ISSN 2616-5775 Vol. 2, Issue 1: 49-62, DOI: 10.25236/AJCIS.010017

# Research on Shenzhen Metro Traffic Based on Complex Network Theory

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***ABSTRACT.*** *In order to better understand the advantages and disadvantages of the existing rail transit network in ShenZhen, this paper provides a reference for the planning and improvement of the rail transit network. Based on the complex network theory, this paper first builds the topology model of P-space and C-space, and then calculates the characteristics of the network topology model in different space, including node degree, network average degree, The maximum degree of nodes in the network and node minimum degree, the maximum and minimum distances of the network, the shortest average network path and network aggregation coefficient. The final conclusion is that under the P space: degree of network distribution is mainly around the network average degree, the average shortest path of the network is very small, the clustering coefficient of the network is very large, and the nodes whose clustering coefficient exceeds 0.97 account for 95.24% of the total nodes The distribution obeys the exponential distribution, which verifies that the ShenZhen rail transit network is a smaller world network.*

***KEYWORDS:*** *Rail transit network, complex network, Space P, Network topology*

## 1. Introduction

Due to its large volume, high speed, safety and reliability, and on-time comfort, metro transportation has made it universally recognized that the fundamental way to solve the traffic problems in big cities is to give priority to the development of urban public transportation systems with metro transportation as the backbone [1]. Since 1990, the rapid development of complex network science, such as the small world effect and the unscaled characteristics, has led to a large number of scholars interested in the research of complex networks. By expressing the interrelationships between units and their units in a system in the real world with the connected edges between nodes and nodes in the network, and using the topological properties of the network to reveal the characteristics of the system in the real world, This abstracted complex network provides a theoretical approach to the study of complexity science.

ISSN 2616-5775 Vol. 2, Issue 1: 49-62, DOI: 10.25236/AJCIS.010017

At the same time, complex network theory has also attracted a large number of traffic scholars. As a complex and large system, the transportation system provides an important research tool for complex networks. It also lays a theoretical foundation for in-depth study of the dynamic process of the transportation network and various characteristics, network topology and its interaction. A large number of scholars have carried out related research using complex network statistical physics. The research on urban transportation network mainly focuses on urban road network and public transportation network. Emanuele Stran [2] and other research through a road network in northern Milan shows the generality of urbanization and the simple nature of the road network. Han Jibin et al [3] used the Space L method to study the characteristics of the Shanghai rail transit network in 2012. The research shows that the Shanghai rail transit network at that time was a scale-free network in L space but not a small world network. Kalapala [4] established a relationship model between the degree distribution index and the fractal dimension when studying the road network topology of the United States, the United Kingdom, and Denmark. Xu Xinping [5] established a weighted complex network of bus transportation networks in three cities in China, and studied the structural characteristics and small world effects of the network. Zheng Xiao et al [6] studied the topology of Beijing's public transport network and analyzed the key nodes in the network. Zhao Yue et al [7] summarized the research progress of complex network theory in urban traffic network analysis and pointed out the existing problems. K. H. Chang et al [8] studied the rail transit networks of several cities and compared their global efficiency with local efficiency. Wang Yunqin [9] selected the removal strategy for the rail transit analysis in Beijing and analyzed the reliability of the network. These studies are all useful for exploring macroscopic properties that are not yet recognized in real complex systems.

## 2. Shenzhen Metro Transportation Network Description and Complex Network Related Concepts

### *2.1 Shenzhen Metro Traffic Network Description*

This paper analyzes the topology of the subway transportation network in Shenzhen. Shenzhen Metro refers to urban rail transit serving Shenzhen, Guangdong Province, China. Its first line was officially opened on December 28, 2004, making Shenzhen the fifth city in mainland China with a subway system. . According to the official website of Shenzhen Metro on June 30, 2017, there are 8 operating lines in Shenzhen Metro, namely: Line 1, Line 2, Line 3, Line 4, Line 5, Line 7, Line 9 and Line 11, a total of 199 stations. The total length of the city's subway operation line is 285 kilometers, and the total mileage of subway operations ranks fifth in China. It constitutes an urban rail network covering six administrative districts of Luohu District, Futian District, Nanshan District, Bao'an District, Longhua District and Longgang District of Shenzhen.

