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Cooperative game amongst prefabricated building chain stakeholders based on improved Shapley value method

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Abstract: The cooperation among stakeholders at all nodes is the premise of the stable operation of the prefabricated building chain and the key factor for the stable development of the prefabricated building industry. The cooperation among stakeholders is inseparable from a reasonable and effective benefit distribution mechanism. Firstly, analyse the prefabricated building chain and the cooperative relationship among stakeholders. Secondly, investigate the influencing factors of interest distribution of the prefabricating project and put forward the distribution principles. Finally, based on the cooperative game theory, the Shapley value method of the prefabricated building chain model is used to distribute the benefits. At the same time, considering the influencing factors of profit distribution, the entropy weight method is used to improve the model. Therefore, it improves the rationality and objectivity of the benefit distribution model and makes up for the theoretical vacancy of the benefit distribution of the prefabricated building industry chain.

Keywords: prefabricated building chain; stakeholder; Shapley value method; entropy weight method; cooperative game.

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1 Introduction

The significant growth in the number of prefabricated buildings is evident in all provinces, cities and enterprises. However, the prefabricated building chain is currently underdeveloped, and the interest distribution among stakeholders at all nodes of the industrial chain is unreasonable, leading to the failure of related enterprises to combine and integrate and jointly play a synergistic effect.

To solve the problem of interest distribution, most scholars at home and abroad use the Shapley value method. Through such a method, the allocation of the interests of union members can reflect the degree of their contribution to the alliance general objective to avoid the distribution of egalitarianism. This method is more reasonable and fair than any distribution method based solely on the value of resource input, the efficiency of resource allocation and the combination of the two, and it also reflects the process of mutual cooperation and gaming among all members (Shapley, 1953). However, Shapley does not consider the risk-sharing factors of alliance members, implying the assumption of equal risk sharing among them. Therefore, when the degree of risk sharing among alliance members is different, the benefit scheme based on Shapley value method must be moderately modified according to the magnitude of risk sharing. Owen (1968) added weights following Shapley

and further perfected the theory. Xue et al. (2020) modified the model by using the Shapley value method to study the benefit distribution scheme of the relevant parties of green building, thus promoting its great development. Chen and Cheng (2020) combined uncertain Analytic Hierarchy Process (AHP) and set pair analysis to modify the weights of the influencing factors of benefit distribution. A benefit distribution model with an improved Shapley value was also built to provide theoretical basis for the benefit distribution among various subjects of Public-Private Partnership (PPP) projects. Shu et al. (2020) took Jilin Province as an example to build a corn industry chain and used Shapley value method to explore the cooperation game and benefit distribution of the main players in the industry chain, promote effective cooperation between the main bodies of the industry chain and improve the quality and efficiency of the corn industry. Duan et al. (2019) introduced the characteristics of the prefabricated building chain and the characteristics and applicability of the cooperative game by using the Shapley value model. They pointed out that cooperative game theory is fully applicable to the interest distribution among the interests related to the prefabricated building chain.

This article constructs the prefabricated building chain, analyses its characteristics and the cooperative relationship between stakeholders at each node and constructs a benefit distribution model of the prefabricated building chain on the basis of the Shapley value method by analysing the influencing factors and principles of benefit distribution using the entropy weight method. The law of rights is revised to improve the rationality and objectivity of the benefit distribution model.

2 Analysis of the prefabricated building chain and its stakeholders

2.1 Composition of the prefabricated building chain

The prefabricated building chain is a dynamic value-added chain with prefabricated buildings as the object, various stakeholders as the carrier and upper-, middle- and lower-downstream enterprises that influence and depend on one another in the direction of risk sharing and benefit sharing (Qi et al., 2015). Its nodes can be divided into upstream, middle, downstream and terminal stages. The specific contents of each stage are shown in Table 1.

In the whole prefabricated building industrial chain, corresponding stakeholder enterprises exist at each node. The specific corresponding contents are presented in Table 2.

The entire prefabricated building industrial chain comprises the above nodes, and each node has a different corresponding enterprise, that is, each link of the industrial chain involves corresponding stakeholders. However, at the present stage, the prefabricated building industry is in its early stage of development, with inadequate industrial chain development, poor cooperative synergies among various stakeholders and unreasonable benefit distribution, all of which restrict the rapid development of the prefabricated building industry. Based on the above problems and analysis, this study constructs the prefabricated construction industry chain and analyses the cooperation relationship among major stakeholders, as illustrated in Figure 1.

