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Optimization of Housing Supply Chain Network Structure and Design of Intelligent Management System Driven by Smart Logistics

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Abstract Vigorously developing the “good house” industry chain and housing supply chain is a necessary way to promote the synergistic development of the industry. Taking intelligent logistics and supply chain management as an entry point, the article constructs an intelligent management system for housing supply chain by combining various information technologies and designs corresponding functional modules to realize the intelligent management of housing supply chain. Then, guided by complex network theory, the basic network of housing supply chain is constructed by combining housing industrialization, and the evolution rules of housing supply chain network are set. The first-order zero model is introduced and improved, and the fast reconnection algorithm is designed to be used in the optimization of the housing supply chain network structure, and its effectiveness is verified through simulation experiments. It is found that the SLFCS of the housing supply chain network structure of the FRM algorithm remains around 20% after the cumulative number of attacks reaches 120. There are large differences in the network structure of housing supply chain in different stages, the network density value in the stabilization stage is about 2.27 times of the network density in the initiation stage, and the transaction termination gate threshold between enterprise nodes will have a large impact on the stability of housing supply chain network. Therefore, relying on intelligent logistics-driven intelligent management system can effectively realize the optimization of housing supply chain network structure and better meet the market housing demand.

Index Terms intelligent management system, housing supply chain, structure optimization, Ⅰ order zero model

I. Introduction

With the continuous development and growth of the logistics industry, logistics management is facing more and more challenges. On the one hand, the logistics network is becoming more and more complex, and on the other hand, the logistics demand is becoming more and more diversified, logistics enterprises need to make full use of modern technical means in logistics management [1]-[4]. In the context of smart logistics, optimizing the supply chain network structure and creating a smart logistics management system in order to improve the efficiency of logistics management and optimize the quality of logistics services [5], [6].

Intelligent logistics is a new type of logistics management established on the basis of data, informatization, and intelligence in the logistics industry [7], [8]. It carries out online monitoring and analysis modeling of all aspects of logistics by making full use of the Internet of Things, cloud computing, big data and other new technological means, and then optimizes the logistics process and logistics system, so as to achieve efficient, fast and precise allocation of logistics resources [9]-[12]. Under the traditional supply chain model, the problems of information non-circulation, non-transparent information, and imprecise information affect many aspects of marketing, logistics, production and service, etc. Enterprises need to rely on manual mastery of information, which is difficult to achieve comprehensiveness, accuracy and real-time [13]-[16]. The emergence of intelligent logistics can make the efficient sharing of information between upstream and downstream enterprises in the supply chain, the automated collaboration of production and circulation links, realize the optimization of the supply chain synergy, enhance the coordinated utilization efficiency of the whole chain of resources, so as to enhance the core competitiveness of the supply chain, and lay a foundation for the long-term development of enterprises [17]-[20].

In terms of logistics management system, the traditional logistics management system is often a single-point management, that is, the information between each link is not connected. With the continuous development of IoT technology, the information processing of logistics management systems has become more and more convenient, connected and efficient, and the logistics industry has radiated to all areas of logistics starting from supply chain management [21]-[24]. Intelligent logistics management system is based on the innovative application of artificial intelligence technology, which can realize the intelligence, automation and optimization of the logistics process, and the whole system can be divided into supply chain management module, transportation management module, warehousing management module, sales management module, distribution management module, etc., which realizes the real-time monitoring of information in the whole process of logistics production by building the whole process automation of the whole logistics system and the intelligent management of information , information query and feedback [25]-[28].

In this paper, driven by intelligent logistics, we designed a housing supply chain intelligent management system through various technologies, and proposed a fast reconnection algorithm based on the Ⅰ-order zero model to optimize the housing supply chain network structure. Firstly, it introduces the knowledge related to intelligent logistics and supply chain management, and builds a housing supply chain intelligent management platform with “one chain and five modules” by relying on various information technologies. Secondly, the basic structure of housing supply chain network is established from the housing industrialization system, and the evolution rules of housing supply chain network are designed by combining the complex network theory. In order to optimize the housing supply chain network structure, this paper takes the Ⅰ order zero model as the basic algorithm and designs the FRM algorithm for network structure optimization. Finally, the effectiveness of the above method is verified by optimization simulation and evolution simulation, aiming to further strengthen the operational stability of the housing supply chain network.

II. Intelligent management system for the housing supply chain

The construction of “good houses” is not only an important target task of housing and urban-rural construction reform in the new period, but also an important initiative to promote the transformation and upgrading of real estate, construction and other industries, and it is necessary to build a housing industry chain with industrialized thinking and promote the synergistic development of the housing supply chain, so as to realize the virtuous cycle and sustainable development. Relying on the intelligent management system of the housing supply chain, it realizes the interconnection of information on housing demand aggregation, supply transactions, ancillary services, enterprise credit, etc., and strongly promotes the orderly docking of supply and demand in the upstream and downstream of the industry.

II. A.Intelligent Logistics and Supply Chain Management

II. A. 1) Intelligent Logistics

Intelligent logistics is an advanced and comprehensive intelligent logistics system, which relies on information technology and extensively uses technological tools such as the Internet of Things, artificial intelligence, big data analysis and cloud computing in order to achieve precise control, dynamic monitoring and visualization management of each link in the logistics process. By adopting advanced technologies in the logistics system, the smart logistics system can collect and process information in real time, simulate the decision-making process of the human brain, optimize the system layout, and achieve high-quality, high-efficiency, and low-cost collaborative work in each link [29].

Intelligent logistics can improve the degree of intelligence of cargo transportation, can promote the interaction of information between people and things, things and things, and can significantly improve the level of intelligence of the entire logistics system.

II. A. 2) Supply chain management

The supply chain is a process of activities related to the production, distribution and sale of all products from suppliers to customers. Supply chain management is to combine the market and customer demand, through the core enterprise and the coordination of the enterprises in the supply chain, to win-win cooperation as the basic principle, so that the core competitiveness of the supply chain related parties can be improved. At the same time, it reduces the operating costs of enterprises, and improves the effectiveness of the control of logistics, information flow, capital flow and other aspects of the supply chain through the use of advanced management technology and methods, and gradually forms a strategic alliance relationship [30].

Taking the actual operation of the supply chain as an example, in the operation process of a supply chain, an enterprise is in the core position. This enterprise plays a coordinating role for the information flow, the scheduling of logistics and the capital flow in the supply chain. From this aspect, the basic structure of the supply chain is obtained as shown in Figure 1, which mainly includes node enterprises, core enterprises, capital flow, information flow and logistics.

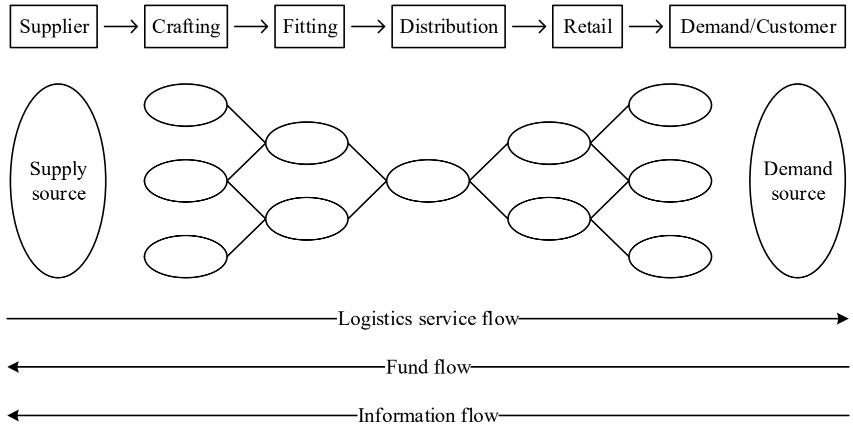


Figure 1: The basic structure of the supply chain

The supply chain is not only a chain of materials that connects suppliers to customers, but it is also a value-added chain. Materials add value as they are processed and transported through the supply chain, and in an environment of accelerated competition in the global manufacturing industry, it is also a network structure around the core enterprise rather than simply a chain structure from suppliers to customers.

