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Research on Topological Characteristics of Suzhou Subway Based on Complex Network Theory

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ABSTRACT. *With the expansion of the city scale, the passenger traffic of urban rail transit is increasing, and more and more rail transit stations and lines are overloaded, which puts higher requirements on the safety and reliability of urban rail transit networks. In order to analyze the topological nature of the complex network of the subway, this paper takes Suzhou City as an example, selects 93 subway stations from the three metro lines in Suzhou as of the present sample as sample data, uses complex network theory to conduct research, and builds a neighboring site based. Undirected unweighted network model. The study found that the average traffic network of Suzhou Metro is 2, the clustering coefficient is 0, and the average shortest path is 13. Through the analysis of the Suzhou Metro transportation network, it may be instructive for the future construction of the Suzhou Metro network.*

KEYWORDS: *Suzhou subway, complex network, topology characteristics*

1. Introduction

The urban transportation system is the carrier of all urban transportation activities and the lifeblood of the normal operation and development of the city. The urban comprehensive passenger transportation system is the most important component of the comprehensive transportation system and bears huge transportation volume. With the development of the national economy, the expansion of the city scale, the travel demand has become more complicated, and the urban traffic problem has become more apparent. In megacities such as Beijing and Shanghai, pure ground transportation has been unable to meet normal travel needs. Urban rail transit has developed into an inevitable way to alleviate traffic problems in the process of urbanization in China, the United States, Japan and Europe, with its advantages of high volume, high efficiency, safety, on-time, energy saving and environmental protection.

There are 660 cities in China, and there are very few cities that can build rail transit. In August 2016, Luoyang became the 43rd rail transit construction city approved by the State Council. It is estimated that by 2020, the number of cities that meet the national subway standards will increase from 43 to 50. As of July 2016, a total of 27 cities in China (the Mainland) have opened urban rail transit, with a total operating mileage of 3,288 kilometers, more than 100 lines and 2,083 stations. As of October 2017, there are 3 Suzhou rail transit lines, namely: Line 1, Line 2, Line 4 and its branch lines, all adopting the subway system, with 97 stations in total, including 5 interchange stations. The operating mileage is 121 kilometers.

The development of urban rail transit system has provided a strong guarantee and power for the development of urban economy, which has brought great convenience to residents' daily travel and eased the traffic pressure of the city. However, with the rapid development of urban rail transit, the flow of passengers has increased greatly, and the rail transit has the characteristics of closedness. In the event of an accident, or some operational errors or system failures in the operation of urban rail transit, May cause very serious consequences. While vigorously building rail transit road network to improve the capacity of transportation capacity, it is also necessary to ensure the safe, reliable and efficient operation of urban rail transit, in order to provide a reliable guarantee for urban construction.

2. Research status at home and abroad

Latora and Marchiori (2001) introduce the definition of efficiency coefficient, and use the efficiency coefficient to describe the small world network. The small world effect can be expressed as global and local efficiency. And applying the efficiency coefficient to study the Boston Metro network, its research found that in the unauthorised network, the Boston subway is inefficient when the distance factor is not considered; in the right network, it is partially inefficient and globally efficient; and the subway and public transport are public. The composed network is locally efficient and globally efficient; and it is speculated that a large closed transportation network should have a small world. Sen et al. (2002) studied the small world characteristics of the Indian metro network. Angeloudis et al. (2006) studied the complexity of metro networks in some cities around the world. Tao Wang et al. (2006) also conducted statistical analysis of metro networks in some cities in China. The research structure shows that the metro network in big cities has different properties in L space, and has small world characteristics in P space, and the degree distribution is approximated as exponential distribution [7].

Yunqin Wang (2008) and Zhiqiang Wang (2009) respectively evaluated the connectivity reliability of rail transit networks in Beijing and Shanghai, and simulated and analyzed the selectivity and random failure of nodes [9] [10]. Wei Liu (2009) studied the impact of rail transit network on urban traffic network and concluded that adding more rail transit lines would make the traffic complex network model more stable [11]. Jingjing Chen (2010) introduced the reliability measurement index of complex networks, and measured its reliability from the aspects of network adaptability, stability and effectiveness.

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3. Subway network construction

3.1 Introduction to the current status of Suzhou Metro

The Suzhou Rail Transit Network now has 3 lines and 97 stations, of which 93 are non-repeating stations, 94 pairs are adjacent stations, and the operating mileage is 121 kilometers.

