survey, the questionnaire was developed based on responses from a preliminary survey conducted with a smaller group of experts and a review of relevant literature (see Appendix B). An academic professional specializing in risk management reviewed the preliminary questionnaire responses, leading to the development of a structured questionnaire for Delphi round one (see Appendix C). During this 1st round, the panel was asked to rate pre-identified risk factors on a Likert scale from 1 to 5 across 14 main risk categories associated with the HVPTL project in terms of their impact on time, cost, and quality and to suggest additional factors within these categories as needed. Subsequently, the second round of the survey was conducted. The same questionnaire was redistributed to the panel of experts without introducing additional risk elements. Feedback from the first round, presented as percentages of total responses for each rating and including each respondent's previous ratings, was provided to the panelists (see Appendix D). They were then invited to review and potentially revise their initial ratings based on the collective feedback from the panel. Subsequently, the five most critical risk factors were selected for further analysis using the average ranking method, which has been used in past studies [56–58]. This method involved calculating the sum of the weightage of criticality ranks assigned to each risk element by all respondents (Σ(wi)), which was then averaged by the total number of responses (Σ(wi)/Σ(xi)). The resulting averages were ranked from highest to lowest using a spreadsheet. Following the identification of the top five critical risk elements, analytic hierarchy process (AHP) analysis was employed to individually examine the criticality of these selected elements further.

2.3. AHP Analysis and Selection of Sample Size

Following the completion of the Delphi survey data collection aimed at prioritizing the most critical risk factors, the analytic hierarchy process (AHP) was adopted for risk-factor prioritization. AHP is a recognized multi-criteria decision-making methodology that facilitates systematic comparisons of alternatives by integrating qualitative and quantitative criteria. This method offers a structured framework, breaking down complex problems into a hierarchical structure of more manageable components. By utilizing AHP, the study sought to ensure a rigorous and systematic approach to prioritizing risk factors, thereby facilitating a more informed and objective decision-making process based on expert evaluations and opinions. In previous studies on multi-criteria decision making (MCDM), the analytic hierarchy process (AHP) has been recognized for its capability to achieve high consistency without requiring a large sample size [59–62]. As such, the recommended number of participants for AHP analysis typically ranges between 5 and 15 to maintain efficiency and consistency [63,64]. In this study, 16 responses were received, and 12 participants were selected for AHP ranking based on the consistency ratio (CR) to ensure robust and reliable results. A separate questionnaire was used to get input from experts to calculate importance weight (see Appendix E). The work experience of the experts and positions held in the organizations are depicted in Figure 4 and Table 1, respectively.

Table 1. Work experience of the experts.

Work Experience (x) in Years	Number of Experts
$x < 5$	0
$6 \leq x < 10$	9
$11 \leq x < 15$	1
$16 \leq x < 20$	5
$20 \leq x$	2

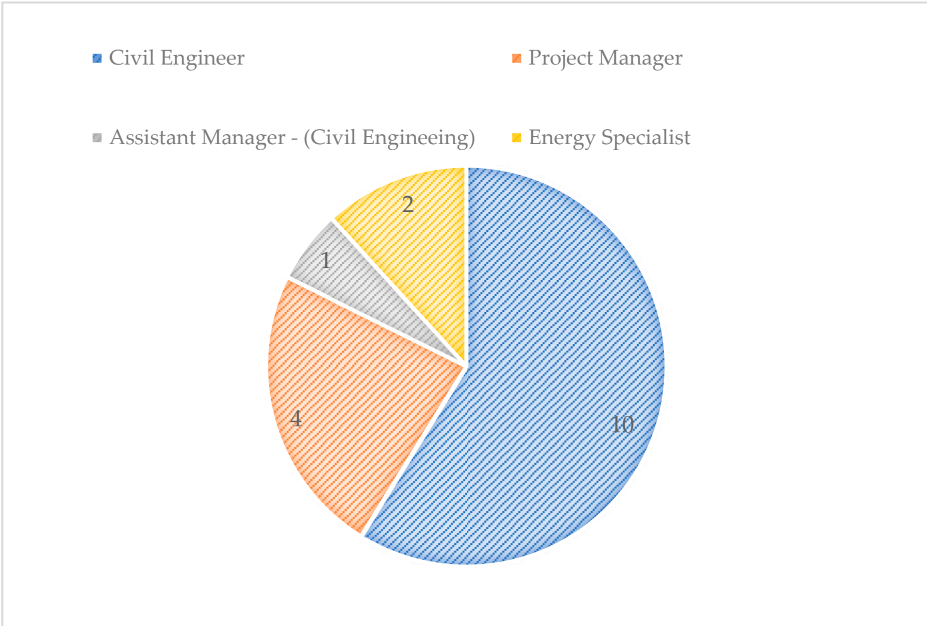

Figure 4. Positions of experts participating in Delphi and expert surveys.

3. Results

3.1. Initial Identification of Risk Elements Under Each Main Risk Category

Numerous studies have been conducted to identify the potential causes of delays in HVPTL construction projects. Pall et al. conducted extensive research to pinpoint the causes of delays in power transmission projects. Through an intensive literature review, they identified 82 potential causes, which were categorized into nine major categories [30]. Their findings revealed a distinct complexity in power generation projects compared to non-power linear construction projects, with 85% of the causes of time overruns being unique to power generation projects. Additionally, approximately 63% of the factors contributing to time overruns in power distribution projects were found to be similar to those in non-power linear construction projects, underscoring the multifaceted nature of power transmission projects.

In a case study conducted by Sasaki and Nakayama focusing on power transmission lines, nine risk categories were identified through a combination of literature surveys and expert interviews. From these identified risk factors, regulatory risk, financial risk, and political risk were determined to be the most critical factors [65]. However, the study did not provide details regarding the composition of the expert panel, raising concerns about potential biases in favor of the client's perspective. Consequently, the study appears to have paid limited attention to the technical and managerial challenges that may have been encountered during the project, suggesting a need for a more balanced and comprehensive risk-assessment approach.

In a study by Okudan et al. the associated risks in the construction of large-scale ultra-high-voltage projects in China were analyzed. The study employed a four-step method for risk identification, including risk decomposition, expert interviews, risk-point listing, and specialist discussion and revision [66]. Following this process, five primary dimensions of risks were identified, which were further categorized into 16 secondary dimensions using a Likert scale based on the risk map framework, considering both "risk importance" and "risk occurrence probability", as outlined by Jia-Xu et al. [67]. Table 2 below provides a summary of the risk categories identified through the literature review conducted in this research.

To identify risk elements in the context of HVPTL construction, 14 main risk categories were established based on an initial literature survey. These main risk categories were derived by consolidating the similar risk categories presented in Table 2 from the literature. Figure 5 illustrates the derived risk categories specific to HVPTL construction. Accordingly, client/consultant, design-related, tendering/bidding, contractual, communication, material/equipment, government/regulatory, sub-contractor, contractor-related, natural/environmental, social/community, funding agency, construction, and human resources were considered the main risk categories in the present study. Then, the risk elements were identified under each main risk category through a preliminary survey and the literature review, as elaborated in Figure 6.

Table 2. Summary of the risk factors identified in the literature.

