

# The Taxi Problem at The Airport

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**Abstract.** This thesis aims to propose an optimization and improvement plan for the cab problem in airports. In this paper, under the premise of driver's revenue as the core element, combining the number of passengers waiting in line, the number of vehicles in line in the storage pool, the distance back to the city and other influencing factors, two scenarios of waiting in line to pick up passengers and returning empty to haul passengers are hypothesized, with gaining revenue over paying cost as the final measure. This problem sets up two decision scenarios as a way to build a decision model for cab driver selection. To collect the relevant data of a domestic airport and its city cabs, in order to ensure the rationality and reliable reference value of the data, Nanjing Lukou Airport is selected as the research object after a lot of data collection, and the relevant data provided by the public information of the website and the very accurate APP are used to study the flight information on July 13, 2022. For Nanjing Lukou Airport, the change of airport traffic in different time periods is relatively large, so according to the relevant data obtained, the benefits of different schemes are considered comprehensively, and the model established in Problem 1 is solved to obtain the benefits of Scheme A and B at different moments of the day, so as to give six time periods of the driver's decision scheme.

**Keywords:** Airport, cab, driver revenue, decision model.

## 1. Introduction

As China's economic development level and people's income increase, air travel is taking up a larger and larger share of many travel modes, and cabs, as one of the main ways for people to leave the airport, bring convenience to passengers while also causing a lot of trouble to the airport management [1,2]. The revenue of cabs at airports is related to the driving mileage of passengers, and passengers' destinations are far and near, bringing more and less revenue to airport cab drivers. Therefore, if the cabs are not managed properly and the benefits of cabs are not balanced, it is very likely that short-haul passengers will not be able to wait for a long time in the airport waiting area or cabs will wait for long-haul passengers at the airport because they do not want to carry short-haul passengers [3]. The situation of "people waiting for cars" and "cars waiting for people".

It seems that the traditional airport cab dispatching system management mode can no longer meet the needs of passengers and drivers [4-6]. Therefore, in order to ease the contradiction between drivers and passengers, solve the balance of supply and demand, and improve the service quality, this paper builds a management model based on the traditional airport cab dispatching system, which is based on the "airport cab management system", shortens the waiting time as much as possible, and strengthens and optimizes the management through intelligence, so as to solve the problems caused by the traditional model[7-8]. The paper also aims to solve the problems caused by the traditional model.

This study intends to solve the following two problems.

(1) Analyze and study the influence mechanism of factors related to cab driver's decision, consider the change pattern of the number of airport passengers and cab driver's revenue, establish the cab driver's choice decision model, and give the driver's choice strategy.

(2) To collect the relevant data of cabs in a domestic airport and its city, give the selection plan of cab drivers in this airport, and analyze the rationality of the model and its dependence on related factors.

## 2. Analysis of the problem

### 2.1. Analysis of Question 1

There are many factors that influence the driver to make the strategic choice of waiting for a guest or returning to the city with an empty vehicle; therefore, the core factor, i.e., the driver's benefit status, is discussed in a categorical manner to build a decision model for cab driver choice [9]. If the time spent waiting in line for passengers is significantly less than the time spent returning empty, the driver chooses to enter the queue in the storage pool; if the time spent waiting in line for passengers is greater than the time spent returning empty, it is necessary to compare whether the driver's benefit is greater than the cost paid. Based on the number of passengers waiting in line and the number of vehicles in line in the storage pool, the time cost of waiting is estimated and combined with the benefit of carrying passengers back to the city to arrive at the expected benefit of taking this decision. Assuming an empty return, the empty running loss is taken as a cost, and the revenue generated by hauling passengers downtown from the waiting time saved by the return is estimated, which also gives the expected revenue of taking the empty return decision. The above assumptions are analyzed and compared to obtain the decision model, as shown in Fig. 1.

