For office use only

T1 ________________

T2 ________________

T3 ________________

T4 ________________

Team Control Number

12345

Problem Chosen

C

For office use only

F1 ________________

F2 ________________

F3 ________________

F4 ________________

2019
MCM/ICM
Summary Sheet

Airport Taxi Operation Model Based on Big Data of Taxi

Most airports in China separate the delivery (departure) and reception (arrival) channels apart, so drivers who take passengers to the airport should decide whether to queue up in the "boarding area" to pick up passengers, or simply empty out and return to the city to pick up passengers. This paper quantifies the factors that affect taxi decision-making, ride efficiency and revenue, establishes a specific model, and studies the taxi driver's decision-making method and the airport's reasonable management of taxi.

Aiming at problem 1, this paper analyzes the income and expenditure of two cars which making different decisions in this period.

Aiming at the second problem, this paper collected airport related information and analyzed the result information of GPS track data of Shanghai taxi by ArcGIS, and conducted information docking and model integration for the established model of the first problem.

Aiming at the third problem, this paper chooses the management mode of the pick-up area which is suitable for two-way parallel, analyzes the driving characteristics of the taxi in the "boarding area".

Aiming at the fourth problem, this paper chooses the improved "short-distance ticket" mechanism as the "priority" arrangement scheme, and takes PVG as an example to establish the model of net income per unit time of long-distance buses.

Contents

1 Introduction

1.1 Problem Background

Most passengers take a taxi from the airport to their destination. Most airports in China separate the delivery (departure) and reception (arrival) channels. Passengers need to queue up in the designated " boarding area " and take the taxi in order according to the arrangement of the airport management personnel. Taxi drivers who take passengers to the airport have two choices: stay in line at the airport and wait to take the passengers back to the city or go straight back to the city with the taxi empty. There are a variety of reasons may affect the taxi driver's decision, such as personal experience, airport visibility information and other uncertain information.

1.2 Our Work

1. **Analysis of problem one:** We can model the passenger carrying state of the taxi in a certain period of time under the two choices of airport passenger queuing and returning to the city, and then make a decision based on the net income of the two choices in this period as a comprehensive evaluation index.
   In the choice of airport passenger queuing, the time influencing factors such as the initial number of passengers, flight frequency and the number of car storage pools are taken into consideration to calculate the queuing time, and the net income of this choice is determined by the travel mileage of passengers. Under the option of directly emptying and returning to the urban area to carry passengers, the empty driving mileage and the operation mode after entering the urban area are simulated, and then the net income is calculated by including the cost anincome of empty driving.

2. **Analysis of problem two:** Taking Shanghai PUDONG international airport(PVG) as the sample object, the annual statistical information of civil aviation and the specific situation data of the airport were collected, and the model in question 1 was used to calculate the waiting market of the vehicles waiting in line to carry passengers at the airport.
   Using ArcGIS to tag the map by collected GPS data of Shanghai taxi, to analyze regional city traffic and passenger distribution, and combining the taxi fuel consumption and the valuation model. By comparing the income and expenditure of taxis leaving the airport after picking up passengers and their travel time, as well as the income and expenditure of taxis returning directly to the city, the decision-making results were obtained, and the rationality of the model was analyzed by the sensitivity.

3. **Analysis of problem three:** Determine the two-lane taxi pickup management mode, analyze the passenger behavior mode, and calculate the pickup time. Taxis queued in the airport to go to the "boarding area" drive in the following mode, and every time a batch of cars arrive at the "boarding area", they need to stop and pick up passengers, that is, the taxis in the queue need to stop intermittently, and then

restart to drive forward. According to the driving mode, the spatio-temporal trajectory model of taxi in "boarding area" is established. The average stay time and the capacity of the taxi are taken as the quantitative indexes of the efficiency of taking the taxi into consideration and assuming the continuous arrival of the taxi. The efficiency and rationality of the model were analyzed when the number and position of the boarding points were different and the number of the same batch of boarding taxis were different.