II. B.Intelligent management system for the housing supply chain

II. B. 1) Overall system framework

In order to better promote the orderly development of the housing supply chain, this paper builds a housing supply chain intelligent management platform with “one chain and five modules” based on the existing information technology means and combined with the means related to intelligent logistics. Relying on this platform, it can realize the comprehensive collection, accurate matching and analysis and governance of housing supply and demand data, and provide support for the promotion of multi-principal cooperation and the enhancement of the stable development of the housing supply chain.

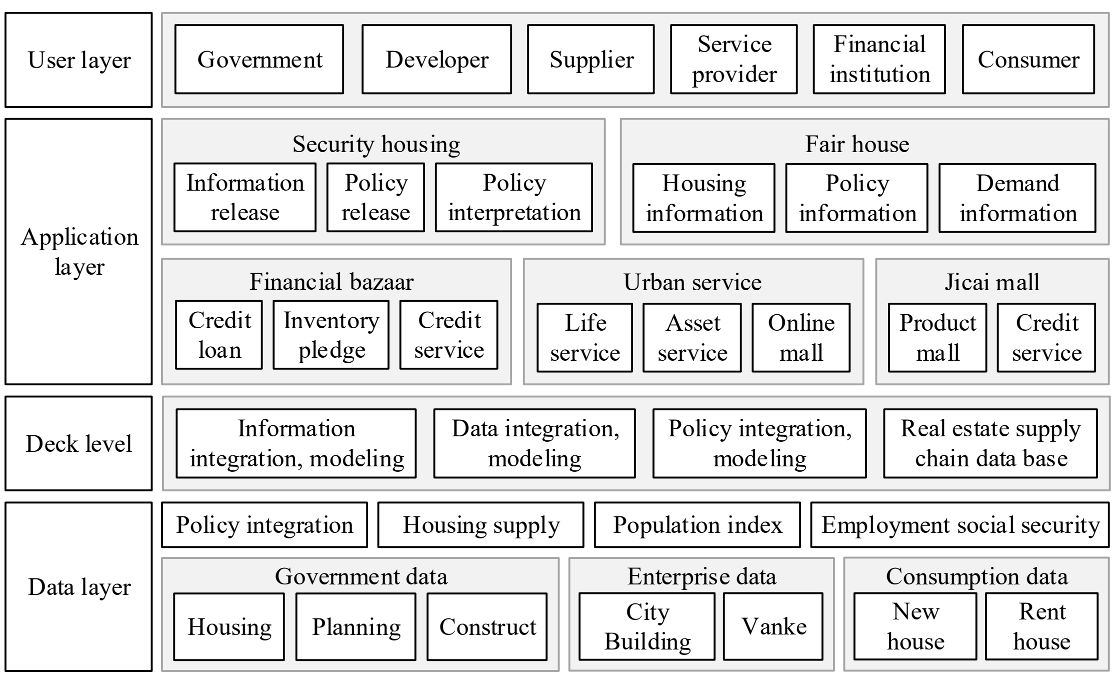


Figure 2: Management platform of housing supply chain

The framework of the housing supply chain intelligent management system is shown in Figure 2, which is composed of four layers from bottom to top: data layer, platform layer, application layer and user layer, and observes that each layer can only refer to resources of the same layer and the lower layer, and cannot refer to resources of the upper layer. The data layer is the centralized database, containing government data, enterprise data and consumer data. The platform layer is the basic housing information model based on IFC, IDM and IFD standards, which is created and modified by the design unit for the whole life cycle of the project, and can be invoked by other participants in the supply chain. The application layer is a web-based interactive platform based on XML standards, which can be realized by a variety of application software and other software to better help consumers access the corresponding featured services. The user layer is the top layer of the system framework, which links various subjects in the housing supply chain to better address different types of housing needs.

II. B. 2) Platform functional modules

In the intelligent management platform of housing supply chain, it will provide full-cycle, intelligent and high-quality products and service contents for multiple subjects such as the government, developers, builders, material suppliers, financial institutions and intermediaries, consumers, etc., and provide them with full-cycle, intelligent and high-quality products and service contents in multi-application scenarios, such as policy consulting, housing transaction, housing service, bidding and purchasing, financial service and digital transformation, etc., so as to promote the accurate docking of supply and demand, and to facilitate the supply chain with supply chain innovation and promote the supply chain of housing. Upgrade.

The “One Chain” is a data platform for the housing supply chain, and the “Five Modules” is a service module for guaranteed housing, which creates an operation and management platform for guaranteed housing leasing, and provides one-stop guaranteed housing services for the entire process of searching, viewing, and renting online. The Good Housing Market module gathers high-quality real estate enterprises and adopts the “DTC” (direct-to-consumer) model to provide integrated online and offline sales services, creating a good housing platform for the public to buy with peace of mind and confidence. The financial service module provides one-stop financial service solutions for enterprises and users with innovative financial products and services. City service module, connecting the “last kilometer” of residential service, providing users with intelligent, diversified and accurate quality services. Mining Mall module gathers high-quality suppliers, provides the whole process of mining services, realizes cost reduction and efficiency enhancement, and empowers the digital transformation of enterprises.

III. Optimization of the network structure of the housing supply chain

With the increasing level of the national economy, the housing construction industry has developed rapidly, while the development of the housing construction industry has boosted the growth of the national economy, and the development of housing construction and development enterprises has also led to the development of the related industrial chain. For this reason, the supply chain centered on housing construction and development enterprises plays an important role in the construction of the national economy. However, the logistics chain of land, construction materials and equipment, and housing construction and development products; the capital chain of housing development funds, land acquisition funds, construction funds of development products, and sales of development products; and the information chain of housing market demand, regional real estate planning, and national macro-control policies all have a direct impact on the sustained stability of the housing supply chain.

III. A. Housing supply chain networking

III. A. 1) Housing industrialization system

The industrialization of housing means the industrialization of housing, which is the embodiment of the industrialization of construction in the field of housing construction, and refers to the construction of housing by means of industrial production, that is to say, taking the standardization of housing construction as the basis and prerequisite, and taking the industrialization of housing construction as the means to integrate the production and operation of housing and to realize the socialization of collaborative services in housing. “Industrialization” itself means adopting advanced scientific and technological means, using modern machinery and equipment to replace traditional handicraft production and construction of housing, thereby improving production efficiency and product quality. The fundamental purpose of promoting the industrialization of housing is to improve the productivity of the housing industry through the development and use of scientific and technological productivity, adjusting the industrial structure, integrating industrial resources and realizing industrial upgrading.

Housing industrialization involves the implementation of specific projects, including standardized design, factory production, mechanized assembly, specialized logistics and other connotations. Standardized design is the prerequisite for the realization of housing industrialization, refers to the housing product parts and components, and then through the standardization of parts and components to achieve the standardization of design. Factory production refers to the centralized, large-scale prefabricated production of housing components in the factory workshop, to achieve a high degree of concentration and integration of the various stages of traditional manual production. Mechanized assembly refers to the on-site construction process is completed entirely through mechanical lifting, with a high degree of continuity. Specialized logistics refers to the need for on-site lifting of housing components to achieve specialized logistics and transportation.

The framework of the housing industrialization system has five main components, including the technical guarantee system, building structure system, component system, quality guarantee system and performance recognition system. The core task of promoting housing industrialization is the systematic improvement and implementation of these five systems.

