Research on Rich-Club Phenomenon in Beijing Urban Area Based on Trajectory Data

Xiaotong Guo*

*Corresponding author: 20120742@bjtu.edu.cn

School of Traffic and Transportation, Beijing Jiaotong University, Beijing, China

Abstract: With the development of urbanization, urban transportation facilities have become more and more perfect, and the connection and interaction between different areas of the city have become easier. However, few studies have explored the forms of such connections and interactions between different areas of the city. Therefore, based on the GPS track data of taxis in Beijing, this study constructed directional and weighted urban travel networks, through the OD of residents' travel tracks. In addition, the forms of connections and interactions between urban areas in Beijing are investigated with the help of complex network. It is found that the relationship and interaction between urban areas in Beijing presents a typical rich-club phenomenon, and there are core members in the rich-club. Moreover, the urban areas mapped by these core members are related to the railway stations in Beijing. There are key members in the core members of the rich-club, and these key members have more interaction with other core members, and act as a bridge for other core members to connect with each other.

Keywords: Traffic Network, Trip OD, Rich-Club, GPS Data, Taxi, Region Interaction, Beijing.

1. INTRODUCTION

With the stability of urban structure, urban residents' travel has become regular gradually. It has become a hot research topic [1, 2] to explore urban structure by using the travel trajectories of urban residents. A hierarchical and highly complex urban travel network can be constructed through the travel trajectories of urban residents. Urban mobility networks can generally be grouped into two categories: (i) small mobility networks at the city and zone scale, which refers to mobility between smaller communities within a city or transboundary administrative region; (ii) large mobility networks at the regional level between cities, provinces or countries. Due to the increasing availability of large-scale data sources such as census data, high-speed rail data and social media, a lot of researches focus on analyzing the spatial patterns and connections of large mobile networks [3, 4]. Nevertheless, few studies focus on small mobile networks. The related researches can explore the connections and interactions between urban areas based on GPS track data of taxis or private cars and swipe card data of buses or subways. From this, the paper can provide guiding opinions for urban transportation planning and urban epidemic transmission modeling.

An important research area of complex networks is the application of network metrics. In this study, rich-club coefficients are used to quantify the nature of connections and interactions

BDEDM 2023, January 06-08, Changsha, People's Republic of China

DOI 10.4108/eai.6-1-2023.2330275

between nodes. Rich-club coefficient is used to detect the oligopoly characteristics dominated by "rich" (high degree or high strength) nodes in the directed network. In complex networks, rich-club phenomenon refers to influential or prominent nodes that strongly interact with each other to form a cohesive subgroup while maintaining contact with "poor" nodes [5]. Rich-club phenomenon is reflected in many networks [3, 4, 6], which can be used to measure the rich-club phenomenon in different real networks. For example, Wei et al. [4] revealed the rich-club effect of human migration during Chinese Spring Festival based on the data of people returning home and returning to work during the Spring Festival. The results show that rich cities dominate the interconnection with non-rich cities, influence the entire network, and significantly reshape the network structure. In addition, the study reveals the importance of "rich" nodes in complex network dynamics, such as cascading failures, targeted attacks, and epidemic spread.

Rich-club phenomenon exists in large mobile networks. However, few have focused on the following two questions: (i) whether Rich-club exists in small mobile networks; (b) What are the attributes of rich-club members in small mobile networks? In order to answer these two questions, this study builds an urban travel network with directed authority based on Beijing taxi trajectory data and Beijing rasterization data, and investigates the rich-club phenomenon of inter-regional connections and interactions in Beijing and the nature of the members who constitute the rich-club.

2. METHODOLOGY

2.1 Network Construction

The travel of residents strengthens the connection between different areas of the city, and the travel volume between different areas of the city reveals the interaction between urban areas and quantifies the strength of this interaction. Therefore, this study constructs a complex network $G_{od} = (V, E)$ based on residents' travel trajectory OD to research into the connections and interactions between different areas of the city. The node v_i in urban travel network G_{od} represents the grid point mapped by the starting point O or end point D of a resident travel trajectory. A directed connection is established between the starting point v_i of the travel trajectory and the ending point v_j of the travel trajectory, otherwise the direction is the same as the direction of the trajectory, denoted as e_{ij}. The weight w_{ij} on the edge w_{ij}, is equal to the number of trajectories passing through the directed edge e_{ij}.

