Research on Airport Taxi Problem Based on Cell Transmission Simulation Model

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Abstract. In order to solve the decision-making problem of taxi drivers at the airport, it constructed a non-aggregate stochastic utility model, a cell transmission simulation model, and a queuing model. Besides, it used software programming and drawing software such as MATLAB, SPSS, EXCEL, and rapid flow chart comprehensively. Finally, this paper solves the taxi problem at the airport and gives relevant suggestions.

Keywords: Airport Taxi; Decision-making; Disaggregated Stochastic Utility Model; Cell Transmission Simulation Model; Queuing Model

1. Introduction
After getting off the plane, quite a few passengers will choose to take a taxi to the city and surrounding areas. However, most domestic airports have separated taxi transfer channels. Taxi drivers at airports generally only make decisions based on personal experience. However, in actual operations, there are still many deterministic and uncertain factors that affect the rationality of taxi drivers’ decisions.

2. Based on the Cellular Transmission Simulation Model, the Research on the Influence Mechanism of the Relevant Factors of the Taxi Driver’s Decision-making

2.1. The Ideas of Research
Throughout the process, the behavior of passengers includes waiting in line, getting on and off. The behavior of the driver is to transport passengers and find the next passenger. In order to make the model conform to reality, the paper uses a cellular transmission simulation model to simulate the behavior of taxis carrying passengers. Combining the personal factors of the driver and the personal factors of the passenger, it finds out how the taxi driver should make decisions.

2.2. Establishment of Disaggregated Random Utility Model

2.2.1. Generation Model of Traveling Passengers
The following assumes that on each node and cell of the urban road network, the time interval
for each passenger to enter the taxi follows the Poisson distribution. Take the following method to obtain the taxi behaviors of passengers at different locations at the same time: only one person is allowed, and its starting point and destination are not given. When riding the bus, the passenger’s starting point and purpose are solved by combining the requirements of it. Then, according to the passenger data of the city, the customer rides of the next time is solved, and the problem of a line of passengers is integrated.

2.2.2. Passenger’s Departure Model

It is assumed that the passenger demand $R_{ij}$ for passengers from any place $i$ in the city to arrive at another place $j$ within a unit time is known,

Then the number of passengers $R_i$ sent from the location $i$ in unit simulation time is:

$$R_i = \sum_j R_{ij}$$

(1)

When a passenger wants to take a taxi, the probability $p_D(i)$ that the passenger's departure location $i$ is:

$$p_D(i) = \frac{R_i}{\sum_k R_k}$$

(2)

Finally, through calculation, the probability $p_D(j)$ that the destination that the passenger wants to reach is the place is:

$$p_D(j) = \frac{R_{ij}}{R_i}$$

(3)

2.2.3. Simulated Non-aggregate Stochastic Utility Model of the Way Passengers Going to the Airport

Disaggregated stochastic utility model[2][3] is used to simulate the travel mode chosen by passengers. Assuming that the number set of all travel vehicles in a city is $M$, then the generalized travel cost of the passenger $q$ who travels can choose the first mode of $m, m \in M$ is the transportation, and the free of it can expressed as $C_{qm}$:

$$C_{qm} = a_q P_{qm} + b_q H_{qm} + c_q W_{qm}$$

(4)

The above formula is explained as follows:

$P_{qm}$ is the cost of the $m$ type of transportation. The expected travel time of passengers is composed of expected travel time $H_{qm}$ and expected waiting time $W_{qm}$. $a_q, b_q, c_q$ is the passenger’s $q$ cost, the weight of the journey time, and the waiting time, which represents the passenger’s personal attributes. $a_q$ is affected by passenger income, and the urgency of passengers to the airport is positively correlated with $b_q, c_q$. The time that passengers wait for a taxi is positively correlated $c_q$. 


