Project Management of Assembled Buildings Based on the I-M Model (Construction) Risk Path Identification and Management Study

Shihan Wang [1, #], Chenyang Sun [2, #], Guotong Zhou [3, #, *]

[1] Management Institute, Xi'an University of Science and Technology, Xi'an, China, 710600

[2] School of Management, Qingdao University of Technology, Qingdao, China, 266520

[3] School of Civil Engineering, Qingdao University of Technology, Qingdao, China, 266520

* Corresponding Author Email: 15192523177@163.com

#These authors contributed equally

Abstract. Prefabricated building is the development trend of the construction industry in the future. The construction of prefabricated building project is different from the traditional cast-in-place project. It has the characteristics of high construction standard, difficult management and strict requirement of component accuracy. The construction and management process of prefabricated building project may be affected by various uncertain risk factors. In this paper, various uncertain risk factors in the construction of prefabricated building projects are taken as the research object, and the hierarchical structure diagram of the main influencing factors is constructed by using the interpretative structural model (ISM) model and the cross-influence matrix multiplication (MICMAC) method, and the dependence and driving force of the main influencing factors are classified to reveal the mechanism of various uncertain risk factors. On the basis of clarifying the mechanism of various risk factors, a detailed summary is made. This study is conducive to accurately identifying various uncertain risk factors and straightening out the mechanism of action between influencing factors, and providing a certain methodology for reducing risks in construction.

Keywords: ISM; MICMAC; prefabricated building; construction management; risk management.

1. Introduction

The construction of prefabricated building projects is mainly to transport the components of prefabricated components to the construction site and assemble them into buildings on site. Prefabricated building is a cross-era transformation from traditional building projects to industrialized building projects. With the vigorous development of the national social economy, prefabricated buildings have followed, which greatly fits the social conditions of rapid economic and population growth. Therefore, the research on the construction management of prefabricated building projects can play an important role in the development of prefabricated building projects in China.

At present, some scholars have done some research on prefabricated building projects. Guo Liu [1] used domestic independent BIM in the industrialization of new buildings represented by prefabricated buildings, and promoted the transformation of China 's construction mode from extensive construction mode to intensive mode. Wang Dan [2] and others introduced contingency theory and discount progress to replace the constant weight weighting method and correlation algorithm in the traditional matter-element extension method to construct the risk evaluation model of prefabricated building construction, so that the evaluation results were more accurate. Zhou Yilun [3] and others used the combination of ANP and GCM to effectively deal with the problem of mutual influence between the safety performance evaluation indicators of prefabricated building construction. Li Qiangnian [4] carried out safety evaluation of prefabricated building construction based on entropy correction BWM, avoiding the disadvantage of strong subjectivity and eliminating the one-sidedness of calculating weights separately. Wang Qiankun [5] applied the IM-FCM fusion model to the field of safety risk management of prefabricated building construction, identified key risks, and predicted the risk coupling evolution trend and dynamic evaluation risk level from a quantitative perspective.

The research content of this paper is to accurately identify a series of risk influencing factors in prefabricated building projects, judge the correlation between each influencing factor, and construct the overall system of influencing factors, which plays an important role in the efficient management of prefabricated building projects. By referring to various literatures and forming an expert group to analyze the primary and secondary factors of various accidents, 16 risk factors were finally obtained. Firstly, this paper uses SPSSPRO software to calculate the adjacency matrix and reachability matrix of relevant data, divide the hierarchical structure, and construct the ISM hierarchical direction map. Then, the cross-impact matrix multiplication classification method (MICMAC) is used to analyze the influencing factors. According to the dependence and driving force, each influencing factor is divided into three categories: autonomous cluster, independent cluster and dependent cluster.

2. Identification of risk factors in construction management of prefabricated building projects

2.1. Personnel risk

Personnel risk is reflected in four aspects, namely, the technical level of construction personnel [6], construction personnel safety awareness [6], staff fatigue [7] and prefabricated component installation personnel operation standard degree [7]. The main task of the construction personnel is to install the prefabricated components in a reasonable way in the drawing position of the prefabricated components according to the prescribed process. Because of the uneven technical level of the personnel themselves, weak safety awareness, high fatigue under long-term working conditions and weak operational norms, it is easy to cause accidents in the assembly process due to personnel risks.

