Airport Taxi Decision and Management Model based on Maximum Benefits

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Abstract. Airport taxis are an important means of transportation for airport passengers. In order to avoid the waste of airport taxi capacity, we will establish a judgment formula based on the comprehensive supply and demand relationship and profit relationship. And we will select other important factors by cluster analysis as a supplement to establish a judgment algorithm and validated the algorithm by multiple linear regression and examples. Then we use the queuing theory to determine the position of optimal taxi pick-up point and achieve the long-distance and short-distance taxi driver income balance by dividing the level.

Keywords: queuing theory; Multiple linear regression; Cluster analysis; BP neural network.

1. Introduction

After the taxi drivers arrive at the airport and customers get off the car, drivers usually face two choices: to return to urban area with empty taxi or to queue up in the storage pool and return to urban area with new customers. The factors that influence decision-making are multi-faceted. If drivers can't make a reasonable decision, it will lead to a waste of taxi resources. Due to the unreasonable setting of the pick-up point, sometimes there will be a phenomenon in which the taxi queues to carry passengers or the passengers line up to ride in the boarding area, which wastes the time of the passenger or the driver. Short-distance passengers who cannot be refused have caused inconvenience to airport taxis, resulting in uneven income.

We will study the above problems, and take Shanghai Pudong Airport as an example to propose solutions from three aspects: driver decision algorithm, car parking area setting, and short-distance passenger taxi priority policy.

Table 1. Symbol table

| Abbreviation | Description | Unit |
|--------------|-------------|------|
| $t_i$        | Time        | Hour |
| $F_i$        | Fuel cost   | RMB  |
| $M_i$        | Taxi income | RMB  |
| $y$          | Number of flights arriving within a certain period of time | frame |
| $x$          | Number of taxis in the storage pool | vehicle |
| $\alpha$     | Average number of passengers per aircraft | people/frame |
| $\gamma$     | Average proportion of the number of person who choose taxis per aircraft to the total number of people | % |
| $P_i$        | Taxi income | RMB  |
| $W_0$        | Taxi driver's average hourly earnings | RMB/hour |
| $l$          | Distance from the airport to the city | Kilometer |
2. Process and Method

2.1 Decision Algorithm

2.1.1 Pre-judgment

Assuming that the number of passengers at the airport is greater than the number of passengers in the storage pool, the supply is in short supply, the driver has reason to enter the storage pool to wait, otherwise the decision can be made without comparison. It is known that each taxi carries an average of 2 passengers, and the number of vehicles required is:

\[ x_0 = \frac{y \times n \times y}{2} \]  

(1)

When the actual number of parking spaces in the storage pool is \( x > x_0 \), the taxi driver returns to the urban area, otherwise he or she enters the storage pool.

2.1.2 Determination of Queuing Time

Assuming that the queue time is \( t \) and it takes 20 seconds for the passenger to get on a taxi. So, the \( t \) required is:

\[ t = \frac{x}{180} \]  

(2)

2.1.3 Profit Calculation for Two Options

Method1: Enter the storage pool to queue. The waiting time in the storage pool is \( t \), the gas consumption per kilometer in the queue is \( c \), the fuel consumption cost in the urban area is \( F_1 \), and the passenger fee is \( M_1 \). The profit in this period is \( P_1 \). So, the \( P_1 \) and \( M_1 \) required are:

\[
\begin{align*}
P_1 &= M_1 - F_1 \\
F_1 &= c t
\end{align*}
\]  

(3)

Method2: Empty back to the city. On the basis of Method1, the average hourly income of the taxi driver is \( W_0 \), and the passenger fee is \( M_2 \), then the profit \( P_2 \) during this period is:

\[
\begin{align*}
P_2 &= M_2 - F_1 \\
M_2 &= W_0 t
\end{align*}
\]  

(4)

Let \( P_1 = P_2 \), when the waiting time is \( t_0 \), you can get:

\[ t_0 = \frac{M_1}{W_0} \]  

(5)

\( t_0 \) is the decision time for the two choices. If the real waiting time is \( t < t_0 \), then the airport waits for the same time to make more profit, and driver should choose to enter the storage pool to queue.

And we transform the above model into a decision algorithm. In addition, we also trained BP neural network algorithm through data, and used Monte Carlo method to generate random number series for verification, but the effect is not good, and will not be described here.

