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Analysis of time-varying characteristics of bus weighted complex network in Qingdao based on boarding passenger volume

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HIGHLIGHTS

- Agglomerative hierarchical clustering algorithm for calculating the boarding stop.
- Adjacency-stop bus complex network of Qingdao city is not a scale-free network.
- Bus travel demand is high correlated to space, but low correlated to time.

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ABSTRACT

Mastering the demand characteristics of a city's bus travel and understanding the demand structure from time and space are of great significance for a city's public traffic management. From the point of weighted complex network, this paper constructs the adjacency-stop bus complex network of Qingdao city in China using Space L method, and analyzes topological characteristics of the network. For the first time, by means of node weighting, the space–time characteristics of Qingdao bus travel demand are analyzed from the point of view of node strength. Through the analysis of the distribution characteristics of node strength at different periods of working and non-working days, it is found that node strength overall obeys SPL (Shift Power Law) tending to exponential distribution, which shows that the distribution of passenger flow in Qingdao bus travel is uneven, but not extremely uneven like power-law distribution. Comparing the changes of boarding volume at different time in one day both of working day and non-working day, the key bus stops and pivots of public transportation is extracted; and combined with the spatial distribution characteristics, it is found that there is a high correlation between bus travel demand and spatial attribute in Qingdao City, and a low correlation between bus travel demand and time attribute.

1. Introduction

Since emergence of the small-world network [1] and scale-free network [2], researches on the complex network have stepped into various fields [3,4]. Public transportation system is a complex giant system with spatiotemporal complexity. Complex network has provided an important tool for the research of public transportation system. It has also built a solid

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foundation for the deep research on dynamic process with its various features, as well as the network topology and its mutual interaction. In recent years, an increasing number of researchers have applied the theory of complex networks to conduct empirical analysis on the topological characteristics of public transport networks [5–12]. In 2005, Sienkiewicz [13] analyzed the topological characteristics of public transport networks from 22 cities in Poland and found that the node degree follows power-law distribution or exponential distribution. Ferber [14] along with other working staff has made statistical analysis on the topological characteristics in Berlin, Paris and other cities and found that the cities' bus networks follow exponential distribution or power-law distribution in the space *L* and space *P*. In 2007, Chen [15] adopted the space *P* method to study the bus transit network of Hangzhou, Nanjing, Beijing and Shanghai and arrived at the conclusion that the degree of such networks possess the characteristic of exponential distribution. In 2009, Zhou Ming [16] and other researchers studied the topological characteristics of Jinan bus network and Jinan public transport network, concluding that the two networks showed scale-free network features, of which the transfer network also shows the characteristics of small-world. In 2010, Zheng Xiao [17] adopted space *L* method to analyze the topological features of Beijing adjacency-stop network, and analyzed the scale-free features of Beijing public transport network. 2010 Harold Soh [18] have analyzed the travel routes of rail (RTS) and public transportation systems (BUS) in Singapore from a weighted complex network perspective. In 2014, Zhang [19] made a complex network topology analysis on the public transport network in Guilin, proving the characteristics of scale-free and small-world networks. In 2016, articles of A. A. De Bona [20] analyzed the topological structure of public transportation system in Curitiba through space *P* method and presented a comparative analysis of the results from Curitiba, three cities from China (Shanghai, Beijing, and Guangzhou), and three cities from Poland (GOP, Warszawa, and Ł'od'z), which show that the bus network has features of both small-world and scale-free.

With the development of intelligent transportation system, more and more public transportation operation data are provided to researchers. The number of weighted network modeling and analysis combined with system running status is increasing. Among them, researches on passenger flow weighting based on IC card data cover most. In 2013, Huang Ailing [21–23] carried out a research on the passenger volume weighted public transport network of Beijing, which arrived at the conclusion that the node degree and strength all follow the scale-free distribution and possesses small clustering coefficient and small average shortest distance. In 2015, Andor H'aznagy [24] analyzed the urban public transportation systems of 5 Hungarian cities. They built directed and weighted public transport networks, where the weights represent the capacities of the vehicles (bus, tram, trolleybus) in the morning peak hours. They calculated descriptors of global network characteristic and various centrality measures of the network nodes in both weighted case and unweighted case. By comparing the results obtained for different cities, they get a highly detailed picture of the differences in the organization of the public transport. In 2016, Xiaolei Zhang [25] analyzed the bus weighted complex network of Qingdao based on the dynamic travel time between two adjacent stops.

In terms of current research on complex network of weighted public transport, most of them are modeled by edge weighting. In this paper, a node-weighted adjacency-stop bus network based on boarding passenger volume is constructed. Boarding passenger volume at different stops can directly reflect the bus travel command in different areas of a city. Through calculation and measurement of the topology characteristics at different time periods on different dates, this paper analyzes the time-varying characteristics of boarding passenger volume of Qingdao bus network. The specific research ideas in this paper are as follows: (1) Research on the OD information extraction method of bus travel based on IC card data. (2) Research on the modeling method of bus complex network in Qingdao based on space *L*. (3) Based on the data provided by the Bus Group of Qingdao city, the paper analyzes the topological characteristics of Qingdao public transport network and the time-varying characteristics of boarding passenger volume.

2. Traveling OD information excavating from IC card data of single swiping mode

Bus IC card data contains the information that when passengers get on and get off a bus. Combined with bus running data, employing a series of data-excavating methods, the spatio-temporal information of passengers can be inferred, so as to acquire the OD information. At present, bus IC system in most cities of China adopts the single swiping mode by which passenger swipes only when they get on the bus [18]. From this type of IC card data to extract passenger travel OD information, two problems is solved including: matching the stops where passengers get on the bus and inferring the stops where passengers get off the bus.

2.1. Matching of the boarding stop

Bus IC card data used in this paper only contain card number, swiping date, swiping time, line number, amount and other information, where there is no swiping stop information. Therefore, it is necessary to introduce bus running data that contains stop information and the time when bus arrive at and leave this stop. Combining these two data, the specific process of getting boarding stops includes the following two steps.