2.2. Material condition risk

The risk of material conditions is reflected in three aspects: low quality level of prefabricated components [8], high actual service life of hoisting machinery [8], and low level of equipment maintenance. The high level of material conditions is to reduce or eliminate construction accidents due to non-human factors in the construction process, thereby ensuring the downgrading of risks. Therefore, the quality level of prefabricated components must meet the relevant standards. The hoisting machinery needs to adopt new machinery with a short life, and the maintenance level of the equipment needs to be verified by a special person.

2.3. Construction risk

The construction risk is reflected in four aspects, which are the wrong choice of hoisting method [9], the wrong choice of sling [9], the defect of construction organization design and the failure to check the hoisting method before construction [9]. The construction risk mainly exists in the daily construction process. Because the construction is an extremely complex process, when the hoisting method is selected wrong or the sling is selected wrong, the risk of the hoisting process will occur. At the same time, the organization design of construction in the early stage of construction is likely to have defects in the design itself. In addition, if the hoisting method is not checked before construction, the risk of construction process will be increased.

2.4. Environmental risk

Environmental risks are reflected in two aspects, namely, harsh natural environment [6], unstable space environment of prefabricated component hoisting site [7], and insufficient national policy orientation. The existence of environmental factors is mainly to ensure the stability of the outside world during the construction process. Because the choice of construction location may be varied, so the natural environment will exist extremely bad situation. At the same time, the construction site is complex, and the space environment of the prefabricated component hoisting site will be unstable, which will increase the construction risk. The environmental factors are oriented by national policies and play an extremely important role in the progress of the project.

2.5. Late operational risk

The later operational risk is reflected in two aspects, namely, the property management company has no relevant experience [10] and the regular maintenance and testing measures are not in place [6]. The prefabricated building construction project is not fully popularized, so there will also be risks in the later operation. When the property management company has no relevant prefabricated building management experience and regular maintenance inspection is not in place, the existence of later operation risks is greatly increased. The specific adjacency matrix is shown in Table 1.

Table. 1 Construction management risk factors of prefabricated building projects

Second index	Thrid index	Numbering	Indicator description	Reference
Personnel risk	Technical level of construction personnel is not up to standard.	X_1	The training time and work experience of construction personnel vary greatly.	[6]
	Construction personnel safety awareness is weak.	X_2	Construction personnel 's awareness of self-safety and others ' safety is not in place.	[6]
	Staff fatigue is high	X_3	When the construction personnel work for a long time, the fatigue is high, and it is easy to neglect and cause safety accidents.	[7]
	Degree of operation specification of prefabricated component installation personnel is low.	X_4	Because the degree of pre-job training is not deep, it is easy to cause the low degree of operation specification of installation personnel.	[7]
Material condition risk	Low quality level of prefabricated components.	Y_1	Different components have different manufacturing standards, and low-quality components are easy to be mixed in.	[8]
	Actual service life of hoisting machinery is higher.	Y_2	Hoisting machinery with high service life is prone to failure.	[8]
	Low level of equipment maintenance.	Y_3	Unmaintained machinery is prone to failure and the safety index is low.	
Construction risk	Selection of hoisting method is wrong.	Z_1	Different assembly components require different hoisting methods.	[9]
	Sling selection error	Z_2	Different installation positions and heights require different lifting methods.	[9]
	Defects in construction organization design.	Z_3	Organization design management is insufficient,	[9]

			ignoring the construction quality and efficiency.	
	Before construction, the hoisting method was not checked.	Z_4	There may be errors in hoisting methods or some methods are riskier.	[9]
Environmental risk	Natural environment is harsh.	K_1	The foundation is complex and the meteorological conditions are unstable.	[6]
	The space environment of prefabricated component hoisting site is unstable.	K_2	The side building is unstable, and the construction site personnel are disorderly.	[7]
	The lack of guidance of national policy.	K_3	Lack of relevant policies to support the development of prefabricated buildings	
Late operational risk	Property management companies have no relevant experience.	H_1	Property company management confusion	[10]
	Regular maintenance inspection measures are not in place.	H_2	Aging of building components	[10]

3. ISM-MICMAC coupling model

The comprehensive application of ISM-MICMAC model to hierarchical division and attribute discrimination of many elements in the system can comprehensively and systematically study the construction risk path identification and management of prefabricated construction projects. The specific steps are as follows :

3.1. ISM METHOD

In 1973, Warfield proposed the Interpretative Structural Model (ISM) method[11]. The structural model analysis method is a method for analyzing the hierarchical structure of the elements in the system[12]. The ISM model is used to analyze the macro and micro level problems. Based on the combination of computer programming and human experience, the risk factors with many variables, unclear structure and complex relationship between each other are stratified and graded. The specific steps of establishing ISM model are as follows :

STEP1: Identify research questions and select factors reasonably.

