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Research on Key Risk Factors and Risk Transmission Path of Procurement in International Engineering Procurement Construction Project

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Abstract: As the core link of Engineering Procurement Construction (EPC) projects, procurement involves a huge amount of money and has a wide range of influence. Once the procurement risks of EPC projects occur, it is easy to cause a domino effect, which can have a huge impact on the cost, schedule and quality of the construction project. Therefore, this paper took international EPC projects as the research object, identifying 25 risk factors related to procurement through case analysis, literature analysis and expert interviews. Integrated Interpretative Structural Modelling (ISM) and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) method was used to establish the interrelationships between risk factors. Based on the results, procurement risk transmission paths for international EPC projects are developed, and key risk factors are found. Moreover, corresponding risk management suggestions are put forward. The research results impel contractors of the international EPC projects to pay close attention to the key risk factors in the project procurement process. After recognizing the risk transfer path, contractors can take measures to avoid risk to reduce the possibility of project failure as soon as possible. This research can provide support for managing procurement risk in the international EPC project.

Keywords: international EPC projects; procurement risk; key risk factors; risk transmission path; ISM; MICMAC

1. Introduction

Research on EPC project risk management has a long tradition. From a macro perspective, systematic research on risk identification, evaluation and response for EPC projects has been carried out, and various research results have been influential in risk management for construction projects. At present, the owner structure in the international construction market has undergone major changes, with a large influx of new owners represented by private capital and investment funds and more emphasis on intensive management, so the contracting projects are more large-scale, and EPC projects with a total investment of more than 1 billion US dollars have increased significantly. Procurement is the core link of EPC projects [1]. The procurement cost of international EPC projects can account for 40–60% of the total investment, which has a very large impact on project cost, schedule and quality [2]. Since the large-scale trend of international EPC projects makes the amount involved in procurement increasingly extensive, the management of procurement risks is more urgent. International EPC project procurement involves many types of materials and equipment. As a result, the standards and processes are complex. There are many variables in the procurement process, and it is affected by policies, laws, natural climate, social environment and other aspects. Consequently, contractors face significant procurement risks.
The PMBOK Guide [3] defines a project risk as “an uncertain event or condition that, if it occurs, has a positive or negative effect on at least one project objective”. Engineering procurement means the complete process that the construction of a project needs to propose a procurement plan, select a suitable supplier, sign a purchase contract, receive goods and services, and complete payment according to the contract. The procurement risk studied in this paper refers to some unexpected situations that may occur in the complete procurement process, which may affect the achievement of the procurement purpose, mainly referring to the negative impact on the project.

Too little work has been devoted to the procurement risks of international EPC construction projects. Existing research recognizes the critical role played by procurement risks. Kim et al. analyzed the risk factors of overseas factory projects and found that three major risk factors, including material procurement delay, major equipment price changes and major equipment delivery delays, have an important impact on cost and schedule in the procurement stage [4]. However, the procurement risks identified in the study are incomplete. In terms of procurement risk evaluation, some scholars have used the risk matrix model, AHP method as well as fuzzy comprehensive judgment method to study the evaluation index system and evaluation method of procurement risk for the EPC project [5,6]. Expanding the research field to include procurement management, It is not difficult to find that procurement management is more concerned than procurement risk. Zhang et al. [7] made an integration and reconstruction of every part of EPC project procurement through adding supply management mode and building supply chain procurement management mode of EPC project which is proper for now and future development. In the process of studying procurement management in foreign-funded construction projects, 16 key procurement issues were revealed, and strategies were proposed to overcome the procurement issues [8]. Limited research indicates that procurement management aims to avoid procurement issues and improve procurement efficiency. Considering the contradiction between the fragmentation of procurement activities and the integration advantages of the EPC model, some scholars introduced the concept of supply chain integration into the procurement of EPC projects [9,10], which can effectively help to avoid some procurement risks and improve procurement performance. Advanced procurement management models can help contractors deal with procurement risks, and theories related to supply chain management were introduced into research on procurement risk management. The establishment of an advanced material procurement organization model for the project, such as the supply chain integration model, can improve procurement efficiency [11]. Conflicts between contractors, owners and suppliers can be naturally resolved if procurement players cooperate with each other and seek the maximum of the group benefit under the individual rationality constraint, and every player can obtain more benefits than before [12].

With further study into EPC project risk, scholars have begun to conduct systematic research on EPC project risks in subdivided fields, such as quality risk, cost risk, owner risk, supplier risk, schedule risk, etc. of EPC projects. However, procurement risk is neglected, and systematic research on procurement risk identification, transmission and management are very lacking. In the existing research on risk management of EPC projects, procurement risk has rarely been studied directly, and has often only been identified as one or several risk factors among all risk factors. Generally, procurement risk is only mentioned in many risk factors when conducting risk identification and evaluation. In particular, no study, to our knowledge, has focused on it as a single research object in EPC construction projects. Existing research on procurement management of engineering projects has emphasized the threat of procurement issues to the achievement of project objectives, but it is also worth further studying how procurement risk prevents the achievement of project objectives.

