Airport Taxi Dispatching Based on VISSIM and Multi-objective Programming Model

Boying Lv¹*, Yishuai Tian¹, Botao Liu¹

¹College of Hydraulic & Environmental Engineering, China Three Gorges University, Yichang, 443002, China.

ABSTRACT

This paper solved the problem of how to manage the distribution of airport taxis and balance the revenue of long- and short-haul passenger taxis. In this research, we established a multi-objective programming model, which was solved using genetic algorithms to obtain a reasonable distribution scheme in airport with the highest riding efficiency: set up a pick-up location in the middle of the pick-up area, requiring all cars to leave uniformly when fully loaded, and release an average of 78 taxis per batch in every single boarding location. In addition, with the queuing theory we set the basic parameters of the road. Taking the income balance difference as the objective function, we used the VISSIM software to simulate the simulation. Then the short-term “priority” arrangement plan was: Calculate the ratio of the travel time of the short-distance taxi to the distance from the airport to the city center. If the ratio is less than 0.0659, the taxis that meet the conditions are allowed to be given priority after return. The results have some guidance and strong practical significance.

Keywords: VISSIM; Airport taxi; Genetic algorithm; Short-distance “priority”
1. Introduction
The queuing of airport taxis has become one of the reasons that seriously affect airport congestion. How to manage airport taxis and balance the revenue of long- and short-haul passenger taxis is an important issue to improve the degree of airport distribution [1,2]. The management scheme of airport taxis must not only consider the efficiency of passenger collection and distribution, but also ensure that the waiting time of taxis cannot be too long. For taxis with long waiting times in the car pool and receiving short-distance orders, compared to long-distance order drivers, it will bring poor economic benefits, resulting in imbalances in long-distance and short-distance driver income [3]. Therefore, it is very important to design a ride plan in the passenger area and how to give a certain “priority” to short-haul passengers to and from the taxi to balance the revenue [4].

Predecessors have made many contributions to taxi scheduling issues and route optimization. For example: Wei Zhang [5] and others used genetic algorithms to obtain the maximum payment ratio and cruising distance to ensure the interests of taxi passengers and drivers, thereby making bypass carpooling a reality. Zhaowei Qu [6] and others based on the taxi GPS data and combined the TSLM model to study the impact of the passenger's maximum acceptable distance on the TSLP. Babaei et al. [7] studied the case of Zanjan city in Iran and established a linear scale to obtain a function to reduce total travel time, total waiting time and taxi route optimization. Kim [8] et al. studied the airport gates and used algorithms such as tabu search to solve the problem of taxi congestion on the airport ramp, resulting in delayed boarding, and made the circulation on the passenger terminal and ramp effective. Ma [9] et al. based on the traditional taxi operation mode, applied genetic algorithms to solve the multi-objective optimized route model of taxi carpooling, and conducted a case study based on a 24-node network. Jiang [10] used the IPSO and CPSO algorithms to solve the problem of taxi dispatch at the airport, thereby reducing the waiting time of taxis during peak periods.

However, most of the existing literature only solved the problem of airport route planning [11,12] or the forecast of taxi numbers [13], and few studies have been conducted on the number of taxis released in each batch and the specific locations of the boarding locations. Therefore, this paper first established a multi-objective programming model based on reducing the conflict between people and vehicles, and maximizing efficiency and comfort. Then, we used genetic algorithm to solve the vehicle scheduling scheme. To provide a certain feasible solution for the airport taxi management department, we used the queuing theory model based on the definition of income balance, having taken the income balance difference as the objective function, and having used VISSIM software to simulate the simulation, formulate the priority rules for short-haul passenger taxis.

2. Model assumptions
(1) After the taxis carry passengers, they are released in batches. Only when the last car leaves, the next batch of taxis and passengers can be introduced.
(2) Passengers travelling by taxi can board at most one person, and each car can only take one order at a time.
(3) Passengers arrive first in line and choose the vehicle closest to them
(4) Assuming that the taxi follows the traffic rules and order, no accidents occur while driving

3. Establishment of Airport Taxi Ride Dis-
patching Model

3.1 How to ensure the safety of passengers

First of all, we considered how to ensure the safety of passengers and vehicles. There may be safety hazards such as pedestrian congestion and rear-end collisions when riding in the airport waiting area. According to relevant literature\(^\text{[15]}\), it can be known that the hidden safety hazards of passengers getting on the bus were mainly the conflict between people and vehicles, that was, the situation where people and cars compete for roads, as shown in Fig.1.

