

Study on Risk Identification and Key Risks of Prefabricated Building Supply Chain Based on Grounded Theory

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Abstract. Supply chain management is an important challenge faced by prefabricated buildings. The transfer of prefabricated modules will inevitably be accompanied by the transmission and diffusion of risks. It is precisely because of the inherent characteristics of the prefabricated building supply chain risks that the current prefabricated building completion rate is low. Based on this, the Grounded Theory is used to identify the risks of prefabricated construction projects from the perspective of the supply chain, and build a full-stage risk system; and introduce the Interpretation Structure Model Theory to analyze the interrelationship between risk factors, and obtain different risk levels; finally, specific risk control measures are proposed for deep-seated factors, which provide new ideas for the development of prefabricated buildings.

1 Introduction

In 2020, Corona Virus Disease 2019 broke out globally. During the fight against the epidemic, the Huoshenshan and Leishenshan hospitals, which were completed and put into use within 10 days, played a vital role in quickly responding to the epidemic and treating patients. The use of "steel box-type house assembly construction" is an important technical support for the rapid construction of the hospitals. As a new construction and production method, the prefabricated construction not only provides new ideas for the country to quickly respond to similar emergency situations in the epidemic, but also has a shorter construction period, high efficiency, energy saving and environmental protection compared with traditional cast-in-place buildings. The benefits to society, economy and environment are significant. However, according to the latest data, 420 million square meters of newly constructed prefabricated buildings nationwide were started in 2019, accounting for approximately 13.4% of the newly built building area [1]. The development of prefabricated buildings faces many challenges and problems in the actual application process.

As shown in Fig.1, International knowledge domains related to prefabricated building research can be divided into "Greenhouse Gas Emissions(#0)", "Affecting Prefabricated Construction Promotion(#1)", "Prefabricated Modular Units(#2)", "Prefinished Volumetric Construction(#3)", "Prefabricated Construction Supply Chain Management (#4)", "Steel Beam(#5)", "Modern Method(#6)", "Using Large-diameter Reinforcing Bars(#7)", "Assemblies Installation(#13)" etc. It can be seen that "prefabricated

building supply chain management" (#4) is currently a hot research topic. With the development of prefabricated buildings, domestic scholars have carried out many studies. Jiang [4] showed that the reason for the long-term stagnation of prefabricated structures is the lack of professional research on the integrity of prefabricated structures and the design and construction management. Liao [5] analyzed the problems existing in the development of prefabricated buildings from the perspective of green buildings, and found that the existing policy support is insufficient and industrial management is not perfect. Zhai [6] and other studies have shown that the low degree of supply chain integration, the inability to freeze the design in the early stage, the high cost, the lack of supporting policies and related standards are the main factors restricting the development of prefabricated buildings in China. However, most domestic researches focus on phased research on risk identification, assessment and management countermeasures in a certain dimension of prefabricated construction projects, such as production, design, construction research, practical application research, performance, quality and cost research, etc. It is rare to conduct risk analysis on the whole process of the supply chain, and form a systematic and structured risk model.

Prefabricated construction is a mode that part of the work of on-site is moved to the factory. After professional design, prefabricated modules and components are processed by large-scale production methods, and then the components are transported from the factory to the site for assembly. This is a traditional two-echelon supply chain (factory → off-site) [3]. The transfer of modules will inevitably be accompanied by the transmission and diffusion of risks, which exist in all

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stages of prefabricated construction projects and ultimately act on the main body of the project. Therefore, this article uses grounded theory to analyse the interview results and literature, extracts prefabricated building supply chain risks in depth and scientifically, builds a risk system at all stages of the supply chain, to a certain extent, overcomes the divergence between traditional qualitative research and quantitative research, and finally leads to the depth of results. Validity, standardization, and reliability are greatly improved. And with the help of

the Interpretation structure model to analyse the relationship between risks, explore the root causes and action paths of risks, decompose complex system problems into multi-level structures that are convenient for understanding and analysis. Finally provide reference for construction companies in the process of adopting the prefabricated construction mode, and promote the sustainable development of the prefabricated construction industry.