Reference	Risk Factor																									
	Administrative/Corporate	**Land Acquisition**	**Communication**	**Social**	**Regulatory**	**Political**	**Force Majeure**	**Employer/Owner-Related**	**Tender/Contractual**	**Incompetent Consultant**	**Contractor-Related**	**Managerial**	**Preliminary Design/Initial Design/Costing**	**Revenue/Billing**	**Economical/Financial**	**Logistics/Supply**	**Technical/Technological**	**Drawing/Detailed Design-Related**	**Construction**	**Material-Related/Products**	**Equipment/Technology**	**Sub-Contractor**	**Labor/Worker**	**Operating**	**Site Condition/Geographical/Geotechnical**	**Natural Environment**	**External/Miscellaneous**
[68]								x			x							x	x								
[30]	x							x			x							x	x	x	x		x				x
[35]	x										x										x		x				
[69]	x					x																					
[36]								x		x	x		x					x		x	x					x	
[65]					x	x	x						x	x			x							x		x	
[28]									x				x		x			x	x								
[70]					x	x									x	x		x	x							x	
[71]						x						x			x		x							x	x		x
[72]						x			x			x			x		x								x		
[73]						x		x				x	x		x				x		x	x					x
[74]															x		x		x							x	
[42]			x	x	x	x	x								x	x	x		x	x					x	x	
[75]				x		x									x				x								
[76]	x	x	x	x					x		x		x	x		x			x	x					x	x	
[77]				x	x	x									x		x		x							x	
[78]					x								x		x	x						x	x		x	x	
[79]							x	x			x		x			x		x		x	x					x	
[37]			x							x	x																
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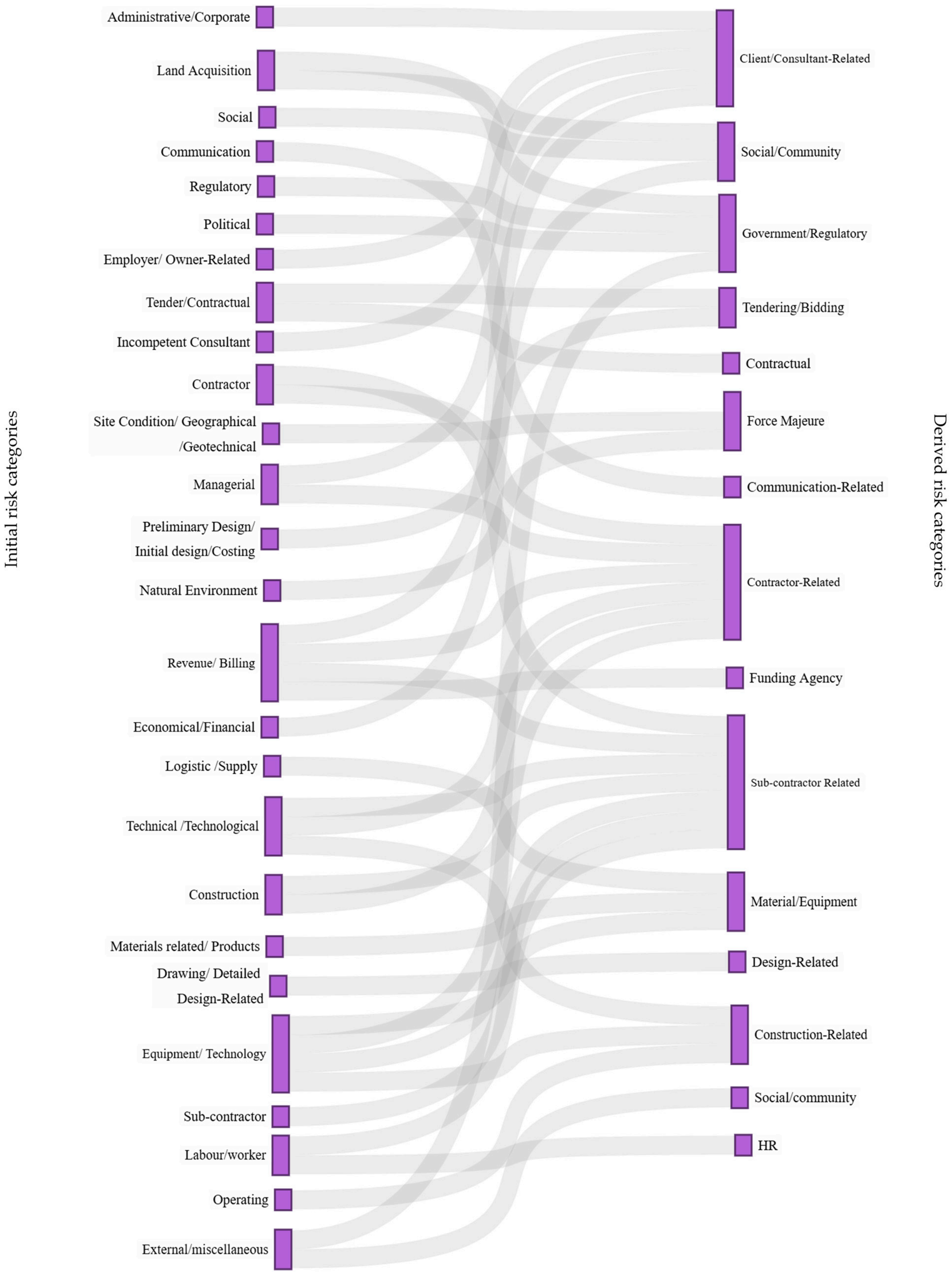


Figure 5. Derivation of the main risk categories related to the HVPTL project.

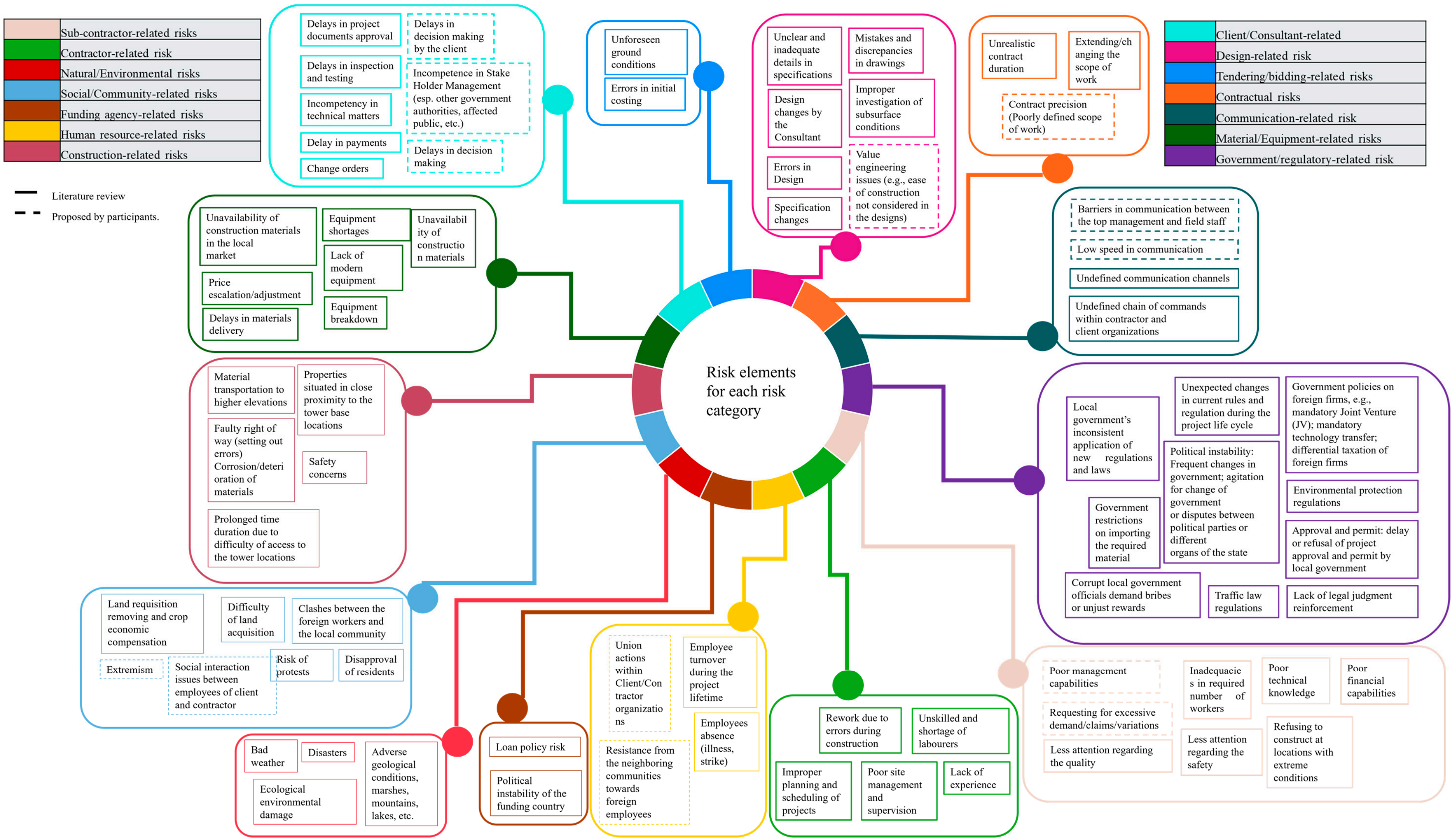


Figure 6. Risk elements identified in preliminary survey and literature review.

