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Assessment of Airport Taxi Dispatching Based on Psychological Account Principle Decision Model -- A Case Study of Shanghai pudong Airport

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ABSTRACT

In this paper, a decision model based on psychological account principle and a queuing theory model based on (M/M/1) system are established to solve the problem of providing more reasonable choices for airport taxi drivers. Combined with reverse test method, control variable method and other methods to analyze the problem. Taking Shanghai pudong airport as an example, the error coefficient of critical decision value is calculated to be around 0.13, and the model is reasonable. It is concluded that weather has great influence on decision making and seasonal change has little influence on decision making.

Keywords: Psychological account principle; Reverse test; Control variable method

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1. Introduction

Nowadays, with the development of economy and science and technology, civil aviation has become the first choice for people to travel or go on business trips. And most of the passengers have to go downtown or nearby attractions when they get off the plane. As for the alternative transportation of airports, China pays more attention to the diversification of transportation modes. Generally, airport buses are used as the main transportation mode connecting airports and urban areas, while taxis, as a supplement to this public transportation mode, play a great role. Of course, there are passengers who need to take a taxi from downtown to the airport, and the taxi driver who takes them to the airport usually has two choices:

(A) To the arrival area to queue for passengers to return to the city. Taxis must wait in line at the designated "car pool" and take passengers in line according to "first come, second come". The waiting time depends on the number of taxis and passengers in line, which requires a certain time cost.

(B) Return directly to the city to solicit customers. Taxi drivers pay no-load fees and may lose potential passenger revenue.

How to choose to maximize the benefits? Is a problem worth studying. The two options have their own advantages. Taxi drivers can get information about the number of flights arriving in a certain period of time and the number of vehicles already in the pool, and they can choose the decision that will benefit them more based on their personal experience. In real life, weather, different time periods and other external factors will have a certain impact on the driver's decision-making results. In addition, the choice of airport drivers will have an impact on the traffic in and around the airport. In order to make the driver's choice more reasonable, from the perspective of psychological perception, this paper comprehensively considers the external influence and the influence of the driver's internal psychological change, establishes a model to calculate the comprehensive benefits of different choices, and achieves the maximum benefits by comparing the comprehensive benefits of the two strategies.

2. Model assumptions

Hypothesis 1: passengers will not get off until the destination is reached;

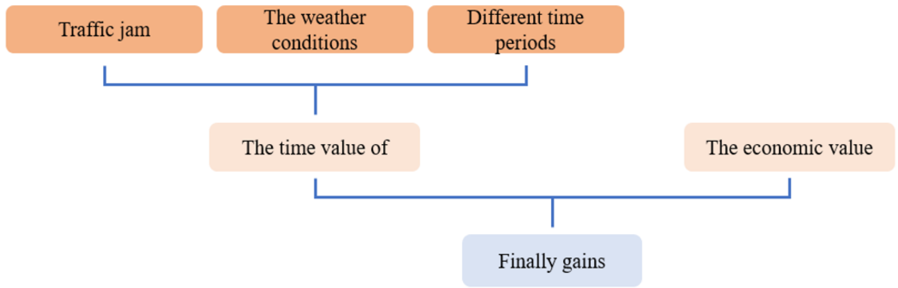
Hypothesis 2: the driving speed of the taxi remains the same;

Hypothesis 3: the fuel consumption in the taxi waiting process can be ignored;

Hypothesis 4: all passengers in the airport take approximately the same time to get on the taxi;

3. Problem analysis

First of all, analyze the related factors affecting the taxi driver decision-making and analysis of the influence mechanism, if the driver is select passenger at the airport, then the weather conditions, different time periods and other external factors will affect the airport taxi driver waiting time, can according to the influence extent of loss aversion effect [2] analysis and the final income how much money can be calculated according to the valuation table; Secondly, according to the principle of psychological account, the change of passenger number and driver income are considered to realize the effective integration of multidimensional attribute gains and losses, and the selection decision model is established and the selection strategy is given. The idea is as follows:



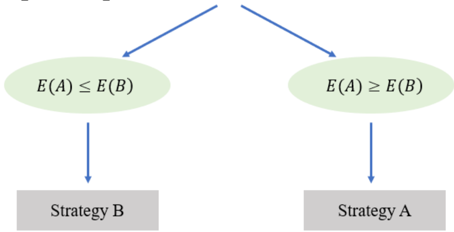


Fig.1: Idea diagram

Then, the established model is applied in practice to collect the data of a domestic airport and the relevant data of the taxi in its city, and the selection strategy is obtained by using the model, and the rationality of the model and the dependence of the model on relevant factors are analyzed. This paper collects relevant data of Shanghai pudong airport and analyzes the rationality of the model by using the passenger throughput of each quarter of 2014.The total passenger throughput in each season in 2014, weather conditions in June and other data were collected to analyze the dependence of the model on relevant factors.

4. Model building

4.1 Theoretical basis

$a.$ Psychological perception management: mainly consider the subjective perception of customers (in this paper, taxi drivers), and the impact of subjective perception on the real waiting time in terms of objective waiting time;.

$b.$ Introduces time value and converts time attribute into economic attribute: this paper refers to time value and converts time change into increase or decrease in income;

$c.$ Reverse test: it is mainly used to test the rationality of the method. When the result is obtained by using a certain method, the feasibility of the method is tested again according to the result.

$d.$ Control variable method: for a problem affected by multiple factors, the method often used when considering the effect of a single factor is used to simplify the problem into a single-factor problem for analysis. Each factor is analyzed separately, and the final comprehensive evaluation is made.

4.2Factors influencing taxi drivers' decision-making and their influencing mechanism

When it comes to the choice of taxi drivers, the main influencing factors are usually the real waiting time and the final benefit. Traffic congestion and weather conditions are significantly correlated with these two factors, and time and benefit can be used to represent the influence of other relevant factors [1].

$a.$ Influence mechanism of real waiting time: In the process of waiting in the taxi line, it is assumed that the passengers get on the bus at the same speed, because in a certain period of time, the number of passengers is certain, so all the taxis in line, there must be taxis that do not receive the guests, and taxis that successfully carry passengers. And the taxi driver who did not receive the guest satisfaction must be worse than receiving the guest; Taxi drivers who successfully carry passengers have good satisfaction. According to relevant literature conclusions, based on the relationship between perceived waiting time and perceived economic loss and drivers' satisfaction with waiting process [2], there are:

$$\begin{cases} \varepsilon = -A_1 \cdot y_1 - A_2 \cdot y_1 + b_1 \\ y_1 = B_1 \cdot t + b_2 \\ y_2 = C_1 \cdot y_1 + b_3 \end{cases}, \quad A_k, B_k, C_k > 0$$

Type, ε represents the satisfaction of taxi drivers;

y_1 represents the perceived waiting time;

y_2 represents the perceived economic loss;

t represents the real waiting time;

b. Influence mechanism of return trip final return:

This paper assumes that the driver must carry passengers from the city to the airport, so the focus of the discussion is the choice from the airport to the city. According to the rule that the greater the profit, the more satisfied the driver will be, the more satisfied the driver will be. Therefore, the greater the profit, the more satisfied the driver will be.

4.3 establish the queuing theory model of $(M/M/1)$ system:

When a flight arrives, taxi passengers and taxis will both arrive at the bus area and the holding pool according to the exponential distribution and wait in line. The problem of taxi queuing and carrying passengers can be regarded as the queuing theory model of (M/M/1) system. The number of taxis in line is d, the number of taxi passengers n per flight is n'. The taxi driver can be assured based on his own experience and the known data available $d \geq n'$;

$Step1$: calculation of the real waiting time t_i of the ith taxi:

$$\begin{cases} t_i = w \cdot i \\ w = \dfrac{h}{\lambda} \\ h = \dfrac{\rho}{1-\rho} \\ \rho = \dfrac{\lambda}{\mu} \end{cases}$$

Type, λ is the arrival rate of taxi;

w represents the average system consumption time;

μ represents the average service rate;

h is the average number of vehicles in the system.

