Study on the structure characteristics of the passenger flow network in Beijing subway：Based on complex network theory

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Abstract: The discovery of the basic law in the subway network system is important to promote the coordinated development of traffic management science and traffic science and technology. Based on complex network theory, this paper constructs a weighted complex network model of passenger flow in Beijing subway in order to study the characteristics of it. The network model is analyzed in the following aspects , the centrality of the weighted degree, the weighted clustering coefficient and the cluster identification. It is found that a small number of sites have a greater degree of centrality, and bear a larger passenger capacity; at the same time, the behavior of the passenger flow has a clear order and cluster. Therefore, it provides a scientific basis for the management of passenger flow in Beijing city.

Introduction

Rail transport plays an increasingly prominent role in the development of the city's social and economic development, but also has become one of the strategic emerging industries in china. The contradiction between the limited resources of the city and the rapid expansion of the population makes the research on urban public transport system become the focus of government and research institutions. In the current research, a lot of researches have focused on the planning and design of the road network, the optimization of traffic management and the operation management of the transportation system. However, due to the different functions of cities in different regions and different social and economic environment, the characteristics of traffic demand is different, thus causing the contradiction between the supply and demand of traffic. Therefore, in the road network structure design, passenger demand and distribution characteristics, such as the complexity of the characteristics.

Metro City traffic system is a complex characteristic of the system (Gao Ziyou, 20062010). From the static point of view, the metro system is composed by the relationship between the subway stations, subway lines and stations and lines a exists in the network in the form of an organic whole Zhang Jianhua (, 2012, Zhang Lijia, 2014). Therefore, many scholars around the subway network structure characteristics were studied, bollob ndez s (2003) proposed complex network model of subway, and optimize the travel time, improve travel efficiency. Some scholars have found that the Boston metro network and public transport network has small world characteristics (Latora, 2002; Angeloudis, 2006). Lee (2008) studied the complex network structure and passenger flow of Seoul Metro. Droppo (2004) studied the topology of the subway network routing problem, Sohrabi (2010) studied the robustness of the subway network problems, etc.

However, from the dynamic point of view, each person in the traffic system is an independent characteristic of the individual, due to the different travel destination and destination distribution, determines the traffic demand characteristics of different. It is loaded on the subway network with the dynamic characteristics of the flow of information, making this static metro network system has a dynamic and complex characteristic. And the passenger flow by the geographical characteristics, activities of daily living, spatial structure, work, study, etc. factors of influence caused by the passenger flow distribution is uneven and diversity of characteristics, also makes the traffic supply and demand contradictions intensified, leading to increase the difficulty of the traffic management, traffic to reduce the efficiency of the operation of the system.

Construction of complex network of passenger flow in Subway

In this paper, the Beijing city in April 2013 was selected as a sample of the subway passenger flow data, in 2013, Beijing opened 15 subway lines, involving a total of 185 sites. Subway passenger network broke the traditional geographical subway network, but in the subway stations as "nodes" in the network; passenger travel behavior as the "edge" of the network, the passengers from a subway station on the train, another subway station and get off, between the two subway station edge; passengers traveling on a subway line number as network edge weights, which will constitute a subway passenger directed weighted complex network.

Because Beijing subway daily traffic is very large, almost every two sites will have a passenger's travel behavior, so the formation of the subway passenger flow network is almost a complete map. In the study of this paper, there are 31592 kinds of theory, the actual results for the species, a total of 92.31% of the bus line.

The cumulative distribution of travel behavior is shown in Fig 1. The horizontal coordinate is the cumulative percentage of the number of bus routes, and the cumulative percentage of the longitudinal coordinates is the cumulative percentage of the number of passengers in the car. Can be found in line a few bear a lot of travel behavior, namely 9.92% of the bus lines will assume the half of the travel behavior; 29.83% car lines bear 80% of the travel behavior; and not pour half of the (44.56%) car lines carrying capacity can reach 90%. Beijing subway passenger flow distribution is very uneven, which is caused by the emergence of a large number of individual sites in Beijing passengers to form the cause of congestion.

