Research on the Spatial Structure of the Construction Industry Chain Network Based on the Perspective of ' Region-City '

Likun Zhao[1*],Xin Zhang[2], Zhenjiang Liu[3] and Xiangze Xing[4]

{*zlk@ncut.edu.cn[1],zhangxinxin@mail.ncut.edu.cn[2],lzj0611@mail.ncut.edu.cn[3], xzz13930218384@163.com[4]}

School of civil engineering, North China University of Technology, Shijingshan District, Beijing 100144, China

Abstract. The relationship between enterprises is the key to industrial relationships. Strengthening the analysis of industrial spatial networks based on the relationship between enterprises in the construction industry is of great significance to enrich the theoretical research of industrial networks in the construction industry.Based on the transaction relationship data of listed companies in the construction industry and their top five suppliers and customers from 2014 to 2022, this paper constructs the urban network in China, and analyzes the spatiotemporal evolution characteristics of the urban network in the construction industry based on the perspective of inter-enterprise transaction connection. The results show that during the study period, the overall spatial structure of the network spreads from the center of the urban agglomeration to the outside, provincial strong associations were distributed in Beijing, Shandong province, Shanghai, Guangdong province, and the surrounding provinces, and the urban agglomerations on the north slope of Tianshan mountain in northwest China gradually developed and spread within the construction industry urban agglomerations, with the release of urban agglomerations policies, the development and evolution of the network structure gradually transformed into a more balanced and complex stable state.

Keywords: corporation relation; Complex network; industry chain; City networks

1.Introduction

With the interactive development of globalization, informatization, and urbanization, the world urban system has entered the stage of network development[1]. As the most important carrier of various "factor flows" such as capital, talents, information, services, and products, enterprises are constantly changing and shaping the pattern of the world urban network with their rapidly growing trans-regional and transnational strategic layout. The enterprise network formed by the trans-regional layout is one of the effective tools for describing the connection between regions and cities[2]. The corresponding urban network is constructed and analyzed by collecting the relevant information of the suppliers and customers of the construction industry enterprises. The research of urban industrial networks based on the perspective of enterprise is to construct a three-mode network translated from enterprise network to urban network, namely "enterprise-enterprise network city network urban agglomeration network"[3][4]. The relationship between enterprises does not have the relationship between upper and lower levels, which is more in line

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with the level of urban network and the connotation of cooperation and complementarity, and focuses on the business traffic data between enterprises, which can reflect the real economic relationship[5][6]. The connection between enterprises based on real economic activities is an effective way to build urban networks. A city is a gathering place for enterprises. Establishing inter-enterprise connections through the transaction relations between enterprises can reflect the closeness of the connections between the cities where the enterprises are located and reflect the real economic connections between cities, which is one of the effective ways to reflect the urban industrial network. Taking the city as the network node of enterprise connection, the transaction connection between enterprises is projected as the link between cities, and the "construction industry enterprise network" with the city as the node is formed in space[7].

Compared with the composite urban network research covering a variety of industries, the urban network research carried out for a specific industry can reveal the pattern of enterprise distribution and spatial organization in the industry and reflect the difference in urban network shape under the influence of different economic activities, which has a unique value[8]. Therefore, more and more attention has been paid to urban network research based on the contact data of enterprises in a specific industry in recent years. At present, some scholars have carried out preliminary exploration of the urban network constructed by the financial industry[9][10], manufacturing industry[11], logistics industry[12], service industry[13][14],pharmaceutical industry[8], tourist industry[15] and cultural industry[16], but few studies have examined the connections and networks among cities from the perspective of the enterprise network of the construction industry. As an important material production sector of the national economy, the construction industry has a close relationship with the development of the entire national economy and the improvement of people's living standards. The construction industry is a pillar industry of our national economy[17]. According to the statistics of the construction industry over the years, with the rapid growth of the national economy, the investment rate of fixed assets increased year by year, the added value of the construction industry rose steadily and became the pillar industry to stimulate the rapid growth of the national economy. The generation and implementation of construction industry projects often involve cooperation between different enterprises, so there is a high dependence on local and trans-regional economic and social networks[17].

Based on this, this paper selects listed companies in the construction industry in China, and through the collection, collation, and cartographic analysis of the transaction data associated with listed companies in the construction industry and their suppliers and customers, explores the spatial structure characteristics of urban networks in China from the perspective of the construction industry and reveals the differences between the construction industry city network and other types of urban networks. To enrich the relevant research of China's urban network and provide a new understanding of the production organization of the construction industry.