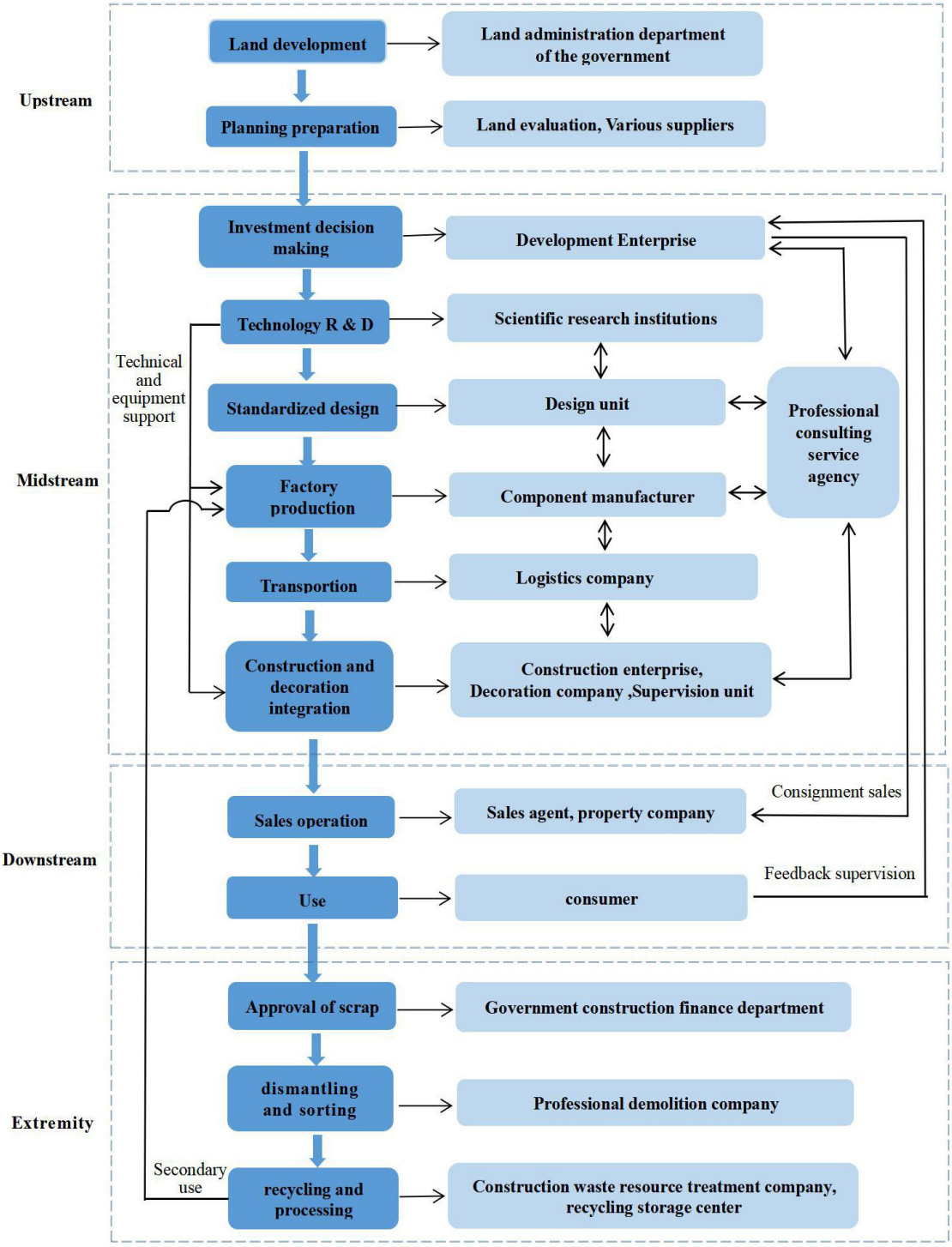
Table 1 Content table of node composition of prefabricated building chain

Upstream (Supply)	*Midstream (Production)*	*Downstream (Sales service)*	*Extremity (Recycle)*
Land reserve and development.	Investment decision making.	Sales and operation.	Demolition and scrap.
Building materials production and circulation.	Technology R & D.	Consumers use.	Recycling of construction waste.
Mould design, production and circulation.	Standardised design.		
Sleeve and grouting material production testing and circulation.	Factory production.		
Large tower cranes and other equipment leasing.	Parts and components transportation.		
	Integration of construction and decoration.		

