

# Analysis of Complex Network Characteristics of Bus Stations in City: A Case Study of the Changsha-Zhuzhou-Xiangtan Urban Agglomeration

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**Abstract:** *Based on the current situation and operation of urban bus network stops, this paper uses complex network theory to analyse the topology of the constructed network. Taking the ChangZhuTan bus network as an example, the Space-L method is selected to establish a network topology model, and the topological characteristics of different networks are analysed by calculating the static indicators of the network (degree, degree distribution, average path length, clustering coefficient, etc.). The research results show that the ChangZhuTan bus network has scale-free network characteristics, but the small-world characteristics are not obvious, and the results of the indicator calculation are consistent, which provides a reference for urban transport. The results show that the ChangZhuTan bus network has scale-free network characteristics, but the small-world characteristics are not obvious, and the results are consistent with the index calculation, which puts forward reference suggestions for urban transportation planning and development.*

**Keywords:** *Urban public transport; Topology; Complex network; Scale-free characteristics*

## 1. Introduction

As an important part of urban infrastructure, urban bus road networks play an important role in linking cities. As transport conditions continue to develop, issues such as the topological characteristics of increasingly complex transport networks have attracted the attention of many researchers. Starting from the Seven Bridges problem,<sup>[1]</sup> many researchers have discovered the ability to abstract complex systems into networks and to recognise the essence of network systems.

At this stage, more and more scholars are using complex network theory to analyse transportation networks, and the study of networks such as urban rail transit,<sup>[2]</sup> railway passenger transport,<sup>[3]</sup> urban buses,<sup>[4]</sup> and aviation is gradually deepening,<sup>[5]</sup> with more research on rail transit networks in large cities, but relatively little analysis related to bus road networks in most small and medium-sized cities. This paper will introduce some common important topological indicators such as average degree and degree distribution to analyse the bus road network, taking the ChangZhuTan bus system as an example, and calculate and analyse the network node characteristics to provide a reference for the construction planning of the bus network.

## 2. Topology model construction and analytical indicators

### 2.1 Constructing the model

A network is a graph formed by nodes and connections. If nodes are connected according to defined rules, the resulting network is called a regular network, and if the network is connected according to some organising principle, it is called a complex network. Space-L, Space-P, and Space-R are the main methods for constructing traffic network topology models, where the Space-L method treats stations as nodes, and only adjacent nodes on the line are connected to each other.<sup>[6]</sup>

The guidelines for constructing the topology model in this paper are as follows.

(1) Only one edge is connected between two adjacent nodes (with the same name) through which multiple bus lines pass.

(2) Lines include only the general bus route network and do not include tourist lines, maglev trains,

or subways.

(3) Stations with multiple entrances and exits, such as Changsha Railway Station (Nanping) and Changsha Railway Station (Beiping), are defined as only one station.

## 2.2 Network structure analysis indicators

### 2.2.1 Node degree: $k_i$ , degree distribution: $P(k)$

The node degree  $k_i$  is the number of neighbouring nodes directly connected to the node, while the network mean degree  $K$  is the average of all node degree values in the network. If the adjacency matrix of a network  $G$  is denoted as  $a_{ij(N \times N)}$ , the node degree  $k_i$  and the average degree  $K$  can be expressed as

$$k_i = \sum_{j=1}^N a_{ij} \quad (1)$$

$$K = \frac{1}{N} \sum_{i=1}^N k_i \quad (2)$$

and the following relationship exists between  $K$  and the number of connected edges  $e$

$$K = \frac{2e}{N} \quad (3)$$

In general, the higher the degree of a node, the more important the node is to the network, and the higher the average degree value, the more dense the network is.

### 2.2.2 Average path length and diameter

The average path length  $L$  is the average distance between all pairs of nodes in the network, while the distance  $d$  is the path between node  $i$  and node  $j$  that contains the least number of connections, and the network diameter is the maximum distance between all pairs of nodes. For a network containing  $N$  nodes,  $L$  can be represented as

$$L = \frac{1}{N(N-1)} \sum_{i=1}^N \sum_{j=1}^N d_{ij} \quad (4)$$

### 2.2.3 Clustering coefficient

The clustering coefficient measures how closely the neighbouring nodes of a node in a network are connected to each other. The clustering coefficient of a node is defined as

