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A Fuzzy AHP Approach to Evaluating Contract Risk in Power Transmission Projects

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ABSTRACT
Risk assessment in Engineering Procurement Construction (EPC) contract management is crucial for understanding potential vulnerabilities and mitigating uncertainties in project execution. The study examines contract risk management in power transmission (PT_ projects, to identify and rank the factors that influence contract-related risks. A fuzzy Analytical Hierarchical Process(AHP) was applied to evaluate, normalize and prioritize the relative importance of these factors across the entire project cycle. Subsequently, Interpretive Structural Modeling (ISM) and MICMAC analysis were employed to establish a structural model and assess the driving and dependence power of the factors. The factors were identified through an extensive literature review and consultation with 75 experts from PT projects in India, representing diverse domains of PT project execution, including academicians, contract management specialists, project managers, financial analysts, risk management consultants, site engineers, overseeing power transmission projects. Their combined experience provided a comprehensive and practice-driven perspective on contract risk assessment. The analysis revealed that financial risk constitutes the most critical risk factor in PT contract management, exerting the highest influence across the project life cycle. The study further establishes the hierarchical structure of interrelated risks and their dependency patterns, offering a nuanced understanding of contractual vulnerabilities in PT projects. By elucidating the impact of various risks, the study provides valuable insight into reducing project uncertainties and establishes a preferred framework for effective contract risk management in PT projects. The derived preference structure can guide EPC firms, utilities, and the regulatory bodies in strengthening governance and decision-making in PT projects
Keywords: Engineering Procurement Construction, PT, Analytical Hierarchy Process, Contractual Risk.

INTRODUCTION:

Construction is one of the world's largest and fastest-growing industrial sectors, which plays a significant role in a developing country like India (Datta et al., 2022). India's construction sector is a pivotal component of its economy, contributing significantly to GDP and employment. As of 2023, the industry was valued at approximately USD 884.72 billion and is projected to reach USD 2,134.43 billion by 2030, growing at a compound annual growth rate (CAGR) of 12.6%. It employs over 70 million people, making it the second-largest employment generator in the country. That means the construction industry has an extensive influence on people's lives. This becomes more significant in power transmission projects(PT), specifically, substations and transmission lines which has a primary objective of managing the installation of equipment required to regulate power flow within the electric system(Ghatak & Garg, 2022). These activities require substantial capital expenditure (CapEx), estimated at INR 304,050 crores during FY-2020 to FY-2025 in India (Buckley & Trivedi, 2021). To execute such large-scale investments, Engineering Procurement Construction (EPC) contract model is widely used, wherein the contractor assumes legal responsibility for project delivery(Firoz et al., 2019).

Despite these high CapEx commitments, PT projects in India lack systematic prioritization and measurement of contract risk factors. Risks refer to as the effect of uncertainty on objectives, where uncertainty is the state of deficiency of information related to the likelihood of occurrence of future events and their possible consequences (ISO 31000, 2018). Risks are classified as known, unknown, and known-unknown (Kendrick, 2015), and neglecting them leads to project failure, poor performance, cost overruns, and damaged reputations (Ghatak & Garg, 2022; Mills, 2001). This raises the critical question: Why are such crucial risks not systematically addressed in PT projects (Buckley & Trivedi, 2021)? The compelling circumstances and growing competition prompt many ventures to rethink the strategies for managing and mitigating diverse risks to ensure business sustainability. However, the construction industry has been slow to adopt risk management due to cultural barriers, lack of knowledge, negative perceptions, and distrust toward risk analysis (Uher and Toakley, 1999). As risks impact project execution at every stage, from conceptualization to completion, the PT projects are particularly vulnerable given their scale and complexity.

These projects involve multiple stakeholders, are deeply tied to socio-economic dependencies, and rely heavily on governmental, economic, and legal frameworks (Ghatak & Garg, 2019). The adverse events increasingly disrupt projects, causing reputational damage and instability to these frameworks(Zheng, 2023; Annamalaisami & Kuppuswamy, 2022). Beyond research that merely identifies and ranks individual risk leading to project failure, there is a pressing need for the studies that explore the interconnections and interdependencies among these factors.Thus, it becomes crucial to identify potential contract risk factors early, enabling strategic mitigation, effective decision-making, and fostering organizational learning (Dwiedi et al., 2021; Sahin et al., 2015; Tomastik et al., 2015).

Considering the research gap of no prior literature defining and evaluating the contract risk management of the PT project in India, the main purpose of the study is to identify the significant risk factors in the EPC contract and prioritize them through risk mapping. Though available literature reflects discussion on risk management but ranking them based on the importance is not emphasized so far. The current study aims to identify and rank key contract risk factors in the context of Indian PT projects. The study takes up an integrated methodology of risk mapping, Interpretive Structural Modelling (ISM), Matrice d'Impacts Croises Multiplication Applique a Classement(MICMAC) to identify and establish the relationship among the contract risk factors and also recognize the driving-dependent contract risk factors between them. Further, Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is adopted to rank these factors, due to its capacity to manage uncertainty and reduce subjectivity in pairwise comparisons (Saaty, 1980; Kuswandari, 2004). A fuzzy AHP is chosen over AHP to reduce subjectivity and inaccuracy in the pair-wise judgement process, where fuzzy AHP makes use of a membership function to fit in vagueness that arises from decision-making (Kuswandari, 2004). This study thus focuses on a structured approach for risk estimation, enabling contractors to systematically prioritize and manage contract risks (Buckley & Trivedi, 2021) with the following research objectives:

RO1: To identify contract risk factors on expert views of academicians and PT project practitioners.

RO2: To identify the ordered association among contract risk factors

RO3: To classify the factors based on driving power and dependence power, and to recognize the utmost significant factors.

The structure of the remaining manuscript is as follows: Section 2 provides the review of the relevant literature, Section 3 outlines the integrated methodology employed to model contract risk factors. Section 4 presents the results, followed by a discussion on key findings and proposed interventions for contract risks management. Finally, Section 5 offers concluding remarks and highlights directions for future research.

2. Literature Review

The EPC contracting approach has become a dominant method in construction markets. It has its distinct advantages over the traditional Design–Bid–Build (DBB) model, such as reducing financial uncertainty, improving productivity, minimizing disputes, and creating greater profitability potential for contractors (Guo et al., 2010; Galloway, 2009; Hale et al., 2009; Xia & Chan, 2008). However, the same structure that grants EPC its efficiency also transfers substantial risks to the contractors. The contractors, who act as the sole entity responsible for delivering the entire project. Which means contractors must bear risks across all stages—from bidding and design to construction, operation, and even maintenance. Contractors also navigate the uncertainties of project management (Galloway, 2009; Choi et al., 2021; Shen et al, 2017; Yin & Wang, 2013; Nurdiana & Susanti, 2020; Pekings, 2009). When risks are underestimated or inadequately predicted, projects often incur major losses, with the magnitude of damage generally increasing in proportion to project size (Gunduz, 2015). For this reason, research on risk management in EPC projects has attracted increasing scholarly and professional attention (Yang et al, 2019).

Risk management is a structured process involving six components: risk planning, risk identification, qualitative and quantitative risk analysis, risk response planning, and risk monitoring, as defined by The Project Management Body of Knowledge, developed by the Project Management Institute (Rose, 2013). At its core, the theory of risk management lies in recognizing potential risks, anticipating their likelihood, and implementing effective countermeasures in a timely manner—an approach that is considered a prerequisite for ensuring successful performance in EPC projects (Spikin, 2013). Risk identification and analysis thus form the foundation of subsequent management stages, as understanding risk factors that adversely impact project outcomes is crucial for designing effective mitigation strategies (Yin & Li, 2014; Yang et al, 2015; Kassem et al, 2019).