Table 2 Units involved in prefabricated building chain table

Upstream (Supply)	*Midstream (Production)*	*Downstream (Sales service)*	*Extremity (Recycle)*
Land administration department of the government.	Development enterprise.	Operating unit.	Government construction finance department.
Land evaluation agency.	Advisory Service Agency.	Sales company.	Building demolition Company.
Building material supplier.	Design unit.	Property company.	Steel recycling Company.
Production equipment supplier.	Component manufacturer.		Component crushing Company.
Mold supplier.	Logistics company.		Construction waste resource treatment company.
Sleeve and grouting material supplier.	Construction enterprises.		Recycling storage centre.
Testing institutions.	Decoration company.		
Tower crane lessor.	Supervision unit.		

Figure 1 Industrial chain of prefabricated building



The prefabricated building chain runs through the entire life cycle of prefabricated buildings and is divided into 13 chain links, from land development, planning preparation, investment decision making, standardised design, factory production, transportation, construction and decoration integration to market sales and property. From management to the approval of scrapping, dismantling and sorting, recycling and processing, the industry chain has high-integration requirements for each participant and requires organic coordination among all participants (Yang et al., 2016).

The upstream is the supply link, including land development and preliminary planning preparation and is responsible for supplying the midstream with the land, materials and equipment necessary for the construction of prefabricated buildings. Specifically, the upstream involves land reserve and development, building material production and circulation, mould design, production and circulation, sleeve and grout production testing and circulation, large-scale tower crane and other equipment leasing.

The middle stream is the production link, including investment decision making, technology research and development (R&D), standardised design, factory production, transportation and construction and decoration integration. This link is responsible for the production of prefabricated buildings on the basis of the land, equipment and materials provided by the upstream. The middle stream is the core part of the industrial chain. In this link, professional consulting service institutions connect development enterprises, design units, material component supply enterprises and construction enterprises to facilitate information exchange and problem feedback among them in an orderly manner and reduce the problem of disconnection among the main bodies of the existing industrial chain. In the production process, the technical R&D link provides technical and equipment support for the integration of factory production, construction and decoration, whereas the R&D institute provides new design ideas to the design unit, which feeds back the parts that must be developed in the design to the R&D organisation and provides new component production schemes to the prefabricated component factory; components enter the transportation link after the production of prefabricated part factory; then, construction enterprises and decoration companies realise the final production of prefabricated buildings; finally, development enterprises entrust the finished prefabricated buildings to professional sales teams and property companies for sales operation and management. The whole process is closely linked with one another, with smooth information exchange and timely feedback, which greatly promotes the cooperation among all stakeholders in the key link of the industrial chain and lays a foundation for the distribution of benefits of the industrial chain (Chen, 2019).

The downstream is the sales and service segment, which mainly consists of the sales and operation; consumers use two chains, which are responsible for the sales and operation of prefabricated buildings. In this part, before a user makes a purchase, a sales agent first signs the commodity purchase contract, including the residential quality guarantee certificate, the residential operation manual and other documents, clarifies the quality warranty responsibility and dispute handling methods and establishes the user supervision mechanism to facilitate feedback and supervision in the later period.

The end is the demolition and recycling link, which mainly includes three chain links, namely, approval and scrapping, demolition and sorting and recycling. It is responsible for the demolition and recycling of construction waste after the use of prefabricated buildings. A recycling storage centre is established to return materials or components that can be repeatedly processed and recycled to the component processing plant for secondary use, maintain the green and environmental protection of prefabricated buildings and promote their sustainable development.

Through the above stages, the development, design, production, transportation, construction, sales, use and recycling of prefabricated buildings form an organic whole. Each stage is closely linked to the pursuit of maximising economic, environmental and social benefits.

2.2 Definition of stakeholders in the prefabricated building chain

In the prefabricated building chain, each stakeholder has different contributions to the added value of the industry chain and the benefits they receive; as the development directions of prefabricated buildings, market demands and national policies change, they also make timely and appropriate adjustments to form an adaptable dynamic chain (Mints and Kamyshnykova, 2021). Through field research and visit, the above stakeholders are divided into key stakeholders, important stakeholders, general stakeholders and marginal stakeholders in terms of their roles in prefabricated buildings, intensity of risk bearing and degree of benefit (Wu, 2005), as shown in Table 3.