With the large-scale trend of EPC projects, the importance of procurement risk in EPC project risk management is increasing day by day. During the implementation of international EPC projects, the interaction between various risks affects each other,
which brings difficulties to risk management. Unclear research about risk transmission mechanisms can easily lead to the dynamic evolution of low-risk events in complex construction projects into high-risk major events, bringing huge losses to the entire project [13]. Therefore, it is necessary to study the transfer process between risk nodes. At the same time, according to the large proportion of funds occupied by procurement in the total investment, it is necessary to systematically study the procurement risk of EPC projects as the research object.

In order to provide a theoretical basis and methodological guidance for EPC project procurement risk management, the research takes the international EPC project procurement risk as the research object, aiming to clarify the procurement risk transfer path of international EPC construction projects and make the relationships between procurement risks clear. This paper systematically studies risk factors of the procurement for international EPC projects, and then analyzes the relationships between risk factors and the transfer path of the procurement risk for international EPC projects. From the contractor’s point of view, suggestions responding to procurement risk in international EPC projects are proposed. This paper provides a theoretical basis and reference suggestions for relevant enterprises in the industry to carry out procurement risk management for international EPC projects.

2. Literature Review

The general contracting method, such as Engineering–Procurement–Construction (EPC), has been commonly adopted in international construction markets [14,15]. EPC has advantages over the traditional Design-Bid-Build (DBB) method of achieving clients’ expectations of reduced financial uncertainty, improved productivity, and reduced disputes, in addition to expanding contractors’ potential profitability [16,17]. However, as the single entity responsible for the delivery of international EPC project, contractors are responsible for the whole execution of the EPC project and bear enormous risks transferred from clients at each stage from bidding to maintenance, related to both project activities and the complex international environment [15,18–22]. Insufficient risk prediction often leads to a significant loss to the project and the contractor’s project damage increases in proportion to the size of the project [23]. Therefore, research on risk management in Engineering–Procurement–Construction (EPC) projects has received increasing attention [24]. In PMBOK, which is formulated by the Project Management Institute (PMI), the risk management process is divided into six parts: risk planning, risk identification, qualitative risk analysis, quantitative risk analysis, risk response plan, and risk monitoring [25]. The risk management theory of “understanding the potential risks of the project, preventing them in advance, and taking effective measures in a timely manner” is undoubtedly the prerequisite for good performance in international EPC projects [26].

The EPC project risk identification and analysis are the basis for subsequent risk management and EPC project management [27,28]. The identification of risk factors that cause a negative effect on the success of EPC projects can help develop strategic responses to risks and enhance the chances of project success [29]. The most commonly used risk identification methods are literature research, expert interview and case analysis. Limited studies have systematically identified various risks of international EPC projects, which can be divided into external risks and internal risks. These risks come from the natural environment, social environment, owners, subcontractors, suppliers and other stakeholders [29]. Risk assessment is a controversial issue, but it is considered the most valuable part of the risk management process [30,31]. Analytic Hierarchy Process (AHP) and fuzzy comprehensive evaluation are the most commonly used methods for risk evaluation. Zhao et al. [32] established the risk identification system based on the gray whitening weight function and adopted the fuzzy comprehensive evaluation method to evaluate the construction risk of the EPC project led by the design enterprise. Yang et al. [33] employed the AHP method and fuzzy comprehensive evaluation meth-
od to evaluate the risk of international EPC projects. Wu and Zhou [34] identified 11 critical risk factors (CRFs) based on the literature review and 4-dimensional risk analysis to compose the risk assessment index system and used extended fuzzy synthetic evaluation method to conduct risk assessment. The level of completeness of risk identification and accuracy of risk assessments determined the reliability of risk management practice [35].

It is a challenging task to properly manage risks in international EPC projects [15,22]. The high uncertainties of the international markets and the complicated EPC processes make it unrealistic for the contractors to manage project risks only relying on their own capability [35,36]. Previous literature has shown that the process of risk management mainly relies on the sufficiency of information [37]. Coherent information is particularly important to enhance the systematic and proactive efforts for early warning, effective negotiation, and timely problem resolution [38,39]. Contractors can establish partnership relationships with other participants to facilitate open communication for integration of the necessary information efficiently [24]. Many researchers have advocated the partnering strategy for effective risk management by cooperating with the involved participants with win-win value [40–44]. Effective management of the overall EPC project risk relies on contractors’ competent capabilities and maximizing the resources of stakeholders by partnering [45]. By partnering, various participants contribute their valued resources and collaboratively solve risk issues in terms of trust, teamwork, and joint problem resolution [46–48]. Partnering can not only directly enhance EPC risk management, but also improve the effect of risk management through enhancing contractor capabilities [49]. Thus, it is crucial for EPC contractors to develop partnering relationships with project participants and aim to facilitate integrated risk management processes by incorporating external information derived from the partners [50,51].

