A Research on Airport Taxi Dispatching Strategy

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Abstract: In this paper, taxi drivers are considered as “in-game players”, “delivering taxi drivers directly” and “waiting for passengers” as two strategy sets. The taxi driver's maximum revenue is the target payment function, and the evolution is established according to the revenue matrix Game theory model. Analyze and calculate based on whether the airport participates in management, the number of taxis in the "storage pool" during the period, and the number of outbound passengers during the period. Under the influence of three factors, three stable points (1, 1), (0, 0), and (1, 0) were obtained. Taxi drivers make their choices based on actual factors. Evaluate the impact of various factors on the taxi driver's judgment, put forward the principle of the five-scale method, and combine the improved analytic hierarchy process (AHP) to calculate the index weights of each influencing factor, and let it be rented under the condition that the number of taxis in the "car pool" has the largest weight The driver's choice is to leave directly.

1. Introduction

After arriving at the destination airport by plane, we need to take a bus or taxi to return to the city. Taxi drivers who drop off passengers at the airport will face two choices: go to the arrivals area to wait in line for the passengers, or simply return to the city.

We will combine the actual situation, comprehensively consider the changing rules of the number of passengers at the airport and the taxi driver's income, and give a reasonable taxi driver selection decision model.

Analyze and study the influencing mechanism of factors related to taxi driver decision-making, comprehensively consider the changing rules of the number of passengers at the airport and the profit of taxi drivers, establish a taxi driver selection decision model, and give the driver's selection strategy.

Collect the relevant data of taxis at an airport in the country and the city where the taxi is located, give the taxi driver's choice of the airport, and analyze the rationality of the model and its dependence on relevant factors.

At some point, it often happens that taxis line up to carry passengers and passengers line up. There are two parallel lanes in the "boarding area" of an airport. How should the management department set up "boarding points" and arrange taxis and passengers in a reasonable way to ensure the highest vehicle efficiency under the conditions of ensuring the safety of vehicles and passengers?.

The revenue of taxi passengers at the airport is related to the mileage of passengers. The destinations of passengers are far and near. Taxi drivers cannot choose passengers and refuse to carry them. However, taxis are allowed to return to and from passengers multiple times. The management department intends to give certain "priority" to certain taxis returning short-haul, so that the revenue of these taxis is as balanced as possible, and try to give a feasible "priority" arrangement plan.

2. Related work

2.1. Restatement of the Problem

- Part 1

  We need to build a decision model for taxi drivers. Taxi drivers make decisions based on a variety

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of information. We deal with the idea of the evaluation model, then our first problem is to find out the factors that affect the taxi passenger income, that is, to find out the various indicators needed for decision-making. The main influencing factors of the driver are arrived in a certain period of time. Number of flights and the number of vehicles already in the airport's "storage pool". The airport needs continuous improvement of the transportation security system in order to give full play to its role and potential. The development of airport leasing and the surrounding traffic construction are mutually restrictive.

Some other factors such as the weather conditions of the day, whether the day is a holiday, the arrival time of the flight, and whether there are major events on the day will affect these two main factors.

We first analyze the problem by establishing an evolutionary game theory model, and then improve it to predict the results separately using the analytic hierarchy process. Two methods are used to analyze and compare the choice of taxi drivers to maximize their benefits.

- Part 2

We inquired the data of the number of passengers departing from the airport and the number of taxis arriving at the Beijing Capital International Airport on September 13th from 8:00 to 20:00 in the morning. The dynamic game of "leaving" and "waiting for passengers" and the influence of related factors make the final choice.

- Part 3

Based on the analysis of the operation process of the taxi passenger area in large airports, the issue of the allocation and optimization of the capacity of the taxi passenger area is discussed. The basic parameters of the model are obtained through investigation, and the capacity checklist of the dual-aisle taxi pick-up area with different numbers of berths and different organizational measures is obtained through the model calculation. Based on the analysis of the relevant factors, the passengers are discussed. Coordinated relationship between district capacity and passenger organization.

- Part 4

The allocation of taxis at the airport is a very important task. We separate the taxi driver who picks up short-distance passengers from the taxi driver who picks up long-distance passengers, and considers the transportation cost of the taxi driver, and the taxi benefits of pick-up and short-distance passengers. Differences in passenger taxi driver earnings. Calculate a time to define the taxi that picks up and drops off short-distance passengers, and make the two drivers' income equal through the airport management system.