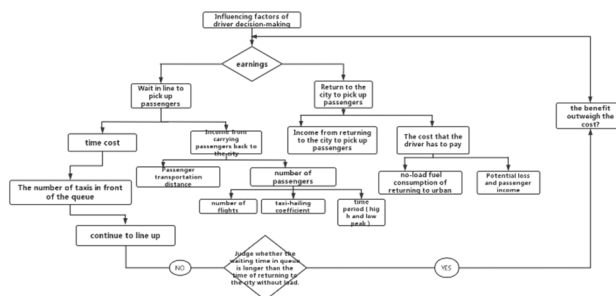


Fig. 1 Model diagram of decision-making affecting taxi driver selection.

### 2.2. Analysis of Problem 2

To collect the data related to a domestic airport and its city cabs, we need to select the airports with typical characteristics as the sample for analysis. First, we need to exclude airports that are too small in size, because their annual passenger throughput is small and cab traffic is small, and the sample size is not sufficient to meet the requirements of this question for data statistics. Secondly, international airports that are too large in size are excluded, because international airports have complex and diverse traffic patterns, and there are many influencing factors that need to be taken into consideration, which makes it more difficult to collect and analyze the data for this question. After a large number of national airport queue data search and collection, and combined with the city cab operation, Nanjing Lukou Airport was selected as the reference sample for subsequent processing and analysis, which can make the sample with reasonable accuracy.

## 3. Model building and solving

### 3.1. Data processing and analysis of Question 1

#### 3.1.1 Model building

There are many factors that influence the driver's strategic choice to enter the storage pool to wait for guests or return to the city with an empty vehicle, therefore, the main factor, i.e., the driver's revenue status, is discussed in a categorical manner. Driver revenue is the main determinant of driver decision [8], and time cost should be considered in the calculation of revenue. For the queuing case, the driver needs to wait in the storage pool for a period of time, and then drive to the city center after picking up passengers, thus the time used by the cab from the storage pool to the city center can be found, which is the sum of the queuing time and the passenger carrying time. For the emptying

scenario, the driving time of the cab from the pool to the city center is the same as the queuing scenario, so the passenger carrying time in the city center is considered to be the same as the waiting time in the queuing scenario, thus ensuring that the time interval referenced by the two decision options is the same.

Let the driver enter the storage pool to wait for the guests as option A, and the driver return to the city empty to haul passengers as option B.

The model shows that the factors that influence the driver's decision are: the time spent waiting in line for passengers, the revenue from carrying passengers to their destinations, the time spent returning to the city with no passengers, and the revenue from carrying passengers in the city. Continuing the analysis of these factors, it can be found that the driver's decision is mainly determined by the number of vehicles in the storage pool, the distance traveled, and the cab fare  $f(x)$ . The number of vehicles in the pool determines the waiting time, and the return trip and the cab fare together affect the revenue gained from carrying passengers.

Let the benefit obtained by option A be  $Z_A$  and the benefit obtained by option B be  $Z_B$ . According to the analysis, it is clear that no matter which option is chosen, we have  $Z = Q - C$ , where  $Z$  is the benefit of the option,  $Q$  is the fare to be paid by the passenger, and  $C$  is the cost consumed by the different options.

(1) Option A

First, we discuss the cost of time consumed by waiting in line for passengers. Time cost is the "time value of money", which refers to the difference in the quantitative production of a certain amount of money at different points in time [9]. In the case of a cab driver, when he chooses to enter the queue in the pool, the time spent in the queue results in a time cost. It may be assumed that the time cost per unit of time is  $c_1$ , then the time cost under decision option A can be derived as

$$C_A = c_1 \cdot t_2 \tag{1}$$

According to the number of passengers, the number of cabs needed in the corresponding time period can be introduced, and then the average interval  $T$  between cabs carrying to passengers can be obtained. Combining the current queue position  $n_p$  of cabs and the time  $t_0$  spent by cabs traveling from the storage pool to the ride area, the queue waiting time is obtained as

$$t_2 = T \times n_p + t_0 \tag{2}$$

A cab arriving in the city to haul passengers has a certain potential gain, which is related to the distance the passenger travels to the destination. Let the driver receive a passenger who arrives at the destination at a distance  $(x_2 - x)$ , the fare is  $f(x)$ , and  $\varepsilon_t$  is the mileage utilization rate at different moments, then the possible gain for the cab driver is

