Method of Taxi Carpooling Probability and Wait Time Based on Poisson Distribution

Article *in* Zhongguo Gonglu Xuebao/China Journal of Highway and Transport · May 2018

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Original research paper

A Method of Taxi Carpooling Probability and Wait Time Based on Poisson Distribution

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Abstract: To reflect the success rate of urban taxi carpooling, accurate description of the carpooling effect, analysis on the problem of taxi carpooling by the probability of carpooling and waiting time. The Poisson distribution in taxi carpooling is discussed based on the principle of Poisson distribution, the probability model of taxi co multiplication is established, a waiting time model of taxi is constructed based on the probabilistic model and the N weight Bernoulli experimental principle. It was been discussed that the number of taxis, no-load rate, average speed and travel destinations distribution effect on carpooling probability and wait time. Nanjing taxi GPS data is selected for case study, the model is verified. Experimental results show that taxi passenger vehicle data obeys the Poisson distribution by K-S test, the number of taxis, load rate and distribution of the taxi with destination have greatly influences on carpooling probability, the speed has little influences; taxi ridesharing mainly suitable for daily travel during peak hours; it can improve efficiency by Repeatedly carpool ways. It shows the effectiveness and practicality of the model, and provides carpooling reference for traffic management departments and co- rider.

Key words: traffic engineering; carpooling probability; wait time; poisson distribution; urban taxi;

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基于泊松分布的出租车合乘概率及等待时间建模

摘 要：为了反映城市出租车合乘的成功率，准确描述合乘的效果，利用出租车合乘概率和等待时间对合乘问题进行分析。依据泊松分布原理，讨论了出租车合乘中出租车载客车辆的泊松分布，建立了基于泊松分布的出租车合乘概率模型，并通过概率模型结合N重伯努利实验原理，构建了出租车合乘等待时间模型，探讨了出租车数量、空载率、平均行驶速率和行驶目的地分布对合乘概率和合乘等待时间的影响。以南京市雨花南路路段出租车GPS数据为研究对象，对模型进行验证。实验结果表明，出租车载客车辆数据通过K-S检验，其分布服从泊松分布，在路段内出租车的数量增大，空载率降低，行驶目的地分布相对集中，城市出租车合乘的概率会增加，合乘的等待时间会减少；出租车平均行驶速度相对稳定，对出租车合乘概率和等待时间影响较小；出租车合乘适宜在日常出行的高峰时段采用，可通过一次载客多次合乘的方式提高合乘效率。该模型具有一定的有效性和实用性，能够为交通管理部门和合乘者选择合乘提供参考。

关键词：交通工程；合乘概率；等待时间；泊松分布；城市出租车;

0 Introduction

With the acceleration of urbanization, urban road traffic congestion and environmental pollution have become the focus of attention. Many cities adopt various traffic measures to solve the problem of urban traffic congestion; Taxi carpooling as one of the programs is implemented in many cities [1-3], such as Beijing, Shanghai, Guangzhou and other cities. There is important practical significance to study the city taxi waiting time and the probability problem. Because it can provide faster and more convenient by carpooling reference point, improve the city taxi carpooling income, improve the city taxi carpooling efficiency, and alleviate traffic congestion on the roads, reducing the city environmental pollution.