The four levels of stakeholders have different goals and instinctively seek to maximise their own interests in the process of cooperation (Freeman and Evan, 1990). Therefore, avoiding conflicts is difficult when distributing the overall interests of the prefabricated building chain, and the enthusiasm of each enterprise to cooperate becomes worse. The disconnect between the upper and lower nodes of the industry chain and the low degree of information sharing and collaborative operations severely restricts the production efficiency and quality of prefabricated buildings throughout the life cycle, which is not conducive to the continuous improvement of industry productivity.

2.3 Connotation of benefit distribution in prefabricated building chain

The carrier of the prefabricated building chain is the stakeholders of each node, and its common goal is to maintain the healthy operation and sustainable development of the industrial chain in order to obtain greater profits.

Table 3 Classification table of prefabricated building chain stakeholders

Key stakeholders	*important stakeholders*	*General stakeholders*	*Marginal stakeholder*
The development enterprise.	The government department.	Research and development institutions.	Building demolition Company.
Construction enterprises	Supervision unit.	Advisory service agency.	Construction waste disposal company.
Design units.	All kinds of suppliers such as material mould.	Logistics company.	
Component. manufacturer.		Operation, sales, property management company.	

Compared with the self-management of each stakeholder, the overall management of the prefabricated building chain is more difficult, at the same time, the overall benefit distribution of the in chain is also difficult to the internal benefit distribution management. The benefits obtained from the whole chain can be divided into tangible interests and intangible interests, which include profits, technological achievements, product income, service income, technology transfer income and so on. Intangible interests include brand trademark, corporate reputation, social image, learning experience, etc.

The problem of benefit distribution in the industrial chain means that all stakeholders improve their interests by increasing their own input or contribution under the contract of benefit distribution scheme. At present, the key is to find a fair and just method of interest distribution to solve the problem, and to obtain greater profits by adopting effective benefit distribution strategy, designing reasonable interest distribution mechanism and encouraging stakeholders to increase their own investment and to promote the sustainable and stable development of the industry.

2.4 Factors influencing the benefit distribution of prefabricated building chain stakeholders

2.4.1 Position within the industry chain

The prefabricated building chain is a dynamic value-added chain that serves prefabricated buildings. Its length is long because each member has a different degree of interest related to the industry chain; the status of each member is obviously different. Evidently, key stakeholders have more voice in benefit sharing than other stakeholders, followed by important stakeholders and general stakeholders and marginal stakeholders are the worst.

2.4.2 Risk-sharing size

One of the basic principles for the smooth and continuous operation of the prefabricated building chain is 'risk sharing and benefit sharing.' The risks of prefabricated buildings mainly include cost risk, design risk, technical risk, construction safety risk, market risk, information transmission risk, fault risk and force majeure risk. In the construction of prefabricated buildings, different members of the industrial chain face various risks of different sizes and types; the more risks they undertake, the more likely they gain benefits. That is, the greater the risks borne by different stakeholders, the higher the costs to balance the risks and the greater the expected benefits. Therefore, risk sharing is also one of the important factors affecting the benefit distribution of prefabricated building chain stakeholders (Duan, 2019).

2.4.3 Contribution ratio

Great differences are observed in the capabilities, core competitiveness and resources invested in the construction process of each member of the prefabricated building chain. The construction of a prefabricated building project requires a large amount of capital to be invested in technology R&D, professional design and material supply in the early stage. The funds of each member vary in amount due to different tasks. In the middle and late stages of construction, especially in the construction stage, some mistakes may occur due to immature technology and other reasons and the funds and time paid by each member to solve problems vary in amount. In general, the contribution of industry chain members to the industry chain alliance becomes the premise and basis of benefit distribution. Different members contribute to the benefits of the industry chain in various proportions; thus, the expected benefits are naturally different. The more contributions they make, the more expected benefits they receive. Therefore, the contribution ratio is a major factor affecting the benefit distribution of prefabricated building chain stakeholders.

