Analysis of the Destruction Resistance of Multi-mode freight network in Beijing-Tianjin-Hebei urban agglomeration

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ABSTRACT

Based on the county-level unit cities in the Beijing-Tianjin-Hebei urban agglomeration as nodes, the multi-mode freight network topology model between urban agglomerations is constructed, and Python is used to realize random attack simulation and Intentional attack simulation of multi-mode freight network and single-mode freight network of urban agglomeration, and the multi-mode freight network and single-mode freight network of urban agglomeration are evaluated by maximum connectivity index and network efficiency index. This paper selects the Beijing-Tianjin-Hebei urban agglomeration as an example object, mainly measures the destruction resistance of the road-railway multi-mode freight network of the urban agglomeration, hoping to provide decision-making support for the freight safety and improve the destruction resistance of the freight network to natural and man-made disasters in the Beijing-Tianjin-Hebei region.

Keywords: Beijing-Tianjin-Hebei urban agglomeration, destruction resistance, multimodal freight network

1. INTRODUCTION

Urban cluster development is an important development direction of China's urbanization process in the new era, and various cargo transportation modes in urban agglomerations are relatively perfect, but in recent years, natural disasters such as floods, typhoons, and earthquakes still pose a serious threat to the security of China's urban agglomeration freight network, so strengthening the destruction resistance of cargo transportation network is still the top priority of China's transportation development.

In recent years, scholars have done a lot of in-depth research on the risk resistance of traffic networks based on complex network analysis. Hu Ping et al. [1]analyzed the topological characteristics of the network and studied the destruction resistance of the network under random attacks and Intentional attacks ， taking the Chengdu bus network as an example. Li Chengbing et al. [2]took Hohhot - Baotou - Ordos urban agglomeration as an example to conduct empirical research, construct a road-rail weighted multi-mode transportation network model, simulate the destruction resistance of the network and identify key stations in the road network. Shen Li et al. [3]used complex network theory to measure the static destruction resistance of subway-bus composite network under different attack modes to judge the importance of nodes and edges in composite networks. Chen Jing et al. [4]analyzed the proportion of average shortest path and maximum connectivity subgraph of multimodal transport enterprise transportation network after random attacks and intentional attacks (key nodes) of nodes, so as to analyze network vulnerability. Zhang Yuhong et al. [5]proposed the anti-invulnerability metrics of network connectivity rate and network travel time reliability, and studied the destruction resistance of urban public transport network under the condition of considering the reliability of travel time. Johnson Caroline A et al.[6] consider the effect that spatially-correlated failures have on network robustness using only spatial properties of the hazard and topological properties of networks. Milena O et al.[7] provides a comparative overview of some network topology graph metrics, showcases their advantages and limitations in analyzing the robustness of internet topology, and outlines a conceptual toolset. Yang Jingfeng et al. [8]proposed node importance evaluation indicators based on node betweenness centrality index and degree centrality index node in urban rail transit network.

At present, the research on the anti- destruction of transportation network mainly focuses on passenger transport, and this paper focuses on the cargo transportation of urban agglomeration, selects the Beijing-Tianjin-Hebei urban agglomeration as the analysis object to construct a multi-mode freight network of urban agglomeration, and evaluates the destruction resistance of urban agglomeration freight network under the condition of cascade failure. Since the ports of the Beijing-Tianjin-Hebei urban agglomeration are mainly seaports responsible for the external transportation of urban agglomerations, this paper mainly studies the indestructibility of the two modes of cargo transportation, road and rail, which are responsible for internal transportation in urban agglomerations.

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2. CONSTRUCTION OF URBAN AGGLOMERATION NETWORK MODEL AND ANALYSIS METHOD OF DESTRUCTION RESISTANCE

2.1 Network model construction

In this paper, road transportation and railway transportation are used to construct the freight network of urban agglomeration, and the Space-L modeling method is used to construct a single-mode freight network and a multi-mode freight network, and a weightless undirected network diagram is constructed G_c ,They are a single railway transport network G_1, a single road transport network G_2, and a multi-mode road-rail transport network G_3. Each network diagram consists of $G=\{V,\ L\}$, V is the set of nodes in the network, and L is the set of connected edges in the network. Model building follows these rules:

(1) The railway transportation network takes the county-level administrative districts in the urban agglomeration as nodes, and the existence of railway stations in the same county-level administrative area can be regarded as nodes, and if there are direct railway lines in two county-level administrative districts, it can be regarded as having a connecting edge, and the railway station is only counted as a railway freight station.