From the domestic and foreign research literature, we found that the problem of carpool is mainly concentrated in two aspects. On the one hand, it mainly focuses on the system, mechanism and cost, and it mainly studies the taxi carpooling mode, taxi carpooling of the supervision system, the reasonable collection of fees and so on[4-6]. On the other hand, it mainly focuses on the algorithm and model establishment, It mainly studies the use of intelligent algorithms, data mining, multi-objective planning algorithm to achieve the taxi carpooling [7-9]. Zhang Jin and He Ruichun use simulated annealing algorithm to realize the matching of taxi and passenger [10]; Shao Zengzhen proposed the use of heuristic algorithm to achieve vehicle carpooling [11]; Cheng Jie put forward a dynamic taxi model based on genetic algorithm[12]. On the whole, the previous research focuses on the two aspects of the guarantee of the carpooling system and the realization of the carpooling algorithm, and the study of the carpooling probability in the carpool problem is relatively small. Although the ZUO Zhong-yi [13] to establish carpool success rate distribution model based on passenger vehicle number distribution and direction correction factor, Combined with the arrival time distribution of taxi, the calculation model of waiting time of taxi ride is established by using the geometric distribution principle. But the model starts from the angle of carpool passengers, discusses the success rate and waiting time of carpool, and does not make a comprehensive analysis of other factors, such as the number of taxis and the no-load rate.

In this paper, the Poisson model of location and operation time of urban taxi is established under the assumption , The probability of urban taxi carpooling and waiting time are studied under the number of different taxis, the average taxi driving speed, taxi no-load rate and taxi travel destination distribution. Based on the GPS trajectory data of urban taxi, the passenger probability and waiting time are calculated. Thus, the validity and practicability of the model are validated and analyzed

1 Taxi carpooling probability and waiting time model

1.1 Assumptions for model establishment

(1)Taxi drivers and passengers are willing to carpool, and the number of carpool passengers is less than the number of passengers in the taxi.

(2) There are only two kinds of taxis running on the road, that is, empty load and passengers, and the taxis that carry passengers can provide carpool service.

(3) After the end of the carpooling, the next carpooling shall be taken without considering the carpool on the way of carpool.

(4)The speed of the taxi is uniform, ignoring the delay caused by the intersection and traffic congestion, and the uneven speed caused by the traffic condition.

(5)In the same direction lane, the headway of the taxi is greater than the length of the body

1.2 Poisson distribution analysis of urban taxi

Let i be the point of carpool position in the urban road, when passengers arrive at the carpool position, We began counting the taxis passing by, the urban taxi's carpool position meets the following conditions:

(1) $x(0)=0$

(2) $x(t)$ is an independent stationary increment process

(3) $x(t)$ satisfies the following two formulas：

$$P\{x(t+h)-x(t)=1\}=\lambda h+o(h) \tag{1}$$

$$P\{x(t+h)-x(t)\geq 2\}=o(h) \tag{2}$$

Condition (1) means the number of taxis starts at t=0.From the t=0, the taxi is in a carpool position, independent of the taxi that had already passed the carpool point position.

Condition (2) indicates that the probability of having a taxi within the time interval from t to $t+h$ is independent of t, and is proportional to the length of the interval h.

Condition (3) means that the taxis in the carpool position have only one car, and there is no phenomenon that the two taxis are passing at the same point at a certain time, within a small interval of time.

For the carpool point position, the urban taxi obeys Poisson distribution and the traffic flow arrives randomly, let

$$P_n(t)=P\{X(t)=n\}=P\{X(t)-X(0)=n\} \tag{3}$$

According to the condition (2) and the condition (3), the following formula can be obtained:

$$\begin{aligned} P_0(t+h) &= P\{X(t+h)=0\} \\ &= P\{X(t+h)-X(0)=0\} \\ &= P\{X(t)-X(0)=0, P\{X(t+h)-X(t)=0\} \\ &= P\{X(t)-X(0)=0\}P\{X(t+h)-X(t)=0\} \\ &= P_0(t)[1-\lambda h+o(h)] \end{aligned} \tag{4}$$

$$\frac{P_0(t+h)-P_0(t)}{h}=-\lambda P_0(t)+\frac{o(h)}{h} \tag{5}$$

Let $h\to 0$

$$P_0^{'}(t)=-\lambda P_0(t) \tag{6}$$

$$\ln P_0(t)=-\lambda t+C \tag{7}$$

Because $P_0=P\{(X(0)=0\}$

$$P_0(t)=e^{-\lambda t} \tag{8}$$

When n=1, $P_0(t)=e^{-\lambda t}$ and $P_1(0)=1$,

$$P_1(t)=\lambda t e^{-\lambda t} \tag{9}$$

It can be obtained by mathematical induction.

$$P_k=\frac{(\lambda x)^k}{k!}e^{-\lambda x} \tag{10}$$

It can be proved that the taxi arrives at the carpool point and obeys Poisson distribution. P_k indicates the probability of reaching the k vehicle within the counting interval x, λ represents average vehicle arrival per unit time, x is the duration of each count interval.

