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Macro Empirical Model of Quantity Balance between Urban Taxi and Tailored Car in Different Chinese Typical Cities

Lu-Yang Wang
Information System and Management Institute, National University of Defense Technology
Changsha, China
Email： nudtwangly@163.com

Gui-Hui Li
Information System and Management Institute, National University of Defense Technology
Changsha, China

Yong-Hong Chen
Department of public passenger transport management service, Jinan Transportation Bureau
Jinan, China

Jian-Ping Xing
School of Microelectronics, Shandong University
Jinan, China
Email : sduxingjianping@163.com

Bing Cui
Department of public passenger transport management service, Jinan Transportation Bureau
Jinan, China

***Abstract*-Aiming at the current status of urban taxi and tailored car industry, using navigation car networking communication technologies for obtaining taxi operation management data accurately, in combination with the travel characteristics of the urban residents and migrant population, this paper establish a taxi quantity confirming method and to calculate the optimal number, which putting the taxi unloaded ratio as main parameters. Then take Jinan's taxi industry as an example application of the model validation, to obtain rational quantity between taxi and tailored car. Also the result of other three typical cities is given and compared. Finally provide scientific decisions combined with current traffic problem.**

Keywords-taxi operation; tailored car; unloaded ratio; schedule model of taxi quantity.

I INTRODUCTION

In current city, traffic is the basic needs and manifestations of human life, which is closely related to the formation and development of city. As an important component of public transport, taxi has been closely connected with people's daily way to travel. In many cities of our country, with the taxi industry growing rapidly and city's expanding, there have been many kinds of problems such as traffic congestion. Therefore, the reasonable urban passenger taxi retains quantity can effectively ease the urban traffic congestion phenomenon, convenient for the healthy development of the taxi industry. At meanwhile, the tailored car market gradually active, and inject fresh blood to the city traffic. But due to the imperfect tailored car market supervision, it has brought some problems and leads to the development of tailored car to an awkward stage. However, the development of urban taxi and tailored car is not necessarily a mutual constraints and contradictions. How to establish a fair regulatory policy about tailored car, reasonably balance its market delivery amount with urban taxi, is the best way to solve the current situation of that contradiction.

In recent years, many scholars have carried out the research on the method of determining the amount of taxi. Douglas[1] proposed a model based on the aggregation of demand and supply, studied two taxi service modes, under the competition and monopolization market balance of supply and demand. Wei Wang[2] proposed the method to determine taxi quantities with unloaded ratio, according to the survey information of population travel characteristics in the planning period, but that is too subjective and poorly flexible. Diana Chen et al.[3] established the forecasting model, by analyzing the influence factors and the development law of the taxi operation condition, but its condition is limited to the relative stability of the crowd travel requirements. Zhongwei Hu[4] use floating car data to estimate its amount, but lack of support for actual data cases. In addition, the researchers also used neural network model[5], distributed data model[6], network equilibrium model[7], and other methods to estimate the amount of delivery. Those method or parameters are used by estimate or statistical data, leading that the deviation of results is large and arduous to be verified, so it is difficult to be accepted.

This paper based on the new technology of the vehicle navigation and communication in Jinan taxi BEIDOU/GPS operation data extraction, obtain the basic operating parameters of the taxi daily operation, then get the whole state of the taxi. And according to the actual situation of the city itself, build a model related to the taxi quantities. Then take the city of Jinan as an example with actual operation

data into the model calculation and analysis, get a reasonable amount of taxi industry, and contact the practical development prospects of tailored car industry to put forward some scientific proposals. Also the result of other three typical cities (Beijing, Dalian and Chengdu) is given and compared.

II RELATED CONCEPT AND CALCULATION METHOD

A. *Taxi Operation Related Concepts*

(1) Valid driving: the traveling state of taxi when having passengers. The corresponding driving distance is called the valid driving distance.

(2) Invalid driving: the traveling state of taxi when having no passenger. The corresponding driving distance is called the invalid driving distance.

(3) The total mileage: the sum of valid driving distance and in valid driving distance in a day.

(4) Average operating speed: the ratio of the total mileage and the operating time of a taxi.

(5) Average effective passenger trips: the average number of passengers when taxi in valid driving.

(6) The unloaded ratio: in the unit time, the ratio of the total mileage to the invalid driving distance.

(7) The single ride: the process of passengers from getting into the taxi to getting off taxi, or the process of getting off the taxi to the next time.

B. *Methods for Determining the Operation Data of Taxi*

Table 1 gives the method of calculating the parameters of the vehicle running data. And the whole state parameters of the taxi can be obtained by means of Table 1.