According to professional knowledge, literature reference and case analysis, the system elements are sorted out, and the set of influencing factors { S_1 , S_2 ,..., S_n } is established.

STEP2: List the correlation of each leading factor and establish the adjacency matrix.

Determine whether there is a correlation between the factors, and generate the adjacency matrix $A=(a_{ij})_{n\times n}$. The calculation formula is as follows:

$$a_{ij} = \begin{cases} 0, S_i\ has\ no\ effect\ on\ S_j \\ 1, S_i\ has\ an\ effect\ on\ S_j. \end{cases} \tag{1}$$

STEP3: Generate reachable matrix

According to Boolean operation rules, the adjacency matrix is iteratively calculated by SPSSPRO software according to formula (1), and the reachable matrix M =(mij)n×n is finally generated[13]. The calculation formula is as follows:

$$M = (A + I)^k \tag{2}$$

When *(A+I)* $\neq (A+I)^2 \neq (A+I)^3 \neq \ldots \neq (A+I)^k = (A+I)^{k+1}$, the reachable matrix is $M=(A+I)^k$, $k \leq n\text{-}1$ (n is the matrix order).

STEP4: Hierarchical decomposition of reachability matrix

By decomposing the reachable matrix, the reachable set $R(S_i)$, the antecedent set $A(S_i)$ and the common set $C(Si)$ are obtained, where $C(S_i) = R(S_i) \cap A(S_i)$, and the identical elements in $R(S_i) = C(S_i)$ are found as the first layer of the interpretative structural model. Then, the rows and columns of all elements in the first layer are deleted from the reachability matrix to form a new reachability matrix. Then continue to find the elements contained in the second layer of the interpretative structural model from the new reachability matrix; by analogy, find out all the factors contained at all levels. The calculation formula is as follows:

$$R(S_i) = \{S_x | S_x \in S, m_{ix} = 1, x = 1, 2, \ldots, n\}(i = 1, 2, \ldots, n) \tag{3}$$

$$R(S_i) = \{S_x | S_x \in S, m_{ix} = 1, x = 1, 2, \ldots, n\}(i = 1, 2, \ldots, n) \tag{4}$$

$$C(S_i) = \{S_x | S_x \in S, m_{ix} = 1 m_{ix} = 1, x = 1, 2, \ldots, n\}(i = 1, 2, \ldots, n) \tag{5}$$

STEP5: Hierarchical division of influencing factors, drawing interpretive structural model

Based on the reachability matrix, the explanatory structure model diagram is drawn according to the hierarchical division results and logical relationship of factors.

3.2. MICMAC METHOD

The factor hierarchy is divided by constructing the ISM model. The cross-impact matrix multiplication classification (MICMAC) is used to analyze the influencing factors, and the status and role of the influencing factors are deeply divided to determine the corresponding dependence E_i and driving force F_j.[14] The factors are divided into autonomous clusters, dependent clusters, contact clusters and independent clusters, and finally targeted countermeasures and suggestions are proposed, which can provide some reference for guiding the risk identification and management practice of prefabricated construction projects[15]. The calculation formula is as follows [16]:

$$E_i = \sum_{i=1}^{n} a_{ij} \; (i = 1, 2, \ldots, n) \tag{6}$$

In the formula, k_{ij} is the risk factor in the reachable matrix *M*, *i* is the row where the risk factor is located, and *j* is the column where the risk factor is located. A_{ij} is an element in the reachable matrix *M*.

