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Modeling and Characteristic Analysis of Bus and Subway Composite Transportation Network

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Abstract

In recent years, China is in a new stage of rapid urbanization. The phenomenon of multi network integration of public transport network and subway network has appeared in urban transportation network. How to build a three-dimensional integrated, intelligent and efficient modern comprehensive transportation system has become a new proposition of the times. From the perspective of complex network, through network modeling and feature analysis, this paper studies the collaborative relationship between public transport network and subway network, studies the improvement of network performance by composite transportation network, analyzes the combination of public transport network and subway network in Shanghai from the perspective of network topology parameters, and studies the impact of the combination of different transportation networks on the overall transportation network.

Keywords

Complex Networ; Composite Traffic Network; Network Modeling; Topology Parameters; Network Performance.

1. Introduction

In the background of transportation industry, China has a large population, limited per capita resources, and is in the process of rapid urbanization. Traffic congestion in big cities is very common. Among them, urban public transportation plays a particularly key role in changing the phenomenon of urban congestion [1], and the development direction of urban public transportation focuses on the multi-network integration of subway network and bus network [2]. National governments at all levels have also issued planning and policies for the development of comprehensive transportation network. The official website of the National Development and Reform Commission has issued relevant policies to put forward higher requirements for the comprehensive development of the transportation network in the Yangtze River Delta region. Shanghai Municipal Government has also issued policies pointing out that it is necessary to continuously improve and improve the comprehensive transportation system of hub type, function and network, actively implement national strategies such as the construction of transportation power and the integrated development of Yangtze River Delta, and build a three-dimensional integrated, intelligent and efficient modern comprehensive transportation system [3].

In theoretical studies in the field of transportation, traditional traffic flow methods are used to analyze network accessibility and evaluate network efficiency based on parameters such as traffic travel time, travel distance, capacity and efficiency of network connection, so as to provide reference for planning and layout of transportation network [4]. There are also complex network methods to establish a spatial structure model of the traffic network, analyze the characteristics of the traffic network through network topological parameters and related centrality indicators, and evaluate the layout planning of urban comprehensive traffic [5].

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With the continuous expansion of the scale of urban transportation network, there are more and more internal connections of the transportation system, and the mutual influence and dependence of subway network and bus network are also increasing, thus forming a comprehensive and integrated transportation system. Hope that through this article, therefore, the method of topological network traffic network space structural model is established, the calculation of the single transport network and composite traffic in the network topology parameters, the structure of transit network characteristics were analyzed, and the comparison with the single transport network, the structure of the differences between composite traffic in the network traffic and transport way of network performance improvement.

2. Literature Review

2.1. Traditional Transportation Field

There have been a large number of studies in the field of urban transportation, some focusing on the direction of network modeling, combing the development stage of the research in the field of transportation network modeling, so as to provide reference direction for the future research of urban transportation network modeling [6]. Research on traffic network system from the perspective of network topology [7]. There are studies on the global characteristics of networks from the perspective of the interaction between topology and dynamics in complex systems [8]. It is necessary to study the small world nature of aviation network from the perspective of complex network framework [9]. There are studies on the rationality of urban road network layout from the perspective of accessibility [10]. There are studies on the connection effect between traffic networks, and pay attention to the failure of the connection between urban road traffic networks [11]. There are studies on the application of complex network theory in urban traffic network research from the perspective of system cognition and integration framework [12].

2.2. Composite Transportation Field

In the field of composite transportation network, some scholars solve the integration problem of different transportation networks by designing the composite transportation network model of multimodal transportation and putting forward the way of constructing algorithms [13]. Other scholars use the multi-mode composite network topology model generation algorithm to support the analysis of composite paths [14]. The first mock exam is to study the topological consistency of traffic network from single mode to compound mode. [15] Other scholars have studied the problem of user random equilibrium allocation in multi-mode composite transportation network [16]. In addition, it is also studied to simulate the system capacity of composite traffic network through models and algorithms [17]. In addition, the combination of public transportation system and subway transportation system is studied to improve the performance of transportation network [18].

3. Method and Data

3.1. Complex Network Method

The research of complex network is developed on the basis of graph theory and geometric topology. It is an important branch of discrete mathematics. It originated from the proposal of "Konigsberg seven bridge problem". Since then, the research of complex networks has developed continuously in the fields of natural science and social science. Two articles published by Watts[19] and Albert[20] respectively mark the beginning of a new era of complex network research. They respectively reveal the small world characteristics and scale-free characteristics in complex networks, and create a new research direction in the field of complex networks.Small world, scale-free and random networks are shown in Figure 1. Since then, a

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large number of scholars have used this new theoretical tool to study various large-scale complex systems in the real world, including transportation networks, biological networks, communication networks, social networks and so on.