$Step2$: calculate the probability P of the ith taxi waiting successfully in a certain period of time:

According to the passage, the number of flights and the number of cars in the pool are the known information of the taxi driver. In addition, drivers also have their own experience, so there will not be passengers without a taxi;

$$P = 1 - \frac{h - \overline{n'}}{h}$$

Type, h represents the average number of vehicles in the system during this period;

$\overline{n'}$ refers to the average number of passengers taking taxis in flight $\overline{n}$ during this period;

P refers to the probability that taxis can successfully carry passengers when participating in the queue;

4.4 Establish a decision model based on the principle of psychological account:

This model establishes the transaction utility function, introduces the time value, unifies the two attributes of time and return, converts time into the return standard, and realizes the effective integration of multidimensional attribute return and loss.

$Step1$: characterizing returns per unit time $\varphi : \varphi = \dfrac{W}{T} \quad W = W_1 + W_2 \quad T = t_0 + t$

Type, W represents the transaction utility function;

W_1 represents the time value function;

W_2 denotes the revenue function;

t stands for waiting time;

T represents the total time taken from the airport to the city;

t_0 represents the time consumed during the taxi journey, $t_0 = s/v$, s is the distance between the airport and the urban area, v is the taxi travel time.

$Step2$: describe time value k: $k = \frac{N_0}{T_0}$

Type, N_0 represents the average monthly income of taxi drivers in the city where the airport is located;

T_0 denotes the total monthly working hours of taxi drivers in the city where the airport is located;

$Step3$: describe the time value function W_1:

The last carrying time is selected as the reference[1]. It is assumed that the taxi arrives at the airport from the urban area, so the reference time is t_0.The will meet $T \geq t_0$, there are: $W_1 = k^{\alpha}[(-t_0)^{\alpha} - (-T)^{\alpha}]$

Type, α represents the diminishing marginal sensitivity parameter for return, which is $\alpha = 0.358$[1]

W_1 here is after the attribute conversion, conversion into income criteria;

$Step4$: describe profit function W_2:

The last passenger return is selected as the reference[1], and the reference is $M_0 = -m_0 + m$;Among them, m_0 is the no-load charge from the airport to the city; m is the charge for carrying passengers from the airport to the city. According to the analysis, it must be met $M \leq M_0$, there are: a. When $M = M_0$, $W_2 = [(-M_0)^{\alpha} - (-M)^{\alpha}]$; b. When $M < M_0, W_2 = -\lambda_1[(-M)^{\beta} - (-M_0)^{\beta}]$;

Type, λ_1 represents loss aversion parameter, if $\lambda_1 > 1$suggesting that individuals are more sensitive to loss. Here take $\lambda_1 = 1.383$[1] ; β represents the diminishing marginal sensitivity parameter for loss. Here take $\beta = 0.594$[1] ;

$Step5$: analyze the benefits of each selection strategy:

a. If the plan A is selected and the passenger is successfully carried: $\varphi_{A1} = W_1 / T$;

b. If the plan A is selected, but failed to carry passengers: : $\varphi_{A2} = (W_1 + W_2)/T$, $M = -m_0$;

c. If plan B is chosen, potential benefits exist, that is, waiting will be successful: $\varphi_{B2} = W_2 / t_0$, $M = -m_0 - m$;

d. If plan B is chosen, the potential benefit does not exist, that is, waiting will not succeed in carrying passengers: $\varphi_{B2} = W_2 / t_0$, $M = -m_0$;

$Step6$: calculate the revenue expectation of choices A and B:

$E(A) = \varphi_{A1} \cdot P + \varphi_{A2} \cdot (1-P)$

$E(B) = \varphi_{B1} \cdot P + \varphi_{B2} \cdot (1-P)$

Where, $E(A)$ represents the revenue expectation of option A; $E(B)$ represents the revenue expectation of option B; Choose the most profitable program to implement.

4.5 Establishment of rationality analysis model based on reverse test:

In order to analyze the rationality of the model, this paper establishes the rationality analysis model based on the reverse test method. Under the condition that the results of the first model are obtained, the model results are re-tested, and the two results are compared to analyze the rationality of the model.

