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# The Optimal Queuing Strategy for Airport Taxis

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**ABSTRACT** In recent years, with the increase in the frequency of residents' trips, the problem of taking taxis in airports, train stations, and other transportation hubs has received wide attention, especially when we need to evacuate people in major emergencies such as epidemics, the traffic efficiency of these transportation hubs is critical. To improve the efficiency of passengers taking taxis at airports, the Hohhot Baita Airport in China is taken as an example, this paper studies the optimal queuing strategy of airport taxis under the condition of different numbers of pick-up points and drive lanes. based on the queuing theory, and the Monte Carlo simulation is adopted to obtain the average time spent by passengers to take taxis under different taxi-taking strategies, as well as the optimal number of taxi pick-up points and the optimal number of taxis in the boarding area under the condition of different numbers of lanes. The results show that the two-lane queuing model was significantly better than the single-lane queuing model, and the time optimization ratio exceeded 25%. However, the two independent lanes queuing mode could further reduce the average taxi-taking time by about 30%. The research results have an important reference value for the improvement of existing taxi lanes and the design of newly-constructed taxi lanes in airports, train stations, and other transportation hubs.

**INDEX TERMS** Airport taxis, double queuing, Monte Carlo, pick-up points, drive lanes.

## I. INTRODUCTION

With the continuous improvement of people's living standards and the increase in the number of vehicles, the frequency of residents' trips has increased significantly. At airports, train stations, and other large-scale transportation hubs, the problem of taxi passengers' queuing problem is becoming increasingly prominent. As the first choice of many passengers and the business card of the city, In 2019, the taxi passenger volume accounts for 27.2% of the annual passenger traffic volume [1], taxis are one of the important transportation modes connecting the transportation hubs; the queuing efficiency is related to the travel experience of passengers, and it will affect the city's image [2]–[4]. Meanwhile, passenger-cargo transfer centers such as airports and railway stations generally have the characteristics of the large passenger-cargo amount and short stay time; if passengers cannot be evacuated in time, it would generate high waiting-time cost [5]–[7]. Therefore, improving the evacuation efficiency of airports and train stations can reduce the waiting time of taxi passengers, effectively improve traffic congestion, and reduce the cost generated due to the queuing

problem of taxi passengers [8]–[10]. At present, domestic and foreign scholars' research on the taxi-passenger queuing problem mainly focuses on two directions: the dual-queuing model and the system simulation.

In terms of the dual-queuing model, combining with the queuing theory, Kendall [11] proposed the taxi-passenger queuing problem for the first time and believes that the taxi-passenger queuing is two-way, on the one hand, the taxis waiting for the passengers need to queue up; on the other hand, the passengers waiting for the taxis also need to wait in line [12]–[14]. In the queuing process, the long waiting time has a significant negative impact on the passengers' service experience [15], [16]. Therefore, it is necessary to further improve the application of the double-queuing model in the taxi-passenger pairing problem. Takahashi *et al.* [17] adopted the double-queuing theory to study the synchronous queue problem with two buffers with limited capacity. Wang *et al.* [18] studied the taxi-passenger double queuing system under the social optimal conditions. Wang and Liu [19] established a double queuing system for passenger taxi services and proposed a dynamic taxi dispatch strategy to adjust the taxi arrival rate according to the congestion status of the taxi stands. However, by summarizing the existing literature, it is found that, in current

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studies concerning the double-queuing model, there are few researches considering the impact of the number of taxi lanes, the number of taxi pick-up points, and the number of taxis in the boarding area on the taxi-taking efficiency of passengers at the airport at the same time.

In terms of system simulation, both the number of taxi lanes and the number of taxi pick-up points will affect the queuing efficiency of taxis and passengers. To meet the demand of taxi transportation and alleviate the mismatch of supply and demand between taxi and passengers, Yang *et al.* [20] proposed a model of urban taxi fleet size calculated based on GPS tracking data. Sun *et al.* [21] analyzed the traffic capacity of the taxi passenger-picking system under the condition of single drive lane, conducted a correlation fitting analysis on the process of taxi queuing, passenger picking-up, and taxi leaving, and obtained the conclusion that in the single-lane taxi queuing system with a certain number of parking places, the number of taxi parking places is inversely proportional to the marginal growth rate of the traffic capacity. Yun *et al.* [22] established a double-layer optimization model for the service station number of the taxi queuing system under the condition that all taxi service stations are busy, then through the simulation and the comparison between the obtained data and original data, the optimal number of taxi lanes was obtained. Wang and Yan [23] established a new taxi passenger assignment model and analyzed the scheduling of passengers and taxis in different situations.

