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Complex Network Analysis of Highway Network in Guangdong Province in China

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Abstract

In this paper, complex network theory is introduced to analyze the highway network in Guangdong Province (GDHN), the topology structure of GDHN was presented using the L space methodology. Then the network properties, such as degree distribution, closeness centrality, betweenness centrality, have been applied to analyze the statistical features of the GDHN. The results shows that the hubs supporting the communication of different highways are mostly located in the Pearl River Delta area. The highway development levels between different regions are very unbalanced. At last, some suggestions about the future construction of GDHN are proposed.

Key words: Complex network theory; Guangdong highway network; Topological structure; Network property

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INTRODUCTION

With the integration of world economy and the expansion of international trade, transportation networks become more and more important to the economic and social development of a region. Transportation networks support the movement of people, goods and information , thus its structure and performance are of crucial importance to many aspects of economic and social activities.

In recent years, there has been rapidly growing interest in investigating the statistical and dynamical features of different transportation networks. Key studies include but are not limited to the air networks of China, US, India and worldwide (Li & Cai, 2003; Barrat, Barthélemy, & Vespignani, 2004; Bagler, 2008; Guimerà, Mossa, Turtschi, & Amaral, 2005), the railway networks of China and India (Wang et al., 2008; Ghosh , Banerjee, & Sharma, 2011), the public transportation networks of Singapore and Poland (Soh et al., 2010; Sienkiewica & Holyst, 2005), the underground transportation networks of Boston and Shanghai (Latoraa & Marchiorib, 2002; Zhang, Xu, Hong, Wang, & Fei, 2011) and the highway networks of Hungary and India (Donald & Buckwalter, 2001; Mukherjee, 2012). A lot of complex network approaches are applied in these studies and many new topological properties of these networks are revealed.

Guangdong is a coastal province in the southern part of China. Its location and other conditions provide a valuable opportunity to enhance economy and international trade. In 2013, Guangdong province accounts for about 11% of China's total GDP and 26.2% of China's total international trade. Guangdong's logistics mostly rely on the road networks, especially the highway networks. About 63.4% of the total road freight is carried on highway networks while the share of highway mileage in the total road mileage is only 2.2% in Guangdong province. In this scenario, it is of utmost importance to study the topological properties of the Guangdong Highway Network (GDHN).

This paper is organized as follows. Section 1 discusses the data of this study and the network construction methodology. In Section 2, we will analyze the topological properties of GDHN systematically and propose some suggestions. Finally, the conclusions are given in Section 3.

1. DATA AND NETWORK CONSTRUCTION

In this study, the data are mainly collected from Guangdong Province transport department website and "Guangdong Highway Map" which was published by the People's Traffic Press. Highways are bidirectional , so we consider GDHN as an undirected network. Therefore, the GDHN can be abstracted by an undirected network $G = < V, E >$, where $V = \{v_i | i = 1,2,3,\ldots,N\}$ is the set of nodes and $E = \{e_{ij} = (v_{i\,,}\ v_j) | v_i\ ,\ v_j \in V\ \}$ is the set edges. The GDHN is comprised of 148 nodes representing stations and 211 edges representing the links between stations.

There are mainly two methodologies for representing a network, L Space and P Space. L Space consists of nodes representing cities, stations and sea ports and a link between two nodes exists if they are consecutive stops on the route. Nodes in the P Space are the same as in the previous topology; here an edge between two nodes means that there is a direct bus, train, or metro route that links them. In this study, L Space would be applied because it can better reveal the physical picture of the GDHN.

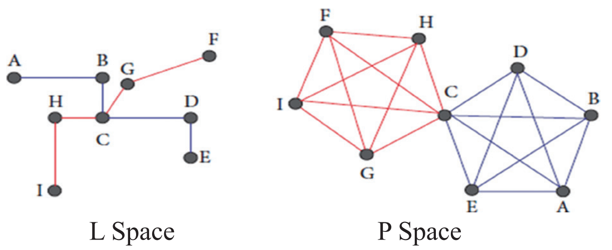

Figure 1
Explanation of L Space and P Space

2. ANALYSIS OF TOPOLOGICAL STRUCTURE OF GDHN

Figure 2 shows the topological structure of the GDHN. Obviously, the highway network in the Pearl River Delta has a much bigger density than in other parts of Guangdong Province. In the Pearl River Delta area, the developed cities, such as Guangzhou, Foshan, Shenzhen, Dongguan and Huizhou, have formed several beltways and Guangzhou has the highest density of beltways

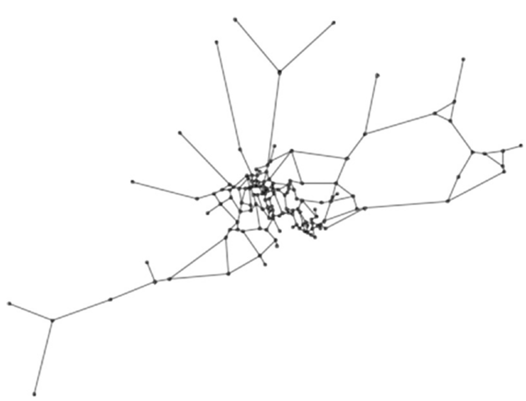

Figure 2
Topological Structure of GDHN

2.1 Degree Distribution

Degree is defined as the number of other nodes that are linked to a specific node in the network, which is one of the measures of centrality of a node in a network. It symbolizes the importance of a node in a network. The larger the node degree it has, the more important it becomes. The node degree k_{vi} is for node V_i, representing the quantity of nodes connecting to node V_i. The mathematical expression is as follow:

$$kvi = \Sigma_{j=1}^{N} X_{ij}\,.$$

Among them, N is the number of total nodes; if V_i is connected with V_j, then X_{ij}=1, or X_{ij}=0.