In practice, EPC project risks have been categorized into multiple dimensions. For instance, Jayasudha & Vidivelli (2016) identified ninety risk factors in Indian construction projects, which they grouped into thirteen categories: technical, time, construction, design, legal, market, management, financial, political, environmental, social, safety, and physical. Wiguna & Scott (2006) took a broader approach by classifying sixteen risk factors into four categories: external and working conditions, economic-financial, techno-contractual, and managerial. Their analysis showed that the lower the project's risk exposure, the fewer the negative impacts on monthly project progress. Similarly, El-Sayegh (2008) divided risks into political, socio-economic, natural, and other external types, emphasizing that although external risks often carry high weight, they are not always directly tied to the construction process. Sudirman et al. (2018) proposed a simpler internal–external dichotomy, identifying factors that significantly influence the success of fast-track construction programs.

Other studies further refine these classifications. Sadeghi et al. (2016) identified twenty-six recurring risks in EPC projects and organized them into eight categories:

economic, political-legal, natural-physical, third-party (external), and scope, contract, design, owner, and construction (internal). Song et al. (2013), focusing on incineration projects in China, identified ten key risks, including decision-making, government approvals, policy-legal factors, technical and contractual issues, natural conditions, public opposition, municipal solid waste supply, payments, and revenue risks. Miller & Lessard (2001) similarly classified risks into three broad types: market-related (demand, finance, supply chain), execution-related, and institutional risks. Olsen & Osmundsen (2005) highlighted the relevance of risk management in supply-chain-based construction, while Ling & Hoi (2006), examining Singaporean firms operating in India, stressed socio-political risks, financing challenges, volatile currency exchange rates, and cultural differences as key barriers.

The economic environment itself compounds these risks, as predictions in uncertain markets can never be completely accurate (Nevitt & Fabozzi, 2000). Such unpredictability often manifests as lower productivity, cost overruns, and weaker overall performance (Mills, 2001). The consequences of poorly managed risks are therefore significant, ranging from escalating expenditures to inadequate project outcomes or even outright project failure (Raz et al., 2002). For instance, Dey et al. (1994) highlighted critical risk categories in Indian pipeline projects, such as technical, financial, economic, political, natural, and legal factors. These findings align with Banaitiene and Banaitis (2012), who emphasized that effective risk management is a core determinant of successful project management outcomes.

Beyond categorization, risk assessment remains a contested but crucial step in project management (Baloi & Price ,2003; Smith et al., 2006). Widely used methods include the Analytic Hierarchy Process (AHP) and fuzzy comprehensive evaluation. For example, Zhao et al. (2020) developed a risk identification system based on gray whitening weight functions combined with fuzzy evaluation to assess construction risks in EPC projects led by design enterprises. Yang et al. (2015) applied AHP and fuzzy methods to evaluate risks in EPC projects, while Wu & Zhou (2019) identified eleven critical risk factors through literature review and four-dimensional analysis, constructing an index system for assessment using extended fuzzy synthetic evaluation. The reliability of risk management practice ultimately depends on the completeness of risk identification and the accuracy of assessment (Wang et al., 2013).

Nevertheless, managing risks in EPC projects remains highly challenging. Contractors often lack the capacity to manage uncertainties alone due to the complexity of EPC processes and the volatility of markets (Tang et al., 2007). Prior research consistently emphasizes the role of information sufficiency in effective risk management (Dikmen et al., 2007). Coherent and timely information enables systematic efforts for early warning, effective negotiation, and prompt resolution of issues (Chan et al., 2010; Zou at al., 2010). In this regard, partnering strategies have been strongly advocated as a means of enhancing EPC risk management. Establishing collaborative relationships with project stakeholders facilitates knowledge sharing, builds trust, and enables joint problem-solving, thereby improving the overall quality of risk management practices (Yang et al.,2019; Eriksson et al., 2010). Successful EPC risk management therefore depends not only on the competencies of contractors but also on their ability to leverage resources and expertise through partnerships (Wang et al., 2016). Incorporating external knowledge and stakeholder collaboration strengthens the integration of risk management processes and creates conditions for systematic, proactive mitigation (Du et al., 2016).

Ultimately, the literature makes clear that risks in EPC and PT projects are multi-dimensional, spanning technical, financial, political, socio-economic, legal, environmental, and cultural factors. Almost all the studies emphasized on financial risks. These risks influence every phase of project execution and, if left unmanaged, result in reduced productivity, cost overruns, reputational damage, and project failures. Effective risk management—anchored in

Source	Payment	Drawing approvals	Legal disputes	Unclear Scope	Technical Specification	Penalties	Inspection and Testing	Delivery of Sites	clear statement	alternative dispute resolution	Force Majeure	Type of Contract	Material Delivery	contract documents	ROW's (Right of Way)
Aboushiwa & Bower (2000)												v			
Assaf S A and Al-Hejji S (2006)		v	v				v					v			
Adwan and Soufi (2016)														v	
Bhattacharyya & Dey (2007)			v												
Chan, Kumaraswamy (1997)			v												
Cheng et al. (2000)												v			
Chan et al (2004)			v						v						
Doloi, H. et al., (2012)	v	v			v		v						v		
Gardezia et al., (2013)	v	v	v												
Gunduz et al, (2013)		v			v										
Gul polat et al., (2014)	v			v	v	v									
Gebrehiwet T. and Luo, H. (2017)		v						v	v	v	v				
Hung and, Wang (2016)				v			v					v			
Jha, K. N. and Iyer K.C. (2006),				v											
Jinbo Song et al., (2013)			v												
Jayasudha & Vidivelli (2016)														v	
Jawad A. Alsuliman (2019),			v					v							
Marzaouk and Rasas (2014)		v			v	v									
NAOUM et al., (2004)				v											
Niazai, and Gidado (2012)	v				v	v						v	v		
Nundwea & Mulengab (2017),		v			v										
Nie-Jia Yau and Jyh-Bin Yang's (2012),					v			v							
Pillai N V and Kannan K P (2001)						v									
Patil S K et al (2013),				v			v	v							
Pall, G K et al. (2016)								v				v			
Osorio et al (2014)									v						
Shenhar et al., (2001)	v	v			v										
Sepasgozar et al (2006)															v
Salama et al (2008)						v	v								
Subhav Shing et al., (2018)					v								v		
Tang (2015)	v														
Yang (2009)									v						
Zakari Tsiga et al., (2017)				v								v			

Figure 1(i): Contract Risk Factors of PT Projects mentioned in Literature

comprehensive identification, systematic assessment, timely mitigation, and collaborative partnerships—emerges as a strategic necessity for contractors seeking to enhance performance and competitiveness in the global construction landscape (Song et al., 2020).

The current study portrays risk management in EPC contract and focuses to find an concrete problem of PT project. The existing literature (Figure 1-i) and the discussion with power sector professional Figure (1-ii) lists some criteria and sub-criteria and are depicted in Figure 1(i & ii).