III. A. 2) Housing supply chain network

The final completion of housing products need to experience a longer production cycle than the general industry, the design department how to design according to customer requirements, housing components how to assemble according to the design, housing components how to design production, construction team how to organize the design of construction according to the specific circumstances of housing products, the use of auxiliary equipment and so on. All need the timely exchange of information between the nodes of the supply chain enterprises, and the effective deployment of materials and funds, in which intelligent logistics plays a more important role. Housing supply chain network structure shown in Figure 3. Housing supply chain should take the owner's demand as the starting point, with residential development enterprises as the core enterprise, strengthen the control of logistics, information flow, capital flow, so that the engineering machinery and equipment providers, construction material providers, subcontractors, owners, etc., from winning the bid to construction, shuttle acceptance and maintenance of the organic composition of the functional network system.

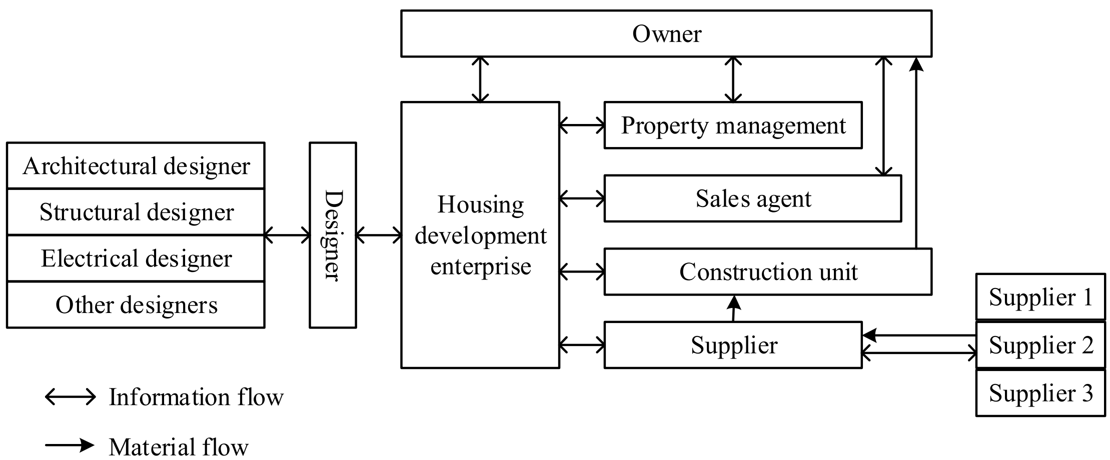


Figure 3: Network structure of housing supply chain

As can be seen from the figure, there are three main stakeholders in the housing supply chain, i.e. owners, designers and housing development enterprises. Designers can be subdivided into design subcontractors for architectural design, design subcontractors for structural design, etc., while housing development enterprises play the role of assigning tasks and coordinating the whole. A network is a network of organizations or organizations formed to meet the needs of various types of owners and clients in the housing industry. Collaboration is a new way to enhance the competitive advantage of a company by completing a project that meets the requirements within the desired time frame and at the lowest cost. Collaboration requires that each participant in the housing supply chain not only share the same organizational goals, but also establish efficient constraints, mutual trust and information sharing mechanisms.

III. B. Supply Chain Network Evolution Model

III. B. 1) Complex network theory

Existing research considers a network to be complex if it has a self-organizing, small-world, or certain similarity, or scale-free nature. That is, a complex network will express a high degree of complexity characteristics. Complex networks are large in size and will exhibit a complex topological network structure; a complete complex network includes many nodes, and edges connected between nodes. Complex networks have the following statistical characteristics:

(1) Degree distribution and average degree

In complex networks, k_i is generally used as the degree value of node i in the network. The degree distribution function $p(k)$ is a very important feature in complex networks. $p(k)$ denotes that if a node is arbitrarily selected in the network, then the probability that the degree value of that node is equal to k is exactly the ratio of the number of nodes in the network with degree value to the number N of all nodes in the network [31]. Namely:

$$P(k)=\frac{1}{N}\sum_{i=1}^{N}\delta(k-k_i) \tag{1}$$

So, if the value of degree k is greater, then it means that the node is important in the network.

The average degree refers to the average of the degrees of all the nodes, which actually refers to the closeness of the network, i.e., the number of connections between the nodes. Then:

$$\langle k\rangle=\frac{\sum_{i=1}^{N}k_i}{N} \tag{2}$$

The larger the average degree, the tighter the network, and the smaller the average degree, the sparser the network.

(2) Agglomeration coefficient

The agglomeration coefficient of a network can be used to measure the aggregation of each node in the network, thus reflecting the agglomeration characteristics of a network. Generally speaking, if node i and other k_i nodes are connected to each other, in a completely ideal state, the maximum number of edges between these k_i nodes can be established is $k_i(k_i-1)/2$. However, considering the realistic situation, the number of edges that k_i nodes are connected to each other is E_i [32]. The clustering coefficient C_i of the nodes is defined as the ratio of E_i to $k_i(k_i-1)/2$, i.e.:

$$C_i=\frac{2E_i}{k_i(k_i-1)} \tag{3}$$

(3) Average Shortest Path

The average shortest path refers to the average value of the distance between individual nodes and can be used to measure the efficiency and delivery performance of a network. It can be expressed as:

$$L=\frac{1}{N(N+1)}\sum_{i\geq j}d_{ij} \tag{4}$$

where d_{ij} is the distance between node i and node j.

In general, the smaller the average shortest path is, the more it will speed up the flow of logistics and information within the network, i.e., the faster the network transmission efficiency [33].

III. B. 2) Network evolution rules

Based on the housing supply chain network established in section 3.1.2, this paper designs the corresponding housing supply chain network evolution rules for it, so as to lay the foundation for promoting the optimization of the housing supply chain network structure.

First define location attractiveness. The nodes in the housing supply chain network include owners, designers, housing development enterprises, etc. Their roles in the housing supply chain can be described by different location parameters, which are used to evaluate the possibility of establishing a cooperative relationship between the two nodes and their priorities. In the model, each node i is given a “location” value, denoted as $w_i\in R^n$, and w_i is a n-dimensional variable, and the location attractiveness parameter is used to evaluate the degree of mutual attraction between the node and other nodes in the network.

$$W_{ij}=w_i*w_j/(1+|w_i-w_j|),i=1,2,... \tag{5}$$

The larger the product of two node position values and the closer they are to each other, the greater the attraction. In order to prevent $|w_i-w_j|=0$, so the formula is processed by adding 1 to the denominator.

The evolution rules of the housing supply chain network are as follows:

(1) Housing Supply Chain Network Initialization. A network with m_0 initial nodes and e_0 edges is generated at the very beginning of the evolution i.e. at $t=0$, and transaction volumes are randomly generated $A_{ij} \in [0,1]$. Each node is given a position parameter value $wi, i=1,2,...,m_0$ that obeys a power rate distribution between (0,1). For the value A_{ij} of the transaction volume between node i and node j, an edge is broken if it is less than the edge break gate threshold P_O set in the network. It is also stipulated that for nodes with degree 0 will drop out of the housing supply chain network due to the absence of trading partners.

(2) Meritocratic growth in the local world. At the t th moment, a new node j is added, assigning it a value w_j of the position parameter distributed by a power rate between (0,1). The local world of the new node j consists of M_t pre-existing nodes with which it has a greater degree of attraction, where:

$$M_t = m + t \tag{6}$$

$$m \le M_t \le t + m_0 \tag{7}$$

At the moment $t+1$, the degree of attraction W_{ij} between the new node j and each of the existing old nodes i is calculated by Eq. $W_i = w_i * w_j / (1+|w_i - w_j)$, and the M_t nodes with greater degree of correlation are selected to form the Local world of the new node j. The connection probability of node $i(i \in Local)$ to the new node j is calculated by using the expression whose prioritized probability of connection is Π, and with this prioritized probability, a node m is selected from Local to connect to the new node j. The prioritized connection probability is:

$$\prod_{Local}(j->i) = a * k_i / \sum k_j + b * s_i / \sum s_j \tag{8}$$

where s_i is the strength of node i, $s_i = \sum A_{ij}$, i.e., s_i is the sum of the transaction volumes of neighboring nodes directly connected to node i with node i, and k_i is the degree of node i. This probability takes into account the cumulative value of node degree and node transaction volume (node strength) in the above equation, $a+b=1$, and $a>0, b>0$. At this point, for nodes in the network that have a trading relationship, a new edge transaction volume between nodes is randomly generated $A_{ij} \in [0,1]$.