2.1.4 Impact of Other Factors on Decision Outcomes

This paper analyzes the impact of weather factors and time period factors on passenger capacity. We selected 3 days of data and used Matlab for cluster analysis to explore relevance. The result of the decision is further revised, and the result is shown as follows:
Table 2. Clustering results of related factors and passenger capacity

| type          | Two types                                      | Three types                                   |
|---------------|-----------------------------------------------|-----------------------------------------------|
| Frist type    | Time, passenger capacity, temperature         | time                                          |
| Second type   | Weather, rainfall                             | Passenger capacity, temperature               |
| Thrid type    | /                                             | Weather, rainfall                             |

According to the clustering results, the following conclusions can be drawn: It is recommended that the taxi driver evaluate the weather conditions. When the outside temperature is extreme in the summer and winter seasons, the passenger load is higher, the chance of receiving the order is larger, and the passenger may be inclined to return to the city.

2.2 Decision Algorithm Verification

2.2.1 Instance Verification

We selected Shanghai Pudong Airport as a verification example and obtained information about Pudong Airport. Through the above decision algorithm, we have reached the conclusion as shown in Table 2. The 14 periods covered by the color, that is, the supply shortage period. The value in the last column is 1 for the choice to stay. The final decision to stay is basically consistent with the pre-judgment and the actual situation, which proves that the pre-judgment model and calculation are reasonable. The pre-judgment and final result error rate are about 8%, which is acceptable.

![Fig 1. Relevant basis and results of the judgment.](image1)

2.2.2 Correlation Analysis of Related Factors

We performed multiple linear regression analysis on the main factors on which the algorithm relied by SPSS. We use var1-var5 to represent the number of vehicles in the storage pool, the number of flights entering the port, the relationship between supply and demand, P1, P2, and use var7 to indicate the decision result. The results are as follows:

![Fig 2. Model comprehensive fitting degree](image2)

![Fig 3. Model Synthesis Degree of Freedom](image3)

It can be seen from the above chart that the multi-factor fitting degree reaches 0.741, which indicates that the algorithm has a high degree of rationality and high dependence on the influencing
factors. The comprehensive degree of freedom indicates the flexibility of the algorithm, which is 9.735, indicating high flexibility.

2.3 Determine the Location of the Pick-up Point in the Taxi Area

2.3.1 Determination of the Number of Parking Spaces

Assuming that the condition for the vehicle to enter the passenger zone from the storage pool is that there are free parking spaces. From the time the first car enters the passenger zone, the time it takes to stop at the parking space obeys uniform distributions whose mean is 5s and deviation is 2s. After the vehicle in front stops at the parking position, the time required for the vehicle to stop at the rear berth obeys uniform distribution whose mean is 3s and deviation is 1s. We calculated the full passenger time of the passengers carried in 231 taxis. The analysis shows that the passengers’ boarding time is approximately obeying the exponential distribution whose mean is 15s. The capacity of the airport taxi pick-up system C can be expressed by the formula:

\[ C = \frac{\mu n x k}{t} \times 3600 \]  

(6)

\( \mu \) is the passenger coefficient; n is the number of berths; k is the total number of simulated rounds; t is the sum of the simulation times. When the number of parking spaces increases from 1 to 10, the following table is available:

| Number of parking spaces | the last parking space utilization | \( t \) | C  |
|--------------------------|----------------------------------|------|-----|
| 1                        | 78.5                             | 23089| 227 |
| 2                        | 77.2                             | 32410| 326 |
| 3                        | 75.9                             | 40968| 387 |
| 4                        | 74.9                             | 48689| 438 |
| 5                        | 73.1                             | 62662| 480 |
| 6                        | 72.5                             | 62663| 508 |
| 7                        | 72.2                             | 71895| 512 |
| 8                        | 72.8                             | 81461| 521 |
| 9                        | 72.4                             | 91063| 526 |
| 10                       | 73.3                             | 103329| 492 |

When the number of berths is 7, the improvement of traffic capacity is not obvious, and the increase of the number of berths leads to an increase in management difficulty. Therefore, the simulation experiment shows that the optimal number of berths in the passenger zone of a single-lane taxi is 6.

2.3.2 Comparison of the Efficiency of the Combination of the Pick-up Points

Considering the difficulty of regulation and the efficiency of riding, this paper sets the upper limit of the number of boarding points to be the same as the number of parking spaces and gets the optimal ride efficiency of different combinations by queuing theory algorithm as follows.
Table 4. Optimal combination of parking spots

| Number of points | Efficient arrangement         | Maximum efficiency (Vehicle/hour) |
|------------------|-------------------------------|-----------------------------------|
| 1                | R1                            | 180                               |
| 2                | R1, R2; R2, R1                | 313                               |
| 3                | R1, R2, R3                    |                                   |
|                  | R1, R3, R5                    | 415                               |
|                  | R1, R4, R5                    |                                   |
| 4                | R1, R2, R3, R4                |                                   |
|                  | R1, R3, R4, R6                | 497                               |
|                  | R1, R3, R5, R6                |                                   |
| 5                | R1, R3, R4, R5, R6            | 563                               |
| 6                | R1, R2, R3, R4, R5, R6        | 617                               |

Fig 4. Parking space planning model

2.4 Driver Income Equalization

2.4.1 Queue Time under the Balance of Income

Assuming a mileage of less than 25 kilometers and a journey time of less than one hour is called a short trip. Taking Pudong Airport as an example, we have four towns that meet short-term conditions: Zhangjiang Town, Caolu Town, Heqing Town, and Chuansha Town.