Because the Shenzhen subway transportation network mainly studied in this paper is mainly the networked network in the city, among the 8 lines currently

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running, only 5 of them are studied, namely 1, 2, 3, 4, 5 Line, so other subway lines are not included in the research content of this article. The statistics on the subway transportation network of the current five lines in Shenzhen are shown in Table 1:

*Table 1 Statistics of urban subway transportation network in Shenzhen*

| City | Total line | Total number of sites | Non-duplicate site | Two-wire node |
|---|---|---|---|---|
| ShenZhen | 5 | 131 | 105 | 26 |

*Remarks: Table 1 shows the five Shenzhen metro line networks studied in this paper. Therefore, Table 1 is not the data of all the lines of the Shenzhen Metro currently running.*

### 2.2 Complex network knowledge

The research on the topology structure of Shenzhen subway transportation network is based on the theory of complex network. The basic theoretical concepts of the relevant complex networks are as follows:

(1) Network topology construction method concept

The topology of the network is the basis for studying the characteristics and functions of the network structure. There are four main methods for constructing the topology of the subway transportation network: Space L, Space P, Space B, and Space C. The specific meanings of the nodes and lines of the four methods are shown in Table 2.

*Table 2 Method for constructing network topology*

| Topology | Node | Line |
|---|---|---|
| Space L | Station | The line between the stations, directly connected to the two sites |
| Space P | Station | Representing one site to another site does not require transfer |
| Space C | Line | Represents direct transfer between two lines |
| Space B | Station and Line | The representative site is part of a line |

① Space P method: The traffic station is regarded as a node. If two stations have direct subway lines, then they have joints; if not, the stations are not connected.

② Space L method: Treat the traffic site as a node. If the two sites are adjacent on a certain subway line, they have connections.

(2) Degree and degree distribution

① Degree: The number of edges connected to a node in a traffic network is the degree of the node.

②Degree distribution: In the network, the degree distribution p (k) is expressed as the probability of a node with a node degree of k.

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③ Cumulative distribution: The degree distribution represents the probability distribution function p (k) of all nodes in the network. In order to reduce statistical errors and improve fitting accuracy, the general expression used is the cumulative probability distribution function:

$$\mathrm{p}(\mathrm{k} \geq \mathrm{k}') = \sum_{k=k'}^{\infty} p(k') \tag{1}$$

(3) Maximum shortest distance in the network, network average shortest path

① The maximum and shortest distance in the network: That is, the diameter in the network..

② Network average shortest path: The path with the fewest edges between any two nodes in the network. The network average shortest path is defined as the average of the shortest path between any two points:

$$\mathrm{L} = \frac{1}{\frac{1}{2}N(N-1)} \sum_{i>j} d_{i,j} \tag{2}$$

Where: N represents the number of network nodes.

(4) Node clustering coefficient and network clustering coefficient

① Node clustering coefficient: In the network, node i has ki connected to other nodes, then there are up to ki(ki-1)/2 edges between the ki neighbors. If in fact, there are between ki nodes When the Ei edges are connected, the clustering coefficient defining i is:

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

Where: ki is the number of edges connected to node i; Ei is the number of edges between ki nodes; Ci is the clustering coefficient of node i.

② Network clustering coefficient: The clustering coefficient C of the entire network is the average of the clustering coefficients of all nodes (total number N) in the network.

$$\mathrm{C} = \frac{1}{\mathrm{N}} \sum_{i=1}^{N} C_i \tag{4}$$

(5) Complex network topology features

Currently, there are four types of complex networks. Different types of complex networks have different network topology characteristics. For details, see Table 3:

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*Table 3 Analysis of four types of network topology features*

| Network model | Average path length | Aggregation coefficient | Degree distribution |
|---|---|---|---|
| Rule network | Big | Big | distributed |
| Random network | Small | small | Poisson distribution |
| Small world network | Small | Big | index distribution |
| Scale-free network | Small | Big | Power law distribution |

The urban subway transportation network constructed under different spaces will have different topological characteristics, which may belong to different types of complex networks. Later, we can analyze the topology construction under P space according to the characteristics of the topology structure of Shenzhen subway transportation network. Which type of complex network is used to better analyze its structure.