3.2. Validity of the Identified Risk Elements in the Context of the HVPTL Project

During the preliminary survey, participants were asked to rate the validity of the identified risk elements across various categories. Figure 7 presents the acceptance rates for each risk category. In the "client/consultant-related" category, all identified risk elements were unanimously accepted by the preliminary survey participants. Additionally, three new risk elements were proposed during the initial survey (Figure 6). For the "design-related risks" category, as shown in Figure 7a, four out of five risk elements received consensus approval, while elements 2.2 and 2.7 were deemed non-related by a single respondent. The rationale provided was that the project specifications remained unchanged throughout the project lifecycle, and the risk element "improper investigation of subsurface conditions" might better fit another category. One new risk element was introduced by an initial survey panel member (see Figure 6). All literature-identified risk factors under the "tendering/bidding-related risks" category were deemed 100% relevant by the participants. Similarly, all identified risk elements under the "contractual risks" category received a 100% relevancy rate. An additional risk element was proposed by an initial survey panel member (see Figure 6).

Figure 7b shows that one out of two risk elements in the "communication-related risks" category was widely accepted. Despite initial disagreements, further review highlighted its significance, prompting its inclusion in subsequent evaluations. Two additional risk elements were suggested during the initial survey (see Figure 6). In Figure 7c, the evaluation of "material/equipment-related risks" reveals that four out of seven elements were accepted as relevant to HVPTL projects. Specifically, "unavailability of construction materials" and "equipment shortages" received 80% approval, whereas "lack of modern equipment" garnered only 60%. The latter was revised to "lack of use of modern equipment", while the former two were retained unchanged. The preliminary survey's findings on sub-contractor-related risks are presented in Figure 7d. Five out of six identified risk factors were deemed significant by the participants, with two additional factors recommended by the panel. Figure 7e elaborates on government and regulatory risks. Out of 10 identified elements, five were deemed relevant. Experts recommended merging elements 7.1 and 7.10 into a single risk factor, termed "sudden and unexpected changes in government regulations and policies".

All identified risk elements in the "contractor-related risks", "natural/environmental risks", "social/community-related risks", "funding agency-related risks", and "human resource-related risks" categories received a 100% relevancy rate. Furthermore, participants proposed two additional risk elements for the "social/community-related risks" category (see Figure 6).

In summary, a total of 65 risk elements, categorized under 14 distinct risk categories, were reviewed during the preliminary survey. Of these, 51 risk elements received consensus approval as being relevant to HVPTL projects. Nine risk elements were accepted by only four panel members, three received acceptances from three out of five members, and one risk element faced rejection by the majority. Additionally, experts proposed the inclusion of 10 new risk elements for subsequent survey iterations. Figure 8 presents the revised risk elements after the preliminary survey.

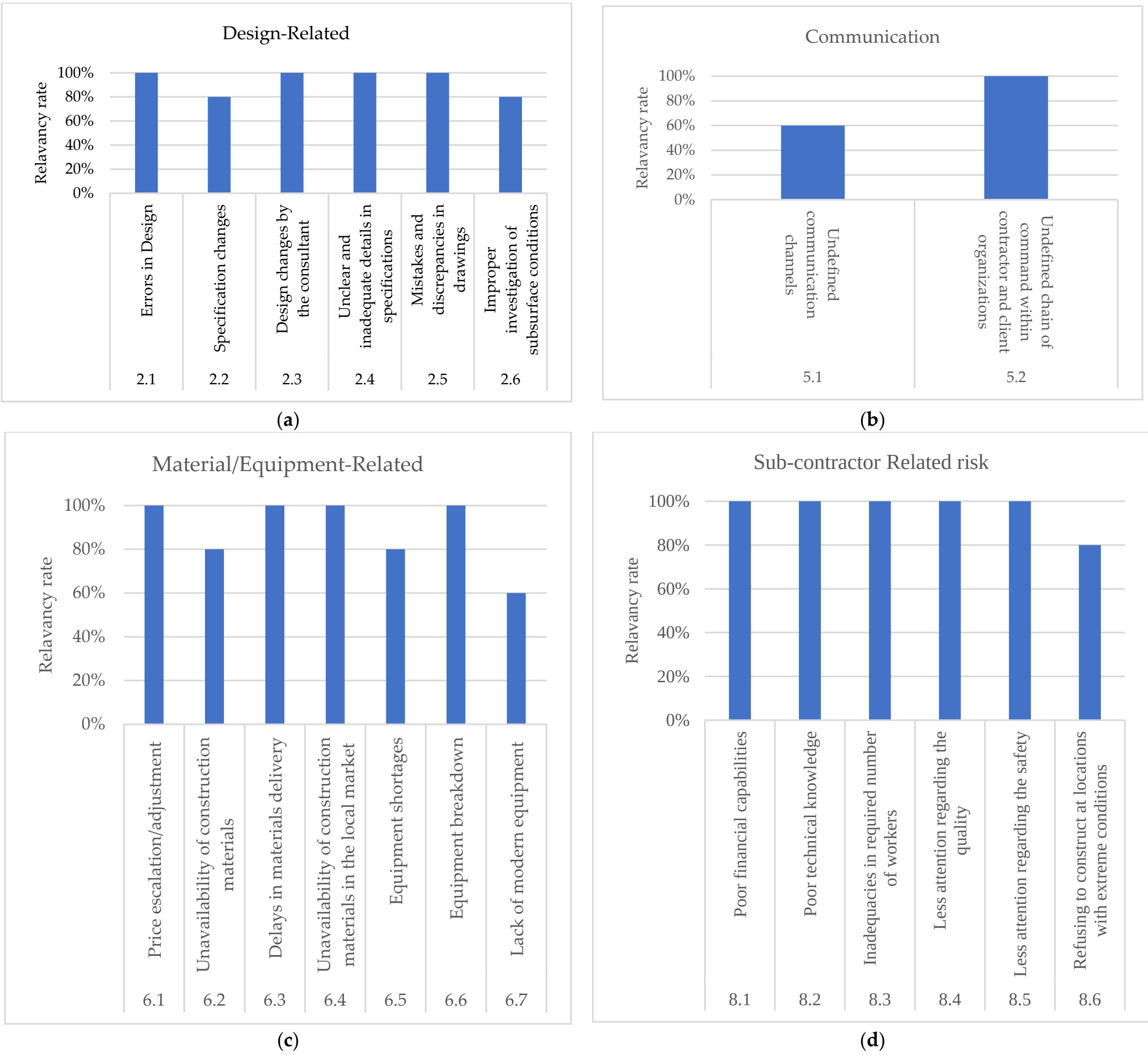
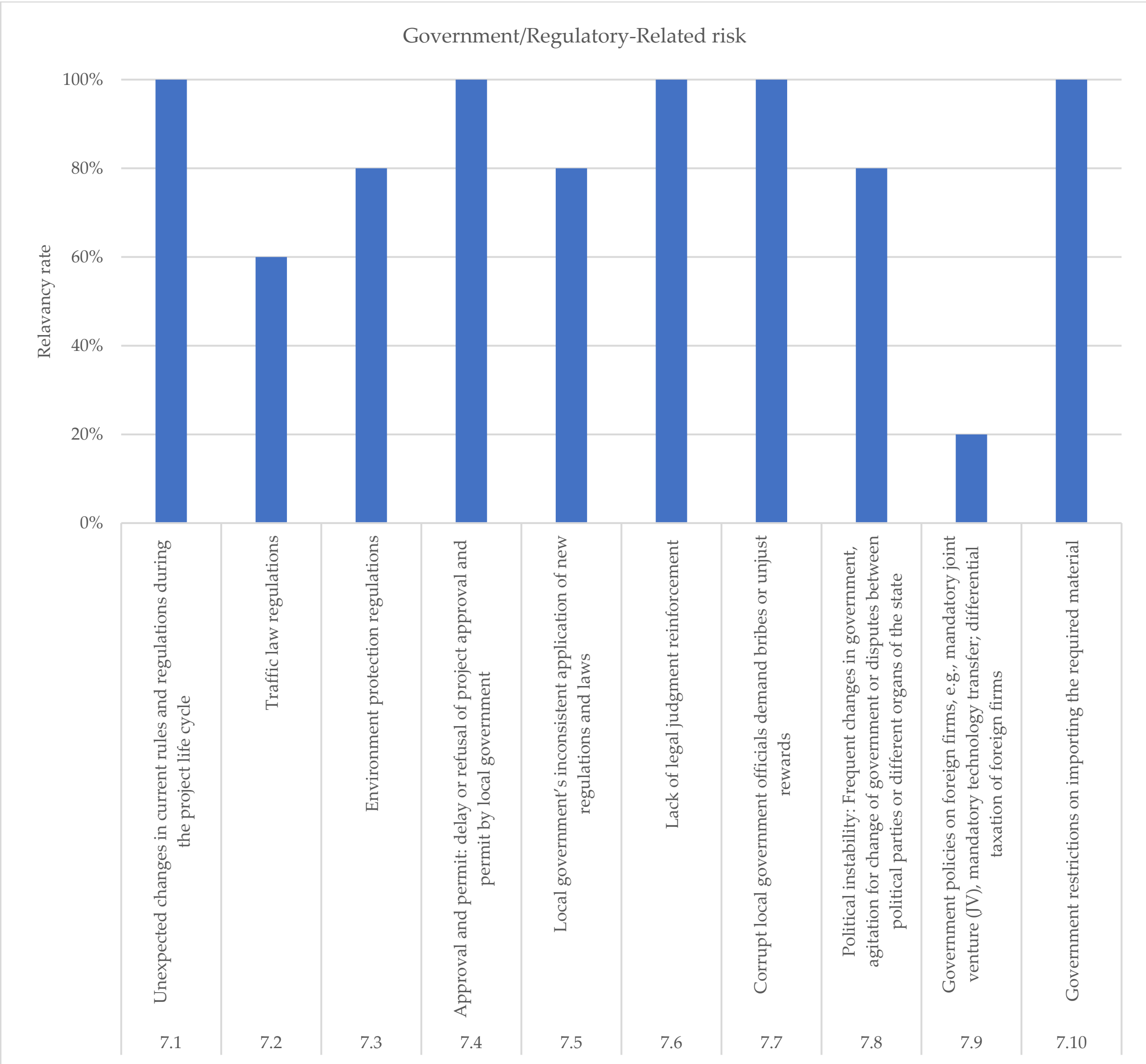