2.4.4 Collaboration degree

The prefabricated building chain has many relationships with different levels, upstream and downstream relationships and mutual value exchanges. The cooperation degree of each member in the industry chain has a deep impact on the smooth operation of the industry chain; such a degree is also a major factor affecting the benefit distribution in the industry chain. The higher the enthusiasm for cooperation between members and their associated enterprises, the higher the collaboration degree, the more the overall benefits created by the industry chain, the greater the interest of the main body of each chain link and the easier the benefit distribution within the industry chain. Members with a high cooperation degree can obtain higher benefits than other members with a low cooperation degree to stimulate the enthusiasm of each member for cooperation and promote the fair and reasonable distribution of benefits.

2.5 Principle of benefit distribution for prefabricated building chain stakeholders

2.5.1 Benefit sharing, mutual benefit and win-win situation

Benefit sharing and mutual benefit are the most basic principles to be observed in the benefit distribution of prefabricated building chain stakeholders. The prefabricated building chain is an alliance of interests. All of its members serve the prefabricated building project. They form a whole, each one is prosperous and everyone loses. At the same time, game theory indicates that the benefits gained by the members after joining the cooperative alliance should be equal to those obtained before joining the cooperative alliance. All members should share the values and benefits created by the whole chain in the principle of mutual benefit and win-win situation, and each member is indispensable.

2.5.2 Fair, reasonable and scientific distribution

The second principle of interest distribution among stakeholders in the prefabricated building chain is 'fair,

reasonable and scientific distribution'. The benefits of the prefabricated building chain alliance come from the contributions and cooperation of all members. Therefore, the principle of fairness and reasonableness requires that the process of benefit distribution, regardless of the overall profit of the industry chain, must be based on the status of each member in the industry chain. The risk-sharing size, contribution proportion, cooperation degree and other factors should be considered for fair distribution. This consideration helps increase the enthusiasm of alliance members, reduce opportunistic behaviour in the alliance and increase the overall benefits of the alliance. At the same time, the principle of scientific distribution should be considered. Industrial chain benefits must be distributed using a scientific method and through a formal process. Although key stakeholders, such as development enterprises, are in a dominant position in the interest distribution, such a distribution is related to the critical interests of all members of the entire industrial chain; therefore, the distribution scheme must be scientific and reasonable to avoid bias.

2.5.3 Principles of democratic decision making and consultation

Benefit distribution is the most sensitive and conflict-prone issue in the industry chain alliance. In this process, each member has his own interest demands, and the differences in the culture and management system of each member have different degrees. Obstacles also exist in the exchanges of technology and knowledge, inevitably leading to contradictions and disputes. At this time, all members must follow the principle of consultation, focus on the overall situation and negotiate and resolve disputes in a cooperative manner to ensure the normal progress of the interest distribution in the industry chain.

2.5.4 Principle of linking benefits and risks

According to Sub-section 2.3.2, the risk-sharing size is an important factor affecting the benefit distribution in the industry chain. The prefabricated building chain is a huge system with complexity and risk. Each member is in the industry chain alliance due to differences in statuses and responsibilities. The degree of risk sharing assumed is different, and differences must exist in the risk compensation received. Owing to the uncertainty of technology and market environment, the core members of the industry chain alliance more likely face risks and bear losses; meanwhile, marginal stakeholders less likely bear failure when facing risks.

2.5.5 Principle of open and transparent information

The benefit distribution of the prefabricated building chain is an activity that every stakeholder participates in and is related to the critical interests of each member. This process must be conducted in accordance with multiple links, such as data indicators and distribution methods. That is, from plan formation to its implementation at the end of the entire process, it must be ensured that all members can fully obtain open and transparent information, and that no problems, such as information hiding or even black-box operation, can occur.

3 Construction of the stakeholder benefit distribution model in the prefabricated building chain

3.1 Mathematical model of Shapley value method based on cooperative game

A cooperative game is a type of game in which participants can jointly reach a binding and enforceable agreement. The most important thing in a cooperative game is alliance and distribution. The income distributed by each participant from the alliance happens to be the maximum total income of various alliance forms, and the income distributed by each participant from the alliance is not less than the income from independent operations (Balza-Franco et al., 2017).

In the interest distribution problem of the prefabricated building chain, the multiparty cooperative game problem of the stakeholders of each node of the industry chain is the multiparty unlimited repeated game problem (Dong and Zhang, 2015).

Assuming that n stakeholders exist in the cooperative game of the prefabricated building chain, it is expressed by set $N=\{1,2,\ldots,n\}$. Any subset S of N is called an alliance. $V(S)$ is regarded as the characteristic function of alliance S and represents the income of alliance S. The nature of $V(S)$ is as follows:

1 $V(\varnothing)=0$, That is, the benefit is 0 when no cooperation exists among stakeholders.