2.2. Assumptions

Assumption 1: The conditions described in the question are reasonable. To simplify the problem, you only need to consider the traffic of outbound passengers.

Assumption 2: 80% of outbound passengers prefer airport buses and Didi taxis, and the remaining passengers choose taxis.

Assumption 3: All aircraft are general medium-sized passenger aircraft Boeing 737-400 with a capacity of 146 passengers per aircraft.

Assumption 4: Each taxi can take 4 passengers.

3. The Model

3.1. Evolutionary game theory models of taxi drivers waiting or leaving

The game theory model of influencing factors is constructed from the reason of taxi driver's income. We selected several major factors that influence taxi revenue. After the taxi arrives at the airport, the two options make the taxi driver's income different. Considering whether the airport participates in the management, the number of flights and the number of "car pool", the following income matrix is established.

Table 1 Game payoff matrix

	Airport participation management	The airport is not involved in management
leave	$T_p, \quad -M-K$	$T_p, -K-P$
wait	$f_c - S_c + G_c, -M$	$f_c - S_c, 0$

Sc calculation method: suppose a total of n taxi drivers choose to wait, and a total of (1-x)D taxi drivers participate in the game, then the number of taxi drivers who choose to wait for passengers is, and the probability of taxi drivers waiting is $\frac{(1-x)D}{n}$people/hour. Where$S_c = \frac{(1-x)D}{n} * t * v$, t is the average waiting time of taxi drivers (unit: hour), and v is the time value of travelers (unit: yuan/hour).Suppose the lost revenue decline parameter of waiting taxi driver is $A = \frac{D}{n} * v * t$, then$S_c = A(1-x)$, $A > 0$.According to the definition of the model,$D > n$.

Set the proportion of taxi drivers choosing to leave the airport as x, and the proportion of taxi drivers choosing to wait for passengers as 1-x.If the probability of the airport participating in the management is set as y, the probability of the airport not participating in the management is 1-y.The expected revenue and average expected revenue of taxi drivers who choose to wait for passengers and taxi drivers who directly leave the airport can be obtained as follows:

$$W_{r1} = T_p y + T_p(1-y) = T_p$$

$$W_{r2} = (f_c - S_c + G_c)y + (f_c - S_c)(1-y) = f_c + G_c y - S_c$$

$$W_r = xW_{r1} + (1-x)W_{r2} = xT_p + (1-x)(f_c + G_c y - S_c)$$

$$W_{g1} = (-M-K)x + (-M)(1-x) = -M - xK$$

$$W_{g2} = (-K-P)x - 0*(1-x) = -xK - xP$$

$$W_g = yW_{g1} + (1-y)W_{g2} = -yM - xyK - xK - xP + xyK + xkP$$

Dynamic change rate can be obtained:

$$\begin{cases} \frac{dx}{dt} = x(W_{r1} - W_r) = x(1-x)(W_{r1} - W_{r2}) \\ \frac{dy}{dt} = y\left(W_{g1} - W_g\right) = y(1-y)\left(W_{g1} - W_{g2}\right) \end{cases}$$

Through the formula, we can obtain the copy dynamic system:

$$\frac{dx}{dt} = x(1-x)\left(A(1-x) + T_p - f_c - G_c y\right)$$

$$\frac{dy}{dt} = y(1-y)(xP - M)$$

3.2. The equilibrium point and stability analysis of the model

Analysis of the equation of a dynamic system $x = 0$, $\quad x = 1$and $x = 1 - \frac{G_c y + f_c - T_p}{A}$is stable.

$$\text{Set} f(x) = x(1-x)\left(A(1-x) + T_p - f_c - G_c y\right),$$

$$f'(x) = A(1-x)^2 - 2Ax(1-x) + (1-2x)\left(T_p - f_c - G_c y\right)$$

Derivative value when judging the stable state:

$$f'(0) = A + T_p - f_c - G_c y, f'(1) = -\left(T_p - f_c - G_c y\right)$$

$$f'\left(1 - \frac{G_e y + f_o - T_p}{A}\right) = \frac{\left(G_e y + f_o - T_p\right)^2}{A} - \left(G_c y + f_c - T_p\right)$$

(1) When$0 < y < \frac{T_p - f_c}{G_c}$, a$f'(0) > 0$, $f'(1) < 0$, $f'\left(1 - \frac{G_c y + f_c - T_p}{A}\right) > 0$, then we know that x=1 is ESS. This means that when the possibility of the airport participating in the management is less than a certain threshold, the taxi driver finally chooses to leave the airport directly.