TABLE I. PARAMETER CALCULATION METHODS BASED ON TAXI RUNNING DATA

Parameter	Calculation formula	Parameter meaning
Average travel distance of passengers by taxi	$D=\frac{1}{n}\sum_{i=1}^{n} l_{zi}$	l_{zi} is single passenger trip distance, where i is operating times, n is total operating times in the investigation days
Taxi daily average operating distance	$\overline{D}=\frac{1}{d}\sum_{i=1}^{n} l_{zi}$	d is sampling number of days
Average driving speed	$v=\frac{1}{n}\sum_{i=1}^{n} v_i$	v_i is average speed of single ride
Average working hours of the driver	$T=\frac{1}{d}\sum_{i=1}^{n} T_i$	T_i is single operation time
Unloaded ratio	$K=\frac{\sum_{i=1}^{n} l_{ei}}{\sum_{i=1}^{n}(l_{ei}+l_{zi})}$	l_{ei} is the invalid driving distance before a single ride

III TAXI QUANTITY MODEL

In modern urban traffic, the operating status of taxi is closely related to the number of local urban residents and floating population. And the taxi unloaded ratio can reflect its operation efficiency intuitively. Therefore, taking the urban residents and urban migrant population travel turnover as the starting point, and considering the key factor of the unloaded ratio at the same time, then build a model to predict the reasonable scale of taxi.

A. *Taxi Travel Turnover*

The taxi travel turnover from passengers mainly from two aspects: local residents and urban floating population. Its calculation formula is written as:

$$W=R\cdot A\cdot P\cdot D \tag{1}$$

1) *Daily travel turnover of urban residents*

The daily travel turnover of urban residents which taxi undertaken is calculated as:

$$W_1=R_1\cdot A_1\cdot P_1\cdot D_1 \tag{2}$$

In formula: W_1 is the daily travel turnover of urban residents (10^4people ·km); R_1 is total population of urban residents (10^4people); A_1 is per capita travel times of urban residents (times/day); P_1 is the proportion of taxi in urban residents' travel structure, scilicet the share ratio (%);D_1 is

the average travel distance of urban residents who choose taxi travel mode (km).

2) *Daily travel turnover of urban floating population*

The daily travel turnover of urban floating population which taxi undertaken is calculated as:

$$W_2 = R_2 \cdot A_2 \cdot P_2 \cdot D_2 \tag{3}$$

In formula: W_2 is the daily travel turnover of urban floating population (10^4people·km); R_2 is total population of urban floating population (10^4people); A_2 is per capita travel times of urban floating population (times/day); P_2 is the proportion of taxi in urban floating population's travel structure, scilicet the share ratio (%); D_2 is the average travel distance of urban floating population who choose taxi travel mode (km).

B. *Total Daily Valid Driving Mileage*

When taxi in operation process, the number of passengers carried is always changing. So it should take into account the average number of taxi passengers to calculate the total mileage when carrying passengers, which is called the total valid driving distance. It is calculated as:

$$L = \frac{W_1}{S_1} + \frac{W_2}{S_2} \tag{4}$$

In formula: L is the total valid driving distance of urban taxi (10^4km);

S_1 denotes the average effective number of passenger trips when urban residents choose by taxi.

S_2 denotes the average effective number of passenger trips when the floating population chooses by taxi.

C. *Calculation of Taxi Quantity*

In this paper, as the definition of the unloaded ratio said, the percentage of the total mileage to the invalid driving mileage, its formula is:

$$K = 1 - \frac{L}{T \cdot V \cdot n} \tag{5}$$

Among them, K is the unloaded ratio; T is the taxi daily average operation time(h); V is taxi average operating speed(km/h); n represents the quantity of taxi (Veh).

Transform the above equation, and then get the calculation formula about taxi quantity:

$$n = \frac{L}{(1-K) \cdot T \cdot V} \tag{6}$$

In real life, there are obvious differences in the time distribution about taxi passenger source. Daytime is the working hours and the peak period of population travel, provides the main source of passengers. At night, the traffic flow can be greatly reduced, so the demand of taxi will also be reduced. Therefore, it will deviate from the actual situation when use average daily travel volume to calculate. In addition, it also should be considered that part of taxis are not in the operating state in a day, due to personal accident, vehicle maintenance, traffic punishment and other reasons.