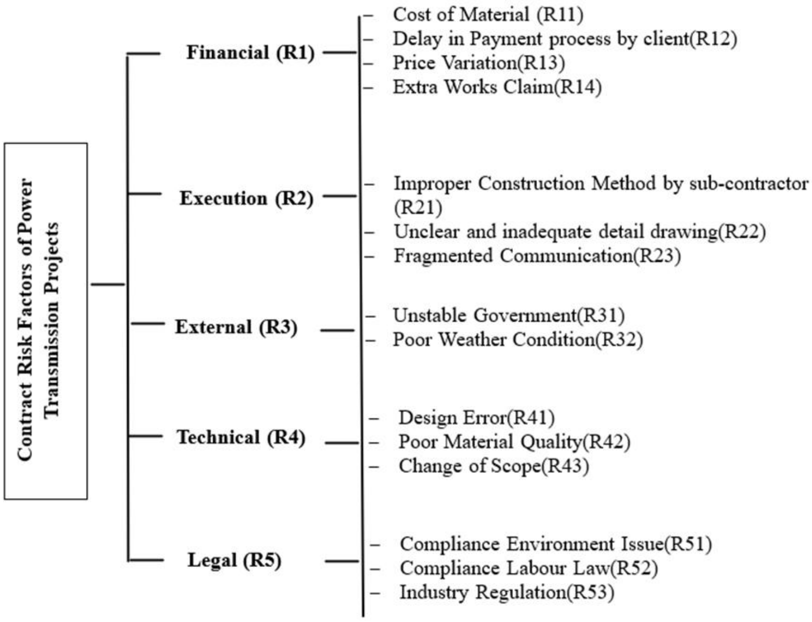


Figure 1(ii): A 2-tiered structure of Contract Risk Factors of PT Projects taken for current study

Source: Author's own after literature review and discussions with PT project professionals

3. Methodology

The study efforts to find and make an order of contract risk factors of PT projects in India. The study is steered in two stages. In the first stage, the contract risk factors of the project have been identified. In the second stage, the proposed integrated methodology has been used to model these identified contract risk factors. Initially, the identified criteria and related factors, grounded in the available studies on the topic and expert view, were used to frame an interview opinion form/questionnaire. The opinion form/questionnaire design was finalized in two circles. Initially, based on a literature survey, 32 plus contract risk factors identified. The most pertinent risk factors were determined utilizing Delphi approach with the help of 15 specialists. A purposive sampling technique was adopted to choose the experts for this examination. Therefore, the specialists were decided based on their experience (at least 15 years) and expertise in power transmission project execution. The expert panel provided insights on the identified contract risk factors and helped finalize the factors taken for further analysis.

A total of 15 participants comprising contract management specialists(5), project managers(3), financial analysts(2), risk management consultants(2), site engineers(3), overseeing power transmission projects, were consulted to identify contract risk factors. Using the Interpretive Structural Modeling ISM framework (Warfield, 1973), a Yes/No questionnaire was administered, and only those factors were retained which had at least 50% of respondents agreed upon. The steps for followed for discussion include:

1. Online semi-structured interviews
2. A pairwise comparison
3. Model validation and result interpretation

Experts were also encouraged to suggest additional risk factors and responses were collected independently to avoid bias. The process, similar to El-Razek et al. (2008), was supplemented with semi-structured interviews to validate and refine the list. Ultimately, five major factors were identified as the primary contract risk factors with a total of fifteen sub-factors, as shown in figure 1(ii). Out of identified 32 factors , 15 factors were found to be appropriate during the discussions; thus selected 15 factors were included in the study to progress further. Thereafter, the final opinion form/questionnaire was used to interview 55 PT project experts (PT) as EG1, EG2, EG3 groups under Operational level, Management level and Strategic level respectively and 05 academicians (AC) as EG4 experts dealing in the project management course delivery. The sampling split of the experts' profiles is given in Table 1 The interrelation among the recognized 15 factors was done using a pairwise judgement, in the second step. AHP and ISM was used to grade factors. The structural self-interaction matrix (SSIM) information was collected for ISM. In the following sections, AHP and ISM methodologies are discussed in detail.

Table 1: Profile of participating experts

Expert Group (EG)	No of Experts in group	Title role (Academia-AC /PT Project)	Position of Expert Group	Experience in Years
EG1	40	PT	Operational Level	20
EG2	10	PT	Management Level	16
EG3	05	PT	Strategic Level	22
EG4	05	AC	Project Management Professors	18

Source: Author's own

3.1 Fuzzy AHP Approach

The combined approach of F-AHP and MCDM leverages the strengths of both methods while addressing their limitations. Fuzzy set theory has been incorporated with the MCDM tools to eliminate the ambiguity and biases present in human opinion(Mardani et al., 2019) as given below:

Fuzzy set theory

Zadeh(1965) first introduced the fuzzy set theory (FST) to deal with the vagueness and ambiguity present in human decisions with the help of linguistic values. Fuzzy set theory has been integrated with other techniques and applied to various areas. If a membership function u_A (x) is related with a fuzzy set Ã, so that the function maps every element of X to the interval [0,1], then the mapping can be defined as: u_Ã (x)→[0,1]

The fuzzy set Ã = 〚x,u〛 _Ã (x),x E X

Ãwhere x is the alternative and u_Ã (x), is the fuzziness. A triangular fuzzy membership function can be specified with the help of three parameters (a, b, c), where a, b, and c are the lower, middle, and upper weights of the triangular fuzzy number (TFN) Ã, respectively, as shown in Figure 2(i).

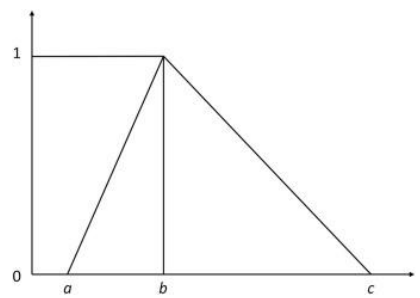


Figure 2(i): Representation of a triangular fuzzy number Ã.

pplication of Fuzzy AHP

The AHP is an MCDM tool developed by Saaty(1980) for solving decision-making problems and finding the influence of factors based on human judgment. The AHP method attempts to rank the factors based on their relative importance. The method transforms complex problems into a simple hierarchical structure despite uncertainty or subjective opinion(Tawana et al., 2023)

AHP is a tool to make decision with multiple criteria. It is an advancement in mathematics and statistics and was given by Saaty (1980). The technique is used for uncertain conditions primarily. The decision problem is divided into sub-sections and each sub-section is understood separately. The technique diminishes the risk of making inappropriate decisions (Mumcu & Gok, 2021). The Analytic Hierarchy Process (AHP) is a technique of "measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales" (Ayalew et al., 2022). It is based on human thinking and opinion (Chakrabortty & Ryan, 2020) AHP reports the problems related to various decision criteria (Gupta, Dawar, & Goyal, 2018), thus considered as a known and easy tool for making choices based on importance (Figueira et.al, 2005). But AHP shows volatility of its scale(Ayalew et al., 2022), unsuitability to a few situations (Kumari et.al,2018). Fuzzy AHP approach removes these problems in which language lexes are transformed to numbers to resolve decision problems. Triangular fuzzy numbers (TFN) are commonly taken to mark the language scale. When l(lower)=m(middle)=u(upper), then the TFN is based as real number. Figure 2(ii) reflects the language gauge .These TFNs are normalized into crisp values using the defuzzification technique, named converting fuzzy data into crisp scores (CFCS), developed by Opricovic and Tzeng(2003).