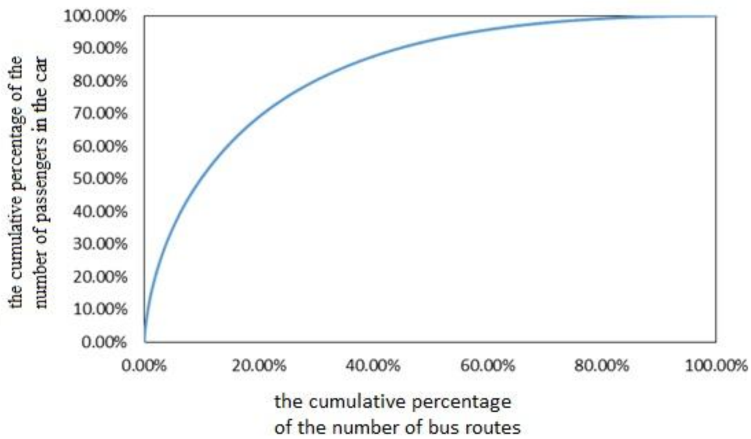

Fig. 1 cumulative distribution of travel behavior

In order to study the essential characteristics of the passenger flow network of Beijing metro, the threshold value is selected to filter the weighted complex network. This paper selects the total load of travel behavior, 80% of the bus lines as a filter that retained 29.83% of travelling route, involving a total of 179 site, 9423 travelling route, forming the subway passenger to the weighted complex networks such as shown in Fig 2.

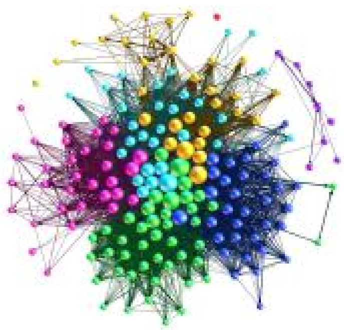

Fig 2 Beijing subway passenger flow to the weighted complex network (the number of nodes indicates that the site of the greater the flow, different colors represent different clusters)

Subway traffic complex network

Complex networks theory said that the associated structure among the elements of the system decides the function of the system is running, The analysis of the subway traffic complex network structure characteristics can help us to know the subway traffic in the essential characteristics on demand. Therefore, this article analyzes the degree of centricity, weighted degree of centricity, weighted aggregation coefficient based on complex network method, and then classify cluster and analyze network based on the cluster partition algorithm, indepth study characteristics of Beijing metro passenger flow distribution ,and put forward policy and suggestions about subway passenger flaw and management.

Degrees centricity. Degrees of metro traffic complex network centricity indicator is on the right to network, only considering the edge number of a site with other sites in the network, without considering the edge weights. Site of the greater degree of value indicates that the betternetwork connectivity of the passenger flow in subway.Due to the complexity of subway traffic network is directed networks, so the centricity divides into the outgrees centricity and indegree centrality. Outdegree centricity represents the number of edges that the site link to other sites, in-degree centrality suggests the number of edges that other sites link to the site. The degree of centricity Di in the site i is expressed as:

$$D_i = \sum_{j \in N_i} d_{ij} \qquad (1)$$

N_i represents the site i near the collection, d_{ij} is the edge of site i and site j, if there exists edge, it is 1, or it is 0.

