

Development of a Centralized Risk Register Framework for Enhancing Risk Management in Electric Power Transmission Projects in Developing Countries: The Case of Malaysia

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Abstract: Electric power transmission (EPT) construction projects are inherently complex and high-risk, exposed to technical, economic, environmental, and external uncertainties that often lead to delays, cost overruns, performance issues, and safety incidents. These challenges are particularly critical in developing countries, where the rapid expansion of energy infrastructure is constrained by limited financial resources, institutional capacity, and fragmented project knowledge. Traditional risk management approaches remain largely subjective and lack centralized mechanisms for systematic knowledge capture and dissemination, resulting in recurring issues and inconsistent project performance. This study aims to strengthen risk management in EPT projects through the development of a centralized risk register framework tailored for developing countries. A mixed-methods approach was adopted, involving document reviews of completed EPT projects to extract and classify risk data, followed by expert validation and prioritization through focus group assessments. The study identified 79 significant risks, grouped into 11 categories, with the analysis revealing that the most critical risks pertain to design coordination failures, inadequate safety management, delays in material supply, land acquisition issues, and contractor manpower shortages, all of which collectively affect project performance. The study consolidates these findings into a sector-specific risk register, serving as a structured repository to support systematic risk identification, assessment, and response planning in EPT projects. The centralized risk register seeks to promote knowledge retention and dissemination of risk information; enhance EPT project delivery through improved consistency, institutional learning, and evidence-based governance; and ultimately support more resilient and cost-effective infrastructure development in developing economies such as Malaysia. DOI: 10.1061/AJRU6.RUENG-1817. © 2026 American Society of Civil Engineers.

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Introduction

Electric power transmission (EPT) is a vital component of the power sector alongside generation and distribution (Yu et al. 2011; Pall et al. 2016). It refers to the transportation of bulk electricity from generation plants to distribution networks, often across long distances, with transmission lines and substations serving as its fundamental infrastructure (Paynter and Boydell 2011; Kiessling et al. 2003). As electricity demand continues to grow, the development

and maintenance of reliable EPT infrastructure has become increasingly important for ensuring stable power supply, economic competitiveness, and societal well-being. This need is particularly critical in developing countries, where rapid urbanization, industrialization, and expanding populations place significant pressure on energy systems, while resource constraints exacerbate the challenges of delivering resilient and sustainable transmission infrastructure.

Similar to other large-scale construction projects, EPT projects are frequently affected by multiple challenges, with project delays representing one of the most critical issues (Yusof and Sivadas 2006; Pall et al. 2016; Nor et al. 2021). Delays often translate into cost overruns, disruptions in the production of essential energy infrastructure, and ensuing impacts on technological advancement and economic growth. The nature of EPT projects, often characterized by technical complexity, wide geographical spread, and exposure to environmental, social, and regulatory constraints, creates a broad spectrum of risks. These risks, if not managed effectively, can jeopardize project objectives related to time, cost, quality, and performance and safety.

Risk in construction projects is generally defined as an uncertain event or condition that, if it occurs, has a positive or negative effect on project objectives (PMI 2017). In the context of EPT projects in developing countries, risk factors may arise from technical failures, procurement issues, financial limitations, land acquisition disputes, environmental restrictions, stakeholder conflicts, or regulatory changes. The cumulative effect of such risks underscores the necessity for structured and proactive risk management practices. Numerous studies have demonstrated that adopting systematic risk

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management frameworks enhances project success rates by mitigating delays, controlling cost escalations, and improving overall resilience of infrastructure delivery (Parihar et al. 2015; Szymański 2017; Chin et al. 2020; Ahmad et al. 2020).

Risk management processes are generally designed to identify, analyze, and respond to risks in a structured manner. Central to this process is the risk register, a widely recognized tool for documenting, assessing, and communicating risk information (Patterson and Neailey 2002; Dunovic et al. 2013; Irizar 2014; Leva et al. 2017; ISO 2018). The risk register consolidates information such as risk descriptions, likelihoods, impacts, and response strategies, thereby serving as both a management tool and a communication platform among project stakeholders.

While project-specific centralized risk registers are common, a centralized risk register system provides additional strategic advantages. Such a system consolidates risk information across multiple projects within an organization, enabling identification of recurring risks, comparison of mitigation effectiveness, and development of organization-wide knowledge bases (Dunovic et al. 2013). This facilitates institutional learning, strengthens knowledge dissemination, and reduces the likelihood of repeating past mistakes. Furthermore, a centralized approach supports more robust decision-making by allowing organizations to evaluate risks not only at the project level but also across the entire portfolio of EPT developments.

EPT projects are inherently high-risk, exposed to technical, economic, and external uncertainties that can result in delays, cost overruns, safety incidents, and environmental consequences. These outcomes not only jeopardize project success but also undermine national energy security and development objectives (Yusof and Sivadas 2006; Pall et al. 2016; Pham et al. 2020; Oyedele et al. 2021; Nor et al. 2021; Liu et al. 2023). Effective risk management is therefore essential to ensuring the timely, resilient, and sustainable delivery of EPT infrastructure.

Research Gap and Significance

Although risk management in EPT projects has been widely discussed, prevailing practices remain heavily reliant on subjective judgement and fragmented documentation, with limited adoption of systematic tools or institutional knowledge repositories (Saffin and Laryea 2012). Consequently, critical risks are frequently overlooked, mitigation measures are inconsistently applied across projects, and institutional knowledge is often eroded due to personnel turnover and poor record-keeping (Patterson and Neailey 2002). These limitations reveal critical gaps in current EPT risk management practice and underscore the need for more systematic research and structured knowledge solutions.

In particular, an empirical gap exists, as there is a lack of studies that systematically identify and analyze actual risk data from completed EPT projects, especially in developing economies where existing insights are predominantly extrapolated from developed-country contexts. This gap has constrained the sector's ability to generate context-specific risk data that reflect the realities of EPT projects. Additionally, the absence of a sector-specific risk repository to support consistent decision-making, knowledge retention, and structured risk governance has hindered organizational learning and continuous improvement, indicating a practical-knowledge gap in EPT project delivery and performance. Finally, the consequences of poor project delivery are more severe in developing countries, where resource limitations and rapid infrastructure expansion magnify the impacts of recurrent project failures, highlighting a population gap that necessitates research grounded in developing-nation contexts. By centering on the Malaysian EPT's sector, this study

responds to these gaps and contributes empirical evidence and practical tools relevant to other developing economies with similar infrastructural and economic environments.