2 $V(S_1\cup S_2)\geq V(S_1)+V(S_2), V(S_1\cap S_2)=\varnothing$, That is, the benefits of cooperation between two parties are greater than the sum of their individual benefits.

In the cooperative game problem of the benefit distribution of the prefabricated building chain, φ_i represents the distribution of income of the i-th member under cooperation N. The specific formula is as follows:

$$\varphi_i \sum_{S\in S_i} W\left(|S|\right)\left[V(S)-V\left(S/\{i\}\right)\right], \quad i=1,2...,n \tag{1}$$

$$W\left(|S|\right)=\frac{\left(n-|S|\right)!\left(|S|-1\right)}{n!} \tag{2}$$

Among them, S_i is all the subsets of member i in set N; $|s|$ is the number of elements in subset S; $W\left(|S|\right)$ is a weighting factor, which represents the probability of stakeholder i participating in alliance S; $V(S)$ is the benefit of subset S; $V\left(S/\{i\}\right)$ is the benefit that can be obtained after removing stakeholder i from subset S; the difference between $V(S)$ and $V\left(S/\{i\}\right)$ represents the contribution of stakeholder i to the benefit of subset S.

3.2 Improved mathematical model of Shapley value method based on entropy weight method

3.2.1 Min-Max normalise the original data matrix

Min-Max normalisation, also known as discrete standardisation, is a linear transformation of the original data, mapping the data to [0, 1] (Ma and Wang, 2006). Deviation standardisation can retain the existing relationship in the original data but can eliminate the dimension and the data range impact. Assuming that stakeholders in the prefabricated building chain have n members to be evaluated and m evaluation indicators, the original matrix $R=\left(r_{ij}\right)_{n\times m}$ is formed.

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1,j} \\ r_{21} & r_{21} & \cdots & r_{2,j} \\ \cdots & & & \cdots \\ r_{i,1} & r_{i,2} & \cdots & r_{i,j} \end{bmatrix}$$

Among them r_{ij} is the affected value of the i-th member under the j-th index. Min-Max is used to normalise the original data matrix. The conversion formula is as follows:

$$a_{ij}=\frac{r_{ij}-r_{ij\min}}{r_{ij\max}-r_{ij\min}} \tag{3}$$

Standardised matrix $A=\left(a_{ij}\right)n\times m$ can be obtained after conversion.

3.2.2 Calculate the weight of each index value

After the original data matrix is normalised, the entropy weight method is used to calculate the entropy value and entropy weight of each indicator.

1) Calculate the proportion of the index value of the i-th item under the j-th index.

$$p_i=\frac{a_i}{\sum_{i=1}^{n}a_i} \tag{4}$$

2) Calculate the entropy value of the j-th index.

$$e_j=-k\sum_{i=1}^{n}p_{ij}\cdot\ln p_{ij},\qquad k=\frac{1}{\ln n} \tag{5}$$

3) Calculate the entropy weight of the j-th index.

$$w_j=\frac{\left(1-e_j\right)}{\sum_{j=1}^{m}\left(1-e_j\right)} \tag{6}$$

3.2.3 Determine the correction factor

On the basis of the initial Shapley value, comprehensively consider the factors affecting the benefit distribution of stakeholders in the prefabricated building chain; according to the weight w_j of each index, the comprehensive influence degree β_j of the adjusted factors on the benefit distribution of each participant is obtained (Li et al., 2008).

$$\beta_j=R\cdot w_j \tag{7}$$

After the adjustment, the actual income distribution value of each stakeholder is V_i.

$$V_i=\varphi_i+\left(\beta_j-\frac{1}{n}\right)\cdot V\left(s\right) \tag{8}$$

Among them, φ_i is the initial benefit distribution value of member i, β_j is the degree of the comprehensive influence of the adjusted factors on the benefit distribution of all participants, n is the number of participants and $V(S)$ is the cooperative benefit of S.

Through the above steps, the influencing factors affecting the benefit distribution of prefabricated construction industry chain position within the industry chain, risk-sharing size, contribution ratio and cooperation degree were introduced into the Shapley value method mathematical model based on cooperative game, and the improved Shapley value method benefit distribution model based on entropy weight method was obtained.