To sum up, each passenger is determined \( a_q \) according to income; each passenger is determined \( b_q \) according to the urgency of the trip; when determining \( c_q \), two cases 1 and 3 must be considered. For this reason, the larger item of \( c_q \) is determined by 2 and 3 respectively. Assuming that passengers aim to minimize the total travel cost, the utility \( U_{qm} \) of passengers \( q \) choosing the \( m \) mode of transportation is:

\[
U_{qm} = -\theta C_{qm} + \varepsilon_{qm}
\]

(5)

In the above formula, \( \theta \) is a non-negative constant, and \( \varepsilon_{qm} \) is the random utility of choosing the \( m \) transportation mode for passengers \( q \) and obeys the extreme value distribution[4]. According to the Logit model[5], the probability \( p_{qt} \) of passengers \( q \) choosing a taxi is:

\[
p_{qt} = \frac{m^{-\theta c_q}}{\sum_j m^{-\theta c_q}}
\]

(6)

In the process of solving from the above formula, the price of passengers \( q \) taking a taxi is:

\[
p_q = \begin{cases} 
  f_0, & s_q < s_0 \\
  f_0 + f_1 (s_q - s_0), & s_q \leq s_0
\end{cases}
\]

(7)

In the above formula, \( f_0 \) is the starting price of the taxi, \( f_1 \) is the unit mileage price, \( s_0 \) is the starting mileage calculated by the taxi, and \( s_q \) is the passenger’s \( q \) travel mileage.

Finally, the simulation \( w_{qt} \) is determined by the following steps:

Step 1: When the passenger’s \( q \) departure point happens to be waiting for an available taxi, then \( w_{qt} = 0 \);

Step 2: When passengers \( q \) can expect an empty taxi to arrive in the time interval, then \( w_{qt} \) equals Expected empty car arrival time minus current time;

Step 3: If neither step 1 nor step 2 are established, \( w_{qt} \) is the accumulated waiting time of passengers in the simulation. Passengers who choose to take a taxi will check whether there are any available taxis waiting in line at the current location. If they call the boarding procedure, they will join the passenger queue to wait.

2.2.4. Taxi Passenger Process

The following figure shows the general process of taxi passengers:

Figure 1 Schematic Diagram of Taxi Carrying Passengers
2.2.5. Passengers Boarding a Taxi
When passengers go to an empty taxi at a certain place, the taxi location depends on whether the boarding location is a node or a road section. The node agrees to park an empty taxi to wait for the customer, then there are two situations where the customer gets in the car: the first is that the customer just hits the empty car when they get out of the car; the second is that the taxi meets after arriving at a certain place a line of customers. But often the last one is the most common.

2.2.6. Empty Car Search Decision Model
Due to the randomness of the appearance of passengers, the process of finding passengers when the driver is empty is the key to the taxi driver’s decision-making. The following figure shows the possible search directions for taxi drivers when they do not cast a section.

Figure 2 Possible Search Directions of Time-space Vehicles in Different Locations
According to the above picture, it is easy to see that the search process of the taxi driver on the road section is as follows:
When the driver finds that there are no passengers on the road section, the taxi will continue to drive along the road. When the driver arrives at the node, there will be multiple choices, and he can also stop and wait. Suppose the driver wants to reduce his empty time as much as possible to avoid losses. Based on years of driving experience, he can roughly judge the arrival speed of passengers on a certain road section. Therefore, the empty vehicle search policy at the node is as follows: determine the passenger rate $\nu$ in the future for a period of time, and the number of empty vehicles at the current location is $x$, if $\nu \geq x$, then estimate the location where the passenger can be encountered at the next moment, otherwise, the vehicle will reach probability $p_i$ of waiting for 1 simulation clock before being able to board the next passenger is [1]:

$$p_i = \frac{\nu}{x} \left(1 - \frac{\nu}{x}\right)^{i-1}, \nu < x$$

(8)

The search time of the current position obtained by calculating the mathematical expectation is [1]:

$$w_i = \begin{cases} 1, \nu \geq x \\ \sum_{i=0}^{\nu} \nu \left(1 - \frac{\nu}{x}\right)^{i-1} = \frac{x}{\nu}, \nu < x \end{cases}$$

(9)

2.2.7. Simulation of Cell Transmission Model
(1) Road Network Cell Division and Cell State
The cell transmission model is used to simulate the traffic flow. Combined with the theory, the road section is divided into two types of ordinary sections, and the cell length is equal to the distance traveled by any car in a unit time. In the figure below, the starting point cell represents the cell with the smallest number on the road section, the end cell represents the cell with the largest number, and the other cells are collectively referred to as intermediate cells[7].

![Diagram of Cell Division Based on Road Section](image)

**Figure 3 Diagram of Cell Division Based on Road Section**

The cellular transmission model is a macroscopic traffic flow model[8], which does not consider the small behavior of vehicles. Since the first problem is related to taxis, taxis must be handled specially in the MATLAB program. Separation of taxi data facilitates the model’s processing of taxi data.