1.3 *A carpooling probability model for urban Taxis*

L stands for selected urban roads, Suppose the average speed of the taxi is V, M_L indicates the number of taxis shared on the road L, O indicates the taxi no-load rate, T indicates the waiting time after the carpool passengers arrive at the carpool point. The average distance between taxis is $\frac{L}{M_L}$, the average time between taxis is $\frac{L}{M_L V}$.

$$\lambda = \frac{1}{\frac{L}{M_L V}} = \frac{M_L V}{L} \tag{11}$$

The probability of reaching the k vehicle within the counting interval T is:

$$P_k = \frac{(\frac{M_L VT}{L})^k}{k!} e^{-\frac{M_L VT}{L}} \tag{12}$$

According to the taxi GPS track data, the numbers of taxis are counted and the taxi no-load rate is calculated:

$$O = \frac{T_N - T_Z}{T_N} \tag{13}$$

T_N is the number of taxis, T_Z is the number of passenger taxis.

The number of passengers and the number of passengers in the taxi determine the success of the carpool, the probability of a carpool passenger being able to travel with a passenger taxi is:

$$P_{ci} = \sum_{ci=1}^{4} p_{4-ci} \tag{14}$$

P_{ci} indicates the probability that ci passengers can take a taxi, ci indicates the number of passengers participating in the carpool($1 \le ci < 4$).

When passengers arrive at the carpool point, they decide whether to take a ride or not for each taxi passing , the success of judgments depends on whether the destination of the passenger is similar to the destination of the taxi, the passenger taxi destination is clustered through the urban road L. The central location of each administrative area in the city are $n_1, n_2, \cdots n_k$, calculates the distance between the destination of the passenger taxi and the central point location of each administrative area, $D(t_i, n_j), i=1,2,3\cdots n, j=1,2,3\cdots k$, if $D(t_i, n_k)=\min\{D(t_i, n_j), i=1,2,3\cdots n, j=1,2,3\cdots k\}$ is satisfied, so $t_i \in n_k$, statistics the number of taxis arriving at each administrative area through the carpool point, the number of taxis arriving in each administrative area are $m_1, m_2, \cdots m_n$ .The distribution rate of taxi destinations is calculated to provide a basis for the probability that passengers will travel to each administrative area.

Table1 distribution ratio of City Taxi destination

distribution rate	Clustering data set			
	m_1	m_2	$\cdots$	m_n
P_{m_i}	$\frac{m_1}{\sum_{i=1}^{n} m_i}$	$\frac{m_2}{\sum_{i=1}^{n} m_i}$	$\cdots$	$\frac{m_n}{\sum_{i=1}^{n} m_i}$

The probability that the passengers waiting for the K vehicle in the counting interval T can be expressed as:

$$P_{Tk}=P_k=\frac{\left(\frac{M_L VT}{L}\right)^k}{k!}e^{-\frac{M_L VT}{L}} \tag{15}$$

The probability that passengers cannot wait for a carpool within an interval T can be expressed as:

$$P_T=\sum_{k=0}^{+\infty}\frac{\left(\frac{M_L VT}{L}\right)^k}{k!}e^{-\frac{M_L VT}{L}}O^k \tag{16}$$