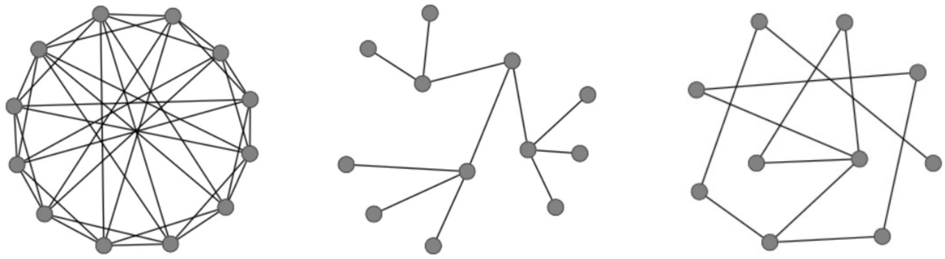

Figure 1. Small world, scale-free and random networks

In a complex system with a large number of structural units, the constituent units can be regarded as nodes, and the relationship between the units is regarded as edges. The complex network model established by this method can be used to study the characteristics of the network. In the modeling of transportation network, there are three methods: Space L, space P and space R, which are respectively applied to the establishment of geographic model, station service model and line service model. Geographic model can better restore the real situation in the traffic network. The station service model can be used to study the influence relationship between traffic lines and stations, while the line service model can be used to study the interaction relationship between traffic lines. In this paper, the space l model is used to establish the topological model of the traffic network, which is used to study the relevant parameters in the complex network. Taking the stations in the bus and subway as the nodes of the network, the existence of line connection between the two stations is regarded as the existence of connection between the nodes of the network, and the topological network model is established.

3.2. Modeling of Complex Networks

The network modeling is based on Shanghai Metro system and public transport system. The subway data is from the official website of Shanghai Metro in 2021, and the public transport data is from the Shanghai public transport network in 2021. The geographical model of the bus subway composite network is established through the space l method, that is, the stations in the transportation network are regarded as nodes in the network, The line connection between adjacent stations is regarded as the connection in the network. As long as there is line connection in the same type of transportation network, the adjacent stations are regarded as the connection. If the distance between the bus station and the subway station is less than 500m, the bus station and the subway station are regarded as the connection. The undirected and unauthorized topological network model is established through Cytoscape software. The topological network parameters of public transport network, subway network and composite transportation network are calculated respectively, and the network characteristics are analyzed from the perspective of network topological parameters. In this paper, the complex network topology parameters used in the study of Shanghai bus and subway composite transportation network mainly include node degree, clustering coefficient, average shortest path , betweeness centrality and closeness centrality [21]. Their respective meanings are shown in the table below.

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Table 1. Meaning of network topology parameters

Topological parameters	Calculation formula	Parameter meaning	Geographical significance
Degree	$K_i = \sum_{j=1}^{n} a_{ij}$	Refers to the number of sites that are connected to this node by all other nodes	External contact degree of the station
Average shortest path	$L = \frac{\sum d_{ij}}{N(N+1)/2}$	It refers to the average length of the shortest path from this station to other stations in the transportation network	Travel path length of the station
Clustering coefficient	$Ci = 2M_i/[k_i(k_i-1)]$	It refers to the probability that the stations connected by one station in the transportation network are also connected with each other	Cluster effect of station
betweeness centrality	$C_{Bi} = \sum \frac{Dkj(i)}{Dkj}$	It refers to the number of times the node acts as a bridge in the network and the probability of being in the middle of the point pair	Traffic flow load of the station
Closeness centrality	$C_{Ci} = \frac{1}{\sum_j d(i,j)}$	It refers to the proximity between one station and other stations in the transportation network.	Ease of network access

4. Empirical Results

4.1. Analysis of Network Global Topology Parameters

The established traffic network model is shown in the figure below, the subway network has 345 nodes and 396 edges, the bus network has 14207 nodes and 20328 edges, and the composite network has 14552 nodes and 22403 edges. In the established network model, we can find obvious differences. The scale of subway network is significantly smaller than that of bus network, and the ratio of the number of edges and nodes of subway network is significantly lower than that of bus network, and even lower than that of composite network.