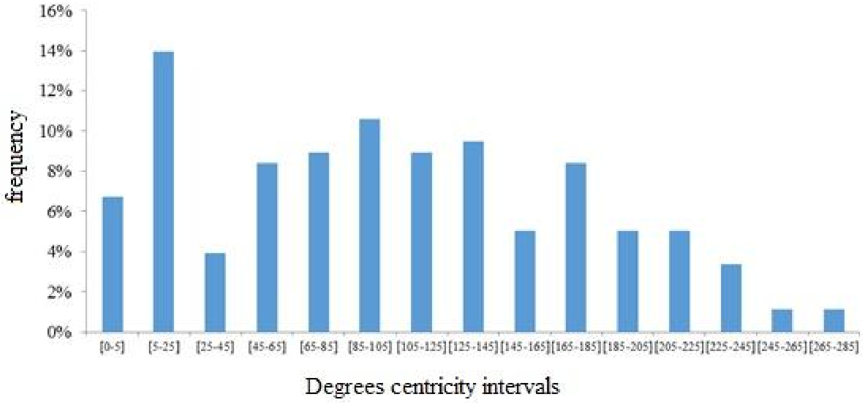

Fig. 3 the statistical distribution of the complex network of subway traffic

Analysis of the degree of the metro passenger flow and complicated network centricity statistical analysis is shown in Fig 3, degree centrality is concentrated in the [25] 5, [45145], explaining the behavior of Beijing subway unicom moderate degree. 14% subway station have 5 to 25 driving direction, 46% subway stations have 45 to 145 driving direction, the direction includes two subway behavior, that is, going away from the site and reaching. At the same time, the subway behavior with a few sites has great connectivity, The source of the passenger flow to hop on and off this site are from more than 140 other sites.

Central weighted degree. Subway traffic complex network centricity weighted degree is for weighted index of network, we not only take the number of edge which is a site links with other sites in the network into account, but also consider even the edge weights. The bigger site of the weighted degree centricity indicates that the site bearing greater passenger flow pressure in subway passenger flow in the network. Weighted degree centrality is divided into the weighted the centricity and weighted into degrees centricity. A site of the weighted degree of the centricity suggests traffic with the site to other sites, weighted in-degree centricity said other sites to the site's traffic. The site I weighted degree centricity W_i is expressed as:

$$W_i = \sum_{j \in N_i} w_{ij} \qquad (2)$$

Among them, the Ni said the site near the collection, i wij is the passenger flow of the i and j site traffic, including from the i station to the j site and the j site to the i site.

Site traffic and the correlation has a strong affinity, as is shown in Fig 4, it is the subway site traffic complex network centricity and weighted degree centricity scatter plot. What can be found from Fig 4 is the degree of centricity and weighted degree centrality has a strong positive correlation, namely the better bus site correlation, the greater the traffic capacity of the site.

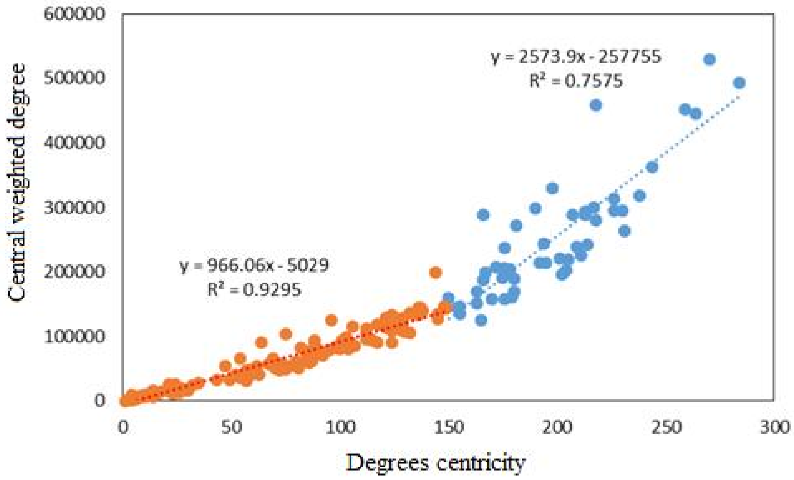

Fig 4 subway traffic complex network site centricity and weighted degree centricity correlation

However, one of the interesting phenomenon is that the degree of centricity under 150 sites, the degrees of centricity and weighted degree centricity shows strong linear regression, the goodness of fit is 0.93. Regression coefficient is 966.06, indicating that when these sites increase one new driving behavior direction, in which direction will add 966 passengers or so. However, great changes have taken place incentricity and degrees in more than 150 sites, the degrees of centricity and weighted degree centricity also show strong linear regression, the goodness of fit is 0.76. Regression coefficient achieves 2573.9, suggesting that this kind of site increase one new driving behavior direction, in which direction will add around 2574 passengers. Compared to the degree of centricity which is under 150 site, a new increment is2.66 times.

