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Research on the Topological Characteristics of Qingdao Rail Transit Network Based on Complex Network Theory

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Abstract

Based on the complex network theory of Qingdao Urban Rail Transit road network, this paper establishes a model of site network to research the rationality of the planning routes and the importance of the sites under different topological characteristics. Compare the indicators of the past and the planned network from the perspective of Space-L, it is learned that the established site Qingdao Station and the planned site West Wujia Village Station should pay more attention to the further planning. By contrast, the planned track line have been significantly improved the accessibility of the center and the coverage of surrounding sites. The node degree distribution follows the exponential distribution, which has the nature of a random network. Some sites like Qingdao railway station, although the node degree value is not ranked in the forefront, the higher betweenness centrality indicate the significance of long-term development. Finally, this paper puts forward some constructive suggestions on Qingdao urban rail transit network.

Keywords

Complex network; Urban rail transit; Topological characteristics; Node degree.

1. INTRODUCTION

Li P compared and analyzed the connectivity between Shanghai, Guangzhou and Beijing by establishing an urban rail transit network model with lines as nodes [1]. The characteristics of Shanghai's urban rail transit network with characteristic indicators were analyzed by Du F and study the robustness of the network after being attacked by faults [2]. Li W D used the Space-L method to weight the topology of New York rail transit and studied the characteristics of its network through random attacks [3]. Lu zhuqing evaluated the network according to the recent rail transit line network in Wuhan, and optimized the stations with large traffic pressure in the interval according to the characteristics of the line network [4]. Pu H establishes a two-layer public transit complex network model on the basis of the muti-layer complex network [5]. Zhijie Y analyzed the evolution process of the Shanghai network based on six typical topology indicators [6].

This paper focuses on the overall topological characteristics of the network. Based on the multiple complex indicators such as node degree and the distribution, betweenness centrality, eccentricity, etc. The paper evaluates the rationality of the planning line network structure according to the comparison with the existing network, which is of great practical significance for the planning of the long-term urban rail transit line network and the setting of stations in Qingdao in the future.

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2. RESEARCH OF URBAN RAIL TRANSIT

2.1. Construction of Site Network Model

Taking the completed railway transit network of Qingdao Urban Rail Transit and the third phase of the construction planning railway transit network as an example, the Qingdao long-term planning network includes 9 general lines and 10 speedy lines, with a total length of 872 kilometers. It is expected that 12 operating lines will be completed in 2026, the total mileage will be reached 370.7 kilometers, as shown in Figure 3. The complex network model in 2021 and 2026 are shown in Figure 4 and Figure 5, where the nodes in the figure are the corresponding stations on the line, among Figure 3 represents the established site network in 2021, generating 131 nodes and 133 edges, while the planned site network represented in Figure 4 has a common network with 267 nodes, 292 edges.

