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Research on Investment Risk Management of Chinese Prefabricated Construction Projects Based on a System Dynamics Model

Ming Li, Ganbin Li *, Yanqing Huang and Liyan Deng

School of Tourism and Urban Management, Jiangxi University of Finance & Economics, Nanchang 330013, China; liminglaoshi2017@gmail.com (M.L.); hyq7317@gmail.com (Y.H.); dengly2017@gmail.com (L.D.)

* Correspondence: liganbin2017@gmail.com; Tel.: +86-152-7912-4289

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Abstract: Prefabricated construction, a new direction for the future development of the Chinese construction industry, can maximize the requirements of "green". As a new form of green building, prefabricated construction is of particular interest. On account of the immature development of the green building market in China, the investment risk for prefabricated construction is higher than for traditional architecture. Hence, it is especially important to improve its investment risk identification and management. This study adopts system dynamics and builds a risk identification feedback chart and risk flow chart, to comprehensively identify investment risks that projects in China may face and to process quantitative estimation of investment risk factors. Key factors influencing project investment risks are found, and corresponding measures are pointedly proposed. This paper may provide guidance and a reference for promoting the sound development of prefabricated construction in China.

Keywords: prefabricated construction; investment risk management; system dynamics model

1. Introduction

Prefabricated construction refers to all kinds of constructions that are produced by factories and to buildings produced by an assembly method [1]. Compared with traditional on-site pouring operations of a building project, the construction process can effectively reduce the sewage, harmful gases, dust emissions, and construction noise pollution, and generally reduce the impact of construction on the surroundings. This building method is conducive to the improvement of labor productivity, and the design and the construction methods can enhance the overall quality and energy saving rate of water, and therefore can satisfy the term "green", which promotes the healthy and sustainable development of China's construction industry and meets the need of national economic development [2]. Thus, the development of assembly architecture has become the effective approach to realizing the "five-year energy conservation and environmental protection" plan and low carbon development objective [3]. In September 2016, the general office of the State Council formally issued a document about the guidance on vigorously developing prefabricated construction. In March 2017, the building energy saving and science and technology department of the Ministry of Housing and Urban-Rural Department in China released its working points of promoting the comprehensive development of prefabricated construction. Prefabricated construction, as a form of green building providing energy savings and environmental protection, will be the new direction for the future development of the construction industry in China [4].

However, as a new form of green building, prefabricated construction has its own characteristics, that is its material production and construction method differs greatly from traditional architecture.

Because the current relevant standards are not perfect, the construction and management of the technology are not mature, earthquake resistance and stress performance are poor, research on and development of supporting materials are lacking, and the component production process is backward, prefabricated construction puts forward higher requirements for each stage of the whole life cycle. The risk associated with a prefabricated construction project is more prominent than that of a traditional one. It not only relates to schedule, quality, and cost, but also extends to the pursuit of low carbon, environmental protection, higher requirements, and the environmental sustainability of the development. Therefore, strengthening research on prefabricated construction risk management is important for the promotion of the development of prefabricated buildings in China [5].

On the basis of current characteristics of the development of the prefabricated construction market in China, using the analysis method of system dynamics and the experience of previous studies, this paper analyzes the risk factors of the development of prefabricated construction projects systematically. The key risk factors influencing the prefabricated construction are found, and the corresponding risk management measures are put forward, so as to provide guidance and reference to promote the sound development of prefabricated construction in China. The significance of this paper mainly manifests in the following three points: Firstly, there is a lack of research on prefabrication, and it is necessary to discuss the risk factors of prefabricated construction projects from the perspective of developers. Secondly, system dynamics is a comprehensive scientific tool which helps to find root causes from the inner structure of a system. Thirdly, key factors are found by utilizing system dynamics, and several well-directed suggestions are put forward.

2. Research Method

System dynamics, based on feedback control theory by using computer simulation technology, is a quantitative method to research complicated social and economic systems [6]. Since Professor Forester from Massachusetts Institute of Technology developed the method in the 1950s, it has been successfully applied in many strategies and decision analyses of enterprises, cities, regions, nations, and even the world, and is known as the "strategy and decision laboratory" [7]. In the sense of system methodology, system dynamics is a method uniting the structure, the function, and the history. On account of system theory, it absorbs the essences of cybernetics and information theory, which is a horizontal discipline synthesizing natural science and social science. More specifically, system dynamics mainly includes the following points: Firstly, it regards animate and non-animate systems as information feedback systems, and each of them has the information feedback mechanism; secondly, it divides study subjects into several subsystems, and sets up networks of causalities among these subsystems; Thirdly, the research method of system dynamics involves establishing computer simulation models, flow diagrams, and equations. It offers the basis for drawing up strategies and decision-making.

Construction project risk is an extremely complex system which can be regarded as a form of a natural risk generating system and a group awareness decision management system. The two systems and the various elements of the subsystems interplay and correlate. The continuously developing process (shown in Figure 1), using system dynamics to analyze the risks of prefabricated construction, is scientific and feasible.

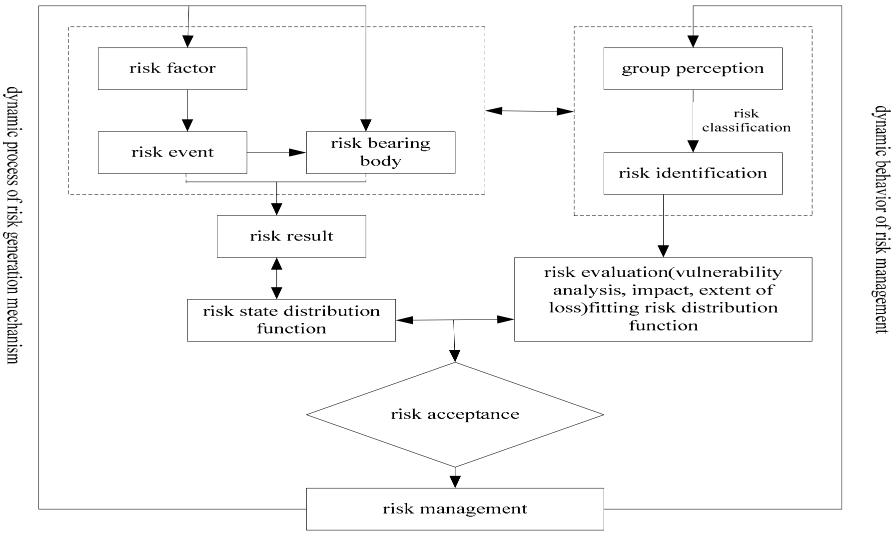

Figure 1. Sketch of risk characterized as a dynamic process.