(2) The road transportation network takes the county-level administrative districts in the urban agglomeration as nodes, and the existence of expressway stations in the same county-level administrative area can be regarded as nodes, if there are direct expressways in two county-level administrative districts, it can be regarded as the existence of connecting edges, and highway nodes only count expressways.

(3) The multi-mode road-railway transportation network is formed by the interaction between the railway transportation network and the road transportation network, if the same county-level administrative districts exist in the two transportation networks, that is, the nodes of the same county-level administrative districts in the two transportation networks are connected to the edges, and the two modes of transportation of road and railway in the same county-level administrative area can be used for cargo transit.

2.2 Attack strategy setting

(1) Random attack strategy

An indiscriminate attack is carried out on nodes in the transportation network, and the probability of each node being attacked is the same.

(2) Degree attack strategy

The nodes in the transportation network are sorted according to the degree value, and the node with the largest attack degree value is prioritized, that is, the larger the number of neighbors of the node, the priority is attacked.

$$K_i = \sum_{j=1}^{N} A_{ij} \tag{1}$$

(3) Betweenness attack strategy

Nodes with the largest number of betweenness are sorted according to their size.

$$B_i = \sum_{j \neq l \neq i} \left[N_{jl}(i) / N_{jl} \right] \tag{2}$$

N_{jl} represents the number of shortest paths between nodes V_l and V_j, and $N_{jl}(i)$ represents the number of shortest paths between nodes V_l and V_j through node V_i.

2.3 Setting of destruction resistance evaluation indicators

In this paper, two evaluation indicators are used for the evaluation of the destruction resistance of the transportation network: the relative size of the maximum connectivity graph and the network efficiency.

(1) Maximum connectivity

Maximum connectivity is the ratio of the number of nodes in the maximum connectivity subgraph to the total number of nodes. Smaller maximum connectivity indicates greater damage after an attack and less destruction resistance to the network.

$$G = \frac{N^{'}}{N} \tag{3}$$

G is the maximum connectivity, $N^{'}$ is the maximum number of nodes in the connectivity subgraph, and N is the total number of nodes in the network.

(2) Network global efficiency

The network global efficiency represents the reciprocal mean of the shortest path for nodes in the network. The global efficiency of the network reflects the network connectivity to a certain extent, and the higher the global efficiency of the network, the stronger the destruction resistance of the network.

$$E = \frac{1}{N\left(N-1\right)}\sum_{i \neq j}\frac{1}{d_{ij}} \tag{4}$$

E indicates the global efficiency of the network and d_{ij} represents the shortest path from V_i to V_j .

3. CASE ANALYSIS

The Beijing-Tianjin-Hebei urban agglomeration is one of the most economically active areas in China, and it is also one of the most severely affected areas by natural disasters in China this year, so the Beijing-Tianjin-Hebei urban agglomeration is used as the object of analysis to study the anti-destruction of freight networks, and the study of its anti-destruction ability is of great help to improve China's resistance to natural disasters and man-made disasters.

3.1 Construction of Beijing-Tianjin-Hebei Road-Railway Freight Network Topology

This paper obtains the information of the expressway network in the Beijing-Tianjin-Hebei region through the 2023 China Transportation Atlas and abstracts it into 158 county-level highway nodes to construct the road transportation network. Through the schematic map of national freight business stations issued by China National Railway Group Co., Ltd., the railway freight information of the Beijing-Tianjin-Hebei urban agglomeration was obtained and abstracted into 102 county-level railway nodes to construct a railway transportation network. the topology map of the freight network of the Beijing-Tianjin-Hebei urban agglomeration is constructed by combining the road transportation network and the railway transportation network, as shown in the Figure 1 Topology diagram of road-rail transportation network(a), and integrated into the same diagram through the nodes and edges of the road transportation network and the railway transportation network, as shown in the Figure 2 Topology diagram of road-rail transportation network(b).