Based on these conditions, take the parameters x , y represent the taxi in yT hours to assume x percentage of travel volume ,f represent the proportion of taxis which are in operation. So the improves formula is written by:

$$n = \frac{xL}{(1-K) \cdot yT \cdot V \cdot f} \tag{7}$$

IV CASE RESEARCH—ANALYSIS OF TAXI QUANTITY IN JINAN

A. *Profile*

Jinan is the capital of Shandong province, located at the west of Shandong. About taxi industry, Jinan's taxi mainly run by 40 companies, part of which also driven by few individual drivers. Its operating way has 3 modes: individual management, contract lease, public management. As of 2015, the city has 8548 taxis, of which the individual taxi has 160 cars. According to Jinan relevant department statistics and comprehensive traffic report, in 2015, the total population of Jinan is 699.88 ten thousand people. Among them, the population of urban area is 352.17 ten thousand people, and the urban floating population is 33.4 ten thousand people. Meanwhile, the passenger flow concentration time mainly distributed in 7 a.m. to 9 p.m. ,which indicates the taxi traffic active time is 14 hours, accounted for around 90% about total travel volume throughout one day in Jinan. In addition, quite a few taxis are not in operation due to various reasons, so select the coefficient of elasticity to 90%.

B. *Taxi Quantity Model*

To reduce the computational complexity, now make some reasonable assumptions: assuming the average travel mileage, the average speed of taxi and the number of passenger in one ride is fixed; assuming the average effective number of passenger trips and the travel distance between residents and floating population are the same.

1) *Determination of basic parameters*

According to the GPS data of Jinan sampling taxi, the average daily mileage, the average operating speed can be obtained. Meanwhile it can also be obtained some information like average speed under the traffic congestion period and the normal traffic period, by contrasting and fitting data. On the other hand, there is a certain connection between the determination of taxi amount and the unloaded ratio. So keeping the unloaded ratio in about 35% would achieve the best results on controlling taxi quantity.

Parameters of the model formula and related collected data can be seen in table 2.

TABLE II. BASIC SURVEY DATA

Parameters	Unit	Parameters	Unit
Total population of residents	352.17 (10^4people)	Taxi average operation time	19 h
Total population of floating people	33.4 (10^4people)	Active time of urban traffic	14 h
Resident travel times	2.1	Proportion of travel volume under the active time	90%
Floating population travel times	2.78	Carrying time in traffic congestion period	4 h
Taxi share ratio of residents	6.5%	Carrying time in normal traffic period	10 h
Taxi share ratio of floating people	35%	Taxi speed during normal traffic period	24.2 km/h
Average number of passengers	1.9 per/veh	Taxi speed during traffic congestion period	12 km/h
Average distance when carrying passengers	6.56 km	Elasticity coefficient	0.9

2) *Improvement of basic parameters*

Taking into account the current urban traffic congestion in Jinan, the speed difference between the traffic congestion period and the normal traffic period in a day is relatively large. In model, it will lead to a large difference of results if using the average speed on calculation. Therefore, there is a good way that put the average operating time of original model divide into congestion period and normal period to consider. Also the average speed can be divided into that two periods to calculate. So the daily average travel distance of taxi can be modified as:

$$\overline{D} = T_p \times V_p + T_g \times V_g \tag{8}$$

Go in detail, T_g is the taxi average operating time during traffic congestion period (h). V_g is the taxi average speed during traffic congestion period (km/h). T_p is the average operating time during traffic normal period (h). V_p is the average speed during traffic normal period (km/h).

3) *The calculation of model*

Using the improved basic data and computational method, and control the unloaded rate in the range of 30% to 40%, then substituted them into model to calculate:

$$n = \frac{xL}{(1-K)\cdot yT \cdot V \cdot f} = \frac{0.9\times L}{(1-K)\times \overline{D}\times 0.9} = \frac{L}{(1-K)\cdot \overline{D}} \tag{9}$$

Its additional condition in formula is $T_g + T_p = yT = 14$ (h). Consequently get the results about taxi quantity:

Upper limit:

$$n = \frac{(352.17\times 2.1\times 0.065\times 6.56 + 33.4\times 2.78\times 0.35\times 6.56)}{(1-0.4)\times(24.2\times 10 + 12\times 4)} = 1.5987\ (10^4 \text{veh}) \tag{10}$$

Lower limit:

$$n = \frac{(352.17\times 2.1\times 0.065\times 6.56 + 33.4\times 2.78\times 0.35\times 6.56)}{(1-0.3)\times(24.2\times 10 + 12\times 4)} = 1.3703\ (10^4 \text{veh}) \tag{11}$$

In general, the reasonable amounts of taxi range from 13703 to 15987 vehicles.

C. *Influence Factors*

Through the model, it can be seen that there is a certain functional relation between taxi quantity and related parameters, which is linear or non-linear. Here are some variable factors related to the quantity determination to discuss the effect on results of above model.