2. Research methods and data sources

2.1 Research Methods

To analyze the evolution of the direct spatial connection network between construction enterprises and their suppliers and customers, supported by economic geography theory and

urban network theory, this study starts with the analysis of global characteristics and network structure.

The steps of this research are as follows:

(1) review the research progress of intercity networks in other industries based on the perspective of enterprise connection.

(2) Build the intercity network data based on the connection between enterprises in the construction industry chain based on the transaction flow data of A-share listed companies and their top five customers to form the basic database of this research.

(3) The overall network structure, evolution of network structure, and local network structure of the network [18]are analyzed from the national scale by using the complex network[19][20].

2.1.1 Network density

Network density reflects the degree of connectivity between nodes in a network[21]. The higher the network density, the closer the relationship between the network nodes. The formula is:

$$D = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} d_i(\mathrm{i,j})}{n(\mathrm{n}-1)}$$

D is the network density; n is the number of urban nodes; i and j are the cities where the transaction relationship takes place; $d_i(i,j)$ is the amount of trade between cities; D is between 0 and 1; The closer the value of network density D is to 1, the closer the relationship between cities in the network is.

2.1.2 Average shortest path

The average path length can be used to measure the average number of shortest path edges between any two cities in the network[22]. The value of the average path length reflects the overall connectivity of the network. The calculation method is as follows:

$$L = \frac{1}{\frac{1}{2} n(\mathrm{n\text{-}1}) \sum_{i>1} d_{ij}}$$

Where L is the average path length, n is the number of nodes, and d_{ij} is the number of shortest path edges between nodes i and j. A smaller value of the average path length indicates that the network has strong reachability, good connectivity, and high network operation efficiency, and it is easier to enhance the anti-interference ability of the network and improve the network toughness. Therefore, the average path length value is inversely proportional to the network toughness.

2.1.3 Network correlation degree

Network relatedness generally reflects the robustness and vulnerability of a network. Robustness and vulnerability are two relative concepts[23]. Generally, the higher the robustness of a network, the lower the vulnerability, and vice versa. The value range of network correlation degree is also [0,1], and generally needs to be measured by the reachability between nodes in the network. Assuming that the number of nodes is N, the maximum number of connections in the directed network is $N*(N-1)$, and L is the actual number of connections. If the number of unreachable (no connection) between any two nodes in the network is U, the network correlation degree is:

$$R = 1 - \frac{2U}{N(\mathrm{N}-1)}$$

2.1.4 Network clustering

The clustering coefficient is used to describe the clustering of nodes in the network[24], that is, how tight the network is. The clustering coefficient calculation method of a node i is as follows:

$$C_i = \frac{2E_i}{K_i(\mathrm{K_i}-1)}$$

K_i is the degree of node i, and E_i is the actual number of edges generated between adjacent nodes of node i. The average of all clustering coefficients in the network reflects the degree of node clustering in the whole network. The calculation method is:

$$C = \frac{1}{n\sum_i^n C_i}$$

The greater the clustering coefficient, the greater the impact of the network on the city, the stronger the transmission and interaction function between nodes, the higher the degree of dependence between nodes, the worse the robustness of the network, the lower the anti-interference ability to the outside world, in the case of any local interruption, there will be more network connections interrupted, so the average clustering coefficient is inversely proportional to the level of network toughness.

2.2 Data Sources

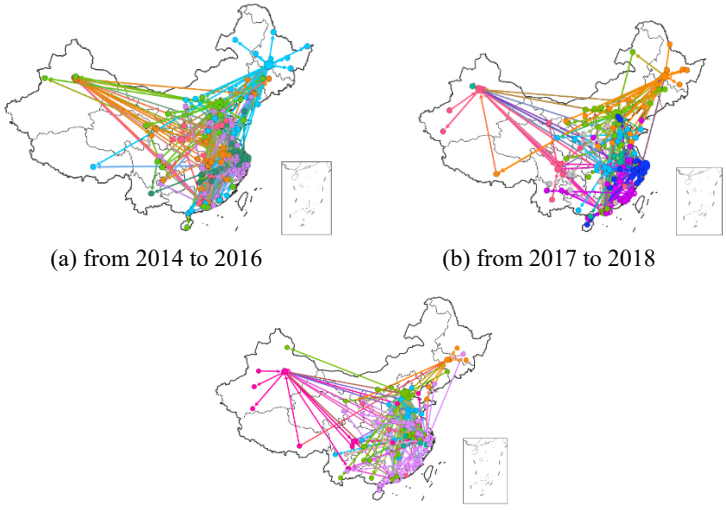
The analysis area of this study covers Chinese cities, and the research data span from 2014 to 2022. The data of listed construction companies and their top five customers and suppliers come from the China Research Data Service platform. The name, quantity, address, and transaction amount information of listed companies and their top five customers in major cities of China during 2014-2022 were systematically collected and obtained, and the address information of some enterprises was supplemented by the four-database-one platform. Through data matching, the transaction volume of listed companies and customers and the information of the cities