4. **Analysis of problem four:** At present, the common "priority" arrangement scheme of both domestic and foreign airports is to provide short-distance taxi with a "short-distance ticket" mechanism that can return to the airport under certain conditions without queuing to pick up passengers. This problem from the improved mechanism of "ticket" as a "priority" arrangement scheme, taking PVG as an example to establish net income per unit time is on the bus model, model of ordinary car net income per unit time is short and the "first" car model of net income per unit time is short, and then test the "priority" arrange "ticket" really achieving the target of taxi profit as far as possible balanced.

2 Preparation of the Models

2.1 Assumptions

- Assume that the research object of the model is located in a single central city with a high degree of distribution, and the urban road network is annular radial, that is, it is composed of radial lines passing through the downtown area and ring lines surrounding the city.
- Assume that the follow-up operation of the taxi directly emptied and returned to the urban area to pick up passengers is always within the urban area and its surrounding areas.
- Empty driving is assumed to be an operation task with 0 profit.
- Assume that in this model, all arriving flights operate completely according to the schedule plan, that is, real-time flight information is not considered.
- Assumed that the models established by question 1 and question 3 are independent, that is, the airport queuing time of question 1 has nothing to do with the capacity of question 3.
- We ignore the distance between the boarding point and the entrance and exit of "boarding area", and it is assumed that passengers will be evenly distributed to each boarding point.
- Assumed that all taxis receiving "short-haul tickets" will choose to return to the airport and wait for the next passenger assignment.

2.2 Notations

The primary notations used in this paper are listed in **Table 1**.

Table 1: Notations

Symbol	Definition
r	The distance between a taxi and downtown.
d	The distance between the taxi and the airport.
Sd	The distance between the taxi and the airport.
L	The distance between the airport and the edge of the city.
v	The speed of the taxi.
S_e	The first empty mileage of the taxi back to the city.
S_j	The mileage of passengers picked up by taxi at the airport.
S_{jc}	The mileage of passengers picked up by long-distance taxi at the airport.
S_{jd}	The number of trips taken by a short taxi at the airport.
S_s	The mileage of passengers picked up by taxi in the city.
S_{sf}	The passenger mileage of the taxi in the city is attached to the empty mileage.
$jmin$	The distance from the airport to the nearest landmark.
I	The number of operational tasks completed in a billing cycle after the taxi is directly emptied and returned to the city to pick up passengers.
Po_i	The direct distance from the airport when the taxi starts the i-th operation task within a settlement period after the taxi is directly emptied and returned to the city to pick up passengers.
δ	The ratio of the direct distance to the distance traveled by a taxi in an urban area.
S_{s0}	The distance a taxi picks up a passenger in the city, $S_{s0} = s_s * \delta$.
P_r	The probability of encountering passengers during the distance of d between the taxi and the city center.
T_j	The total amount of time it takes for a taxi to wait in line at an airport to pick up passengers at the airport.
T_{sI}	The total time taken by the taxi from the decision to empty and return to the city to pick up passengers to the completion of the sub-operation task within the I-th billing cycle.
T_{j1}	The time it takes for a taxi to pick up passengers at an airport.
ΔT	The time long - haul or short - haul buses waiting at the airport.
α	The turning Angle between the ray and the straight line in the taxi track is selected.
S_z	The number of seats on a single flight at the airport.
$zmax$	Maximum seat capacity of a single passenger plane at the airport.
$zmin$	The minimum number of seats for a single passenger plane at an airport.
f	Airport annual statistics of the historical passenger load rate.
P	The number of passengers who choose to leave by taxi on a single flight.
k_d	The percentage of passengers who choose to leave the airport by taxi during the daytime.