$$C_i = \frac{2e_i}{k_i(k_i-1)} \quad (5)$$

$e_i$  denotes the number of connected edges among the  $k_i$  neighbouring nodes of a node, when  $k_i = 0$  or  $k_i = 1$ ,  $C_i = 0$ ; When the neighbouring nodes of node  $i$  are connected,  $C = 1$ ; when the neighbouring nodes of node  $i$  are not connected to each other,  $C = 0$ . The degree of clustering of the whole network can be characterised by the average clustering coefficient of all nodes, defined as

$$C = \frac{1}{N} \sum_{i=1}^N C_i \quad (6)$$

### 3. Analyses of urban bus network features

#### 3.1 The network's average degree $k$ and degree distribution $P(k)$

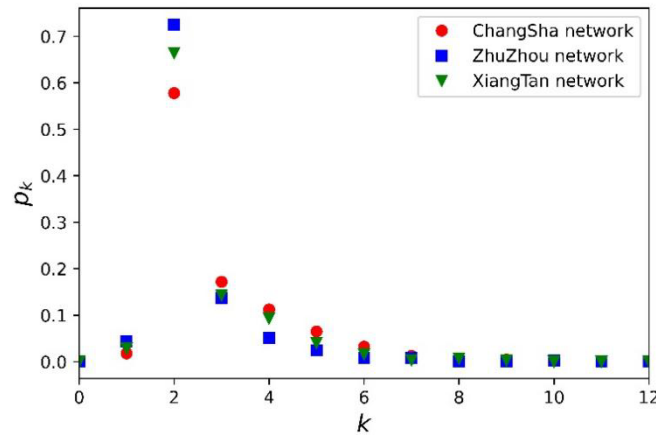
Through the computation of the data, Table 1 presents the fundamental indicators and analytical findings of the topology of the bus road networks in Changsha, Zhuzhou and Xiangtan.

*Table 1: Topological indicators of the ChangZhuTan bus network*

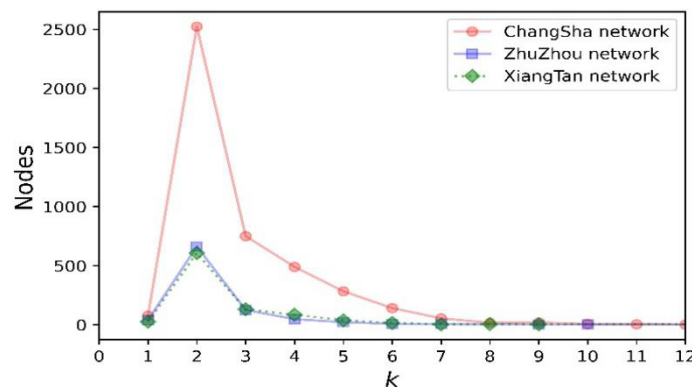
City	$K$	$C$	$L$
ChangSha	2.89	0.091	11.19
ZhuZhou	2.41	0.030	15.94
XiangTan	2.61	0.075	13.54

As seen in Table 1, the average degree of the bus route network ranges from 2.4 to 2.9, and the average path length of the routes ranges from 11 to 16, indicating that 11 to 16 bus stops are required to travel from a certain stop to any other stop on the bus route network in ChangZhuTan.

Figure 1 gives the degree distribution of the bus road networks in the three cities. It can be seen that the degree distribution of the topology of the ChangZhuTan bus road network tends to be Poisson distributed, with fewer nodes having large degree values, i.e. there are fewer large public exchange stations. Figure 2 shows the relationship between the degree of stations and the corresponding number of stations in the three cities.



*Figure 1: The degree distribution of the ChangZhuTan network's topology*



*Figure 2: Correspondence between degree values and number of stations*

As can be seen from Figure 1 and Figure 2, stations with a degree of 2 account for more than half of the network, and this type of station may have two buses passing through or be the starting and ending station for two buses. The maximum degree values calculated for the ChangZhuTan sites are 12, 10 and 9 respectively, and the corresponding number of sites is no more than 3. This indicates that most of the bus sites in this network have fewer lines than others, while a few sites pass through very dense lines, which shows that the distribution of the road network is uneven.