3. Research Status of Risk Management in Assembly Building

3.1. Risk Characteristics of Fabricated Buildings

As with traditional project risk, the risk of prefabricated construction emphasizes the adverse consequences of the risks to prefabricated construction projects. However, the target system of prefabricated construction has changed and expanded compared with the general construction goal. The risk consequences may affect the economic, environmental, and social goals in the prefabricated construction goal system, which makes the risks of a prefabricated building more prominent than those of a traditional one [8].

First of all, the traditional construction project objectives include quality, progress, investment, and security objectives. Prefabricated construction projects extend to the environment and society, which results in increased risk events. Secondly, compared with short-term goals of traditional construction and mainly risks happening in the construction process, prefabricated construction targets also include many long-term goals, such as the long-term performance of the project, its environmental impact, the example it sets, and so on. Achieving these goals in the entire life cycle of the project means that the prefabricated construction risks are also pertinent to the whole life cycle. Thirdly, prefabricated constructions have the typical expression of economic externality. The long-term benefits are difficult to quantify and cannot be directly reflected. Related systems are not perfect, and in this condition, the risk management difficulty of investors and constructors increases. Fourthly, in the international energy saving and emission reduction environment, while China has formulated a series of policies to promote the development of prefabricated construction, prefabricated construction in its infancy. Foreign risk management regarding prefabricated constructions is not mature either, so experience is limited. Promoting prefabricated construction has various restrictions in China and it increases the risk of prefabricated construction practitioners in China.

3.2. International Research Status

The risk of prefabricated construction has begun to draw international attention and has achieved certain results. Wen et al. pointed out that the technology and management of prefabricated construction are still in immature stages. There are many security risks in the construction process, which results in a certain threat to the staff [9]. Judging from market research, Ganiron found that demand is the key to successful product promotion, and the cost and benefit is the pursuit of customers, so prefabricated construction is subject to market risk [10]. Rahardjo et al. considered Bantul and Bandung in Badan city as research subjects, and their results show that precast systems can save wood, reduce construction costs, and protect the environment, ultimately representing a form of green building, however these were associated with a high price [11]. Elżbieta et al. discussed the prefabricated construction development in Poland, which received low acceptance [12]. Panjehpour et al. thought that although prefabricated construction has many advantages, the designer should consider the problems of prefabricated systems, like the roof and walls, and integrate them into different application systems [13]. Faludi et al. used the whole life cycle assessment model to evaluate the sustainability and optimal performance of prefabricated construction [14]. Through their investigation, Jaillon and Poon found that although the prefabricated building can save time and cost, few people consider the design idea of the whole life cycle, including the removal of flexible materials and efficient use of resources [15]. Ganiron et al. considered that the primary reason why prefabricated construction developed rapidly in developed countries was necessity [10]. Barker et al. proposed a framework of quantitative risk for analysis, in which a model was used to measure the sensitivity of the uncertainty of the basic parameters' probability distributions, as affected by the consequences of extreme events [16]. This approach avoided the human influence factor of an expert assessment method and had a good influence on the risk-related decision making. Alejandro et al. transformed the risk function into an infinite-dimensional Banach space of linear programming and the general simplex algorithm was given [17].

3.3. Chinese Research Status

In comparison with the international status, the development of prefabricated construction in China started later, and therefore related research is also very limited. Shi et al. set Shanghai as an example, and thought that policy, technology, and talent are the key factors restricting prefabricated construction development in Shanghai [18]. Li defined the basic risk variables as risk elements and proposed that the project objectives (such as period, cost, etc.) often fluctuate when the risk elements fluctuate randomly. This kind of transmission is called risk transmission [19]. He also introduced the 3-dimensional model of generalized project risk element transmission theory, in which a risk element transmission analytical model was proposed in order to study the transmission impact of project period risk elements [20]. Based on SWOT, Dai et al. comprehensively analyzed the strengths, weaknesses, opportunities, and threats of prefabricated construction development in China [21]. Li et al. empirically analyzed the existing state of the construction cost in the development of prefabricated construction systems, and discussed differences between economic indices of prefabricated and cast-in-place technologies. They took "high cost" as the bottleneck of prefabricated building development, and the main reason why prefabricated building is expensive [22]. By identifying the risk of investment, Zhang established a risk evaluation index system to obtain the investment risk evaluation system of prefabricated construction [23]. Li et al. quantitatively analyzed the influencing factors of prefabricated construction by utilizing the DEMATEL model, revealing the relationships among various factors and the key influencing factors [5]. Qi et al. used the entropy method to analyze the whole life cycle of prefabricated construction, including decision-making, design, component production, and the transportation, construction, and operation of these five stages [24]. Qi and Zhu combined the characteristics of each stage of the prefabricated construction, constructed the risk evaluation index system, and comprehensively and reasonably determined the prefabricated construction evaluation grade by the hierarchical grey evaluation method [25]. Through the identification of investment risk, Lu established the risk evaluation index system, in order to build an investment risk evaluation system for prefabricated construction [26]. Documents mentioned above have a certain reference value for researching the risk of the development of prefabricated construction in China.

3.4. A Comparison between This Paper and Previous Researches

There is substantial research on the risks that developers face in prefabricated construction projects. Documents considering system dynamics as the research method are of an equally large number. Nevertheless, there is hardly any study combining the risks of prefabricated construction projects and system dynamics. This paper innovatively establishes a system dynamics model for risk identification of prefabricated construction and processes the risk assessment of prefabricated construction projects. Four key factors threating a project's implementation are found, and several suggestions are put forward to properly solve the risks that developers may be confronted with. This paper aims at making a contribution to the prefabricated construction industry in China and even in the world through simulated and quantitative analysis.