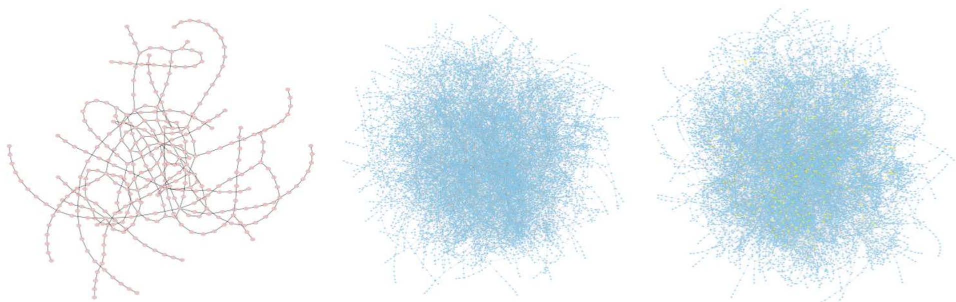

Figure 2. Subway network, bus network and composite transportation network model

From the perspective of global network parameters, different traffic network models are analyzed. The average node degree of subway network is 2.296, that of bus network is 2.857, and that of composite network is 3.074. It shows that the average number of adjacent stations in the bus network is higher than that in the subway network, which may be caused by the construction cost and geographical attributes of subway stations and bus stations. However, in the composite network composed of subway network and bus network, the average node degree increases to a certain extent, which shows that the connectivity attribute between bus stations and subway stations is significantly higher than that between stations with the same attribute in the two networks, and the contribution of the connection between heterogeneous stations to the composite network is significantly higher than that between homogeneous stations. The average clustering coefficient is 0.009 in subway network, 0.063 in bus network and 0.077 in composite network. From this, we can see the difference of different types of

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transportation networks. The aggregation degree of subway network is significantly lower than that of bus network, that is, the possibility of connection between adjacent stations in bus network is much greater than that of subway network. The principle is that the construction cost and difficulty of subway network are different from that of bus network, By increasing the connection degree between adjacent stations of subway network stations, the cost-benefit ratio of station clustering and clustering is much lower than that of public transport network, which is easier to increase the regional traffic convenience through station clustering and clustering, Moreover, in the composite network, the cluster effect between subway stations and bus stations is also higher than that between stations of the same type. It is a combined effect in the composite network, which increases the regional connectivity. In the subway network, the average shortest path of the overall network is 16.112, 16.545 in the bus network and 15.6 in the composite network. It shows that the average distance between stations in the subway network is smaller than that in the public transport network, that is, the average number of stations to travel through the public transport network is slightly larger than that through the subway network, but the average shortest path in the combined composite network is smaller than that in the two single networks, It shows that the combination has a certain optimization effect on the overall network.

4.2. Network Differences in Station Dimensions

Through the comparison between composite network and single network, in the composite network, the node degree addition effect of subway network on public transport network is not obvious, so it is difficult to analyze the impact of subway network on public transport network through node degree. However, in the composite network, the node degree addition effect of bus network on subway network is more obvious. In the comparison based on the average shortest path , the average shortest path of most stations in the composite network is reduced compared with the original network, but the shortest path length of some stations is increased. In the comparison of network parameters with near centrality, the near centrality of most stations in the composite network is increased, The near centrality value of only a small number of stations decreases, which is opposite to the change of the average shortest path . Through the comparison of the betweeness centrality parameter values between the composite network and the single network, it can be found that the bridge intermediary function of the stations in the network is weakened due to the superposition of the traffic network. The decline of their intermediary status in the network does not mean that the importance of the stations is declining, but that the attack resistance of the whole network is strengthened, The decrease of dependence on key nodes. From the change of the clustering coefficient of traffic stations, it can be found that the value of the clustering coefficient in the composite network rises and falls compared with that in the single network, but there are more stations rising as a whole. Moreover, most stations in the public transport network have no connection with subway stations, and only a small number of stations are affected by subway stations, resulting in the change of clustering coefficient, so as to form a transportation network station cluster centered on subway stations.

5. Conclusion

In the urban subway system, the number and connection of stations are not many, but through the high efficiency of its transportation system, it can cover different regions of Shanghai and greatly improve the cross regional traffic performance. The public transport system has a huge base of stations and line connections, and has achieved comprehensive coverage of different regions of the whole Shanghai, but its network operation efficiency is not high, and the connectivity of different regions is insufficient. However, through the connection between subway stations and bus stations, the external connection degree of stations in the network has

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been enhanced, and the clustering coefficient of the network has been significantly improved in the composite network. A large number of bus stations take subway stations as the center to form a highly connected traffic clustering center, so as to achieve complementarity in network performance. And the average shortest path in the composite transportation network is shorter than that in the single transportation network, which shows that the combination of subway network and bus network is optimized for travel in the transportation network.

In the dimension of nodes, it can be found that in the composite network, the node degree of subway stations is significantly improved, and subway stations with higher node degree are easier to connect with more bus stations. In terms of the average shortest path , we can find that the composite network has a more obvious effect on the reduction of the average shortest path of bus stops, indicating that the subway network plays a great role in promoting the connectivity of bus network. In terms of betweeness centrality, the composite network can make the bus stops play a more intermediary bridge role in the transportation network and reduce the dependence on subway stations. In terms of clustering coefficient, bus stops enhance the influence of subway stations on surrounding clusters.

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