4. Calculation and Analysis

4.1. ISM calculation and analysis

Each of the major influencing factors does not exist independently of the other factors, and there are complex interactions among them to influence each other, in which case the ISM model should be applied. First, an ISM discussion group was formed to study the correlation between the influencing factors. In this paper, a total of 15 experts in the assembly industry were invited to form a discussion group (including 5 experts from universities, 5 experts from enterprises, and 5 experts from the government), and a scientific and objective scoring was conducted to confirm the relationship between the influencing factors through equation (1), i.e., the adjacency matrix was constructed in the manner of 0 to 1. If the result is 1, it means that S_i has influence on S_j , and if the result is 0, it means that S_i has no influence on S_j . The specific adjacency matrix is shown in Table 2

Table. 2 Adjacency matrix

	X1	X2	X3	X4	Y1	Y2	Y3	Z1	Z2	Z3	Z4	K1	K2	K3	H1	H2
X1	0	0	0	1	0	0	0	1	1	0	1	0	0	0	0	0
X2	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
X3	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
X4	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0
Y1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Y2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Y3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Z1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Z2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z3	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
Z4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
K1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
K2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
H1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
H2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

Based on the data in Table 2, the adjacency matrix is calculated iteratively according to equation (2) by bringing into SPSSPRO software according to the Boolean operation rules, and the final reachable matrix M is generated as shown in Table 3, and the calculation hierarchy is graded as shown in Table 4, and the ISM hierarchy directed graph is drawn as shown in Figure 1.

Table. 3 Reachable matrix M

	X1	X2	X3	X4	Y1	Y2	Y3	Z1	Z2	Z3	Z4	K1	K2	K3	H1	H2
X1	1	0	0	1	0	0	0	1	1	0	1	0	1	0	0	0
X2	0	1	0	0	0	0	0	0	1	0	1	0	1	0	0	0
X3	0	0	1	1	0	0	0	1	1	0	1	0	1	0	0	0
X4	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0
Y1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Y2	0	0	1	1	0	1	0	1	1	1	1	0	1	0	0	0
Y3	0	0	1	1	0	0	1	1	1	1	1	0	1	0	0	0
Z1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
Z2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Z3	0	0	1	1	0	0	0	1	1	1	1	0	1	0	0	0
Z4	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
K1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0
K2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
K3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
H1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
H2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1