(3) Edge fracture. Edge disconnection will occur when the transaction between nodes in the housing supply chain network is too low. That is, for the changed network, if the value of A_{ij} is less than the gate threshold P_0, the transaction between nodes ends thereby losing the connection, i.e., at this point Order $A_{ij} = 0$.

(4) Node Exit. After the housing supply chain network is updated, it is stipulated that for node i with degree 0, it will exit the housing supply chain network.

(5) Simulation of termination conditions. Return to step (2) until the housing supply chain network reaches the specified network size N. The values of m_0 (the number of initial enterprise nodes in the network), e_0 (the number of initial edges between enterprise nodes in the network), P_0 (the transaction termination threshold between enterprise nodes), m (the number of edges between newly added nodes and the old enterprise nodes at each time), and N (the total number of enterprise nodes) in the above evolutionary model can be set in advance.

III. C. Supply chain network structure optimization

III. C. 1) First-order zero models

In general, the main purpose of using network zero models is to detect nontrivial properties of the empirical network, which requires a gradual approximation of the properties of the original network from rough to exact. Different orders of network zero models are not independent of each other, and there is an inclusion relationship according to the constraints from less to more, i.e., $0k \supseteq 1k \supseteq \cdots (n-1)k \supseteq nk$. Any n nd order zero model will contain the properties of the $(n-1)$ rd order zero model.

The main purpose of the Ⅰ order zero model is to ensure that it has the same node degree distribution as the original network. The Ⅰ order zero model and the original network not only have the same number of nodes, the same average degree, but more importantly have the same node degree distribution $p(k)$, the degree distribution is the distribution of the probability or number of node degrees in the original network. If $n(k)$ is the number of nodes with degree k in the original network, the degree distribution is $p(k) = n(k)/n$.

The I-order zero model is a very important reference for the original network. In order to determine whether the original network has some nontrivial property, it is necessary to statistically analyze whether this property of the original network is significantly different from the zero model network.

Assuming that a statistic of the network, such as the number of times a certain subgraph occurs in an actual network is $N(j)$ and the average of the number of times it occurs in the zero model is $\langle N_r(j)\rangle$, the ratio of the two is:

$$R(j)=\frac{N(j)}{\langle N_r(j)\rangle} \tag{9}$$

In practice, if $R(j)>1$, then it means that the actual network design or evolution process facilitates the emergence of that topological feature. Conversely, if $R(j)<1$, then it means that the actual network design or evolution process inhibits the emergence of the topological feature.

III. C. 2) Network structure optimization

In order to maintain the degree distribution of the housing supply chain network and quickly improve the robustness of the housing supply chain network and better optimize the structure of the housing supply chain network, this paper proposes a fast reconnection (FRM) algorithm based on the first-order null model.The FRM algorithm consists of three main phases, namely:

(1) Weighting each edge by comparing the difference between the degree values of the two endpoints of each edge.

(2) Prioritizing the two edges with higher weights based on the edge weights.

(3) Remove the original edges and create connected edges between nodes with similar degree values, provided that the network does not generate heavy edges and self-loops, and the network connectivity and robustness metrics increase.

The FRM algorithm uses the absolute value of the difference between the degree values of the nodes to assign weights to each edge in the network, then:

$$w_{ij}=|d_i-d_j| \tag{10}$$

where d_i denotes the degree value of node v_i and w_{ij} denotes the weight of edge (v_i,v_j). The larger the value of the edge weight, the greater the difference in the degree values of the two endpoints of that edge.

The FRM algorithm measures the difference between the degree values of the two endpoints of each edge by weighting each edge with the above equation. The probability of selecting two edges based on the edge weights is directly proportional to the weights of the edges, i.e., the following rule is satisfied:

$$\Pi_{ij}=\frac{w_{ij}}{\sum_{(u,v)\in E} w_{uv}} \tag{11}$$

According to the above equation, the FRM algorithm selects the edge with the larger weight value, i.e., the edge where the large degree node is connected to the small degree node. By selecting two edges with larger edge weights, the FRM algorithm can quickly find edges with large differences in degree values, thus quickly improving the robustness of the network through the reconnection operation.

Based on the way the nodes in the housing supply chain network connect their edges, the network is said to be homogeneous if nodes with large degree tend to connect with nodes with large degree. If nodes with large degree tend to connect with nodes with small degree, the network is said to be heteropairing. The homopair coefficient is usually used to measure the homopairing of a network, i.e.:

$$\rho=\frac{1}{N}\frac{\sum_{(i,j)\in E}^{N}(d_i-d_j)^2}{\sum_{i=1}^{N}d_j^3-\frac{1}{2M}\left(\sum_{i=1}^{N}d_i^2\right)^2} \tag{12}$$

where, d_i denotes the degree value of node v_i, N denotes the number of nodes in the network, and M denotes the number of edges in the network.

Analyzing the above equation, it can be seen that the reconnection mechanism based on the 1st order zero model does not change the degree value of the nodes during the reconnection process, so $\sum_{i=1}^{N} d_j^3 - \frac{1}{2M}\left(\sum_{i=1}^{N} d_i^2\right)^2$ is a constant in the computation process, denoted as σ , i.e:

$$\rho = 1 - \sum_{(i,i)\in F} (d_i - d_j)^2 / \sigma \tag{13}$$

Then the coefficient of congruence of the network is related only to the square of the difference between the degree values of the two endpoints of each edge. Therefore, the difference in the co-matching coefficients of the 3 ways of connecting edges can be expressed as:

$$\rho_{(1)} - \rho_{(2)} = \frac{2(d_{(2)} - d_{(3)})(d_{(1)} - d_{(4)})}{\sigma} \geq 0 \tag{14}$$

$$\rho_{(2)} - \rho_{(3)} = \frac{2(d_{(1)} - d_{(2)})(d_{(3)} - d_{(4)})}{\sigma} \geq 0 \tag{15}$$

$$\rho_{(1)} - \rho_{(3)} = \frac{2(d_{(2)} - d_{(4)})(d_{(1)} - d_{(3)})}{\sigma} \geq 0 \tag{16}$$

From Eq. $\rho_{(1)} \geq \rho_{(2)} \geq \rho_{(3)}$, i.e., the first way of reconnection causes the largest increment of congruence. Therefore, the FRM algorithm performs the reconnection operation according to the first way of connecting edges, i.e., it creates two edges between nodes with similar degree values based on the degree value by non-incrementally ordering the four nodes of the two edges selected based on the edge weights. Similarly, the network is not allowed to create heavy edges and self-loops during the reconnection process and the network is connected.

IV. Analysis of the evolution of the housing supply chain network

Cultivating the development of the housing market supply chain is conducive to further optimizing the real estate supply structure, meeting the housing demand of urban residents, especially new citizens, easing the contradiction between housing supply and demand, and promoting the healthy development of the real estate market. The data-driven development of housing supply chain is an inevitable requirement in the era of big data, and the combination of intelligent management system of housing supply chain will help to comprehensively improve the level of housing services, promote the deep development of housing supply chain, and better serve the people's livelihood.