## 3. Analysis of Shenzhen Metro Traffic Line Network

There are four topological methods in Section 1.2 of this article, with nodes as nodes and lines as nodes. In order to better analyze the topological structure of the Shenzhen subway transportation network, this section uses the five subway lines to be studied in Shenzhen as the node, which is the Space C method in Table 2 to study the topological characteristics between subway traffic lines. The resulting temporary matrix is as follows:

$$A\ (i, j)=\begin{bmatrix} 0 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 \end{bmatrix} \quad (5)$$

Among them, i = 1, 2, 3, 4, 5 lines; j = 1, 2, 3, 4, 5 lines. Indicates that i lines and j lines can be transferred directly, otherwise. Using MATLAB software to analyze the topology of the temporary matrix (5), some characteristic values of the topology of the line can be obtained, such as node degree, network average, node maximum and node minimum, clustering coefficient of each node and Network average agglomeration coefficient, etc. See Table 4 and Table 5 for details:

*Table 4 Topological structural characteristic values of Shenzhen subway traffic lines*

| City | Average | Maximum degree | Minimum degree | Network average clustering coefficient |
|---|---|---|---|---|
| Shenzhen | 3.6 | 4 | 3 | 0.8667 |

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*Table 5 Clustering coefficient of each node in the topological structure of Shenzhen subway traffic line*

| Line node | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Clustering coefficientCi | 0.6667 | 0.6667 | 1.0000 | 1.0000 | 1.0000 |

As can be seen from Table 4, the overall network average is 3.6, which means that one line is connected to 3.6 lines on average, which means the transferability between the Shenzhen subway lines and the accessibility of the entire network. Compared with the overall average of the Shanghai network of 6.33, it can be seen that the accessibility and transferability of the subway network in Shenzhen is relatively low, but the current research on the network of five lines in Shenzhen has developed with Shanghai. Compared with the mature subway network, the low accessibility is understandable, and there are currently planned subway lines in Shenzhen. I believe that the accessibility and transferability of the network will gradually increase. The maximum degree of the entire topology is 4, which is line 2, line 3, and line 4, which can be transferred from line 2, line 3, and line 4 to another line, indicating 2 out of 5 lines. Lines 3 and 4 have higher accessibility and transferability. The minimum degree is 3, which is line 5, and line 5 is connected with lines 2, 3, and 4, that is, line 5 can be transferred to line 2, line 3, and line 4. The clustering coefficients of each node of the network are shown in Table 5. The average clustering coefficient of the network is 0.8667, and the entire line network is still relatively tight.

## 4. Analysis of Shenzhen Metro Traffic Network

### *4.1 Shenzhen Metro Transportation Network Serial Number-Site-Line Table*

In the second section of the paper, the topology analysis of the subway traffic line network in Shenzhen is carried out. Because the topology of the line network is relatively simple, the characterization and research significance of the entire subway traffic network is not detailed enough, so further need for the subway traffic in Shenzhen. The location and relationship of each site in the network is analyzed. It has been shown in 1.1 that the data studied in this paper are the 1, 2, 3, 4, and 5 lines currently running in Shenzhen. According to the subway line map of these 5 lines, the serial number-site-route diagram of Table 6 can be the serial number is a non-repeating label for all stations in Shenzhen. One station name corresponds to one serial number, that is, the transfer station repeated in the line site can only appear once. There are 131 stations in the five lines studied in this paper. The station name is the name of the station corresponding to each serial number, and the line is the subway transportation line through each station.

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*Table 6 Shenzhen Metro Traffic Serial Number—Site—Line Table*

| Serial number | site name | site name |
|---|---|---|
| 1 | Luohu Station | 1 |
| 2 | International Trade Station | 1 |
| 3 | Old Street Station | 1,3 |
| 4 | Grand Theatre Station | 1,2 |
| 5 | Science Museum Station | 1 |
| 6 | Huaqiang Station | 1 |
| 7 | Gangxia Station | 1 |
| 8 | Exhibition Center Station | 1,4 |
| 9 | Shopping park station | 1,3 |
| 10 | Xiangmihu Station | 1 |
| … | … | … |
| 127 | Fanshen Station | 5 |
| 128 | Baoan Central Station | 5,1 |
| 129 | Baohua Station | 5 |
| 130 | Linhai Station | 5 |
| 131 | Qianhaiwan Station | 5,1 |