Divide taxis into two categories:

Short-distance route: airport - (short-haul) destination - airport (queuing) - (long distance) urban area. Long-distance route: Airport - (long distance) urban area. Let $C$ be the income from sending passengers back to the city center. $\bar{C}$ is the income after returning to the urban area. $\lambda_0$ is the time
to arrive at a short destination. $h_1$ is a normal queue time. $h_2$ is the priority queue time. $h_3$ is the time from the airport to the urban area. $R$ is a short-term gain. When the profit of the two types of routes is equal:

$$C + \overline{C}(2h_0 + h_2) = R + C$$  \hspace{1cm} (7)

We can get:

$$h_2 = \frac{R}{2} - 2h_0$$  \hspace{1cm} (8)

Let the total duration is: $2h_0 + h_3 + h_1$
The short-distance route (normal queue) benefits are: $R + C$
The short-distance route (priority queuing) benefits are: $R + C + \overline{C}(h_3 + h_2)$

**Long-distance route revenue is:** $C + \overline{C}(2h_0 - h_2)$

### 2.4.2 Priority Arrangement Planning in the Storage Pool

Electronic checkpoints are set at the entrance and exit of the storage pool. When the taxi enters the storage pool, the electronic monitoring records its license plate number and starts timing. The vehicles returning from different locations are diverted in the storage pool. Each town return vehicle has a different waiting time, and when it is reached, it can be preferentially entered the parking space. According to the distance from Pudong Airport to different locations, the priority will be arranged: Zhangjiang Town> Chuansha Town> Caolu Town> Heqing Town. When multiple vehicles are allowed to enter the parking space at the same time, they are released according to the priority from large to small. Schematic diagram of storage pool management is shown in Figure 6.

### 2.4.3 Model Verification

In order to verify the practicability of the model, this paper has entered relevant data according to the actual situation, as follows:

**Table 5. Taxi to townships related data**

| Town          | Time/h | Distance /km | Income/¥ | Night Income/¥ | h1/h | h0/h |
|---------------|--------|--------------|----------|----------------|------|------|
| Caolu Town    | 0.48   | 22.9         | 76       | 98.8           | 1.41 | 0.54 |
| Zhangjiang Town| 0.37   | 17.1         | 54       | 70.2           | 0.95 | 0.29 |
| Chuansha Town | 0.33   | 18           | 58       | 75.4           | 1.146| 0.55 |
| Heiqing Town  | 0.47   | 24.9         | 84       | 109.2          | 1.70 | 0.86 |

We brought it into the model to get the taxi revenue. The results are as follows:

**Table 6. Comparison of taxi income**

| Town          | 12:30-13:30 | 13:30-14:30 | 14:30-15:30 | Increase in |
|---------------|-------------|-------------|-------------|-------------|
| Caolu         | 231         | 231         | 283         | 22.63%      |
| Zhangjiang    | 209         | 209         | 276         | 31.96%      |
| Chuansha      | 209         | 209         | 283         | 35.41%      |
| Heiqing       | 213         | 213         | 274         | 28.48%      |

**We can get:**

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As can be seen from the chart, after the priority policy, the profit received by drivers who received short-term orders increased by at least 18%. This policy is good for balancing taxi revenue.

3. Summary

In this paper, we have established a decision-making suggestion algorithm based on the relationship between supply and demand and income of airport taxis. Then we analyze the influence of weather, temperature and other factors on decision-making through clustering algorithm and use it to supplement the suggestion. We validated the algorithm with Shanghai Pudong Airport as an example, and demonstrated the reliability of the model by using SPSS to perform multiple linear regression analysis on the influencing factors of the model. Based on the algorithm of queuing theory, we calculated that the optimal parking space in the waiting area is 6 and the optimal combination of the boarding points in different situations is obtained. By classifying short-distance vehicles, we established a short-haul priority mechanism and brought the data from Pudong Airport for verification. The verification results were good and the profit of short-haul vehicles increased by at least 18%.

In summary, an airport Taxi Decision and Management Model Based on Maximum Benefits is established and the model will be used to increase the revenue of airport taxi drivers and the efficiency of airport taxi rides, reducing the waste of taxi resources.

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