Although the system simulation analyzed the impact of the number of pick-up points and the number of lanes on the queuing efficiency of the taxis and passengers, it hasn't thoroughly considered the connection problem of passengers taking taxis one after another during the queuing process and ignored the impact of the queuing behavior of taxis and passengers on the overall outcome. Ji *et al.* [24] analyzes the evolution of law and traffic efficiency of road traffic flow under the condition of taxi random and fixed-point parking behavior. Naor [25] studied the behaviors of passengers in the queuing system and analyzed the joining behavior of passengers in the queues under the equilibrium conditions. Afeche *et al.* [26] studied the problem of passenger taxis from the perspective of cross-network and analyzed the behavioral characteristics of the passengers. Wong *et al.* [27] established a mathematical model based on the absorbing Markov chain to describe the movement of the taxis. Yin *et al.* [28] analyzed the distribution network of taxis from different angles and established an evaluation model for the status of the taxis. Ji *et al.* [29] Based on taxi automatic vehicle location data, studies the behavior of taxi drivers to serve customers.

Based on the above research on the queuing behavior of taxis and passengers, through the field investigation of the taxi-taking process in Hohhot Baita Airport, it is found that it often takes a long time for passengers to place their luggage when taking the taxis, and the resulting error has a greater impact on the entire queuing system. Therefore, this paper divides the queuing behaviors of taxis and passengers into three parts: the passengers' queuing behavior,

the taxis' queuing behavior, and the passengers' behaviors of placing luggage and getting on the taxis afterward. On this basis, combining with the double-queuing model and the system simulation method, this paper analyzed the optimal queuing strategy of airport taxis, and the research results have important significance for the improvement of the city's image and the rapid evacuation of airport passengers during emergencies.

## II. PROBLEM DESCRIPTION AND ASSUMPTIONS

### A. PROBLEM DESCRIPTION

The essence of the taxi-passenger queuing problem is a transformation of the queuing problem, it is a double-queuing problem of service providers and service receivers transformed from the traditional queuing problem [30]. At the airports, train stations, and other passenger hubs and centers, the taxi-passenger queuing problem is of high regularity. Generally, there are three situations: first, there are few passengers and many taxis; second, there are many passengers and few taxis; third, there are many passengers and many taxis. In terms of queuing problems in the first two situations, due to the low arrival rate of passengers or the low service rate of taxis, queuing and waiting is inevitable, so there is less room for optimization [31].

Therefore, the target problem studied in this paper is the optimal queuing strategy of airport taxis and passengers under the condition that there are plenty of taxis and passengers. The specific content includes: how many pick-up points and lanes should be arranged? how to arrange the passengers to get on the taxis in batches so that the average queuing time of the taxis and passengers could be the shortest. The schematic diagram of an airport with multiple taxi pick-up points and lanes is shown in Figure 1. In the figure, the left part is the taxi arriving area, it is called the taxi pool; the right part is the passenger waiting area, it is called the boarding area.

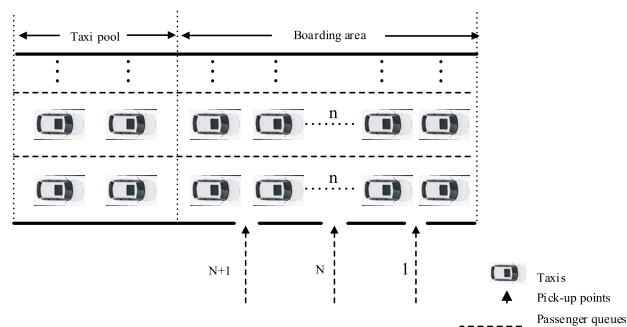


FIGURE 1. Strategy for airport taxi-taking with multiple pick-up points and multiple lanes.