4 Analysis of calculation examples

There are many upstream and downstream enterprises in a reinforced concrete prefabricated residential building project in Changchun China. Now we consider a simple industrial chain, which includes development enterprises, design units, component production enterprises and construction enterprises, code-named 1, 2, 3,4. Under the background of the country vigorously promoting the prefabricated construction industry, the four enterprises want to form a cooperative alliance of the prefabricated construction industry chain. The approximate income of the four enterprises when they operate independently and cooperate in different combinations is shown in Table 4.

In the Shapley value method mathematical model, suppose I is a prefabricated building chain containing n enterprises and consider one of the simple industrial chains, including development companies, design companies, component manufacturers and construction companies; the codes are 1, 2, 3 and 4. According to the case, the four companies operate independently and the ratios of benefits differ when they cooperate with different combination (Wang, 2018). Table 4 presents the details.

From the data in Table 4 and Formulas (1) and (2), the benefits of each stakeholder can be obtained. Taking development enterprises as an example, Table 5 shows the benefit distribution.

Table 4 List of benefits of stakeholders in the industry chain

Stakeholders of the prefabricated building chain	*General benefit （Unit: millions of yuan）*
1	22
2	5
3	8
4	10
{1, 2}	32
{1, 3}	35
{1, 4}	40
{2, 3}	15
{2, 4}	22
{3, 4}	25
{1, 2, 3}	42
{1, 2, 4}	45
{1, 3, 4}	50
{2, 3, 4}	35
{1, 2, 3, 4}	60

Table 5 Development enterprise benefit distribution table

	1	*1∪2*	*1∪3*	*1∪4*	*1∪2∪3*	*1∪2∪4*	*1∪3∪4*	*1∪2∪3∪4*
$V(S)$	22	32	35	40	42	45	50	60
$V(S/\{i\})$	0	5	8	10	15	22	25	35
$V(S)-V(S/\{i\})$	22	27	27	30	27	23	25	25
$\lvert S\rvert$	1	2	2	2	3	3	3	4
$W(\lvert S\rvert)$	1/4	1/12	1/12	1/12	1/12	1/12	1/12	1/4
$W(\lvert S\rvert)[V(S)-V(S/\{i\})]$	5.5	2.25	2.25	2.5	2.25	1.92	2.08	6.25
Sum	25							

According to Table 5, the initial distribution value of the interests of development enterprises in the cooperative game of this industry chain is 25 million yuan. In the same way, the initial distribution value of the benefits of design units is 8 million yuan; the initial distribution of benefits for construction companies is 11.62 million yuan and the sum of the four income value is 15.33 million yuan, indicating the rationality of the initial distribution of benefits. The income distribution ratios are 41.67%, 13.33%, 19.44%, 25.56%.

Questionnaires are given to university professors and experts in the real estate field who are then invited to discuss the aspects of development companies, design units, component manufacturers and construction companies from the aspects of industrial chain status, risk-sharing size, contribution ratio and cooperation degree. Stakeholders in the industry chain evaluate and obtain the measured values of the factors affecting the improvement of the four models. They also obtain basic data, as shown in Table 6.

Table 6 Basic date table of influencing factors

Stakeholders	*Position within the industry chain*	*Risk-sharing size*	*Contribution ratio*	*Collaboration degree*
Development Enterprise	0.31	0.30	0.30	0.21
Design unit	0.27	0.24	0.22	0.22
Component manufacturer	0.22	0.20	0.23	0.23
Construction unit	0.20	0.26	0.25	0.34

According to Formula (3), the data are normalised to obtain a matrix:

$$A=\begin{bmatrix} 0.786 & 0.714 & 0.714 & 0.071 \\ 0.500 & 0.286 & 0.143 & 0.143 \\ 0.143 & 0 & 0.214 & 0.214 \\ 0 & 0.429 & 0.357 & 1 \end{bmatrix}$$

Calculate the entropy and weight of each influencing factor according to Formulas (4), (5) and (6). The results are presented in Table 7.