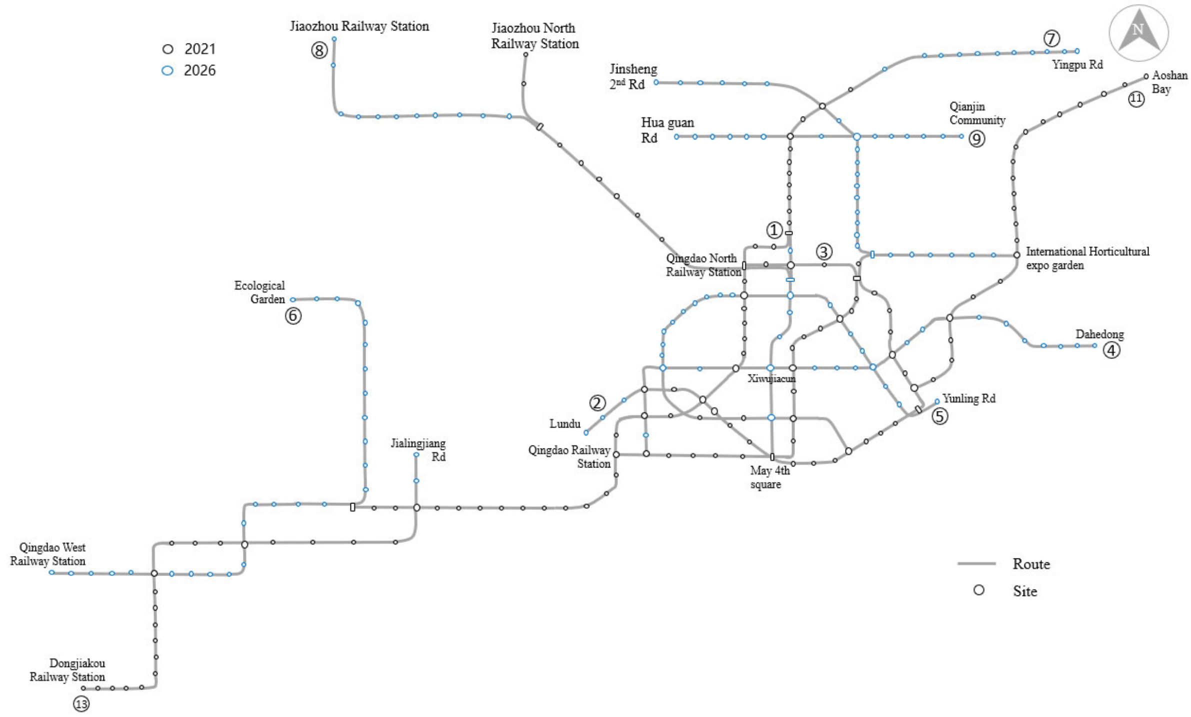

Figure 1. Qingdao rail transit network from 2021 to 2026

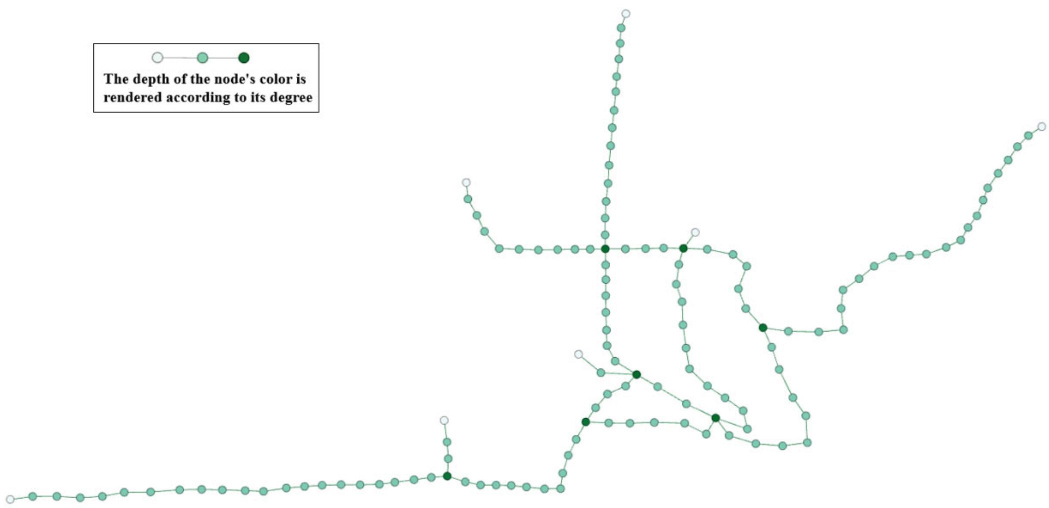

Figure 2. Qingdao rail transit network model in 2021

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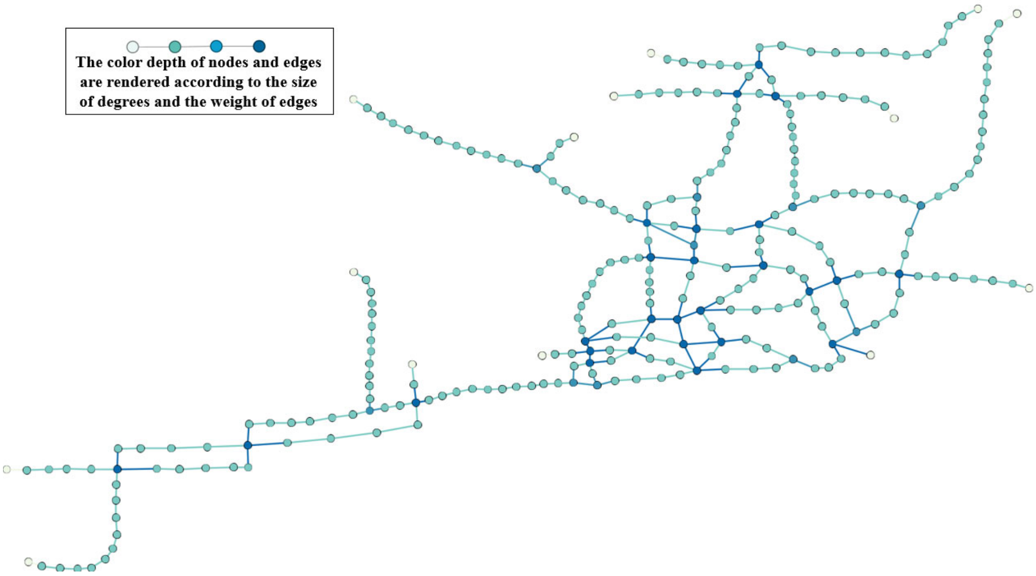

Figure 3. Qingdao rail transit network model in 2026

According to the complex network model of the existing and planning network in Figure 2 and Figure 3, it can be clearly seen that the number of overall stations has doubled, the compactness and timeliness of the entire network have also increased, and the complexity of the lines connected to the stations and stations has deepened. The middle area of the site model network is the economic zone and the metropolitan area. Therefore, the stations in the center scatter more dense than others in the remote, the relevance between the site and the connected edge is stronger.

2.2. Overall Comparison of Network Characteristics

Typical types of network topologies in complex networks include regular networks, stochastic networks, small-world networks, and scaleless networks [7], while their evolutionary characteristics are described by statistical indicators such as degree and degree distribution, betweenness centrality, and Eccentricity, etc.

Through the comparative analysis of the urban rail transit network in Qingdao in 2021 and 2026, and calculated the characteristics of the network in Space-L, the results are shown in Table 1.

Table 1. Comparison of Network Characteristics

Network Characteristics	In 2021	In 2026
