Analysis of spatio-temporal distribution characteristics of passenger travel behaviour based on online ride-sharing trajectory data

Xianlei Dong, Lingyu Wang, Beibei Hu *
School of Business, Shandong Normal University, Jinan, China. * Corresponding author tel: +86 13280027089
E-mail: sddongxianlei@163.com, 1311009466@qq.com, *xizixinxiang@163.com

Abstract: With the rapid development of information technology, the travel mode of "Internet + Transportation" has brought convenience to residents while causing a series of urban traffic problems. Based on GPS data from Didi Chuxing, this paper relates the residents' travel behaviour to their daily activities, and studies the regularity of the pick-up and drop-off activities of residents from the dimensions of time and space. The results are as follows: Firstly, the daily variation trend of residents' travel is unbalanced. At the same time, the travel volume of residents is at a higher level during night. Secondly, the travel of urban residents is closely related to urban areas and urban functional structures. On the administrative scale, the distribution of residents' travel is concentric, and the farther the distance from the downtown area is, the smaller the number of orders is. On the functional scale, the hot functional areas of residents' travel are related to residents’ needs. At last, mastering the distribution of residents' travel hot spots and time will help to understand the residents’ travel mode and the current situation of urban traffic, and provide new ideas for solving traffic problems in big cities.

1. Introduction
At present, the related research on the characteristics of residents' travel behavior mainly starts from the following three aspects. Firstly, researches are based on traditional questionnaires. For example, small sample surveys use travel time, travel mode and commute distance to study the urban commuting behavior and reflect the home-work separation [1]. It constructs a model of resident travel to explore the intrinsic relationship between the spatial and temporal distribution characteristics of residents and their daily activities by focusing on the number of residents’ travel trips, purposes, methods and time consumption [2].

Secondly, based on the taxi trajectory data, the passengers’ pick-up and drop-off activities are identified. And some papers search for the regularity of spatiotemporal distribution of the pick-up and drop-off activities. For example, it analyzes the key factors that influence the spatiotemporal distribution of the pick-up and drop-off activities, and studies the relationship between the spatial and temporal dynamics of passengers and the urban facilities from the perspective of urban spatial dynamics [3]. Based on the pick-up and drop-off activities, scholars have also found the gathering roads and regions of residents' travel in different time periods to understand the residents' travel demand and traffic status in real time [4]. This paper validates the model of intra-urban human mobility by Monte Carlo simulation, which shows the geographical heterogeneity and distance decay effect improve each other when
influencing human mobility models [5, 6]. This paper obtains the regularity of spatial and temporal distribution of passengers by clustering the trajectory data, which can help to reduce the cruise rate, and then alleviate the urban road congestion [7]. Thirdly, based on the geographical statistics method, the pick-up and drop-off activities of taxi passengers can be accurately matched with the geographical location to explore the spatial and temporal characteristics of residents' travel. Current researches visualize the aggregate region, and use POI data to reflect the difference of residents' travel characteristics in different functional areas [8]. Based on the spatial interactivity between each functional area from the aspects of time and distance, it shows that the time elasticity of commuting is the greatest. That is, time is more important to alleviate traffic problems.

In summary, previous studies have focuses on the behavior characteristics of residents' travel from using traditional questionnaires, or using traffic big data to study the relevance between the behavior characteristics of people's travel and urban functional areas, and so on. However, from the perspective of ride-hailing cars, few papers have targeted the correlation study of distinguishing the characteristics and regularities of residents' travel behaviors from time and space dimensions. Based on the ride-hailing cars and taxi trajectory data from the online ride-hailing platform, this paper researches the regularity of the pick-up and drop-off activities of residents from the dimensions of time and space, and reveals the flowing and traveling mechanism of residents within the urban area from a new perspective.

2. Data Source
We obtain the order trajectory data from Beijing online ride-hailing platform (Didi Chuxing). After data filtrating, 439,742 valid orders were obtained, including 66,186 taxi orders and 373,556 ride-hailing orders. Each order data contains 10 fields: Order ID, Driver ID, Vehicle ID (cryptographic), City Name, Order Start Latitude, Order End Latitude, Order Start Time, Order Finished Time, Product Line (Taxi or Ride-hailing), Itinerary ID (for the ride-hailing carpooling list, the Itinerary ID is the same).

Geographically match the original order data. Firstly, the geographic information system (Arcgis) is used to divide the administrative division of the order's pick-up and drop-off activities of passengers. The order data is accurately matched to the vector map and the order data in each administrative area is counted. The original order data is geographically matched by spatial statistics method of Arcgis. Then, the order data is accurately matched to obtain the origin and destination address of orders. Finally, the address-matched order's origin and destination data are classified into the first-level industry of Baidu Map POI, that is, all the data will be categorized into 12 functional areas including shopping, traffic, education, financial, hotel, residential, catering, life service, culture, leisure, medical and government functional areas.