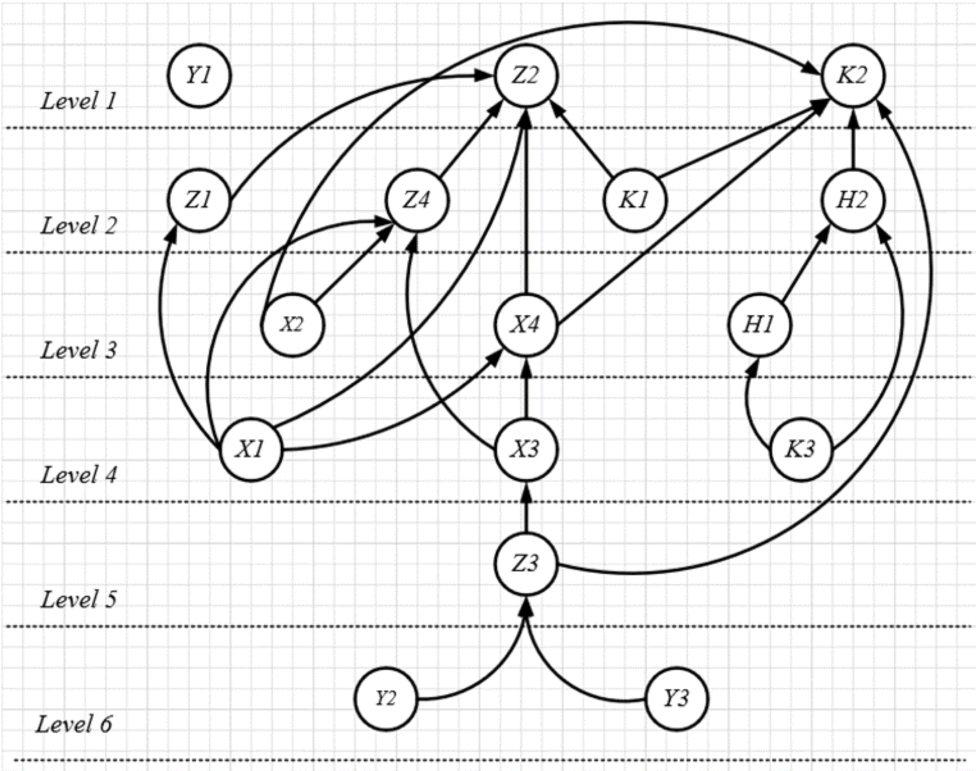

Figure. 1 ISM hierarchy pointing diagram

Through the calculation and analysis of the above-mentioned data, the risk influencing factors can be divided into 6 levels, among which the first level of low quality of prefabricated components, wrong spreader selection and unstable spatial environment of prefabricated components lifting site are the direct factors causing the safety risk of assembled building project management, among which wrong spreader selection and wrong lifting method selection, no calculation of lifting method before construction, poor natural environment The spreader selection error has a direct influence on the selection of lifting method, the lack of pre-construction calculation of lifting method, the harsh natural environment, the substandard technical level of construction personnel, and the low degree of operation standardization of prefabricated component installers; while the harsh natural environment, the lack of regular maintenance and testing measures, the low degree of operation standardization of prefabricated component installers, the weak safety consciousness of construction personnel, and the defects of construction organization design have a direct influence on the unstable spatial environment of prefabricated component lifting site, which also easily cause safety accidents. The low-quality level of prefabricated components in the first layer does not affect each other with other influencing factors and exists independently.

The middle-level risk factors directly or indirectly affect the shallow and deep-level risk factors in different ways, and there is an intricate relationship between each risk factor, so controlling and managing these deep-level risk factors is an effective way to reduce the occurrence of all kinds of accidents in the project.

In the deepest level of the two factors lifting machinery actual use of high age, equipment maintenance level is low are belong to the level of equipment management, strengthen the management of various types of machinery and equipment, maintenance can greatly improve the safety and reliability of construction project management, if ignore the deep-seated risk factors is difficult to be able to solve the relevant problems from the root.

4.2. MICMAC Calculation and Analysis

According to the reachability matrix of ISM in 5.1, the hierarchical structure of each influencing factor can be derived, and the MICMAC model can be used to deeply divide the position and role of each influencing factor to determine the corresponding dependency E_i and driving force F_j. The main purpose of MICMAC calculation and analysis is to analyze the driving force F_j and dependency E of the influencing factors in the project management of assembled buildings, and to classify them into autonomous clusters, dependency clusters, linkage clusters and independent clusters according to their driving force F and dependency E_i.The main purpose of MICMAC calculation and analysis is to analyze the driving force F_j and the dependency E_i of the factors influencing the project management in the assembly building, and thus classify them into autonomous, dependent, linked and independent clusters according to their driving force F_j and dependency E_i . Combining with equations (6-7), the results of driving force F and dependency E_i for each influencing factor can be derived, which are shown in Figure 2.

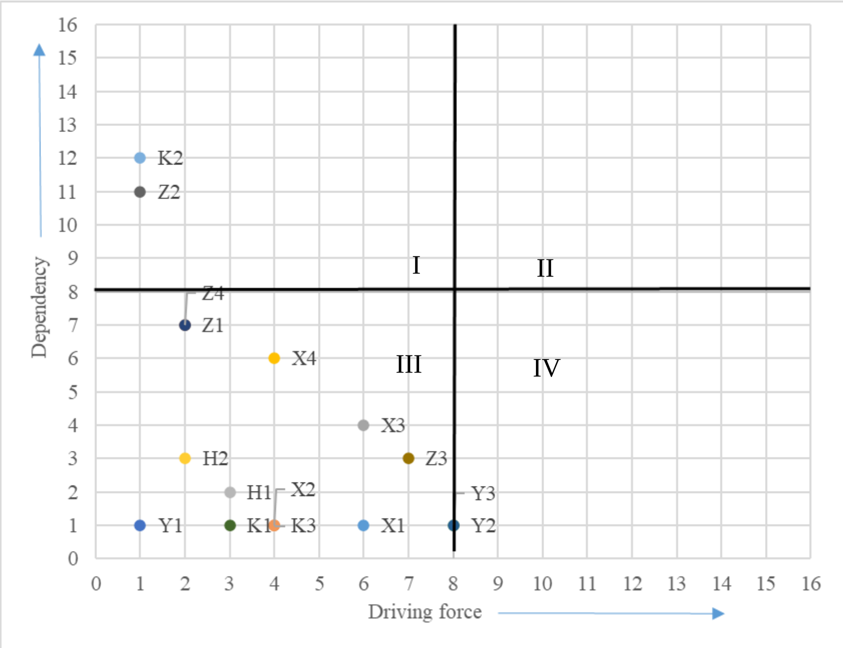

Figure. 2 Power map

MICMAC analysis of the factors influencing the project management of assembled buildings leads to the following conclusions.