Number of Nodes (k)	131	1B
Number of Edges (n)	133	2B
Network diameter	2.031	2.187
Network graph density	67	58
Average clustering coefficient	0.016	0.008
Average path length	0	0.003

According to the results in Table 1, there are a total of 264 stations (node number) in the long-term planning network of Urban Rail Transit in Qingdao, and under the condition of Space-L , the average degree of the planning station network is 2.187, indicating that each station in the network is adjacent to 2.187 stations on average. Therefore, passengers have more travel

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paths to choose, which is conducive to alleviating the pressure of the network. However, the higher average path length represents there are more transfers from one station to another.

3. ANALYSIS OF MULTIPLE CHARACTERISTICS IN QINGDAO

3.1. Node Degrees and Distribution

By fitting the scatter diagram of the probability distribution of node accumulation degree, the fitting functions of the existing network and the planning network are obtained as $P(k) = 0.05e^{-2.98x}$ and $P(k) = 0.06e^{-1.19x}$, the node accumulation degree under the two network structures obeys the exponential distribution. The values of R^2 are 0.771 and 0.867 respectively, indicating that both of them fit well. According to the definition of random network in complex network, if the probability is distributed in exponential form, the connection of nodes is considered as random connection. Therefore, Qingdao urban rail transit station network can be regarded as a random network.