Weighted cluster coefficient. Site suggested the weighted cluster coefficients of correlation degree between neighbour site, if the connection between neighbor sites become closer, the weighted coefficient of agglomeration of the site is greater. Site I C_i^W operates weighted aggregation coefficient is defined as:

$$C_i^w = \frac{1}{W_i(D_i-1)}\sum_{j,k}\frac{(w_{ij}+w_{ik})}{2}a_{ij}a_{jk}a_{ki} \tag{3}$$

Among them, the Wi is for the node weighted centricity, Di is for node i centricity, w_{ij} and w_{ik} represent the weight of two sites i and j, site i and k edge, $a_{ij}a_{jk}a_{ki}$ shew whether site i, j, k is a triangle, if it is a value of 1, meaning that all the three sites have the edge and can get together as a triangle. 0 means no constitute a triangle between three sites.

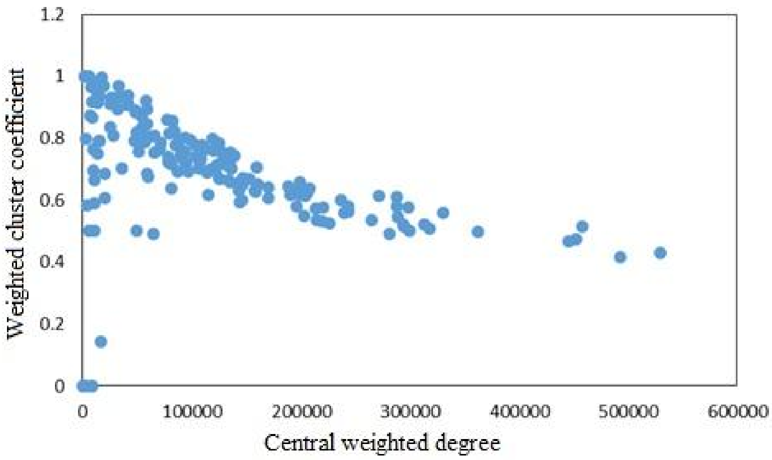

Fig 5 the distribution of the weighted degree centricity and weighted aggregation coefficient

The relationship about subway traffic complex web sites of the weighted degree centricity and weighted aggregation coefficient is shown through a scatter diagram, which has the obviously negative correlation, the weighted coefficient of agglomeration and decreased with the increase of the weighted degree centricity, as is shown in Fig 5. Beijing subway passenger behavior has obvious orderliness, namely have close relationship with other sites that are linked to the sites which bear less pressure of passenger flow, and the relationship between the other sites which are linked with the sites which bear huge pressure of passenger flow site is relatively sparse.

Cluster identification. Cluster recognition about Beijing metro passenger flow in complex network can help us to clear the distribution features of the Beijing metro passenger flow behavior. This paper adopts Blondel (2008) proposed by cluster partition algorithm to cluster in Beijing subway traffic complex network for identification. This algorithm measure the division of complex network cluster degree through the module, the greater the module of complex networks is illustrated in cluster, the more obvious. Degree of module Q is defined as:

$$Q = \frac{1}{2m}\sum_{i,j}\left[w_{i,j} - \frac{A_i A_j}{2m}\right]\delta\left(c_i, c_j\right) \qquad (4)$$

Among them, $w_{i,j}$ for the edge weights of network; i, m = 12 $jw_{i\,j}$; A_i = $jw_{i\,j}$ is connected to the site i of all the weight of the edge and; C_i is the site I assign cluster; Delta c_i, c_j is binary data, when c_i = c_j, this value is 1, otherwise 0.