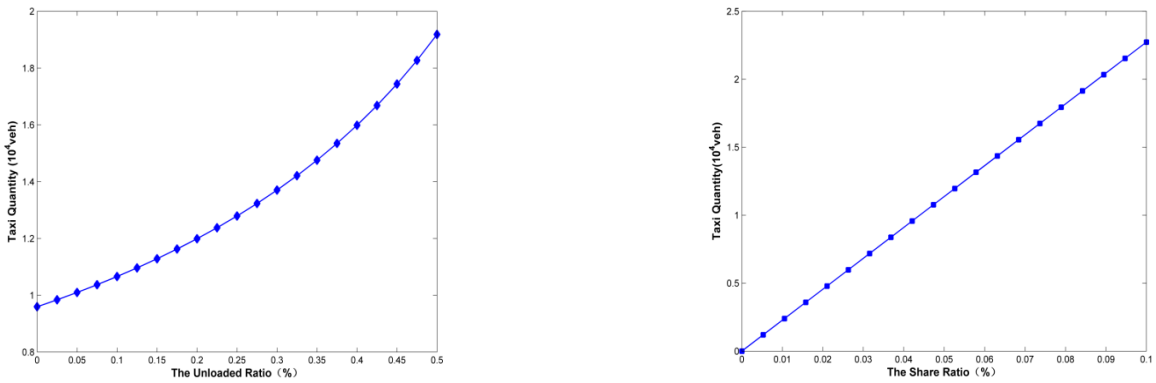
(1) The unloaded ratio

The unloaded ratio reflects the operating efficiency of taxi, which is the crucial factor that affects the taxi amounts and its benefit. Assuming that the remaining parameters keep unchanged, the relationship between the unloaded ratio and taxi quantity is shown in Fig.1(a). It is a directly proportional relation.

(2) The share ratio

Taxi share ratio mearsurement is determined by a multivariate function of multiple parameters: $R = f(k_1, k_2 \ldots\ldots k_n)$ [8]. And the parameter k_n is connected with urban area, population, road area ratio and other factors. When the city develops to a certain scale, the traffic structure becomes relatively stable, and the change of share

ratio is tiny. Consequently to simplify the process, maintain the current proportion of taxi share ratio, which is between residents and floating population, at the level of 1:5.4. Then discuss the effect on the change of taxi quantity when the share ratio has a slight variation. Its variable relationship is shown in Fig. 1(b).



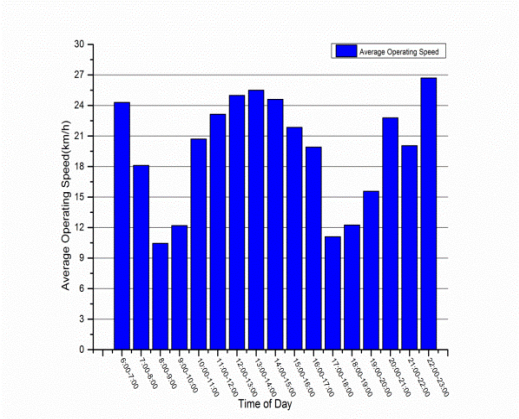
(a) (b)

Figure 1. (a) Changes in taxi quantity under the unloaded ratio.(b) Changes in taxi quantity under the taxi share ratio.

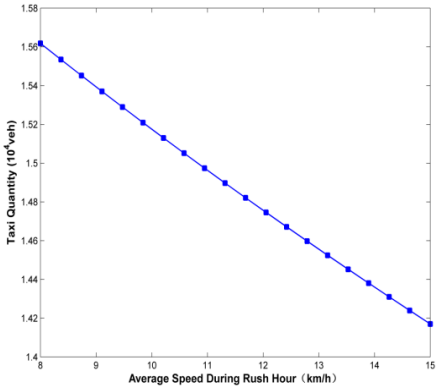
(3) The operating speed

A fitting curve (Fig. 2(a)) can be drawn through the GPS data comparison of sampling taxi, which is concerning its average speed distribution of the whole day operation. (Horizontal axis represents the moment of one day)

As the taxi operating speed and operating time jointly determine its daily operating mileage, thereby they also affect the result about taxi quantity. In reality, Jinan has a large volume of vehicles, and traffic congestion is more serious. So in the morning and night rush hour it is often to form the traffic paralysis phenomenon. Considering some implementary actions, such as restriction measures, to ease the traffic congestion problem and to improve the running speed in traffic peak, discuss the affection on taxi quantity determination when regard the taxi speed, which is under rush hours, as the independent variable. The result is finally shown in Fig. 2(b).



(a)



(b)

Figure 2. (a) Distributions of the taxi average operating speed in active time. (b) Taxi quantity against the average operating speed.