According to the selection of each quarter, compare the selection of each month covered by the quarter, compare whether it conforms to the overall selection of the quarter, and calculate the calculation error coefficient η_q of each quarter, $q \in [1,4]$;

Step1: according to the passenger situation of pudong airport in each month, calculate the selection strategy of each month and get the strategic threshold value of each month j_k, $k \in [1,12]$;

Step2: the selection threshold of each quarter is $J_q, q \in [1,4]$, and calculate the error coefficient of each quarter:

$$\eta_q = \frac{\sum_{k \in M_q} | J_q - j_{qk} |}{J_q}$$

Type, η_q is the error coefficient of the quarter q ,if $\eta_q \to 0$, the more reasonable the model is

M_q represents a collection of months covered by a quarter q ;

J_q represents the queuing threshold of the quarter q , $q \in [1,4]$;

j_{qk} represents the queueing threshold for the month k contained in a quarter q .

4.6 Establish the analysis model based on control variable method:

In this paper, an analysis model based on control variable method is established for the related factors of model dependence. In this paper, three correlative factors are analyzed from the aspects of season, weather and two periods of dark days and daytime of a day.

$Step1$: select variables for control experiment:

In the case of airport taxi, the final revenue and waiting time can indeed replace the influence of other relevant factors on the driver's decision. However, to specify the influence of relevant factors, we need to use the control variable method to analyze the dependence of the analysis model based on this method on weather and season.

$Step2$: conduct control experiment:

(1)The influence of different weather conditions on taxi drivers' decision-making

Collect the weather conditions of each day in a certain period of time, and classify the period according to weather grades A, B and C. The critical value j_k, $k \in \{A、B、C\}$ of each category is the number of vehicles in line, and the critical value σ and the mean value V of the critical value of the strategy are calculated to analyze whether weather has a greater impact.

$$\sigma = j_k^{\max} - j_k^{\min} \quad V_k = \frac{1}{n_k} \sum_{k \in M_k} j_k$$

Type, σ represents the extreme difference of the policy critical value;

$j_k^{\max}$ 、 $j_k^{\min}$ represents the maximum value and minimum value of the policy critical value respectively, $k \in \{A、B、C\}$;

V_k represents the mean value of the critical value of weather grade k strategy;

M_k represents the set of days contained in weather grade k

(2)The influence of different seasons on taxi drivers' decision-making:

The total number of passengers taking taxis in different seasons of the studied airport was collected, the strategic threshold j_k, $k \in \{1、2、3、4\}$ of each category was compared, and the extreme difference σ and average value V of the strategic threshold were calculated, as shown in (1).

5. Case application -- Shanghai pudong airport

5.1 Data collection and analysis

5.1.1 Year data processing

According to the official website of Shanghai statistics bureau[4], the total passenger throughput of Shanghai in each year and the first 7 months of 2019 was found:

Table 1: passenger throughput of Shanghai in the first seven months of 2019

Month	Passenger throughput (10,000)	Passenger reception (10,000)
1	1005.51	524.57
2	959.71	466.08

3	1013.26	505.77
4	1012.28	510.64
5	1045.21	523.49
6	1022.49	519.22
7	1071.70	541.13

The following figure is the double-coordinate polyline chart of passenger reception and passenger throughput at the airport of Shanghai in the first seven months of 2019 made by *matlab* software.