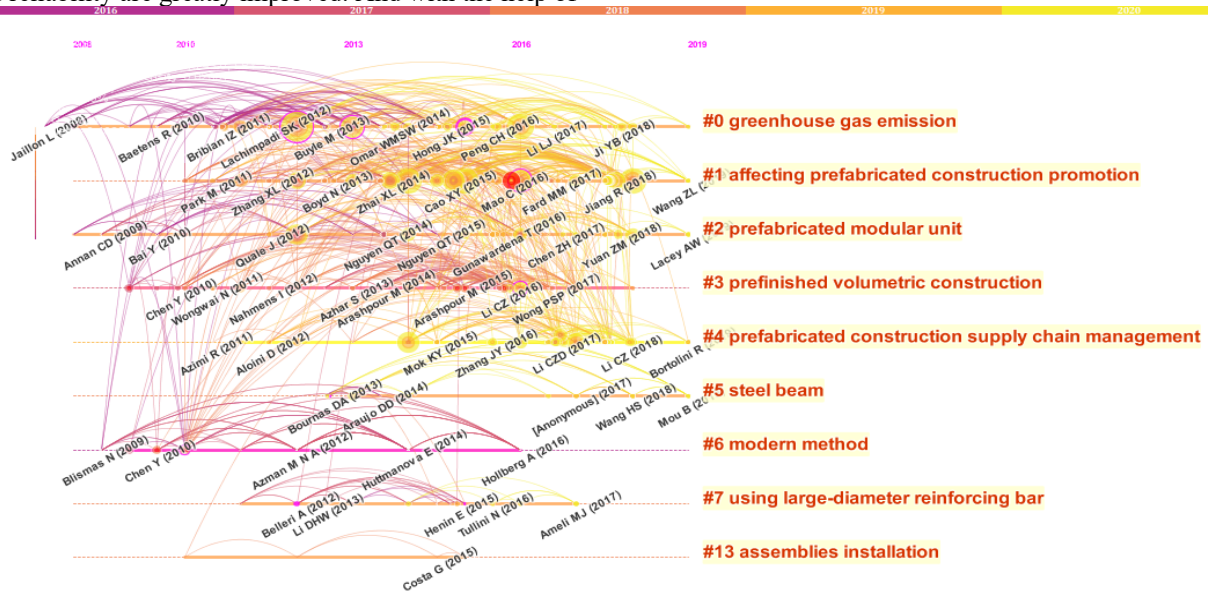


Fig.1. Timeline View

2 Risk Identification of Prefabricated Building Supply Chain Based on Grounded Theory

Grounded Theory is a bottom-up qualitative research method. It was jointly proposed by two Columbia University sociologists, Glaser and STRAUSS, in 1967. It aims to collect a large amount of literature and interview data through a gradual process. Researchers can construct qualitative research theories Model

through open coding, axial coding, and selective coding[7]. The significance of grounded theory lies in the ability to abstract conceptual categories and their internal connections without research hypotheses. Based on this, this study collects original data through literature retrieval and expert interviews, and uses Nvivo 11 software to identify risk factors in the supply chain of prefabricated buildings. The analysis process is shown in Figure 2.