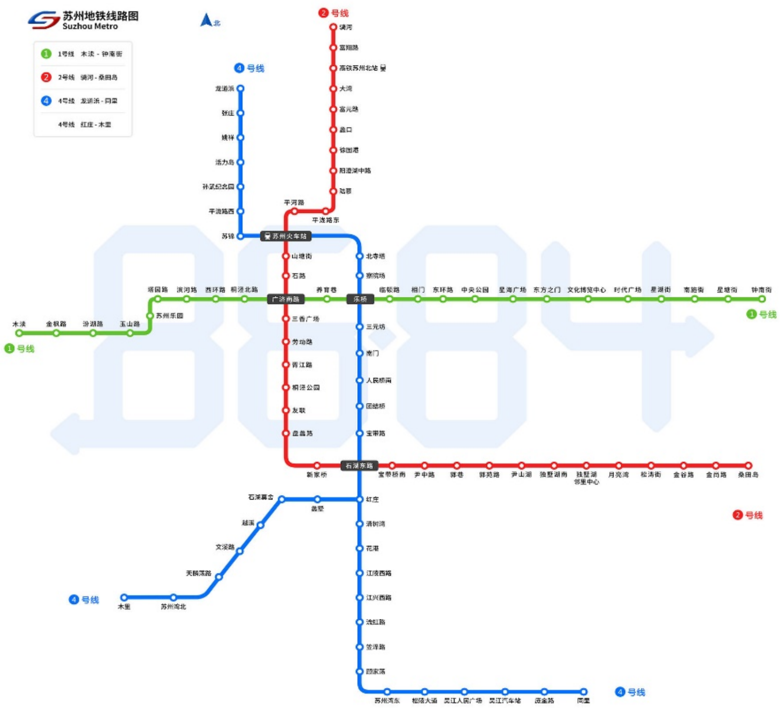

Figure. 1 Suzhou subway line map

All the sites in Figure 1 are numbered for a total of 93 points.

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Table 1 Metro station node number (Part of the site)

Numbering	Site name	Numbering	Site name
1	Mudu	16	Central Park
2	Jinfen Road	17	Xinghai Square
3	Fenhu Road	18	Oriental Gate
4	Yushan Park	19	Cultural Expo Center
5	Suzhou Paradise	20	Time Square
6	Tayuan Road	21	Xinghu Road
7	Binhu Road	22	Nanshi Street
8	Xihuan Road	23	XingTang Street
9	Tongjingbei Road	24	Zhongnan Street
10	Guangjinan Road	25	Qihe
11	Yangyuxiang	26	Fuxiang Road
12	Lechang	27	Suzhou North Railway Station
13	Lindun Road	28	Dawan
14	Xiangmen	29	Fuyuan Road
15	Donghuan Road	30	Likou

3.2 Suzhou Metro Complex Network Analysis

In order to better understand the connection between the various sites in the entire Suzhou Metro transportation network, we studied the connection relationship between the various sites on the subway transportation line. Think of each subway station as a network node. For example, the Mudu Station and Jinfeng Road Station on the Suzhou Metro Line 1 can be regarded as two nodes. The connection between two network nodes is 1 and if it is not connected, it is 0, and the adjacency matrix is obtained:

$$A(i,j)=\begin{bmatrix}
0 & 1 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 1 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 1 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 0 & 0 & 0 \\
\vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\
\vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\
\vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\
\vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\
\vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\
\vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\
0 & 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 1 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 1 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 0 & 1 & 0
\end{bmatrix}$$

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Among them, A (i, j) =1 indicates that the i station is connected to the j station, and the two are connected. If the two stations are not connected, A (i, j) =0. We do not consider the weight of the connection in the subway transportation network. Any two connected stations in the Suzhou Metro network can reach each other. We regard the Suzhou Metro transportation network as an unweighted undirected network. Up to now, the Suzhou Metro has 3 lines, 93 non-repetitive sites, and 94 neighbors. We used Gephi software to draw a topology map of the Suzhou Metro network:

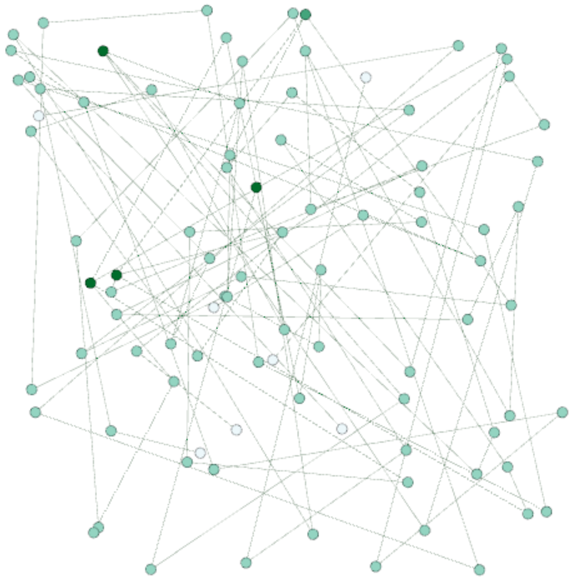

Figure. 2 Suzhou Metro Network Topology

3.3 Analysis of Topological Characteristics of Complex Network in Suzhou Metro

A complex network is a network that is built into entities (such as stations) in complex systems and between entities (such as lines). There are three basic topological characteristics: the average shortest path (the average distance between any two nodes in the network); the clustering coefficient (the ratio of the number of degrees that the node actually exists in the network to the number of edges that may exist in the entire network); Quantification of the probability distribution of node degrees in the network).

3.3.1 Degree and degree distribution

Degree is the simplest and most important concept in characterizing a node. The degree Ki of the node i in the undirected network defines the number of edges connected to the node; in the directed network, the node degree can be further divided into the degree of outdegree and the degree of entry, and the degree of the

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node refers to the point from the node to the other phase. The number of edges of the neighbor nodes, and the degree of ingress of the nodes refers to the number of edges pointing from other nodes to the node. Intuitively, the greater the degree of a node, the higher its importance in the network. The average of all node degrees in the network is called the average of the network. We imported the neighboring matrix into Matlab software and performed related operations in combination with Gephi software to draw the following conclusions:

Table 2 Suzhou Metro Network Node Degree Distribution Table

Node degree	1	2	3	4
Number of nodes	7	81	1	4
proportion	7.53%	87.10%	1.08%	4.30%

It can be seen from the above table that the node degree of the majority of nodes in the Suzhou Metro network is 2, accounting for 87.10% of the total proportion. This shows that the vast majority of subway stations are on a line, connected to two adjacent sites, which is determined by the road conditions. The largest degree is Suzhou Railway Station, Guangjin Road, Lechang and Shihu East Road. The degree is 4, which is connected with 4 stations. It is the largest transfer station in Suzhou Metro network; the node pole with degree 3 Less, generally the starting point of a line is drawn from the intermediate station of another line; the node with degree 2 is the ordinary station on the subway line that is not used as the transfer station and the terminal station; the node with degree 1 is the end At the station, the average value is calculated to be 2.0215.

The degree distribution can reflect the macroscopic statistical characteristics of the transportation network. The degree distribution of the urban metro network is generally a discrete function. The degree of nodes in the network is generally low, and the probability distribution of degrees is not uniform.

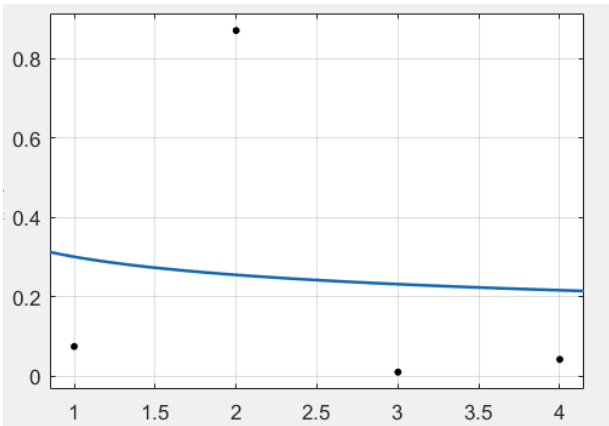

Figure. 3 Node degree probability distribution

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According to the above analysis, it can be known that the Suzhou Metro network has the characteristics of a scale-free network.

3.3.2 Average path length

The average separation distance between any two nodes in the network is instructive for understanding the structure of the network. The distance between two nodes can be defined as the number of sides of the shortest path connecting the two nodes. The maximum distance between any two nodes in the network is called the diameter of the network and is denoted as D. The average path length L of an undirected network is the average of the distance between two nodes in the network, namely:

$$L = \frac{1}{\frac{1}{2}N(N+1)}\sum_{i\geq j} d_{ij}$$

Where: N——the number of nodes in the network;

d_{ij}——the distance between nodes i and j.

The average path length is used to measure the degree of dispersion between nodes in the network, ie how small the network is. Although the number of nodes in many actual networks is large, the average path length L is small relative to N. This phenomenon is the "small world effect."