Continued on next page

Table 1 – continued from previous page

Symbol	Definition
k_n	The percentage of passengers who choose a taxi to leave the airport at night.
c_i	The probability of a single taxi taking i passenger(s), $i = \{1, 2, 3, 4\}$.
A	The historical average number of passengers carried by taxis departing from the airport.
W	The total length of wait for a driver who chooses to stay at the airport to pick up passengers.
Q	The number of taxis already lined up in the "storage pool".
U	Waiting in line for a taxi at the airport.
D	Within the "ride area" is the total time of no passengers.
$Input$	Average number of incoming flights per hour.
Int	The maximum time interval between adjacent arrival flights.
Y_h	The taxi gets gas mileage per kilometer.
Y_j	Local fuel prices.
M_j	The net profit of a taxi in a certain settlement period.
M_r	The total revenue of a taxi during a billing period.
M_c	The fuel cost of a taxi within a certain billing period.
$Z_k(S)$	Taxi mileage pricing rules.
M_l	Net gain per unit time on long-distance bus.
M_s	Net gain per unit time for short distance vehicles.
$K(S)$	The empty capacity of a taxi when it is S away from the city center.
T	A moment in time.
B	The number of single-lane single-batch released taxis is equal to the number of single-lane parking Spaces in the parking area of the airport.
t_w	The time from the beginning of batch release to the last passenger of the batch queuing into the parking area.
$distance$	The position of an adjacent passenger in a queue.
E	The number of car ports in one lane.
v_p	The speed at which passengers walk in line
t_p	Total pick-up time.
t_c	The time when passengers pack up and sit in the car.
t_g	Each batch of the first group of passengers from the boarding point to the corresponding taxi side time.
t_{yi}	The delay time for a taxi driver who is within $(i-1)$ body space of the first vehicle in the fleet
t_n	Driver normal induction - response time.
t_{ri}	Slack time for a taxi driver who is within. $(i-1)$ body space of the first vehicle in the fleet.
cap	The capacity of the "boarding area".

3 The Model of Part I

3.1 A model of airport queueing times

Taxi drivers need to consider the length of the airport queue when they choose to stay at the airport or leave the airport emptily and return to the city to pick up passengers. Compared to the time it takes for a driver to empty a car and return to the city, the waiting time at the airport is less random and more dependent on the number of waiting vehicles in the "storage pool", the number of waiting vehicles in the "boarding area" at the moment, and the arrival of flights after that time when the driver arrives at the airport.

i. Determine the number of people waiting in the "boarding area" and the calculation method for their growth. First, based on the historical average of the number of incoming flights per hour at the airport, calculate the time between each flight.

$$\text{int}/60 = 1/\text{input} \tag{1}$$

Set the upper limit value of the interval between flights simulated by this calculation result, then set the lower limit value as 0, and randomly select a value with equal probability to obtain the simulated arrival time of each flight. Second, the number of seats on each aircraft at the airport is calculated to give the expected number of seats on a flight. Due to the observation experience, the number of medium type aircrafts accounts for the largest proportion, and the number of large and small aircrafts is several. Therefore, this model adopts the normal distribution model to describe the number of seats of the flight.

$$S_z \sim \mathrm{N}(\mu_z, \sigma_z) \tag{2}$$

The μ_z is the expected number of seats on flights at the airport, and it is guaranteed that $zmax$ is less than or equal to $\mu_z + 3\sigma_z$ and $zmin$ is greater than $\mu_z - 3\sigma_z$

Finally, according to the annual passenger load rate of the airport, the number of passengers on each flight was obtained, and the proportion of passengers who chose taxi to leave the airport at different time periods was considered to get the number of passengers going to the "boarding area" at different times. Considering the actual situation, urban public transport will share some of the passenger flow of taxi trips during its operation, so this model chooses to divide a day into two periods, day and night. The daytime period is the urban public transport operation period, while the nighttime period is the non-operation period. In the public transport within 10 minutes' walking distance from the airport exit, the time of the earliest first bus and the latest last bus is taken as the dividing line between the daytime and the night period.

$$P = \begin{cases} S_Z * f * k_d, \ During\ the\ day\ time \\ S_Z * f * k_n, \ During\ the\ night\ time \end{cases} \tag{3}$$