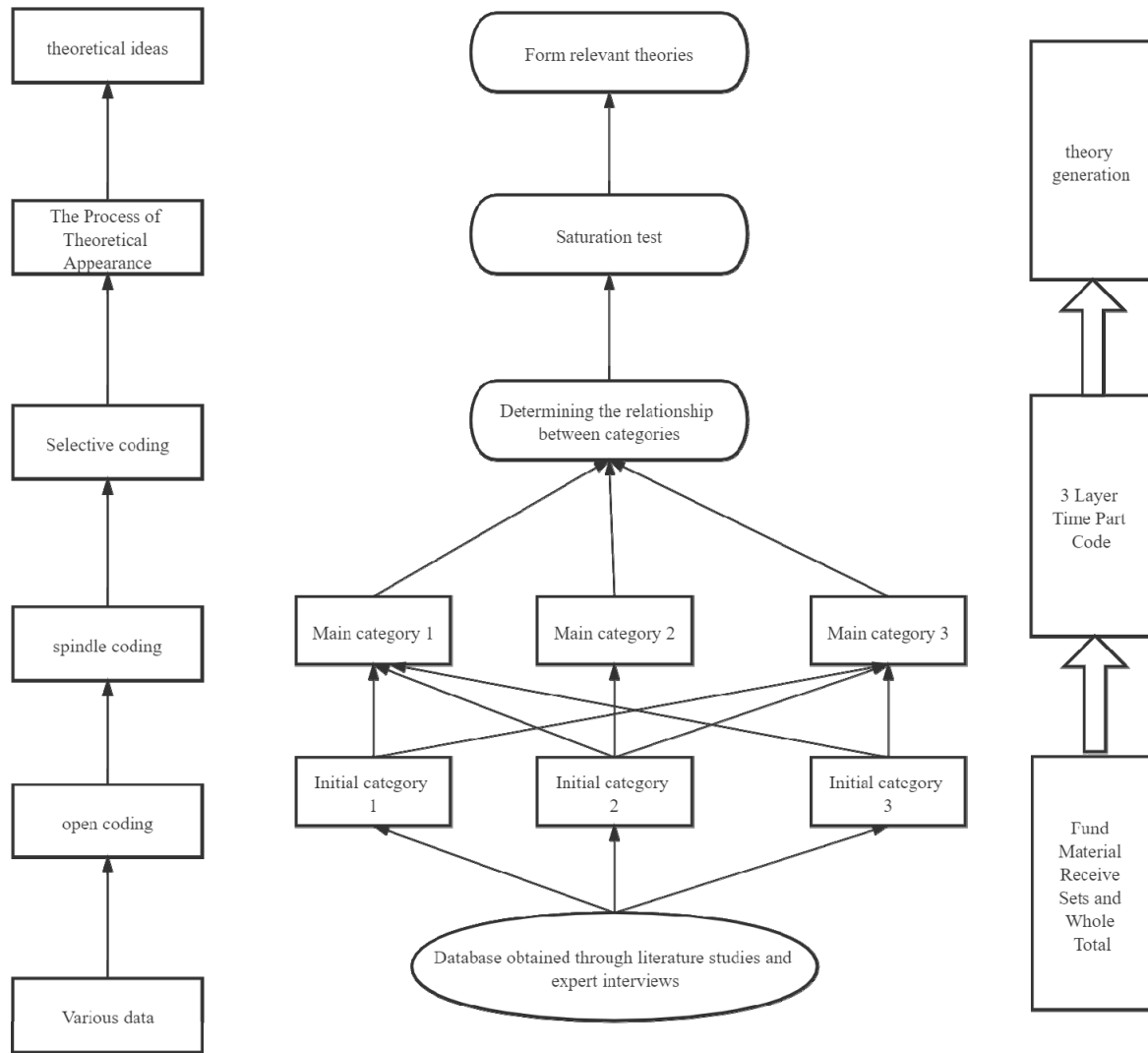


Fig.2. Grounded Theory Analysis Process

2.1 data collection

This study uses literature research and semi-structured interviews to collect data, with interview results as the mainstay, and literature data as a supplement. Nantong is a well-known “town of construction” in China, and its prefabricated construction industry is also at the forefront of China. The interview was conducted with 14 experts and scholars in the field of prefabricated buildings from the Nantong Institute of Prefabricated Buildings and Intelligent Structures, and conducted field research on the prefabricated building construction site, transportation process, construction and manufacturing in advance, so as to formulate a scientific

interview Outline to filter out risk factors. The interview content and target information are shown in Table 1 and Table 2.

On the basis of interviews, supplemented by literature materials, through CNKI, searched journals with the theme of "prefabricated building" from 2016 to 2020, and a total of 424 documents were searched; through WOS (Web Of Science), searched on the subject of "assembly supply chain" in the past five years, and a total of 412 articles were published. Combining the content of the literature and the research direction, after cleaning, the articles with large differences in content were eliminated, and a total of 35 articles were screened out. Thirty articles are randomly selected as main shaft codes, and the remaining 5 articles are reserved for theoretical saturation test.