To manage risks in international EPC project delivery, it is essential for contractors to possess the competent capability to systematically identify risks, assess their impacts, and seek feasible resolutions [26]. An effective risk management plan helps contractors to avoid and spread risks effectively and improve international competitiveness [52]. Computerized systems have been widely proposed in the construction industry as effective aids to proactively control the potential risks and to monitor continuously their status and variation [53]. Yoo et al. [53] developed a computer-based risk management system for NPP projects called Nuclear Risk Management System (NuRMS), which is expected to assist a project manager in monitoring, tracking, and controlling potential impacts of risk events during the overall implementation of NPP projects. In line with the fourth industrial revolution, the demand for engineering project management solutions to apply artificial intelligence (AI) in big data technology is increasing [54]. Su et al. [18] developed a digital EPC contract risk analysis tool for contractors, using artificial intelligence (AI) and text-mining techniques. Lee et al. [55] developed an Invitation to Bidder (ITB) risk management model to analyze risk factors in the bidding stage by applying Watson AI to prevent cost overruns of EPC projects. So-won et al. [54] developed a cloud-based integrated analysis tool applied with big data and AI/ML technology to conduct risk analysis in the bidding, engineering, construction, and OM stages of EPC projects. The successful application of AI/ML technology in EPC field can reduce the potential risk for contractors [18].

After the risks of EPC projects have been fully recognized from a macro perspective, scholars began to conduct more detailed classification research on the risks of EPC projects. EPC projects are faced with huge risks in cost and schedule due to their complex process, numerous subcontractors, long construction period and fixed-price contract [27,49,56–59]. Yin and Li [27] identified cost risks of metallurgical EPC projects, and a risk breakdown structure table was formed. Liu et al. [60] established a risk index system by documentary method, and the cost risk in two different environments at home and abroad was evaluated by hierarchical analysis. Jung [61] identified schedule risks for EPC projects and created a way to prioritize schedule risks. In particular, a project
owner who orders a project sometimes tends to transfer project risk to the contractors by utilizing the characteristics of the EPC project in which the contractor is responsible for project execution, so the risks from the owner gradually become the most challenging issue of many risk factors in the process of project construction [23,62,63]. Gao and Ding [63] identified and measured the risk factors from the owner and put forward countermeasures to provide a scientific risk management basis for the EPC project.

The EPC projects produce a complex final product from a variety of items that are procured externally from suppliers and their costs comprise a major percentage of project cost [64–66]. Therefore, an EPC project requires multiple items from multiple suppliers under multiple contracts, terms and conditions and risks exposure [67]. In order to solve management problems of the EPC projects, the construction industry began to introduce supply chain management ideas, theories and methods [68]. The increasing complexity of construction technology and the risks are facing an overwhelming and fragile supply chain [69]. Only 1 in 1000 large-scale projects is successful [70]. Ke and Xu [68] identified the general contracting EPC supply chain risk and built the comprehensive risk management framework for the general contracting EPC supply chain. Based on the deep analysis of supply chain operation reference (SCOR) model, which is widely used in various fields of industry, this article put forward the preliminary index system of supply chain risk of EPC project by analytic hierarchy process (AHP) [69]. Traditional SCRM methods are not simply transferable to the specific setting of large-scale projects, and the contextualized SCRM taxonomy offers a systematic and structured view on the key supply chain risks in EPC large-scale projects [71–74]. Rudolf and Spinler [74] identified the specific supply chain risk portfolio of large-scale EPC projects. The concept of supply chain integration is also introduced into the procurement of EPC projects, which can effectively avoid some procurement risks and improve procurement performance [9,10].

Procurement is an overlapping function between engineering and construction phases of engineering procurement and construction (EPC) projects. Due to these overlaps, procurement risks may have a cascading effect on project cost and schedule overruns [67]. The widely used method in China is to conduct an empirical analysis to accurately evaluate the procurement risk of the EPC model [75]. Procurement of raw materials was considered one of the five most influential international steel project risks [76]. Vijaya [67] considered six prominent procurement-related risks. Delay in receipt of items (DR) risk, late delivery of materials risk, disruption in communication (DIC) risk and funding problem (FP) risk negatively affect the project schedule [77–82]. Failure to realize technology and requirements (FRTR) risk impacts project quality and customer satisfaction [64,77]. In order to reduce the impact of risks related to procurement on schedule, cost and quality, measures, such as exchange rate risk transfer, adding price adjustment and exit mechanism clauses to contracts, as well as strengthening supervision of equipment manufacturers and equipment manufacturing processes are worthy of reference [52]. To improve material and procurement management, Jo et al. [57] used the Critical Chain Project Management (CCPM) to develop a piping construction delay prevention methodology, incorporating material procurement processes for EPC mega-projects.