The probability that passengers can wait for N taxis and can be carpooling within the counting interval P can be expressed as P_y :

$$\begin{aligned} P_y &= \left(1-\sum_{k=0}^{+\infty}\frac{\left(\frac{M_L VT}{L}\right)^k}{k!}e^{-\frac{M_L VT}{L}}O^k\right)(1-P_{mi})^{n-1}P_{mi}P_{ci} \\ &= \left(1-e^{-\frac{M_L VT}{L}}\sum_{k=0}^{+\infty}\frac{\left(\frac{M_L VTO}{L}\right)^k}{k!}\right)(1-P_{mi})^{n-1}P_{mi}P_{ci} \end{aligned} \tag{17}$$

According to Taylor's formula:

$$e^x=1+x+\frac{x^2}{2!}+\frac{x^3}{3!}+\frac{x^4}{4!}+\frac{x^k}{k!}\cdots \ (-\infty<x<+\infty) \tag{18}$$

P_y Is calculated:

$$\begin{aligned} P_y &= \left(1-e^{-\frac{M_L VT}{L}}e^{\frac{M_L VTO}{L}}\right)(1-P_{mi})^{n-1}P_{mi}P_{ci} \\ &= \left(1-e^{-\frac{M_L VT(1-O)}{L}}\right)(1-P_{mi})^{n-1}P_{mi}P_{ci} \end{aligned} \tag{19}$$

Therefore, the carpool probability is calculated, according to the road length, the number of taxis, the average speed of the taxi, taxi passengers waiting time, no-load rate, the probability of carpool passengers and passenger taxi and the distribution rate.

1.4 Waiting time for carpooling taxi

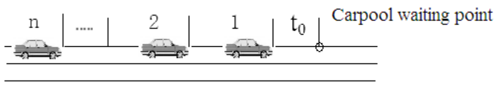

Fig.1 rideshare point latency schematic

图1 合乘点等待出租车时间示意图

With reference to Fig .2, the first taxi arrived at the waiting point interval is t_0 , when the carpool passengers arrive at the waiting point. The first to n taxi arrive at the average time interval of waiting point is t , Carpool passengers in the n taxi carpool success waiting time is T_d [16]:

$$T_d = (n-1)\cdot t + t_0 \tag{20}$$

The probability that passengers will succeed carpooling at the carpool point until the n taxi can be obtained by the Bernoulli experiment:

$$P_i = (1-P_y)^{n-1} P_y \tag{21}$$

The average wait time is represented by using that formula:

$$\begin{aligned}\overline{T_d} &= \sum_{n=1}^{\infty}((n-1)t + t_0)(1-P_y)^{n-1}P_y \\ &= (\frac{1}{P_y}-1)t + t_0\end{aligned} \tag{22}$$

1.5 Carpooling probability model analysis

Taxi carpooling probability is key to urban taxi carpool judgment, by analyzed the formula 19 ,taxi no-load rate changes, changes in average running speed of taxi, taxi number change in waiting time interval and taxi traveling destination distribution and other factors directly affect the taxi carpooling probability. Carpooling probability and impact factor diagram such as shown in figure 2:

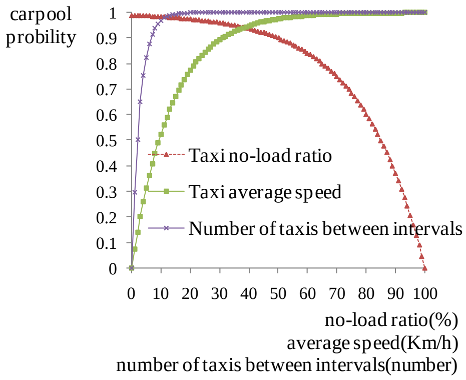

Fig.2 the relationship between probability and influence factors of taxi carpooling

图2　出租车合乘的概率与影响因素的关系图

It can be seen from Figure 2 and formula (18), when the taxi load rate becomes larger, it provides carpool taxi number will be reduced, the probability P_y of passengers waiting the taxi carpooling will be lowered. According to the formula (21), when the probability of carpool becomes smaller, the waiting time of carpooling passengers will be lengthened. On the contrary, the taxi driving speed is higher or the number taxi is more in the interval time, the probability will be greater.