Table.1. Interview Outline

Interview theme	Outline content
The basic information of respondents and their experience in participating in prefabricated buildings	Gender, Name, Area, Unit Participating in Prefabricated Building Projects and Status
Risk factors of prefabricated buildings proposed by respondents under different assumptions	<ol style="list-style-type: none"> 1. Assuming that you are in the construction unit, what factors or risks do you think hinder you from adopting prefabricated buildings ? 2. Assuming that you are in the design unit, what difficulties do you think may be encountered in the design of prefabricated components ? 3. Assuming that you are in the design unit, what difficulties do you think may be encountered in the design of prefabricated components ? What are the risks ? 4. Assuming that you are in the production unit, what difficulties do you think may be encountered in the production of prefabricated components ? What are the risks ? 5. Assuming that you are in the transport unit, what difficulties do you think may be encountered in the transport of prefabricated components ? What are the risks ? 6. Assuming that you are in the installation unit, what difficulties do you think may be encountered in the installation of prefabricated components ? What are the risks ? 7. What part of the supply chain, such as design, production, transportation, installation, has the greatest risk or the weakest market ? 8. Do you think that the current assembly building supply chain industrial chain system is complete enough ? What do you think is the biggest problem in the development of prefabricated buildings ?
Questionnaire on Risk Assessment of Assembly Building Supply Chain	<ol style="list-style-type: none"> 1. Type of work unit. 2. Do you think prefabricated buildings will become the mainstream of future architectural development ? 3. Your working years in engineering (including scientific research) are ? 4. With regard to the current status of prefabricated construction, is your organization more inclined to construct prefabricated construction projects ? 5. Which type of construction form do you think is more promising for residential buildings ? 6. What do you think are the main obstacles restricting the development of prefabricated buildings ? 7. Supply chain risk assessment. 8. Do you have anything to add to the risk factors of prefabricated building supply chain ? * 9. Do you have any suggestions on how to avoid the risk of assembly building supply chain ?

Table 2. Basic information of interviewees

Serial number	Sexuality	Occupation	Areas
R01	males	manager	Research and Development of Concrete Components
R02	males	manager	steel construction system
R03	males	manager	PC components
R04	males	manager	Steel structure accessories system
R05	female	designer	construction design
R06	males	designer	construction design
R07	males	driver	logistics transportation
R08	males	engineer	Installation and assembly
R09	female	university teacher	science research
R10	males	university teacher	science research
R11	males	postgraduate	science research
R12	males	doctoral students	science research
R13	female	doctoral students	science research
R14	males	doctoral students	science research

2.2 Decoding process

2.2.1 Open Coding

Open coding is a process of extracting concepts from the original sentences based on the understanding and induction of the original data and interview results, and then re-integrating the concepts into categories. Through the textualization of literature and interview results, and screening and filtering sentences with unclear semantics

and researching inconsistent sentences, 107 original sentences were finally obtained, and 17 effective concepts were summarized. Through refining understanding and constant comparison, the concept is finally refined into 16 initial categories, which are risk factors affecting the supply chain of prefabricated buildings. Some representative original sentences, conceptualization and categorization results are shown in Table3.