IV. A. Supply chain network structure optimization validation

IV. A. 1) Algorithm performance comparison

In the housing supply chain network (HSC) established in this paper, it mainly contains three sub-networks of owners (HSC1), designers (HSC2), and housing development enterprises (HSC3). In order to verify the performance of the FRM algorithm for optimizing the housing supply chain network structure, this paper conducts comparative experiments on the above four supply chain networks. The median centrality algorithm is mainly used to attack the networks, and the maximum full role connectivity subgraph size (SLFCS) is used to evaluate the optimization effect of different algorithms on the housing supply chain network structure. The comparison algorithms selected in this paper mainly include three edge reconnection algorithms, RM-LCC, SRM-LCC and FSRM-LCC, which are all evolved from the zero model-based construction. The changes of housing supply chain network structure with SLFCS of mediator attack after optimization by different optimized edge reconnection algorithms are shown in Fig. 4, where Figs. 4(a)~(d) show the changes of owners, designers, housing development enterprises and the overall network structure, respectively.

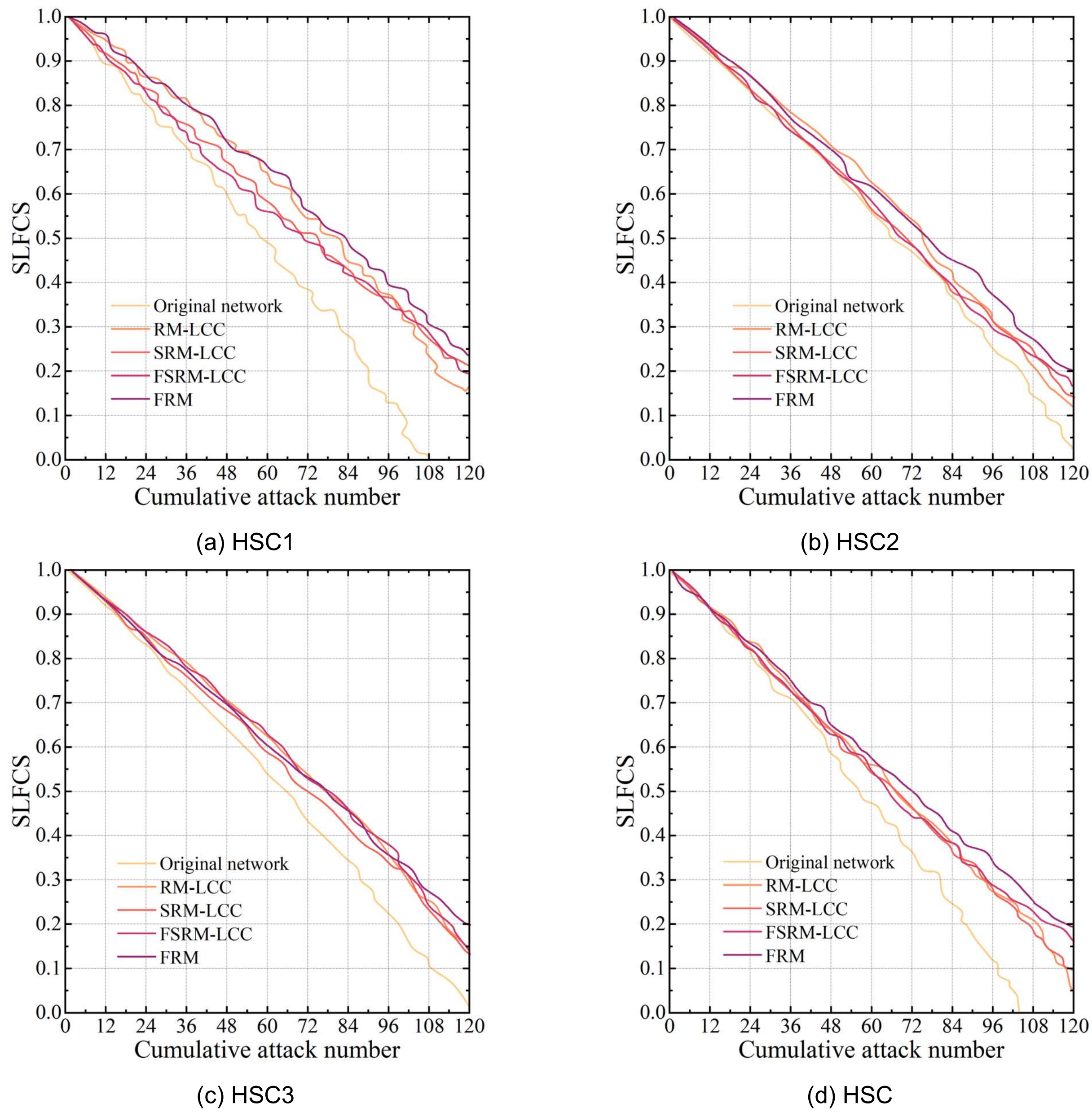
Based on the comparison results of different algorithms, it can be seen:

In the owner's sub-network, the unoptimized network's SLFCS almost goes to zero under the cumulative attack of about 108 nodes, while the network optimized by the FRM algorithm is much more resilient, with the SLFCS still 24.87%, which means that there are still about a quarter of the nodes of the network functioning normally. Specifically, before the cumulative number of attacks on nodes reaches 84, the FRM algorithm is slightly better than the RM-LCC algorithm, and stronger than SRM-LCC and FSRM-LCC. By the time the cumulative number of attacks on nodes reaches 120 nodes, the difference in the effectiveness of the four optimization algorithms gradually diminishes, and all of them improve the SLFCS to the range of 15% to 25%.

The FRM algorithm performs better in the designer sub-network in this network. The optimization effect of the other three algorithms optimized networks in the cumulative attack of 102 nodes is RM-LCC>SRM-CC=FSRM-LCC.Based on the final cumulative attack of 120 nodes, the SLFCS of the designer sub-network optimized based on RM-LCC and SRM-LCC improves 12%~15%, while the network optimized by FSRM-LCC and FRM algorithms optimized networks improved by about 17.5% to 20%.

In the housing development enterprise sub-network before the cumulative attack of 90 nodes, the optimization effect of the other three algorithms is basically the same except that the optimization effect of the SRM-LCC algorithm is weaker, and the FRM algorithm improves the SLFCS by about 20% when the cumulative attack is 120 nodes, while the other three algorithms improve it by about 15%, which indicates that the fast reconnecting RM improved in this paper based on the first-order zero model algorithm has the best network structure optimization effect.

In the housing supply chain network, the FRM algorithm optimizes better when the cumulative attack reaches up to 60 nodes, and continues to attack the network until 108 nodes, the algorithms show different differences, and the algorithms are ranked according to the best to the worst as FRM>FSRM-LCC>SRM-LCC>RM-LCC.



(a) HSC1 (b) HSC2

(c) HSC3 (d) HSC

Figure 4: Changes in SLFCS

Table 1 shows the time spent by different algorithms in performing network structure optimization. As can be seen from the table, the FRM algorithm proposed in this paper spends the lowest time in the overall network structure optimization, which is only 3.248s, and reduces 65.78%, 57.09%, and 27.74% of the time spent compared to the RM-LCC, SRM-LCC, and FSRM-LCC algorithms, respectively. Combined with the above optimized housing supply chain network structure SLFCS after FRM algorithm results in the optimal, which fully demonstrates that the FRM algorithm designed in this paper can achieve the fastest efficient network structure optimization in a shorter time.