With the above steps, based on the aircraft type, flight schedule and historical statistics of the airport, it is possible to know the number of passengers who choose to take a taxi to leave the "boarding area" at each time.

ii. Determine the relationship between the number of waiting vehicles in the "storage pool" and the number of waiting vehicles in the "boarding area". Since this model is a driver decision-making model, the analysis scope is only in the time area from the driver to the departure of the airport, that is, only the number of waiting vehicles in front of the driver is considered. The decrease rate of the number of vehicles waiting in front is correlated with the loss rate of the number of people in the "taking area". Since the maximum number of passengers in a taxi is 4, the probability of the number of passengers in a taxi is set as 1 to 4 respectively, so that the weighting number of passengers in a single taxi after weighting is equal to the historical average number of passengers in the taxi departing from the airport.

$$c_1 + 2 * c_2 + 3 * c_3 + 4 * c_4 = A \tag{4}$$

By using the simulation, the number of passengers carried by each vehicle waiting in front can be simulated according to the above probability, and the number of passengers lost in the "boarding area" can be known when the number of vehicles waiting in front drops by one.

$$\mathrm{W} = U * Q + D \tag{5}$$

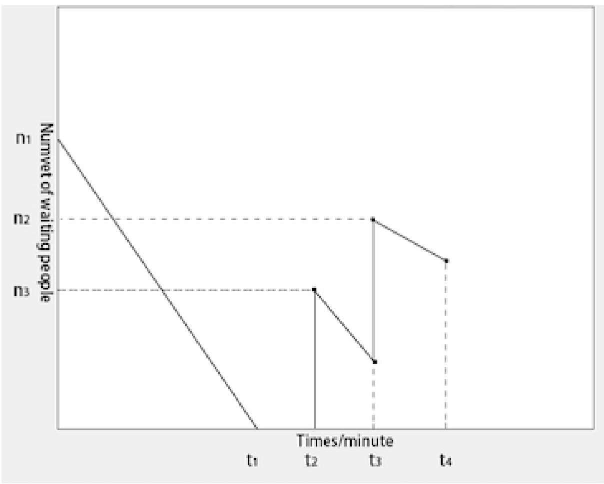


Figure 1: Number of people waiting in "boarding area" - time chart

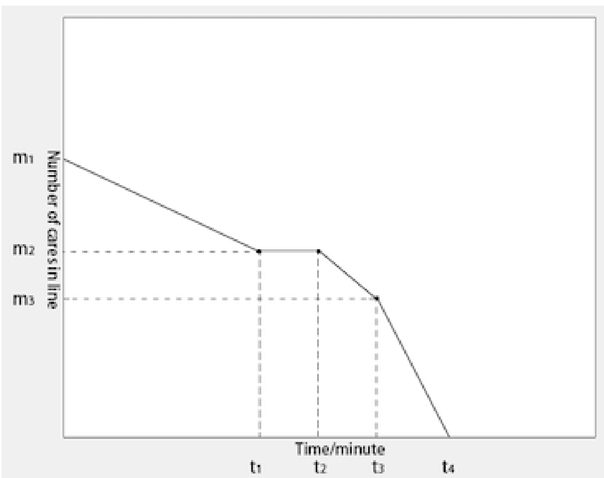


Figure 2: Number of queues in front of the "boarding area" - time chart

3.2 The model of empty mileage on the way back downtown

For the taxi driver who directly emptying and returning to the city to pick up passengers, the no-load charge paid on the return journey is one of the main components of his net income, and to calculate the no-load charge, the empty driving distance must be determined first. This model defines empty driving distance as the length of the route a taxi takes from the airport to the first passenger.