Figure 7. *Cont.*



(**e**)

Figure 7. Relevance rate for the identified risk elements under each category ((**a**) Design-Related risk, (**b**) Communication risk, (**c**) Material/Equipment-Related, (**d**) Sub-contractor Related risk, (**e**) Government/Regulatory-Related risk).

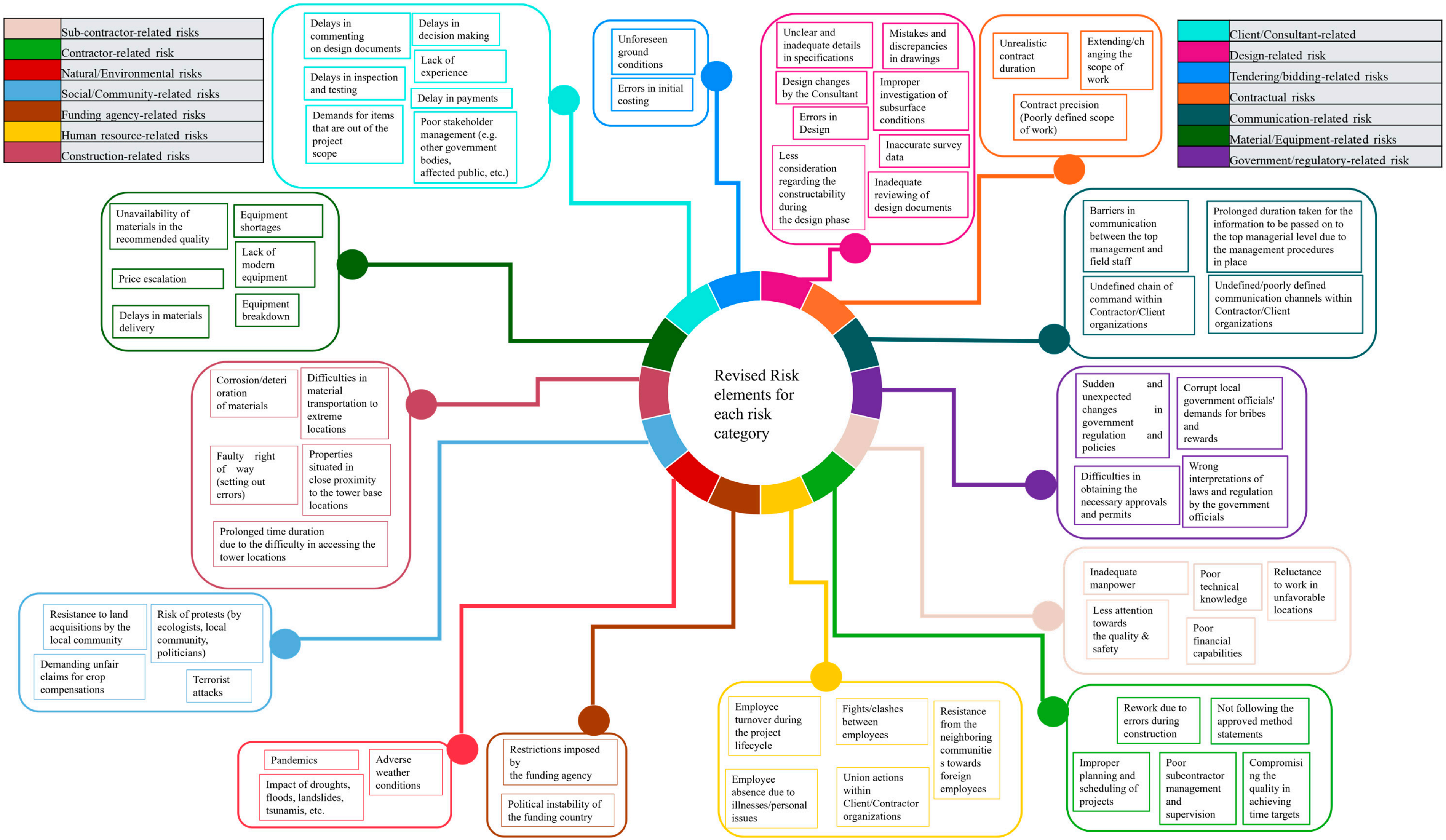


Figure 8. Final risk elements under main risk categories.

3.3. Ranking of Risk Elements Using Average Ranking Method with Delphi Surveys

The primary objective of the first Delphi round was to evaluate the criticality level of the validated risk elements identified through the preliminary questionnaire. For this phase, a panel of 20 experts was selected. The structured questionnaire was distributed to the panelists via an online platform, and in-person hard copies were also accepted. After two weeks of diligent follow-up, responses were obtained from 16 out of 20 panel members, yielding an 80% response rate. Selection criteria for panel members included their experience in HVPTL projects, educational background, and comprehension of the research objectives. Each panel member possessed a minimum of six years of experience in Sri Lankan HVPTL projects, with all holding bachelor's degrees in engineering. Furthermore, nine out of the 16 members had pursued postgraduate degrees. At the time of the survey, panel members were engaged in various roles including contractor, funding agent, client, and consultant. Based on the analysis conducted using the average ranking method in the first Delphi round, the top five risk factors were identified, as presented in Table 3.

The second round of the Delphi survey aimed to enable panel experts to analyze their responses from the first questionnaire and either confirm or revise them to achieve a common consensus. In this round, each panel member received a questionnaire containing their previous responses alongside the percentage distribution of responses from the entire panel for each answer. Details regarding the preparation of the Delphi round-2 questionnaire were provided in the preceding chapter. All 16 panel members responded to the second-round questionnaire, resulting in a 100% response rate. The results from the second Delphi round, along with the analysis conducted using the average ranking method, identified the top five risk factors, as outlined in Table 3. Figure 9 presents box and whisker plots of the weights assigned by the respondents during the Delphi survey. The plot effectively illustrates the distribution and variability of weights recorded across different rounds and respondents. Notably, the median weight remains relatively consistent across rounds, suggesting stability in the central tendency of the data. However, the interquartile range varies notably, indicating fluctuations in the spread of weights. Outliers are also observed in certain rounds, potentially indicating anomalies or unique observations. Overall, there is relatively consistent agreement among the participants regarding the weights assigned to the risk elements.

Table 3. Top five risk elements identified during Delphi rounds one and two.