Since construction phase activities consume the largest portion of the project budget and time, most of the previous studies concentrated solely on the performance of construction phase, while the performance of engineering and procurement phases received the least attention. However, the schedule and cost performance of procurement phase can be highly affected by “resource shortage” and “price fluctuation”, respectively [59]. Muneeswaran et al. [78] identified poor procurement system as an important reason for delays in construction industry context. Procurement risk was identified as an important category of a project’s risk profile [83]. A number of researchers have identified procurement as a major area of constraint and opportunity, which can be exploited to improve the overall project performance [65,66,84,85]. Thus, management of procurement
risk is important to ensure the availability of the right item at the right time for the right activity and to avoid any detrimental effect on the success of the project [67]. However, procurement risk has rarely been studied directly. De Araujo et al. [85], through a structured literature review on project procurement management, revealed that only 0.4% of articles cited risks as a factor during decision making. In addition, no study to date has examined the risk transfer path of EPC projects. Evidently, more in-depth research needs to be implemented in the area of procurement risk for international EPC projects.

3. Materials and Methods

Aiming to identify the relationships between procurement risk factors of the international EPC project, the ISM approach was employed to identify and classify relationships between variables. This methodology involves three steps [86]: (1) identification of risk factors related to risk factors through case study, literature study and expert interviews; this generated a risk list; (2) elaboration of the structural model; and (3) MICMAC development with a cluster diagram showing the factors’ driver and dependence power. The following flowchart describes these steps, as summarized in Figure 1.

![Figure 1. Research flowchart.](image)

3.1. Multi-Cases Study, Literature Research and Expert Interview

Aiming to identify risk factors, a number of EPC projects were selected. The selection principles were as follows: (1) Select failure cases where contracts cannot be performed, representative EPC projects that successfully performed contracts but suffered huge losses, and other projects that encountered major problems in the procurement of EPC projects. (2) The case information was complete and reliable. (3) The location distribution of the cases was as comprehensive as possible, involving Africa, Latin America, the Middle East, and other regions of the world. (4) The types of construction projects should be as comprehensive as possible, including not only infrastructure projects such as rail transit and highways, but also industrial construction projects such as sugar factories and cement factories. In the end, a total of 5 international EPC projects were selected from 2008 to 2015, namely the Mecca Light Rail Project in Saudi Arabia, the A2 Expressway Project in Poland, the Guyana East–West Road Project, the Riyadh Cement Compa-
ny Phase II Project in Saudi Arabia (RCC Project) and Bolivia San Buenaventura Sugar Factory Project (EASBA Sugar Factory Project).

After risk factors were synthesized from multiple cases, risk factors were further screened. The literature research method was used to further screen for risk factors. The purpose of using the literature research method was to improve the reliability of risk factor identification and to verify whether theoretical saturation was reached. Risk factors that appeared less than five times in the literature were eliminated. No new risk factors appeared in 10 consecutive papers, indicating theoretical saturation was reached. To re-assure the reliability of risk factor identification, experts were invited to review the risk factor list. Experts in the field of risk management were asked for their opinions on the list of risk factors. There is no consensus in the literature regarding the number of experts to be consulted for satisfactory execution of the method, and it was suggested to select at least eight experts [86,87]. To increase the group’s heterogeneity, one way is to select experts from academia and practice [88,89]. Therefore, in this study, three experts from academia and 10 experienced managers were interviewed.

3.2. Interpretative Structural Modelling (ISM) Methodology

Interpretive structural modeling (ISM), proposed by Warfield in 1973, is a well-established methodology for identifying relationships among specific items, which defines a problem or an issue [90]. In this technique, a set of different directly and indirectly related elements are structured into a comprehensive systematic model [91,92]. For any complex problem under consideration, a number of factors may be related to an issue or problem, and ISM develops insights into collective understandings of the direct and indirect relationships, which describe the situation far more accurately than the individual factor taken into isolation [89]. Mathiyazhagan et al. [93] used ISM qualitative analysis to understand the mutual influences amongst the twenty-six barriers by survey. Jung et al. [94] leveraged ISM to analyze the relationships between 20 CSFs for OSC to derive a hierarchical model consisting of seven levels. In this study, ISM is employed to understand the direct and indirect relationships between the risk factors related to the procurement of EPC project.

Having decided on the element set and the contextual relation, a structural self-interaction matrix (SSIM) is developed based on pairwise comparison of variables [89]. In previous studies, data from experts were collected to analyze the direct relationship between the variables by constructing an SSIM. Experts were asked to use four symbols (V, A, O, X) to describe the relationship between the variables in an upper triangular matrix [86,93]. However, in this study, another description is adopted. Experts need to fill in a matrix of order 25, obeying the following rules:

- If factor $S_i$ directly leads to factor $S_j$, then $A(S_i, S_j) = 1$, otherwise $A(S_i, S_j) = 0$; If factor $S_j$ directly leads to factor $S_i$, then $A(S_j, S_i) = 1$, otherwise $A(S_j, S_i) = 0$.