where they are located are obtained to form a structured basic database of this study, and the information vacancy data is eliminated. Cities at the prefecture level and above are taken as the research units for merging and processing. The specific processing method is to match the addresses of listed companies and customers to the corresponding cities and build the database of power-directed paths among Chinese cities through classification and summing.

3. Spatial connection network of construction enterprises: global characteristics analysis

3.1 Characteristics of intercity association network of construction enterprises

In this study, the spatial association network of regional construction enterprises is constructed based on the inter-city transaction network data of the construction industry, and the inter-city association value of the construction industry is divided into 5 levels weak association, weak association, medium association, strong association, and strong association based on the natural breakpoint method[25]. The data is visualized with Gephi software, and the results are shown in the figure 1. All of them show the spatial differentiation characteristics of strong in the east and weak in the west and highly clustered in the five major urban agglomerations.



(a) from 2014 to 2016 (b) from 2017 to 2018

(c) from 2019 to 2022

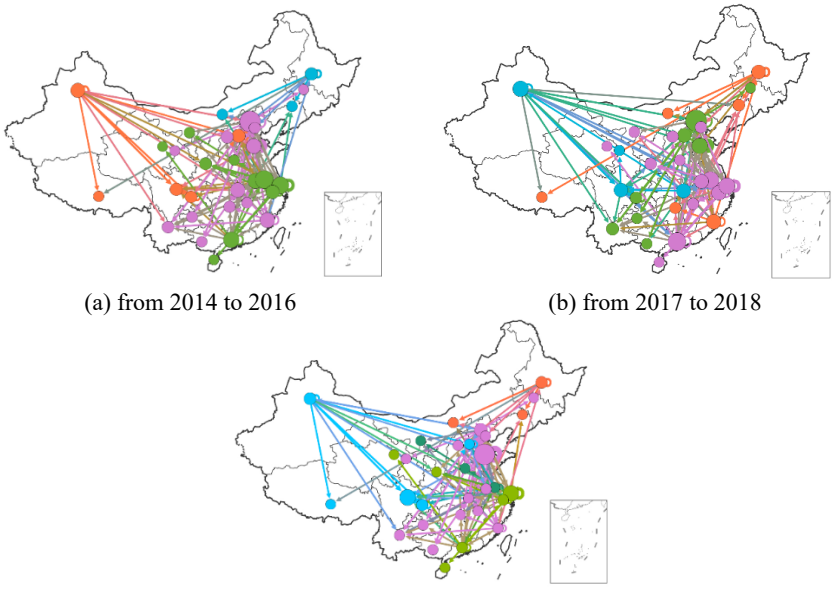
Figure 1. Intercity correlation chart of construction enterprises from 2014 to 2022

Based on the inter-city association network of the construction industry, the spatial connections between cities in the construction industry continue to strengthen over time, and the evolution of the spatial connection network is gradually complex, showing a transition from a regional centered network to a balanced complex network structure. However, the strong connections are basically distributed in the eastern coastal areas. Specifically, from 2010 to 2013, the divergent regional network with Beijing as the core and the expansion of Beijing, Tianjin and Hebei formed a diamond-shaped structure with strong associations with the Yangtze River Delta

region, the Guangdong-Hong Kong-Macao Greater Bay Area and Chengdu-Chongqing region, while other regions mainly showed sparse network structure formed by weak, and medium associations. From 2014 to 2016, the strong correlation structure moved closer to the eastern region, and the correlation degree of construction enterprises in the Beijing-Tianjin-Hebei region, the Yangtze River Delta region, and the Guangdong-Hong Kong-Macao Greater Bay Area was further enhanced, and the North-South radiation was further enhanced. From the perspective of other correlations, the intercity correlation of construction enterprises gradually extended outward, and the regional correlation gradually strengthened. From 2019 to 2022, the three-core network structure in the eastern region has been continuously strengthened, the strong correlation has further increased, and the overall network structure of the eastern region radiates to other regions has been formed. The regional structure has been transformed into a giant radiative and strong correlation network in the eastern and central regions, and the giant relationship network in the eastern and central regions is more closely connected, and gradually forms radiation to the central and western regions and develops into a nationwide strong correlation network.