In real life, airports are generally built in sparsely populated suburbs far from urban areas, so it is easy to know that the probability of encountering passengers in the distance from the airport is relatively small; in the process of the taxi gradually entering the city, the number of citizens who need to take the bus is also increasing, which means the probability of meeting passengers to take the taxi is gradually increasing; However, when the taxi is near the city center, the number of people waiting for the bus has exceeded the limit of the regional taxi service capacity, the taxi is basically in the state of uninterrupted work, and the probability of encountering passengers is close to the maximum. As the above change law of taxi passenger carrying probability approximately conforms to “the occurrence stage of growth curve function, the change speed is relatively slow; development stage, change speed is accelerated; mature stage, change speed tends to slow again "characteristic, Therefore, the typical Logistic function in the growth function curve was improved to describe the relationship between the taxi passenger carrying probability and the distance from the airport.

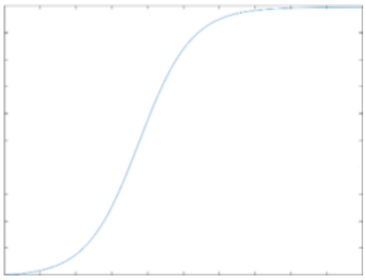


Figure 3: Image of Growth Function(Logistic)

$$P_r = \frac{1}{\frac{1}{k} + ab^r} + \mathbf{c}^4 \tag{6}$$

At the same time, use the following formula to represent the distance between the position and the airport when given the probability value of taking a bus:

$$r_P = \ln b \left(\frac{k - P_r}{akP_r} \right) \tag{7}$$

In probability theory and mathematical statistics, we call the event with a probability very close to 0 (generally 5% to 10%) and a very low frequency in a large number of repeated experiments as a small probability event, and on the contrary as a large probability event. In the model, 85% is selected as the probability value of receiving passengers with high probability, that is, the expected distance between a large number of taxi returning directly from the airport and picking up the first passenger is $r_{85\%}$.In order to simulate the randomness in real life, a uniform random number within the interval where the random coefficient ω is [0.9,1.1] was selected, and the empty driving distance model in urban areas was returned:

$$S_e = \omega * r_{85\%} \tag{8}$$

3.3 The model of a passenger track

Whether it's passengers waiting in a taxi line at an airport, passengers running into each other on their way back to the city or passengers in an urban operation, the number of miles traveled per passenger is the result of a number of small, independent, random factors; According to the central limit theorem, "under general conditions, the mean value of a large number of mutually independent random variables converges to a normal distribution according to distribution after appropriate standardization". Therefore, passenger travel mileage under three conditions is subject to a normal distribution with different parameters. Considering that the passenger travelling in the airport has a strong long-distance travel, and the passenger travelling distance near the city or within the city shows a more obvious discrete type, so set

$$S_j \sim \mathrm{N}\left(\mu_j, \sigma_j\right) \quad S_s \sim \mathrm{N}\left(\mu_s, \sigma_s\right), \quad \mu_j > \mu_S, \quad \frac{\sigma_j}{\mu_j} < \frac{\sigma_S}{\mu_S} \tag{9}$$

At the same time, passengers taking the bus in the airport generally have urban orientation, that is, most of the passengers' destinations are in urban areas, so the travel track model can be abstracted as a curve and a broken line formed by a ray: a curve that expresses the geometry of a highway from the airport to the city center; the other is one of a cluster of radiation that starts at the intersection of the highway and the edge of the city. However, the travel direction of passengers picked up near the city or within the city can be approximately regarded as a random travel that is biased towards the city, that is, the travel destination in the city is a point on the circumference with the boarding point as the center and S_{s0} as the radius, which has the characteristics of leaning towards the city on the statistical level.