4. A System Dynamics Model for Risk Identification of Assembly Building

4.1. System Dynamics Characteristics of Risk

Risk is the combination of the probability and the consequences of an event. It is a complicated and dynamic feedback system, and risk analysis by system dynamics is helpful to obtain a deeper understanding of risk. System dynamics is a kind of qualitative modeling method which emphasizes the combination of qualitative analysis and quantitative analysis. In the process of modeling, deeply analyzing the system can give further understanding of the internal structure of the system, and further insight into the behavior of the system, which is an effective method to solve related problems in complex systems. Due to the dynamic complexity of project risk, the traditional methods and technology cannot effectively identify and deal with the risk of the project. So, utilizing system dynamics method in project risk management, especially in the risk dynamic complexity of a prefabricated construction project, has obvious features and advantages.

4.2. Analysis of Risk Factors in Prefabricated Building

Compared with traditional construction, developers constructing prefabricated buildings face many new risks. Through consulting and comparing the plentiful literature, this paper finally adopts five main risks [27]. These are relevant for the current prefabricated construction industry in China. Detailed analyses are listed below:

(1) Economic risk. Due to new product technology requirements for prefabricated construction, the requirement for imported equipment and materials is also increased. This is very sensitive to fluctuations in international currency exchange rates. Besides, because building materials prices are relatively high, the loan interest rate is larger, and the economic risk that developers bear is thus increased.

(2) Company internal risk. At present, prefabricated construction in China is at the initial stage. Developers have limited knowledge of prefabricated construction. Companies are lacking experienced managers, reference cases, and research objectives. The assessment is not accurate, the market positioning is not clear, and prefabricated construction projects need a lot of money. These factors present risks for investing in and developing prefabricated construction.

(3) Technical risk. Modularization is the foundation of prefabricated construction. The current formation of a modular system in China is still not perfect. Modularization lacks coordination, which affects the standard construction of the assembled building. Parts and components are the key to promoting the development of prefabricated construction. Prefabricated construction requires a high level of production of scientific and technological content, and some production and installation of parts and components must be accurate to the millimeter level. But, most construction enterprises in China lack the scientific and technological capacity to provide this accuracy. On the whole, the development of component systems in China compared with foreign countries with advanced construction industries is relatively backward and lacks the required technical standards. Because prefabricated construction involves the assembly of many large and heavy components at the scene, the construction is difficult. The construction enterprises have often not handled such advanced construction methods, which causes the construction difficulties. Furthermore, the lack of qualified personnel and an experienced management team also seriously affects the quality of the construction and management of the prefabricated construction project.

(4) Policy and legal risk. The relevant laws and regulations and the evaluation standard of green building are not perfect, which leads to higher policy and legal risk of a prefabricated construction project than with a traditional one. Prefabricated construction requires a large number of approval procedures, which are of low. In addition, the government pays less attention to advocacy, public acceptance of prefabricated construction is low, and prefabricated construction may not coordinate with the local humanistic environment, all of which will bring certain risks to the project.

(5) Market risk. At present, the method of prefabricated construction has not been popularized in China, therefore the market is not comprehensively understood. Misunderstandings of some aspects and low carbon building consciousness has seriously hindered the promotion of prefabricated construction. Prefabricated buildings are relatively scarce. It is more expensive and there is a lack of consumers who perceive prefabricated construction as superior. An effective market demand cannot be formed and there is a lack of market incentives, resulting in significant market risks.

4.3. Establishment of a Feedback Model for System Dynamics

During the investment and decision-making period, the risk identification of prefabricated construction projects is performed by developers. The total control layer controls the prefabricated construction project risk and the specific control objectives can be divided into control project risk, quality risk, cost risk, security risk, environmental risk, and green star certification risk. Risk factors influencing the target control are economic risk, technological risk, management risk, natural risk, policy risk, and other risks. Detailed relationships are as shown in Figure 2.

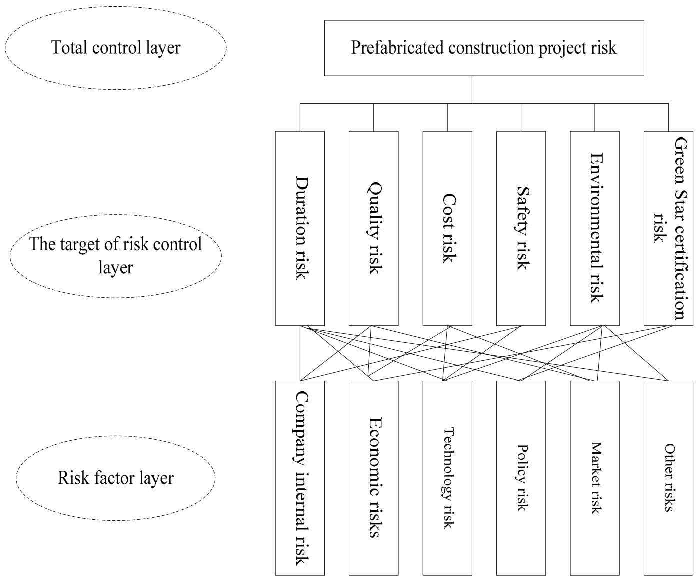

Figure 2. The risk level of the prefabricated construction project from the perspective of developers.

Through the analysis and summary of existing literature and searching and screening the database [28], on the basis of the five risks summed up above, this paper further identifies sub factors, and then analyzes the risks of investment in and construction of a prefabricated construction project that developers may face from the internal and external environments. With the method of system dynamics, using Vensim Personal Learning Edition (PLE) to set up a feedback model (Figure 3) of risk identification in a prefabricated construction project, we developed the tree diagram (Figure 4) of risk causes relating to a prefabricated construction project, which comprehensively identifies the risk factors [29].