Table 3. Open coding process

Initial category	Effective concept	Original sentence
F1 Imperfect design	Insufficient design Incomplete drawing design	"Deepening design is a very important part of prefabricated buildings. After the design is completed, the risks of all links will be reduced a lot; and the drawings need to be signed by the person in charge during the design process, which is also convenient for better determination of responsibilities." "Improper management by the designer will have an impact on product quality, product delivery time and construction convenience."
F2 Design changes	Frequent design changes Irregular design process	"There may be loopholes in the design plan that lead to design changes." "The design level of designers is low, and the design process is not standardized and other factors will cause design changes, which will adversely affect the final quality of the product, and even cause safety accidents in serious cases."
F3 Unreasonable design scheme	Poor feasibility of the design plan	"Some design schemes can achieve the desired effect under ideal conditions, but they do not consider the actual construction level and raw material restrictions. They seem to be perfect, but in reality they are difficult to achieve."
F4 Unqualified component quality control	Equipment failure Improper staffing Insufficient technical level Low quality of components	"The materials purchased by the people who purchase concrete do not meet the requirements, making the construction quality unqualified." "The quality and safety of raw materials such as steel bars and concrete before entering the construction site is affected by the supplier, and these are most likely to become direct factors leading to safety accidents during the construction process." "The efficiency of the machine is not high, it cannot meet the demand, the personnel arrangement is unreasonable, the skill of the workers is not up to standard, and the production components are not qualified." "The quality risk of the components may lead to the risk of the entire construction project, affect the entire construction process, and cause the risk of short-term suspension or long-term shutdown. Therefore, construction companies must strictly control the quality of materials, especially for the secondary inspection of components when they enter the construction site. " "Insufficient management level and untimely supply of material suppliers will cause delays in the supply of products to production units and low production efficiency."
F5 Improper storage of components	Poor component storage environment Mismanagement	"The storage of materials is affected by the environment, improper management, moisture, wear, and corrosion will seriously affect the quality of the construction."
F6 Limited supplier selection	Less suppliers in emerging areas	"Prefabricated construction is still an emerging field after all, with fewer suppliers and fewer options."
F7 Uncertainty during transportation	Transportation accidents of complex materials and components on road conditions	"Installation can be said to be the most important risk in the supply chain, because someone will sign the design, but there are currently no professional assembly-type installation technicians, and it is difficult to find the direct person in charge if there is a problem; There are also driver levels and road congestion on holidays. " "The transportation of materials and components is one of the characteristics of the construction industry, which is different from other industries. Due to the particularity of the materials, there will be certain requirements for the transportation of materials and equipment. Can the construction progress be carried out smoothly and whether the materials can be delivered in time? Very important, especially for prefabricated buildings, the distribution of prefabricated beams, columns and slabs directly affects the construction process."
F8 Unreasonable transportation plan arrangement	Design Staff assignments Equipment management Material management Progress Control	"During the construction process, unreasonable personnel allocation, improper use of equipment, improper schedule arrangements and other management risk factors will cause the construction unit to lose profits and delay the construction period."
F9 Transportation restrictions	There are restrictions on component size, loading technology, and vehicle selection	"Prefabricated building components may be too large and have peculiar shapes. The width of roads affects construction and transportation; there are also certain restrictions on loading technology and model selection." "The environment of construction projects is an important factor for construction safety. The environment includes Surrounding environment, operating environment, natural environment, etc. Although environmental factors do not often cause safety problems and rarely cause safety accidents, they also have certain impacts on the construction of prefabricated buildings, and the operating environment has a greater impact on safety."
F10 Poor quality control during installation	There are bumps and wear when the components are installed	"During the hoisting process, bumps and wear are likely to occur, which will affect the quality of the construction, and even result in returning to the factory for redo."