$$Q_B = \varepsilon_t \cdot f(x) \cdot (x_2 - x) \tag{3}$$

Therefore, the benefit obtained by scenario A is

$$Z_A = Q_A - C_A = f(x) \cdot x_1 - T \times n_p - t_0 \tag{4}$$

(2) Option B

Cabs that choose to return to downtown on empty save the cost of waiting time over cabs waiting at the airport, consume the cost of emptying on the way back, and have a potential gain of 0 passengers from the airport to downtown on the entire highway.

No-load cost consumed.

$$C_B = c_2 \cdot x_2 \tag{5}$$

where  $c_2$  is the average fuel consumption per kilometer of the cab and  $x_2$  is the distance between the airport and the destination after pulling in passengers.

Taxis have a certain potential gain after arriving in the city to pull passengers, and the gain is related to the distance passengers travel to their destinations. Let the distance to the destination of the

passenger received by the driver  $(x_2 - x)$  and the rate of  $f(x)$ , then the possible gain for the cab driver is

$$Q_B = f(x) \cdot (x_2 - x) \tag{6}$$

Where  $x$  is the distance from the airport to the passenger boarding point and  $x_2$  is the distance from the airport to the passenger's destination.

Therefore, the gain obtained by option B.

$$Z_B = Q_B - C_B = f(x) \cdot (x_2 - x) - c_2 \cdot x_2 \tag{7}$$

Where

$$f(x) = \begin{cases} f_1, t \in [6,22] \\ f_2, t \notin [6,22] \end{cases}$$

$$f_1 = \begin{cases} 9, x \leq 3 \\ 9 + 2.4 \times (x - 3), x > 3 \end{cases} \tag{8}$$

$$f_2 = \begin{cases} 11, x \leq 3 \\ 11 + 2.7 \times (x - 3), x > 3 \end{cases}$$

We consider that the driver's decision model is mainly determined by the revenue forecasts of the two options, and therefore construct the driver's decision factor as

$$W = Z_A - Z_B \tag{9}$$

From the perspective of maximum profitability, the following decision strategies for drivers were obtained.

$$\begin{cases} W > 0, \text{Choose to stay at the airport} \\ W = 0, \text{Arbitrary program selection} \\ W < 0, \text{Return to the city with no load} \end{cases} \tag{10}$$

In order to facilitate giving the system strategy for different time periods, we decided to divide the day into six time periods based on passenger flow as well as cab flow: 8:00-12:00; 12:00-16:00; 16:00-20:00; 20:00-24:00; 0:00-4:00; 4:00-8:00.

### 3.1.2 Model Analysis

By analyzing this model, we can draw the following results: the driver's decision is mainly determined by the distribution pattern of passenger flow in each time period, and the driver's decision should change when the distribution pattern of passenger flow in each time period is different. This can be analyzed qualitatively: tourist season, morning and evening peak, weather, holidays and other factors will directly affect the flow of passengers at the airport, resulting in changes in the distribution pattern of passenger flow at each time period, which will lead to changes in the cab driver's decision-making scheme, and the cab driver should consider both A and B options. This is how the mechanism of the influence of relevant factors is formed to a large extent.

Seasonal changes not only affect changes in the number of passengers, but the trend or pattern of their traffic may also change. For example, after the Chinese New Year peak season in February, from the perspective of capacity deployment, domestic lines continued to remain stable, while the growth rate of international lines converged. The growth rate of domestic line capacity (ASK) was 9.9%, and the year-on-year growth rate remained around 10% for the past 4 months; the growth rate of international line ASK was 33%, down 2.7% YoY. It can be seen that seasonal factors have an important influence on the number of passengers, the main subject of this question. At the same time, due to the arrival of the airline off-season, the cab passenger market will also be challenged by the off-season accordingly. The decision scheme is given by dividing the passenger flow into regular segments according to the pattern of passenger flow, and giving the decision scheme for each segment separately, so the seasonal factor, has a great influence on the model results, but due to the limited

access to data, it is not possible to make a specific analysis for each of the four seasons of the year, so the general analysis idea is given. As shown in Fig. 2.