Saaty scale	Language scale	fuzzy scale (Triangular)	Reciprocal of fuzzy scale (Triangular)
1	Criteria 'i' and 'j' are of equal importance	$\tilde{1} = (1,1,1)$	$\tilde{1}^{-1} = (1,1,1)$
3	Criteria 'i' is moderately more important than 'j'	$\tilde{3} = (2,3,4)$	$\tilde{3}^{-1} = (\frac{1}{4},\frac{1}{3},\frac{1}{2})$
5	Criteria 'i' is strongly more important than 'j'	$\tilde{5} = (4,5,6)$	$\tilde{5}^{-1} = (\frac{1}{6},\frac{1}{5},\frac{1}{4})$
7	Criteria 'i' is very strongly more important than 'j'	$\tilde{7} = (6,7,8)$	$\tilde{7}^{-1} = (\frac{1}{8},\frac{1}{7},\frac{1}{6})$
9	Criteria 'i' is absolutely more important than 'j'	$\tilde{9} = (9,9,9)$	$\tilde{9}^{-1} = (\frac{1}{9},\frac{1}{9},\frac{1}{9})$
2 4 6 8	The intermittent values between the two adjacent scales	$\tilde{2} = (1,2,3)$ $\tilde{4} = (3,4,5)$ $\tilde{6} = (5,6,7)$ $\tilde{8} = (7,8,9)$	$\tilde{2}^{-1} = (\frac{1}{3},\frac{1}{2},1)$ $\tilde{4}^{-1} = (\frac{1}{5},\frac{1}{4},\frac{1}{3})$ $\tilde{6}^{-1} = (\frac{1}{7},\frac{1}{6},\frac{1}{5})$ $\tilde{8}^{-1} = (\frac{1}{9},\frac{1}{8},\frac{1}{7})$

Source: Kannan et al., 2013; Jain et al., 2019

Figure 2(ii): Language gauge for pairwise judgment of each criterion

for pairwise opinion of each criterion. Fuzzy AHP is proposed because it is difficult divide the opinion of the decision-maker in AHP and fuzzy-AHP removes the fuzziness of AHP (Kabir, 2014). Fuzzy- AHP uses the fuzzy valuations ratios. In this study, Buckley (1985) for AHP is used to calculate the universal ranking or weight.

According to Figure 2(ii), the place between criteria and sub-criterion is characterized from equally important, to absolutely more important and interpreted into weights of one (1), three ($\tilde{3}$), five ($\tilde{5}$), seven ($\tilde{7}$), and nine ($\tilde{9}$), respectively (A tilde "~" shows a fuzzy set).

Since, MCDM takes up the complex problems reliant on the answer procedures selected by decision-making people (Azhar et al., 2021), the study attempted to recognize the serious problems in EPC contract of PT projects and to prioritize the identified factors using risk mapping. Risks related to PT projects contracts were recognized with literature review and the opinion of 15 PT project experts in India. The specific, articulate and very informal questions were framed under five criteria which include: Financial; Execution; External; Technical; and Legal criteria, coded as R1, R2, R3, R4, R5 respectively. There were different factors under each criterion as shown in Figure 1(i). Financial

`	Financial				Execution			External		Technical			Legal		
	R11	R12	R13	R14	R21	R22	R23	R31	R32	R41	R42	R43	R51	R52	R53
	Cost of mate	Delay in payme	Price Variati	Extar Claim	Improper construction method by subcontractor.	Unclear and inadequate detail drawing	Fragmented Communication	Unstable Go	Poor Weath	Design Erro	Poor Materi	Chainge of Scope	Complianc environment issue	Compliance Labour Law	Industry Regulations
Cost of materials	0.00	1	3	0.3333333	5	6	0.3333333	7	0.5	6	3	7	5	6	5
Delay in payment process by client	1.00	0.00	0.5	0.3333333	1	4	0.5	5	0.2	5	0.5	1	4	6	5
Price Variation	0.33	2.00	0.00	0.5	7	7	4	8	3	7	3	7	5	6	5
Extar Claim Works	3.00	3.00	2.00	0.00	6	4	0.5	7	0.5	6	4	6	5	6	3
Improper construction method by subcontractor.	0.20	1.00	0.14	0.17	0.00	1	0.25	4	0.2	1	0.5	1	3	5	3
Unclear and inadequate detail drawing	0.17	0.25	0.14	0.25	1.00	0.00	0.25	1	0.1428571	1	0.3333333	1	2	6	4
Fragmented Communication	3.00	3.00	0.25	2.00	4.00	4.00	0.00	7	1	6	4	6	4	6	5
Unstable Government	0.14	0.20	0.13	0.14	0.25	1.00	0.14	0.00	0.1666667	1	0.1428571	1	1	1	1
Poor Weather Condition	2.00	5.00	0.33	2.00	5.00	7.00	1.00	6.00	0.00	7	4	8	4	5	5
Design Error	0.17	0.20	0.14	0.17	1.00	1.00	0.17	1.00	0.14	0.00	0.1666667	1	1	1	1
Poor Material Quality	0.33	2.00	0.33	0.25	2.00	3.00	0.25	7.00	0.25	6.00	0.00	7	3	5	5
Chainge of Scope	0.14	1.00	0.14	0.17	1.00	1.00	0.17	1.00	0.13	1.00	0.14	0.00	1	1	1
Complianc environment issue	0.20	0.25	0.20	0.20	0.33	0.50	0.25	1.00	0.25	1.00	0.33	1.00	0.00	1	1
Compliance Labour Law	0.17	0.17	0.17	0.17	0.20	0.17	0.17	1.00	0.20	1.00	0.20	1.00	1.00	0.00	1
Industry Regulations	0.20	0.17	0.20	0.33	0.33	0.25	0.20	1.00	0.20	1.00	0.20	1.00	1.00	1.00	0.00

Source: Author's own

Figure 2(iii): Pairwise comparison matrix for the drivers of Expert 1.

`	Financial				Execution			External		Technical			Legal		
	R11	R12	R13	R14	R21	R22	R23	R31	R32	R41	R42	R43	R51	R52	R53
	Cost of mate	Delay in payme	Price Variati	Extar Claim	Improper construction method by subcontractor.	Unclear and inadequate detail drawing	Fragmented Communication	Unstable Go	Poor Weath	Design Error	Poor Materi	Chainge of Scope	Compliance environment issue	Compliance Labour Law	Industry Regulations
Cost of materials	0.000	0.052	0.391	0.048	0.147	0.150	0.041	0.123	0.073	0.120	0.146	0.143	0.125	0.107	0.111
Delay in payment process by client	0.090	0.000	0.065	0.048	0.029	0.100	0.061	0.088	0.029	0.100	0.024	0.020	0.100	0.107	0.111
Price Variation	0.030	0.104	0.000	0.071	0.205	0.175	0.489	0.140	0.436	0.140	0.146	0.143	0.125	0.107	0.111
Extar Claim Works	0.271	0.156	0.260	0.000	0.176	0.100	0.061	0.123	0.073	0.120	0.195	0.122	0.125	0.107	0.067
Improper construction method by subcontractor.	0.018	0.052	0.019	0.024	0.000	0.025	0.031	0.070	0.029	0.020	0.024	0.020	0.075	0.089	0.067
Unclear and inadequate detail drawing	0.015	0.013	0.019	0.036	0.029	0.000	0.031	0.018	0.021	0.020	0.016	0.020	0.050	0.107	0.089
Fragmented Communication	0.271	0.156	0.033	0.285	0.117	0.100	0.000	0.123	0.145	0.120	0.195	0.122	0.100	0.107	0.111
Unstable Government	0.013	0.010	0.016	0.020	0.007	0.025	0.017	0.000	0.024	0.020	0.007	0.020	0.025	0.018	0.022
Poor Weather Condition	0.181	0.260	0.043	0.285	0.147	0.175	0.122	0.105	0.000	0.140	0.195	0.163	0.100	0.089	0.111
Design Error	0.015	0.010	0.019	0.024	0.029	0.025	0.020	0.018	0.021	0.000	0.008	0.020	0.025	0.018	0.022
Poor Material Quality	0.030	0.104	0.043	0.036	0.059	0.075	0.031	0.123	0.036	0.120	0.000	0.143	0.075	0.089	0.111
Chainge of Scope	0.013	0.052	0.019	0.024	0.029	0.025	0.020	0.018	0.018	0.020	0.007	0.000	0.025	0.018	0.022
Complianc environment issue	0.018	0.013	0.026	0.029	0.010	0.013	0.031	0.018	0.036	0.020	0.016	0.020	0.000	0.018	0.022
Compliance Labour Law	0.015	0.009	0.022	0.024	0.006	0.004	0.020	0.018	0.029	0.020	0.010	0.020	0.025	0.000	0.022
Industry Regulations	0.018	0.009	0.026	0.048	0.010	0.006	0.024	0.018	0.029	0.020	0.010	0.020	0.025	0.018	0.000