3.2 Characteristics of inter-provincial correlation network of construction enterprises

Based on the inter-provincial transaction network data of the construction industry, this study constructs the spatial association network of regional construction enterprises and uses Gephi software to visualize the data. The results are shown in the figure 2.



(a) from 2014 to 2016

(b) from 2017 to 2018

(c) from 2019 to 2022

Figure 2. Inter-provincial association chart of construction enterprises from 2014 to 2022

Based on the inter-provincial external connection network of the construction industry, with the evolution of time, the spatial connection of the industrial chain of the construction industry enterprises continue to strengthen, and the evolution of the spatial connection. Network is

gradually complex, showing the transition from the regional center network to the balanced complex network structure, but the strong connection is basically distributed in Beijing, Shandong, Shanghai, Guangdong, and the surrounding provinces. Specifically, from 2014 to 2016, the strong correlation was mainly divided into four core regional networks and other local networks. The divergent regional network with Beijing as the core and the expansion of Beijing, Tianjin and Hebei formed a diamond-shaped structure with strong associations with the Yangtze River Delta region, the Guangdong-Hong Kong-Macao Greater Bay Area, and Chengdu-Chongqing region, while other regions mainly showed sparse network structures formed by weak, weak, and medium associations. From 2014 to 2016, the strong correlation structure moved closer to the western region, and the correlation degree of construction enterprises in the Beijing-Tianjin-Hebei region, the Yangtze River Delta region, and the Pearl River Delta region was further enhanced, and the North-South radiation was further enhanced. From the perspective of other correlations, the correlation of provincial construction enterprises gradually extended outward, and the regional correlation gradually strengthened. From 2018 to 2021, the three-core network structure in the east continued to strengthen, and the strong correlation further increased, and the overall network structure of the eastern region radiated to other regions was also formed.

4. Spatial linkage network of construction enterprises: Analysis of network structure

4.1 Inter-city network characteristics of construction enterprises

As shown in the following table 1.The structural network density of Chinese construction enterprises from 2014 to 2016 is 0.029, from 2017 to 2019 is 0.028, and from 2020 to 2022 is 0.035. From the overall value, the intercity network density of China's construction enterprises is low, the intercity network connection is not close enough, and the network has been in a weak connection.

From 2014 to 2016, the average path length of the construction enterprise connection network was 3.662, from 2017 to 2019, the average shortest path length was less to 2.351, and from 2020 to 2022, the average length reached 3.346. The transmission efficiency of the urban network of China's construction enterprise is still generally low and has declined compared with before. The overall connectivity of the network is weak.

Table 1.Characteristic values of construction enterprise networks from 2014 to 2022

Year	Network density	Network correlation	Average path length	Core edge structure	Average clustering coefficient
2014-2016	0.029	0.939	3.662	0.067	0.160
2017-2019	0.028	0.117	2.351	0.015	0.143
2020-2022	0.035	0.302	3.346	0.012	0.149

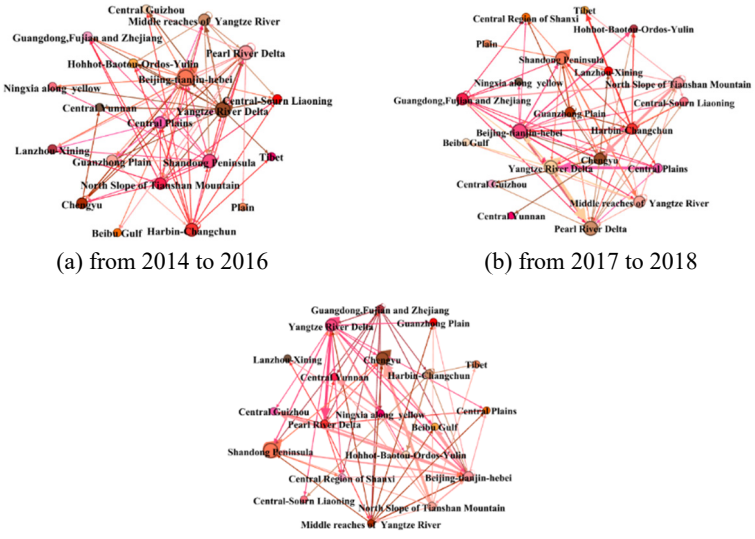
Network correlation is the degree to which nodes in a network diagram are connected to each other. The more ways there are between two points, the higher the degree of correlation of the points. If there is more than one path between any two points, the more cohesive the entire network is. The network correlation degree of Chinese construction enterprises was 0.939 in