Table 1: The time-consuming situation of different algorithms (s)

Network	RM-LCC	SRM-LCC	FSRM-LCC	FRM
HCS1	9.236	8.846	5.367	4.021
HCS2	9.674	8.471	5.302	3.843
HCS3	9.513	8.754	5.684	3.906
HCS	9.492	7.569	4.495	3.248

IV. A. 2) Analysis of the results of edge linking

In the optimization process of housing supply chain network structure, this paper proposes a fast reconnection algorithm based on the first-order zero model, which aims to better realize the edge reconnection of different nodes in the housing supply chain network structure. In order to further explore its effectiveness on edge reconnection, this paper classifies the connected edges of housing supply chain network into four different categories, i.e., active connected edges, vanishing connected edges, new connected edges and super connected edges. Active edges are defined as edges that have interaction behaviors in both historical and future housing supply chain networks (i.e., the weight of active edges is greater than 0 in both historical and future housing supply chain networks). Disappearing edges are defined as edges that have interactions in the historical housing supply chain network but not in the future housing supply chain network (i.e., the weight of the disappearing edge is greater than 0 in the historical housing supply chain network but equal to 0 in the future housing supply chain network). New edges are defined as edges that interact only in the future housing supply chain network (i.e., the weight of the new bicentennial is 0 in the historical housing supply chain network but greater than 0 in the future housing supply chain). Superbicentennials are defined as nodes whose weights are at 15% in the entire time period.

Based on the database of China Housing Provident Fund Center, the housing transaction data from 2016 to 2023 are obtained to establish the housing supply chain network, and the FRM algorithm designed in this paper is used to differentiate the weights of different types of connecting edges. The average weights of different types of edges in the housing supply chain network over time are shown in Figure 5.

Obviously, in the housing supply chain network structure, the evolution trajectory of the four types of edges is completely different, and the average weight of super nodes under the super edge is much higher than that of other types of edges in all time periods, and there is a clear overall trend of increasing weight. The average weight of edges is greater than 0 in all time periods, while the average weight of vanishing edges is much lower than that of active edges in the first 27 months, and decreases directly to 0 in the remaining nine months; in contrast to vanishing nodes, the average weight of newly added edges increases rapidly in the last 12 months, and the growth trajectory in the last month has a large slope and exceeds that of active edges. This indicates that new nodes have a high probability of becoming super-connected edges. The above phenomenon shows that the classification of the connecting edges is very helpful to predict the trend of the existence of different types of nodes in the future housing supply chain network, and also demonstrates the rationality of the existence of the four types of connecting edges in the structure of the housing supply chain network. Relying on the division of the weights of the connecting edges, different nodes can better realize the link, which is conducive to optimizing the network structure of housing supply chain and providing reliable connecting nodes to promote the stability of housing supply chain.

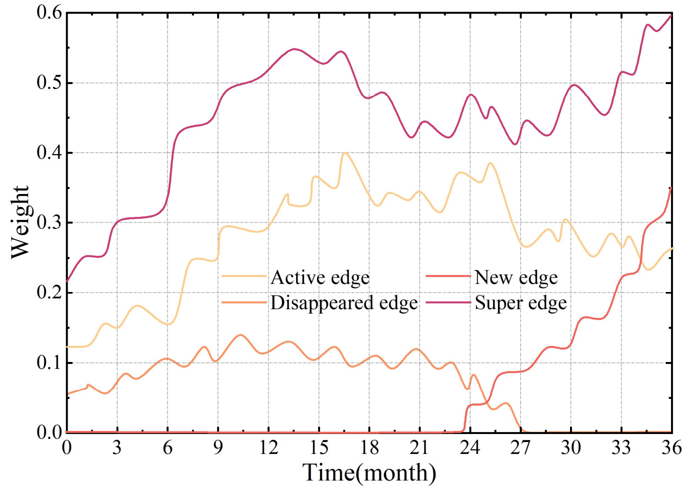


Figure 5: The evolution of the four side weights

IV. B. Analysis of the evolution of the housing supply chain network

IV. B. 1) Network Evolution Simulation

Based on the housing supply chain network model designed in the previous section, computer simulation is carried out for this model in this section. Taking 5000 node firms from this network, assuming that the initial nodes are 10 and 10 nodes are added per unit, with node positional attractiveness set to 0, 0.4 and 0.8, respectively, computer simulation of the housing supply chain network evolution model is carried out to analyze the topology of the network.

We used C++ to simulate the housing supply chain network, and then used MALTAB to plot and analyze the simulation results, which has the advantage of making good use of the running speed of C++ and the graphic processing function of MALTAB in analyzing the housing supply chain network evolution model, which can effectively improve the speed of computing. Figure 6 shows the degree distribution of the nodes of the housing supply chain network.

As can be seen from the figure, when the value of node location attractiveness is 0, the degree distribution of the housing supply chain network is an exponential distribution, which is because the choice of network nodes is random, indicating that in the housing supply chain network between enterprises do not take into account other factors, randomly choose to cooperate, is bound to form a "pot of rice" state of the world. When the value of node location attractiveness is 0.8, the degree distribution of housing supply chain network is a power law distribution, the network shows no scalar characteristics, indicating that in the housing supply chain network will inevitably appear in the core enterprise, in such a housing supply chain network, although most of the enterprises rely on some core enterprises to survive, but the housing supply chain network is stable. When the value of location attractiveness is 0.4, the degree distribution of the housing supply chain network is between the power law distribution and the exponential distribution, and the supply chain network is between the random network and the scale-free network. It can be seen that this network is characterized by a straight exponential distribution, which can adjust the network structure according to the node location attractiveness and make the supply chain develop in a balanced way, avoiding the rich getting richer and the poor getting poorer, and avoiding the phenomenon of "big pot rice".

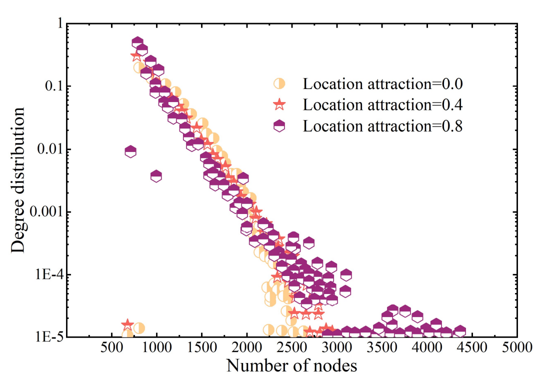


Figure 6: The degree distribution of network nodes

IV. B. 2) Network evolution results

For the housing supply chain network evolution model established in this paper, it will mainly go through three stages of initiation, development and stabilization in the evolution process. In order to further analyze the evolution of the housing supply chain network at different stages, on the basis of the two evaluation indexes of aggregation coefficient and average shortest path selected in the previous section, this paper also selects network density as an additional evaluation index. Using UCINET software to measure the relevant characteristics of the housing supply chain network at different stages, the results of the evolution of the housing supply chain network at each stage are obtained as shown in Table 2.

As can be seen from the table, the density of housing supply chain network increases year by year under the premise of fixed network size. In the initiation stage, the density of the housing supply chain network is 0.185, indicating that the communication and interaction among the subjects are less and weaker in this stage. In the stabilization stage, the density of the housing supply chain network is 0.419, which is about 2.27 times of the density of the network in the initiation stage, indicating that the interaction and cooperation between subjects in the stabilization stage is significantly stronger than that in the initiation stage, and that the subjects are more closely connected, which provides a better network foundation for the communication and synergy of the housing supply chain. Generally speaking, in the initiation stage of the housing supply chain network, the level of collaboration among the evolving subjects at each level is generally not high, but with the gradual evolution of the housing supply chain network, the density of the overall network gradually increases, the cooperation and interaction among the subjects gradually increases, and the network structure gradually evolves from the loose in the initiation stage to the tight.

The aggregation coefficient of the housing supply chain network is 0.658 in the initiation stage, and after the development stage, the aggregation coefficient reaches 0.793 in the stabilization stage, which indicates that the aggregation coefficient of the overall network is at a high level in the process of the housing supply chain network evolution and shows a gradual upward trend with the evolution of the network structure. It shows that in the start-up stage, the connection between the information participating subjects is not too close relative to the unfolding stage and the development stage, and the overall network cohesion is weaker, resulting in the phenomenon that there are more unreachable nodes in the network, the lack of symmetry, and the weak network connectivity, which leads to the low level of the overall cohesion of the network.