![Fig. 1 The Schematic diagram of traffic hazards in the airport waiting area](image)

Combining the traffic safety formula\(^\text{[15]}\), we can know that in order to ensure the safety of vehicles and passengers, on the one hand, the number of boarding positions needed to be limited, and the number of boarding positions was proportional to the number of collisions; on the other hand, passengers can be set to board the car from the end of the fleet, but it was necessary to comprehensively consider the riding efficiency to determine the boarding position; it was also necessary to provide for departures in batches. After receiving guests, you cannot leave immediately. You must wait for all passengers to board and leave together.

3.2 How to choose a pick-up location

In the case of ensuring the safety of passengers and vehicles, taking a boarding position as an example, comparing the boarding time of the boarding positions at different positions in order to obtain the boarding position with the shortest time and the highest efficiency. Set the number of taxis for each release to 2N. The three positions of the boarding position were shown in Figure 2, 3, and 4.
With reference to Fig.2, passengers board the vehicle from front to back. According to Hypothesis 3 of the model, passengers line up to take the vehicle closest to them, then the time required for all passengers to board the vehicle is $T_1$:

$$T_1 = \frac{2N(m+n+l)+b}{v}$$

Where: the interval between passengers is $l$, generally $l = lm$, the length between the centers of two lanes is $b$, the interval between taxis is $n$, and the average length of taxis is $m$.

Combined with Fig.3, when passengers line up from the middle of the fleet to both sides, the time required for all passengers to get on the train is $T_2$. Its symbolic meaning is the same as the above formula.

$$T_2 = \frac{b + N(l + n + m)}{v}$$

Combined with Fig.4, passengers queue up to get on the bus from the end of the queue, so the time required for all passengers to get on the bus is $T_3$, as follows:

$$T_3 = \frac{2N(m+n+l)+b}{v}$$
By calculating the three bus times under the open position of the above three bus positions, and comparing the respective bus times, it can be concluded that the bus position with the shortest time and the highest efficiency is located in the middle section of the bus area.

### 3.3 Determination of objective function

Based on the opening of a best place to get on the bus, we continued to discuss how to arrange taxis to carry passengers to maximize efficiency. The management department hopes to arrange the maximum number of passengers to board the bus in the shortest time for each release. Therefore, two objective functions were set as follows: maximization of boarding efficiency and minimization of travel distance.

**Maximize the efficiency of taxi driver departure**

The time a taxi enters the area and waits for passengers to board is called boarding time. When all passengers are on board, the controller allows the taxi to leave the area. Only when the last car leaves can the next cabs and passengers be brought in. When the airport passengers arrive at the peak, efficient departure can speed up the passenger transportation and improve the airport service quality. Therefore, the objective function is the shortest service time, and the formula is as follows:

$$
\min \max (t_1, t_2, \ldots, t_n) \quad (i = 1, 2, \ldots, N)
$$

Where:
- $i$ represents the $i$-th passenger who needs to take a taxi driver;
- $t_i$ refers to the time from the boarding position of the $i$-th passenger to the boarding position.

**Maximize passenger comfort**

According to the assumption that the three passengers take the nearest bus in line, and the last passenger walks the longest distance, in order to improve the service level of the "last station", the average travel path of each passenger at the bus station is reduced, and the comfort level of passengers is defined, taking the shortest average travel path as the objective function, as follows:

$$
\min \frac{\sum_{i=1}^{N} I_i}{N}
$$

Where:
- $I_i$ represents the distance from passenger $i$ to taxi;
- $N$ is the total number of passengers.

### 3.4 Determination of decision variables

The passenger serial number is $i (i = 1, 2, \ldots, N)$,

$$
S_{ij} = \begin{cases} 
1, & \text{Passenger } i \text { chooses taxi } j \\
0, & \text{else}
\end{cases}
$$

Taxis will wait in the area until passengers get on the bus. The vehicle remained stationary while the passengers chose the taxi they wanted to take. Think of the passenger and the taxi as particles, respectively, to get the passenger from the queue into the bus area until the time to get on the bus is as follows;
Near lane
\[ t_y = \begin{cases} \frac{il + j(n+m)}{v} & \text{Far lane} \\
\frac{il + \sqrt{j^2(n+m)^2 + b^2}}{v} & \end{cases} \quad (i = 1,2,L,N; \; j = 1,2,L,N) \]

Where:

- \( t_y \) represents the time taken by the \( i \)-th passenger to board the \( j \)-th taxi longitudinal to the boarding position.

- Generally, \( m = 4, \; n = 5, \; b = 0.3, \; l = 1 \), in meters.