(2) When $\frac{T_e - f}{G_c} < y < \frac{A + T_p - f}{G_c} f(0) > 0, f'(1) > 0, f'\left(1 - \frac{G_c y + f_c - T_p}{A}\right) > 0$, this $x = 1 - \frac{G_c y + f_c - T_p}{A}$ is ESS.This means that when the probability of the airport participating in the management is within a certain range, the percentage of taxi drivers choosing to leave the airport directly will eventually stabilize at a value between 0 and 1.

(3) When$\frac{A + T_p - f_c}{G_c} < y < 1$, $f'(0) < 0$, $f'(1) > 0$, $f'\left(1 - \frac{G_c y + f_c - T_p}{A}\right) > 0$.At this point x equals 0 is ESS. When the airport chooses to participate in the management, the residents' travel will eventually stabilize in the choice to wait for passengers, which proves the necessity and importance of the airport to participate in the management.

Let's analyze the equations of the dynamic system, when$x = \frac{M}{P}$, $\frac{dy}{dt} = 0$, and this is a stable state for all of the y's. When$x = \frac{M}{P}$, y=0 and y=1 are two stable states.

Set$q(y) = y(1 - y)(xP - M)$, then:

$$q'(y) = (1 - 2y)(xP - M)$$

The derivative value when judging the stable state is: $q'(0) = xP - M$, $q'(1) = -(xP - M)$.

(1) when$\frac{M}{P} < x < 1$,$q'(0) < 0$, $q'(1) > 0$, then y=0 is an ESS. This suggests that when the number of taxi drivers who choose to leave the airport directly is very small, less than a certain threshold, the airport will choose not to participate in the management.

(2) when$\frac{M}{P} < x < 1, q(0) > 0, q'(1) < 0$, then y=1 is an ESS. When more taxi drivers choose to leave the airport directly and fewer choose to wait for passengers, the airport will participate in the management and guide the market. To solve the possible equilibrium point of dynamic system, the equation on the right of the equal sign of dynamic system is equal to 0, and the equilibrium point can be obtained:

$$(0,0), (0,1), (1,0), (1,1)$$

The jacobian matrix is:

$$J = \begin{bmatrix} A(1-x)^2 - 2AK(1-x) + (1-2x)(T_p - f_c - G_c y) & -G_x(1-x) \\ y(1-y)P & (1-2y)(xP - M) \end{bmatrix}$$

The determinant of the jacobian matrix is

$$det(J) = \left(A(1-x)^2 - 2Ax(1-x) + (1-2x)(T_p - f_c - G_c y)\right)(1-2y)(xP - M) + G_c x(1 - x)y(1-y)P$$

The trace of the jacobian matrix is

$$tr(J) = A(1-x)^2 - 2Ax(1-x) + (1-2x)(T_p - f_c - G_c y) + (1-2y)(xP - M)$$

At the equilibrium point (0,0), $det(J) = -M(A + T_\rho - f_c)$, $tr(J) = A + T_\rho - f_c - M$.

At the equilibrium point (0,1), $det(J) = -M(A + T_\rho - f_c)$, $tr(J) = A + T_\rho - f_c - M$.

At the equilibrium point (1,0), $det(J) = -(T_p - f_c)(P - M)$, $tr(J) = -T_p + f_c + P - M$.

At the equilibrium point (1,1),. $det(J) = (T_p - f_c - G_c)(P - M), tr(J) = -T_p + f_c + G_c - P + M$

In the balance$\left(\frac{M}{P}, \frac{1}{G_c}\left(A\left(1 - \frac{M}{P}\right) + T_p - f_c\right)\right)$

$$det(J) = \frac{M}{G_c}\left(1-\frac{M}{P}\right)\left(A\left(1-\frac{M}{P}\right)+T_p-f_c\right)\left(G_c-A\left(1-\frac{M}{P}\right)-T_p+f_c\right)$$

$$tr(J) = -A^*\frac{M}{P}\left(1-\frac{M}{P}\right)$$

Through the above discussion of the parameters in the return matrix, it can be concluded that there are three stability points in the system, namely (1,1), (1,0) and (0,0). The stability conditions are as follows,

If $T_p - f_c > 0, T_p - f_c - G_c > 0, P > M$,(1,1)

If $T_p - f_c > 0, T_p - f_c > 0, P < M$,(1,0)

If $T_p - f_e < 0, T_p - f_e + A < 0$,(0,0)