Rank	Risk Category	Risk Element	Delphi Round No.
1	Client/Consultant-Related	Delays in decision making	Round 01
1	Client/Consultant-Related	Lack of experience	
3	Contractor-Related	Improper planning and scheduling of task	
4	Contractual	Unrealistic contract duration	
5	Sub-contractor-Related	Inadequate manpower	
1	Contractor-Related	Improper planning and scheduling of task	Round 02
2	Tendering/Bidding-Related	Errors in initial costing	
3	Client/Consultant-Related	Delays in decision-making	
3	Client/Consultant-Related	Lack of experience	
5	Design-Related	Inaccurate survey data	

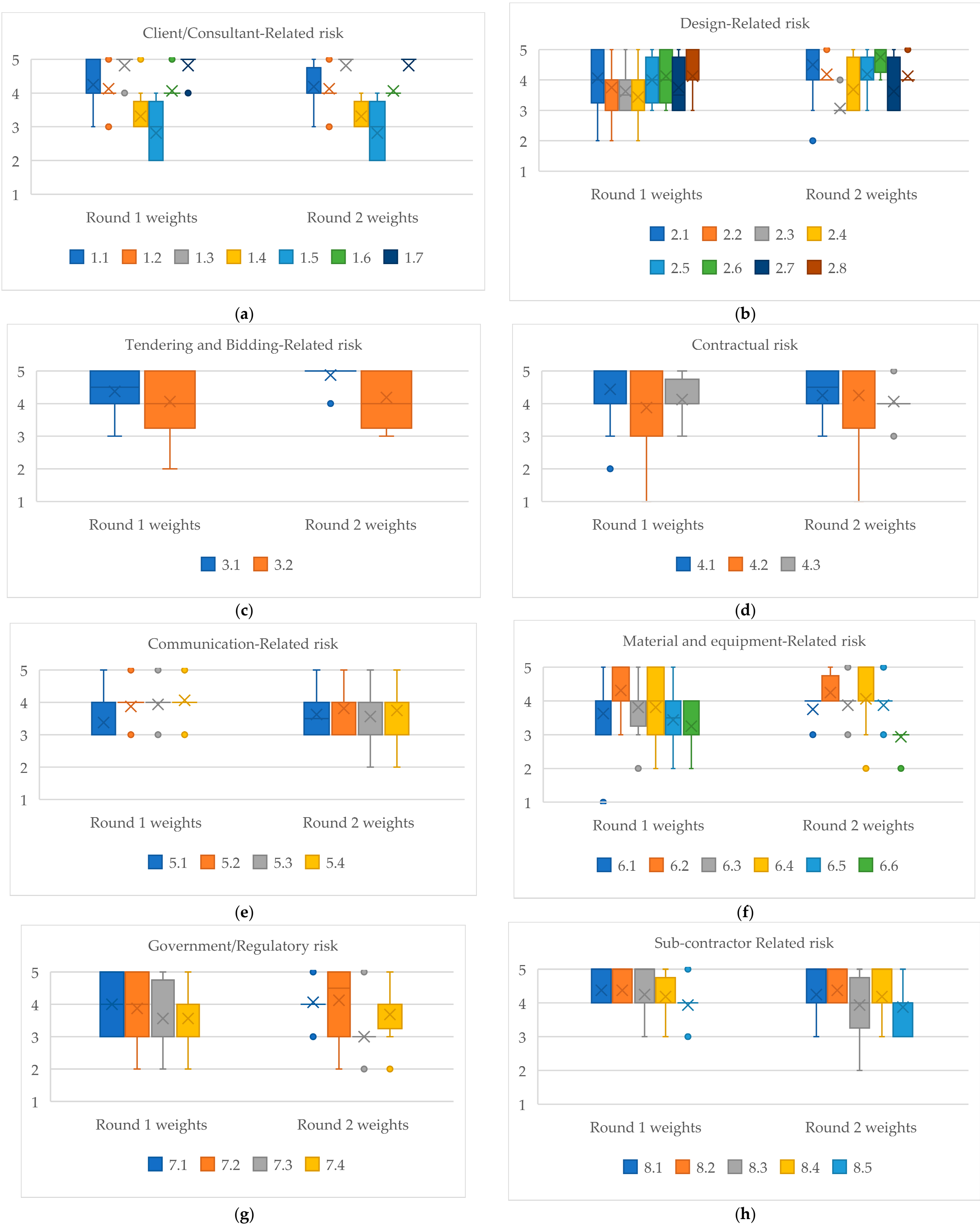


Figure 9. *Cont.*

ID	Risk element
1.1	Delays in commenting on design documents
1.2	Delays in inspections and testing
1.3	Delays in decision making
1.4	Delay in payments
1.5	Demands for items that are out of the project scope
1.6	Poor stakeholder management (e.g., other government bodies, affected public, etc)
1.7	Lack of experience
2.1	Errors in design
2.2	Design changes by the consultant
2.3	Unclear/inadequate details in specifications
2.4	Mistakes and discrepancies in drawings
2.5	Incomplete investigations of subsurface conditions
2.6	Inaccurate survey data
2.7	Inadequate reviewing of design documents
2.8	Less consideration regarding the constructability during the design phase
3.1	Errors in initial costing
3.2	Unavailability of design data during the bidding phase (e.g. geotechnical data)
4.1	Unrealistic contract duration
4.2	Extending/changing the scope of work
4.3	Contract precision (poorly defined scope of work)

ID	Risk element
5.1	Undefined/poorly defined communication channels within Contractor/Client organizations
5.2	Undefined chain of command within Contractor/Client organizations
5.3	Barriers in communication between the top management and the field staff
5.4	Prolonged duration taken for the information to be passed on to the top managerial level due to the management procedures in place
6.1	Price escalations
6.2	Delays in material delivery
6.3	Unavailability of materials in the recommended quality
6.4	Equipment shortages
6.5	Equipment breakdowns
6.6	Lack of use of modern equipment
7.1	Sudden and unexpected changes in government regulation and policies
7.2	Difficulties in obtaining the necessary approvals and permits
7.3	Wrong interpretations of laws and regulation by the government officials

ID	Risk element
8.1	Less attention towards the quality & safety
8.2	Inadequate manpower
8.3	Poor technical knowledge
8.4	Poor financial capability
8.5	Reluctance to work in unfavorable locations
9.1	Improper planning and scheduling of tasks
9.2	Poor subcontractor management and supervision
9.3	Rework due to errors during construction
9.4	Compromising the quality in achieving time targets
9.5	Not following the approved method statements
10.1	Adverse weather conditions
10.2	Impact of droughts, floods, landslides, tsunamis, etc.
10.3	Pandemics
11.1	Risk of protests (by ecologists, local community, politicians)
11.2	Resistance to land acquisitions by the local community
11.3	Demanding unfair claims for crop compensations

ID	Risk Element
11.4	Terrorist attacks
12.1	Restrictions imposed by the funding agency
12.2	Political instability of the funding countries
13.1	Faulty right of way (setting out errors)
13.2	Corrosion/deterioration of materials
13.3	Difficulties in material transportation to extreme locations
13.4	Properties situated in close proximity to the tower base locations
13.5	Prolonged time duration due to the difficulty in accessing the tower locations
14.1	Employee turnover during the project lifecycle
14.2	Employee absence due to illnesses/personal issues
14.3	Union actions within Client/Contractor organizations
14.4	Fights/clashes between employees
14.5	Resistance from the neighboring communities towards foreign employees

Figure 9. Box and whisker plots of weights assigned by respondents. (1—least critical; 2—less critical; 3—moderately critical; 4—highly critical; 5—extremely critical). ((**a**) Client/Consultant-Related risk, (**b**) Design-Related risk, (**c**) Tendering and Bidding-Related risk, (**d**) Contractual risk, (**e**) Communication-Related risk, (**f**) Material and equipment-Related risk, (**g**) Government/Regulatory risk, (**h**) Sub-contractor Related risk, (**i**) Contractor-Related risk, (**j**) Natural/Environmental risk, (**k**) Social/Community-Related risk, (**l**) Funding agency-Related risk, (**m**) Construction-Related risk, (**n**) Human resources-Related risk).