Module degrees as incremental delta Q is defined as:

$$\Delta Q = \left[\frac{\sum c_{in} + A_{i,in}}{2m} - \left(\frac{\sum tot + A_i}{2m}\right)^2\right] - \left[\frac{\sum in}{2m} - \left(\frac{\sum tot}{2m}\right)^2 - \left(\frac{A_i}{2m}\right)^2\right] \qquad (5)$$

Of which, C_{in} represents all the weight of the edge in the cluster C, and tot represents the weight of all sites and other sites in the cluster C, even the weight of the edge, A_i represents the weight of site, even the weight of the edge, A_i and in represent the total weight of the site i to cluster in all sites, even the weight of the edge, in the C m said all the weight of the edge in the net.

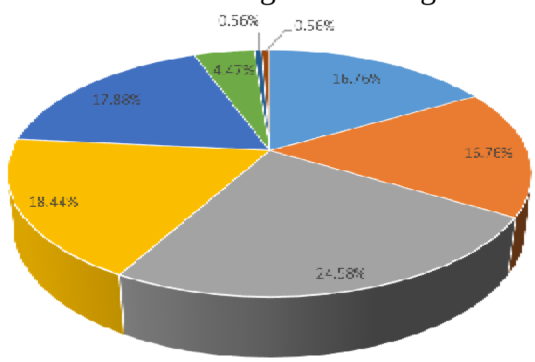

Fig 6 the distribution of sites in Beijing subway traffic complex network cluster number

The result of complex network of Beijing metro passenger flow through the algorithm to cluster partition is shown in Fig 2, different colors represent different clusters. Module for 0.228 shows in Beijing subway traffic complex network has evident cluster characteristics. The algorithm identifies altogether eight clusters, each cluster contains different number of sites, different specific distribution ratio is shown in Fig 6. What can be found is that there are five cluster contains more stops, accounting for 94.41% of the total site. The largest cluster contains 44 sites, that there are close traffic contacts between the 44 sites.

Discussion and Conclusion

The discover in basic laws in the subway network system is an important part to improve traffic management science, and science and technology for the coordinated development. Passenger traffic demand characteristics based on geography subway network can be mined through the establishment of the metro passenger flow directed weighted complex network model, so as to master relevant information on the demand side.

Based on Beijing metro passenger flow as the research sample, this paper establishes the Beijing subway traffic complex network model, deeply analyzing from several aspets as the degree of centricity, weighted degree of centricity, the weighted coefficient of agglomeration and cluster. The suggestions for our planning and management of Beijing subway revelation through the analysis of degrees centricity and weighted degree centrality are moderately reducing the sites that have the larger in and out of traffic site number of degrees of centricity centricity and weighted degree, such as Guo Mao, Dong Zhimen, Xi Zhimen and Da Wang Road sites, meanwhile, have the function of transfer station. As for this type of site, what should be considered is the demand characteristics of passenger flow getting on and out, to fulfill the purpose of shunt, new sites can be established near the site, rather than just considering increasing the line. But new sites will inevitably result in cost increase, however, compared with the congestion cost and security cost still need further exploration. Through the analysis of the weighted cluster coefficient, we found that Beijing metro passenger flow behavior has obvious differentiation. The sites that are connected to the sites where the traffic load pressure relatively small are more likely to have traffic behavior, this provides effective basis for the early warning system for passenger behavior. However, for bearing pressure of passenger flow site, early warning for passenger flow behavior is relatively difficult, but it can be targeted through subsequent statistical characteristic. Beijing metro passenger flow network cluster identification can help us get a more clearly understanding of its characteristics of passenger flow behavior distribution, which has obvious cluster. Metro passenger flow targeted decentralized management provides effective scientific basis.

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