2.2 Rich-Club Coefficient

The rich club coefficient[7] $\varphi(k)$ is used to measure the phenomenon of rich clubs in complex networks. In the topological network, all nodes are ranked according to the richness (node degree or strength) parameter k. The nodes whose richness is greater than k are considered to constitute the rich-club. For each club, r is the magnitude of richness, $E_{>r}$ represents the number of edges connecting network nodes with richness greater than r, $W_{>r}$ represents the sum of the weights of these edges, and $W_{l,rank}$ represents the lth weight of network edges. $\varphi(k)$can be denoted as follows,

$$\varphi_w(r) = \frac{W_{>r}}{\sum_{l=1}^{E_{>r}} W_{l,rank}} \tag{1}$$

Based on the existing urban travel network G_{od} degree distribution, to create a random network G_{null} as the benchmark. The urban travel network G_{od} and the random network G_{null} are calculated by Eq.(1) to obtain $\varphi(k)$ and $\varphi_{null}(k)$, respectively. The rich club effect $\rho(k)$ is obtained by the ratio of $\varphi(k)$ and $\varphi_{null}(k)$, as shown in Eq.(2).

$$\rho(k) = \frac{\varphi(k)}{\varphi_{null}(k)} \tag{2}$$

$\varphi_{w,null}(r)$ is the rich club coefficient obtained from the corresponding random network used for comparison. Then, the rich club effect is measured as follows:

$$\rho_w(r) = \frac{\varphi_w(r)}{\varphi_{w,null}(r)} \tag{3}$$

Among them, $\rho_w(r)$ greater than 1 indicates the existence of rich club characteristics. There are two ways to select a rich club node for a directed power network. Using the degree of nodes ($r = k$) to determine the rich club nodes is the first method, and the other method is based on the intensity of nodes ($r = s$). Both of them can be used to prove the importance of nodes, and these two richness parameters are used in this study.

3. DATA

3.1 Study Area

Beijing($115.7^{\circ}E \sim 117.4^{\circ}E,\ 39.4^{\circ}N \sim 41.6^{\circ}N$), the capital of China, the political, cultural and technological center of China, is an international metropolis. As of 2020, the total area is 16,410.54 square kilometers under the jurisdiction of 16 districts. According to the research needs, 1km×1km grids are selected, and there are 16897 grids in the study area totally. Then, the passenger travel trajectory is mapped to the study area grid. Finally, the grid is used as the candidate node to construct the urban travel network.

3.2 Taxi Data

This paper uses the GPS trajectory data of taxis for five days in July 2015. Among them, each data contains 6 key attribute fields, as shown in Table 1, which record the longitude and latitude position and state of a taxi at a certain time. GPS devices in taxis record data every 2 to 4s. After data preprocessing, 235940 passenger travel tracks are obtained. The Euclidean distance from the starting point (O) to the end point (D) of the travel trajectory is taken as the passenger travel distance *d*. Considering that the travel distance is too short or too long, it has no theoretical and practical significance, therefore, this paper only keeps the travel trajectory of passengers whose travel distance *d* is between 0.5 km and 200 km.

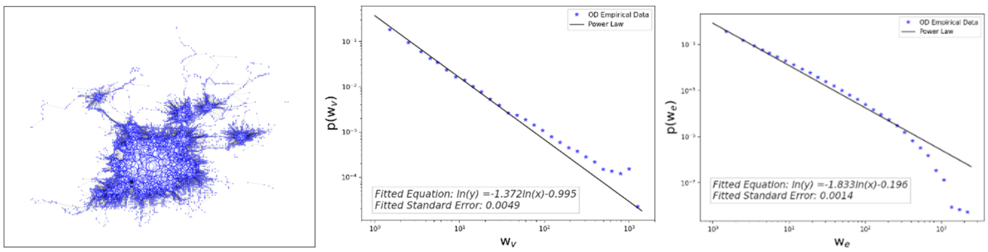
Table 1. Description of taxi's GPS location data

Attribute	Sample	Description
taxi license plate	BP**81	license plate number
time	2015/6/30 23:01:35	time when data is uploaded
longitude	116.416382	longitude when data is uploaded
latitude	39.828822	latitude when data is uploaded
speed	11	instantaneous velocity when data is uploaded
status	1	Zero means empty driving, and one means carrying passengers

4. RESULTS

4.1 Urban Travel Network

Based on the resident travel trajectory data and Beijing raster data, the urban travel network is constructed, as shown in Figure 1(a). During the construction of the network, the longitude and latitude attributes are given to the nodes of the network, which can visually see the ground connections between different urban regions in Beijing. From Figure 1(b) and (c), the distribution of node strength and the number of edges of different nodes in the network are represented, respectively. It can be seen that both of them conform to power-law distribution.