4. Discussion

4.1. Comparison of Results from Delphi Rounds

This section discusses the comparison of the results for each risk category obtained from the Delphi rounds. In the first Delphi round, the panel members had reached a common consensus that the most critical risk elements out of all the risk elements were delays in making decisions by the consultant and the inexperienced nature of the consultant. The same risk elements were ranked in 3rd place by the panel (see Table A1). Therefore, it is evident that the success of HVPTL projects is directly influenced by the competency and past experience of the client. The two most critical factors under the design-related risk category substantiated by round two were inaccurate survey data, ranking at number five, and errors in design at number six. Both of these elements were brought significantly up the ranking in the 2nd round of consensus building. The other element under this category that made a significant shift in ranking in Delphi round two is "design changes by the consultant", which moved up from the 40th rank in the 1st round to the 16th rank in the 2nd. As shown in Table A1, the inaccurate survey data risk element is among the top five most critical risk elements affecting the HVPTL projects.

Out of the two risk elements under the category of "tendering/bidding", the element "errors in initial costing" moved up the ranks to the 2nd most critical risk element due to the experts' common consensus in the 2nd Delphi round. This is because, especially in the post-pandemic market, pricing and rates are most sensitive to escalation and money-value depreciation, which affect project profits. During the first round of the Delphi survey, the unrealistic nature of the contract duration was identified as the 4th most important risk element. But, during the 2nd round of the survey, this was given a lesser priority. The risk element "extending and changing the scope of work" was ranked as the 11th most important risk category, which can be either a positive or a negative risk. The addition of more work over an extended period of time can be considered a positive risk for an HVPTL project. As illustrated in Table A1, communication-related risk elements were not ranked among the top categories by the panel of experts. Also, it can be seen that during the second round of the Delphi survey, the ranks of the risk elements went down, except for risk element 2.1, but that risk element was ranked as the 50th element. Taking into consideration the lower ranks all of the risk elements under this category have been placed at, it can be safely deduced that the "communication-related risks" category as a whole is insignificant in terms of criticality.

The most critical risk element under the material category, according to the consensus of the panel of experts, is "delays in material delivery", which was ranked 11th in round two of the Delphi survey. The element "lack of use of modern equipment" was ranked 59th and, therefore, in the bottom-most five risk elements and was deemed to have a lower weight in terms of its risk criticality. Under the government/regulatory risk category in the 1st round of the Delphi survey, the experts had a common consensus to rank the risk element "sudden and unexpected changes in government regulation and policies" as the most critical risk element under this category, placing it at rank No. 22. In contrast, in the 2nd round of the Delphi survey, the common consensus was that the element "difficulties in obtaining the necessary approvals and permits" was consented by the panel to be the most critical element out of the three risk elements under the category, placing it in the 23rd rank. Post-Delphi round two, out of the two risk elements under the funding agency-related risk category, the panel of experts ranked the element "political instability of the funding countries" to be the more critical factor, ranking it at 23. The other element "restrictions imposed by the funding agency" was ranked to be a less critical factor; it was placed in the 36th rank after Delphi round two.

As presented in Table A1, there were three risk elements that had more importance than the other risk elements under the sub-contractor-related risk category. Inadequate manpower of sub-contractors, less attention toward quality and safety, and poor financial capabilities were considered the most important risk elements under the sub-contractor category. Improper planning and scheduling of tasks by the contractor was the most critical risk factor identified by the panel of experts after the 2nd Delphi round. This was ranked as No. 3 during the first round of the Delphi survey. During the second round, the panel of experts came to the consensus that this was the most critical risk element of all the identified risk elements. In addition, "poor sub-contractor management and supervision" and "compromising the quality in achieving time targets" were ranked number eight and seven, respectively. Risk element 3.4 was not among the top 10 risk elements during the first round. But at the end of the 2nd round, it was ranked as the 7th most significant risk element, and identification of this risk element by the panel of experts can be considered as a special case. It is evident that during round one of the Delphi survey, the risk element "pandemics" was weighed by all experts as one of the most critical elements of risk, ranking it 7th. However, in round two of the Delphi survey, the "pandemic" element moved down the ranks due to the consensus of the experts. The opinions of the experts could have been influenced by the recent ongoing pandemic situation. The round one survey was conducted just after the pandemic was declared; hence, the progress of work in the field of construction was severely affected, but after normalizing and pandemic management had started to set in, the work was no longer obstructed, and the negative impact on the construction industry slowly lessened.

After two Delphi rounds, the panel of experts ranked the risk elements "faulty right of way (setting out errors)" and "prolonged time duration due to the difficulty in accessing tower locations" as the most critical risk elements under the risk category of construction risk. Also, the significance of taking prolonged time periods for construction due to the difficulty in accessing tower locations was identified as an important risk factor during the second Delphi round. The results of Delphi round two for the category of human resources, as presented below in Table A1, show that two out of the five risk elements are ranked in the bottom-most five risk elements; "union actions within client/contractor organizations" is 60th, and "fights/clashes between employees" is at 63rd, ranked as the bottom-most risk element and, therefore, the least critical risk factor for HVPTL projects. This result translates to better interpersonal relations and friendly/professional work environments across the work hierarchy in HVPTL projects, according to the panel experts, and hence poses the least concern. The most critical risk element under this category, according to the experts' consensus, is "employee turnover during the project lifecycle", which was ranked 27th in Delphi round two.

4.2. Ranking of Top Five Critical Risk Factors Related to HVPTL Projects

Following the identification of the top five critical risk factors (CRFs) in the Delphi survey, the analytic hierarchy process (AHP) was employed in the third round to refine the ranking of the CRFs. A dedicated questionnaire was developed to facilitate pairwise comparisons of each risk element with others, as detailed previously. Subsequently, responses were solicited from all 16 participants involved in the study. The CR values for each participant's responses are presented in Table 4. Upon review, responses from participants with IDs 1, 3, 15, and 16 were deemed ineligible and thus excluded from further analysis. The remaining responses were considered for the final ranking of the top CRFs.

Table 4. CR values of the responses received from the AHP questionnaire.

CR Value (%)	Respondent ID
1	4, 13
2	5, 6, 8, 9, 10
3	7, 11, 14
4	2
5	12
6	-
7	3, 16
8	15
9	1

Analysis of Table 5 reveals that the risk element retaining the highest ranking remains consistent with the findings of Delphi round two. Consequently, "improper planning and scheduling of tasks by the contractor" retains its status as the most critical risk element. However, the rankings of risk elements two and three were altered following the AHP round, with "delays in decision-making by the client/consultant" being ranked as the second most important risk element. The weights assigned to the third and fourth risk elements, 16.0% and 14.9%, respectively, are closely aligned, suggesting comparable significance between "lack of experience of the client" and "errors in initial costing". The fifth-ranked risk element in Delphi round two, and the lowest-ranked risk element in the AHP round, is "inaccurate survey data". Notably, the weight attributed to this risk element in the AHP analysis is 7.2%, substantially lower than the 14.9% weight of the fourth-ranked risk element. The consensus indicator of the AHP analysis demonstrates an 84.3% consensus level. Within the parameters established by Saaty [81], it can be inferred that a significant level of consensus has been attained among the panel of experts.

Table 5. Ranking of top five CRFs using AHP.

Rank	CRF	Weights
No. 01	CRF1: Improper planning and scheduling of tasks by the contractor	43.9%
No. 02	CRF2: Delays in decision-making by the client/consultant	18.0%
No. 03	CRF3: Lack of experience of the client/consultant	16.0%
No. 04	CRF4: Errors in initial costing—tendering/bidding-related	14.9%
No. 05	CRF5: Inaccurate survey data—design-related	7.2%

Researchers have long focused on critical risk factors (CRFs) in construction projects. Table 6 presents a comparative analysis of the top five CRFs identified in this study with findings from similar research endeavors evaluating CRFs in construction projects. While precise consensus may not have been achieved among the selected six articles, it is notable that the top five CRFs identified in this study are corroborated by existing literature.

Table 6. Comparison of top five CRFs with similar studies.