Previous research did not stipulate the lower limit of the number of experts required for the investigation. This study referred to the research of Lyer and Sagheer [87] and invited four experts with rich scientific research or practical experience in the field of risk management in the international construction project. Calculating the average of the comparison between two elements, the average value of 0 or 1 indicated that the expert opinion on the relationship between the two factors is highly consistent. The average value between 0 and 1 indicated that experts disagree on the relationship between the two factors. In order to reach a consensus among experts, the Delphi method can be used to continue the investigation. Ask the experts to revise their answers for two factors with an average value between 0 and 1. After repeating two rounds of the Delphi survey, if there is still an average result between 0 and 1, please refer to the study of Wang et al. [95]. The absolute majority of experts believe that the factor $S_i$ directly causes the factor $S_j$, then, they think that the factor $S_i$ has a direct impact on the factor $S_j$. That is, the average value is equal to 0.75, then $A(S_i, S_j) = 1$, otherwise $A(S_i, S_j) = 0$. Finally, the adjacency matrix can be produced.
From the adjacency matrix, a reachability matrix was built, which is the basis for building the structural model [86]. The reachability matrix is a matrix that expresses the direct or indirect relationship between elements [87]. It can be obtained by adding the adjacency matrix and the identity matrix through certain Boolean operations, and the matrix calculation is performed until the equation establishes: 

\[(A + I)^{n+1} = (A + I)^n \neq (A + I)^{n-1}\] (I is the identity matrix) [96]. In this study, after six times of iterative calculation through Excel, the reachability matrix is generated.

In order to obtain the hierarchical structure of risk factors, the reachability matrix is decomposed, and the reachable set and the antecedent set of each factor are obtained, respectively. The reachable set of given variables include the variable itself and the other variables it influences, and the antecedent set for given variables consist of the variable itself and the other variables that influence it. The reachable and antecedent sets can be written as shown in Equations (1) and (2). The intersection set is constructed using Equation (3):

\[R(S_t) = \{j \in S/e_{ij} = 1\}\] (1)
\[A(S_t) = \{j \in S/e_{ji} = 1\}\] (2)
\[M(S_t) = R(i) \cap A(i)\] (3)

After the hierarchical division is completed. The variable for which the accessibility and intersection sets are the same becomes the maximum level variable in the ISM hierarchy. Variables identified in Level I are discarded from the set of other variables. The process continues until the level of all variables is found. Finally, the ISM model is constructed according to the level of all variables. The implementation steps of the ISM method are as follows:

- Identify risk factors for international EPC project procurement;
- Determining “influential to” relationships between risk factors—invite experienced experts to complete SSIMs (one for each expert);
- Constructing the adjacency matrix according to data from SSIMs;
- Calculate the reachability matrix;
- Carry on hierarchical division;
- Build the ISM model.

3.3. Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) Methodology

As a forecasting method created by Michel Godet, MICMAC is a structural analysis tool used to structure ideas [97]. The MICMAC analysis is used to classify and validate the factors obtained from ISM to obtain results and draw conclusions [98]. Therefore, ISM and MICMAC are often used in combination to complete relationship analysis for hierarchical structure and strength. Ramos et al. [99] utilized ISM and MICMAC to identify and understand relationships between risk types in agri-food supply chain. Janssen et al. [100] used an integrated ISM–MICMAC approach to analyze the dynamics of interactions of challenges for adopting and implementing IoT in smart cities.

On the basis of ISM, the MICMAC analysis method can expand the research of ISM and can be used to analyze the driving force and dependence between risk factors. Based on the reachability matrix, dependency and driving power can be calculated. The driving power is measured by the total number of variables that a certain variable can influence, which can be given by summing the matrix line. The dependency power is the total of variables that influence a certain variable, which can be given by summing the matrix column. Subsequently, a cluster diagram is developed to show driving power and dependency power.
4. Results

4.1. List of Risk Factors

In order to identify risk factors, five eligible cases were selected to collect risk factors. At the same time, 20 papers [101–120] were used to screen out risk factors with a frequency of more than 20% and help to reach theoretical saturation. After experts and experienced managers checked the preliminary list of risk factors and gave some suggestions, the final list of risk factors was produced. Combined with experts’ opinions, the final list of risk factors is shown in Table 1, including 25 factors, which constitute the risk factor set \( S = \{ S_1, S_2, \ldots, S_{25} \} \).

| Key Risk Factor | Literature Number | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | Frequency |
|-----------------|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| S\(_1\) Exchange Rate Fluctuations | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 15 |
| S\(_2\) Political Situation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 14 |
| S\(_3\) Inflation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 13 |
| S\(_4\) Sociocultural Factors | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 13 |
| S\(_5\) Local labor supply situation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 13 |
| S\(_6\) Natural Environment | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 13 |
| S\(_7\) Market supply of local materials and equipment | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 13 |
| S\(_8\) Design Changes | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 13 |
| S\(_9\) Design, Procurement and Construction Interface Management | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 13 |
| S\(_10\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 12 |
| S\(_11\) Legal Policies and Institutions | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 12 |
| S\(_12\) Applicable Standards | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_13\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_14\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_15\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_16\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_17\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_18\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_19\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_20\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_21\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_22\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_23\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_24\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |
| S\(_25\) Goods Clearance and Transportation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 |

Table 1. List of risk factors.
4.2. ISM Results

After four SSIMs were developed, the adjacency matrix is shown in Figure 2. After six times of iterative calculation through Excel, the reachability matrix is produced, as shown in Figure 3, and the level partition is shown in Table 2.