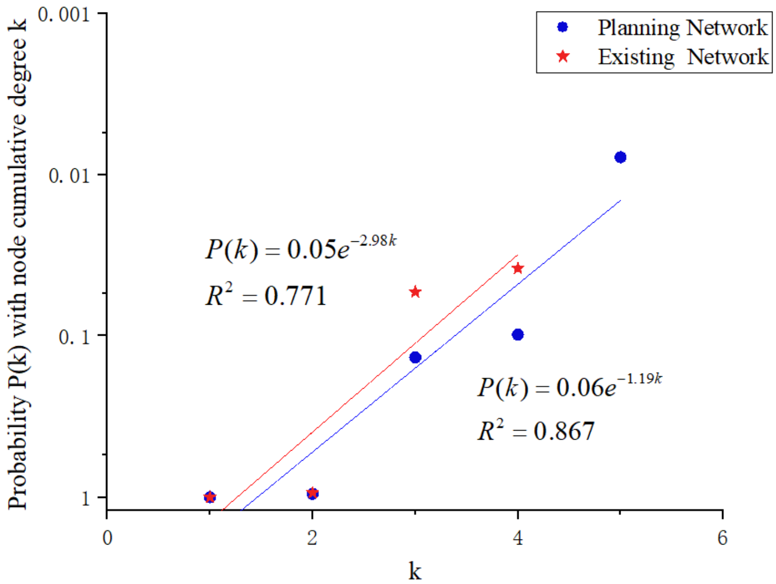

Figure 4. Node Degree Probability Distribution

3.2. Betweenness Centrality

In urban rail transit network, betweenness centrality refers to the ratio of the number of all shortest paths from some nodes to others and the total path of the network [8]. The expression of betweenness centrality is shown in equation (1):

$$C_B(i) = \sum_{i,j \in V(j \neq k)} \frac{\varepsilon_{jk}(i)}{\varepsilon_{jk}} \tag{1}$$

Where: ε_{jk} represents the number of shortest lines from station j to station k, $\varepsilon_{jk}(i)$ represents the number of shortest lines from station j to station k and passing through station i.

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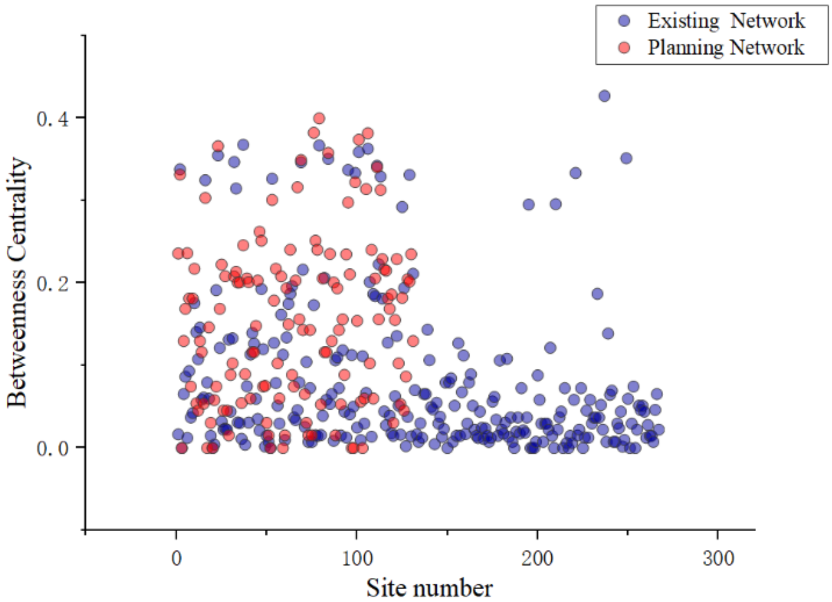

Figure 5. Betweenness Centrality of Sites

The Figure 5 indicates the centrality of most sites is in the range of 0 to 0.427, only West Wujia Village, a new station in the planning network, reaches 0.427. This shows that the site will have a greatest impact due to the large passenger flow and other factors, and passengers will pass through West Wujia Village most when seeking the shortest path, the site will have a stronger connection capacity for other stations.

In Table 2, the existing and planning stations with the top three betweenness centrality are listed. Although the node of some sites is not high, the larger betweenness centrality is enough to prove their significance. Qingdao Railway Station has a great influence in the existing and planning network due to the factors such as large passenger flow and complex transfer relationship.

In addition, the overall average of the centrality of the planned network is 0.08, which is lower than the existing. It shows the connection between nodes of the whole network has reduced by 50%. Therefore, the phenomenon should be improved further in the follow-up network.