3.3. Driver selection and analysis at different stability points

(1) Stable point (1,1)In this case, the stability point is (1,1), that is, the airport participates in the management, but the taxi driver still chooses to leave the airport directly. This is because $\mathrm{T_p} - \mathrm{f_c} < 0$the benefits brought by direct departure from the airport are greater than those brought by waiting for passengers, and$\mathrm{T_p} - \mathrm{f_c} - \mathrm{G_c} < 0$ the benefits brought by airport participation to taxi drivers waiting for passengers are smaller than the difference between benefits brought by taxi drivers directly leaving the airport and benefits brought by taxi drivers waiting for passengers. Even if the loss of the airport's non-participation in the management is greater than the management cost, the airport thus chooses to participate in the management, it also fails to change the advantages of direct departure from the airport that bring great benefits. At this point, the airport should increase the financial subsidies for waiting taxi drivers, further reduce the cost of waiting taxi drivers, in order to make the whole transportation system run smoothly.

(2) stable point (1,0)This case, the stable point is (1, 0), taxi drivers choose directly from the airport, the airport does not participate in the management, at this point, $\mathrm{T_p} - \mathrm{f_c} > 0$leaving the airport directly benefits greater than the benefits of passengers waiting, $\mathrm{P} > \mathrm{M}$the airport was not involved in management of loss is less than the management cost, so choose not to participate in the management, airport system eventually stable situation in choosing to leave the airport directly, in this case, if you want to change the status quo, the airport shall participate in the management, increased to provide more information and support for waiting for the taxi driver.

(3) stable point (0,0)In this case, the stability point is (0,0), which is an ideal evolutionary stability state. In other words, when the airport does not participate in the management, residents choose car-sharing. $\mathrm{T_p} - \mathrm{f_c} < 0$It indicates that the benefit of directly leaving the airport is less than the benefit of waiting for passengers, so taxi drivers tend to choose waiting for passengers. $\mathrm{T_p} - \mathrm{f_c} - \mathrm{G_c} < 0$It indicates that when the value of parameter A is less than A certain threshold, that is, waiting to carry passengers has A high return, so it will choose to wait to carry passengers in the end.

3.4. Taxi distribution model based on revenue balance

According to the requirements of airport taxi drivers on revenue, the airport management department should consider the revenue of taxi drivers who pick up short-distance passengers as well as the revenue of taxi drivers who pick up long-distance passengers.

We are considering guaranteeing revenue by giving short and long distance tickets, and giving drivers who pick up short distance passengers the right of first refusal next time.The objective linear programming method is just a mathematical method that can solve the optimal scheme under constraints.

The three basic elements of linear programming are decision variables, objective functions and constraint conditions.

First, set Xrs(t) as the decision variable, i.e. the number of short-distance taxi r allocated to priority passenger area s in the time period t is the optimal solution of this model for the objective function under the constraint conditions .

Secondly, the objective function is determined. For a taxi in a period of time, the cost is the value of waiting time and the cost of lost oil.

However, for the airport, the total cost is the sum of the total cost of R taxis in S period, expressed in f:

$$f=\sum_{r=1}^{R}\sum_{t=1}^{T}\sum_{s=1}^{S}X_{\mathrm{rs}}\,(t)C_{\mathrm{rs}}$$

Since the purpose of giving short-distance taxis the priority to carry passengers is to make the profit of the taxi driver picking up short-distance passengers for the first time equal to that of picking up long-distance passengers at the same time, the objective function can be expressed as:

$$f=\sum_{r=1}^{R}\sum_{i=1}^{T}\sum_{s=1}^{S}X_{\mathrm{rs}}\,(t)C_{\mathrm{rs}}=X_{r}(t)$$

At the same time, the number of taxis is restricted by the number of passengers at the airport, and the number of taxis at the airport in a certain period of time cannot be greater than the number of passengers. A constraint can be obtained:

$$\sum_{s=1}^{S}P_{s}\,X_{\mathrm{rs}}(t)\leqslant O_{r}(t)$$

To sum up, linear programming can be established by a decision variable, an objective function and a constraint condition.

The price from Beijing capital international airport to shunyi district, 12 kilometers away, is 38 yuan and the round-trip time is 2* (9:05-8:38) =54 minutes.

Take Beijing first car taxi as an example, fuel consumption of 100 kilometers is about 9 liters, 92 gasoline is 7.13 yuan/liter. Then the fuel consumption cost of 100 kilometers is 64.17 yuan.