![Adjacency matrix A.](image1)

![Reachability Matrix M.](image2)
For each factor, if the intersection M (S_i) is equal to the reachable set R (S_i), the factor is singled out and becomes the maximum level variable in the ISM hierarchy. As shown in Table 2, M (S_i) and R (S_i) of factors S_{14}, S_{17}, S_{19}, S_{22}, and S_{24} are equal. Therefore, factors S_{14}, S_{17}, S_{19}, S_{22}, and S_{24} are regarded as Level 1 factors of the model structure. Similarly, the level of all factors is found, and the model is constructed. In the process of model construction, we found that the reachable sets and antecedent sets of the sixth-level factors S_3, S_5, S_{12}, and S_{16} are very similar. The four factors S_3, S_5, S_{12}, and S_{16} can be regarded as a whole; that is, the macro social and cultural environment.

Each risk factor is regarded as a node. According to the hierarchical division result, an arrow pointing from i to j is drawn if there is a relationship between factor i and j. Additionally, the connections between factors are shown in the diagram; that is, the ISM model as shown in Figure 4.
4.3. MICMAC Results

After obtaining the ISM model, the MICMAC method is applied to analyze the relationship strength of risk factors, so as to provide more targeted suggestions for the prevention of procurement risks in international EPC projects. Collecting the data of the driving power and dependency power of each risk factor based on the reachability matrix, the cluster diagram is developed as shown in Figure 5. A total of 25 factors are divided into four groups, which are independent group, linkage group, autonomous group and dependent group.

4.4. Risk Transmission Path of Procurement for International EPC Projects

Through the analysis of the ISM model of procurement risk factors, four risk transmission chains are obtained as shown in Figure 6, including macro social and cultural environment risk transfer chain, natural environment risk transfer chain, quality of purchasing managers risk transfer chain, and exchange control risk transfer chain.
Figure 6. Procurement risk transfer path.

A total of 51 risk transmission chains have been formed, including 21 macro social and cultural environment risk transmission chains, 15 natural environment risk transmission chains, 14 procurement management personnel quality risk transmission chains and one foreign exchange control risk transmission chain.

5. Discussion

From the above research, it has been found that there are many factors that can affect the schedule, cost and quality of international EPC projects through activities with regard to procurement, and there are complex relationships among these factors. If managers from EPC units can clearly understand the complex relationship among these risk factors and take some measures to cut off the risk transfer path in a targeted manner, it will be beneficial to the advancement of international EPC projects.

According to the comprehensive analysis of Figures 3–6, it can be concluded that:

- Risk factors can be divided into surface risk factors, middle risk factors and deep risk factors according to the ISM model. Additionally, the locations of factors are related to the relationship strength.
• Factors located in the Level 6 of the ISM model belong to deep risk factors, which are imperceptible risk factors that subtly affect surface risk factors and they usually have a strong driving force.
• Factors belonging to Level 1–2 of ISM are surface risk factors with higher dependency, which are obvious risk factors in international EPC projects and direct factors that can be affected by middle risk factors.
• Level 3–5 of the ISM model are middle risk factors, which play a mediating and transmitting role in the risk transfer path.

Surface risk factors include Changes in the Price of materials and equipment (S14), Quality control of materials and equipment (S17), Supplier performance capability (S19), Design, procurement, and construction interface management (S32) and Supplier coordination and management (S44). These five risk factors belong to the dependent group, with strong dependence and weak driving force, indicating that these five risk factors are caused by the stock risks accumulated in the process of project advancement, usually at the end of the risk chain. Therefore, they are easily noticed by managers. Moreover, there is a strong mutual relationship between quality control of materials and equipment (S17) and supplier performance capability (S19), which is in line with the findings of Song and Hao [52]. They pointed out that strengthening the qualification evaluation of suppliers could help to ensure satisfying material quality.

Once the surface risk factor occurs, it will have a greater direct impact on the schedule, cost, or quality of the project. For example, natural environment affects (S7) goods clearance and transportation (S36), which affects design, procurement and construction interface management (S32), and ultimately leads to delays in the project schedule. This is a typical risk chain. Design, procurement and construction interface management (S32) are the most superficial risk. It is also the first risk factor that managers pay attention to when carrying out risk management, but the deepest risk factor is the natural environment. In order to cut off the risk chain and avoid the occurrence of risks, it is crucial for managers to pay attention to deep-level risk factors.

Deep risk factors can be divided into two categories, one is controllable risk factors that can be expected and eliminated, including quality of purchasing managers (S15) and information control capability (S18), and the other is uncontrollable risk factors brought by force majeure, including natural environment (S7), government intervention (S30), legal policy and institution (S4), sociocultural factors (S4), political situation (S32), and international relations (S36). These eight risk factors belong to independent groups with a strong driving force and weak dependence, which can be regarded as the original risk of international EPC project procurement. Once these risks occur, although they will not have a direct negative impact on the project, they may lead to the formation of “risk chains” . Therefore, managers should grasp and pay attention to original risks when carrying out procurement risk management and can refer to the ISM model for bottom-up risk management and control.