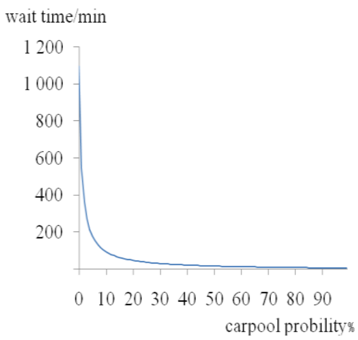

Fig.3 the relationship between taxi ridesharing probability and waiting time

图3 出租车合乘概率与等待时间的关系图

Carpool taxi waiting time is one of evaluation index by carpooling success, according to the long time waiting for passengers can tolerate, if the waiting time is longer, carpool is less likely. Can be seen from Figure 3, if the probability of carpool is bigger, the carpool waiting time is smaller and the likelihood of carpool is higher.

2 Example analysis

This paper uses GPS data from Taxi Company in Nanjing on September 1, 2010, a total of 7726 taxis and 1806873 records. After the taxi GPS trajectory data preprocessing and calculated 453019 records of 6503 taxis, Nanjing

Yuhua Road, Yuhuatai district for the selection of test points, to verify the correctness of this model.

2.1 Parameter determination

Carpool coordinates is located at 118°46'1.73" E. Longitude and 31°59'44.90"N. Latitude in yuhua road. Yuhua Road is located at 118 degrees 45'57.36 and 31 degrees north latitude 59'46.76 "to the" east longitude 118 degrees 46'5.17 and 31 degrees north latitude 59'43.85". The verification data are 2792 records of 765 taxis at each time the whole point after 20 minutes in Yuhua Road, Nanjing, on September 1, 2010.

2.2 model solution steps

(1)The establishment of Nanjing City Yuhua Road taxi driving data set, $TC1 = \{t_1, t_2 \cdots t_n\}$, from the data set to extract taxi number, taxi travel time, taxi latitude and longitude coordinates, taxi speed and taxi carrying status and other data, these data will be used as taxi driving data:

$$t_i = (vehicledmid_i, gpstime_i, gpslongitude_i, gpslatitude_i, gpsspeed_i, passengerstate_i)$$

(2) Calculate length L of the test road, and calculate the distance l between the initial position of the test section and the carpool point.

(3) The average number M_L of taxis and the average travel speed V of taxi and the average no-load rate O of taxi are calculated by using the taxi data in the data set $TC1$ at each time interval.

(4) According to the t_i in the data set $TC1$, we can get the destination, location and time of the passenger taxi through the carpooling point. A data set $TC2 = \{m_1, m_2 \cdots m_n\}$ is established based on the taxi parameter $passengerstate$ equal to 1 (representing passenger capacity) or equal to 0 (representing empty car), The variable m_i is composed of a taxi sign, a taxi running time, a taxi latitude and longitude coordinate and a taxi passenger carrying state.

$$m_i = (vehicledmid_i, gpstime_i, gpslongitude_i, gpslatitude_i, passengerstate_i)$$

(5) The GPS coordinates of the central points of the Nanjing each administrative region are as follows: $n1$ said the Xuanwu District center position coordinates of GPS (118.7978,32.0486), $n2$ said theQinhuai District center position coordinates of GPS (118.7948,32.0385), $n3$ said the Gulou District center position coordinates of GPS (118.7697,32.0661), $n4$ said the Jianye District center position coordinates of GPS (118.7315,32.0033) , $n5$ said the Yuhuatai District center position coordinates of GPS (118.7789,31.9922),