D. *Optimal Number Forecast about Taxi and Tailored Car*

From the analysis of impact factors, it can be seen that taxi quantities have a closely correlation with the change of unloaded ratio, taxi share ratio and its average operating speed. Referring to the current international advanced urban taxi policy, control the unloaded ratio at about 35% to get the optimal effect. At the same time, combined with the implementation of Jinan traffic optimization in the future, choose the share rate at the level of 6%, and the speed during rush hours control in about 14 km/h (speed in non-rush hour period changes little). And the other parameters basically remain unchanged. Then put above data into the taxi quantity model and obtain the result that is about 13272 vehicles. According to international experience, the calculation result can meet the standard that per 10000 individuals occupy the quantities of taxi in 20 to 30 vehicles, which accord with the requirements of the “road traffic

planning and design standard" issued by the nation. That can manifest a good market acceptance, and is conductive to the development of public transportation industry. At present, Jinan actually has more than 8500 vehicles of taxi. There is a certain gap between the results of taxi quantity model. Taking into account those existing problems in Jinan, it can make full use of the advantage of tailored car industry and introduce the tailored car into urban transport to share city's passenger transit volume. So the quantity of tailored car can be determined as: $\Delta n = 13272 - 8548 = 4724\ (\mathrm{veh})$. That is to say, it can supply approximately 4724 vehicles of tailored car to put into operation for this city.

E. *Results Analysis*

In order to prove this algorithm accuracy and universality, this paper selects the other three typical cities in China, like Beijing, Dalian, then collect data and measure its city taxi number, which compared with their actual number at the same time. The results are shown in table 3. It can be seen that in some cities the calculated results are in accord with the actual situation, and their each numerical value is basically in line with the optimal standard about taxi usage per million people. And then the feasibility and universal applicability of our proposed method is also illustrated.

TABALE III. CALCULATION OF TAXI QUANTITY IN SOME TYPICAL CITY

City	Urban population (10^4people)	Average travel times	Taxi share ratio	Average distance when carrying passengers	Calculation number of taxis	Actual number of taxis
Beijing	2114.8	2.75	7.8%	5.89 km	9.135 (10^4veh)	6.66 (10^4veh)
Dalian	305.1	2.71	5%	5.53 km	8713 (veh)	8592 (veh)
Chengdu	581.63	2.58	6.2%	5.66 km	18025 (veh)	17684 (veh)

Through building the model on calculating Jinan taxi reasonable quantities, eventually this method get results that the reasonable scale of urban taxi in Jinan should keep in about 1.32 ten thousand vehicles. Which controlling the unloaded ratio at around 35%. And that is higher than today's actual taxi amounts. The consequence is in accordance with the phenomenon appeared today about taking a taxi with difficulty or refusing to take passengers. So it is necessary to increase the amounts of taxi. But combined with the actual situation, blindly increasing taxi number will intensify competition in the industry revenue. Deeply it will increase the traffic congestion problem. Now the tailored car appeared as an emerging transportation, can provide well passenger service without increasing the traffic capacity. According to incomplete statistic, Jinan now owns more than 3000 vehicles tailored cars to meet passengers travel demand. Based on this paper results, the taxi quantity changed little in recent years due to the policy influences, so put those 3000 vehicles tailored cars into use to undertake the passengers transported volume together with urban taxi, then that will basically reached the optimal amount of taxi estimates. With the rise of tailored car industry in the future, it will put more vehicles into operation and gradually reach a reasonable level. To direct at the present situation of taxi industry in Jinan, this measure can achieve a host of things at one stroke.

V CONCLUSIONS

What scales of urban taxi quantities should control is a paramount content on the urban traffic system. This paper based on taxi status, function and the characteristics of its industry, also combined with the relevant data information recorded by BEIDOU/GPS, eventually get the actual situation of urban taxi operation by statistical analysis. Then use some basic data like population, the unloaded ratio, et cetera, to establish the schedule model of taxi quantity. And then, it investigates a slice of key factors to find their affection on the taxi quantity determination, which can ulteriorly obtain the best number range about taxi quantity. This paper improves the model in the facet of parameter settings, in view of the actual situation of different cities, and possesses a superior flexibility and operability. In practical application it can also achieve a multitude of excellent results. But to determine taxi quantity is a complicated problem, it is influenced by omnifarious factors. Therefore, there are quite a few limitations in this model. On the one hand, there is no related to the impact of income factors, while taxi pricing, industry competition and other profit factors occupy a large proportion on affecting taxi quantity in its market share. On the other hand, to ascertain the unloaded ratio it has much subjectivity, which value could affect the final actual results. Therefore, this method still need to be further studied.

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