Among eight original risk factors, legal policies and institutions (S4), sociocultural factors (S4), political situation (S32), and international relations (S36), which are located in Level 6 of the ISM model, have strong connections, indicating that these risk factors all affect each other in the macro social environment. Once the risk of one aspect occurs, it is easy to trigger the “butterfly effect”. In addition, in this study, the two risk factors, natural environment (S7) and quality of purchasing managers (S15), have the lowest dependence value, indicating that they are scarcely affected by other factors and are difficult to control. Therefore, it is suggested that measures should be taken to avoid the risk as far as possible.

Furthermore, among 51 risk transmission paths, the original risks of 50 risk transmission paths are risk factors belonging to the independent group in the cluster diagram, including natural environment (S7), legal policy and institution (S4), sociocultural factors (S4), political situation (S32), international relations (S36), and quality of purchasing managers (S15), which are deep risk factors with high driving force. Therefore, these risk
factors are the key risk factors worthy of attention in the risk management of EPC projects. In previous studies, risk factors, except quality of purchasing managers (S15), has been directly paid close attention to. In this study, quality of purchasing managers (S15) was found to be a crucial risk factor. Wang et al. [36] emphasized improving contractor capabilities can facilitate risk management. Perhaps this finding can provide some support for their opinion.

The middle-level risk factors are all located in the autonomous group except for the Purchasing process (S23), which is located in the dependent group. Middle risk factors are located in the middle of the risk transfer chain and play a linking role in the process of risk propagation. Compared with deep risk factors, their driving force is lower, and their dependence is higher. When managers conduct procurement risk management, they should pay special attention to five risk factors, such as contract clause research and execution (S8), applicable standard (S9), design changes (S11), owner appointed equipment supplier (S20), and design initiative (S25), which are located in the marginal area near the linkage group in Figure 5, where the dependency value and the driving force value are relatively high. If these risks occur, the possibility that the project is adversely affected is greatly increased. In addition, it is worth noting that there is a strong connection between the two risk factors of exchange rate fluctuation (S1) and exchange control (S13). Once the exchange rate fluctuates, the government in the project location is likely to control exchange to carry out macro-control. When operating the procurement risk, it is important to pay attention to the relationship between these two risk factors to avoid the growth of project cost caused by exchange rate fluctuations.

6. Recommendations

In this paper, the ISM and MICMAC method are used to systematically analyze the procurement risk factors for international EPC projects. The results show that the procurement risk factors of international EPC projects have a wide range of sources, and the risk factors can affect each other. Combined with the analysis of the ISM model and the relationship strength among factors, the following suggestions are put forward from the perspective of the general contractor for the international EPC project.

1. Pay attention to the analysis of the macro environment, actively respond to the risks brought by the macro environment, and appropriately adopt measures to avoid risks.

In the country where the project is located, the natural environment, economic environment, social culture, legal policy and system, political situation, etc. are all potential procurement risk factors, and they are deep-level risk factors that may lead to a series of other risks. Risk managers should have a comprehensive understanding of the macro environment in the project location in the early stage of the project, and always pay attention during the progress of the project, keeping a high degree of sensitivity to relevant information. In project locations with a harsh natural environment, frequent social and cultural conflicts and a relatively tense political situation, the imported materials and equipment should be delivered as low-risk logistics as possible. Additionally, it is advisable to purchase commercial insurance for the purchased materials in the warehouse to avoid risks. If the currency of the country where the project is located is not strong, it is necessary to reduce the proportion of the owner’s payment in the local currency, or include the losses caused by exchange rate fluctuations into the contract to avoid the risk from exchange rate fluctuations. If contractors enter a new contracting market for the first time, it is efficient to cooperate with a consultancy experienced in risk management of international EPC projects.

2. Select high-quality and capable procurement management and risk management personnel to enhance the contractor’s own capabilities.

An excellent procurement management team consist of a group of high-quality and capable personnel responsible for procurement management and risk management. A
procurement management team with excellent ability in information control, quality management and supplier management can reasonably predict possible future events and risks and can take appropriate measures to transfer and avoid risks, and even take advantage of risks to profit. It is suggested that the general contractor of an international EPC project should select splendid personnel qualified for procurement management and risk management to form a risk management team, which can help to avoid adverse effects on the schedule, cost and quality of the project due to the situation, such as inaccurate information control, poor communication with relevant parties, inadequate research on contract terms, unqualified quality of purchased materials and equipment and so on, which are caused by insufficient managerial quality and ability.