3. Results
3.1. Spatial Distribution of Passengers' Travel
Differences in geographic location and regional functions among different administrative districts lead to different spatial distribution of passenger travel. The distribution of orders (including the pick-up and drop-off activities of passengers) in 16 administrative districts of Beijing is shown in Figure 1. And one order includes a pick-up activity and a drop-off activity. We consider the distribution of average daily pick-up activities as the distribution of average daily orders.
Figure 1 The average daily orders of taxis and ride-hailing and the proportion of the pick-up and drop-off activities of passengers in each administrative district (The proportion of the pick-up activities to drop-off activities is equal to one in any administrative district.).

From the distribution of the pick-up activities, the daily average order demand of various administrative districts in Beijing is quite different, as shown in Figure 1. Chaoyang District has the largest order volume. The daily average order volume accounts for 29.46% of the total order volume, respectively. Located in the central area of Beijing, Chaoyang District has regional advantages, relatively developed economy, a large number of permanent residents and large population density, which leads to the increasing demand for ride-hailing service. Yanqing County, Pinggu District, Fangshan District, Huairou District, Miyun County, and Mentougou District have relatively small daily orders, which are located in the remote suburbs of Beijing with underdeveloped economy, weak talent attraction and small density. As a result, the demand for ride-hailing service is small.

The distribution of the pick-up and drop-off activities of passengers is unbalanced. From Figure 1, we can know that the average number of the pick-up activities per day is significantly higher than that of the average number of the drop-off activities in Chaoyang District, Haidian District and Xicheng District. While in Changping District, Fengtai District, Shunyi District, Dongcheng District, the situation is to the contrary. The imbalance between the pick-up and drop-off activities in different administrative districts reflects the phenomenon of cross-regional mobility of passengers, as shown in Figure 2. From the proportion of cross-region orders to the total number of orders in this district, Dongcheng District has the highest proportion of cross-region orders on taxi(ride-hailing), and followed by Xicheng District, which are 86.09%(73.51%) and 79.88%(63.46%), respectively. The population policies of Dongcheng District and Xicheng District in recent years have led to the migration of the people to the surroundings and peripheral areas, resulting in residents’ cross-district travels.

Figure 2 Order flow status in different districts

From the flow of cross-regional orders, the cross-regional orders (including cross-regional inflow orders and outflow orders) in Chaoyang District are the most. The proportion of cross-regional outflow orders on the taxi(ride-hailing) to total cross-regional outflow orders is 29.53% (24.53%). And the proportion of cross-regional inflow orders is 22.97% (22.39%). Chaoyang District gathers wealthy
scientific and technological innovation resources, attracting people's travel, employment and even life through industrial agglomeration. Under the background of relaxing the core functions of the non-capital, Chaoyang District's radiation-driven role is obvious. And the radiation diffusion of high-tech industries and their achievements has strengthened people's inter-regional mobility.

It is noteworthy that passengers' travel behavior in the six districts of Beijing are closely related, mainly in the case that the cross-regional orders from Dongcheng District or Xicheng District to the other five administrative districts account for more than 92% of the total cross-regional orders in the district. The number of cross-regional orders from Chaoyang District, Haidian District or Fengtai District to the other five administrative districts accounted for more than 68% of their total cross-regional orders. First of all, Geographically, the City Six District is located in the center of Beijing, with closed geographical location. Secondly, the City Six District, a central carrying area of Beijing's capital function, is a center for national politics, culture, international exchanges and scientific and technological innovations of the whole country, and the exchange among the regions is frequent, which makes the travel behavior of residents closely linked in City Six District.

The specific geographic locations of the pick-up and drop-off activities are classified into 12 functional areas to further analyze the characteristics of residents' travel, as shown in Figure 3. The number of the pick-up and drop-off activities in the residential and food function areas is relatively high, respectively accounting for 34.17% (26.41%) and 17.19% (25.50%) of the daily average orders. These two types of functional areas are densely populated and have a large flow of people. As hot spots for orders (including the pick-up and drop-off activities), they reflect the daily demand of residents to a certain extent. The number of orders in cultural and life service functional areas are relatively small, which account for 4.63% (0.70%) and 1.14% (1.10%) of the daily average orders. On the one hand, these functional areas are relatively less distributed in cities. On the other hand, they are also affected by geographic locations, such as culture functional areas. Most of the culture functional areas are located in the city center, and the roads are crowded. People mostly choose to travel by public transportation.