Based on the results of existing research, this paper takes the Hohhot Baita Airport in China as the research object, through an in-depth investigation on the airport taxis, and after fully understanding the taxi-taking rules of airport passengers, this paper constructs an optimization model based on the queuing theory, and adopts the Monte Carlo method

to simulate the average time for passengers to take taxis under different taxi-taking strategies, and finally obtains the optimal taxi-passenger queuing strategy under the conditions of different numbers of pick-up points and lanes. The model and method proposed in this paper are not only suitable for the optimization of taxi queuing strategies at current traffic hubs but also have important reference value for the improvement of existing lanes and the design of newly constructed lanes.

**B. BASIC ASSUMPTIONS**

This paper made the following basic assumptions for modeling:

- Assumption 1: There are plenty of passengers and taxis;
- Assumption 2: The taxi driver is skilled in driving and the moving speed is relatively stable;
- Assumption 3: The average walking time of passengers is relatively stable can well follow the instructions of the attendants and the variance is relatively small.

**C. EXPLANATION OF SYMBOLS**

- L: The average front-and-back distance between taxis parked in the taxi pick-up areas, its value takes 5.3m according to the standard size of the parking space;
- W: The average left-and-right distance between taxis parked in the taxi pick-up areas, its value takes 2.5m according to the standard size of the parking space;
- R: the number of passengers in the taxi, its mean value is  $\bar{R}$  and the variance is  $\text{Var}(R)$ ;
- $\Delta t$ : The departure time interval of passengers at the pick-up point, its mean value is  $\bar{\Delta t}$  and the variance is  $\text{Var}(\Delta t)$ ;
- V: The walking speed of passengers from the pick-up points to the taxis, its unit is meter/second (m/s), the mean value is  $\bar{V}$ , and the variance is  $\text{Var}(V)$ ;
- $T_f$ : The time it takes for passengers to place their personal belongings and get on the taxis, the unit is seconds (s), the mean is  $\bar{T}_f$ , and the variance is  $\text{Var}(T_f)$ ;
- $T(n)$ : The time it takes for taxis to move  $n$  units of car length distance from the taxi pool to the boarding area, the mean value is  $\bar{T}(n)$  and the variance is  $\text{Var}(T(n))$ .

**III. MODELING OF AIRPORT TAXI QUEUING PROBLEM**

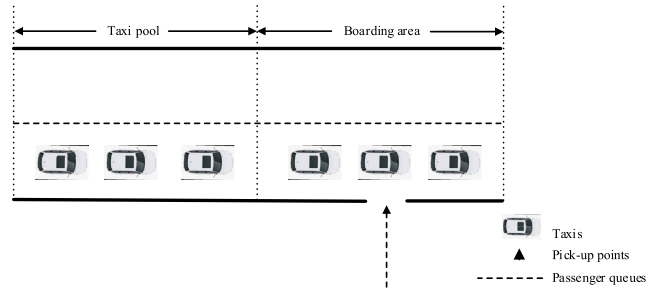
Targeting at the conditions of different number of pick-up points, different number of lanes, and different number of taxis in the boarding areas, this paper carried out research on the optimal queuing problem of airport taxis as follows.

**A. OPTIMAL TAXI STOP-START STRATEGY UNDER THE CONDITION OF SINGLE PICK-UP POINT AND SINGLE LANE**

In terms of the single pick-up point and single lane taxi-taking method, the decisions need to be made are: at which positions should the taxi pick-up points be arranged; at which positions should the taxis be parked; and how many taxis should be arranged to pick up passengers at a time.

Considering the walking distance and walking speed of passengers, if it is assumed that, only after each batch of taxis

that picked up the passengers has driven away, can we arrange the next batch of passengers to take the taxis, then the optimal pick-up point should be arranged in the center of the taxi queue, as shown in Figure 2.



**FIGURE 2. Strategy for taxi-taking with single pick-up point, single lane, and three taxis in the boarding area.**

After the positions of the pick-up points and the taxi parking places have been determined, the management decision to be made is how many taxis should be arranged to pick up passengers at a time.