To address these gaps, both scholars and practitioners have highlighted the need for structured frameworks and tools that strengthen risk governance (Patterson and Neailey 2002; Dunovic et al. 2013; Irizar 2014; Leva et al. 2017). A centralized risk register offers such a mechanism by systematically consolidating risks, their potential impacts, mitigation strategies, and assigned responsibilities. Despite its potential, adoption of risk registers in the EPT sector remains limited, and where they are used, they are often treated as static compliance documents rather than dynamic knowledge management systems. Consequently, valuable insights are not effectively retained or disseminated, resulting in inefficiencies and repeated exposure to similar risks.

This study seeks to address the identified gaps by developing a centralized risk register framework tailored to EPT projects in developing countries. It is guided by the need to understand persistent challenges in managing risks within EPT projects, particularly in contexts with limited resources and rapid infrastructure expansion, using Malaysia as a representative case of a developing-nation context. Accordingly, the study seeks to answer the following research questions.

1. What are the key processes embedded within current risk management frameworks in EPT projects?
2. What are the principal risks affecting EPT project delivery?
3. How do these risks vary in terms of likelihood and potential impact?
4. How can risk knowledge be systematically captured, codified, and disseminated to strengthen risk governance across organizations in EPT projects?

Through the examination of existing risk management frameworks, identification of key risks, and consolidation of findings into a structured register, this research aims to strengthen organizational capacity to capture, retain, and disseminate critical risk data and knowledge in EPT projects. The study's objectives are as follows:

1. To examine existing risk management frameworks in EPT projects and assess their effectiveness in capturing and mitigating critical risks.
2. To systematically identify and prioritize the key risks that influence EPT project delivery and performance.
3. To evaluate the identified risks in terms of their likelihood, potential impact, and interdependencies, providing empirical evidence for decision-making.
4. To develop a sector-specific centralized risk register framework that consolidates critical risks, supports knowledge retention and dissemination, and enables consistent risk governance to enhance project delivery in EPT projects.

The significance of this study is particularly relevant in developing countries such as Malaysia, where EPT projects are technically complex and play a critical role in supporting national energy security, industrial growth, and socio-economic development. However, risk management practices in these contexts are often constrained by fragmented documentation, limited institutional capacity, and insufficient mechanisms for knowledge retention, which can result in recurring risks and inefficiencies across projects.

This study contributes to the knowledge base in risk management by systematically identifying and prioritizing risks in EPT projects, providing empirical evidence that reflects the realities of EPT projects in Malaysia. At the sector and organizational level, the proposed centralized risk register framework offers a structured mechanism to consolidate risk information, standardize assessment procedures, and facilitate knowledge sharing across projects. By making critical risk knowledge more accessible, the framework supports informed

decision-making, enables more consistent application of mitigation strategies, and strengthens organizational learning.

In terms of project performance, the framework can guide project teams in anticipating and prioritizing the most significant risks, thereby reducing delays, cost overruns, and operational disruptions. Over time, the structured capture and dissemination of risk knowledge can inform future projects, enhancing institutional memory and improving governance of infrastructure delivery. While this study focuses on the Malaysian context, the findings and framework provide practical guidance that can be adapted by other developing economies facing similar challenges in EPT project management and infrastructure development.

Research Methodology

This study adopts a mixed-methods research design, combining qualitative and quantitative approaches to develop a holistic understanding of risk management practices in EPT projects. The qualitative component, conducted through document review, provides in-depth insights into organizational practices and historical risks, serving as the foundation for developing a centralized risk register. The quantitative component, carried out through expert assessments, enables the prioritization and validation of these risks based on the practitioners' professional judgments. This dual approach is justified in the literature as it enables triangulation of evidence, enhances validity, and ensures both context-specific depth and generalizable findings (Creswell and Clark 2017; Bryman 2016; Martinez et al. 2012; Ahmed and Kelman 2018). Integrating these approaches ensures systematic identification of risks while allowing robust evaluation of their relative significance, enhancing both credibility and practical relevance.

The research process was executed in three sequential stages:

1. document review;
2. risk factor selection; and
3. expert assessments through focused group discussions.

For document review, an extensive review of organizational documents was conducted within a state-owned energy company in Malaysia, a developing country actively delivering EPT projects. The review aimed to examine standard operating procedures for risk management and identify historical risks from project-level risk registers. Risks from 32 completed projects spanning 2012–2024 were examined. The 10-year timeframe was selected because EPT projects are typically large-scale, long-duration undertakings, and only a specific number of projects exist within the organization in the 1 year. This period allows the study to capture recurring and evolving risk patterns across multiple projects, ensuring that the findings are representative and relevant for both current and future risk management practices. The 32 projects were distributed across multiple states in both the East and West Malaysia, reflecting a representative mix of project types, scales, and contractor arrangements.

The data were analyzed using qualitative thematic analysis (Braun and Clarke 2006) to identify recurring patterns in risk events and management practices. This process produced a centralized risk register that both institutionalizes organizational knowledge and provides an analytical dataset for further evaluation. From this register, a subset of risks was prioritized for detailed assessment. Extracted risks were screened and refined to remove duplicates and incomplete records, and only those appearing more than three times across the 32 projects were retained. This approach minimized participant fatigue while ensuring coverage of the organization's most significant exposures. Low-frequency but potentially catastrophic risks were reviewed separately to ensure that rare but high-impact events were not overlooked.

The retained risks were categorized with reference to well-established techniques such as the risk breakdown structure (RBS) (O'Har et al. 2017; PMI 2017). As a hierarchical framework that systematically organizes project risks into predefined levels, RBS facilitates comprehensive identification, prioritization, and management of risks across projects and supports the use of standardized templates to capture essential risk information, including categories, descriptions, dates identified, impact, likelihood, ratings, response strategies, and responsible personnel (Jeon et al. 2023; Sohrabinejad and Rahimi 2015). In this study, RBS provided a systematic basis for consolidating historical risk data from EPT projects, ensuring that both recurring and high-impact risks were accounted for in the development of the central risk register.

For expert assessments, a purposive sample of 45 project personnel directly involved in EPT project risk management was engaged. This included the project execution team (PET), comprising project managers, project engineers, construction engineers, and installation engineers, and the functional team (FT), consisting of project controllers, design engineers, quality engineers, and executives. PET personnel oversee the project lifecycle with emphasis on cost, schedule, and delivery, while FT personnel provide specialized input during design, construction, testing, and commissioning, focusing on quality assurance and design integrity.