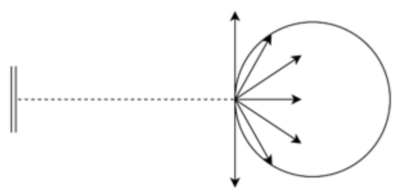


Figure 4: Abstract figure of passenger travel path of airport

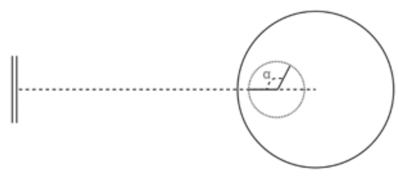


Figure 5: Abstract figure of urban or intra-urban passenger travel trajectory

3.4 The follow-up operation model based on model 3.3

According to the hypothesis of the model, a taxi driver who directly empties and returns to the city to pick up the first passenger on the way back to the city maintains a state of picking up passengers in and around the city; moreover, in order to unify the representation, both this model and subsequent models regard empty driving as a special passenger carrying operation task with no passenger income and only fuel consumption. Considering that even in the urban area and the surrounding area with a high probability of carrying passengers, there will still be an empty driving rate of at least 10%, so even in the urban area, the taxi must switch between carrying passengers and empty driving. In order to make the modeling form clear and concise and most close to the real situation, make empty driving the subsidiary mileage of each operation task, in which the mileage of empty driving is jointly determined by the operating mileage and the empty driving rate of the taxi at the location:

$$S_{sf} = S_s * \mathrm{K}(S) \tag{10}$$

By binding the operating mileage with the attached empty driving mileage, the model for the follow-up operation of the taxi driver directly emptying and returning to the city to pick up passengers is obtained. That is, the operation model can be expressed as follows: take the passenger reception point after the taxi leaves the airport as the center of the circle, and point to the end point of the operation task with the driving track model in 3.3; at the same time, the end point is taken as the starting point of the attached empty driving, and the running track model is applied to point to the end point of the empty driving, and the end point is the starting point of the next operation task; this cycle can be repeated directly empty back to the city to pick up the subsequent operation of the taxi diagram.

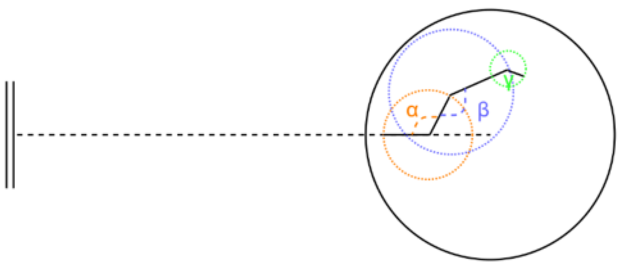


Figure 6: Follow-up operation track abstract diagram

3.5 The model of driving distance - operating time

The travel distance-operation time model is a function that expresses the relationship between the distance traveled by the taxi to complete all operation tasks in a certain settlement period and the time taken to travel the distance. NathanH. Through a study of six British cities, he found that the average vehicle speed was related to the distance from CBD; take the radiation road in the city center as the research object, divide the road into several sections according to a certain distance for observation, and establish a model based on the observation data [1]. After testing, it is better to use the model to describe the driving speed inside the city. Therefore, this model is selected as the functional expression of taxi driving speed in this paper:

$$\mathrm{v} = \mathrm{a} - \mathrm{b}e^{cd} \tag{11}$$

Where, a,b and c are all coefficients.

Using calculus is known, the location of the taxi by the distance from the airport d_1 moves to d_2 position it takes time for $\int_{d_1}^{d_2} \frac{dSd}{v}$. Therefore, for the taxi making the decision of airport passenger queuing, the combination of its travel track model leads to the fact that its distance time model is a piecewise function of the time accumulation of curve and straight line:

$$T_{j1} = \begin{cases} \int_0^{S_j} \frac{dS\mathrm{d}}{v} & S_j \leq L \\ \int_0^{\mathrm{L}} \frac{d\mathrm{Sd}}{v} + \int_{\mathrm{L}}^{\mathrm{Sd}} \frac{d\mathrm{Sd}}{v} & S_j > L \end{cases} \tag{12}$$

Sd can be given by the cosine theorem:

$$\mathrm{Sd} = \sqrt{L^2 + (S_j - L)^2 - 2L(S_j - L)\cos\alpha^4} \tag{13}$$

For the taxi that makes the decision to directly empty and return to the city to pick up passengers, the time it takes to complete all operational tasks is as follows:

$$T_{sI} = \int_0^{S_e} \frac{dS\mathrm{d}}{v} + \sum_{i=2}^{I} \int_{Po_i}^{Po_{i+1}} \frac{dS\mathrm{d}}{v} \tag{14}$$