Therefore, multiple objective functions, corresponding constraint conditions and decision variables were determined, and a human-vehicle arrangement model based on objective programming was established, which is as follows:

\[
\begin{align*}
\min & \quad \max (t_1, t_2, L, t, L, t_N) \quad (i = 1,2,L,N) \\
\min & \quad \sum_{i=1}^{N} l_i/N \\
\sum_{i=1}^{N} S_{ij} = 1 \quad (j = 1,2,L,N) \\
\sum_{i=1}^{N} S_{ij} = 1 \quad (i = 1,2,L,N) \\
\end{align*}
\]

4. Priority scheduling scheme based on VISSIM simulation

4.1 Income equilibrium

Take the taxi queue in the airport storage pool as the timing moment, and define the taxi’s profit rate \( \alpha \) as the ratio of the taxi revenue to the urban area from this moment \( q_m \) to the urban arrival time \( t_m \) ratio. The income equilibrium degree was the difference between the two departure rates of short-distance taxi and long-distance taxi. It was required that the income of the two taxis be as balanced as possible, that was, there must be a minimum of the income balance.

\[
\min \left\{ \frac{q_m - q_m^2}{t_m - t_m^2} \right\}
\]
Therefore, the question turned into how to define the short return time \( t_e \), that was, the time required for a taxi to return to the airport. Considering the diversity of the situation in airports across the country, if you collect existing actual data or only consider the impact of short-haul definition time, you cannot get general rules, so VISSIM simulation was used.

### 4.2 VISSIM Simulation Based on Queuing Theory

Because the distance \( l_m \) from the airport to the city center was different, the management department should also consider the distance from the airport to the city center in a short distance, so these two factors were used as numerical simulation variables. We used VISSIM to simulate a large number of different values of short-distance time and the distance of taxis to the urban area. After outputting time parameters, we calculated the balance of different situations. Taxi queuing can be regarded as a single-point queuing method \[^{15}\]. Taxi is used as the research object. Only when one car leaves the queuing system can the next taxi be accepted for service. The applicable model for this layout is the M/M/1 queuing model with a negative exponential distribution of taxi arrival mode \[^{16}\], and the probability density of the time interval \( T \) for the arrival is given by:

\[
    f_r(t) = \begin{cases} 
    \frac{\lambda e^{-\lambda t}}{t} & t \geq 0 \\
    0 & t < 0 
    \end{cases}
\]

Observe the service status of the queuing system, which can be divided into busy periods, idle periods and off periods. Define the busy rate \( \rho \) to describe the busyness of the system, the expression is as follows:

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

Among them, \( C \) is the number of service platform settings, \( \lambda \) is the average taxi arrival rate, \( \mu \) is the number of taxis leaving the system per unit time and is defined as the average service rate.

### 4.3 Queuing model

Establish an airport taxi queuing model based on the relevant theories of queuing theory. \[^{16}\]

When the system is in a busy period and the input-output rate reaches a relatively stable state, the average queue length \( L_s \) and average stay time \( W_s \) of the taxis in the system are used as the main output parameters of the queuing system. The corresponding expressions are as follows:

\[
    E(L_s) = \frac{\rho}{1 - \rho} \\
    E(W_s) = \frac{\lambda}{\mu(\mu - \lambda)}
\]

In summary, the final model was expressed as follows:

\[
    \min \left\{ \frac{q_{m1}}{t_{m1}} - \frac{q_{m2}}{t_{m2}} \right\} \\
    \text{s.t.} \left\{ \begin{aligned}
    t_a & \leq t_e \leq t_b \\
    t_m & = W_s + t_s \\
    q_m & = \varepsilon \cdot t_m \cdot v_m \\
    l_a & \leq l_m \leq l_b
    \end{aligned} \right.
\]

Where \( l_a, l_b \) is the search interval that defines the time for short distances, and \( l_a, l_b \) is the
search interval that the airport is away from the city center, $c$ is the average revenue per kilometer of the local taxi, $v_m$ is the average speed of the taxi, and $t_s$ is the time to return to the city center after finishing the line.

5. Model solving and result analysis

5.1 Airport Taxi Ride Dispatching Model

The solution was solved by genetic algorithm \cite{14}, and the algorithm flow chart was shown in Fig. 5. Set population size $N = 50$, mutation probability $P_m = 0.1$, iteration times 1000. Taking 1 car as the step length, the time and the shortest average path needed for 50~100 cars to enter the bus group were calculated respectively. The variation results of the shortest walking distance, total ride efficiency and number of released taxis are plotted in figure 6 and 7. We can get the total efficiency of different taxis under different release conditions. Therefore, the dispatching of airport taxis can meet the requirement of releasing 78 taxis at a time, which can achieve the maximum efficiency of 0.59 and the shortest distance on foot for passengers was 117.9 meters.