Assuming that at each time  $n$  taxis are arranged to pick up the passengers, then the time it takes to complete a batch of taxi-taking actions is determined by the taxi at the farthest position from the pick-up point. It is not difficult to find that if the pick-up point is arranged in the center of  $n$  taxis, the distance from the taxi furthest from the pick-up point to the taxi point is  $\frac{n-1}{2}L$ . Therefore, the total time it takes to complete a batch of taxi-taking actions is:

$$T(n) + (2R - 1)\Delta t + \left(\frac{n-1}{2}L\right)/V + T_f \quad (1)$$

where,  $T(n)$  represents the moving time of the taxi;  $(2R-1)\Delta t$  represents the queuing time of the passenger farthest from the taxi and is the last one in the queue. As for the passengers queuing behind it, with the queue moves forward, they are relatively close to the positions to taxi-taking, so it is not necessary to take their queuing time into consideration;  $\left(\frac{n-1}{2}L\right)/V$  represents the walking time of the passenger farthest from the taxi;

$T_f$  represents the time it takes for passengers to place their personal belongings and get on the taxis.

According to the above discussion, the following optimal taxi stop-start model with single pick-up point and single lane can be established:

$$\text{Min} \left( T(n) + (2R - 1)\Delta t + \left(\frac{n-1}{2}L\right)/V + T_f \right) / n \quad n = 2, 3 \dots \quad (2)$$

where,  $n$  is the decision variable.

**B. OPTIMAL TAXI STOP-START STRATEGY UNDER THE CONDITION OF MULTIPLE PICK-UP POINTS AND SINGLE LANE**

When multiple taxis are arranged to enter the boarding area at a time, only one pick-up point would greatly increase

the walking distance of the passengers, thereby affecting the overall queuing efficiency. For this reason, multiple pick-up points should be considered. When all passengers are arranged in one row, the passengers in front of the queue are assigned to the designated pick-up points, as shown in Figure 3. As we consider the taxi queuing strategy under the condition of multiple pick-up points and multiple taxis in the boarding area, it is not difficult to prove that, when the number of taxis entering the boarding area is an integer multiple of the number of pick-up points, the taxi-taking efficiency is the highest.

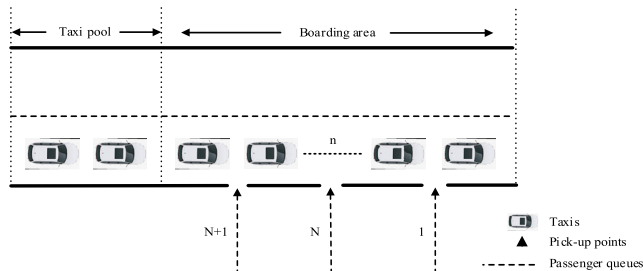


FIGURE 3. Strategy for taxi-taking with multiple pick-up points and single lane.

Assume there are  $m$  pick-up points, each time,  $m * n$  taxis are arranged to pick up the passengers, then the time it takes for a batch of taxi-taking actions is determined by the taxi farthest from the pick-up point. It is not difficult to calculate that the distance from the taxi furthest from the pick-up point to the pick-up point is  $\frac{n-1}{2}L$ . The time it takes to complete a batch of taxi-taking actions is:

$$T(m * n) + (2R - 1)\Delta t + \left(\frac{n - 1}{2}L\right) / V + T_f \quad (3)$$

Therefore, an optimal taxi stop-start model with multiple pick-up points and single lane can be established as shown in Figure 3:

$$\text{Min} \left( T(m * n) + (2R - 1)\Delta t + \left(\frac{n - 1}{2}L\right) / V + T_f \right) / (m * n) \quad (4)$$

$m = 1, 2 \dots ; n = 2, 3 \dots$

where,  $m$  and  $n$  are decision variables.

### C. OPTIMAL TAXI STOP-START STRATEGY UNDER THE CONDITION OF MULTIPLE PICK-UP POINTS AND MULTIPLE LANES

The efficiency of the single-lane queuing model may not be the best. For this reason, this study further considers the taxi queuing mode with multiple pick-up points and multiple lanes, as shown in Figure 1. It is not difficult to prove that when the total number of taxis in the boarding area is an integer multiple of the product of the pick-up point number and the lane number, the taxi-taking efficiency is the highest.