(a) (b) (c)

Figure 1. Urban travel network

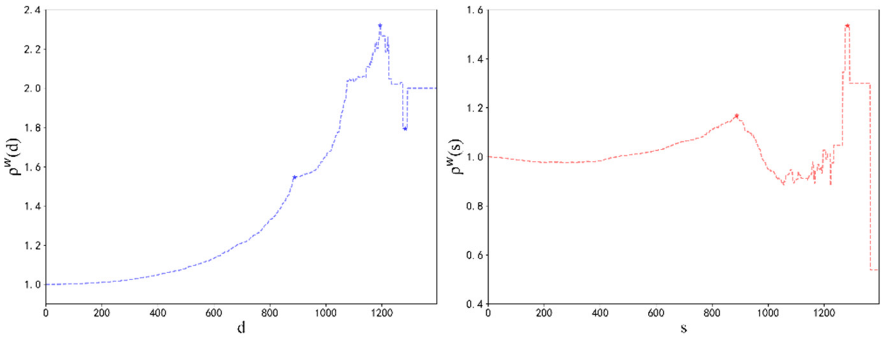
4.2 Urban Rich-Club Phenomenon

The results of the rich club coefficient based on the node degree and the node strength are shown in Figure 2(a) and (b) respectively. As shown in Figure 2(a), the rich club based on the node degree is always greater than 1, indicating that there is a rich club in the network, and the regional tendency of the Beijing city area to be widely associated with its region is associated with similar areas. As shown in Figure 2(b), there is a general value of greater than 1 in the rich club, which is associated with a similar regional tendency and a similar region. Note that there are two great values of the curve, indicating that the rich club of the city's urban areas has a two-level structure, and the rich club has a core member.

From Figure 2(b), the value of node strength *s* corresponding to the second extreme point is 1276. Nodes with node strength *s* greater than 1276 are defined as core members of Beijing urban regional rich-club, and four core members are finally determined. Their grid numbers and corresponding urban areas are 9163(Beijing South Railway Station), 8798(Beijing West

Railway Station), 8269(Beijing West Railway Station) and 8976(Beijing West Railway Station), respectively. Note that the core members of Beijing Urban Regional Rich Club are all related to train stations, and the contact and interaction between train stations are relatively frequent. This may be related to the need for passengers to transfer between different stops.

As shown in Figure 2(b), when the value of node strength *s* is greater than 1364, the node with grid number 8976(Beijing West Railway Station) exits the rich club, and the rich club coefficient between different urban regions of Beijing is less than 1, hence the rich club cannot be formed in the urban region of Beijing. Accordingly, Beijing West Railway Station is a key member of the rich club. It has more interaction with other core members and acts as a bridge for other core members to connect with each other.



(a) (b)

Figure 2. Rich-club coefficients based on degree and strength

5. CONCLUSIONS

Firstly, this study constructs the urban travel network based on Beijing taxi trajectory data and Beijing raster data. Furthermore, the forms of connections and interactions between different urban areas in Beijing from the perspectives of degree and intensity are investigated. It can be found that there is a rich-club phenomenon in the connections and interactions between different urban areas in Beijing. From the perspective of degree, the regional tendency of the extensive connection with other regions in the urban area of Beijing is to have the connection with similar regions. From the perspective of strength, the areas with large inflow and outflow in Beijing tend to be related to similar areas.

In addition, the rich club composed of different urban areas in Beijing has a two-level structure, and there are also core members in the rich-club. Through qualitative analysis, it is found that the areas where these core members are located belong to the adjacent areas of different railway stations in Beijing, which means that residents who take taxis near railway stations are more inclined to go to another railway station, and their purpose is likely to be transfer. Among these core members, there is a key member -- the area where Beijing West Railway Station is located, which is the key to connect other core members. It can be seen that Beijing West Railway Station is the core of Beijing. Beijing West Railway Station not only has a good connection with other "poor" areas in Beijing, but also plays a key role in the connection and interaction of "rich" areas.

REFERENCES

[1] Nie, W.P., Zhao, Z.D., Cai, S.M., Zhou, T., Understanding the urban mobility community by taxi travel trajectory, Communications in Nonlinear Science and Numerical Simulation, 2021, 101.

[2] Shen, Yue., Yan Y.Wei., Daily activity space of residents in Beijing suburb giant community based on GPS data. Journal of geographical, 2013, 68(04):506-516.

[3] Zhu, R.X., Wang, Y.J., Lin, D., Jendryke, M., Xie, M.X., Guo, J.Z., Meng, L.Q., Exploring the rich-club characteristic in internal migration: Evidence from Chinese Chunyun migration, Cities, 2021, 114.

[4] Wei, Y., Song, W., Xiu C.L., Zhao, Z.Y., The rich-club phenomenon of China's population flow network during the country's spring festival, Applied Geography, 2018, 96:77-85.

[5] Consterdine, E., Everton, A., European migration network: Immigration of international students to the EU: Empirical evidence and current policy practice. Science, 2012, 290:1768-1771.

[6] Zhang, Y.F., Thomas, S., Unveiling the rich-club phenomenon in urban mobility networks through the spatiotemporal characteristics of passenger flow, Physica A: Statistical Mechanics and its Applications, 2021, 584.

[7] Zhou, S., Mondragon, R.J., The rich-club phenomenon in the Internet topology, in IEEE Communications Letters, 2004, 8(3):180-182.