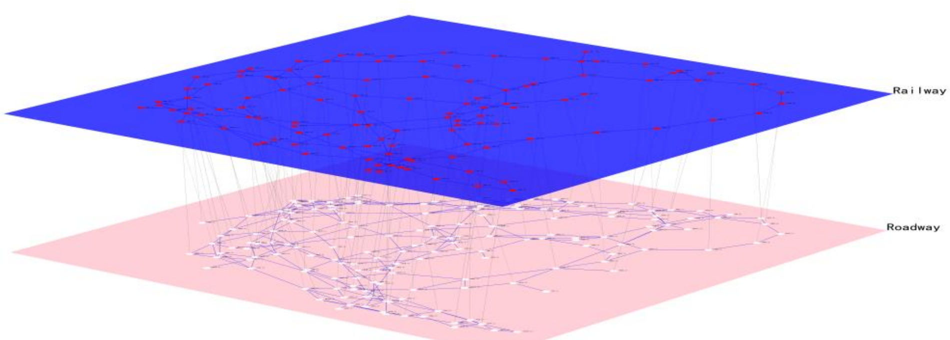

Figure 1 Topology diagram of road-rail transportation network(a)

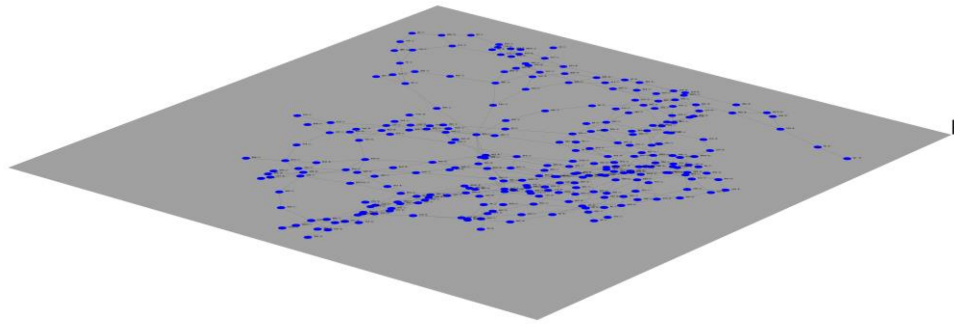

Figure 2 Topology diagram of road-rail transportation network(b)

3.2 Simulation analysis of the destruction resistance of freight network in Beijing-Tianjin-Hebei urban agglomeration

Based on Python, this paper simulates random attacks and Intentional attacks on the Beijing-Tianjin-Hebei multi-mode freight network and single-mode freight network, calculates the maximum connectivity and network efficiency after node failure, and takes maximum connectivity and network efficiency as the indicators of freight network destruction resistance index.