2014-2017, decreased to 0.117 in 2017-2019, and gradually rose to 0.302 in 2020-2022. This indicates that the cohesiveness of the whole network is still in a low state. Core-edge structure is a special structure composed of several interrelated elements, the center is closely connected, and the periphery is sparse and scattered. It is the most efficient and easy to sustainable development structure, with strong stability. The core degree index reflects the closeness of the connection between network nodes and measures the important position of nodes in the network. Overall, the fitting degree of the core edge structure of the industrial chain network of China's construction industry enterprises gradually decreased from 2014 to 2022, and the overall inter-city network connection degree is not close enough. The average clustering coefficient is used to describe the clustering of nodes in the network, that is, how tight the network is. The average clustering coefficient of the industrial chain network of China's construction industry enterprises was 0.160, 0.143, and 0.149 in 2014-2016, 2017-2019 and 2020-2022, respectively, indicating that the node clustering situation of the industrial chain network of China's construction industry enterprises was not good and not close enough.

4.2 Local network characteristics of urban agglomerations of construction enterprises

To further explore the local network characteristics, the network among key urban agglomerations is analyzed. According to the 19 major urban agglomerations specified in the 14th Five-Year Plan of the state, the transaction network among urban agglomerations should be built.

4.2.1 Network characteristics of urban agglomerations among construction enterprises



(a) from 2014 to 2016 (b) from 2017 to 2018

(c) from 2019 to 2022

Figure 3. Correlation diagram of construction enterprise urban agglomerations from 2014 to 2022

As shown in Figure 3.From the perspective of network core edge characteristics, the core status of the four major urban agglomerations, namely, Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta and Chengdu-Chongqing City cluster, is relatively stable, while the node

status of the middle reaches of the Yangtze River, Chengdu-Chongqing, Guan Zhong, North slope of Tianshan Mountain, and Harbin Changchang City cluster are significantly improved, and the network multi-centrality is significantly improved. In 2020, the overall network will be degraded, and the network connectivity will decline. From the perspective of the overall network density, the network density increased from 0.571 in 2014 to 0.632 in 2019, and then decreased to 0.584 in 2020, showing the characteristics of first rising and then decreasing, which means that links between some urban agglomerations have been interrupted, such as the one-way trade relationship between the Central Plains Urban agglomerations and the Lanxi urban agglomerations have been interrupted. The average weighted degree increased from 144.6 in 2014 to 221.2 in 2019, confirming the view that network trade links are more and more concentrated among a few cores of urban agglomerations. In 2020, the network density further decreased to 0.531, and the average weighted degree of the network decreased to 9.632, indicating that the COVID-19 epidemic has a significant weakening effect on the network density and intensity among urban agglomerations in China.

4.2.2 Network characteristics among urban agglomerations of construction enterprises

Further analyze the internal network structure of the six major urban agglomerations: Beijing Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, middle reaches of Yangtze River, Chengdu-Chongqing, and Shandong Peninsula.

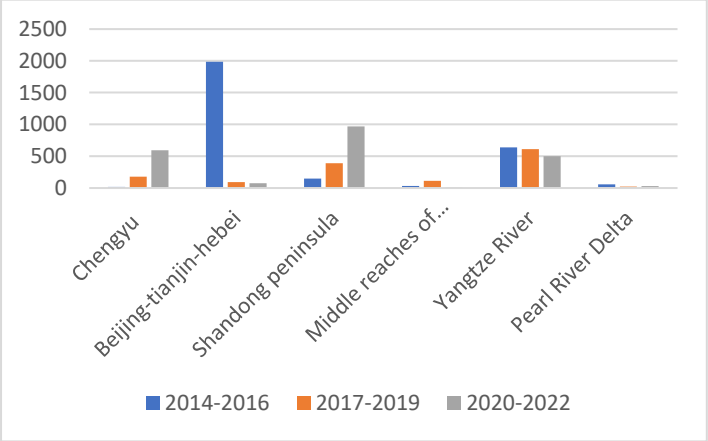


Figure 4. Internal transactions of construction enterprises in urban agglomerations from 2014 to 2022