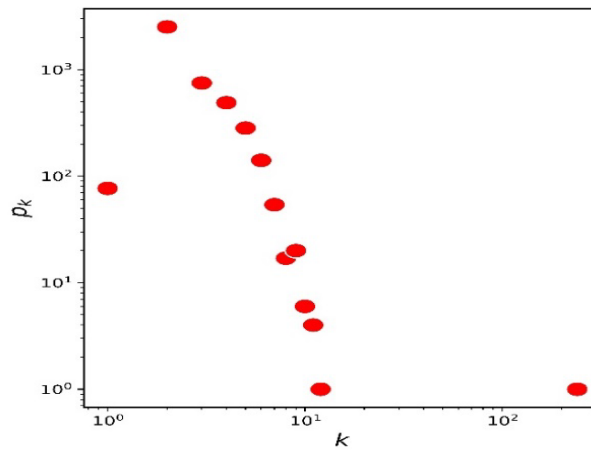


Figure 3: Degree distribution in logarithmic coordinates

Figure 3 gives a plot of the relationship between the degree distribution in double logarithmic coordinates, which shows that the stations with the smallest and largest degree values are less effective in the distribution, but the network as a whole shows a power-law distribution, which means that the bus route network has scale-free characteristics.<sup>[7]</sup>

### 3.2 Average path length and clustering coefficient

The number of nodes in Changsha's bus route network is calculated to be 4,367, while Zhuzhou and Xiangtan have 920 and 914 nodes respectively. As can be seen from the data in Table 1, Changsha's bus route network has more than four times the number of points than Zhuzhou and Xiangtan, but the average path length is smaller, indicating that Changsha's bus route system is more rational and developed compared to the other two cities', which is in line with intuitive perception.

Due to the large difference in the sample size of stations on the ChangZhuTan bus network (not including metro and other transport) eligible for analysis, Figure 4 only gives a path length distribution map for Changsha, while Zhuzhou and Xiangtan have a smaller number of nodes to see, the results are not obvious.

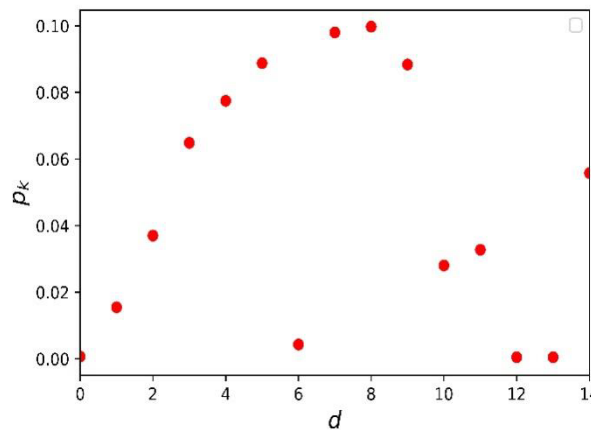


Figure 4: Distribution of the network's shortest path lengths

As can be seen from the graph, excluding the value of 6 for the path length, the entire bus network basically obeys a gamma distribution with the highest probability of a distance of 8 and a network diameter of 76. This is due to the fact that the network has the most stops and the longest distance all the way from the first bus stop in Chigangchong to the terminal stop in Jumping Horse Town.

The clustering coefficient reflects the degree of aggregation of lines at individual stations, while its average value reflects the density of lines in the overall network. It is calculated that the bus network in ChangZhuTan is fully connected and there are no stations with a clustering coefficient of 0. This means that the network can always reach another station after transferring from any station and the connectivity is good. However, half of the sites were statistically found to have low clustering

coefficients, which is one reason for the poor stability of the network, as the fewer links between the nodes' neighbours means that most of the bus route traffic has to be carried through this node, resulting in a heavier load on the site. The small-world character of the network is therefore not obvious.<sup>[8]</sup> The overall network is therefore relatively sparse, and the accessibility of the road network needs to be improved.

#### 4. Conclusion

By using some common indicators of complex network theory (degree, degree distribution, etc.) to analyse the ChangZhuTan bus road network, this paper draws the following conclusions.

1) The overall network of ChangZhuTan has a relatively obvious scale-free network characteristic, but since the stations and lines in Zhuzhou and Xiangtan are much smaller than those in Changsha, the distribution of the shortest path length is not obvious, which also indicates that the overall network of ChangZhuTan has not yet shown the characteristics of a small world network.

2) The degree distribution of the network was calculated and found to be close to a Poisson distribution. There are fewer nodes with a relatively large degree, indicating that there are fewer stopping points containing most bus routes.

3) The overall clustering coefficient of the network is not high, resulting in excessive throughput at a few stations and causing traffic congestion. It is recommended that more transport hubs be built to reduce the load on a few stations and increase the capacity and throughput of nodes with higher degree values.

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