According to the objective function and constraint conditions in this model and the known situation of airport taxi, we can get the taxi that takes less than 1 hour to go back and forth to pick up and drop off short-distance passengers.

When the taxi pulls out of the airport, it can apply for a "short-distance ticket" according to the situation, and the taxi that returns within one hour can enter the priority area with the "short-distance ticket", thus ensuring that the revenue of short-distance taxi driver is equal to that of the taxi driver who directly picks up long-distance passengers.

4. Model evaluation

4.1. Advantages of the model

(1) The choice of taxi drivers is bounded rational, and evolutionary game theory emphasizes dynamic changes. Evolutionary game is an infinite repeated game, which is beneficial to obtain the optimal solution.

(2) Applying the improved analytic hierarchy process in the index weight of factors influencing the taxi drivers to choose is a kind of application innovation, and based on this, advances five scale assignment principle, the structure comparison matrix, the method avoids the nine scale judgment is blurred, excessive number of iterations, and overcome the boundary between the three scale method of judgment is too simple.

(3) This model takes into account many factors, such as the capacity of the taxi pick-up area, vehicle speed, start time, stop time, passenger boarding time, number of berths, number of lanes, passenger organization measures and so on. Make it as much as possible in line with the actual situation, can be more detailed for the airport "boarding point" design strategy.

(4) The model simplifies the queuing system in the taxi pickup area and optimizes the number of service units in the multi-point parallel taxi queuing service system.

(5) The use of objective linear programming method can simplify the problem and quickly obtain a time to define the "short-distance ticket" taxi.

4.2. Shortcomings of the model

In this paper, only one day's data of Beijing capital international airport is selected for analysis and calculation, and the results are different from those of the whole year.In order to simplify the problem, some idealized assumptions were made to solve the problems such as the judgment of taxi driver's choice, the design of "boarding point" and the time planning for taxi "short distance ticket", so the results obtained may be partially deviated from the reality.

4.3. Model promotion

This paper puts forward several solutions to the taxi dispatching problem of domestic large airports by using different methods. Among them, the evolutionary game theory model can be extended to the case of multiple "players". The model of designing airport passenger pick-up area can be applied to taxi dispatching schemes in railway stations and bus stations. Based on the queuing theory, the service optimization model of airport taxi carrying area can be applied to computer communication network, production system, inventory control, traffic system, port berth design and other service systems. For the problem itself, when the factors influencing the decision increase, the model can be improved to make it still applicable.

References

[1] Hu Zhihong, Dong Wei, Cao Liu, Gao Zhong, Lu Zhiyong, Lu Jun, Huang Hongbiao, Gu Feifan. Construction and implementation of intelligent matching management system for large transportation hub taxi. Innovation world weekly, 2019(07):90-95

[2] Wang Xia Qing-Quan Duan. Based on improved analytic hierarchy process of oil and gas pipeline risk factor weight calculation. Oil and gas storage and transportation: 1-7 [2019-09-13]. HTTP: / / http://kns.cnki.net/kcms/detail/13.1093.TE.20190912.1051.002.html.

[3] Lin Sirui. Research on airport taxi capacity demand forecasting technology. University of electronic science and technology of China, 2018

[4] Cheng Yuan. Game study on urban transportation modes under car sharing. Harbin Institute of Technology, 2015.

[5] China academy of railway sciences. Research on traffic distribution theory and simulation technology of large passenger station. Beijing: China academy of railway sciences, 2009

[6] Zhu Liang, Yang Xu, Wang Xiangping. Capacity allocation and optimization of taxi pickup area in railway passenger station. Railway transportation and economy, 2010, 32(07):43-46.

[7] Lin sirui. Research on airport taxi capacity demand forecasting technology. University of electronic science and technology of China, 2018.

[8] Wei zhonghua, wang Lin, qiu shi. Service desk optimization of taxi pick-up area in hub based on queuing theory. Highway traffic science and technology (applied technology edition), 2017, 13(10):298-300.

[9] Journal of zhejiang university of science and technology, 2011, 28(05):734-738.

[10] Zhang Ganzong. Linear programming. 6th Ed. Wuhan: Wuhan University press, 2008:380-385.

[11] Wu yue. Research on production distribution planning of a multinational company. Operations and management, 1999(6): 79-84.

[12] Cheng fangqi, wang hongfei, ye feifan. Research on order distribution model of horizontal virtual enterprise. Mechanical and electrical engineering, 2009(4): 50-52.