F11 Installation of mechanical equipment maintenance or improper operation	Maintenance of tower cranes and other mechanical equipment Operating specifications	"Because prefabricated buildings require a lot of large-scale machinery and equipment, the risk factors of machinery and equipment cannot be ignored. The influencing factors of mechanical equipment include maintenance and maintenance of mechanical equipment, standardization of tower crane lifting operation, tower crane layout, mechanical equipment depreciation rate, mechanical equipment depreciation rate, lifting load, selection of auxiliary spreaders, etc. "
F12 Poor quality of installers	Lack of training Lack of qualifications	"At present, there is a lack of professional system-trained installers in the field of prefabricated buildings. Lack of qualifications will cause installation errors, poor quality, and affect the quality of the building."
F13 Insufficient supervision	Wrong judgment, missed judgment Data authenticity	"Risk of misjudgment and missed judgment. Due to the limitation of sampling sample size and the random risk of sampling, the unqualified batch is judged as qualified, or the unqualified batch is not detected. The authenticity of raw material quality data, engineering inspection records, acceptance records, and other internal engineering technical data directly affects the authenticity of the safety evaluation of prefabricated building construction. "
F14 Low level of information sharing	Differences in market information Information asymmetry	"Sometimes there may be deviations in the interpretation of the information when the upper-level information is passed to the lower-level. For example, each region has its own interpretation of the requirements for the assembly rate." "If procurement managers do not understand the market conditions in time, they will often increase procurement costs. Therefore, the difference in market information and the asymmetry of information will affect the entire procurement process of construction companies."
F15 Safety incident	Possible safety accidents during transportation and installation Unreasonable design may also have security risks	"Traffic accidents during transportation, over-height tower cranes during installation, danger to construction personnel, etc. Unreasonable design may also have potential safety hazards."
F16 The adverse impact of the social environment	Low degree of standardization	"As an emerging industry, prefabricated buildings have a low degree of standardization in many aspects."
F17 Adverse effects of the social environment	Influence of Construction Engineering Environment, Operation Environment and Natural Environment	"The environment of a construction project is an important factor for construction safety. The environment includes the surrounding environment, work environment, and natural environment. Although environmental factors do not often cause safety problems and rarely cause safety accidents, they also have a certain impact on the construction of prefabricated buildings, and the operating environment has a greater impact on safety. "
F18 The impact of national policies	Policy changes Capital control Slow approval system and complicated procedures	"Specifications, manuals, and industry standards have limitations and will need to be revised after a period of time." "The government directly takes the lead in the construction of prefabricated buildings, formulates policies and measures, creates a relatively loose market environment, and can provide effective financial support." "The changes in the macro environment will have an impact on the company's product market, raw material supply, profitability and quality."
F19 Excessive cost	Design cost Manufacturing cost Transportation cost Construction cost	"Cost control runs through the entire process of the prefabricated building supply chain. Good cost control can greatly reduce costs and help promote the development of prefabricated buildings."
F20 Contract disputes	Contract disputes between enterprises	"Contract disputes also go through the entire process of the prefabricated construction supply chain. Reducing contract disputes is conducive to friendly cooperation between the contracting parties and achieving a win-win situation."

2.2.2 Axial Coding

Axial coding is based on the conceptualization and categorization of open coding, and uses the exclusive analytical tool of grounded theory-the model model to construct the connection of each subcategory. In the continuous comparison of the effective concepts and

subcategories, The process of realizing relationalization and primary-secondaryization, so as to summarize the main category. With the help of the model, five main categories of design risk, manufacturing risk, transportation risk, construction risk, and total risk have been developed.

Table 4. Spindle coding process

Main category	Subcategory	Category connotation
M1 Design risk	Imperfect design	Insufficient deepening design or incomplete drawing design
	Design changes	Frequent changes to the design drawings caused by changes in the owner's needs or the mistakes of the designers

M2 Manufacturing risk	Unreasonable design scheme	The designer did not comprehensively consider the raw materials, the construction site environment, the level of construction personnel and other factors, resulting in poor feasibility
	Unqualified component quality control	Unqualified component quality caused by inadequate component quality control
	Improper storage of components	Component damage caused by improper storage environment or improper storage management
	Limited supplier selection	Fewer suppliers in emerging fields make supplier choices limited
M3 Transportation risk	Uncertainty about the transport process	Uncontrollable road conditions and transportation accidents cause uncertainty in the transportation process
	Unreasonable transportation plan arrangement	Unreasonable transportation plan arrangements cause transportation delays and thus delays in construction schedules
	Transportation restrictions	There are restrictions on the selection of vehicles caused by the size, shape and loading technology of the components
M4 Construction risk	Poor quality control during installation	The quality of components caused by bumps and wear during the installation process is seriously degraded
	Installation of mechanical equipment maintenance or improper operation	Equipment damage caused by improper equipment maintenance or improper operation by construction personnel
	Poor quality of installers	Installation errors caused by lack of ability of the installers affect the quality of the building
M5 Common adventure	Insufficient supervision	Misjudgments and omissions caused by insufficient supervision on the construction site
	Low level of information sharing and poor communication	The low level of information sharing between upstream and downstream enterprises and poor communication have adversely affected the entire construction process
	Safety incident	Safety accidents during manufacturing, transportation, and construction
	Adverse effects of the social environment	The continuous changes in the social environment have caused the standardization of the entire construction process to continue to change accordingly
	Adverse effects of natural environment	The natural environment of the construction site directly determines the design, and the surrounding environment and operating environment will affect manufacturing, transportation and construction
	Impact of national policies	Changes in the entire industry caused by changes in national policies caused by changes in the macro environment
	Excessive cost	Including design cost, manufacturing cost, transportation cost, construction cost and other costs
	Agreement disputes	Contract disputes between enterprises due to the boundaries of rights and responsibilities or interest disputes