Assume there are  $m$  pick-up points and  $k$  lanes, each time,  $m * k * n$  taxis are arranged to take passengers, then the time it takes to complete a batch of taxi-taking actions is determined

by the taxi farthest from the pick-up point. The distance from the farthest taxi to the pick-up point is  $\frac{n-1}{2}L + (k - 1)W$ . Therefore, the total time it takes to complete a batch of taxi-taking actions is:

$$T(m * n) + (2R - 1)\Delta t + \left(\frac{n - 1}{2}L + (k - 1)W\right) / V + T_f \quad (5)$$

Therefore, an optimal taxi stop-start model with multiple pick-up points and multiple lanes can be established as shown in Figure 1:

$$\text{Min} (T(m * n) + (2R - 1)\Delta t + \left(\frac{n - 1}{2}L + (k - 1)W\right) / V + T_f) / (m * n * k) \quad (6)$$

$m = 1, 2 \dots ; n = 2, 3 \dots ; k = 1, 2 \dots$

where,  $m$ ,  $n$  and  $k$  are decision variables.

### D. OPTIMAL TAXI STOP-START STRATEGY UNDER THE CONDITION OF SINGLE PICK-UP POINT AND TWO LANES

The above models mainly discuss the optimal taxi arrangement in the boarding area and the design of pick-up points in general conditions, among these models, the model for multiple pick-up points and multiple lanes is quite versatile. To this end, this paper respectively discussed the optimal taxi arrangement in the boarding area under different pick-up points and selected the optimal queuing strategy with the shortest average taxi stay time.

From the model for multiple pick-up points and multiple lanes, we can obtain the optimal pick-up point number and taxi number arrangement model under the condition of two lanes:

$$\text{Min} (T(m * n) + (2R - 1)\Delta t + \left(\frac{n - 1}{2}L + W\right) / V + T_f) / (m * n * 2) \quad (7)$$

$m = 1, 2 \dots ; n = 2, 3 \dots$

where,  $m$  and  $n$  are decision variables.

The taxi-taking strategy under the condition of two lanes is shown as Figure 4.

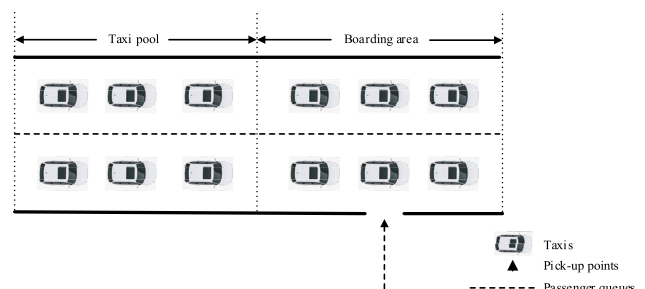
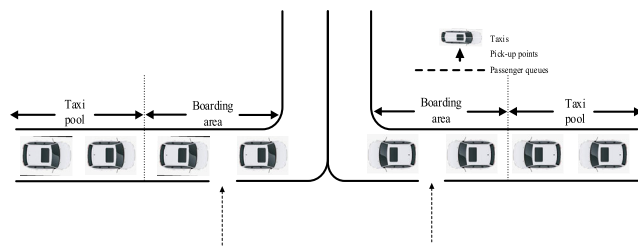


FIGURE 4. Strategy for taxi-taking with single pick-up point, two lanes, and six taxis in the boarding area.