![Fig. 5 Genetic Algorithm Flowchart](image)
To promote a single boarding location to more than one boarding location. The boarding position was open in the middle of the road in the bus area to maximize the efficiency of the bus, so the location of the boarding position has been determined. By changing the number of bus places, the bus time under the condition of different number of bus places was obtained, and was drawn in Fig. 8. The analysis shows that the number of different boarding positions changed, making the number of taxi release doubled, but the total efficiency would not change.

Based on the comprehensive analysis, although the more the number of boarding positions, the shorter the load time was, the more the number of boarding positions will make the management cost too high. The specific number of boarding positions should be determined by taking the airport management cost into consideration.

5.2 Priority scheduling scheme based on VISSIM simulation

Simulation parameter design

First of all, basic parameters of the simulation need to be set. According to relevant literature
[17], input parameters required by the airport taxi queuing theory model were obtained. Basic parameters of the road surface, such as road width, were set according to the actual situation, as shown in Table 1.

## Table 1 Parameter setting of simulation system

| types of the parameter                      | size  | types of the parameter                      | size  |
|--------------------------------------------|-------|--------------------------------------------|-------|
| Vehicle speed /m·s⁻¹                       | 8     | Passenger entry clearance time /s          | 35    |
| Parking space/m                            | 1.5   | Average clearance time at taxi entrance /s | 90    |
| Pedestrian walking speed /m·s⁻¹             | 1.2   | The road width /m                          | 3.5   |
| Average flow rate at taxi entrance/car     | 15    | Average yield per kilometer / yuan         | 3     |
| The average taxi departure time in the pickup area/s | 30    | Number of main and parallel lanes          | 3     |

### Simulation scheme design

Based on the necessary parameters of road vehicles obtained from the above model, VISSIM simulation was used to analyze the basic situation of road traffic and made reasonable adjustments [18], so as to obtain the schematic diagram of road design from the airport to the urban area and the simulation of taxi waiting for passengers in the airport bus area, as shown in figure 9 and 10 respectively.

![Traffic simulation from airport to urban area](image1)

**Fig.1** Traffic simulation from airport to urban area

![Simulation of taxi waiting at the airport for pick-up](image2)

**Fig.2** Simulation of taxi waiting at the airport for pick-up
The short-distance definition time and distance from the urban area were changed with steps of 0.01 and 0.1 respectively, and VISSIM simulation solution method \[^{[19]}\] was used to calculate the parameter values in the model under each data, and then the equilibrium degree of the objective function was calculated. The relationship between the equilibrium degree and the short-distance definition time and the distance from the airport to the urban area was drawn as Fig.12.

If we want to make the revenue of long-distance taxi and short-distance taxi as far as possible, we can analyze the specific situation of the region. Therefore, the general rule can be drawn as follows: when the ratio between the short-distance defined time allowed by the management department and the distance from the local airport to the city center is less than 0.0659, short-distance taxis meeting the above conditions can be allowed to be released in priority.

6. Advantages of the model

1) The safety of passengers and vehicles was fully taken into account in the bus

Fig.3 Simulation of overall effect

Fig.4 3D map of simulation short distance defining time, distance from urban area and balance
scheduling scheme, and the location of the boarding position was discussed, which was seldom discussed in the previous literature.

2) The multi-objective programming model further extended and applied the quantity change of vehicle position to make the result more profound.

3) VISSIM was used to simulate the roads around the airport, effectively solving the problem of lack of data, and the method was innovative.

7. Shortcomings of the model

1) Genetic algorithm was used to solve model 1, and the approximate solution of the global optimal solution was taken as the optimal solution of the model

2) In this paper, when constructing VISSIM software for simulation, many parameters were calibrated under ideal conditions, so there were certain subjective factors, and the conclusion would be deviated from the actual situation.

8. Promotion of the model

The model established in this paper was consistent with the actual situation, which had certain guidance and strong practical significance. The airport taxi ride scheduling problem involved the efficiency of road traffic, congestion, human-vehicle conflict and other issues, which can be used to improve the ride efficiency. In addition, the vissim-based simulated taxi traffic and priority scheme can be applied by relevant management departments, which helps to encourage short-distance passenger drivers to commute to and from the airport and the city, and promotes the airport to collect and disperse passengers.

9. Conclusion

This paper used a linear programming model and genetic algorithm to solve the problem of airport setting "boarding position", taxi and passenger arrangement. Through VISSIM simulation, a method for balancing the benefits of some short-distance taxis and long-distance taxis was obtained. We can know that each time 78 taxis were released and they all left when the bus was fully loaded. The shortest time was 131s, the average shortest path was 117m, and the best scheduling scheme under the condition of multiple boarding points was promoted. If the ratio of the distance from the city center to the distance from the local airport is less than 0.0659, the taxi will meet Condition given priority.

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