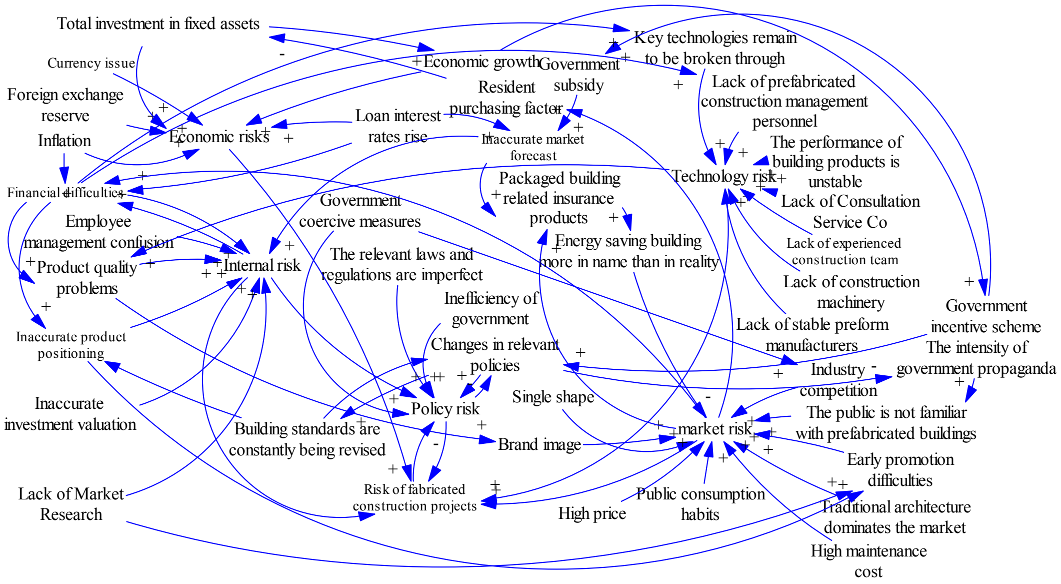

Figure 3. System dynamics risk identification feedback model diagram of a prefabricated construction project.

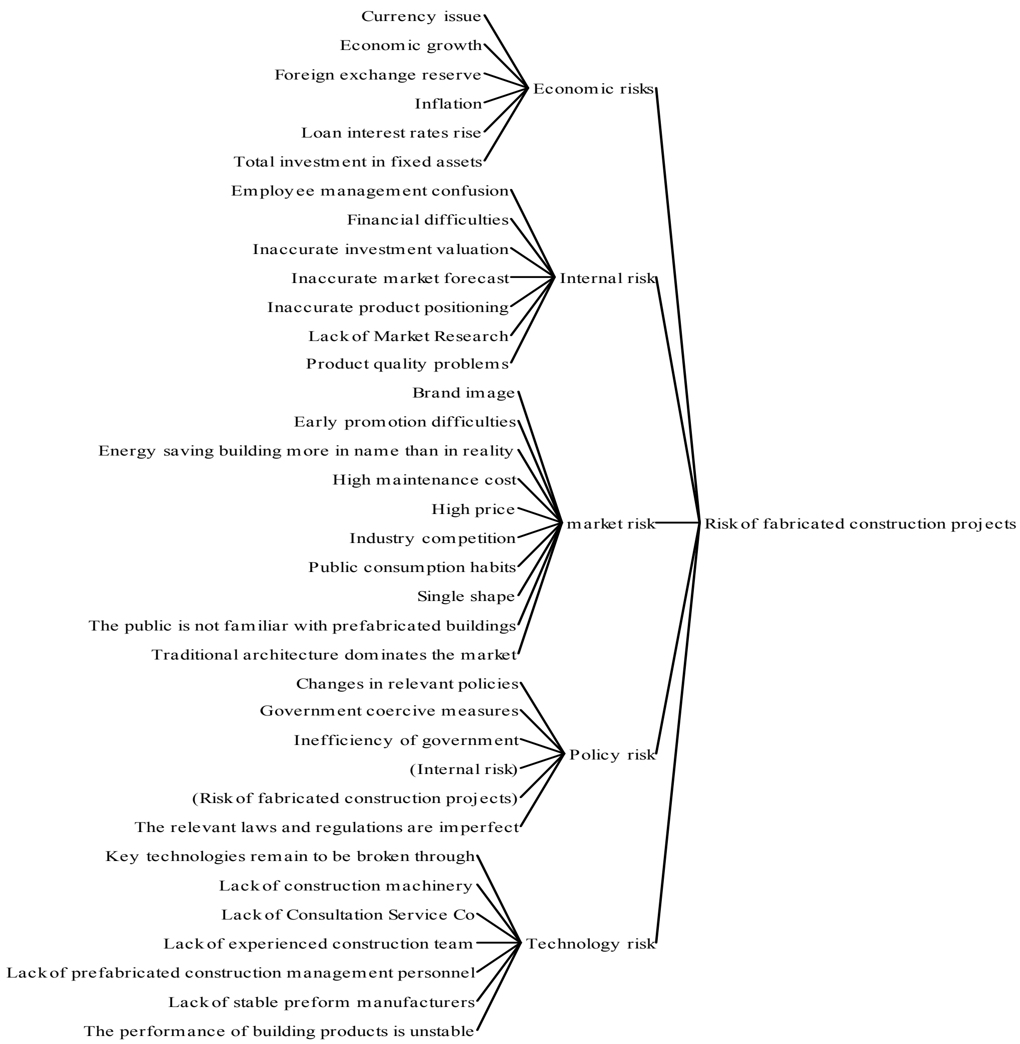

Figure 4. Analysis of risk tree of a prefabricated construction project.

4.4. Identification of Major Risk Paths

According to Section 3.2, it is clear that there are five main risks, including economic risk, company internal risk, technical risk, policy and legal risk, and market risk. By utilizing Vensim PLE, the feedback model is set up as shown in Figure 3. Then, we find these five main risks in Figure 3. Take "economic risk" as an example, click it and then click the button "loops". A pop-up window will be seen which contains 10 loops related to economic risk. The longest loop would be chosen as it is the most detailed one to show their correlation. In conclusion, there are 5 main risk paths in the feedback model:

(1) Internal risk(−)→Financial difficulties(+)→Lack of prefabricated construction management personnel(+)→Technology risk(+)→Product quality problems(+)→Brand image(+)→Market risk(−)→Resident purchasing factor(−)→Total investment in fixed assets(+)→Economic growth(+)→Economic risks(+)→Policy risk(−)→Changes in relevant policies(+)→Building standards are constantly being revised (+)→Inaccurate product positioning(+)→Internal risk(−).

(2) Economic risk(−)→Economic growth(+)→Total investment in fixed assets(−)→Resident purchasing factor(+)→Market risk(−)→Brand image(−)→Product quality problems(−)→Technology risk(+)→Key technologies have not broken through(−)→Financial difficulties(+)→Internal risk(+)→Inaccurate product positioning(−)→Building standards are constantly being revised(+)→Changes in relevant policies(+)→Policy risk(+)→Economic risks(+).