3. Strengthen communication with owners and attach importance to the management of suppliers.

The owners and suppliers are the core stakeholders of procurement for international EPC projects. Some procurement risks come directly from the owners and suppliers. If the owners and suppliers can be managed from a system perspective, the risks from them can be controlled at the source. There are many equipment and materials in international EPC projects. The source of suppliers is complex, and the supply cycle is long. The lack of strict control of the time and quality in supplying will lead to increased costs and even loss of reputation for contractors. Therefore, it is suggested that the contractor should conduct a strict qualification review on the supplier to ensure the strength and credit of the supplier. At the same time, it is necessary to restrict the contractor’s behavior by clarifying the contract terms and increasing the cost for breaking the contract. In addition, the owner may designate suppliers of some equipment or applicable standards in the main contract. In this regard, the contractor should strengthen communication with the owner and minimize the situation where the owner specifies a supplier. At the same time, the contractor can also appropriately introduce the suppliers with whom he often cooperates to the owner, so as to have more purchasing initiative. If it is unavoidable of the owner to designate a supplier, the contractor shall specify the consequences of such events as procurement delay and cost increase caused by the owner’s designation of the supplier in the main contract terms, so as to avoid the situation where the supplier sits on the ground and raises the price and fails to perform the contract conscientiously, which results in great losses to contractors.

7. Conclusions

The COVID-19 pandemic has brought about major changes in the international political and economic situation. Complex international relations, frequent wars and regional conflicts have brought greater challenges to the risk management of international construction projects. First of all, the sudden pandemic has had an unprecedented impact on and posed a significant challenge to the international engineering supply chain. The flow of people, logistics, capital, and information is seriously blocked. Consequently, the supply chain is disordered, inefficient, or even broken, causing project shutdowns and production shutdowns. Secondly, procurement has become more and more difficult. International inflation is at a high level; the epidemic and war have kept commodity prices high, and exchange rate fluctuations have had a huge adverse impact on project costs. At the same time, the supply of shipping containers is in short supply, which not only increases the cost of the project, but also brings trouble to cross-border procurement and transportation. In addition, political turmoil, terrorist attacks, wars and armed conflicts frequently occur, which threaten the personal safety of employees who implement projects overseas and normal operation of assets. All of the above bring huge risks to the international construction project. Therefore, more in-depth and targeted research is needed in the field of risk management of international construction projects in the post-epidemic era. Researchers and managers should pay attention to the huge risks
that epidemics and wars bring to procurement and security of international construction projects.

The complexity of the international EPC project leads to numerous procurement risk factors, and there is complex interaction between the procurement risk factors. Under the EPC model, the contractor is solely responsible for the design, procurement and construction of engineering projects. Therefore, the contractor faces greater risks. At present, the lack of awareness of the procurement risks for international EPC projects leads to the inability of the contractors to scientifically and effectively control the procurement risks. From the perspective of general contractors, this study systematically analyzes the procurement risks of international EPC projects based on integrated ISM and MICMAC and has a clear understanding of the relationship between these risk factors. The main contribution of this study is to identify 25 risk factors related to procurement in international EPC projects and prevent, and to demonstrate direct and indirect relationships between procurement risk factors. The integrated ISM and MICMAC method provides a new idea for the study of key risk factors and risk transmission paths. In this study, the hierarchical structure of the ISM model helps determine the procurement risk transfer path, and the risk transfer process becomes clear. Consequently, it becomes possible to find potential risk factors leading to adverse outcomes. Combined with the analysis results of MICMAC, it is further determined that the social macro environment (S3, S4, S12, S16), natural environment (S7) and quality of purchasing managers (S15) are the deep risk factors with a strong driving force. Therefore, keeping a close eye on them as key risk factors can provide great support for effective risk management.

Professional managers can benefit from this study, since it was possible to understand how risk factors related to procurement affect project objectives for quality, schedule and cost. The key risk factors identified in this study are consistent with the realities faced by current practical construction projects. The complex international social environment and the COVID-19 epidemic have caused huge losses to international construction projects, and there the huge difficulties faced by the procurement of materials and equipment. In this case, qualified managers with excellent ability can provide support for problem-solving, while managers with insufficient ability can make the situation more complex for the project. In this sense, the applicability of this research serves as a guideline for solving the substantive issues. Some measures provided in the study to deal with procurement risk are valuable for the current procurement risk management in the international construction project. At the same time, the integrated method of ISM and MICMAC can also be effectively applied in the risk management of international construction projects.

There are some limitations to this research. First, the area covered by the selected five cases is not broad enough, mainly concentrated in West Asia and South America, which may make some risks with regional characteristics to be ignored. Differences in the environment can lead to differences in the risks of construction projects. If it is not possible to cover all the regions of the world that are keen on construction, it is suggested that future research can conduct targeted research on risk management of construction projects for specific regions. Secondly, due to the difficulty in obtaining accurate data, this study is biased towards qualitative research. As a result, the importance of risk cannot be measured with intuitive data. The relationships between risk factors in practical construction projects are more complex, so it is meaningful to focus more on obtaining data from practice, which is used to conduct quantitative research. After all, the critical purpose of risk management research is to use the scientific method to draw lessons from experience to guide practice. Moreover, all cases from five years ago are used to synthesize risk factors, which may not fully reflect all the risks faced by international EPC projects at present. In the wake of COVID-19, the international environment has undergone profound changes, and international EPC projects are facing new problems. Future studies should try to use cases in the post-epidemic era as materials to solve the
new and thorny issues that international EPC contractors are facing in the process of risk management now.

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