Source: Author's own

Figure 2(iv): Normalized direct relation matrix.

criterion has four factors, Execution criterion has three factors, External criterion has two factors, Technical criterion has three factors and Legal Criterion has also three factors, thus making a total of fifteen contract risk factors. These risks are ranked through AHP as the decision tool and a framework is created which portrays the link between each risk. The recorded steps are appeared in Figure-1(ii), 2(iii)-2(v).

R11	11.8%	5
R12	6.5%	7
R13	16.2%	1
R14	13.0%	4
R21	3.8%	8
R22	3.2%	9
R23	13.2%	3
R31	1.6%	14
R32	14.1%	2
R41	1.8%	13
R42	7.2%	6
R43	2.1%	10
R51	1.9%	11
R52	1.6%	15
R53	1.9%	12
	100.0%	

Source: Author's own

Figure 2(v): Importance scores of drivers

3.2 Interpretive Structural Modeling: ISM

ISM, a concept originally given by Warfield (1973), can predict interrelation of factors, ranking of factors as per the importance of the factor and significance of each factor. In ISM, a digraph determines the dependency and driving power of each factor on other factors.

ISM and MICMAC analysis was carried out on 15 contract risk factors of PT projects, identified after literature review and discussion with PT project practitioners. The steps followed to do calculations of the ISM Model (Ruben et al., 2018) are given as:

1: Factors Documentation The contract risk factors of PT projects, have been recognized after literature review and discussion with PT project practitioners.

2: *Structural Self-Interaction Matrix* (SSIM) building Four codes i.e., V, A, X, and O (Raj et al.,2009) are used for the making the Structural Self-Interaction Matrix for developing relationships among two factors (Table 2). The codes were assigned values as given below(Table 2):

i. Code 'V' when factor R11 brings on R12 i.e., R11→R12 but reverse is not true.

ii. Code 'A' when factor R12 brings on R11 i.e., R12→R11 but reverse is not true.

iii. Code 'X' for a bi-directional relation when factor R11 brings on R12 i.e., R11→R12 or R12 brings on R11 i.e., R12→R11.

iv. Code 'O' when no relation between the factors.

Table 2 : SSIM- Structural Self-Interaction Matrix(Author's own)

Code	Contract Risk Factors	R11	R12	R13	R14	R21	R22	R23	R31	R32	R41	R42	R43	R51	R52	R53
R11	Cost of materials	1	O	X	O	O	O	A	O	A	O	O	O	A	O	O
R12	Delay in payment process by client		1	O	O	O	O	O	A	O	A	A	O	A	A	A
R13	Price Variation			1	O	O	O	O	O	O	O	O	O	O	O	O
R14	Extra Claim Works				1	O	A	A	O	O	A	O	A	O	O	O
R21	Improper construction method by subcontractor.					1	O	A	O	O	V	A	O	O	O	O
R22	Unclear and inadequate detail drawing						1	A	O	O	V	V	V	O	O	O
R23	Fragmented Communication							1	O	O	V	V	V	O	O	O
R31	Unstable Government								1	O	O	O	O	V	V	V
R32	Poor Weather Condition									1	O	O	O	O	O	O
R41	Design Error										1	V	V	O	O	O
R42	Poor Material Quality											1	V	O	O	O
R43	Change of Scope												1	A	A	A
R51	Compliance environment issue													1	X	X
R52	Compliance Labour Law														1	X
R53	Industry Regulations															1

Source: Author's own

3: *Initial Reachability* Matrix development According to Ruben et al. (2018) The initial reachability matrix has been developed by converting the Four codes i.e., V, A, X, and O have been converted into binary numbers (1 or 0)as given below, to develop ISM (Table 3)

i. Code 'V' is changed to value '1' if given factor R11 leads to R12 and value '0' is specified in a backward relation i.e. R12 leads to R11.

ii. Code ‘A’ is changed to value ‘0’ when factor R12 leads to R11 and value ‘1’ is specified in a forward relation i.e. R11 leads to R12

iii. Code ‘X’ is changed to value ‘1’ when there is bi-directional relationship between both the factors.

iv. Code ‘O’ is changed to value ‘0’ when the specified factors have no relationship.

Table 3: Initial Reachability Matrix

Contract Risk Code	R11	R12	R13	R14	R21	R22	R23	R31	R32	R41	R42	R43	R51	R52	R53
R11	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
R12	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
R13	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
R14	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
R21	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
R22	0	0	0	1	0	1	0	0	0	1	1	1	0	0	0
R23	1	0	0	1	1	1	1	0	0	1	1	1	0	0	0
R31	0	1	0	0	0	0	0	1	0	0	0	0	1	1	1
R32	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
R41	0	1	0	1	0	0	0	0	0	1	1	1	0	0	0
R42	0	1	0	0	1	0	0	0	0	0	1	1	0	0	0
R43	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
R51	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1
R52	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1
R53	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1

Source: Author’s own

4: *Final Reachability* Matrix building Final reachability matrix has been built using Transitivity rule and inspecting the transitivity linkage among factors. Transitivity rule (Singh et al.,2007) states if factor ‘R11’ is connected to ‘R12’ and factor ‘R12’ is connected to ‘R13’, it means factor ‘R1’ is undoubtedly connected to factor ‘R13’. All ‘0’ values have been shown with the maximum values ‘1’ for transitivity and transformed all 0s to 1*.(Table 4)

Table 4: Final Reachability Matrix(Author’s own)

Contract Risk Code	R11	R12	R13	R14	R21	R22	R23	R31	R32	R41	R42	R43	R51	R52	R53
R11	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
R12	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
R13	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
R14	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
R21	0	1*	0	1*	1	0	0	0	0	1	1*	0	0	0	0
R22	0	1*	0	1	1*	1	0	0	0	1	1	1	0	0	0
R23	1	1*	1*	1	1	1	1	0	0	1	1	1	0	0	0

R31	1*	1	0	0	0	0	0	1	0	0	0	0	1	1	1
R32	1	0	1*	0	0	0	0	0	1	0	0	0	0	0	0
R41	0	1	0	1	1*	0	0	0	0	1	1	1	0	0	0
R42	0	1	0	1*	1	0	0	0	0	1*	1	1	0	0	0
R43	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
R51	1	1	1*	1*	0	0	0	0	0	0	0	1	1	1	1
R52	1	1	1*	1*	0	0	0	0	0	0	0	1	1	1	1
R53	1	1	1*	1*	0	0	0	0	0	0	0	1	1	1	1

Source: Author's own

5: *Final Reachability Matrix partitioning* Reachability (row-wise), and antecedent (column-wise) sets are identified in final reachability matrix (Warfield, 1973) to get the hierarchy of contract risk factors of PT projects. The common factors from each set are put above the intersection sets and removed in further repetition which is extended to the sixth level (Table 5-10).