$n6$ said the Pukou District center position coordinates of GPS (118.6279,32.0595) , $n7$ said the Liuhe District center position coordinates of GPS (118.8214,32.3222), $n8$ said the Xixia District center position coordinates of GPS (118.9081,32.091989), $n9$ said the Jiangning District center position coordinates of GPS (118.8401,31.956053), $n10$ said the Lishui District center position coordinates of GPS (119.0277,31.652), $n11$ said the Gaochun District center position coordinates of GPS (118.8928,31.3312)。

Calculate the distance $D(m_i, n_k)$ between the destination of the taxi m_i and the location of the central point of the administrative area ni . If $D(m_i, n_k) = \min\{D(m_i, n_j), i = 1,2,3 \cdots, j = 1,2,3 \cdots 11\}$, then $m_i \in n_k$. Statistics on the number of taxis in n_k $(k = 1, 2, \cdots 11)$, calculated distribution rate P_{mi} .

(6) Based on the parameter values and the model, in the carpool point of the city taxi carpooling in probability and waiting time can be calculated in carpooling point.

2.3 Results and Analysis

By using the established carpool probability model and the carpool waiting time model, the paper analyzed the carpool point of Yuhua Road in Nanjing in 20 minutes after each time.

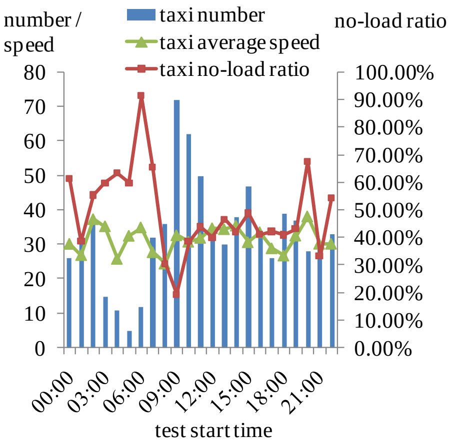

Fig.4 taxi distribution of number and no-load rate and the average speed

图4 出租车数量、空载率、平均行驶速率分布图

As we can see in fig.4, the number of taxis is relatively small from 3:00 a.m. to 7:00 a.m., the number of taxis is relatively large from 8:00 a.m. to 17:00 p.m. From the taxi no-load rate can be seen, from 8:00 a.m. to 19:00 p.m., the no-load rate is low, from 3:00 to 7:00 at morning and 8:00 at night, no-load rate is high. This shows that the data of taxi GPS compared with the daily taxi travel rules, daytime taxi operation, morning and evening taxis run less.

From the average driving taxi rate can be seen, taxi speed is relatively stable. Due to the impact of road traffic congestion and other factors, it is difficult to improve the carpooling probability in the city by increasing the average speed of the taxi.

According to per minute interval, we can count the number of taxis arrived and analyzed frequency of arriving taxis at Yuhua road in Nanjin from 0:00 to 24:00. In the significant level of 0.05 K-S test, the test results was 0.3629, higher than the significant level of 0.05, we cannot reject the original hypothesis. The arrival frequency of passenger taxi was fitted by Poisson distribution curve. From fig. 5 can be seen, the taxi passenger arrival frequency obeys the Poisson distribution in Nanjing Yuhua Road.

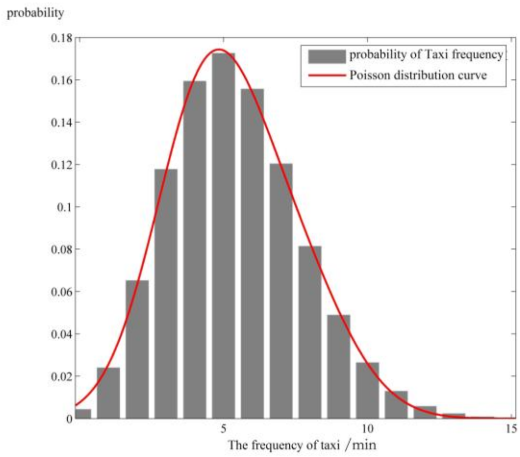

Fig.5 Poisson distribution curve fitting of taxi arrived at the frequency at Nanjing Yuhua South Road