Given the large and complex nature of EPT projects, only personnel with direct experience in such projects were considered for this study, reflecting the limited pool of experts available for specialized EPT projects. Although Delphi and expert assessment panel sizes vary, literature indicates that 15–30 experts are generally sufficient to achieve reliable consensus in construction management research (Adnan et al. 2018; Jorm 2025). By engaging 45 experts with diverse specializations across multiple project roles and stages, this study exceeds commonly recommended panel sizes, ensuring that the data are reliable, robust, and representative.

During the sessions, participating experts collectively discussed and evaluated the selected risk factors, rating each in terms of likelihood of occurrence and potential project impact. Spearman's rank correlation was used to examine the level of agreement between PET and FT groups, ensuring consistency across project perspectives. The expert judgments were synthesized into risk rankings, producing a prioritized list of risks most critical to EPT project delivery. The combination of the panel's number and expertise captured the breadth and depth of the identified risk data, accurately reflecting the technical, managerial, and logistical challenges inherent in EPT projects. While the study focuses on the Malaysian context, the findings provide insights that are relevant to other developing economies with similar project conditions and constraints.

Two analysis techniques will be employed. The relative importance index (RII) method was adopted to calculate and rank risk scores by integrating probability and impact ratings, following established construction risk analysis practices as described in Farid et al. (2020). Table 1 presents original sample calculations produced for this study to illustrate the application of the method. Risks were ranked according to their relative significance. The resulting risk scores were used to identify and discuss the top 10 risks with the greatest potential impact on project objectives.

Table 1. Classification of risk factors with their score

No.	Risk ID	Probability		Impact		Risk score
		Score	RII	Score	RII	
1	R1	Wp1	RII p1	Wi1	RII i1	RII p1 × RII i1
2	R2	Wp2	RII p2	Wi2	RII i2	RII p2 × RII i2

$$RII = \frac{\sum W}{A * N} \quad (1)$$

where RII = relative importance index; W = weight given to each factor by the respondents (scale 1 to 5); A = highest weight (scale 5); and N = total number of respondents.

To ensure the validity of the survey data, respondents will be categorized into two groups according to their project roles, and the potential influence of these differing backgrounds on risk rankings will be examined. It is essential to verify that the variation in professional perspectives does not significantly distort the prioritization of risk factors, as this would affect the robustness of the findings. Establishing consistency between the groups allows the study to justify combining all responses into a single dataset for subsequent analysis of risk factors in EPT projects.

To evaluate the level of agreement, Spearman's rank correlation coefficient (ρ) will be applied, assessing the consistency and reliability of responses (Mosaad et al. 2018). This nonparametric test is well suited for ordinal data and provides a measure of the strength and direction of the relationship between the rankings of the two groups. The analysis will focus on comparing their assessments of both the likelihood of occurrence and the potential impact of identified risks. A statistically significant and sufficiently strong correlation would indicate broad consensus between groups, thereby validating the pooled dataset. Conversely, a weak or inconsistent correlation would suggest the need for differentiated analysis to account for role-based perspectives in EPT risk management. The Spearman's rank correlation formula is shown in the following equation:

$$r_s = 1 - (6 \times \sum d^2) / (N^3 - N) \quad (2)$$

where r_s = Spearman rank correlation coefficient (value ranging from 1 showing the robust direct relationship, and -1 showing strong negative correlation); d = difference in causes ranking of the identified conditions; and N = number of variables.

Spearman's coefficient (r_s) ranges from -1 to 1 . A value of -1 indicates a perfect negative correlation, meaning the variables move in opposite directions. A value of 1 shows a perfect positive correlation, where the variables move in the same direction. If r_s is 0 , there is no correlation between the variables (Hauke and Kossowski 2011; Issa et al. 2013).

In summary, this study adopts a structured, expert-driven methodology that integrates historical evidence with professional judgment, ensuring that the findings are grounded in organizational practice while capturing the breadth and depth of expertise required for EPT projects (Martinez et al. 2012). Historical risk data from 32 completed EPT projects were collected and analyzed through document review and systematic risk screening to remove duplicates and incomplete records while capturing both recurring and high-impact risks. These risks were then categorized using a validated RBS, providing a hierarchical framework for comprehensive identification, consistent prioritization, and effective management across projects (Somi et al. 2020). Structured expert assessments were subsequently conducted with a purposive panel of 45 EPT professionals from both project execution and functional teams, ensuring diverse perspectives across roles, stages, and technical specializations. The expert evaluations complemented the historical data, allowing quantitative and qualitative evidence to reinforce each other and strengthen the robustness of the risk prioritization, particularly where historical records were incomplete (Senić et al. 2025; Lin et al. 2015). Supported by tools such as Google Forms for data organization (Vasantha and Harinarayana 2016) and sample size justification based on established statistical principles (Daniel 1999), this methodology provides a rigorous technique for identifying and prioritizing risks in EPT projects, producing actionable insights relevant to the Malaysian context and transferable

to other developing-country settings. The combined outcomes form the basis for developing a comprehensive central risk register that systematically documents, evaluates, and prioritizes risks in EPT projects, and the following section presents the detailed findings and analysis of this study.

Results and Analysis

Document Review

The document review was undertaken with the objective of identifying historical risks that have significantly affected EPT projects. Drawing on project risk registers from 32 projects completed between 2012 and 2024, a total of 335 risk statements were compiled. Each statement was systematically screened, and the corresponding risk factors were extracted, categorized, and assessed to establish a comprehensive dataset. Of these, 138 were classified as high or critical risks, forming the foundation for subsequent analysis of the most impactful risks to EPT project performance. This prioritization ensured that the study focused on risk identification of greatest relevance to EPT project stakeholders and the development of targeted mitigation strategies.

Duplicate risks recurring across multiple projects were consolidated to prevent overemphasis, while incomplete entries lacking response actions or strategies were excluded, as such entries provide limited value for knowledge dissemination and risk learning. Following this refinement process, the dataset was reduced to 79 distinct and comprehensive risk statements. These were further organized into 11 categories, consistent with prior research on construction project risks, and each was assigned a unique identification code. The emphasis on systematic risk identification in this stage provides a critical foundation for establishing a centralized risk register and for improving the resilience and sustainability of EPT project delivery. The risks are categorized into 11 categories: client-related risk, contractor-related risk, design-related risk, external risk, financial risk, logistic-related risk, pandemic-related risk, material risk, site-related risk, weather-related risk, and workplace safety-related risks. Table 2 presents these 11 categories along with their risk IDs and corresponding risk statements. The percentage distribution of the identified risk categories is illustrated in Fig. 1.