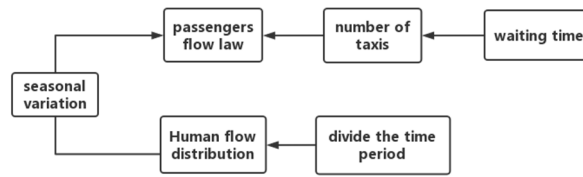


Fig. 2 The influence of seasonal variation

### 3.2. Data processing and analysis of Question 2

#### 3.2.1 Airport selection and data collection

##### 1. Selection of airports

First of all, it is necessary to exclude airports that are too small in size, because their annual passenger throughput is small, cab traffic is small and other shortcomings, the sample size is not enough to meet the requirements of this question for data statistics. Secondly, international airports that are too large in scale are excluded, because international airports have complex and diverse traffic patterns, and there are many influencing factors that need to be taken into account, which makes it more difficult to collect and analyze data for this question. Combined with the city cab operation, Nanjing Lukou Airport was therefore selected as the reference sample [10].

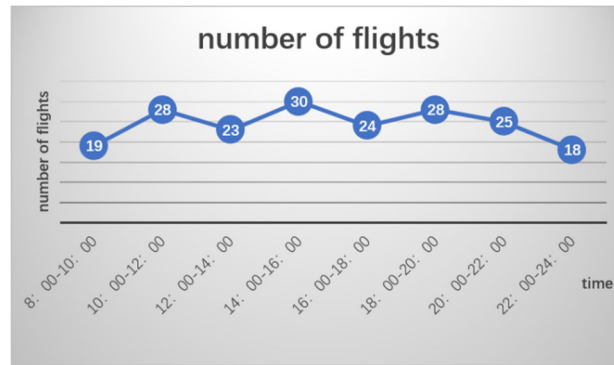
Nanjing Lukou International Airport is located in the Nanjing metropolitan area and the Yangtze River Delta economic circle and core area and is an important window for the external development of Jiangsu economy, with an annual passenger throughput of about 25 million passengers. At the same time, there are more flight schedules opened to more than 70 major domestic cities, which can provide sufficient and reasonable sample capacity for the model analysis and optimization of airport cabs in this paper. Nanjing is the capital city of Jiangsu province, which is developing rapidly, and there are enough cabs available for deployment in the city.

##### 2. Data collection

We consider a non-holiday day as a reference sample for the number of flights and passengers in this paper. The number of flights and the total number of passengers per flight and full load rate were collected and analyzed by using search software, as shown in Figs. 3 and 4. We also found the price list of passenger cars in Nanjing (as shown in Table 1) and the fuel cost per kilometer in Nanjing (7.23 RMB/liter).



Fig. 3 Daily flight number distribution map



**Fig. 4** Daily flight number distribution map

According to Fig. 3 and Fig. 4, we can clearly derive the distribution of the number of daily flights and passengers of Nanjing Lukou Airport on a non-holiday day, which paves the way for the subsequent model validation (Table I).

**Tab. 1** Passenger taxi fare in Nanjing

mileage	daytime(5a.m.-11p.m.)	nighttime(11p.m.-5a.m.)
0-3km	Nine yuan	Eleven yuan
More than 3km	$W_1=2.4$ yuan per kilometer	$W_2=2.7$ yuan per kilometer

In addition, we also need to know the distance traveled by the cab, through the map software, made a sector map of the distance from Nanjing Lukou Airport to the city, according to this analysis, after taking the average value, it was found that the driver from the airport to carry passengers the average value of about 40 km, from which the value of the passenger revenue  $Q$  can be calculated.

$$Q = 9 + 2.4 \cdot (40 - 3) = 97.8(\text{Daytime}) \quad (11)$$

$$Q = 11 + 2.7 \cdot (40 - 3) = 110.9(\text{Night}) \quad (12)$$

The next calculation of the hourly wage for hauling passengers, according to the data we collected, we can know the monthly income distribution of a total of 150 cab drivers, as shown in Table II.