图5 南京雨花南路载客出租车到达频次泊松分布曲线拟合图

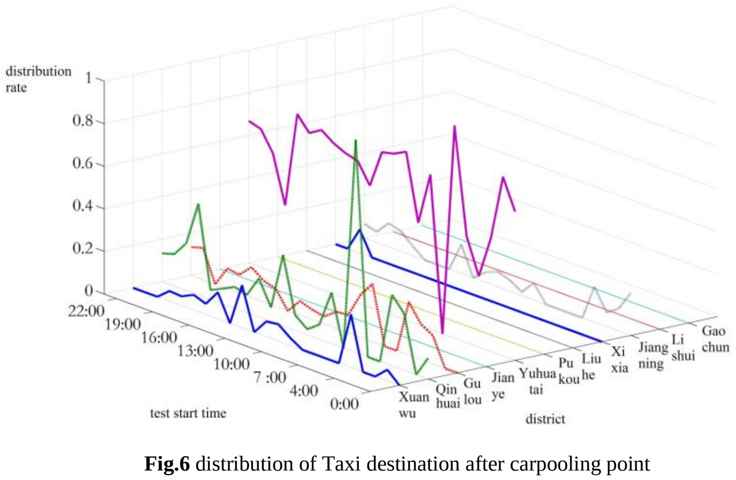

Fig.6 distribution of Taxi destination after carpooling point

图6 经合乘点出租车行驶目的地分布图

As can be seen form fig.6, the taxi passenger travel destination mainly distributed in the Yuhuatai area, Qinhuai District, Gulou District, Xuanwu , Jiangning and so on region, after by carpooling point. Daily travel time mainly concentrated in Yuhuatai and Qinhuai two regions, that taxi travel mainly by the short based, so we should consider the short-range passenger in the carpool.

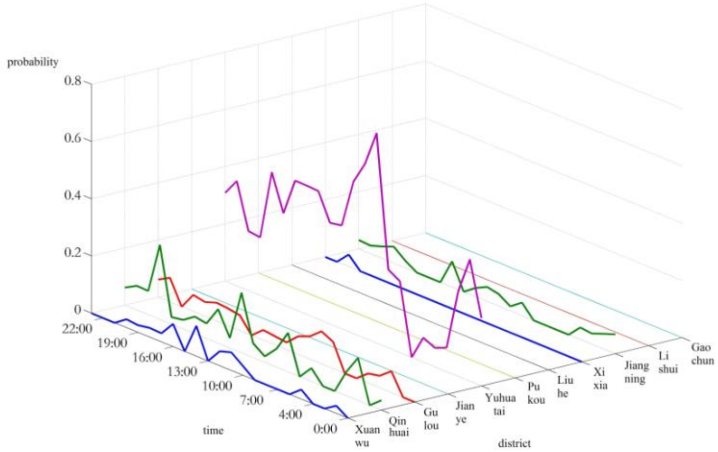

Fig.7 taxi carpooling probability in Nanjing City Yuhua Road

图7 南京市雨花南路合乘点出租车合乘概率图

As can be seen from Fig. 7, the probability of travel to Yuhuatai is higher than that of other regions, and the period of high probability of convergence is mainly at 9:00 a.m. to10 :00 a.m. and 5:00: to 7:00 p.m. As can be seen from Fig. 7, the region with greater probability is mainly concentrated in the administrative areas where the clutch and carpool points are relatively close, such as Yuhuatai, Qinhuai, Drum Tower, Xuanwu and so on, while the probability of carpool probability is very low or impossible in other areas. The reason is the taxi travel mainly in short, long distance travel less, so in the region near of the Yuhuatai region or Yuhuatai region carpool probability was significantly higher than other not adjacent to regions.