The housing supply chain network has an average shortest path of 1.743 between each information participating subject in the startup phase, meaning that the participating subjects in this network only need to pass through 1.743 participating subjects on average to have a connection with any subject in the network. Among them, there are 50 pairs of inter-subject network distance of 1, which is about 36.23% of the total. This indicates that 36.23% of the participating subjects have high synergistic efficiency and only need to pass through 1 subject to establish contact with other subjects. 76 pairs of subjects have a network distance of 2, which accounts for about 55.07% of the total, indicating that more than half of the subjects need to pass through 2 subjects to establish contact with other subjects. 12 pairs of nodes have a network distance of 3, which indicates that there are still 8.7% of the participating subjects who have a weaker degree of contact with other subjects and need to go through 3 subjects to be connected to other subjects. A horizontal comparison of the network distance data between the development stage and the expansion stage shows that the average distance between the development stage and the expansion stage is 1.612 and 1.387, which is 0.131 and 0.356 less than that of the start-up stage, and the synergy efficiency between the subjects is steadily improving. At the same time, the proportion of subjects with a network distance of 2 and 3 has been reduced, and only network relationships with a network distance of less than 2 exist between the participating subjects in the development stage, and the information participating subjects are more closely connected, and the overall synergistic efficiency of the housing supply chain network is stronger, which is conducive to the synergistic development of the housing supply chain network.

Table 2: Network evolution of housing supply chain

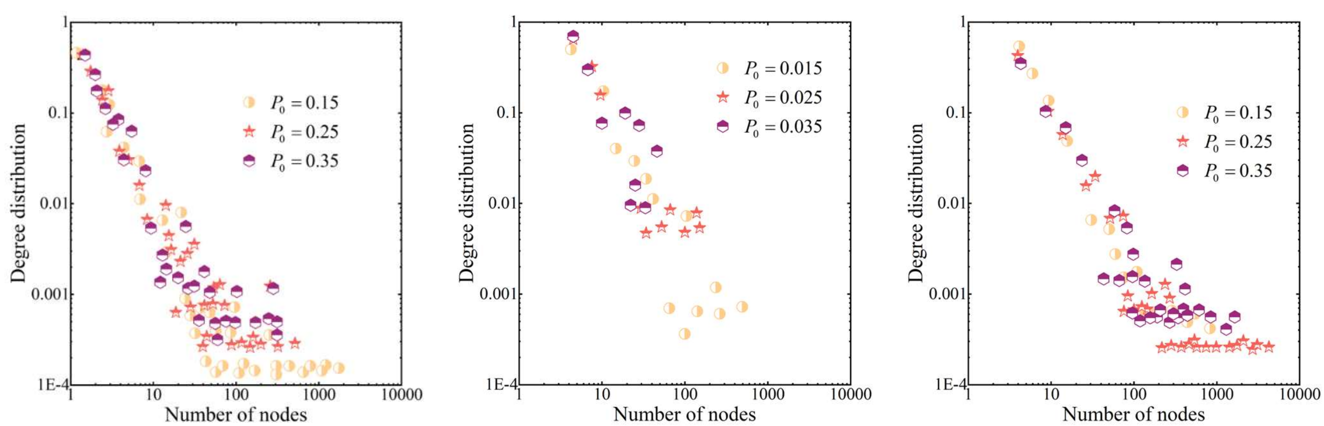
-	Start stage		Development stage		Stabilization phase	
Network density	0.185		0.306		0.419	
Concentration coefficient	0.658		0.742		0.793	
Average Distance	1.743		1.612		1.387	
Geodesic Distances	Freque	Propor	Freque	Propor	Freque	Propor
1	50	36.23%	64	46.38%	82	59.42%
2	76	55.07%	64	46.38%	56	40.58%
3	12	8.70%	10	7.24%	-	-

IV. B. 3) Network growth mechanisms

In the housing supply chain network evolution rule designed in this paper, the change of the transaction termination gate threshold between firm nodes may lead to a shift in the direction of network evolution. Based on this, in order to further analyze the operation and growth mechanism of housing supply chain network, the edge break update method (Case A) in the network evolution rule is modified to re-randomize the newly generated network edge benefits at any time (Case B) as well as re-randomize the edge benefits between nodes at intervals of time for the whole new network, and update the edge benefits only for the newly connected edges at the rest of the time (Case C). Setting the initial network size to 2000 and keeping the rest of the simulation parameters unchanged, the degree distributions of the housing supply chain network evolution in different cases are obtained as shown in Fig. 7. Among them, Fig. 7(a)~(c) shows the degree distributions of different cases, respectively, and Table 3 shows the comparison results of network characteristics for the case of updating edge benefits.

From the figure, it can be seen that the transaction termination gate threshold (P_0) between enterprise nodes directly affects the growth mechanism of the housing supply chain network, and also explains the way of economic operation in economics, while the contents of the table are empty to indicate that the network grows to become a disjunctive graph. For cases A and C, when the transaction termination threshold between enterprise nodes is taken as 0.15, 0.25 and 0.35 respectively, both of them can satisfy the power law growth mechanism. Combined with the data in the table, it illustrates that the larger the inter-enterprise node transaction termination gate threshold is, the larger the elimination rate is in its growth process, and when the inter-enterprise node transaction termination gate threshold is the same, the elimination rate of housing supply chain network in Case C is larger than that in Case A.

For case B, the housing supply chain network can only be maintained when the inter-enterprise node transaction termination threshold is very small, and it is known through simulation that the housing supply chain network will collapse when the inter-enterprise node transaction termination threshold is greater than 0.04. The data in the table also illustrate that case B can only be applied to a small range of inter-enterprise node transaction termination thresholds. It can also be concluded from the experiment that the critical value of the enterprise inter-node transaction termination gate threshold for network collapse will be different due to the different values of the initial node and the number of nodes, and generally in the case of ensuring that the initial node is greater than the number of nodes, the enterprise inter-node transaction termination gate threshold increases with the increase in the number of nodes.



(a) Situation A (b) Situation B (c) Situation C

Figure 7: The degree of network evolution

Table 3: Comparison of network evolution characteristics

P_0	Situation	Initial scale	Evolution scale	C	L
0.015	A	2000	1657	0.571	4.227
	B	2000	749	0.535	-
	C	2000	1524	0.592	4.452
0.15	A	2000	1043	0.584	4.105
	B	2000	-	-	-
	C	2000	852	0.432	-
0.35	A	2000	731	0.593	3.274

	B	2000	-	-	-
	C	2000	86	0.512	-

Based on the above simulation results, the growth mechanism of the housing supply chain network is explained as follows:

Case A indicates that the size of the housing supply chain network tends to grow indefinitely, but this is only an ideal growth model that rarely occurs in the real world. Case B indicates that the growth of the housing supply chain network is stabilized within a certain range, but due to the extremely low threshold of the transaction termination gate between enterprise nodes, it can be described as a growth model in the extraordinary economic period, during which the collaborators are required to maintain the cooperative relationship under low efficiency, otherwise the economy of the whole society will enter the collapse stage. As can be seen in Case C, the size of the housing supply chain network decreases dramatically at each moment of updating marginal efficiency. Then it continues to show a growing trend at other moments, which indicates that at each update of the value of marginal benefits, there will always be a group of enterprises eliminated due to competitiveness, market turbulence, etc., which makes the size of the housing supply chain network decline. However, the overall fluctuating growth explains that when the housing demand with a certain cycle occurs, there will be some enterprises closing down and the supply chain network size drops sharply, and then stimulated by the housing demand, the economy size is again on an upward trend. Comparing cases A~C, case C is more consistent with the real housing supply chain network growth mechanism.