The categorization revealed that contractor-related risks were the most prevalent, accounting for 34.18% of all identified risks with 27 occurrences. External risks ranked second, representing 15.19% (12 occurrences), followed by material-related risks at 11.39% (9 occurrences). Workplace safety risks constituted 10.13% (eight occurrences), while pandemic-related and site-specific risks each accounted for 7.59% (six occurrences). Client-related risks represented 5.06% (four occurrences), whereas design-related risks (3.80%, three occurrences) and logistical challenges (2.53%, two occurrences) were less frequent. Financial risks and weather-related risks were the least common, each representing 1.27% (one occurrence). These identified risks were subsequently assessed through focus group expert assessments, and the results of this assessment are presented in the following section.

Expert Assessment of Risks

Out of the 79 risk factors identified through the document review, 28 were selected for further analysis via focus group expert assessments. The decision to focus on this subset was made to ensure feasibility of expert assessments through focus groups while retaining the most relevant risks for EPT projects. Risks that had occurred more than three times across the 32 reviewed EPT projects were prioritized, as recurrent risks represent the most significant

Table 2. Risk categorization

Risk ID	Risk statement	Risk subcategory
Client-related risks		
R1	The unavailability of the asset owner's representative to attend the factory acceptance test (FAT) due to their tight schedule	—
R2	Delay in obtaining development approval from the State Planning Authority (SPA)	—
R3	Delay in land acquisition	—
R4	Unable to proceed with infrastructure works due to a delay in relocation of existing facility by the client	—
Contractor-related risks		
R5	Awarding a contract to an inexperienced contractor unfamiliar with substation projects or underground cable projects	General
R6	Late approval of critical equipment and civil drawings due to the contractor's poor performance	Design
R7	Late completion of design due to the contractor's poor performance	Design
R8	Discrepancy between electrical design and civil design due to a lack of coordination between the consultants and the reviewer	Design
R9	Late submission of steel structure design calculations and drawings due to insufficient designers from the manufacturer	Design
R10	Difficulty meeting completion management system requirements from the client	General
R11	The prolonged duration of hacking work for an existing power station due to limited information about the power plant	General
R12	Delay in electrical installation work due to noncompliance	General
R13	Unable to achieve the catch-up plan commitment due to the contractor's limited resources	General
R14	Late approval of the environmental management plan by the authority due to untimely submission	General
R15	Late completion of the work (piling work) due to frequent machine breakdowns (piling rig)	Machinery
R16	The unavailability of competent persons to perform cable jointing could potentially lead to poor cable jointing work quality.	Manpower
R17	The unavailability of competent persons to perform testing works could potentially lead to delay in testing and commissioning of the substation.	Manpower
R18	Shortage of qualified personnel for commissioning work due to simultaneous commissioning of multiple projects	Manpower
R19	Low productivity due to insufficient manpower in civil works	Manpower
R20	Personnel constraints in the primary and secondary engineering teams due to multiple contracts executed concurrently	Manpower
R21	Unable to appoint Bumiputera key personnel as required by the contract due to the shortage of Bumiputera key personnel in the market	Manpower
R22	Damage to the existing powerhouse or equipment due to vibration and dust from rock excavation work	Methodology
R23	Damage to the existing retaining wall during earthwork due to the construction work	Methodology
R24	Unable to obtain a timely shutdown to carry out retrofitting works at the remote end of the substation and transmission line turn-in works	Planning
R25	Lack of communication between interfacing parties, including the contractor, civil and structural consultant, PMT, and asset owner	Planning
R26	Delays in the completion of road construction due to the late relocation of utilities services at the proposed road entrance	Planning
R27	Delays in the arrangement of retest FAT for major equipment (transformer)	Planning
R28	Unable to obtain timely renewal for wayleave approval from authorities including JKR and the local council, due to slow action by the contractor	Planning
R29	Deficiencies in work execution cause damage to the transmission line tower during line turn-in works	Workmanship
R30	Excessive settlement level of equipment foundations due to poor earthwork quality	Workmanship
R31	Slope failure due to the contractor's poor workmanship during earthwork	Workmanship
Design related risks		
R32	Changes to the cable route to avoid obstruction along the proposed route	—
R33	The existing equipment foundation design does not match the new equipment's requirements from the manufacturer.	—
R34	Changes in work scope or the addition of new work scope during the execution phase	—
External risks		
R35	Delay in site handover due to a delay in the preceding earthwork contract (another project by the client)	—
R36	Delay in the completion of earthwork due to the delay in the relocation of existing utility services (e.g., Telekom, Sacofa)	—
R37	Delay in the availability of incoming transmission lines (by others) due to the land wayleave issue	—
R38	Change in the identified substation location due to customer requirements	—
R39	Delay in obtaining wayleave from the government agencies	—
R40	The inability to commission the substation or the underground cable because of the delay in completion of the transmission line (another project by the client)	—
R41	Additional requirements from the local authority for the approval of the engineering plan	—
R42	Late finalization of the substation platform level due to the late finalization of the access road (by a third-party contractor appointed by the authority)	—
R43	Unable to obtain wayleave consent from the adjacent property owner for earthwork due to the compensation rate	—
R44	Late approval of the building plan by the local council due to the lengthy approval process	—
R45	Unable to relocate existing local substation and high tension (HT) poles to the road reserve due to the rejection by the authority	—
R46	System constraints could potentially prolong the shutting down to couple the new switchgear	—
Financial risks		
R47	Price fluctuation for construction materials and equipment due to various factors such as the global increase in raw material prices, currency exchange, and inflation	—
Logistic related risks		
R48	Damage to equipment during handling or delivery could possibly necessitate an extended time for repair or replacement	—
R49	Delay in delivery of equipment (e.g., power transformer and 132 kV GIS equipment) due to the long process required for arranging the vessel	—

Table 2. (Continued.)