### *4.2 P-space adjacency matrix of Shenzhen metro transportation network*

According to the method of Space P network topology modeling in Table 2 of this paper, the temporary connection matrix of Shenzhen Metro transportation network under P space can be obtained, which is the temporary matrix, where i and j are the serial number of Shenzhen Metro traffic in Table 6 Station Name—The serial number in the line table, which represents the serial number of the station. In the P space, if there is a subway traffic line between the nodes i and the node j, regardless of whether or not there is another station in the middle, for example, it is indicated from the No. 1 station Luohu Station to the No. 6 site Huaqiang Road Station. Although it will pass through Guomao Station, Laojie Station, Grand Theatre Station and Science Museum Station, it can be directly reached by Metro Line 1, so these two stations are considered connected. Otherwise, for example, it is indicated that there is no direct connection from the Lok Station on the 1st line to the No. 27 station on the 2nd line. The Hubei Station needs to be transferred at the Grand Theater Station on the 4th station, so it is considered they are not connected between them. When i=j, that is, from site i to site i itself, they are treated as not connected, ie. According to the five subway lines in Shenzhen, which are studied in this paper, the form of the connection matrix under P space is obtained as follows:

$$A_p(i,j)=\begin{bmatrix} 0\ 1\ 1\ 1 \dots 1 \\ 1\ 0\ 1\ 1 \dots 1 \\ 1\ 1\ 0\ 1 \dots 1 \\ \dots \qquad \dots \\ 1\ 1\ 1\ 1 \dots 0 \end{bmatrix} \tag{6}$$

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### *4.3 Shenzhen Metro Transportation Network Topology*

According to the adjacency matrix under P space in Section 4.2, the network topology map is obtained by Gephi software. See Figure 1:

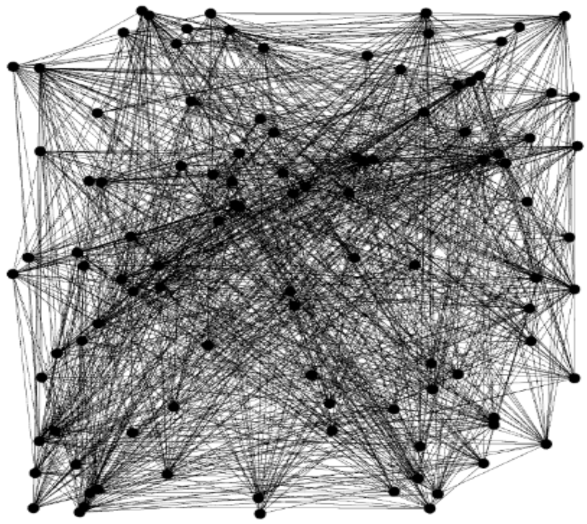

*Figure. 1 Site network topology diagram in P space*

In the network topology diagram of Figure 1, we can see that there are more connection lines in Shenzhen Metro transportation network under P space, and the density of the whole network is higher.

## 5. Calculation and Analysis of Topological Structure Characteristics of Shenzhen Metro Traffic Network

Through MATLAB software and EXCEL software to analyze the calculation of the P-space forward matrix, various eigenvalues of the network topology can be obtained. The eigenvalues studied in this paper mainly include: node degree, node maximum and minimum degree, network average Degree distribution; network average shortest path; clustering coefficient, etc.

### *5.1 Characteristics of Topological Structure Characteristics of Shenzhen Metro Traffic Complex Network under p Space*

The topological characteristic values of the subway transportation network under the calculated P space are shown in Table 7:

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*Table 7 Topological eigenvalues in P space*

| Space type | Average | Maximum degree | Minimum degree | Average shortest path | Longest and shortest path | Minimum clustering coefficient | Maximum clustering coefficient | Average clustering coefficient |
|---|---|---|---|---|---|---|---|---|
| P space | 25.1238 | 60 | 11 | 1.8485 | 2 | 0.4702 | 1 | 0.853 |

### *5.2 Degree and degree distribution analysis*

(1) Node degree under P space

In the P space: the maximum degree in the network is 60, which is the old street station and the shopping park station in the 2nd line. Both stations are transfer stations. From Shenzhen Station and Shenzhen South Railway Station, you can directly reach 60 stations. And Laojie Station and Shopping Park Station can be replaced by Line 1 and Line 3; the minimum is 11, which is the four interchange stations of Metro Line 4 except Shenzhen North Station, Children's Palace, Civic Center and Convention and Exhibition Center. All the nodes below, the number of stations on Line 4 is small but there are intersections with the other four lines. Although there are more stations on Line 1 and Line 3, the line that is currently open for Line 4 is shorter, only 15 Sites, so for sites that are not transfer stations on line 10, the node degree is lower; the overall network average is 25.1238, which means that from any site, the average can reach 25.1238 without transfer. The site, which is also consistent with the number of stations on most subway lines distributed between 20-35.