The intra-transaction data of construction enterprises from 2014 to 2022 are shown in the figure 4. The Chengdu-Chongqing city cluster, the Shandong Peninsula City cluster and the Yangtze River Delta city cluster are gradually increasing their internal transactions, driven by city cluster policies. The Pearl River Delta city cluster and the middle reaches of the Yangtze River City cluster are in a steady state of development, and the Beijing-Tianjin-Hebei city cluster has the largest trend of change. It is the need to explore the effective path of ecological civilization construction and promote the coordination of population, economy, resources, and environment. At the same time, from 2014 to 2016, the coordinated development of the Beijing-Tianjin-Hebei city cluster was rapid, and the internal transaction reached 19.85 million yuan. In 2016, the "Beijing-Tianjin-Hebei Air Pollution Prevention and Control Measures (2016-2017)" was

proposed to adjust the energy and industrial structure and reduce the output of manufacturing industries related to the construction industry, such as metal smelting - steel and non-metal - cement. From 2017, the intra-transaction data of the Beijing-Tianjin-Hebei city cluster declined rapidly and leveled off.

5. Conclusions and Suggestions

5.1 Conclusion

Based on the transaction data of listed companies and their top five supplier customers, this paper transforms the inter-enterprise transaction network into an urban connection network and adopts complex network methods to analyze the spatiotemporal evolution characteristics of the urban network structure of China's construction industry from the perspectives of cities, provinces, and urban agglomerations during 2014-2022. The findings are as follows:

(1) The inter-city association network of China's construction industry enterprises has evolved gradually, showing a transition from a regional center network to a balanced complex network structure, and forming a network structure radiating from the eastern region to other regions. The coverage breadth of the local correlation of municipal fintech is significantly improved, and the tightness of the external correlation network structure is gradually improved, and it is constantly transformed into a giant and highly radiant correlation network in the eastern and central regions.

(2) From 2014 to 2022, the total volume of intercity trade and the number of nodes in China show a trend of first increasing and then decreasing. The overall network density is between 0.029 and 0.035, and the network presents a characteristic of first rapid growth and then slow decline; The average path length of the network is kept between 2.351-3.662, showing the characteristics of a small world. The network connecting the edge structure shows the characteristics of the transformation from a coastal structure to a "T" shape structure.

(3) The network density among urban agglomerations increases first and then decreases, the centrality of the network increases significantly, and the trade flow is concentrated in the connections among a few cores of urban agglomerations; Among the five major urban agglomerations, the intercity transaction network connectivity of the Pearl River Delta urban agglomerations is the best, and the network density is between 0.32 and 0.33. The total trade flow of the Yangtze River Delta is the highest, reaching 78.05 billion yuan, while the average trade flow of the Pearl River Delta is the highest, and the network density and trade flow of the middle reaches of the Yangtze River urban agglomerations and Chengdu-Chongqing urban agglomerations are lower. It is necessary to further increase support for the central and western urban agglomerations.

5.2 Suggestions

Based on the spatial pattern in the "14th Five-Year Plan for Construction Industry Development" and the "14th Five-Year Plan for Urban Agglomeration Planning", and combined with the conclusions of this study, the following optimization strategies are proposed for the urban network structure of China's construction industry enterprises: (1) Improve the network structure and strengthen the interaction between non-core node cities. While maintaining close

connections with the center of urban agglomerations, other cities should avoid too single contact objects, and promote the development of urban agglomerations into complex spatial network structures to promote the improvement of network functions and improve network resilience. (2) Foster secondary central cities. If the polarization effect of Chinese cities is too significant, the regional network structure will be unbalanced, and the pattern of "high in the east and low in the west" will appear. Such network structure is unstable. Provincial capital cities can be used as regional secondary central cities to drive the development of surrounding cities to a certain extent. (3) Strengthen the comprehensive construction of peripheral cities, promote the coordinated development of core cities and small and medium-sized cities, and guide the network structure to become more balanced. Cities in Northwest China have few connections with other cities and are easy to be disconnected from the network in emergencies. To avoid the situation of "the strong get stronger and the weak get weaker", the professional characteristics and functions of the marginal cities should be reasonably positioned, the direction of urban development should be determined, the integrated transportation system within the region should be improved, and efficient division of labor and cooperation within urban clusters should be promoted.

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