Table 2. The Top Three Stations with Betweenness Centrality

Serial Number	Existing Sites	Betweenness Centrality(a)	Planning Sites	Betweenness Centrality(b)
1	Qingdao Railway Station	0.3998	West Wujia Village	0.4271
2	Qingdao North Railway Station	0.3823	Haibo Bridge	0.3678
3	West Town	0.3818	Qingdao Railway Station	0.3669

3.3. Closeness Centrality

It is used to indicate proximity to and connectivity to other nodes in the network center, and the larger the value, the stronger the interchangeability of the site. The normalized expression of near centrality is as follows:

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$$C_c(i) = \frac{n-1}{\sum_{i \neq j}^{n} d_{ij}} \tag{2}$$

Where: n, i, j, d_{ij} are the total number of sites, two different stations, the shortest distance between the two stations.

It is used to indicate the proximity between the center and others and the connectivity of the whole network. The greater this value, the stronger this transfer of the sites [9]. The distribution of the closeness centrality of sites is calculated as shown in Figure 9.

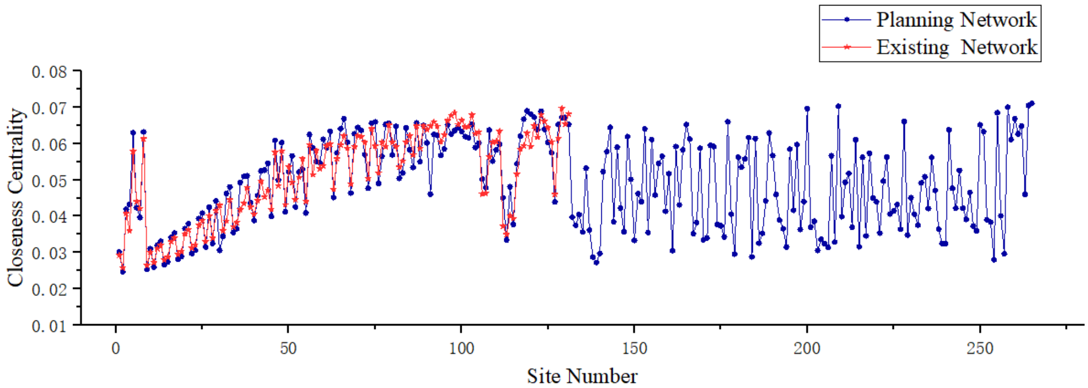

Figure 6. Closeness Centrality of Sites

From the figure, it can be seen that the distribution is generally low and concentrate relatively, and the new sites have a little impact on the value of the existing sites. The three stations with the largest centrality among the existing stations, namely Taitung, Hisense Bridge and May Fourth Square. It becomes Mountain Yanjia, West Wujia Village and Nanchang Road North after the route planning, which demonstrates that the central location of the network moved north as a whole after the planning, and the tightness between the sites was also enhanced.

Table 3. The Top Three Stations with Closeness Centrality

Serial Number	Existing Sites	Betweenness Centrality(a)	Planning Sites	Betweenness Centrality(b)
1	Taitung	0.0697	Mountain Yanjia	0.0710
2	Hisense Bridge	0.0685	West Wujia Village	0.0704
3	May 4th Square	0.0681	Nanchang Road North	0.0702

3.4. Eccentricity

Eccentricity, in contrast to closeness centrality, represents the maximum in the shortest path from one node to the remain, and the larger it is, the farther the node is from the center of the network, i.e:

$$C_E(i) = \max d_{ij} (i \neq j) \tag{3}$$

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Where: i and j are two different sites, d_{ij} is the maximum distance of the shortest path between the two stations.

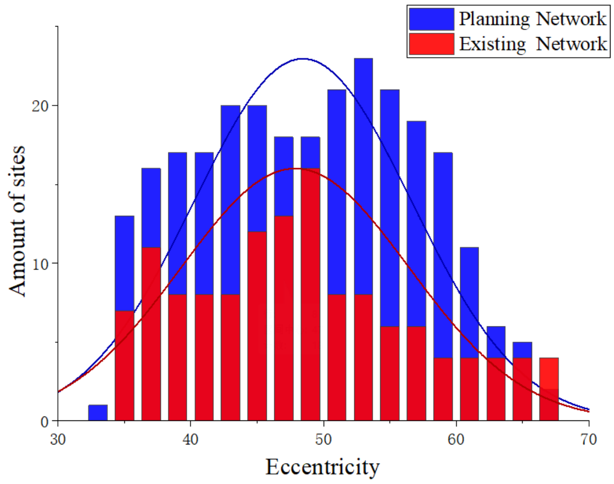

Figure 6. Eccentricity of Sites

From the Figure 6, it can be seen that the value of eccentricity in the planning network is higher than that of the established in the mass. The eccentricity of most stations is within 40 to 60, and it is found that the planning widens the scope of the overall network and strengthens the accessibility between stations on the basis of the existing network.