(3) Technology risk(−)→Policy risk(+)→Changes in relevant policies(+)→Building standards are constantly being revised(+)→Inaccurate product positioning(+)→Early promotion difficulties(+)→Market risk(−)→Resident purchasing factor(−)→Total investment in fixed assets(+)→Economic growth(+)→Government incentive scheme(+)→Government subsidy(+)→Inaccurate market forecast(+)→Internal risk(+)→Financial difficulties(+)→Lack of prefabricated construction management personnel(+)→Technology risk(+).

(4) Policy risk(−)→Changes in relevant policies(−)→Building standards are constantly being revised(+)→Inaccurate product positioning(+)→Early promotion difficulties(+)→Market risk(−)→Resident purchasing factor(−)→Total investment in fixed assets(+)→Economic growth(+)→Government incentive scheme(+)→Government subsidy(+)→Inaccurate market forecast(+)→Internal risk(−)→Financial difficulties(+)→Key technologies have not broken through(+)→Technology risk(−)→Policy risk(+).

(5) Market risk(−)→Resident purchasing factor(−)→Total investment in fixed assets(+)→Economic growth(+)→Government incentive scheme(+)→Government subsidy(+)→Inaccurate market forecast(+)→Internal risk(+)→Financial difficulties(+)→Key technologies have not broken through(+)→Technology risk(−)→Policy risk(−)→Changes in relevant policies(+)→The intensity of government propaganda(+)→The public is not familiar with prefabricated buildings(+)→Market risk(+).

5. Risk Assessment of Prefabricated Construction Projects

In order to find out the key risk factors of project risks, estimation and evaluation of the identified project risk factors are needed. The feedback diagram only realizes the application of risk identification, and a flow chart for risk estimation and evaluation of the project risk factors should also be established.

5.1. Risk Assessment Flow Chart Model

On the basis of the established risk feedback diagram and further analyzing the identified risk factors, one can visually present the internal influence relationships among the risk factors. A risk flow chart is constructed by applying the software (Figure 5).

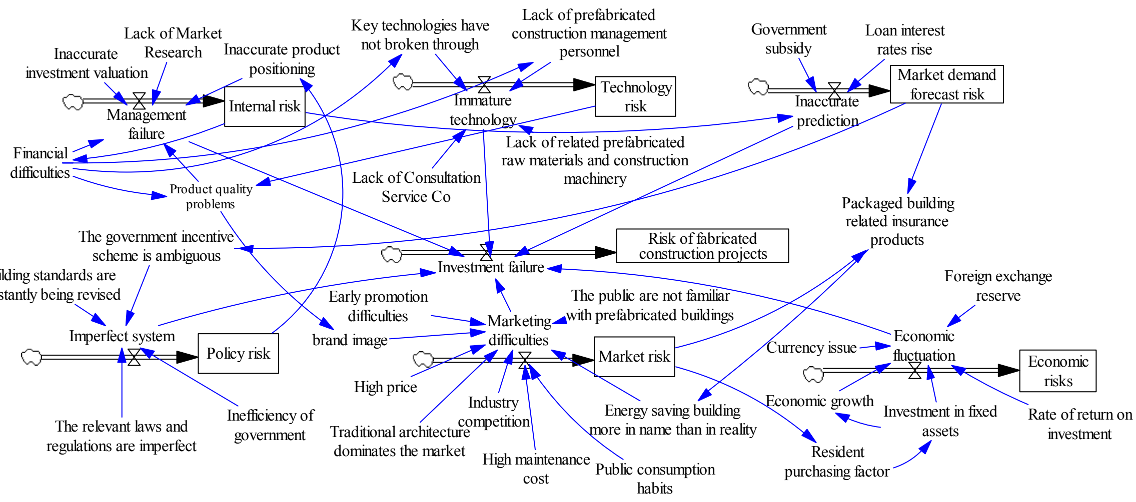

Figure 5. Model risk flow chart.

5.2. Risk Assessment of Factors in a Project

To simplify the analysis, this paper selects some main risk factors from the risk factors involved in models above and eliminates the secondary risk factors in order to assign and process risk estimation [30]. Through comparative analysis, this paper identifies 20 factors as system boundaries. A system boundary is a factor that is only influenced by external factors, rather than internal factors of the system. Among all factors in the model, the volume of currency, foreign exchange reserves, inflation, staff management disorders, investment valuation, lack of market research, the loan interest rate, the government's coercive measures, imperfect laws and regulations, high price, lack of consultation service company, government inefficiency, lack of construction, the dominance of traditional construction machinery, lack of experienced construction teams, lack of stable preform manufacturers, unstable product performance, public consumption habits, and high maintenance cost, are system boundary points.

Scientific valuation of the risk factors is an important step in identifying the key factors affecting the whole system. Risk factor valuation should not only consider the probability they happen but also their impacts on the project. For example, because prefabricated construction in China is in the initial stage, not all aspects of policies are clearly defined. Moreover, market acceptance will affect the income of constructors. The probability of "relevant laws and regulations are not perfect" is great and there is great influence on constructors should the risk be realized. Besides, as the "public consumption habits" factor is relatively high, it will cause a lot of difficulties in the promotion of the prefabricated construction market. The income of constructors will face greater risk, which affects the sustainable, healthy development of the prefabricated construction project. The valuation adopts an expert scoring method, 5 experienced experts from A to E are selected (A is the general manager of Jiangxi Construction Engineering Group Corporation, working for 10 years; B is the engineering manager of China Vanke Co., Ltd. (Shenzhen, China), working for 12 years; C is the marketing manager of China Overseas Property, working for 8 years; D is a professor in the Department of Civil Engineering at Tongji University, working for 20 years; E is the general manager of TAHP Project Management (Beijing) Co., Ltd. (Beijing, China), working for 18 years). After a comprehensive consideration of the probabilities that risk factors happen and their influences on the project, the experts assigned marks to the 20 risk factors. The scores are in the range of 0–1, where 0 means low risk and1 means high risk. The mean value of the scores of the 5 experts is the risk value of each factor, as shown in Table 1.