(2) Degree distribution under P space

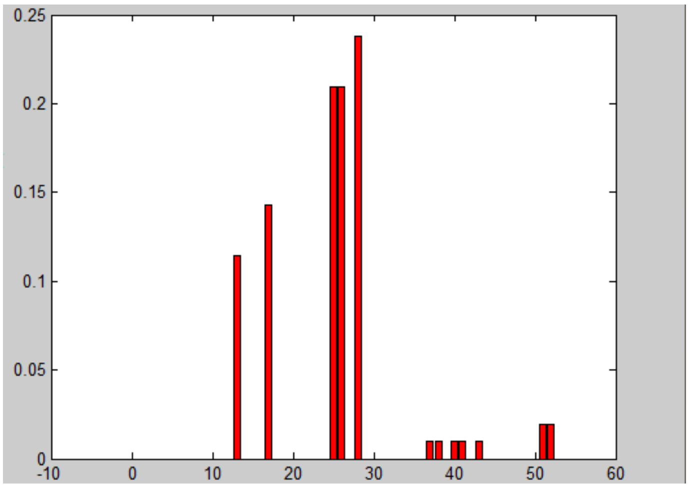


*Figure. 2 Probability distribution of node degrees in P space*

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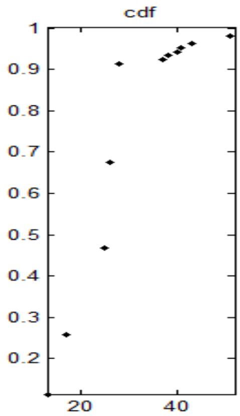


*Figure. 3 Cumulative distribution under P space*

It can be seen from Fig. 2 that under P space, the degree of nodes is relatively large, mainly concentrated between 20-50, the distribution is relatively scattered, and the distribution area is wider. It can be seen from Fig. 3 that the cumulative degree distribution of the node degrees in the P space is a cumulative distribution type that is more in line with the exponential distribution, which is also consistent with the distribution of the network degree in the previous Fig. 2.

### *5.3 Shortest path analysis*

In P space, the longest and shortest path is 2, which means that from one node to another, only a sub-transfer, for example, from Shuanglong Station on Line 3 to Qinghu Station to Line 4, a transfer is required. The network's average shortest path is 1.8485, which means that in P space, from any point in the network to another point, the average distance is only 1.8485.

### *5.4 Clustering coefficient analysis*

In P space, the average clustering coefficient of the network is 0.8530. The reason why the clustering coefficient is so large is that when the station is not a transfer station, according to the method of network topology modeling under P space, its proximity node is where the station is located. All the stations on the subway line are connected under the P space, and the clustering coefficient of these nodes is 1. The maximum clustering coefficient in the network is 1, and the smallest clustering coefficient is 0.4702. Figure 4 shows the frequency of clustering values of nodes in P space. The proportion of clustering coefficient in the network is 41.9%. The ratio of clustering coefficient greater than 0.97 is 95.24%, which also explains the reason why the network average clustering coefficient is higher.

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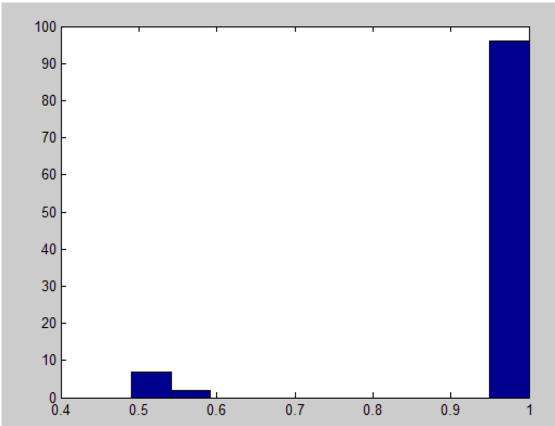


*Figure. 4 Distribution of clustering coefficients in P space*

***5.5 Complex network characteristics analysis***

**5.5.1 Qualitative Analysis of Complex Network Characteristics of Shenzhen Metro Traffic**

According to the calculation and analysis results in Sections 4.1-4.4, the Shenzhen Metro transportation network under P space has the following characteristics:

(1) The average path length of the network is small, 1.8485.