3.5. Centrality of Eigenvector

The centrality of eigenvector emphasizes the importance of the adjacent nodes of a node to itself [10], when the adjacent nodes of the node are more important, the importance of the node will also increase, which is recorded as the formula:

$$E_C(i) = x_i = c\sum_{j=1}^{n} a_{ij}x_j \tag{4}$$

Where: x_i, c are the importance of one node, a proportional constant.

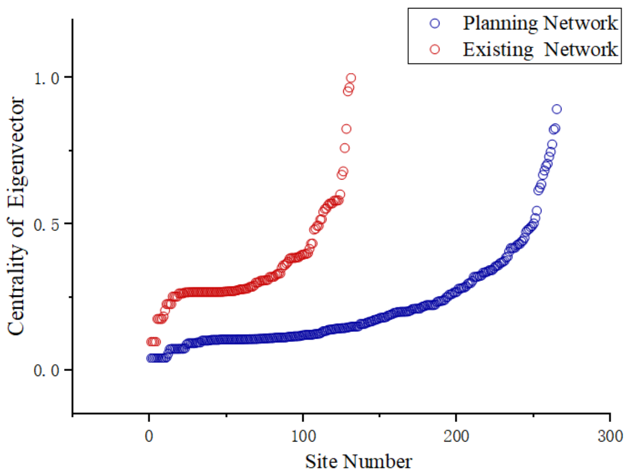

Figure 7. Centrality of Eigenvector of Sites

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According to Figure 7, the overall trend of the centrality of eigenvector in both the existing network and the planning network is relatively close, and the sites with larger values account for only a small part. For example, the values of Aucama Bridge, West Wujia Village and May Fourth Square in the planning network in Table 5 are ranked in the top three, indicating that the nodes of neighboring stations around these sites are more important and more related to the rest of the sites, so they are affected by the importance of neighboring sites easily, and the centrality of these sites in the entire network is stronger.

Table 4. The Top Three Stations with Eigenvector Centrality

Serial Number	Existing Sites	Betweenness Centrality(a)	Planning Sites	Betweenness Centrality(b)
1	May 4th Square	4	Aucama Bridge	1
2	Qingdao North Railway Station	0.9669	West Wujia Village	0.9621
3	Taitung	0.9534	May 4th Square	0.8930

4. CONCLUSION

Taking the Qingdao urban rail transit as an example, this paper uses complex network theory to analyze the topological characteristics of the existing network and the long-term planning network in Space-L, so as to determine the design rationality of the planned line network and the improvement of the overall performance of the network. The results show that: the overall accessibility of the planning network is improved, and the probability of the cumulative distribution of nodes follows an exponential distribution, indicating that the urban rail transit network in Qingdao has the structural nature of a random network. According to the node degree, betweenness centrality, eccentricity and other indicators, to a certain extent, it reflects that the network has not only improved in the number of stations in long-term planning, but also significantly strengthened the connection between existing stations, the interchange relationship of established lines, and the coverage of planning and constructed sites. As an important station in the line network, the new Qingdao Railway Station and West Wujia Village Station in the planning network should improve the operation and maintenance capability of the site in the long-term planning, and the importance of a station in the line can be improved by strengthening the connection between a station and adjacent stations.

Through the analysis and study of the topological characteristics of Qingdao rail transit network, this paper not only provides a reference basis for Qingdao's long-term planning of urban rail lines, but also lays a foundation for the comparative study of rail transit networks between different cities in the future. In future studies, the network comparison between other cities and Qingdao city can be integrated into it, and the node network under the P space and the robustness of the line network after being attacked can be further studied.

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