Risk ID	Risk statement	Risk subcategory
Material risks		
R50	Major equipment failures prolong the time for rectification, leading to a delay in overall project completion	—
R51	Late arrival of equipment and materials (275 kV power cable, multicore cable, NCT, conductors) due to a slow response from the manufacturer on a small order	—
R52	Unavailability of construction materials (e.g., aggregate stone) could possibly cause delays in road construction and compound surfacing work.	—
R53	Discrepancies in construction material due to a lack of quality control by the contractor could potentially lead to rework.	—
R54	Rejection of construction material due to noncompliance with the specification could potentially delay the commencement of site works.	—
R55	Delay in the manufacturing of equipment and steel structures due to the manufacturer's backlog	—
R56	The limited availability of Construction Industry Development Board (CIDB) certified concrete suppliers in the project's vicinity	—
R57	Shortages of concrete supply due to a temporary shutdown of the cement supplier's plant could potentially halt construction work.	—
R58	Delay in completion of piling work due to a shortage of material (e.g., 250 mm square pile) caused by the contractor's poor planning	—
Pandemic-related risks		
R59	Unable to work or temporary site closure due to a stop work order by the authority if site worker infected with infectious disease (e.g., COVID-19)	—
R60	Low productivity due to conditional movement control order (CMCO) and limitation of foreign workers	—
R61	The unavailability of an OEM testing supervisor due to movement control order (MCO)'s travel restriction	—
R62	Delay in resuming the site construction work after the end of MCO due to the time taken to remobilize subcontractors and workers to continue work that was left out before the MCO	—
R63	OEM supervisors could not enter Malaysia because MCOs in their origin country could potentially delay the installation of electrical equipment	—
R64	Delay in production of substation equipment due to factory closedowns due to pandemic (e.g., COVID-19), which affect the equipment drawing submission and the production of the factory	—
Site-related risks		
R65	Encountering a high volume of hard material or rock prolongs the earth excavation duration	—
R66	The unavailability of access roads to the site could potentially lead to a delay in the project commencement.	—
R67	Realignment of the cable route due to a limited working space for cable laying could potentially lead to rework.	—
R68	Slope failure due to unfavourable geological conditions could potentially require rectification work.	—
R69	The presence of a rocky or soft riverbed at the river crossing area poses a significant challenge to the horizontal directional drilling (HDD) operations.	—
R70	Seepage of river water into the newly excavated channel during construction due to site conditions	—
Weather-related risks		
R71	Delay in carrying out field density tests (FDT) for the earth fill layer due to wet ground caused by inclement weather	—
Workplace safety risks		
R72	Accidentally hitting live equipment or electricity cable at the existing substation due to a space constraint for construction works	—
R73	Electrical flashovers due to working close to the existing live equipment could potentially lead to safety incidents.	—
R74	Insufficient safety clearance to carry out piling works for cable trench construction underneath the existing live 33 kV busbar could lead to safety incidents and system tripping.	—
R75	Safety incidents involving public road users due to a lack of safety measures taken by the contractor such as poor traffic management, no barricades along open trenches, etc.	—
R76	Safety incidents involving the local community due to heavy machinery or vehicular movement	—
R77	Insufficient clearance at the public road for heavy equipment transportation to the site due to obstruction by existing structures and public vehicles along the way	—
R78	Complaints by a nearby residence due to excessive construction noise levels exceeding permissible limits	—
R79	Inefficient siltation ponds that cause the silt to flow into the public drainage could potentially cause flash floods in the drainage and loss of property.	—

organizational exposures. This frequency-based screening reduced the list to a manageable size for expert evaluation, minimizing participant burden and helping to preserve the quality of insights. At the same time, low-frequency but potentially catastrophic risks were considered separately to avoid excluding sentinel events with high-consequence impacts.

A total of 45 project personnel directly involved in risk management for EPT projects were invited to contribute their assessments, of which 32 provided complete evaluations. These participants represented two main groups within the organization—the PET and the FT. PET members include project managers, project engineers, construction engineers, and installation engineers, while FT members comprise project controllers, design engineers, quality engineers, and

executives. Although their roles differ, both groups work collaboratively on the same projects. PET personnel are engaged throughout the project lifecycle, focusing primarily on schedules and costs, whereas FT personnel participate in specific phases such as design, construction, testing, and commissioning, with a stronger emphasis on design integrity and quality assurance. The demographics of the participants are presented in Fig. 2.

The demographic profile of the participants reflects a broad representation of personnel within the EPT organization. The majority were male (73.5%), highlighting the gender imbalance commonly observed in the sector, while most participants were in the 31–40 age range, a group combining substantial professional experience with adaptability to new approaches. Engineers formed the largest

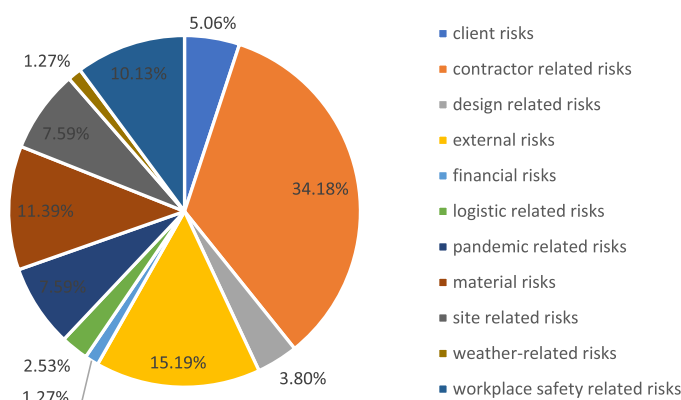


Fig. 1. Risk categorization.

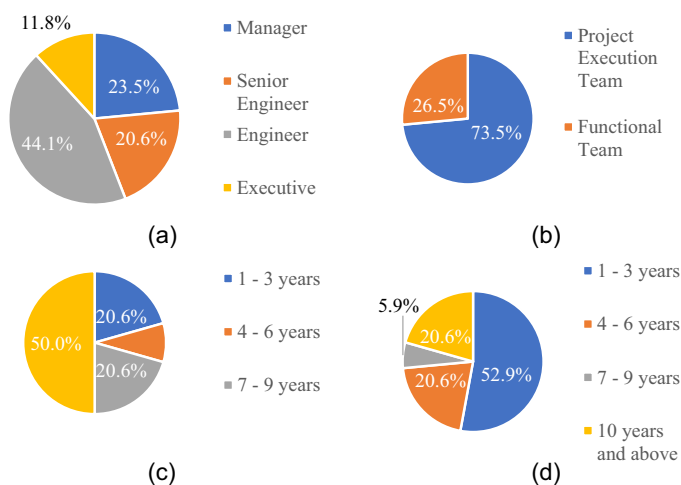


Fig. 2. Demographic profile of the participants: (a) position or role of respondents; (b) division in the organization; (c) years of working experiences in EPT projects; and (d) years of working experiences in risk management.

role-based group (44.1%), followed by managers (23.5%), senior engineers (20.6%), and executives (11.8%), ensuring input from both technical and managerial perspectives. In terms of organizational division, 73.5% were from the project execution team and 26.5% from functional divisions, offering viewpoints from both implementation and support functions. Experience levels further enriched the discussions. While half of the participants had more than 10 years of overall industry experience, only 20.6% reported more than a decade of direct involvement in risk management, reflecting the relatively recent institutionalization of structured risk management practices in EPT projects.