With fig.4 and fig.6, in Yuhua Road at 3:00 a.m-7 :00 a.m., the number of taxis passing through this road is relatively low, and the taxi no-load rate is relatively high, and the distribution of a taxi to other Nanjing City Administrative Region rate is low, carpool passengers and other passenger taxi ride to the other of Nanjing administrative area of the carpooling probability below 20% In Yuhuatai South Road together point. Conversely, the carpooling probability is higher in other periods. You can see from Fig. 7, carpool passengers to Yuhuatai District, Qinhuai District, Xuanwu District, the area carpool probability is higher than that of several other administrative regions, it shows that the greater the distribution rate of taxi destination, the higher the probability of carpool. So in the peak travel periods, if the number of taxis is large, the no-load rate is low and the destination distribution is concentrated, then the probability of carpool is large, and vice versa.

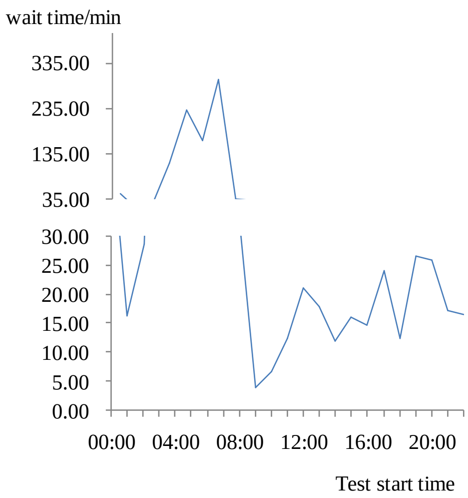

Fig.8 taxi waiting time from carpool point to Yuhua District

图8 合乘点前往雨花区出租车合乘等待时间图

In order to explain the relationship between taxi carpool probability and waiting time, this paper uses the probability data of travel to Yuhua District as the object of discussion. As can be seen from fig. 8, the carpool waiting time in 20 minutes time, it mainly focus on 1:00 a.m., 9:00 a.m.-16:00 p.m., 18:00 a.m. and 21:00 p.m. to 22:00 p.m.. It shows that the carpool probability is positively related to the carpool waiting time, and the less waiting time is focused on the peak time of daily travel, while the other time is relatively small. In conclusion, the following conclusions can be obtained from the experimental results:

(1) The carpool probability is mainly related to the number of taxis, the no-load rate and the destination distribution. By changing the three factor values, the probability of carpool can be improved. Taxi driving rate is relatively stable, the increase speed to improve the probability of the carpool is not easy to achieve in the city.

(2) The high probability of carpool probability and the short waiting time are mainly concentrated in the peak period of daily travel, while other parts are not suitable for carpool.

(3) From the experimental results, it is found that when travel distance is medium and short range, the possibility of carpool is high, when the travel distance is long range, carpool possibility is low. In the carpool, if the taxi carrying capacities meet the conditions, we should consider many carpools, which can effectively improve the carpool performance.

3 Conclusions

Based on Poisson distribution, the carpool probability and waiting time model are established in this paper, Through the above examples analysis we can see that taxi waiting time and the carpool probability model have certain feasibility; At the same time, we can see that the carpool probability and waiting time mainly depend on the number of taxis, the no-load rate and the destination distribution; The calculation results show that, for the city of Nanjing Yuhua Road in the peak travel periods is more suitable for the carpool. In carpool, we can adopt multiple carpooling to improve the effect of carpool. This model can provide the basis for the formulation of urban carpool. This model is validated on the assumption, it will gradually reduce the conditions in the follow-up work, the carpool probability and the waiting time are estimated by using the data close to the real conditions.

Acknowledgments

The work is supported by the National Natural Science Foundation of China (Grant no. 6106402 and 61364026 and 51408288.)

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(Last updated in November 2, 2015)