V. Conclusion

In this paper, a housing supply chain intelligent management system based on intelligent logistics and supply chain technology is proposed, in which a housing supply chain network evolution model is established by combining the complex network, and its structure is optimized by the Ⅰ order zero model. The simulation results show that after optimizing the housing supply chain network structure by using FRM algorithm, the SLFCS after the accumulated number of attacks reaches 120 is still maintained at about 20%, which can effectively realize the optimization of the housing supply chain network structure. The network node location attraction has an adjustment effect on the housing supply chain network structure, and there are large differences in the housing supply chain network structure at different stages, and the network density value of its stabilization stage is about 2.27 times of the network density of the start-up stage. For the growth mechanism of housing supply chain network, setting a reasonable transaction termination threshold between enterprise nodes can effectively ensure the stability of housing supply chain network.

Although this paper has achieved certain results in the research process, there are still certain research deficiencies due to its own knowledge reserve problems. In the subsequent research, we will further explore the evolution trend of housing supply chain network under the changes of logistics, information flow and capital flow in the housing supply chain network, so as to better ensure the stable operation of the housing supply chain network, and further solve the contradictory relationship between mass housing demand and supply chain.

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References

[1] Morales, J. D. (2015). Logistics & transportation executives facing today’s challenges, seek solutions well into the future. Stanton Chase News.

[2] Gupta, A., Singh, R., & Suri, P. (2018). Analysis of challenges faced by Indian logistics service providers. Operations and Supply Chain Management: An International Journal, 11(4), 214-225.

[3] Kanagavalli, G., & Azeez, R. (2019). Logistics and e-logistics management: benefits and challenges. International Journal of Recent Technology and Engineering (IJRTE), 8(4), 12804-12809.
[4] Rajzer, K. (2024). Challenges of international logistics in the face of financial crises. TRANSBORDER ECONOMICS. International Journal on Transborder Economics, Finance, Politics and Statistics., 6(1), 51-58.
[5] Coyle, J. J., Novack, R. A., Gibson, B. J., & Langley, C. J. (2021). Supply chain management: a logistics perspective. Cengage Learning.
[6] Liu, Y. (2017). Review of Logistics Development in China. Contemporary Logistics in China: Reformation and Perpetuation, 163.
[7] McFarlane, D., Giannikas, V., & Lu, W. (2016). Intelligent logistics: Involving the customer. Computers in Industry, 81, 105-115.
[8] Yang, M., Mahmood, M., Zhou, X., Shafaq, S., & Zahid, L. (2017). Design and implementation of cloud platform for intelligent logistics in the trend of intellectualization. China Communications, 14(10), 180-191.
[9] Li, X. (2018). Development of intelligent logistics in china. Contemporary Logistics in China: Collaboration and Reciprocation, 181-204.
[10] Gumzej, R. (2023). Intelligent logistics systems in E-commerce and transportation. Math. Biosci. Eng, 20, 2348-2363.
[11] Chen, X., Chen, R., & Yang, C. (2022). Research to key success factors of intelligent logistics based on IoT technology. The Journal of Supercomputing, 78(3), 3905-3939.
[12] Liu, W., Wang, S., Lin, Y., Xie, D., & Zhang, J. (2020). Effect of intelligent logistics policy on shareholder value: Evidence from Chinese logistics companies. Transportation Research Part E: Logistics and Transportation Review, 137, 101928.
[13] Donald, J. B., David, J. C., M Bixby, C., & John, C. B. (2020). Supply chain logistics management. McGraw-Hill Education
[14] Kain, R., & Verma, A. (2018). Logistics management in supply chain–an overview. Materials today: proceedings, 5(2), 3811-3816.
[15] Christopher, M. (2022). Logistics and supply chain management. Pearson Uk.
[16] Richey, R. G., Roath, A. S., Adams, F. G., & Wieland, A. (2022). A responsiveness view of logistics and supply chain management. Journal of Business Logistics, 43(1), 62-91.
[17] Lin, D., Li, M., Zhan, Q., Song, X., Yang, Y., & Li, H. (2023). Application of intelligent logistics inventory optimization algorithm based on digital supply chain. International Journal of Emerging Electric Power Systems, 24(1), 61-72.
[18] Liu, W., Shanthikumar, J. G., Lee, P. T. W., Li, X., & Zhou, L. (2021). Special issue editorial: Smart supply chains and intelligent logistics services. Transportation Research Part E: Logistics and Transportation Review, 147, 102256.
[19] Liu, Y., & Zheng, J. (2022). Intelligent management of supply chain logistics based on 5g LoT. Cluster Computing, 25(3), 2271-2280.
[20] Li, S., Sun, Q., & Wu, W. (2019). Benefit distribution method of coastal port intelligent logistics supply chain under cloud computing. Journal of Coastal Research, 93(SI), 1041-1046.
[21] Cherchata, A., Popovychenko, I., Andrusiv, U., Gryn, V., Shevchenko, N., & Shkuropatskyi, O. (2022). Innovations in logistics management as a direction for improving the logistics activities of enterprises. Management Systems in Production Engineering.
[22] Lee, C. K., Lv, Y., Ng, K. K., Ho, W., & Choy, K. L. (2018). Design and application of Internet of things-based warehouse management system for smart logistics. International Journal of Production Research, 56(8), 2753-2768.
[23] Gomes, A. C., de Lima Junior, F. B., Soliani, R. D., de Souza Oliveira, P. R., de Oliveira, D. A., Siqueira, R. M., ... & de Macêdo, J. J. S. (2023). Logistics management in e-commerce: challenges and opportunities. Revista de Gestão e Secretariado, 14(5), 7252-7272.
[24] Gargasas, A., Samuolaitis, M., & Mūgienė, I. (2019). Quality management systems in logistics. Management Theory and Studies for Rural Business and Infrastructure Development, 41(2), 290-304.
[25] Dong, D. G. (2023). Design and development of Intelligent Logistics Tracking System based on computer algorithm. International Journal for Applied Information Management, 3(2), 58-69.
[26] Wang, T., Chen, H., Dai, R., & Zhu, D. (2022). Intelligent logistics system design and supply chain management under edge computing and Internet of Things. Computational Intelligence and Neuroscience, 2022(1), 1823762.
[27] Krajcovic, M., Grznar, P., Fusko, M., & Skokan, R. (2018). INTELLIGENT LOGISTICS FOR INTELLIGENT PRODUCTION SYSTEMS. Komunikácie, 20(4).
[28] Li, F., & Li, T. (2022). Intelligent logistics Enterprise management based on the Internet of things. Mathematical Problems in Engineering, 2022(1), 1621082.
[29] Shaohui Zhang,Qiuying Han,Hai Zhu,Hongfeng Wang,Huiling Li & Ke Wang. (2025). Real time task planning for order picking in intelligent logistics warehousing. Scientific Reports,15(1),7331-7331.
[30] Yachen Shen,Huachun Xiang,Jing Li & Zhiyuan Chen. (2025). On the development and implications of a new probabilistic model in financial and supply chain management. Alexandria Engineering Journal,121,402-413.
[31] Hanyang Wang,Yuetao Wang,Zhen Ren,Chengbin Wu & Wenpeng Song. (2025). Cluster-Based Protection Mechanisms for Coastal Traditional Villages: A Complex Network Analysis Approach with a Case Study of Rongcheng, Shandong Province (Part 1). Buildings,15(5),784-784.
[32] Jordana Alaggio,Daniel Barros,Bruno Brentan,Silvia Carpitella,Manuel Herrera & Joaquín Izquierdo. (2025). Assessment of Criticality in Water Distribution Networks via Complex Network Theory. Processes,13(2),408-408.
[33] Yang Zong chang. (2024). A Complex Networks-Based Position-Distance-Related Epidemic Simulation Model for the H1N1: A Case Study. Cybernetics and Systems,55(4),961-980.