**Tab. 2** Monthly income distribution table of 140 drivers in Nanjing

Y1	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	>11
Y2	2	4	6	11	13	106	4	3	1

Note: Y1 represents Monthly salary range/thousands of yuan. Y2 represents number of people.

Finally, we get the average income of drivers in Nanjing is 8700 RMB/month according to the data. We assume that there are 30 days in a month, the driver works 8 hours a day and has 4 days off in a month, we can calculate the hourly earnings of cab drivers  $M$ .

$$M = \frac{8700}{8 \times 26} \approx 42 \quad (13)$$

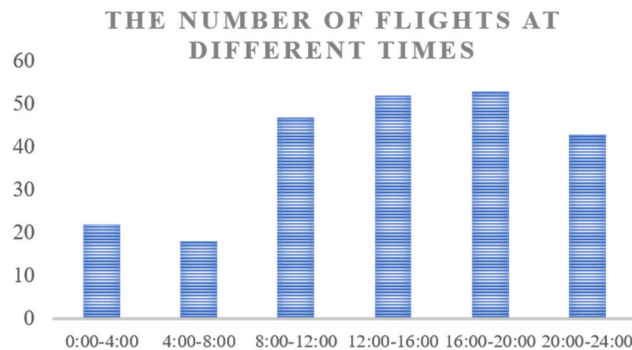
Table III shows the data related to Nanjing Lukou International Airport and cabs, and the data sources are public information of Nanjing Lukou Airport, Baidu map, and related literature. Based on the information found, it is assumed that cabs travel to the pick-up area, from the storage pool to the pick-up area and from the cab to the pick-up area according to the established routes. The average time for cabs to get to the pick-up area is 5 minutes, the average time for each cab to get from the storage pool to the pick-up area is 2 minutes, and the average time for cabs to leave the pick-up area is 0.5 minutes. The average time for passengers with and without luggage was averaged to obtain 0.5 minutes for the time required to board the taxi.

**Tab. 3** Related data of Nanjing Lukou International Airport and Urban Taxi

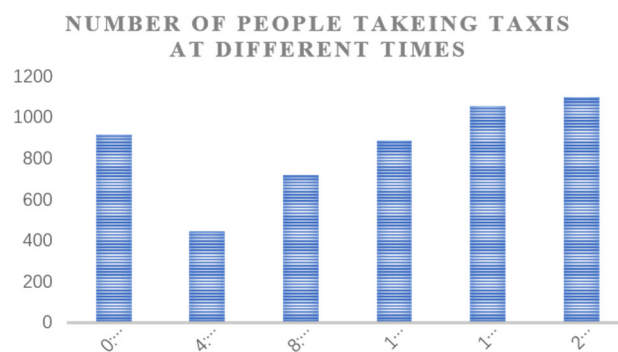
Designation	Symbol	Numerical value
Distance from the airport to the city center	$X_l$	40km
Average taxi speed per hour	$v$	40km/h
Average taxi time to the pick-up area	$t_a$	5min
Average time from storage pool to pick-up area	$t_b$	2min
Average time for taxi to leave the pick-up area	$t_c$	0.5min
Fuel consumption per kilometer	$r$	0.6yuan per kilometer
A choose the average time to travel to the destinatio	$T$	60min
Average time for passengers to get on the bus	$t_l$	0.5min

$T$  is obtained by the cab fare rules in Nanjing. A chooses the next cab driver to pick up passengers at the airport and deliver them to the city center and its surrounding areas. After consulting the information, the distance from the airport to the city center is 40km, the distance from the city center to the surrounding areas is 15km, and the destination range satisfies the normal distribution  $N$ .