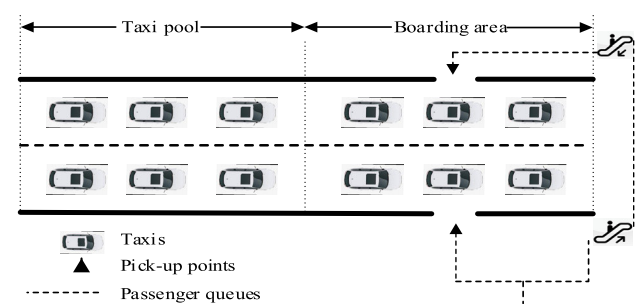


**E. AN IMPROVED DESIGN FOR TAXI STANDS AT THE AIRPORT**

In previous research, we gave more consideration to the design of the taxi-taking strategy of the current airport, and concerned more about the optimization of the taxi-taking strategy for correlated multiple lanes, while ignored the taxi-taking efficiency of independent lanes. Through field investigation, it was found that when too many taxis are parking in the boarding area, it is easy to cause congestion and low efficiency. At the same time, in the process of queuing, the slow movement of passengers, and the placement of their belongings will take a lot of time. To this end, this study considered to turn the two-taxi correlated queuing problem into an independent queuing problem, and the specific queuing strategy is shown in Figure 5 and Figure 6. In Figure 5, we assume that the taxis can drive clockwise and counterclockwise. This queuing strategy transforms the problem of two-lane parallel taxi queuing into the problem of two-lane independent taxi queuing, since the correlation between the two lanes has been removed, it effectively raises the taxi-taking efficiency. In Figure 6, we achieve the same goal as Figure 5 by adding stairs. The organization of taxis and passengers will be easier to operate than the independent lane in Figure 5.



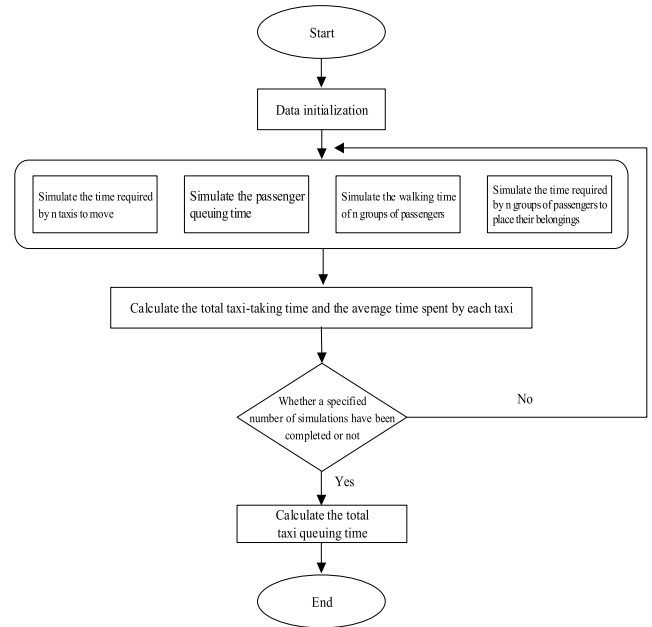
**FIGURE 5. Strategy for taxi-taking with independent taxi lanes.**



**FIGURE 6. Strategy for taxi-taking with parallel two lanes.**

**F. ALGORITHM FLOW FOR THE COMPUTER SIMULATION OF AIRPORT TAXI-TAKING QUEUING PROBLEM**

To thoroughly analyze the different taxi-taking strategies, this paper gave the algorithm flow for the computer simulation of the airport taxi-taking queuing problem, as shown in Figure 7. In this paper, it is assumed that the arrival



**FIGURE 7. Algorithm flow for simulation of different taxi-taking strategies.**

of passengers, the arrival of taxis, and the number of passengers on the taxis obey the Poisson distribution, the queuing of taxis and passengers follows the rule of first-come-first-served, and the movement of passengers and taxis approximately obeys the normal distribution. The time interval for passengers to queue and the time it takes for passengers to place their luggage and get on the taxis approximately obey the negative exponential distribution [32], [33]. For the above four kinds of data, we have obtained enough sample data through field investigation in advance.

The specific calculation steps of the algorithm are as follows:

Step 1: Initialize the basic data, including the number of pick-up points  $m$ , the number of lanes  $k$ , the number of taxis in the boarding area  $m * n * k$ , the data of samples, and the total number of tests.

Step 2: Use the Monte Carlo method to randomly generate the taxi's moving time  $T(n)$ , the passenger departure time interval  $\Delta t$ , the passenger walking speed  $V$ , the time it takes for passengers to place luggage and get on taxis, and the number of passengers in each taxi  $R$ .

Step 3: Use the above random numbers and Formula 3 to calculate the time it takes for the last passenger getting on the taxi  $T_L$ , then the average taxi-taking time of this batch is  $\frac{T_L}{m * k * n}$ .