This process functioned as a structured focus group of experienced practitioners. By limiting participation to individuals directly responsible for EPT project risk management, the study ensured that the data reflected expert judgments grounded in practice. The participation rate of 71.1% (32 out of 45) provided sufficient breadth of input while still maintaining depth of expertise, thereby validating the reliability of the results. These expert assessments were then used to evaluate and prioritize 28 selected risk factors based on both probability of occurrence and potential project impact, enabling the derivation of a ranked list of risks most critical to EPT project performance.

The results obtained from the expert assessments were used to determine the RII values for the probability and impact of each risk

factor. The total weightage (W) or score assigned to the probability and impact of each risk statement was calculated, after which the RII for both probability and impact were computed. Finally, the risk scores were calculated by multiplying the RII for probability by the RII for impact for each risk. The results are shown in Table 3.

Correlation analysis of the survey results was performed with the primary aim of assessing the level of agreement between different respondent groups regarding key risks. This analysis helped to identify potential discrepancies or alignments in risk perceptions across various project roles. In particular, the agreement between the PET and the FT was examined using Spearman's rank correlation.

As highlighted in the demographic analysis of respondents, the study sample consists of two main groups: PET and FT. PET accounted for 73.5% of respondents, while FT represented 26.5%. This distribution reflects the composition of typical EPT project teams, where a larger proportion of personnel are execution-focused (PET). Table 4 presents the comparison of average weightings between PET and FT on the probability and impact of risks, which formed the basis for the Spearman's rank correlation analysis. The results show that the Spearman's rank correlation coefficient for the probability of risk occurrence was 0.675, while the coefficient for the impact of risks was 0.852.

Table 5 presents the ranking of the top 10 risk factors affecting EPT projects, based on calculated risk scores and correlation analysis. The table lists each risk by its unique ID, score, and rank in descending order of significance.

The risk scores range from 0.729 (the highest) to 0.62 (the lowest) within this top 10 list. R72 ranks first with a risk score of 0.729, followed closely by R40 at 0.722 and R73 at 0.713. The subsequent rankings include R19 (0.708), R5 (0.687), R30 (0.677), R8 (0.654), R48 (0.634), R69 (0.629), and R75 (0.62). Notably, the risk scores are closely grouped, especially at the top of the ranking, suggesting that these top risks are all highly significant. The deviation between the top and bottom scores among the top 10 is relatively small, at just 0.109.

Discussion

The risk ranking results reveal several significant patterns that underscore the unique nature of EPT projects compared to conventional construction projects. Notably, workplace safety risks dominate the highest positions, with "accidentally hitting live equipment or electricity cable" (Rank 1), "electrical flashovers due to working close to the existing live equipment" (Rank 3), and "safety incidents involving public road users" (Rank 10) all appearing in the top 10. These findings highlight the inherent hazards associated with working in high-voltage and public-interfacing environments, where accidents may result in severe injuries, fatalities, or large-scale service disruptions. Unlike traditional construction projects, EPT works require construction in energized substations and congested rights-of-way, which magnifies risks to both workers and the public. This pattern aligns with findings by Befrouei (2015), Szymański (2017), and El-Sayegh and Mansour (2015), who highlighted the importance of safety concerns in high-risk infrastructure projects, but it also shows that EPT projects may face a heightened prioritization of safety risks compared to other construction sectors.

Another observable trend is the strong influence of external and interdependent risks. The inability to commission substations or underground cables due to delays in transmission line completion (Rank 2) exemplifies how the success of one project is highly contingent upon the timely delivery of another. This risk category, identified as external, reflects the interconnected nature of EPT systems where substations, transmission lines, and underground cables form

Table 3. Risk scores after assessment

Risk ID	Risk statement	Probability and Impact	ΣW	RII	Risk score
R5	Awarding a contract to an inexperienced contractor unfamiliar with substation projects or underground cable projects	Probability Impact	136 146	0.800 0.859	0.687
R34	Changes in work scope or the addition of new work scope during the execution phase	Probability Impact	126 133	0.741 0.782	0.580
R32	Changes to the cable route to avoid obstruction along the proposed route	Probability Impact	129 135	0.759 0.794	0.603
R48	Damage to equipment during handling or delivery	Probability Impact	130 141	0.765 0.829	0.634
R8	Discrepancy between electrical design and civil design due to a lack of coordination between the consultants and reviewer	Probability Impact	139 136	0.818 0.800	0.654
R53	Discrepancy in construction material due to a lack of quality control by the contractor	Probability Impact	121 130	0.712 0.765	0.544
R73	Electrical flashovers due to working close to the existing live equipment	Probability Impact	128 161	0.753 0.947	0.713
R72	Accidentally hitting live equipment or electricity cable at the existing substation due to a space constraint for construction works	Probability Impact	130 162	0.765 0.953	0.729
R75	Safety incidents involving public road users due to a lack of safety measures taken by the contractor	Probability Impact	128 140	0.753 0.824	0.620
R30	Excessive level settlement of equipment foundations due to poor earthwork quality	Probability Impact	127 154	0.747 0.906	0.677
R50	Failure of the factory acceptance test (FAT) for major equipment	Probability Impact	123 144	0.724 0.847	0.613
R1	The unavailability of the asset owner's representative to attend the FAT due to their tight schedule	Probability Impact	87 96	0.512 0.565	0.289
R44	Late approval of the building plan by the local council due to the lengthy approval process	Probability Impact	114 112	0.671 0.659	0.442
R51	Late arrival of equipment and materials due to a slow response from the manufacturer on a small order	Probability Impact	129 135	0.759 0.794	0.603
R69	The presence of a rocky or soft riverbed at the river crossing area poses a significant challenge to the HDD operations	Probability Impact	128 142	0.753 0.835	0.629
R14	Late completion of the design due to the contractor's poor performance	Probability Impact	130 137	0.765 0.806	0.616
R19	Low productivity due to insufficient manpower in civil works	Probability Impact	142 144	0.835 0.847	0.708
R20	Personnel constraints in the primary and secondary engineering teams due to multiple contracts executed concurrently	Probability Impact	124 128	0.729 0.753	0.549
R47	Price fluctuation for construction materials and equipment due to various factors such as the global increase in raw material prices, currency exchange, and inflation	Probability Impact	125 126	0.735 0.741	0.545
R40	The inability to commission the substation or the underground cable because of the delay in completion of the transmission line (another project by the client)	Probability Impact	144 145	0.847 0.853	0.722
R18	Simultaneous commissioning of multiple projects has led to a shortage of qualified personnel (competent persons and testers)	Probability Impact	118 119	0.694 0.700	0.486
R57	Shortages of concrete supply due to a temporary shutdown of the cement supplier's plant	Probability Impact	115 131	0.676 0.771	0.521
R68	Slope failure due to unfavorable geological conditions	Probability Impact	122 141	0.718 0.829	0.595
R33	The existing equipment foundation design does not match the new equipment's requirements from the manufacturer.	Probability Impact	109 122	0.641 0.718	0.460
R16	The unavailability of a competent person to perform cable jointing	Probability Impact	124 142	0.729 0.835	0.609
R71	Delay in carrying out field density tests (FDT) for the earth fill layer due to wet ground caused by inclement weather	Probability Impact	121 122	0.712 0.718	0.511

Table 3. (Continued.)