Reference	Top Five CRFs				
	Rank-1	Rank-2	Rank-3	Rank-4	Rank-5
Present study	Improper planning and scheduling of tasks by the contractor	Delays in decision-making by the client/consultant	Errors in initial costing—tendering/bidding-related	Lack of experience of the client/consultant	Inaccurate survey data—design-related
[66]	Delays in obtaining approvals and permits from government bodies	Inconsistent application of law by government	Lack of legal judgment reinforcement	Local partners' credit-worthiness	Political instability
[30]	Bad weather	Poor communication and coordination among the project parties	Delays in progressing payments to the contractors or other project parties	Change orders, poor financial capabilities of sub-contractors, improper planning and scheduling of contractor	Unavailability of construction material at site
[72]	Design errors and omissions	Scheduling errors, contractor delays	Construction-cost overruns	Prolonged design duration	Failure to comply with quality
[82]	Inefficient communication	Change in govt. laws and regulations	Inappropriateness of specifications	Political instability	Contractor's financial difficulties
[29]	Delays in material supply	Low skill level of laborers	Delays in approval of drawings and material test samples	Delays in obtaining approvals from public agencies	Rework due to errors in construction
[83]	Delays in construction due to bad weather	Lack of fuel for construction vehicles and machinery	Lack of details and data during the design stage	Setting out errors	Bad weather conditions

The top critical risk factor (CRF), "improper planning and scheduling of tasks by the contractor", identified in this study aligns with findings from three other studies. Additionally, the risk stemming from "delays caused by the client" was identified in two other studies, indicating its significance across multiple research endeavors. Similarly, the risk associated with "inaccurate survey data—design-related" was highlighted in three other studies. Furthermore, the risk related to "errors in initial costing—tendering/bidding-related" was identified in one similar study. Moreover, certain risk factors appeared with higher frequency in the selected similar studies, including:

- risk of delays in obtaining approvals and permits from government bodies;
- risk of unavailability of construction materials;
- risk of not achieving the required quality in construction.

It is important to acknowledge that discrepancies in findings among studies are inevitable due to variations in political, economic, social, legal, environmental, and technological factors within subject environments. Therefore, while the findings of this study can be considered acceptable when compared with similar studies, differences in rankings may arise due to variations in the roles and perspectives of survey participants. As the final stage of this study, expert judgment was utilized to collect risk responses related to the identified top 10 risk elements. Table 7 presents the risk responses received from the experts, providing valuable insights into expert perceptions and considerations regarding critical risk factors in construction projects.

Table 7. Risk responses for top 10 risk categories and risk elements.

Risk Category and Element	Responses Suggested by Experts
Client/consultant—delays in decision-making	Use of contractual provisions, good communication, maintaining good relationship, continuous follow ups, using descriptive and comprehensive documents, use of frequent meetings, use of dispute boards
Client/consultant—lack of experience	Recruiting experienced professional engineers in the relevant field, using third-party expert recommendations to increase the awareness through technical meetings, obtaining third-party consultancy, providing task-oriented training
Contractor—improper planning and scheduling of tasks	Continuous tracking with master program, dedicated professionals for project planning, monitoring contractor's project schedule and resource allocation, issuing early warnings
Contractor—poor sub-contractor management and supervision	Using adequate supervisory staff, sub-contractor training, on-site supervision, using sub-contractor selection criteria, supervisory staff training, providing adequate resources, providing necessary managerial, technical, financial assistance
Contractor—compromising the quality in achieving time targets	Following method statements and checklists, proper supervision, use of separate QA/QC staff
Sub-contractor—less attention toward quality and safety	Close supervision, encouraging quality through intensive schemes, adopting total quality management through several rounds of internal inspection, adhering to method statements, proper use of checklists, strict supervision, financial and technical support
Sub-contractor—inadequate manpower	Using a sub-contractor selection criterion, retain labor through providing basic amenities, intensives, and recognition, maintaining separate work gangs by the main contractor, increasing the number of sub-contractors, distributing one task between several sub-contractors, providing basic amenities, and avoiding laborers leaving the site
Design—errors in design	Use of expert support, conducting comprehensive reviews by experts in preliminary stages, conducting procedural reviews, outsourcing to specialists, conducting internal design reviews, using the review process, use of checklists for review
Design—inaccurate survey data	Verifying before commencing the construction, outsourcing to specialists, use of qualified professionals
Tendering/bidding-related errors in initial costing	Use of expert overview in bidding, maintaining a well-established and experienced team for tendering, reviewing the bid prices with historical data

5. Conclusions

The HVPTL construction sector frequently grapples with time and cost overruns, posing significant challenges to project success. Despite the industry's awareness of these issues, formal risk-management practices remain at a nascent stage. Risk identification, a crucial initial step in the risk-management process, often relies on past experiences and professional judgment. However, studies indicate that the risks inherent in power-related linear construction projects differ substantially from those in non-power linear projects, highlighting the need for tailored risk-management approaches. This study addresses this gap by comprehensively identifying and ranking 63 distinct risk elements across 14 categories specific to the HVPTL industry in Sri Lanka. Findings reveal that improper planning by the main contractor emerges as the most critical risk factor, with outsourcing practices exacerbating the potential for delays. To mitigate this risk, involving experienced professionals in project management and establishing dedicated planning teams are essential.

Furthermore, delays in decision-making by the client/consultant and the inexperience of these stakeholders emerge as significant risk factors. Given that many HVPTL projects in Sri Lanka involve a single entity overseeing both roles, engaging qualified third-party consultants could enhance project efficiency and effectiveness. Errors in initial costing during the tendering and bidding phase also pose substantial risks, underscoring the importance of leveraging experienced professionals and maintaining accurate cost databases. Additionally, inaccuracies in survey data can lead to costly rework during project execution, highlighting the necessity of thorough cross-checks by third-party surveyors.

While this study lays the foundation for formal risk management in Sri Lankan HVPTL projects, several limitations must be acknowledged. Subjective judgments inherent in expert opinions and the study's focus on the Sri Lankan context may limit the generalizability of findings. Future research should focus on developing comprehensive risk-response plans and evaluating their implementation and monitoring processes. Despite these limitations, the conceptual risk index developed in this study provides a valuable framework for identifying and managing risks in HVPTL projects. By incorporating risk-management knowledge into the industry's collective understanding, this study contributes to enhancing project outcomes and mitigating risks in the HVPTL construction sector. Moving forward, validation of the conceptual framework and the development of a robust risk-management framework are crucial steps toward ensuring the success of HVPTL projects, not only in Sri Lanka but also globally.

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Appendix A

Table A1. Ranks obtained during the first and second Delphi rounds.

No	Risk Element	Round 01	Round 02	No	Risk Element	Round 01	Round 02
1.1	Delays in commenting on design documents	11	16	7.2	Difficulties in obtaining the necessary approvals and permits	30	23
1.2	Delays in inspections and testing	14	23	7.3	Wrong interpretations of laws and regulation by the government officials	47	58
1.3	Delays in decision-making	1	3	8.1	Less attention toward quality and safety	10	8
1.4	Delay in payments	56	53	8.2	Inadequate manpower	5	8
1.5	Demands for items that are out of the project's scope	62	60	8.3	Poor technical knowledge	26	11
1.6	Poor stakeholder management (e.g., other government bodies, affected public, etc.)	18	27	8.4	Poor financial capability	11	16
1.7	Lack of experience	1	3	8.5	Reluctance to work in unfavorable locations	30	37
2.1	Errors in design	18	6	9.1	Improper planning and scheduling of tasks	3	1
2.2	Design changes by the consultant	40	16	9.2	Poor sub-contractor management and supervision	7	8
2.3	Unclear/inadequate details in specifications	43	57	9.3	Rework due to errors during construction	40	27
2.4	Mistakes and discrepancies in drawings	52	48	9.4	Compromising the quality in achieving time targets	22	7
2.5	Incomplete investigations of subsurface conditions	22	16	9.5	Not following the approved method statements	26	38
2.6	Inaccurate survey data	14	5	10.1	Adverse weather conditions	30	41
2.7	Inadequate reviewing of design documents	40	50	10.2	Impact of droughts, floods, landslides, tsunamis, etc.	22	11
2.8	Less consideration regarding constructability during the design phase	14	23	10.3	Pandemics	7	16
3.1	Errors in initial costing	5	2	11.1	Risk of protests (by ecologists, local community, politicians)	43	27
3.2	Unavailability of design data during the bidding phase (e.g., geotechnical data)	18	16	11.2	Resistance to land acquisitions by the local community	30	27
4.1	Unrealistic contract duration	4	11	11.3	Demanding unfair claims for crop compensations	59	53
4.2	Extending/changing the scope of work	30	11	11.4	Terrorist attacks	47	62
4.3	Contract precision (poorly defined scope of work)	14	27	12.1	Restrictions imposed by the funding agency	30	36