Table 5: First Iteration- Partition of Reachability Matrix

Contract Risk Code	Reachability_Set	Antecedents_Set	Intersection_Set	Level
R11	1,3	1,3, 7, 8, 9, 13, 14, 15	1,3	1
R12	2	2, 5, 6, 7, 8, 10, 11, 13, 14, 15	2	1
R13	1,3	1, 3, 7, 9, 13, 14, 15	1,3	1
R14	4	4, 5, 6, 7, 10, 11, 12, 13, 14, 15	4	1
R21	2, 4, 5, 10, 11	5, 6, 7, 10, 11	5, 10, 11	
R22	2, 4, 5, 6, 10, 11, 12	6, 7	6	
R23	1, 2, 3, 4, 5, 6, 7, 10, 11, 12	7	7	
R31	1, 2, 8, 13, 14, 15	8	8	
R32	1, 3, 9	9	9	
R41	2, 4, 5, 10, 11, 12	5, 6, 7, 10, 11	5, 10, 11	
R42	2, 4, 5, 10, 11, 12	5, 6, 7, 10, 11	5, 10, 11	
R43	4, 12	6, 7, 10, 11, 12, 13, 14, 15	12	
R51	1, 2, 3, 4, 12, 13, 14, 15	8, 13, 14, 15	13, 14, 15	
R52	1, 2, 3, 4, 12, 13, 14, 15	8, 13, 14, 15	13, 14, 15	
R53	1, 2, 3, 4, 12, 13, 14, 15	8, 13, 14, 15	13, 14, 15	

Source: Author's own

Table 6: Second Iteration- Partition of Reachability Matrix

Contract Risk Code	Reachability_Set	Antecedents_Set	Intersection_Set	Level
R21	5,10, 11	5, 6, 7, 10, 11	5,10, 11	1
R22	5, 6, 10, 11, 12	6, 7	6	

R23	5, 6, 7, 10, 11,12	7	7	
R31	8, 13, 14, 15	8	8	
R32	9	9	9	1
R41	5, 10, 11, 12	5, 6, 7, 10, 11	5,10, 11	
R42	5, 10, 11, 12	5, 6, 7, 10, 11	5,10, 11	
R43	12	6, 7, 10, 11, 12, 13, 14, 15	12	1
R51	12, 13, 14, 15	8, 13, 14, 15	13, 14, 15	
R52	12, 13, 14, 15	8, 13, 14, 15	13, 14, 15	
R53	12, 13, 14, 15	8, 13, 14, 15	13, 14, 15	

Source: Author's own

Table 7: Third Iteration- Partition of Reachability Matrix

Contract Risk Code	Reachability_Set	Antecedents_Set	Intersection_Set	Level
R22	6, 10, 11	6, 7	6	
R23	6, 7, 10, 11	7	7	
R31	8, 13, 14, 15	8	8	
R41	10, 11	6, 7, 10	10	
R42	11	6, 7, 10, 11	11	1
R51	13, 14, 15	8, 13, 14, 15	13, 14, 15	1
R52	13, 14, 15	8, 13, 14, 15	13, 14, 15	1
R53	13, 14, 15	8, 13, 14, 15	13, 14, 15	1

Source: Author's own

Table 8: Fourth Iteration- Partition of Reachability Matrix

Contract Risk Code	Reachability_Set	Antecedents_Set	Intersection_Set	Level
R22	6, 10	6, 7	6	
R23	6, 7, 10	7	7	
R31	8	8	8	1
R41	10	6, 7, 10	10	1

Source: Author's own

Table 9: Fifth Iteration- Partition of Reachability Matrix

Contract Risk Code	Reachability_Set	Antecedents_Set	Intersection_Set	Level
R22	6	6, 7	6	1
R23	6, 7	7	7	

Source: Author's own

Table 10: Sixth Iteration- Partition of Reachability Matrix

Contract Risk Code	Reachability_Set	Antecedents_Set	Intersection_Set	Level
R23	7	7	7	1

Source: Author's own

6: *Digraph and ISM model* making An ISM model (Figure. 5) and a digraph (Figure. 2) are shaped with the help of final reachability matrix partitioning. The arrow in ISM depicts the relationship between the factors.

7: *MICMAC Analysis* MICMAC analysis is useful to discover the difference between dependence and driving power(Sharma,1995). The factors are put into four quadrants (Ruben et al., 2018), MICMAC analysis i.e., Autonomous, Dependent, Linkage, and Drivers (as shown in Table 11-12 and Figure 4).

Autonomous Factors have low driving and dependence power and shown in Quadrant I (Figure. 4). In this quadrant, two contract risk factors are categorized as autonomous factors i.e., Unstable Government (R31) and Poor Weather condition (R32) have low dependence and driving power on contract risks.

Dependent Factors with low driving power and high dependence power as shown in Quadrant II (Figure. 4). Five risk factors are categorized as dependent factors i.e., Cost of material (R11), Delay in payment process (R12), Price Variation (R13), Extra claim works (R14), and Change of scope (R43) are dependent on other factors while executing PT projects and are on the top position of ISM model (Figure 5)

Linkage Factors have robust driving and dependence power as reflected in Quadrant III (Figure. 4). In this quadrant, three critical risk factors are categorized as linkage factors i.e., Improper construction method by sub-contractor (R21), Design Error (R41), and Poor material quality (R42) are unstable with a link to every factor and they impact themselves besides impacting other factors.

Driving Factors show strong driving power and low dependence power as revealed in Quadrant IV (Figure. 4). These factors are also recognized as independent factors. There are five risk factors of PT projects which fall in this quadrant i.e. Unclear and inadequate detail drawing (R22), Fragmented communication (R23), Compliance environment issues (R51), Compliance Labour Law (R52), and Industry regulations (R53) which are not dependent on other risk factors nonetheless if these factors are predisposed then they initiate the other factors.