(2) Update of Cell State

The calculation of the inflow and outflow of the cell is also different depending on the position of the cell on the road section. Next, it establishes the cell state and a new mathematical model. According to it, the relevant model can be derived. As it was shown in the diagram of cell division based on link, cell a is the middle cell of the link, and the recursive formula for the traffic carrying capacity of the link in the direction of increasing cell number is [9]:

$$x_a(t+1) = x_a(t) + y_a(t) - y_{a+1}(t)$$  \hspace{1cm} (10)

$$y_a(t) = \min\{x_{a-1}(t), Y_a(t), (R \setminus V)(X_a(t) - x_a(t))\}$$  \hspace{1cm} (11)

In the above formula,

- $x_a(t)$ : The traffic carrying capacity of the cell, $y_a(t)$ : the inflow capacity of the cell, $X_a(t)$ : the carrying capacity of the cell, $Y_a(t)$ : the inflow capacity of the cell.

According to the road segment-based cell division diagram, cell No. 1 represents the starting point cell of the road section, and the recursive formula of the traffic carrying capacity in the direction of increasing number of the cell is obtained[9]:

$$x_1(t+1) = x_1(t) + y_1(t) - y_2(t)$$  \hspace{1cm} (12)

$$y_1(t) = \min\{In_{nor}(t) + In_{taxi}(t), Y_1(t), (R \setminus V)(X_1(t) - x_1(t))\}$$  \hspace{1cm} (13)

$$y_2(t) = \min\{x_1(t), Y_2(t), (R \setminus V)(X_2(t) - x_2(t))\}$$  \hspace{1cm} (14)

In the above formula, $In_{nor}(t)$ is the number of ordinary vehicles on the road section in the increasing direction, and $In_{taxi}(t)$ is the taxi traffic on the road section. According to the road segment-based cell division diagram, cell n represents the end cell of the road section, and the recursive formula for the traffic carrying capacity of cell n in the direction of increasing cell number is[9]:

$$x_n(t+1) = x_n(t) + y_n(t) - y_{n+1}(t)$$  \hspace{1cm} (15)

$$y_n(t) = \min\{x_{n-1}(t), Y_n(t), (R \setminus V)(X_n(t) - x_n(t))\}$$  \hspace{1cm} (16)
\[ y_{n+1}(t) = \min \{ x_n(t), \text{OUT} \} \]  

(17)

According to the related modeling theory of the cell transmission model, the MATLAB programming software is used to simulate the taxi pickup situation.

2.3. Research on the Rationality of the Decision Model Based on the Cell Transmission Model

The Ideas of Research

The following collects the relevant data of the taxi in the airport and its city to test the rationality of the above test decision model.

2.4. Establishment and Solution of Cell Transmission Model

After simulation, it obtained the actual load rate, empty load rate and average waiting time of the taxi:

![Figure 4 Simulation Rendering of Taxi](image)

Analysis:

\[ \text{The rate of actual load} = \frac{\text{The total time of passenger operating}}{\text{Total operating hours}} = \frac{\text{Total demand time}}{\text{Total operating hours}} \]  

(18)

After many simulation programming of MATLAB program, it is found that the data analyzed and processed has a very high degree of fit with the actual data. The correlation coefficient between the simulated value and the actual value is 0.99.

Therefore, it can be determined that the actual load rate of the taxi derived from the CTM simulation model is absolutely reasonable. This paper believes that the model is reasonable and highly dependent on related factors.

3. III. Based on the Queuing Model, the Analysis of How to Set the “Pick-up Point”

3.1. The Ideas of Research

This paper is based on the analysis of passengers and taxis at the “boarding point” of the airport and the queue of passengers in the “boarding area”. It establishes a mathematical model of queuing theory for passengers to take a taxi, and optimize according to the planning to obtain the “boarding point” setting that can meet the departure needs of taxi passengers. Then, it gets the optimal “boarding point” setting to make the overall ride efficiency highest.