2.2.3 Selective Coding

As the last link of grounded theory coding, selective coding has the function of structuring and nucleating the initial category and the main category. Through the analysis, comparison, summary, and induction of the original text data, 16 initial categories, and 5 main categories, the core category of "factors affecting the realization of prefabricated building goals" that can connect all the main categories is obtained. Design, manufacturing, transportation, and construction are all links of the supply chain. From component design and drawing perfection, to component production level and quality control, to transportation and loading, and installation of tower cranes, all affect the realization of prefabricated building goals. Therefore, "factors affecting the realization of prefabricated building goals" can be used as a fishing line to guide the story line [8].

2.2.4 Theoretical saturation test: test of reliability.

It is the moment when the analyst can no longer develop a new category through alternate collection and continuous analysis of comparative data [9]. Re-encoding the five reserved texts with three levels of coding did not result in a new category that acts outside the core category. Therefore, it can be concluded that the above model has reached a theoretical saturation state.

3 Analysis of Key Risks in the Supply Chain of Prefabricated Buildings Based on Interpretive Structure Models

Establish an expert group and use Delphi Technique to judge the direct causal relationship between risk factors. When 75% of the experts believe that there is a direct

relationship between the two factors, the judgment is valid. The results are shown in Table 6.

Table 5. Risk Factors of Prefabricated Construction Supply Chain

factor	direct acting factor	factor	direct acting factor
F ₁	F ₂ , F ₄ , F ₁₀ , F ₁₅ , F ₂₀	F ₁₁	F ₁₀ , F ₁₅ , F ₁₉
F ₂	F ₆ , F ₈ , F ₁₉ , F ₂₀	F ₁₂	F ₁₀ , F ₁₁ , F ₁₅
F ₃	F ₁ , F ₄ , F ₆ , F ₉ , F ₁₀ , F ₁₅ , F ₁₉	F ₁₃	F ₁₀ , F ₁₅
F ₄	F ₉ , F ₁₀ , F ₁₅ , F ₁₉	F ₁₄	F ₁ , F ₂ , F ₁₀ , F ₁₉
F ₅	F ₄ , F ₁₅ , F ₁₉	F ₁₅	--
F ₆	F ₁₉	F ₁₆	F ₆ , F ₁₉
F ₇	F ₁₅	F ₁₇	F ₇ , F ₁₀ , F ₁₉
F ₈	F ₇ , F ₁₉	F ₁₈	F ₂ , F ₆ , F ₁₆ , F ₁₉
F ₉	F ₁₉	F ₁₉	--
F ₁₀	F ₁₅ , F ₁₉	F ₂₀	--

3.1 Risk mechanism analysis and control measures

3.1.1 Analysis on Risk Mechanism of Prefabricated Building Supply Chain

With the help of the ISM operating program, the reachability matrix is divided into levels by reachability set, antecedent set, and common set, and the explanatory structure model of the prefabricated building supply chain risk is obtained. Finally, the class hierarchy is shown in Figure 3. The 6 levels can be divided into three groups according to the number of factors and their arrangement characteristics: direct factor group (level 1), indirect factor group (level 3 to 5) and deep factor group (level 6).