4. Results and Discussion

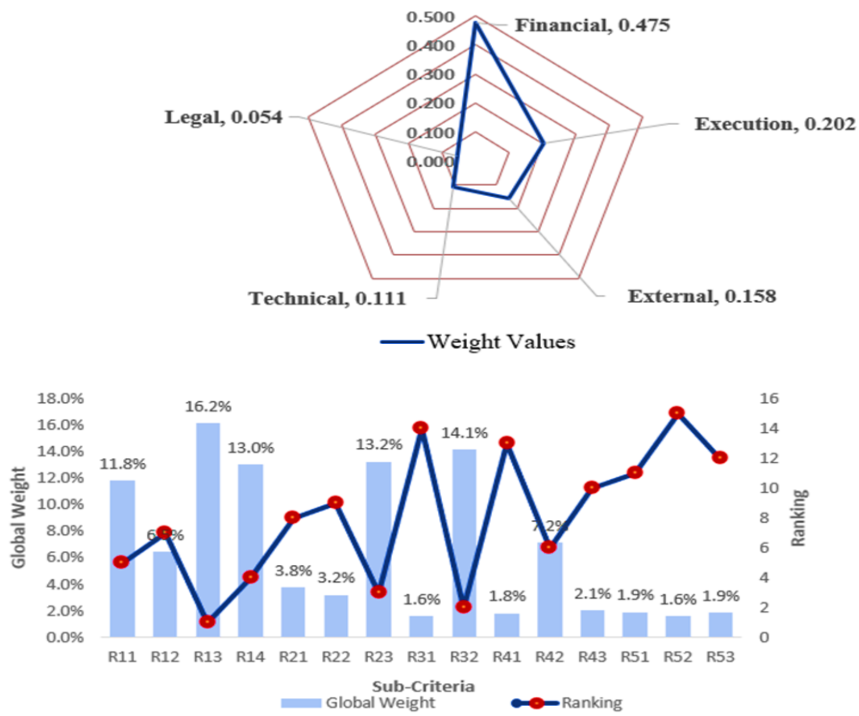
The AHP results depict financial risk (R1) as the dominant contract risk in PT projects (local weight 47.50%), a finding that aligns with sector practice and literature showing that price-variation and material-cost escalation are central concerns for EPC projects. Similarly, empirical analyses of cost-overrun drivers identify materials shortages and supplier delays as major causes of cost escalation supporting the high global weights observed for Price Variation (R1, 16.20%) and Cost of Material (R11, 11.80%) (Pham , 2020). The importance of execution risk (R2, 20.20%) and associated sub-factors such as Fragmented Communication (R23, 13.20%) and Extra Claims Work (R14, 13.00%) is consistent with Indian EPC evidence. This shows recurrent commercial claims, disputes, and coordination failures as frequent causes of delays and cost overruns in EPC projects. Studies of the Indian EPC sector document that extra-work claims and poor claims management are endemic and materially affect schedules validating the strong AHP ranking for execution-related sub-criteria(Jadhav, 2021). External risks (R3, 15.80%), especially Poor Weather Conditions (R32, 14.10%), also register high global weights in the AHP outputs supported by Transmission engineering research that models weather-related transmission line outages (Sony ,2020) justifying the substantive weight assigned to weather and other environmental factors in PT projects. The order of ranking R1>R2>R3>R4>R5 of risks factors is depicted in Table 11 and Figure 3. Figure reflects the global weight of all the sub-criteria. The sub-criteria Compliance Environment Issue (R51- global weight-1.9 percent), Industry Regulations(R53- global weight-1.9 percent), Design Error (R41- global weight-1.8 percent), Unstable Government (R31- global weight-1.6 percent) and Compliance Labour Law (R52 global weight-1.6 percent) are the least important risk factors in PT projects.

Table 11: First and second-level factors weight Scores defining Contract Risks of PT Projects

Criterion	Local Weight	Ranking	Factors	Local Weight	Local Ranking	Global Weight	Global Ranking
Financial(R1)	47.50%	1	Cost of materials(R11)	24.90%	2	11.80%	5
			Delay in payment process by client(R12)	15.20%	4	6.50%	7
			Price Variation(R13)	21.00%	3	16.20%	1

			Extra Claim Works(R14)	38.90%	1	13.00%	4
Execution(R2)	20.20%	2	Improper construction method by subcontractor.(R21)	23.30%	2	3.80%	8
			Unclear and inadequate detail drawing(R22)	23.30%	2	3.20%	9
			Fragmented Communication(R23)	53.30%	1	13.20%	3
External(R3)	15.80%	3	Unstable Government(R31)	50%	1	1.60%	14
			Poor Weather Condition(R32)	50%	1	14.10%	2
Technical(R4)	11.10%	4	Design Error(R41)	22.30%	3	1.80%	13
			Poor Material Quality(R42)	35.80%	2	7.20%	6
			Change of Scope(R43)	41.90%	1	2.10%	10
Legal(R5)	5.40%	5	Compliance environment issue(R51)	33.30%	1	1.90%	11
			Compliance Labour Law(R52)	33.30%	1	1.60%	15
			Industry Regulations(R53)	33.30%	1	1.90%	12
	100%					100%	

Source: Author's own



Source: Author's own

Figure 3: Distribution of Weight Values of Contract Risk Criteria for PT Projects and Factors Determining the Contract Risk in PT Projects

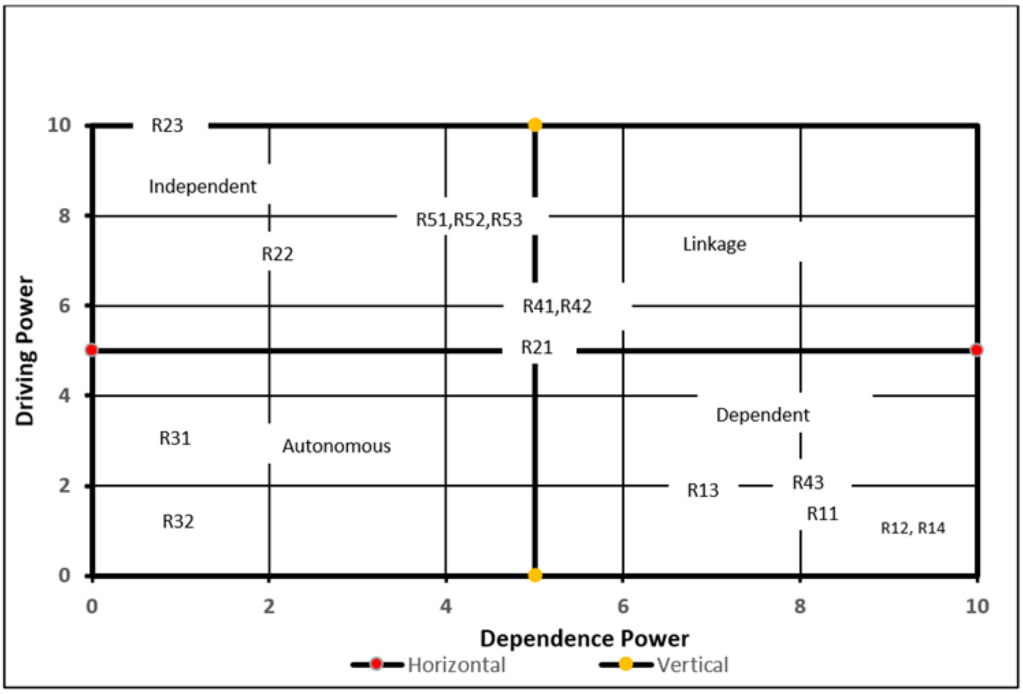
The pairwise evaluations of the criteria unlocked the resulting facts. Within each criterion there is ranking of each sub-criteria considering the local weights. Extra Claims works with local weight of 38.90 percent is the most important factor among Financial risks. Similarly, Fragmented communication (53.30 percent) in Execution risk, and Change of Scope (41.90 percent) in Technical factors. However, all sub-factors in External and Legal risks have been given equal importance with 50 percent and 33 percent local weight for each sub-criterion respectively.