Table A1. *Cont.*

No	Risk Element	Round 01	Round 02	No	Risk Element	Round 01	Round 02
5.1	Undefined/poorly defined communication channels within contractor/client organizations	55	50	12.2	Political instability of the funding countries	26	23
5.2	Undefined chain of command within contractor/client organizations	30	41	13.1	Faulty right of way (setting out errors)	11	16
5.3	Barriers in communication between the top management and the field staff	26	52	13.2	Corrosion/deterioration of materials	43	55
5.4	Prolonged duration taken for the information to be passed on to the top managerial level due to the management procedures in place	18	45	13.3	Difficulties in material transportation to extreme locations	47	56
6.1	Price escalations	43	45	13.4	Properties situated in close proximity to tower base locations	52	41
6.2	Delays in material delivery	7	11	13.5	Prolonged time duration due to the difficulty in accessing tower locations	51	27
6.3	Unavailability of materials in the recommended quality	37	38	14.1	Employee turnover during the project lifecycle	37	27
6.4	Equipment shortages	37	27	14.2	Employee absence due to illnesses/personal issues	58	45
6.5	Equipment breakdowns	52	38	14.3	Union actions within client/contractor organizations	61	60
6.6	Lack of use of modern equipment	57	59	14.4	Fights/clashes between employees	62	63
7.1	Sudden and unexpected changes in government regulations and policies	22	27	14.5	Resistance from the neighboring communities toward foreign employees	60	41

Appendix B. Sample Questionnaire for Preliminary Round of Delphi Survey

Part 1: General Information

1. Name of the respondent:
2. Name of the organization:
3. Designation:
4. Work experience:
    i. 1–5 years: ( )
    ii. 10–15 years: ( )
    iii. 16–20 years: ( )
    iv. 21–25 years: ( )
    v. Over 26 years: ( )

Part 2: Relevancy of the initial identified risk:

This part of the questionnaire will examine the relevancy of the identified risk elements to HVPTL projects. Various risk factors identified from previous studies have been listed below and respondents are requested to provide their view on whether these risk factors are relevant to HVPTL projects in Sri Lanka.

Client/Consultant-Related			
	Risk Elements	Relevant	Not relevant
1	Delays in project document approval		
2	Delays in inspection and testing		
3	Delay in payments		
4	Incompetency in technical matters		
5	Change orders		
Specify any other important risk elements according to your perspective			

Design-Related			
	Risk Elements	Relevant	Not relevant
1	Errors in design		
2	Specification changes		
3	Design changes by the consultant		
4	Unclear and inadequate details in specifications		
5	Mistakes and discrepancies in drawings		
6	Improper investigation of subsurface conditions		
Specify any other important risk elements according to your perspective			

**************Questionnaire continues following the same format for all 14 risk categories*************

Appendix C. Sample Questionnaire for 1st Round of Delphi Survey

This questionnaire examines the criticality of the identified risk elements of high-voltage power transmission line (HVPTL) construction projects. Various risk factors identified through literature survey, expert opinion, and the initial questionnaire are listed below. You are requested to rate these risk factors based on their criticality in terms of time, cost, and quality.

The Likert scale:
1—Least critical
2—Less critical
3—Moderately critical
4—Highly critical
5—Extremely critical

Client/Consultant-Related						
	Risk Elements	1	2	3	4	5
1	Delays in project document approval					
2	Delays in inspection and testing					
3	Delay in payments					
4	Incompetency in technical matters					
5	Change orders					

Design-Related						
	Risk Elements	1	2	3	4	5
1	Errors in design					
2	Specification changes					
3	Design changes by the consultant					
4	Unclear and inadequate details in specifications					
5	Mistakes and discrepancies in drawings					
6	Improper investigation of subsurface conditions					

**************Questionnaire continues following the same format for all 14 risk categories*************

Appendix D. Sample Questionnaire for 2nd Round of Delphi Survey

Instructions:

- The feedback of the panel from **Questionnaire-1** is provided as a percentage of the total responses received for each sub-question. The answer provided by you in Questionnaire-1 is highlighted in yellow
- You are kindly requested to keep the highlighted box as it is if you wish to keep the same answer. If you decide to change your answer from the former, please click on the box you choose now.

The Likert scale:
1—Least critical
2—Less critical
3—Moderately critical
4—Highly critical
5—Extremely critical
Risk Category 1: Client/Consultant-Related

Risk Elements	**Number of Responses as a Percentage (%) of Total Responses**				
	1	**2**	**3**	**4**	**5**
Delays in commenting on design documents	0	0	13	56	31
Delays in inspections and testing	0	0	25	63	13
Delays in decision-making	0	0	6	31	63
Delay in payments	0	0	75	19	6
Demands for items that are out of the project's scope	6	38	31	25	0
Poor stakeholder management (e.g., other government bodies, affected public, etc.)	0	6	31	50	13
Lack of experience	0	13	6	38	44

Risk Category 2: Communication-Related

Risk Elements	**Number of Responses as a Percentage (%) of Total Responses**				
	1	**2**	**3**	**4**	**5**
Undefined/poorly defined communication channels within contractor/client organizations	0	0	50	38	13
Undefined chain of command within contractor/client organizations	0	0	38	44	19
Barriers in communication between the top management and the field staff	0	13	25	56	6
Prolonged duration taken for the information to be passed on to the top managerial level due to the management procedures in place	0	6	31	44	19

**************Questionnaire continues following the same format for all 14 risk categories*************

Appendix E. Sample Questionnaire for AHP Analysis

Instructions:

- The following top five critical risk factors (CSF1–CSF5) for implementing risk-management systems in Sri Lankan construction projects were identified from the results obtained in the previous rounds using the relative important index (RII).

	Risk Category	Risk Element
CSF1	Contractor-Related	Improper planning and scheduling of tasks
CSF2	Tendering/Bidding-Related	Errors in initial costing
CSF3	Client/Consultant-Related	Delays in decision-making
CSF4	Client/Consultant-Related	Lack of experience
CSF5	Design-Related	Inaccurate survey data

- The analytical hierarchy process (AHP) will be used in this round of the survey to provide the ranking for the identified CSFs. The CSFs will be compared as pairs. The following numeric rating method will be used to rank the pairs

AHP Scale of Importance for Pair Comparison (a_{ij})	Numeric Rating
Extreme Importance	9
Very Strong to Extreme	8
Very Strong Importance	7
Strong to Very Strong	6
Strong Importance	5
Moderate to Strong	4
Moderate Importance	3
Equal to Moderate	2
Equal Importance	1

(Item i) 9–8–7–6–5–4–3–2–1–2–3–4–5–6–7–8–9 (Item j).

- You are kindly requested to underline your answers in the following tables

CSF1 vs. CSF2, CSF3, CSF4 and CSF5

CSF1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CSF2
CSF1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CSF3
CSF1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CSF4
CSF1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CSF5

CSF2 vs. CSF3, CSF4 and CSF5

CSF2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CSF3
CSF2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CSF4
CSF2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CSF5

CSF3 vs. CSF4 and CSF5

CSF3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CSF4
CSF3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CSF5

CSF4 vs. CSF5

CSF4	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CSF5

Appendix F. Questionnaire for Developing Risk Response

Instructions:

- The risk factors identified through the literature review, preliminary survey, Delphi rounds one and two, and the Delphi AHP survey are tabulated below. Also, the rank obtained by each risk element is provided for your additional information
- You are kindly requested to suggest the measures to reduce/avoid negative impacts and increase/acquire positive impacts in terms of HVPTL projects in Sri Lanka

Risk Category 1: Client/Consultant-Related

Risk Elements	Rank	Measures Suggested
Delays in decision-making	2	
Lack of experience	4	

Risk Category 3: Contractor-Related

Risk Elements	Rank	Measures Suggested
Improper planning and scheduling of tasks	1	
Poor sub-contractor management and supervision	8	
Compromising the quality in achieving time targets	7	

Risk Category 4: Sub-Contractor-Related

Risk Elements	Rank	Measures Suggested
Less attention toward quality and safety	8	
Inadequate manpower	8	

Risk Category 7: Design-Related

Risk Elements	Rank	Measures Suggested
Errors in design	6	
Inaccurate survey data	5	

Risk Category 14: Tendering/Bidding-Related

Risk Elements	Rank	Measures Suggested
Errors in initial costing	3	

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