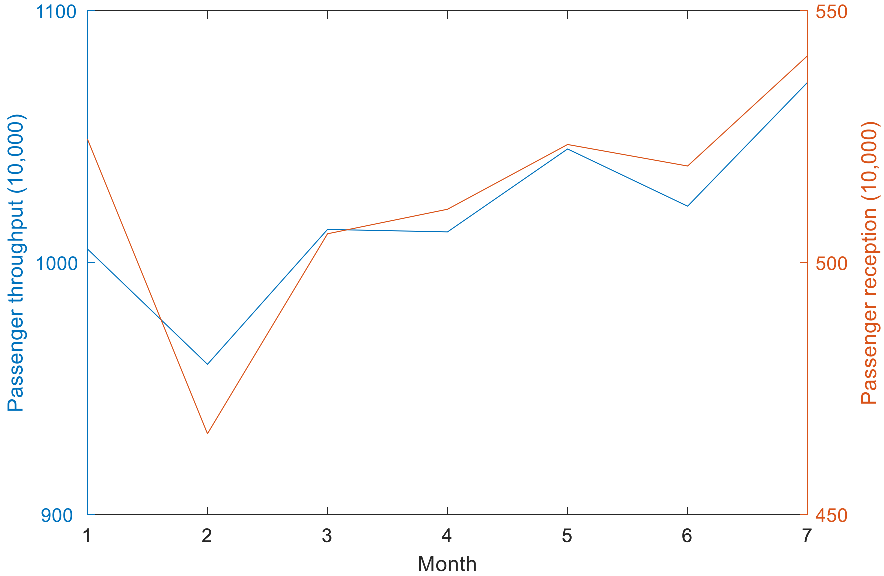


Fig.2: Passenger reception and throughput in Shanghai in the first seven months of 2019

It can be seen from the change trend comparison results of the two polylines that passenger throughput and passenger reception have basically the same change trend with each month, so passenger reception can be calculated with passenger throughput.

In this paper, the passenger throughput of Shanghai civil aviation was calculated from the statistics of Shanghai bureau of statistics, and the total passenger throughput of pudong airport was calculated from the civil aviation administration of China.

Table 2: passenger throughput of Shanghai and pudong in recent six years

Category	Year	Passenger throughput (10,000)	Category	Year	Passenger throughput (10,000)
Shanghai	2013	11763.57	Pudong	2013	7000.12
	2014	11120.37		2014	6600.24
	2015	10622.29		2015	6598.21
	2016	9930.97		2016	6008.50
	2017	8953.66		2017	5168.79
	2018	8229.27		2018	4719.18

Calculate the passenger throughput of pudong airport in each month in 2014. Through the total passenger throughput of Shanghai and pudong in each year, obtain the average proportion of passenger throughput of pudong airport in the total of Shanghai:

Table 3: the proportion of passenger throughput of pudong airport in Shanghai

	2013	2014	2015	2016	2017	2018	平均
proportion	0.57	0.58	0.61	0.62	0.59	0.60	0.59

Because of statistical data is used for many years, and the proportion is smaller, so the average proportion in can be applied to the calculation in the process of data collection, Shanghai bureau of statistics found every year a month of general civil aviation passenger throughput, calculate the proportion can be pudong airport passenger throughput of each month in 2014, the figure below:

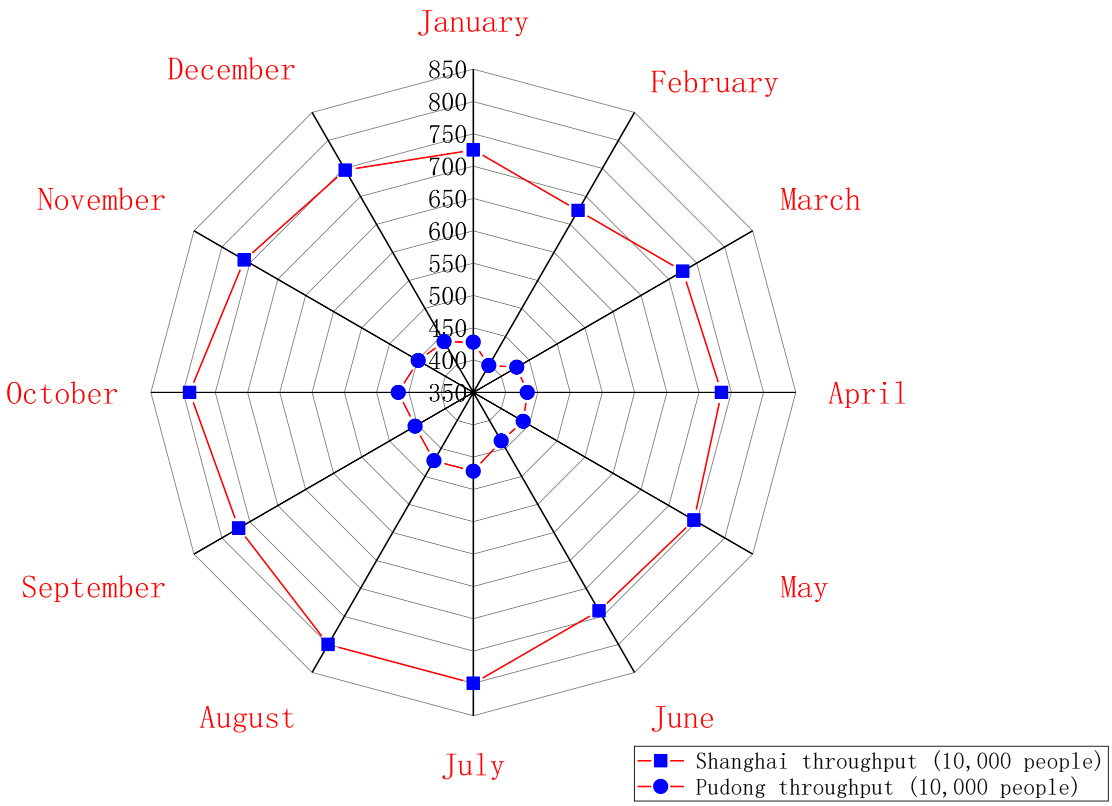


Fig.3: Throughput of Shanghai as a whole and pudong in 2014

For the convenience of analysis, this paper USES origin drawing software to make the data of pudong and Shanghai as a whole into the above radar chart. It can be concluded from the above chart that the overall passenger throughput of Shanghai is basically stable between 7 million and 7.5 million people per month, and the number of pudong airport is around 4.5 million people per month.

5.1.2 Month data processing

Since the daily distribution of the data is independent of each other, and there is no special holiday in June, the daily passenger throughput can be approximately regarded as a normal distribution, i.e., a "normal distribution". The 3σ principle was adopted to determine the variation interval of daily passenger throughput, and the random value function used combined with the passenger throughput related information of the three types of weather in the references[3] to calculate the required data.

In reference[3], the taxi flow data of Shanghai pudong airport were found. In order to facilitate the observation of flow variation rules, the obtained data were made into the following line chart:

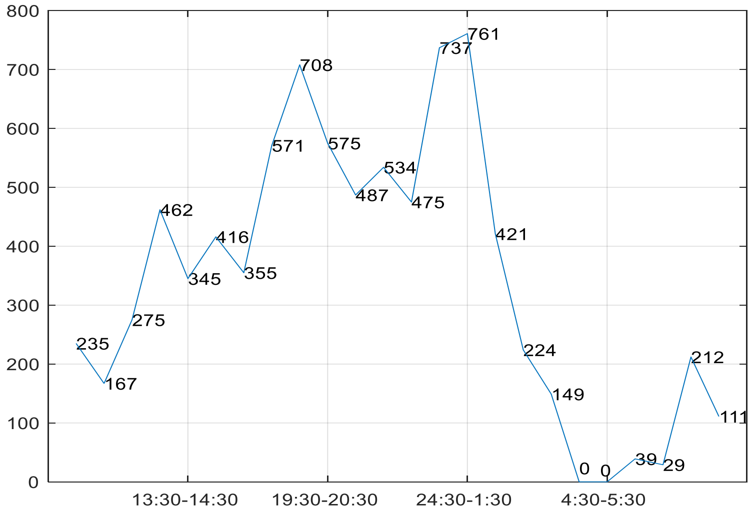


Fig.4: Taxi traffic throughout the day

5.1.3 weather data processing

In the process of literature review, classification of weather and analysis of passenger flow were also found[5]: aircraft flight is greatly affected by weather conditions, and weather is an important factor influencing passenger flow. The following figure shows several classifications of weather:

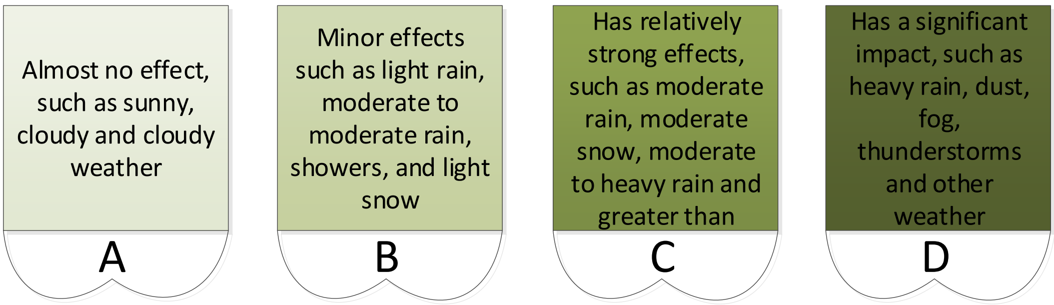


Fig.5: Weather classification

The average number of passengers arriving in Hong Kong in B and C weather is close to each other, while the average number of passengers arriving in Hong Kong in A weather is higher than that in these two types of weather. Although category D weather has A great influence, it is not common to have A great influence on the overall number of passengers, so the influence of category D weather can be ignored in the analysis.

In this paper, the weather of a month in 2014 in Shanghai is randomly selected for statistics, and the classification proportion of weather is as follows:

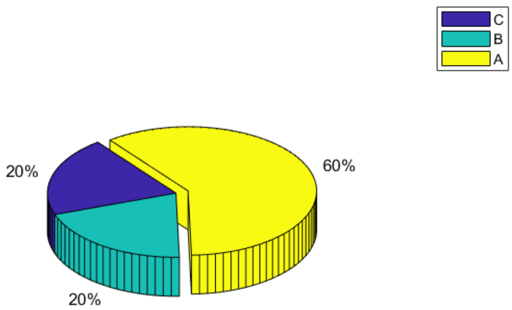


Fig.6: Weather classification in June 2014 in Shanghai

The figure above is the scale distribution obtained after collecting weather data for a month and analyzing. The number of days with good weather is significantly higher than that with bad weather, indicating that the probability of taking passengers to the airport in good weather is higher.

5.2 Model solution and result analysis

According to the data collected from the total monthly passenger throughput of Shanghai pudong airport in the four quarters of 2014, the distance between the airport and the urban area and other data, passengers taking taxis in each flight $n' = n \times 22\%$ [3]. Pudong airport has a total of 346 taxis per hour, so the taxi arrival rate is $\lambda = 0.096$ per second. The average service rate is $\mu = 0.109$.

5.2.1 Selection strategy

Combined with the analysis of relevant data, the critical value will be generated in the selection strategy A and B of airport taxi drivers. The critical value is calculated as shown in the following table through the multi-established model:

Table 4: policy critical values under various external conditions

Category	spring	summer	fall	winter	A kind of weather	B kind of weather	C kind of weather
The critical value	7	8	8	7	5	6	5

Note: the queue length is less than the critical value of decision A, and greater than the critical value of decision B

After analyzing the data, the choice plan of taxi drivers in Shanghai pudong airport under different weather and seasons is as follows:

Fig.7: schematic diagram of the selection scheme

In the figure, the ordinate is the length of the queue cars, and the abscissa is different weather and different seasons. Plan A refers to the arrival area and queuing for passengers to return to the city; Plan B refers to a direct return to the city to solicit customers.

5.2.2 Error test

Using the passenger throughput per month of Shanghai pudong airport in 2014, the expected revenue and strategic thresholds of four quarters are obtained, and the error coefficient of each quarter is calculated accordingly:

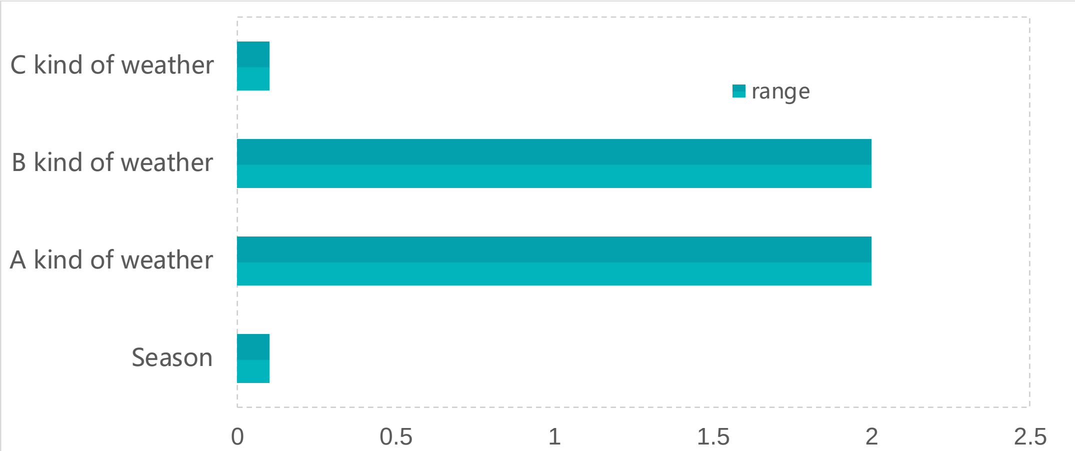
Table 5: error coefficients by quarter

Quarter	The first quarter	The second quarter	The third quarter	The fourth quarter
Error coefficient	0.143	0.142	0.125	0.25

As can be seen from the data in the table, the error coefficient of the first three quarters is small and stable around 0.13, while the error coefficient of the fourth quarter is relatively large. The fourth quarter includes three months of October, November and December, and there is a golden week in mid-october, while December is the time to return home and prepare for the Spring Festival, which will lead to a sudden increase in passenger flow. Therefore, the increase in error coefficient is also in line with the actual situation, which indicates that the model established in this paper is reasonable.

5.2.3 Dependency analysis

In this paper, an analysis model based on the control variable method is established to calculate the strategic critical value of Shanghai pudong airport in June 2014 and the strategic critical value of each of the four seasons of the year is extremely different, as shown in the figure below:



Fi.8: Policy threshold ranges

In statistics, range is often used to describe the dispersion degree of a set of data. Season and can be seen from the diagram, the strategy of critical threshold is poor and class C weather strategy extremely close to zero, the strategy of class A and class B weather extremely critical to 2, indicating that the dependence of the strategy choice of weather factors are relatively high, and the main weather factors is passenger traffic, showed the selection strategy to the dependence of the passenger flow is higher. Weak dependence on seasons.

6. Model evaluation

6.1 Advantages of the model

(1) factors such as psychological perception are taken into account in the problem solving process, and time value is introduced to convert time attribute into economic attribute, which is convenient for analysis and calculation;

(2) The data of huge airport passenger flow is randomly evaluated according to the 3σ principle, which makes the data closer to the actual value and reduces the error.

6.2 Model shortcomings

Since there are many data sources, and some of the data in the processing process are based on the proportion of the whole year instead of the proportion of each month, there may be some errors in the calculated data.

7. Improvement and promotion of the model

7.1 model improvement

(1) when establishing the decision model

based on the principle of psychological account, the effective integration of time and income into multidimensional attribute gains and losses can be combined with the linear weighting method to make the gains and losses from different sources more precise;

(2) in the application of the queuing theory model, the relationship between the length of the train and the length of the boarding point can also be considered to increase the constraint conditions of the length.

7.2 generalization of the model

The decision model based on the principle of psychological account is applied to the transportation choice of passengers, the time spent on the road and the influence of the riding environment on the psychology are taken into account, and the economic expenditure is taken into account to finally make the decision with the least expected revenue and loss.

8. Conclusion

In this paper, a decision model based on psychological account principle and a queuing model of (M/M/1) system are established. Based on an example, the critical value of queue length for driver decision-making under different external conditions is calculated. The error coefficient of critical decision value is all about 0.13, and the model is reasonable. It is concluded that weather has great influence on decision making and seasonal change has little influence on decision making. The results of the model established in this paper are reasonable. In real life, it can also be applied to the problem of queuing at the gas station and the problem of long-distance car seeing off passengers, providing a reference solution for practical problems.

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