3.2.1 Simulation of the destruction resistance of different freight networks under random attacks

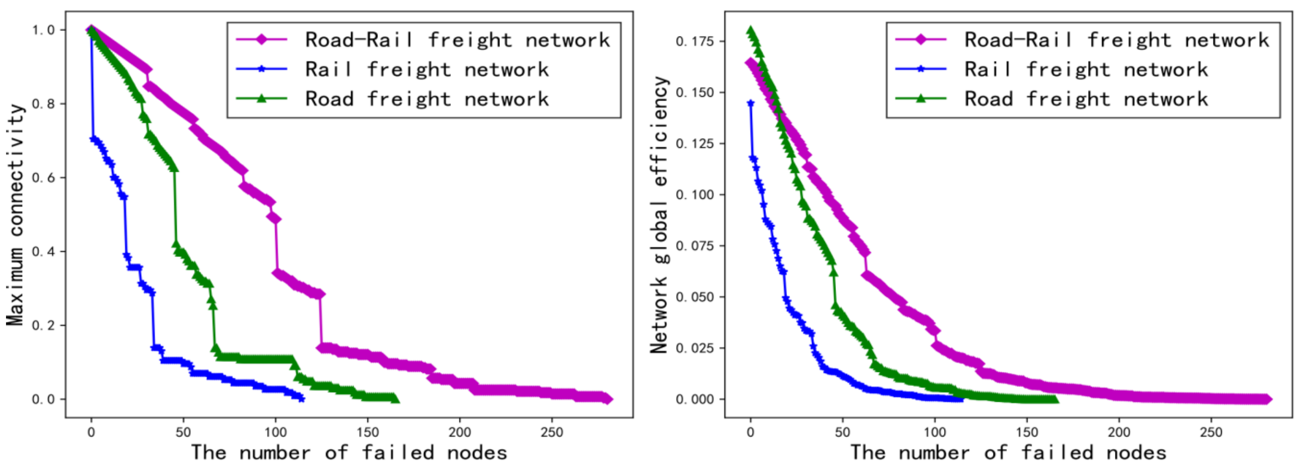

Figure 3 Changes in the destruction resistance of different transportation networks under random attacks

Based on Figure 3, it can be seen that the maximum connectivity and network efficiency of the Beijing-Tianjin-Hebei multi-mode freight network, railway transportation network and road transportation network drop to 0 under random attack, all of which are after the number of nodes is removed by more than 100, which shows strong destruction resistance. In Figure 3, the railway transportation network showed a rapid decline at the beginning of the attack, while the road transportation network and the road-rail multi-mode transportation network still showed a certain degree of destruction resistance after removing a small number of nodes, and the decline rate was slower than that of the railway transportation network. This is because the railway freight node is planned for the construction of railway line, the railway freight network node is not close, and the highway node often has a border relationship with the geographically adjacent node, and the road freight network node relationship is closer, so the road freight network is more instructive than the railway freight network under the failure of some nodes. The multi-mode freight network integrates the road freight network and the railway freight network, which has stronger resistance to destruction than the single-mode freight network of the road and railway under the condition of the failure of the same number of nodes.

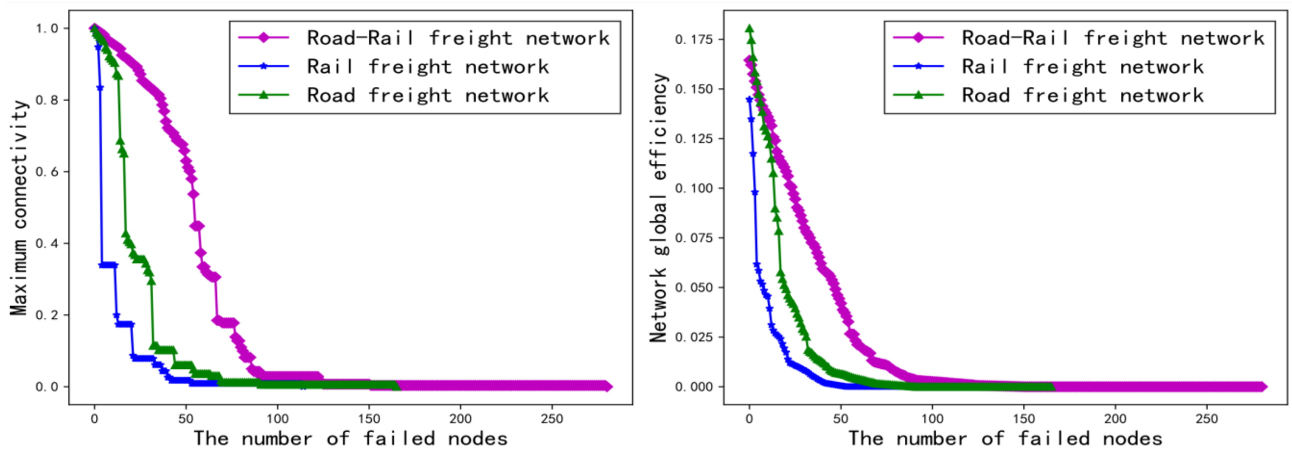

Figure 4 Changes of the destruction resistance of different transportation networks under maximum degree attack