Step 4: Determine whether a specified number of simulations have been completed or not. If not, return to the second step; If the specified number of simulations have been completed, proceed to the next step;

Step 5: Calculate the total average taxi-taking time in the test, then the simulation ends.

### IV. EXAMPLE ANALYSIS

With the rapid growth of ride-hailing, the airport divides the queue of car-hailing and taxi into different lanes. To further verify the feasibility of the model, according to the survey data, used the Monte Carlo method to simulation, and used the R software to programming. Meanwhile, the taxi-taking strategy for single pick-up point and two lanes shown in Figure 8 was taken as an example, and the Hohhot Baita Airport was taken as the object to conduct the field investigation and simulation tests.

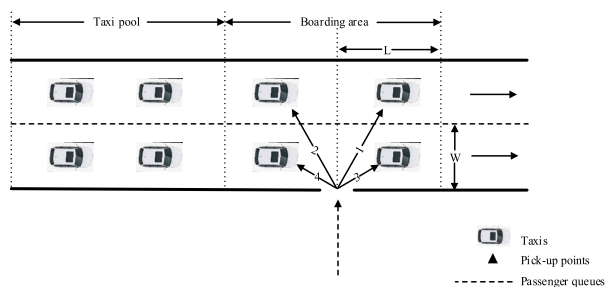


FIGURE 8. An optimized strategy for taxi-taking with single pick-up point, two lanes, and four taxis in the boarding area.

TABLE 1. Time sampling data T (n) of taxis moving by different distances.

Units moved	2	3	4	5	6	7	8
Mean	5.06	5.74	6.90	7.66	8.12	8.58	9.39
Variance	1.43	2.02	1.88	1.25	2.73	1.59	3.82

Tables 1 to 5 respectively give the time required for taxis to move different distances (unit is car length); the time required for passengers to move different distances; the time required for passengers to place their belongings and get on the taxis; the time interval for passengers to get on taxis; and the frequency distribution of the number of passengers in taxis.

Table 1 showed the time of taxi-waiting in Hohhot Baita Airport, and presented the time for taxis moving by different distances. The data was come out based on research records by organizing and summarizing in real conditions. In Hohhot Baita Airport, the time and distance for taxis moving from the taxi pool to the boarding area, as well as the time spent waiting in line were randomly recorded in the data, each record presented a complete passenger-carry process of the taxi.

Table 2 and Table 3 were the data from airport passengers, it showed the time data of passengers moving by different distances, and the time for passengers to store their belongings and take a taxi. The data was come out from the real-time monitoring of certain periods in the airport. It recorded the

TABLE 2. Time sampling data of passengers moving by different distances.

Units moved	2	3	4	5	6	7	8
Mean	13.1	20.0	27.5	29.4	39.7	51.7	55.3
Variance	3.93	6.03	7.34	8.33	9.44	11.0	3.93

TABLE 3. Time sampling data of passengers placing luggage and getting on taxis.

	1	2	3	4	5	6	7	8	9	10
Time required	1.59	1.08	0.88	0.76	1.23	1.06	1.13	1.30	1.17	0.71
	11	12	13	14	15	16	17	18	19	20
Time required	1.63	0.81	1.02	0.77	1.11	1.36	0.93	1.13	0.61	1.50

time passengers spent on walking from the pick-up point to the taxi and putting luggage.

Table 4 and Table 5 showed the time interval for passengers to take taxi. According to the data, we got the frequency distribution of the number of passengers in the taxi, and the time interval for different passengers to take taxi. We found that most passengers traveled alone, a few passengers chose to travel together. Meanwhile, those who were alone tend to get a shorter waiting time.

TABLE 4. Boarding time interval sampling data of passengers.

	1	2	3	4	5	6	7	8	9	10
Time required	5.93	3.09	6.88	2.53	10.2	6.83	4.51	3.22	11.1	22.6
	11	12	13	14	15	16	17	18	19	20
Time required	25.2	12.5	14.7	5.13	5.51	8.33	4.12	3.17	2.92	3.77

According to the basic data in Tables 1 to 5 and the related simulation algorithm, Table 6 was obtained as follows, it includes the average queuing time under the condition of different numbers of taxis in each lane, and the distribution of average taxi queuing time considering the data disturbance in the computer simulation.