The degree distribution $p\ (\ k\ )$ is an important feature that reflects the topology of the network and is defined as the fraction of nodes having degree k in the network.

The average node degree of the GDHN is 2.85. Figure 3 shows the degree distribution of the GDHN. There are more than 70% of nodes with degree value bigger than 2. The station "Paibanglijiao" in Shenzhen has the biggest degree, which is connected to other nodes. There are 37 nodes with degree of 4 and 71 nodes with degree of 3. These nodes serve as hubs in the GDHN, supporting the connection and conversion between different highways. However, they also pose a threat to the daily operations of the highway network, as a failure of one of these major stations can possibly cause a major portion of the network to crash down and halt.

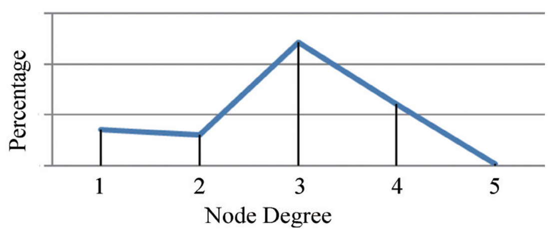

Figure 3
Degree Distribution

2.2 Closeness Centrality

Closeness Centrality is defined as the inverse of the sum of shortest distance from node to all the other nodes, the mathematical expression is:

$$C(V_i) = 1/\Sigma^{n}_{j=1} d(V_i, V_j)\,.$$

Among them, $d(V_i, V_j)$ is defined as the shortest distance between V_i and V_j, which is equaled to the minimum nodes from V_i to V_j in the highway network.

In complex network theory, the shortest path can be described as the convenience from beginning to destination. Closeness centrality measures a node's centrality degree by the distance with other nodes. Closeness Centrality reflects the closeness from one node to all the other nodes in the highway network. The larger the value, the greater influence and the wider range of service the node has. The average of the whole network's closeness centrality reflects operation efficiency of the network, the larger the value, the higher efficient the network has.

Table 1
Closeness Centrality of Top Ten Stations

Node	City
Badou	Guangzhou
Chungang	Guangzhou
Taihe	Guangzhou
Cenchun	Guangzhou
Luogang	Guangzhou
Lapu	Guangzhou
Huochun	Guangzhou
Guangzhouguangyuan	Guangzhou
Bichun	Guangzhou
Xintang	Guangzhou

The top ten nodes according to high closeness centrality are given in Table 1. What surprise us is that all of them are located in Guangzhou. If we look further, we will find that the nodes with high closeness centrality are mostly located in the Pearl River Delta area, especially in Guangzhou, Dongguan and Huizhou.

2.3 Betweenness Centrality

Betweenness centrality is defined as the proportion of the number of shortest paths that pass through node in the total number of shortest path. The mathematical expression of betweenness centrality is:

$$C_B(V_i) = \sum_{j=1}^{N} \sum_{k}^{j-1} \frac{P_{jik}}{P_{jk}} .$$

Among them, P_{jk} is the number of the shortest paths from Node j to Node k. P_{jik} is the number of shortest paths passing Node. In the highway network, the nodes with higher betweenness centrality usually act as a hub with strong influence.

Table 2
Betweenness Centrality of Top Ten Stations

Node	City
Badou	Guangzhou
Lapu	Guangzhou
Taihe	Guangzhou
Benghu	Guangzhou
Shiba	Huizhou
Weiyuan	Dongguan
Baiyunlongshan	Guangzhou
Xiaojinkou	Huizhou
Taiping	Dongguan
Hengli	Guangzhou

The top ten nodes according to high betweenness centrality are given in Table 2. As you can see, they are located in Guangzhou, Dongguan and Huizhou, which is similar to closeness centrality.

2.4 Analysis and Suggestions

We found that the highway development levels between different regions are very unbalanced. In the Pearl River Delta area, the GDHN has formed several beltways. But for the West, the East and the North areas, the structure of highway network is very sparse. As can be seen, nodes are mostly located in 5 cities: Guangzhou, Foshan, Shenzhen, Dongguan and Huizhou. The hubs, the nodes supporting the communication of different highway, concentrate in the east part of the Pearl River Delta area, namely, Guangzhou, Dongguan and Huizhou.

Based on the analysis, we make some suggestions for the future constructions of GDHN.

First of all, the nodes with high centrality value need to be monitored emphatically. Once traffic accident happens, the transportation department needs to forecast the spread speed and the scope of influence rapidly, and effective restoration measures should be taken as soon as possible.

Secondly, in order to improve the operation efficiency of the whole network, more highways need to be constructed, especially from the North and the East to the Pearl River Delta area.

Last but not least, in the future construction planning, the highway grades need to be improved. Effective measures need to be taken to ease the traffic pressure and improve the efficiency of the whole network.

CONCLUSION

Transportation networks communicate the development level of a country/region and form the backbone of economic and social development.

In this study, L Space methodology has been applied to study the topological properties of GDHN: node degree distribution, closeness centrality and betweenness centrality.

Although this study contributes a complex network analysis of the GDHN, given the availability of traffic flow data, it would be much more interesting to study the GDHN as a weighted network. It could definitely reveal a clearer picture of network dynamics. Such a study would not only reveal the topological features but also provide a detailed insight into the network dynamics.

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