Table 3 Suzhou Metro Path Length Distribution Table

Path length	Number of paths	proportion	Path length	Number of paths	proportion
0	393	4.54%	18	285	3.30%
1	467	5.40%	19	263	3.04%
2	456	5.27%	20	240	2.77%
3	391	4.52%	21	219	2.53%
4	391	4.52%	22	185	2.14%
5	392	4.53%	23	162	1.87%
6	390	4.51%	24	130	1.50%
7	390	4.51%	25	118	1.36%
8	391	4.52%	26	98	1.13%
9	391	4.52%	27	79	0.91%
10	302	3.49%	28	60	0.69%
11	318	3.68%	29	48	0.55%
12	349	4.04%	30	26	0.30%
13	363	4.20%	31	16	0.18%
14	366	4.23%	32	9	0.10%
15	334	3.86%	33	4	0.05%
16	318	3.68%	34	2	0.02%
17	303	3.50%			

According to the data in the above table, we use Matlab software to get the following picture:

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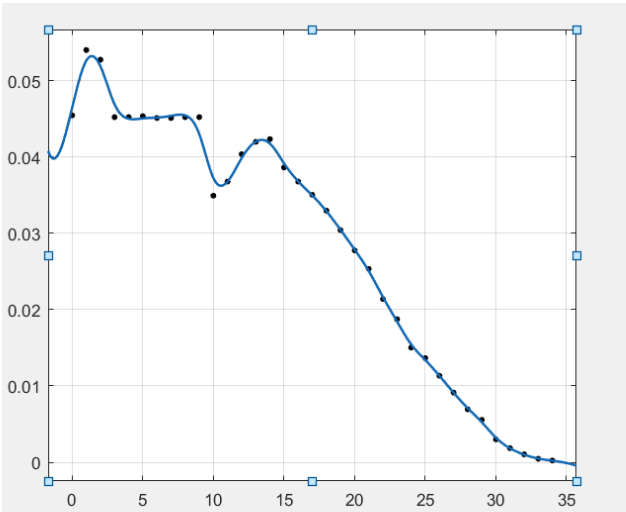

Figure. 4 Shortest path probability distribution map

From the above table and figure, we can conclude that the average path length of the Suzhou Metro network is 13.1543, where the probability of the corresponding path is 1:50 and the maximum distance is 34. The analysis shows that the average path length of the Suzhou Metro network is relatively small compared to the network scale, and it can be considered to have the characteristics of a scale-free network.

3.3.3 Clustering coefficient

The physical meaning of clustering coefficients is the degree of network grouping. The most common definition of clustering coefficients is proposed by Watts and Strogt. It is defined as: a node i in an optional network, and the number of nodes directly connected to it is k_i. This k_i node is called the neighbor of node i, and these nodes are directly The actually existing edge is set to Ei, and the total possible edge is $C_{k_i}^2$, then the clustering coefficient of node i is:

$$C_i = \frac{E_i}{C_{k_i}^2} = \frac{2E_i}{k_i(k_i - 1)}$$

The clustering coefficient C of the entire network is defined as the average of the clustering coefficients of all nodes in the network:

$$C = \frac{1}{N}\sum_{i=1}^{N} C_i$$

$0 \leq C \leq 1$, when $C = 0$, all nodes of the network are isolated nodes, without any connected edges; when $C = 1$, the network is globally coupled, and any two nodes in the network are directly connected.

```
>> [C1, C2, C] = clust_coeff(adj)

C1 =

     0


C2 =

     0


C =

     0
```

Figure. 5 clustering coefficient

We can use Matlab software and the above-mentioned Suzhou subway network topology diagram to see that there is no triangle in the whole network, which indicates that the clustering coefficient of the whole network is zero. A clustering factor of 0 indicates that there are no side connections between stations in the Suzhou Metro network.

4. Conclusion

With the expansion of the city's scale, the traffic problem is getting more and more serious, and it is already a commonplace in urban development. Vigorously developing urban rail transit has become one of the main means of solving urban traffic problems. Rail transit projects in various places have also started to build. With the continuous construction of urban rail transit networks, the scale of the network has also grown, and the network structure and line operations have become more and more complex. Traditional graph theory has been difficult to meet the further analysis of urban rail transit. Nowadays, using complex network theory to study rail transit network has become a new idea.

Based on the complex network theory, this paper studies the topological structure of urban rail transit networks. We analyzed the Suzhou Metro network through Matlab programming and Gephi software and excel statistics. We study and analyze the Suzhou Metro network from three aspects: degree and degree distribution, average path length and clustering coefficient. Through the analysis of

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the data, we find that the average degree of the node of the Suzhou Metro network is 2.0215; the average value of the shortest path of the Suzhou Metro network is 13.1543; the clustering coefficient of the Suzhou Metro network is 0. We conclude that the Suzhou Metro network has the characteristics of a scale-free network.

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