Table 1. Valuation tables for boundary factors.

No.	Factor	Expert A	Expert B	Expert C	Expert D	Expert E	Score
1	Currency issue	0.2	0.1	0.2	0.3	0.4	0.16
2	Foreign exchange reserve	0.3	0.3	0.2	0.4	0.4	0.24
3	Inflation	0.3	0.2	0.4	0.3	0.2	0.24
4	Employee management confusion	0.5	0.5	0.4	0.5	0.3	0.38
5	Inaccurate investment valuation	0.5	0.6	0.7	0.5	0.6	0.46
6	Lack of Market Research	0.6	0.8	0.8	0.7	0.6	0.58
7	Lending rate	0.8	0.7	0.5	0.7	0.8	0.54
8	Government coercive measures	0.6	0.6	0.7	0.8	0.6	0.54
9	The relevant laws and regulations are imperfect	0.8	0.7	0.8	0.7	0.8	0.60
10	Single shape	0.4	0.4	0.3	0.3	0.2	0.28
11	High price	0.4	0.5	0.7	0.6	0.7	0.44
12	Lack of Consultation Service Co	0.3	0.3	0.4	0.5	0.3	0.30
13	Inefficiency of government	0.4	0.6	0.7	0.4	0.5	0.42
14	Lack of construction machinery	0.7	0.5	0.6	0.4	0.4	0.44
15	Traditional architecture dominates the market	0.6	0.7	0.8	0.8	0.7	0.58
16	Lack of experienced construction team	0.6	0.4	0.6	0.5	0.4	0.42
17	Lack of stable preform manufacturers	0.6	0.7	0.8	0.7	0.6	0.56
18	The product is unstable	0.5	0.6	0.4	0.6	0.5	0.42
19	Public consumption habits	0.8	0.7	0.9	0.7	0.7	0.62
20	High maintenance cost	0.5	0.4	0.3	0.4	0.3	0.32

In the interface of Vensim PLE, setting the type of factor as constant, the above factors' scores are inputted to assign the risk state of the factors. After that, the weights of various risk factors should also be determined. This paper utilizes an entropy method to determine the weight of the risk factors, f_{in} means the ith expert give score to the nth factor, q_{in} is the proportion of features. The ith expert gives the proportion of feature to the nth factor, which is shown as:

$$q_{in} = \frac{f_{in}}{\sum\limits_{i=1}^{5} f_{in}} \tag{1}$$

The entropy of the factor n is k_n:

$$k_n = -\sum_{i=1}^{5} q_i \ln q_i \tag{2}$$

x_n is the coefficient of difference of factor f_{in}, and g_n is the weight of factor:

$$x_n = |1 - k_n| \tag{3}$$

$$g_n = \frac{x_i}{\sum\limits_{i=1}^{5} x_i} \tag{4}$$

After calculation, the results are shown in Table 2.

Table 2. Entropy method to determine the weight of each factor.

Factor	q_{in}					k_n	x_n	g_n
1	0.167	0.083	0.167	0.250	0.333	1.602	0.602	0.064
2	0.188	0.188	0.125	0.250	0.250	1.777	0.777	0.082
3	0.214	0.143	0.286	0.214	0.143	1.733	0.733	0.078
4	0.227	0.227	0.182	0.227	0.136	1.767	0.767	0.081
5	0.172	0.207	0.241	0.172	0.207	1.556	0.556	0.059
6	0.171	0.229	0.229	0.200	0.171	1.220	0.220	0.023
7	0.229	0.200	0.143	0.200	0.229	1.203	0.203	0.021
8	0.182	0.182	0.212	0.242	0.182	1.348	0.348	0.037
9	0.211	0.184	0.211	0.184	0.211	1.035	0.035	0.004
10	0.250	0.250	0.188	0.188	0.125	1.777	0.777	0.082

Table 2. *Cont.*

Factor	q_{in}					k_n	x_n	g_n
11	0.138	0.172	0.241	0.207	0.241	1.519	0.519	0.055
12	0.167	0.167	0.222	0.278	0.167	1.797	0.797	0.084
13	0.154	0.231	0.269	0.154	0.192	1.636	0.636	0.067
14	0.269	0.192	0.231	0.154	0.154	1.636	0.636	0.067
15	0.167	0.194	0.222	0.222	0.194	1.163	0.163	0.017
16	0.240	0.160	0.240	0.200	0.160	1.693	0.693	0.073
17	0.176	0.206	0.235	0.206	0.176	1.291	0.291	0.031
18	0.192	0.231	0.154	0.231	0.192	1.673	0.673	0.071
19	0.211	0.184	0.237	0.184	0.184	1.022	0.022	0.002
20	0.263	0.211	0.158	0.211	0.158	1.802	0.802	0.085

Since the valuations and the weights of the risk factors in critical points are obtained, functional relationships among them can be used to assign other risk factors. In the Vensim PLE interface, right-click in the Equations interface to select risk factors, choose the type of auxiliary variables, then input the function relationships between them one by one in the edit equation box. For example, for "policy risk" factor, input "coercive measures * 0.037 + inefficient government * 0.067 + changing related policy + imperfect laws and regulations * 0.004", so as to realize the valuation of policy risk factor. The other equation models of sub-blocks are shown in Table 3.

Table 3. Equation model of each sub-block.

Sub Block	Equation Model
Market demand forecast risk	Government subsidy + Loan interest rates rise * 0.021
Internal risk	Inaccurate product positioning + Product quality problems + Employee management confusion * 0.081 + Inaccurate investment valuation * 0.059 + Lack of Market Research * 0.023 + Financial difficulties + The market demand forecast is not accurate
Economic risks	Total investment in fixed assets + Foreign exchange reserve * 0.082 + Economic growth + Currency issue * 0.064 + Loan interest rates rise * 0.021 + Inflation * 0.078
Technology risk	Key technologies have not broken through + The performance of building products is unstable * 0.071 + Lack of Consultation Service Co * 0.084 + Lack of construction machinery * 0.067 + Lack of experienced construction team * 0.073 + Lack of stable preform manufacturers * 0.031 + Lack of prefabricated construction management personnel
Policy risk	Government coercive measures * 0.037 + Inefficiency of government * 0.067 + Changes in relevant policies + The relevant laws and regulations are imperfect * 0.004
Market risk	High price * 0.055 + Traditional architecture dominates the market * 0.017 + The public are not familiar with prefabricated buildings + Public consumption habits * 0.002 + Early promotion difficulties + Industry competition + Brand image + High maintenance cost * 0.085 + Energy saving building more in name than in reality + Single shape * 0.082

5.3. Analysis and Evaluation of the Valuation Results of Risk Factors

By analyzing the functional relationships of risk factors, the related sensitive factors can be found. And, the corresponding risk values of risk factors can be obtained by making appropriate adjustments to the sensitive factors. After some adjustment to sensitive factors, several high risk factors will eventually be gained, such as "high price", "public consumption habits", "relevant laws and regulations are not perfect", and "key technology breakthroughs", and the tendencies of their risk states to change with the adjustment of sensitive factors is shown in Figure 6.