An ISM-based method was grounded on the ideas of PT project practitioners and academicians to analyze the circumstantial associations among recognized risk factors that a PT project practitioner considers. The relationship among factors portrayed in the ISM hierarchy model (Figure. 5). ISM and MICMAC analysis collectively deliver valued perceptions into the comparative significance of identified factors impacting the EPC projects. In Figure. 4, MICMAC analysis reveals two autonomous factors i.e., Unstable Government (R31) and Poor Weather condition (R32) have low dependence and driving power on contract risks. This signifies that Unstable Government (R31) and Poor Weather condition (R32) do not directly impact the PT project and PT practitioners may not consider these factors as potential risk factors in PT projects.

Table 12: Driving Power and Dependence Power of Contract Risk Factors of PT Projects

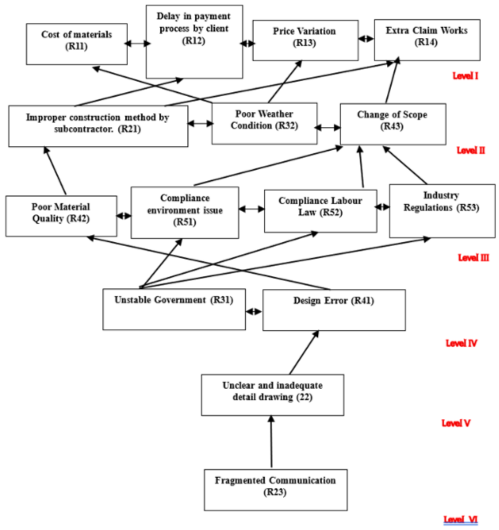
Power	R11	R12	R13	R14	R21	R22	R23	R31	R32	R41	R42	R43	R51	R52	R53
Dependence Power	8	10	7	10	5	2	1	1	1	5	5	8	4	4	4
Driving Power	2	1	2	1	5	7	10	6	3	6	6	2	8	8	8

Source: Author’s own



Source: Author’s own

Figure 4: Dependence power and Driving Power Matrix based on MICMAC



Source: Author's own

Figure 5: ISM Model for Contract Risk Factors of PT Projects

As shown in Figure. 5, seven identified factors at the upper side of the ISM grading model include i.e., Cost of Material (R11), Delay in payment process by client (R12), Price variation(R13), Extra claims work (R14), Improper construction method by sub-contractor (R21), Poor weather condition(R32) and Change of Scope (R43) that PT project practitioners need to understand to avoid the risks. The results are aligned with the past literature. As depicted in Figure 5, three critical risk factors are considered as linkage factors i.e., Improper construction method by sub-contractor (R21), Design Error (R41), and Poor material quality (R42) are unstable with a link to every factor and they impact themselves besides impacting other factors. PT practitioners must pay attention to these factors consistently. At the lower end of the ISM hierarchy model, there are five independent risk factors of PT projects i.e., Unclear and inadequate detail drawing (R22), Fragmented communication (R23), Compliance environment issues (R51), Compliance Labour Law (R52), and Industry regulations (R53) which are not dependent on other risk factors but they will drive the other factors if predisposed, which is also established by the past literature (Chai et al., 2011; Seo & Soh, 2019).

5. Implications, Limitations and Future Research

In examining the details of high-rise construction projects, this study employed a robust analytical framework, employing the described methods to identify and rank factors influencing project delays. The exploration of these factors not only contributes to the theoretical understanding of project delays but also holds practical implications for stakeholders involved in construction endeavors.

5.1 Theoretical Implications

This study enriches the existing body of knowledge on risk management in power transmission (PT) projects by providing a structured prioritization of contract risks through the Analytic Hierarchy Process (AHP). The prior studies (for example, Mills, 2001; El-Sayegh, 2008; Sadeghi et al., 2016) classify risks into broad categories, while the current analysis extends this by quantifying their relative importance. The financial risks are identified as the dominant concern, followed by execution, external, technical, and legal risks, refining the understanding of how contract-related uncertainties impact the PT project outcomes. The study also highlights the interplay between financial volatility and external environmental disruptions. It underscores that risk cannot be treated in isolation but as part of an interdependent system.

5.2 Practical Implications

The practical implications of our research results, enable the EPC professionals to evaluate the importance of risk factors in their projects, especially at the early stage of signing the contracts. The results provide a roadmap for prioritizing risk-mitigation resources. Contractors should embed robust price-variation clauses, and implement proactive claims-handling systems. The dominance of financial risks indicates the need for policy instruments, for example, transparent indices for material costs, dispute-resolution mechanisms to stabilize project execution. Also, the higher ranking of weather related risks calls for integration of climate resilience into infrastructure planning. The study also demonstrates the utility of AHP for risk prioritization and provides a basis for extended hybrid methodologies for more robust multicriteria decision-making in PT projects.

5.3 Research Limitations and Future Research

Despite its contributions, some limitations of the current study must be acknowledged. One, AHP weights were derived from expert judgements within a limited sample of practitioners familiar with Indian PT projects, thus findings may not be generalized to other geographical areas. Two, AHP provides a snapshot prioritization of risks but does not account for the dynamic shifts over the entire lifecycle of a project. For example, the legal risks may appear small during construction but become prominent during operations. It also introduced subjective biases. Third, the analysis treats risks as discrete elements whereas in reality, the risks such as financial volatility, weather impact and inefficiencies in execution ae interlinked.

These limitations give road map to future research directions also. Some of the future research questions include:

FRQ1-In what ways do risk priorities evolve across different phases of PT projects, from conceptualization to operations and how can dynamic risk models capture these shifts effectively?

FRQ2- To what extent do interdependencies among financial, execution, external, and technical risks increase or mitigate overall project risk in PT projects?

FRQ3- How do institutional, regulatory, and cultural contexts influence the relative importance of legal and compliance risks in PT projects in different setup, or comparing developing and developed nations?

6. Conclusions

Despite the fact that contract risks have been emphasized in EPC, but there are a few studies in existing body of knowledge to address the contract risks of power transmission projects in Indian environment. The PT (Transmission channel and Substation) projects characterize an active environment where many events are carried out concurrently as settled contracts between the contractors and the possessors. After briefing the research situation in India, the contract risks were identified and analyzed through a review of literature and face-to-face survey. This study investigated and prioritized contract risk factors in Power Transmission (PT) projects in India using the Analytic Hierarchy Process (AHP). On this basis, this study established that many contract risk factors are originated in PT projects. The study analyses the contract risk factors that are found in PT projects by ranking and developing a structural model. Ranking of contract risk factors is carried out using AHP and structural model was developed using ISM. The findings revealed that financial risks dominate the risk landscape (Ibrahim, 2024; Wanjari & Dobariya (2016). The results underscore that PT projects are highly susceptible to financial instability, environmental unpredictability, and managerial inefficiencies. This supported by existing literature emphasizing the predominance of cost escalation and external disruptions in large infrastructure projects (Ghatak & Garg, 2022; El-Sayegh, 2008). Conversely, the risks factors such as legal issues, design errors, and unstable governance were perceived as less significant which reflects the relative maturity of regulatory frameworks and institutional familiarity within the Indian PT context. This is evident from a well-established regulatory framework in India such as Central Electricity Regulatory Commission and Central Transmission Utility (Economic Laws Practice 2018). The study has been performed in dialogue with PT project practitioners and academic experts dealing in project management courses. Hence, derived results have real-world validity and serve as a foundation work to extrapolate the contract risk factors with wider application.

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Conflict of Interest

The authors declare that they have no competing interests, or other interests that might be perceived to influence the results and/or discussion reported in this paper

Data Availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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.

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