3.2. Time Distribution of Passenger’s Travel
In the following, we compare the time distribution of the pick-up and drop-off activities of passengers for taxi and ride-hailing orders, and then study the rule of time distribution of passengers' travel behavior. Figure 4 shows the daily changes of the proportion of taxi and ride-hailing orders per hour to daily average orders at different time.

![Figure 3](image-url)
Figure 4. The proportion of the pick-up and drop-off activities of taxi and ride-hailing passengers’ orders to daily average orders at different time.

Overall, the proportion of daily changes in the pick-up and drop-off activities on the taxi and ride-hailing are roughly the same. On work days, the morning and evening rush hours of the pick-up and drop-off activities of taxi and ride-hailing passengers’ orders respectively appear at 7:00-9:00 and 16:00-18:00. And the morning rush hours on non-work days is postponed. Specifically, on non-work days, the proportion of the pick-up and drop-off activities on the taxi per hour is 6.92% and 4.98% at 22:00.

From the perspective of taxis and ride-hailing, the order proportion is roughly the same in the morning rush hours. While in the evening rush hours, the proportion on ride-hailing per hour is higher than that on the taxi. In the evening rush hours, the travel demand of passengers increases, which led to the supply less than demand for the taxi. And compared to taxi, ride-hailing has a price advantage. After 22:00, the proportion of orders on the taxi per hour is higher than that of ride-hailing. This indicates that residents have higher trust in taxi than on ride-hailing at night to a certain extent. And some ride-hailing drivers are part-time drivers so they offer fewer night-time services.

3.3. Time Distribution of Passengers Traveling in Different Functional Areas

Figure 5 shows the changes of the pick-up and drop-off activities of passengers on the taxi and ride-hailing to daily average orders in different functional areas. During the period of 0:00-6:00, the proportion of orders per hour in 12 functional areas is at a low level, and the lowest proportion appears at around 4:00. In other time periods, due to the difference in functional area positioning and passenger demand, the orders of different functional areas have a distinct difference in daily changes.

The daily changes in the proportion of the pick-up and drop-off activities of passengers in the leisure, shopping, food and hotel areas are roughly the same on work days. During the morning rush hours from 7:00 to 9:00, the proportion of the pick-up activities on the taxi and ride-hailing is higher than that in the evening rush hours. And in the evening rush hours from 17:00 to 19:00, the proportion is opposite to the morning rush hours. The proportion of passengers on the taxi and ride-hailing is comparatively high from 20:00 to 22:00. In leisure areas, the proportion of the pick-up activities of taxis’ passengers is 21.57% on non-work days, which is 8.51% higher than in the morning rush hours. It shows that residents have a lot of leisure activities at night, while the reduction of public transportation makes the demand for taxis and ride-hailing increase.

Government, medical and financial areas are mainly business oriented. The proportion of the drop-off activities on ride-hailing is larger than that on the taxi, and the proportion of the pick-up activities of passengers is opposite during morning rush hours. In the government area, the total proportion of the drop-off activities on ride-hailing is 25.53% during the morning rush hours on work days, while the proportion of taxi is 16.56%. The cost performance of the ride-hailing is higher than that of taxi, as a result, residents are more willing to choose the ride-hailing. Compared with government departments, the overtime work in the financial and medical functional areas is serious, which leads that the government area’s evening rush hours are more obvious than the other two areas.
Figure 5. Daily changes of the proportion of the pick-up and drop-off activities per hour to daily average orders in different functional areas: (a-O)-(l-O) and (a-D)-(l-D) show the situation of passenger pick-up and drop-off activities on catering, shopping, hotel, leisure, government, medical, financial, education, residential, life service, traffic functional areas.

The daily changes of the proportion of the pick-up and drop-off activities in the education area are similar to that in the residential area. From the difference in the proportion of the pick-up and drop-off activities of passengers, the proportion of the pick-up activities in the residential area is large. Take one as an example; the proportion of the pick-up activities on ride-hailing in the residential area is as high as 9.17%, while the education functional area is only 6.44%. From 10:00 to 16:00, the changes of the pick-up and drop-off activities are stable, and the proportion of the pick-up and drop-off activities of passengers is roughly the same, and the ratio was stable at around 5%. During this period, most of the residents go out to work or study, and the flow of people is small.