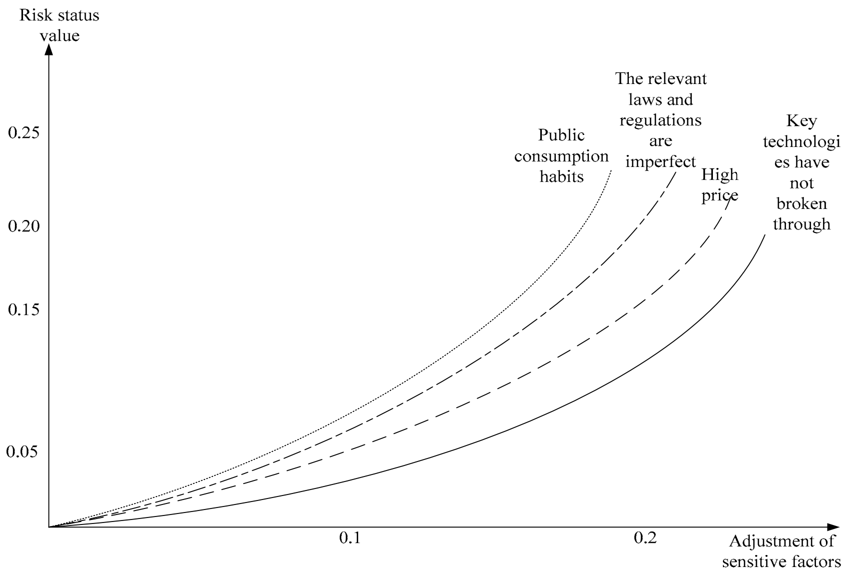

Figure 6. Risk level adjustment under sensitive factors.

6. Practical Implication

After the system dynamics model and risk assessment of prefabricated construction projects were completed, several typical developers in China accepted an interview, including Greenland Group and Vanke. It was found that their responses matched extremely well with the research results of this paper. Several high risk factors like "high price", "public consumption habits", "relevant laws and regulations are not perfect", and "key technology breakthroughs" are the actual problems for these companies. The principles of these companies expressed their interests to risk response strategies below. With limited time to continue follow-up investigation, the contribution that this paper brings to the industry will be presented in follow-up studies.

7. Risk Response Strategy

Through the analysis of the prefabricated construction project risk system dynamics model, it can be revealed that the market risk has the greatest impact on the project. At the same time, the risk factors of public consumption habits, the high price, the key technology breakthroughs, and the fact that related laws and regulations are not perfect greatly contribute to the investment of prefabricated construction projects. For those identified factors having high risks, targeted measures need to be taken to reduce their impact on the project, so as to avoid unnecessary losses.

A new product and a new thing will make a "stimulus" to the public, as sometimes it is difficult for consumers to change their inherent cognitive concepts and consumer habits. Prefabricated construction is only at the beginning stage in China, and the public still lacks awareness. If prefabricated construction products are launched in the market, consumers may be irresolute and buying determination may be affected. As for the constructors, only improvement of the quality of their products can gain consumers' trust. In the meantime, the government should strengthen the propaganda and a number of incentive policies should be formulated as soon as possible. In this way, the consumption could be stimulated, and the prefabricated construction market's influence could be improved.

As prefabricated construction uses precast concrete panels, a large yard area, ancillary equipment, and tools are required. The costs of material transportation and lifting are high, which leads to the high sale price of the finished product. This is an essential factor restricting large-scale development of prefabricated construction. The constructors can only improve construction technology, improve management efficiency, and reduce the cost of enterprise. At the same time, the government should also give some subsidies to producers and support the development of prefabricated buildings in the initial stages of development.

Technological progress is the key to improving the efficiency of construction and is the most effective way to reduce the construction cost. Inferior technology and lack of technological talent are bottlenecks of large-scale prefabricated construction development. Constructors should strengthen their cooperation and invest in scientific research in order to innovate and make breakthroughs in construction technology. Countries should develop platforms for the planning of science and technology innovation and improve the think tanks of industry experts to enhance the technological innovation capability of the industry.

A perfect prefabricated construction market mechanism would guarantee the healthy development of prefabricated construction. The government should introduce some specific action programs relating to prefabricated construction, improve the standard system of prefabricated construction technology, carry out an assessment of the prefabricated construction technology system and the product's promotion, make technical standards of prefabricated construction, enhance the assembled capacity of prefabricated construction, create a prefabricated construction demonstration city to establish an industrial base, and strengthen the personnel working on prefabricated construction projects. By introducing timely incentive schemes which are practical, scientific, and reasonable and by strengthening the guidance of the market, the healthy and rapid development of prefabricated construction can be promoted.

8. Conclusions

Although it is essential to research the risk management of prefabricated construction projects in China, especially from the perspective of the developers, until now such research has been scarce. Moreover, system dynamics is a scientific and comprehensive research method which helps to find the key factors that influence prefabricated construction projects in China. Under these premises and based on the risks the construction unit may face when choosing to invest in and develop a prefabricated construction project, this paper builds a risk identification feedback model diagram and risk flow chart of prefabricated construction project by system dynamics. By means of assignment and analysis of the critical points involved in the networks and further through the functional relationships among the factors, we identify that the high price, the public consumption habits, the fact that the laws and regulations are not perfect, the key technology breakthroughs, are the 4 key factors influencing prefabricated construction project risk. Specific risk response proposals for these key factors are put forward.