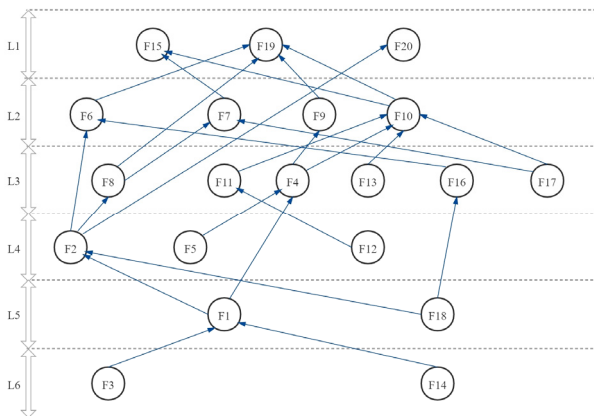


Fig.3. ISM Diagram of Risk Factors in Prefabricated Building Supply Chain

Indirect factors play a role in promoting direct factors, and at the same time, they are affected by deep-seated

factors, which are important medial risks in the hierarchical structure. The indirect factors include design risks, manufacturing risks, transportation risks, construction risks and risks at all stages of the whole process, which constitute the complexity of the supply chain network.

The direct factors belong to the whole process risk: F₁₅(safety accident), F₁₉(excessive cost) and F₂₀(contract dispute); these factors directly affect the supply chain, and strong direct control should be adopted.

For the deep factor group, the factors included are design risk factors: F₃(Unreasonable design scheme); the whole process risk: F₁₄(Low level of information sharing). The low level of information sharing not only means the lack of cooperation between the participants in the supply chain, but also affects the quality of the product. Due to the information asymmetry between the upstream and downstream, errors will occur in many aspects of the product, such as the product design manufacturer's response to the product. If the details require information not to be shared, it will lead to product quality problems, which in turn will lead to safety accidents. Therefore, the low degree of information sharing is a major factor that needs attention. Building Information Model (BIM) is a shared knowledge resource, and its greatest application value lies in the sharing and transmission of model information. Promoting the effective application of BIM during project implementation will greatly improve the quality and effectively promote the development of prefabricated buildings. The deep factor group risk occurs by influencing other risk factors, leading to a series of risk factors being affected. These factors are usually at the bottom of the model and are the most fundamental factor affecting the prefabricated building supply chain [10].

3.1.2 Key risk factors and control measures

In the prefabricated building supply chain risk factor ISM, fundamental factors will have effects on indirect factors, and then eventually trigger direct factors[11]. In order to ensure and improve the effective and normal implementation of prefabricated construction projects, the prevention and control of fundamental factors should be more important, and reasonable risk control measures should be formulated. The specific measures are as follows:

A) Strictly control the rationality of the design plan.

For prefabricated construction projects, design is the first link of the entire supply chain. Ensuring the quality of the design is the first pass to improve the overall quality of the building. The design unit must not only avoid reasons such as self-understanding and inadequate standard understanding, but also have to communicate with the owner to determine the various needs and maximum budget[12]. Putting the design risk control in place can reduce the occurrence of indirect risks and improve building efficiency.

B) Create a reliable information sharing system.

The prefabricated construction project has multiple levels of participants and multiple channels, and the efficiency of information transmission is low, which is easy to cause information pollution and information distortion [13]. If the building information model BIM can be effectively applied in the project implementation process, the quality of the prefabricated buildings will be greatly improved. With great information communication ability to ensure that better information transmission can be achieved at all stages of the prefabricated building supply chain, can the project be completed on schedule and with high quality.

4 Conclusion

1)After sorting out interview data and related literature, based on the grounded theory method, 20 risk factors of the prefabricated building supply chain were identified. The risk factors were screened by the Delphi method, and the whole stage risk system of the supply chain was constructed, and based on the ISM model. A hierarchical transition model of risk factors is established, and the mechanism and path of influence of risk factors are clarified.

2) Through the analysis of the hierarchical transfer model, it is found that the direct risk factors affecting the prefabricated construction project are safety accidents, high costs and contract disputes, and the deep-level risk factors are the unreasonable design plan and the low degree of information sharing. Different factors will affect each other, and then affect the stability of the system. Emphasis on deep-level key risk management and control can effectively improve construction efficiency.

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