3.2. Establishment of Queuing Model

The busyess of the queue is expressed by the busy rate \( \rho \), \( \rho \) is the ratio of the customer arrival rate to the service rate in the queue. It can be calculated by the following formula[10]:

\[ \rho = \frac{\lambda}{C\mu} \]  

(19)

The evaluation index of queuing theory is the length \( L \) of queuing and the waiting time \( W \) of passengers. If the quotient between them is smaller, it is better.
3.3. Establishment of Queuing Model
This paper refers to the relevant literature on queuing theory, and establishes a queuing model based on the queuing mechanism of the rental car "boarding area" in the airport and combining the multi-point parallel taxi queuing service system. When the queuing system in the "boarding area" is in the peak period, and the service intensity of the system \( \rho < 1 \), it can be considered that there will be no infinite queuing phenomenon. On this basis, the input and output of the system are modeled. When the system reaches a steady state, C stations will work together, and the probability that the number of taxi passengers in the system is \( n \) is as follows[11]:

\[
P_0(C) = \sum_{k=0}^{C+1} \frac{1}{k!} \left( \frac{\lambda}{\mu} \right)^k + \frac{1}{C! (1-\rho)} \left( \frac{\lambda}{\mu} \right)^C \tag{20}
\]

\[
P_n(C) = \begin{cases} 
\frac{1}{n!} \left( \frac{\lambda}{\mu} \right)^n P_0(C) & n = 1, 2, \ldots, C \\
\frac{1}{C! C^{n-C}} \left( \frac{\lambda}{\mu} \right)^C P_0(C) & n = C + 1 
\end{cases}
\tag{21}
\]

The waiting time of passengers in line is \( W_S \), the captain \( L_S \) analyzes the system, and obtains [11]:

\[
L_S = L_q + C \rho 
\tag{22}
\]

\[
E(W_S) = \frac{P_s(C)}{C \mu (1-\rho)} 
\tag{23}
\]

\( L_q \) refers to the number of passengers waiting in line in the queuing model, long \( L_s \) refers to the sum of the number of passengers \( L_q \) in line,

Waiting time \( W_q \) refers to the average time from the time the customer enters the platoon model to the "boarding area", the stay time

\( W_s \) refers to the average time, it takes for a customer to complete a series of queues to take a taxi.

3.4. Optimization of Queuing System Model
The above queuing model is optimized and rewritten into an optimal planning model based on queuing. The total cost of determining the waiting time for passengers is \( V_1 = \alpha L_s \), and the construction cost of the "boarding point" is \( V_2 = \beta C \). When \( \alpha \div \rho \) is the smallest, that is, they are the smallest quotient. The queuing model can be further optimized, namely:

\[
\min V(C) = V_1 + V_2 = \alpha L_s(C) \tag{24}
\]

\[
\begin{cases} 
V(C) \leq V(C+1) \\
V(C-1) \leq V(C)
\end{cases} \tag{25}
\]

Among it, \( \alpha \) is the cost of time waiting, \( \beta \) is the cost of severing time and construction fees:

\[
L_s(C-1) - L_s(C) \geq \frac{\alpha}{\beta} \geq L_s(C) - L_s(C+1) \tag{26}
\]

The survey and statistics of the passenger arrival rate and service rate of the taxi “ride area” of Guilin Airport are carried out. The results are shown in the following table:
Table 1. Arrival Rate and Service Rate of Queuing System

|          | (person\'mine) | (person\'mine) | $\alpha \setminus \rho$ |
|----------|---------------|---------------|------------------|
|          | 6             | 4             | 0.002            |

According to the queuing planning model, the taxi queuing at Guilin Airport is optimized, and the calculated results are shown in the following table:

Table 2. Calculation Process of Cost Decision Model

|          |          |          |          |
|----------|----------|----------|----------|
| $L_s(1) - L_s(2)$ | -6.396   | $L_s(5) - L_s(6)$ | 0.007   |
| $L_s(2) - L_s(3)$ | 1.685    | $L_s(6) - L_s(7)$ | 0.001   |
| $L_s(3) - L_s(4)$ | 0.191    | $L_s(7) - L_s(8)$ | 0.0002  |
| $L_s(4) - L_s(5)$ | 0.035    |          |          |

According to the calculation results, it can be seen that when $C=6$, the overall ride efficiency can be maximized under the condition of ensuring the safety of vehicles and passengers. That is, there are 6"boarding points” setting up in the “riding area” of the airport, which is fine.

4. Conclusion

In this paper, the cellular transmission network model can simulate traffic congestion, traffic flow, etc., and the queuing model is widely used in queuing optimization problems. The following is an evaluation of the model: 1. The cellular transmission network model is applied, which reflects the actual characteristics of taxis, people and traffic. 2. The cellular transmission road network model can simulate road sections with heavy traffic. 3. The correlation coefficient between the simulation value of the cellular transmission network model and the real value in life is high, usually above 0.9. 4. This model successfully transformed the queuing theory model into an optimal sexual planning problem, making the problem easy to solve.

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