In life service areas, due to the diverse purposes of residents' travel, the proportion of the pick-up and drop-off of passengers on the taxi fluctuates greatly on non-working days. For example, the proportion of the pick-up activities on the taxi fluctuates within the range of 1.52%-8.33% during the period from 14:00 to 18:00. The proportion of the pick-up activities in the culture area show a steady growth trend after 6:00, and the daily changes are relatively random. To take one example, on non-work days, the proportion of the pick-up activities on the taxi is 0.66% at 7:00, while the proportion surges up to 6.56% at 8:00. Compared with other functional areas, the travel demand of residents in the culture area is not an essential requirement, so the daily changes are random and not stable.

From the perspective of the proportion of the pick-up and drop-off activities, except for the period from 0:00 to 8:00, the proportion of the pick-up activities shows an increasing trend and the proportion of the drop-off activities is on a downward trend. The proportion of the pick-up activities of in the morning rush hours is higher than that of the drop-off activities. The proportion of the drop-off activities is higher in the evening rush hours. During the rush hours in Beijing, the roads are crowded. Most of the residents go to work by subway or other public transport modes. However, due to the long commuting distance and time, residents often transfer in the transportation facilities, using combined transportation.
4. Conclusions
In this paper, based on the trajectory data, we analyze the travel characteristics of residents in different districts and different functional areas of Beijing from the perspective of time and space by using the spatial statistics method of GIS and address matching algorithm. Our conclusions are as follows:

From the perspective of the administrative district, the spatial distribution of residents' travel is concentric, mainly showing that the farther away from the city center, the smaller the number of orders. Driven by the city's functional positioning in different administrative regions, there is a spatial stratified heterogeneity of distribution of orders, which leads to the phenomenon of cross-regional travel. Cross-regional mobility mainly occurs in the City Six District. Similar to the administrative district, the distribution of orders among functional areas are unbalanced because of the various travel purposes of residents. Relevant departments should further adopt reasonable allocation of transportation resources, advocate green travel concepts or other measures to alleviate traffic congestion.

On the whole, daily changes of orders are unbalanced and exist at the obvious morning and evening rush hours. The quantity of order is at a high level at night, and the variation of the proportion of the drop-off activities lags slightly behind the pick-up activities. First of all, the distribution of orders in the morning rush hours on work days is more obvious than that on non-work days, while the distribution of orders in the evening rush hours is the opposite. Secondly, the orders in different functional areas show different time distribution characteristics. For example, in the morning rush hours on non-work days, the proportion of orders per hour in education and residential functional areas are larger than leisure, food, shopping and hotel areas. Researching the distribution of residents’ travel in different functional areas is an important reference for solving traffic congestion problems during rush hours and achieving the fine traffic management.

Due to the deficiency of data and methods, this paper does contain some shortcomings needing to be improved. On the one hand, only using the GPS data can’t completely analyze the characteristics of the residents’ travel behavior. On the other hand, we have not taken into consideration the situation of mixed land. In future research, we will use the multi-source data to analyze the characteristics of residents’ travel behavior, and adopt a more sophisticated quantitative method to study the characteristics of residents' travel behavior.

Acknowledgements
This study was supported by the programs of National Social Science Foundation of China (Grant: 16CJY056).

References
[1] Liu D, Tongyan Q I, Ke Z, et al. J 2009 Beijing Residents' Travel Time Survey in Small Samples. Journal of Transportation Systems Engineering & Information Technology, 9(2):23-26.
[2] ZHOU Suhong, DENG Lifang. J 2010 Spatio-temporal Pattern of Residents' Daily Activities Based on T-GIS: A Case Study in Guangzhou, China Acta Geographica Sinica, 65(12): 1454-1463.
[3] Jiansheng W U, Bo L I, Huang X. J 2017 Spatio-temporal Dynamics and Driving Mechanisms of Resident Trip in Small Cities. Journal of Geo-Information Science, 19(2):176-184.
[4] Han Y, Wang W J 2018 On the Spatial and Temporal Distribution of Resident Trip Based on Taxi GPS Data. Geomatics & Spatial Information Technology, (2):87-89.
[5] Liu Y, Kang C, Gao S, et al. J 2012 Understanding intra-urban trip patterns from taxi trajectory data. Journal of Geographical Systems, 14(4):463-483.
[6] Liu X. J 2016 Inferring trip purposes and uncovering travel patterns from taxi trajectory data. Cartography & Geographic Information Science, 43(2):103-114.
[7] Qin K, Zhou Q, Wu T, et al. J 2017 Hotspots Detection from Trajectory Data Based on Spatiotemporal Data Field Clustering. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W7:1319-1325.
[8] Duan Y M, Liu Y, Liu X H, et al. J 2018 Identification of Polycentric Urban Structure of Central
Chongqing Using Points of Interest Big Data. *Journal of Natural Resources*, 33(5):788-800.