The risk influencing factors belonging to the autonomous cluster (first quadrant) are X1, X2, X3, X4, Y1, Y2, Y3, Z1, Z3, Z4, K1, K3, H1, H2, the risk influencing factors of the autonomous cluster tend to have lower driving force Fj, lower dependency Ei, and are mostly located in the middle level in the ISM model, among which the five factors X1, X3, Y2, Y3, Z3 need our attention because of their lower dependency and their higher driving force. The five factors X1, X3, Y2, Y3, and Z3 need to be emphasized because of their lower dependence and their higher driving force, because they have a higher degree of influence on the upper-level factors and are less influenced by other influences. In addition, the X4 factor, due to its high driving force and its high dependence, indicates that it has a top-down role and has a greater impact on the upper-level factors if they are affected by other factors.

There are no risk influencing factors belonging to the independent cluster (quadrant 2), indicating that there are no such risk influencing factors in the project management influencing factors of assembled buildings.

The absence of risk influencing factors belonging to the linkage cluster (third quadrant) indicates that there are no such risk influencing factors in the project management influencing factors of assembly buildings.

The risk influencing factors belonging to the dependency cluster (fourth quadrant) are Z_2, K_2 two factors, the dependency cluster usually has lower driving force and higher dependency force, and is subject to other risk influencing factors to a large extent, so in order to solve such problems, we need to start from the risk influencing factors in its lower level. For example, the unstable spatial environment of K_2 prefabricated component lifting site is influenced by five factors: weak safety awareness of X_2 construction personnel, low degree of operation specification of X_4 prefabricated component installation personnel, defective construction organization design of Z_3, harsh natural environment of K_1 and inadequate regular maintenance and testing measures of H_2.

5. Conclusion

The risk factor system of construction management of prefabricated building project is constructed, and the ISM model and MICMAC method are used to analyze respectively. The interaction relationship between risk factors and the mechanism of risk events are studied in combination with specific cases to verify the feasibility of the model. The research methods and results are suitable for the deep analysis of risk factors with complex process and many influencing factors. The specific conclusions are as follows :

(1) The ISM model is used to divide the 16 main risk causes into levels, and the multi-layer hierarchical structure diagram of the risk factors of the construction management of the prefabricated building project is obtained. The low quality level of prefabricated components (Y_1), the wrong selection of slings (Z_2) and the unstable space environment at the hoisting site of prefabricated components (K_2) are the shallow reasons for the safety risk of prefabricated building project management. The two factors of high actual service life of hoisting machinery (Y_2) and low equipment maintenance level (Y_3) belong to the equipment management level, which is the deep reason for the risk formation.

(2) Based on the MICMAC model, the risk factors are divided into autonomous clusters, independent clusters, contact clusters, and dependent clusters to determine their mutual dependence and driving force. The technical level of construction personnel is not up to standard (X_1), the fatigue of staff is high (X_3), the actual service life of hoisting machinery is high (Y_2), the maintenance level of equipment is low (Y_3), and the construction organization design is flawed (Z_3). Five factors are the fundamental key factors that constitute the construction management risk of prefabricated construction projects because of their low dependence and high driving force. We need to pay attention to them and focus on them. The two factors of wrong selection of slings (Z_2) and unstable space environment at the hoisting site of prefabricated components (K_2) have low driving force and high dependence, and are greatly affected by other risk factors. Therefore, in order to solve such problems, it is necessary to rely on the lower risk factors.

The risk factors of construction management of prefabricated construction projects are diverse and complex. This study helps to identify various uncertain risk factors and hierarchical relationships in the construction management of prefabricated construction projects, and deeply understand the mechanism of various risk factors affecting each other and leading to construction management problems.

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