It is found from Table 6 that the results obtained from the average values were better than the results considering the data disturbance. However, the results of the average values were in low agreement with the actual situation, so they were not discussed in depth in the paper.

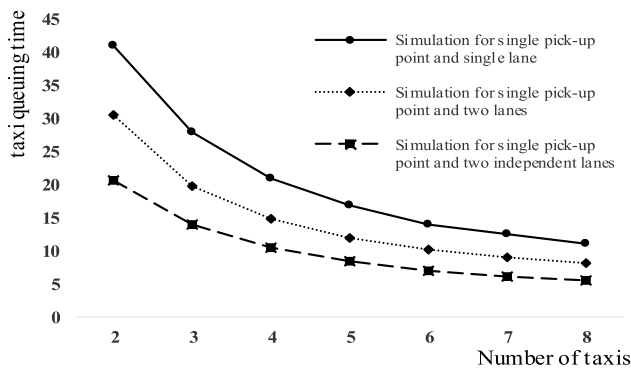
Regardless of which data, with the increase of the number of taxis entering each lane, the average waiting time was shortened. Through Figure 9, it can be seen that the two-lane queuing model was significantly better than the single-lane

**TABLE 5.** Frequency distribution of the number of passengers in taxis.

Number of passengers	1	2	3	4
Frequency	34	19	6	1

**TABLE 6.** Distribution of average taxi queuing time under the condition of different numbers of taxis in the boarding area.

	2	3	4	5	6	7	8
Average value for single pick-up point and single lane	16.7	12.5	10.4	9.19	8.31	7.72	7.32
Simulation of single pick-up point and single lane	40.8	27.8	20.8	16.7	13.8	12.3	11.1
The average value for single pick-up point and two lanes	9.33	7.07	6.01	5.39	4.96	4.67	4.48
Simulation of single pick-up point and two lanes	30.3	19.8	14.8	11.8	10.1	8.83	8.17
Simulation of single pick-up point and two independent lanes	20.4	13.9	10.4	8.33	6.88	6.17	5.54



**FIGURE 9.** The efficiency of different taxi-taking strategies.

queuing mode, and the time optimization ratio exceeded 25%. However, in the end, we found that the two independent lane queuing mode could further reduce the average taxi-taking time by about 30%. Although the average taxi-taking time was shortened as the number of taxis entering each lane in the boarding area increased, with the increase of the taxi number, the amplitude of the average optimization time got smaller and smaller. If the convenience of management, the cost of site design, the too-long moving distance of passengers, the correlations among various data, and the anxiety of passengers in the waiting area are all taken into consideration,

then the optimal number of taxis entering each lane should be taken as 5, and at the same time, the 4-taxi or 6-taxi queuing strategies could be considered as well; however, it is necessary to make sure that the pick-up points should be set in the center of the boarding area.

**V. CONCLUSION**

To improve the taxi-taking efficiency at the airport, based on the queuing theory, this paper constructed models to minimize the average queuing time of passengers under different taxi-taking strategies and used graphs and theoretical derivation to obtain optimal airport taxi queuing strategies for multiple pick-up points and multiple lanes. Also, the Monte Carlo method was adopted to simulate the average taxi-taking time of passengers under different taxi queuing strategies. Finally, the optimal number and location of the pick-up points, the optimal number of taxis in the boarding area, and the optimal drive lane arrangement results were obtained. These models and methods are not only suitable for the optimization of existing airport taxi-taking modes but also have important reference value for the improvement of existing taxi lanes or the design of newly constructed taxi lanes. Due to the huge workload of data collection, only some regions first-hand data had been collected, these data are relatively reliable can provide important support for the rational setting of the parameters. In the future, the models need to be further expanded or improved to take more factors (such as factors of people, vehicles, and the transportation hubs) into consideration, so that they could be applied to the taxi-taking problems of transportation hubs such as airports and railway stations in different cities.

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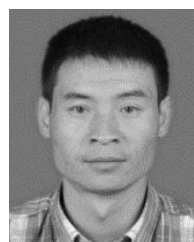
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