Table 7 Entropy and weight of each influencing factory

Correction calculation	*Position within the industry chain*	*Risk sharing size*	*Contribution ratio*	*Degree of collaboration*
Entropy e_j	0.668	0.743	0.871	0.660
Weights w_j	0.313	0.243	0.122	0.322

Finally, it is obtained according to Formulas (7) and (8).

$$\beta_j = \begin{bmatrix} 0.274 \\ 0.241 \\ 0.219 \\ 0.266 \end{bmatrix}$$

$$V_1 = 25 + (0.274 - 1/4) \times 60 = 26.44$$

$$V_2 = 8 + (0.241 - 1/4) \times 60 = 7.46$$

$$V_3 = 11.67 + (0.219 - 1/4) \times 60 = 9.81$$

$$V_4 = 15.33 + (0.266 - 1/4) \times 60 = 16.29$$

That is, the benefit distribution schemes of the four stakeholders adjusted according to the actual influencing factors are 26.44, 7.46, 9.81 and 16.29 million yuan, respectively, and the proportion of income distribution is 31.58%, 21.55%, 19.46% and 27.41%, respectively.

The above data indicate that the overall profits of all stakeholders in the prefabricated building chain are higher than those before cooperation, which is in line with the basic conditions for the formation of alliances in the cooperative game, which shows the rationality of the benefit distribution model. Compared with the Shapley value distribution scheme before the improvement and adjustment, the benefit distribution of development enterprises and construction units slightly improves, suggesting that with the development and improvement of the prefabricated building chain, development enterprises and construction units are still in an important position in the whole industry chain and play a decisive role in the development of prefabricated buildings. The benefit distribution of design units also slightly changes, whereas that of component manufacturers decreases. Therefore, although the importance of prefabricated component factories and parts suppliers are regarded as important, their existence is different from traditional material suppliers in the early stage of the development of the prefabricated building chain, with the implementation of prefabricated building policies and the improvement of market cultivation. Prefabricated buildings are becoming increasingly mature in technology R&D and part production. The number of component production plants is also increasing. Previous technology and market monopolies no longer exist, such as the industrial chain built above. In addition, the benefits of component production plants are reduced and become similar to the existence of material suppliers in the traditional construction industry chain (Cheng et al., 2015).

5 Conclusions

China's prefabricated architecture has entered a period of all-round development, but the unreasonable interest distribution among stakeholders in the prefabricated building chain remains a major problem hindering the development of prefabricated buildings. Based on the current development state of prefabricated buildings and the characteristics of the prefabricated building chain, this article analyses the main body composition and the problems of the prefabricated building chain and constructs the Shapley value benefit distribution model. Considering the status of the industrial chain, risk sharing, contribution ratio and cooperation degree, the entropy value and weight are first calculated and then the improved Shapley value benefit distribution model is obtained. Through the analysis of an example, the rationality of the model is illustrated, and several conclusions are drawn.

1 The Shapley value method is a typical benefit distribution method, which is suitable for the benefit distribution of the prefabricated building chain cooperative alliance, but the prefabricated building chain system is huge, complex and changeable, and the simple Shapley value method distribution model is not enough to reflect its benefit distribution. The analysis of this article is relatively simple, and other influencing factors should be considered. Continuous improvement can reasonably and objectively solve the problem of benefit distribution in the prefabricated building chain.

2 If development and construction companies want to truly increase their profit distribution value, on the one hand, they must increase the promotion and implementation of government policies and promote their development through encouraging policies. On the other hand, such companies must strengthen the independent innovation of enterprises and cultivate high-quality industrial workers and technical personnel in the new construction era, establish an information platform, realise information sharing within the platform, make design changes visible to related parties, improve the speed and accuracy of information transmission and realise construction The design is integrated, the cost of prefabricated construction is controlled and the overall income is improved.

3 The benefit distribution conflicts of the prefabricated building chain can be effectively adjusted through the revised model. Forming a more fair and reasonable benefit distribution plan than before is necessary. This formation requires the joint efforts of the government, the stakeholders of the chain links of the industry chain and the market to make the long-term growth of benefits and reasonable distribution possible for all chain members.

4 The case analysis part of the article adopts a simple chain for model verification, and the scale and details of the case need to be improved in the future to be close to the complexity of the prefabricated industrial chain in real life. The research on the distribution of benefits in the prefabricated building chain is upgraded, and the simple chain is expanded to improve the effectiveness of the model.

At the same time, the benefits of the prefabricated building chain are studied. With the development of prefabricated buildings, its advantages will be seen by more and more people, and further study the multi-faceted benefits and even benefits it can produce and improve the overall structure of benefit distribution. And put forward targeted suggestions to provide a theoretical basis for the next step of the development of the prefabricated building industry chain.

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