By collecting and summarizing the flight situation of Nanjing Lukou International Airport in each time period on July 13, 2022, the average number of arriving aircraft flights at Nanjing Lukou International Airport in each time period is given. According to the data, the average value  $k$  of the number of cab rides during normal daytime hours (6:00-22:00) is 10%-20%, and the average value  $k$  of the number of cab rides during other hours is 30%-50%, then the proportion of cab passengers throughout the day can be obtained [3], so that the corresponding number of possible cab rides for each flight and the number of possible cab rides for a certain time period can be obtained(Fig. 5 and 6).



**Fig. 5** Statistical results of the number of flights at different times



**Fig. 6** Statistics on the number of people taking taxis at different times.

For cab drivers returning to the city with no load, the mileage utilization rate  $\varepsilon_t$  is different at different times of the day when picking up passengers in the city, as shown below.

$$\varepsilon_t = \begin{cases} 0.5, 0 \leq t \leq 4 \\ 0.3, 4 < t \leq 8 \\ 0.4, 8 < t \leq 12 \\ 0.5, 12 < t \leq 16 \\ 0.6, 16 < t \leq 20 \\ 0.2, 20 < t \leq 24 \end{cases} \quad (14)$$

### 3.2.2 Model solving

The flight situation of Nanjing Lukou International Airport on July 13 was selected for study, and the collected data was divided by 2 hours to obtain the number of arriving flights within 2 hours. Using the model developed in Problem 1, the values of the returns for the two options are solved as shown in Table IV below.

**Tab. 4** Driver strategy selection table in some cases

Number of people taking taxis	Number of taxis	time	Z <sub>A</sub>	Z <sub>B</sub>	strategy selection
130	170	1: 00	87	292.4	Empty car return
3	12	6: 24	74	45.6	Wait in line
200	282	9: 55	74	225.6	Empty car return
124	65	15: 32	74	84.5	Empty car return
154	73	19: 45	74	131.4	Empty car return
91	120	22: 37	87	-24	Wait in line

This gives the decision options for drivers under different time periods (Table V).

**Tab. 5** Drivers' decisions at different times

Time	0:00-4:00	4:00-8:00	8:00-12:00	12:00-16:00	16:00-20:00	20:00-24:00
strategy	Empty car return	Wait in line	Empty car return	Empty car return	Empty car return	Wait in line

### 3.2.3 Analysis of the model

The first rationalization is based on Model 1, a cab driver decision making model, which is validated by calculating Model 1 for collecting information about a specific airport and data about local cabs. The model takes two practical perspectives on how cab drivers should make decisions. In each case, the cost of time consumed by the cab driver as well as the revenue is considered, and the difference is made to obtain the decision factor of the driver [6]. Assuming that the time consumed by the cab driver in queue to pick up a passenger or return empty is the same, the driver is only considered if the time spent in queue to pick up a passenger in the city, the gain obtained is compared, comparing the gain at the same time has a certain reasonableness, and the driver's decision given in different cases has a consequent change. The dependence on the relevant factors is mainly through the study of the changing pattern of the number of passengers and the quantitative relationship comparing the number of cabs in the storage pool, where the pattern and the quantitative relationship differ and the driver's decision scheme changes.

## 4. Conclusions

### 4.1. Advantages of the model

The integrated decision model can make the value of benefits intuitively expressed, and cab drivers can make the best decision in different situations; it can simplify the more complex problems into more intuitive ones, and simplify the complexity into simplicity, which can give a more accurate result. The model of problem 1 gives further main ideas to study the situation affected by seasonal

changes on the basis of answering the driver's decision, which enhances the practicality of the model. The modeling approach is simple and easy to implement, and easy to apply to real life.

#### 4.2. Disadvantages of the model

1. The model established in this paper is highly dependent on data, and the accuracy of the data itself cannot be guaranteed exactly.

2. The number of variables involved in this paper is large, and the relevant data are not easily accessible, so the subsequent solution is carried out by means of hypothetical variables, which may lead to inconsistency with reality.

3. The model cannot incorporate all the factors affecting the decision into the calculation, such as the existence of unexpected situations, etc., and there are some statistical errors.

4. When building the airport selection decision model, the calculation of driver queuing time is certainly reasonable, but there are still areas for improvement

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