(2) The clustering coefficient of the network is large. As can be seen from Section 4.4, the proportion of the clustering coefficient of the network is 41.9%. The ratio of clustering coefficient greater than 0.97 is 95.24%.

(3) From the network moderate distribution map in Fig. 2 and the cumulative distribution in the network of Fig. 3, it can be known that the degree distribution in the network is a distribution type that is more in line with the exponential distribution.

Combined with the characteristics of the small world network in Table 3 in Section 1.2, the average path length of the network is small, the network clustering coefficient is large, and the degree distribution of the network obeys the exponential distribution. The topological structure of Shenzhen Metro transportation network under P space meets these three characteristics, so it can be proved that Shenzhen Metro transportation network is a small world network.

**5.5.2 Quantitative Analysis of Complex Network Characteristics of Shenzhen Metro Traffic**

Watts [11] and Strogatz pointed out that small world networks have the same average path length as random networks and high aggregation like regular networks. Small world networks must meet the following two conditions:

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$$\text{Average path length } L \geq L_{Random} = \frac{\ln(N)}{\ln(<k>)} \tag{7}$$

$$\text{Clustering coefficient} C \geq C_{Random} = \frac{<k>}{N} \tag{8}$$

Where: LRandom is the average path length of the random network; CRandom is the clustering coefficient of the random network; N is the total number of nodes in the network; <k> is the average degree of the network.

According to formulas (7) and (8), the average path length and clustering coefficient of random networks of the same scale in Shenzhen metro transportation network are obtained. The same scale here means that the two networks have the same number of nodes, edges and averages. Combined with the data in Table 7, the specific calculation results are shown in Table 8:

*Table 8 Characteristic indicators of Shenzhen metro transportation network and random network of the same scale*

| Characteristic index | Shenzhen Metro Transportation Network | Random network |
|---|---|---|
| Average path length | 1.8485 | 1.4436 |
| Clustering coefficient | 0.8530 | 0.2393 |

It can be seen from the calculation results in Table 8 that the average path length of the Shenzhen subway traffic network is larger than the average path length of the random network compared with the random network of the same scale; the clustering coefficient is also larger than the clustering coefficient of the random network, so it can be quantitatively It is concluded that the Shenzhen Metro transportation network under the P space is a small world network.

Through qualitative and quantitative analysis, this section shows that the Shenzhen Metro transportation complex network is a small world network, which indicates that although the scale of the Shenzhen metro network is widely covered, the path between any two sites is shorter. The communication between the two is relatively smooth, and the service level of the entire subway transportation network is relatively high.

## 6. Conclusion

The main work of this paper is based on the complex network theory, using Space C and Space P method to construct the topological structure of Shenzhen urban subway transportation network, and analyzing the topological structural characteristics of Shenzhen metro transportation network in C space and P space. Concluded as follow:

(1) Using Space C's network construction method to analyze the Shenzhen subway traffic line network, although the form of this network is relatively simple, it can also initially determine the average degree and clustering coefficient of the current subway traffic network in Shenzhen, the whole network. Relatively close, it can basically meet the current travel requirements, but with the increase of population and travel volume, such average and clustering coefficient should be further improved, that is, to increase the number of subways and increase the network density.

(2) As of January 2017, an average of 1 station in the Shenzhen subway transportation network under P space is connected with 25.1238 stations, and the average shortest path has to pass 1.8485 stations.

(3) Under the p space, the overall metro transportation network in Shenzhen has a high degree of value, and the distributed area is concentrated around the network average; while the average shortest path of the network is small, it reflects the average from one station to any station. The number of times that the subway needs to be replaced; the clustering coefficient of the network is very high, and the clustering coefficient of 95.24% of the sites exceeds 0.97. The network as a whole is relatively tight, which is consistent with the content in conclusion (1).

(4) From the results of network topology analysis in Section 4 of the paper, in the P space, the Shenzhen metro transportation network has complex network characteristics, combined with its small average path length and large clustering coefficient, it also proves that it is typical. Small world network.

(5) Combined with the literatures reviewed, the subway transportation networks in Shanghai, Beijing, Guangzhou and other cities are characterized by complex networks. This paper also verifies that the Shenzhen metro network belongs to a small world network in a complex network. Therefore, we can demonstrate that metro transportation networks in large cities are generally complex networks. The calculation of network topology indicators by MATLAB, Gephi and other software can help us to study the internal mechanism of urban metro transportation networks. The urban subway network and the subsequent evolution of the law laid a foundation.

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