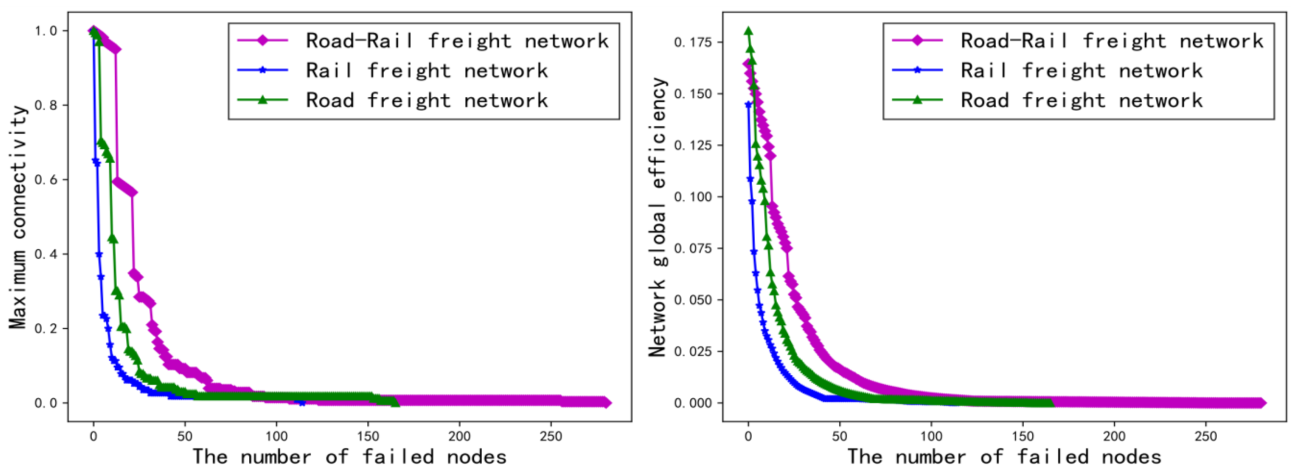

Figure 5 Changes in the destruction resistance of different transportation networks under maximum betweenness attacks

From Fig. 4 and Fig. 5, it can be seen that the number of random failure nodes increases under the maximum degree attack and maximum betweenness attack, and the connectivity and network efficiency of railway freight network, road freight network and road-rail multi-mode freight network are all decreasing sharply, but it is obvious that the road-rail multi-mode freight network has stronger anti-destruction ability than the single-mode freight network.

In addition, based on Figures 4 and 5, it can be seen that the betweenness attack is more damaging to the Beijing-Tianjin-Hebei freight network than the degree attack. This is because the nodes that prioritize the attack of the maximum betweenness attack are often the connection channels between different logistics hub cities, and the maximum betweenness attack will divide the Beijing-Tianjin-Hebei urban agglomeration into smaller urban modules, greatly destroying the connectivity capacity of the Beijing-Tianjin-Hebei urban agglomeration.

4. CONCLUSION

In this paper, the multi-mode freight network of the Beijing-Tianjin-Hebei urban agglomeration is modeled based on complex network theory, and the anti-destruction simulation of the Beijing-Tianjin-Hebei urban road-rail freight network and the single-mode freight network of the Beijing-Tianjin-Hebei city is carried out. The main conclusions are as follows:

(1) Compared with random attacks, maximum attack and maximum betweenness attack have higher destructive capabilities on the freight network of the Beijing-Tianjin-Hebei urban agglomeration, so it is of great help to improve the destruction resistance of the freight network of the Beijing-Tianjin-Hebei urban agglomeration by protecting the city nodes with large median values and high betweenness in the freight network of the Beijing-Tianjin-Hebei urban agglomeration.

(2) The multi-mode freight network of road and railway has higher anti-destruction ability than the single-mode freight network of road or railway. China should promote the deep integration of road transport and railway transport by improving the laws and regulations, technical standards and service rules of multimodal transport, open up the "information island" between various departments, enterprises and regions of road railway intermodal transport, and improve the security and stability of China's freight network.

(3) At present, this paper is based on the simulation of the Beijing-Tianjin-Hebei freight network without right and direction, and does not involve factors such as time, cost and flow in the process of freight circulation, and will make the freight network more in line with the actual operation by adding time, cost, flow and other factors to the freight network between urban agglomerations, which is also the future research direction

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