Risk ID	Risk statement	Probability and Impact	ΣW	RII	Risk score
R52	Unavailability of construction materials (e.g., aggregate stone)	Probability Impact	114 123	0.671 0.724	0.485
R15	Late completion of the work (piling work) due to frequent machine breakdowns (piling rig)	Probability Impact	120 129	0.706 0.759	0.536

Table 4. Spearman's rank correlation

Risk ID	Probability		Impact	
	PET	FT	PET	FT
R5	4.040	3.889	4.160	4.667
R34	3.720	3.667	3.880	4.000
R32	3.840	3.667	3.920	4.111
R48	3.840	3.778	3.960	4.667
R8	4.240	3.667	4.040	3.889
R53	3.640	3.333	3.840	3.778
R74	3.800	3.667	4.640	5.000
R73	3.960	3.444	4.720	4.889
R76	3.960	3.222	4.080	4.222
R30	3.800	3.556	4.480	4.667
R50	3.680	3.444	4.240	4.222
R1	2.560	2.556	2.760	3.000
R44	3.480	3.000	3.280	3.333
R51	3.960	3.333	3.960	4.000
R70	3.720	3.889	4.120	4.333
R14	3.920	3.556	3.920	4.333
R19	4.240	4.000	4.240	4.222
R20	3.840	3.111	3.920	3.333
R47	3.800	3.333	3.720	3.667
R40	4.440	3.667	4.320	4.111
R18	3.600	3.111	3.560	3.333
R58	3.520	3.000	3.840	3.889
R69	3.680	3.333	4.160	4.111
R33	3.280	3.000	3.600	3.556
R16	3.880	3.000	4.200	4.111
R72	3.840	2.778	3.640	3.444
R52	3.480	3.000	3.600	3.667
R15	3.640	3.222	3.680	4.111

Note: Values show average weighting. Spearman's rank correlation coefficient for the probability of risk occurrence = 0.675; and Spearman's rank correlation coefficient for the impact of risks = 0.852.

part of a larger integrated infrastructure. Ting et al. (2022) also identified external risks as a leading source of project overruns, supporting the survey findings in this study. Similarly, logistical challenges such as “damage to equipment during handling or delivery” (Rank 8) reflect external vulnerabilities related to global procurement and transportation, which can be particularly acute in developing countries where remote site access and limited infrastructure increase the risk of damage during mobilization (Yusof and Sivadas 2006). These results indicate that EPT projects are heavily exposed to risks outside the direct control of project managers, underscoring the need for proactive coordination, planning, and contractual safeguards.

A third cluster of risks points to contractor capability and workmanship challenges. Insufficient manpower (Rank 4), awarding contracts to inexperienced contractors (Rank 5), poor-quality earthwork (Rank 6), and discrepancies between civil and electrical design (Rank 7) all highlight how contractor-related risks are central to EPT project outcomes. These issues are consistent with research by Badi et al. (2022), Kamaruddeen et al. (2020), and Saaidin et al. (2022), who emphasized the impact of workforce and design quality issues on delays and overruns. However, in the EPT sector, these risks carry amplified consequences due to the highly specialized expertise required to handle high-voltage works and complex EPC procurement models. Notably, inexperienced contractors pose risks not only to timelines and costs but also to safety, since lack of familiarity with substation or underground cable works increases the probability of technical errors. The cumulative effect of these findings is a strong indication that project success in the EPT sector is particularly dependent on skilled and experienced contractors supported by robust quality assurance frameworks.

The final set of risks reflects site and environmental uncertainties, represented by “unexpected soil conditions at river crossings”

Table 5. Top 10 key risks affecting EPT projects

Rank	Risk ID	Risk category	Risk statement	Risk score
1st	R72	Workplace safety	Accidentally hitting live equipment or electricity cable at the existing substation due to a space constraint for construction works	0.729
2nd	R40	External	The inability to commission the substation or the underground cable because of the delay in completion of the transmission line	0.722
3rd	R73	Workplace safety	Electrical flashovers due to working close to the existing live equipment	0.713
4th	R19	Contractor risk (manpower)	Low productivity due to insufficient manpower in civil works	0.708
5th	R5	Contractor risk (general)	Awarding a contract to an inexperienced contractor unfamiliar with substation projects or underground cable projects	0.687
6th	R30	Contractor risk (workmanship)	Excessive settlement level of equipment foundations due to poor earthwork quality	0.677
7th	R8	Contractor risk (design)	Discrepancy between electrical design and civil design due to a lack of coordination between the consultants and the reviewer	0.654
8th	R48	Logistic risk	Damage to equipment during handling or delivery	0.634
9th	R69	Site risk	The presence of a rocky or soft riverbed at the river crossing area poses a significant challenge to the HDD operations.	0.629
10th	R75	Workplace safety	Safety incidents involving public road users due to a lack of safety measures taken by the contractor	0.620

(Rank 9). This finding, though ranked lower, remains significant given its potential to disrupt horizontal directional drilling (HDD) operations and introduce unforeseen costs. While Issa et al. (2021) emphasized weak soils as a critical factor in infrastructure projects, El-Sayegh and Mansour (2015) and Badi et al. (2022) ranked soil-related risks lower, highlighting geographic variability in risk perception. In EPT contexts, however, challenging soil conditions at critical crossings such as rivers remain a notable concern due to the technical sensitivity of HDD operations.