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References

1. People's Republic of China Ministry of Housing and Urban Rural Development. *Technical Specification for Fabricated Concrete Structures: JGJ1—2014*; China Construction Industry Press: Beijing, China, 2014. (In Chinese)
2. Li, T.; Yuan, Y.; Zhang, M. Application of BIM and RBID in life cycle management of assembly type building. *J. Eng. Manag.* **2012**, *26*, 28–32. (In Chinese)
3. Qi, B.; Zhu, Y.; Ma, B.; Liu, S. Study on the method of comprehensive benefit analysis of modular architecture. *Constr. Technol.* **2016**, *45*, 39–43. (In Chinese)

4. Liu, J. Research on synthetic benefit analysis method of assembly building. *Eng. Technol.* **2016**, *48*, 303. (In Chinese)
5. Li, K.; Qi, B.; Wang, M.; Li, C. Analysis of constraints on assembly building development based on DEMATEL. *Resid. Ind.* **2013**, *8*, 49–51. (In Chinese)
6. Yuan, Y.; Yan, G.; Wang, A.; Zhang, M. Application of system dynamics in construction project risk identification. *Pract. Cognit. Math.* **2010**, *40*, 99–106. (In Chinese)
7. Chai, G.; Xu, Y. Systematic dynamics analysis of construction safety risk of subway project from the perspective of progress. *Sci. Technol. Manag. Res.* **2016**, *36*, 85–90. (In Chinese)
8. Wan, X. Study on Risk Assessment and Share of Green Construction Projects in China Based on Questionnaire Survey and Expert Interview. Master's Thesis, Huaqiao University, Xiamen, China, 2011. (In Chinese)
9. Wen, M.; Wang, H.; Wu, F. The Safety Risk Management of Prefabricated Residential Building. *Sichuan Build. Mater.* **2015**, *5*, 262–264. (In Chinese)
10. Ganiron, T.U. Development and Efficiency of Prefabricated Building Components. *Int. J. Smart Home* **2016**, *10*, 85–94. [CrossRef]
11. Rahardjo, H.A.; Priyasambada; Dinariana, D. Towards Green Building with Prefabricated Systems on Flat Development in Indonesia. *IACSIT Int. J. Eng. Technol.* **2016**, *8*, 1–5. [CrossRef]
12. Elżbieta, R.-Z.; Monika, G. Studies of the Prefabricated Housing Construction Market in Poland. *Sel. Sci. Pap. J. Civ. Eng.* **2014**, *9*, 13–26.
13. Panjehpour, M.; Ali, A.; Abdullah, A. A review of prefab home and relevant issues. *Constr. J. Civ. Eng. Res.* **2013**, *14*, 53–60.
14. Faludi, J.; Lepech, M.D.; Loisos, G. Using Life Cycle Assessment Methods To Guide Architectural Decision-Making For Sustainable Prefabricated Modular Buildings. *J. Green Build.* **2012**, *7*, 151–170. [CrossRef]
15. Jaillon, L.; Poon, C.-S. Design issues of using prefabrication in Hong Kong building construction. *Constr. Manag. Econ.* **2010**, *28*, 1025–1042. [CrossRef]
16. Barker, K.; Haimes, Y.Y. Assessing uncertainty in extreme events: Applications to risk-based decision making in interdependent infrastructure sectors. *Reliab. Eng. Syst. Saf.* **2009**, *94*, 819–829. [CrossRef]
17. Alejandro, B.; Balbás, R.; Mayoral, S. Portfolio choice and optimal hedging with general risk functions: A simplex-like algorithm. *Eur. J. Oper. Res.* **2009**, *192*, 603–620.
18. Shi, J.; Tang, J.; Zhang, K. Study on and Countermeasure for Development of Prefabricated Building of Shanghai. *Hous. Sci.* **2014**, *11*, 1–5. (In Chinese)
19. Li, C.; Wang, L. Research on the Risk Element Transmission Analytic Model of Construction Network Planning Project. *Chin. J. Manag. Sci.* **2007**, *15*, 108–113. (In Chinese)
20. Li, C.; Zhang, L. Research on Multi-risk Element Transmission Model of Enterprise Project Chain. In Proceedings of the 2009 International Conference on Information Management, Innovation Management and Industrial Engineering, Xi'an, China, 26–27 December 2009.
21. Dai, C.; Xu, X.; Zhang, L.; Wang, S. SWOT Analysis of Prefabricated Concrete Building Development in China. *Constr. Econ.* **2015**, *36*, 10–13. (In Chinese)
22. Li, L.; Xiao, Z.; Fu, X. Analysis on Construction Cost of Prefabricated Building. *Constr. Econ.* **2014**, *35*, 63–67. (In Chinese)
23. Zhang, J. Risk analysis of investment in prefabricated building in Chinese market. *Financ. Econ. (Acad. Ed.)* **2014**, *11*, 99. (In Chinese)
24. Qi, B.; Zhu, Y.; Fan, W. Prefabricated construction method to identify life cycle risk factors. *J. Shenyang Constr. Univ. (Soc. Sci. Ed.)* **2016**, *3*, 257–261. (In Chinese)
25. Qi, B.; Zhu, Y. Study on risk assessment method of assembled building. *Eng. Cost Manag.* **2015**, *4*, 30–33. (In Chinese)
26. Lu, L. Risk analysis of investment in prefabricated building in China market. *Archit. Eng. Technol. Des.* **2016**, *15*. (In Chinese) [CrossRef]
27. Wang, J.; Qin, X.; Wan, X. Risk factors identification and risk path analysis on green building project. *Constr. Technol.* **2012**, *41*, 30–34. (In Chinese)
28. Chang, L.; Wang, E. Study on the risk of green building decision-making. *J. Eng. Manag.* **2016**, *30*, 86–90. (In Chinese)

29. Wang, J.; Qin, X.; Wan, X. Identification of risk factors and analysis of risk path of green construction project. *Constr. Technol.* **2012**, *41*, 30–34. (In Chinese)
30. Ceng, X.; Chen, J.; Lu, F. Investment risk assessment of photovoltaic construction project based on Entropy-Topsis model. *Sci. Technol. Manag. Res.* **2015**, *2*, 32–34. (In Chinese)