Overall, the risk ranking results demonstrate a multidimensional risk landscape in EPT projects, where safety, interdependency, contractor capability, logistics, and ground conditions collectively shape project outcomes. These findings add granularity to existing risk management literature by empirically showing that risk salience in EPT projects differs from conventional construction, particularly in the areas of high-voltage safety and systemic project interdependencies. For instance, the prominence of workplace safety risks, particularly electrocution and flashovers, underscores the need for specialized safety frameworks beyond those typically used in general construction. Similarly, external interdependency risks reveal the systemic vulnerabilities of EPT projects, where success depends on coordinated delivery across multiple parallel projects.

The novelty of this study lies in advancing a sector-specific understanding of risk for electrical power transmission projects and empirically substantiating the need for an EPT-focused risk register. Unlike traditional construction risk research, which adopts broad categorizations, this study demonstrates that EPT projects exhibit distinctive risk concentrations, particularly electrocution hazards and project interdependencies, that require tailored governance responses. By systematically identifying and prioritizing these risks, the study contributes new empirical evidence to the body of knowledge on construction risk management and extends current discourse by positioning EPT projects as a unique risk domain within infrastructure development. This offers scholars a clearer conceptual foundation for future research into sector-specific risk modeling, capability development, and safety frameworks for high-voltage environments.

At the project level, the study underscores how unmanaged safety, interdependency, and capability risks can trigger cascading effects on cost, schedule, and successful commissioning. Understanding these risk priorities enables project managers to deploy more targeted controls such as competency-based procurement, interface risk protocols, and enhanced constructability and commissioning reviews. This strengthens overall project performance and supports the delivery of safer and more reliable EPT infrastructure.

From an industry perspective, the findings provide actionable direction for enhancing project governance in the EPT sector. The sector-specific risk register derived from this study supports more consistent and proactive risk management, strengthens contractor selection and oversight, and reinforces the need for specialized safety and competency frameworks. Such insights can help industry practitioners improve resource planning, design coordination, safety culture, and quality assurance processes, ultimately reducing delays, accidents, and rework. These contributions advance sectoral knowledge by shifting risk management from reactive compliance-based responses to a more preventive and system-level approach.

The study's implications are especially significant for Malaysia and other developing countries, where rapid grid expansion is ongoing but institutional risk management capacity remains uneven (Kamaruddeen et al. (2020) and Saaidin et al. (2022)). By proposing the foundation for a national or sector-level risk register, the study offers a pathway for capability building, reduced reliance on foreign specialists, and improved knowledge transfer between projects. For Malaysia, institutionalizing such a mechanism can strengthen

domestic contractor competence, improve governance in public infrastructure spending, and support more resilient and cost-effective delivery of power transmission assets. These insights are transferable to similar developing nations facing parallel resource constraints, governance gaps, and technical challenges.

Conclusion

In summary, this study examined risk management practices in EPT projects, aiming to identify, prioritize, and systematize the key risks that influence project delivery. A mixed-methods approach combined document analysis of 32 completed EPT projects with expert validation through focus group assessments, producing a robust and comprehensive understanding of the sector's risk landscape. The findings reveal recurring challenges across multiple domains, including design coordination, safety management, contractor manpower, material supply, and land acquisition, reflecting the complex, interdependent, and multidimensional nature of risks inherent in EPT projects. By systematically analyzing both historical and expert data, the study contributes to the knowledge of sector-specific risk dynamics that are often different in conventional construction risk management.

The novelty of this research lies in the development of a sector-specific risk register framework tailored for EPT projects. While risk registers are widely applied in general construction, their structured use for EPT projects, characterized by high-voltage hazards, strong project interdependencies, and highly specialized technical requirements, remains limited. By consolidating prioritized risk information into a centralized, structured repository, the register functions as both a knowledge management platform and a decision-support tool. It enables systematic identification, assessment, and response planning, enhancing organizational learning and supporting evidence-based decision-making. This empirical contribution fills a critical gap in construction risk management knowledge, particularly regarding large-scale infrastructure with highly specialized technical contexts.

From an industry perspective, the findings provide actionable insights for construction firms, project managers, and policymakers. The risk register facilitates proactive project governance by allowing stakeholders to anticipate, prioritize, and mitigate critical risks, improving project planning, execution, and overall performance. Integrating perspectives from both technical and managerial roles, the framework supports standardization of risk management practices, capacity building, and development of local expertise, reducing reliance on foreign contractors and fostering a stronger safety culture. These practical contributions help organizations improve resource allocation, strengthen design coordination, and enhance contractor performance across EPT projects.

At the national and developing-country level, the study offers insights directly relevant to Malaysia and other nations experiencing rapid expansion of power transmission infrastructure. Institutionalizing a centralized risk knowledge base promotes resilience, cost-efficiency, and sustainability in large-scale infrastructure projects. Governments and industry organizations can leverage the register to inform policy decisions, foster knowledge transfer across projects, and strengthen infrastructure delivery systems, ultimately supporting economic growth, reliable energy supply, and effective management of national resources.

Despite these contributions, several limitations should be acknowledged. First, the risk register developed in this study has not yet been applied to ongoing or future projects, limiting the ability to validate its long-term effectiveness. Second, the reliance on self-reported expert assessments introduces potential bias, which may be mitigated through triangulation with project performance metrics,

audits, or digital monitoring systems. Third, the cross-sectional design captures a snapshot of risks at a single point in time, which may not fully reflect dynamic project environments or evolving risk factors. Finally, while the purposive expert panel was carefully selected for relevant experience, the findings are based on the Malaysian context and may require adaptation to account for regional variations in project conditions, regulations, and institutional practices.

Future research should focus on validating the risk register in operational settings by applying it to multiple ongoing EPT projects and assessing its impact on risk mitigation, safety, cost, and schedule performance. Longitudinal studies tracking implementation over time would provide insights into the register's practical effectiveness and inform refinements for continuous improvement. Additionally, integrating the register with digital platforms, such as real-time monitoring and data analytics tools, could enhance dynamic risk assessment, reporting, and decision-making. Expanding the framework to account for regional variations in EPT project environments or scaling it for other developing countries would also enhance its generalizability and utility, providing actionable guidance for policymakers, project managers, and stakeholders in similar infrastructure and economics context.

Data Availability Statement

Some or all data, models, or code generated or used during the study are available from the corresponding author by request.

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Author Contributions

Sim Nee Ting: Conceptualization; Formal analysis; Funding acquisition; Methodology; Project administration; Supervision; Validation; Writing – original draft; Writing – review and editing. Thomas Chaong Buma: Conceptualization; Data curation; Formal analysis; Investigation; Methodology. Yee Yong Lee: Conceptualization; Project administration; Validation; Writing – review and editing. Nicholas Hoo Tien Kuan: Project administration; Writing – review and editing.

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