3.6 Revenue decision model based on the above branch model

For the taxi making the decision, the net profit brought by the decision is the most important factor affecting the decision; taking into account that after the completion of the operation task of picking up passengers at the airport, the operation model of the taxi in and around the city is the same as that of the taxi that chooses to empty directly and return to the city to pick up passengers, it can be approximately considered that the net profit expectation of the taxi of the two choices is the same. To sum up, a settlement cycle is defined as the time period when a taxi decides to queue up at the airport to pick up passengers and the time period when the taxi ends the operation task of picking up passengers at the airport; then the net income brought by the two choices in the settlement period is the decisive index of the income decision model.

It is defined that the net income of a taxi in a settlement period is equal to the difference between the total income of the taxi in a settlement period and the fuel consumption cost of the taxi in a settlement period, i.e

$$M_j = M_r - M_c \tag{15}$$

It is defined that the pricing relationship between single passenger revenue and single driving distance S is $Z_k(S)$, the fuel consumption per 100 km is Y_h, and the fuel unit price is Y_j. Then, the settlement period of the taxi queuing for passengers at the airport is

$$T_j = W - T_{j1} \tag{16}$$

The net income in the settlement period is

$$M_{j1} = Z_k(S_j) - S_j * Y_h * Y_j \tag{17}$$

For the taxi directly emptying and returning to the city to pick up passengers, it is difficult to ensure that the end time of the last operational task (no load) coincides with the end time of the billing cycle. Therefore, in order to prevent its operation task from being forcibly separated by the settlement period, the settlement period of the taxi directly emptied and returned to the city to carry passengers can be delayed until the end of the last operation task within the period, that is, T_{sI} satisfies the inequality

$$T_{sl} >= T_j > T_{s(l-1)} \tag{18}$$

At this time, the net income of the taxi in the settlement period is

$$M_{j2} = \sum_{i=1}^{I} Z_k\left(S_{si}\right) - \sum_{i=1}^{I} \left(1 + \mathrm{K}\left(S_{si}\right)\right) S_{si} * \mathrm{Y_h} * Y_j \tag{19}$$

Therefore, the cost-benefit decision model can be expressed as

$$P = \begin{cases} Line\ up\ at\ airports\ to\ pick\ up\ passengers, & M_{j1} > M_{j2} \\ Choose\ to\ empty\ and\ return\ to\ the\ city\ to\ carry\ passengers, & M_{j2} > M_{j1} \end{cases} \tag{20}$$

4 The Model of Part II

4.1 Determine relevant data and model parameters

4.1.1 Introduction to data sources

This question takes Shanghai PUDONG international airport(PVG) as an example. The 2007 Shanghai GPS taxi data set [2], which contains nearly 100,000 pieces of data, is taken as the relevant data of Shanghai taxi. Its features include taxi ID, time, longitude, dimension, included Angle, instantaneous taxi speed and taxi passenger load status, etc.;Based on OpenStreetMap's Shanghai city map export data, Shanghai road network was constructed.

4.1.2 Airport passenger queuing decision model

In the airport queuing revenue decision model, the airport queuing time model, the passenger track model, the travel distance-operating time model and the decision revenue model are comprehensively applied. Relevant data can be divided into airport operation, urban traffic data and taxi revenue model. [3][4]

Data description	Symbol	The numerical
Average number of incoming flights per hour	$input$	33
Average seat on a single passenger plane	μ_z	295
Maximum seat capacity of a single passenger plane	$zmax$	550
Minimum seat capacity for a single passenger plane	$zmin$	124
Airport annual statistics of the historical passenger load rate	f	83.2
The percentage of passengers who choose to take a taxi during the daytime	k_d	15
The percentage of passengers who choose to take a taxi at night	k_n	15
The historical average number of passengers in a single taxi at the airport	A	1.5
Waiting in line for a taxi at the airport	U	0.5

Table 2: Airport operation

Data description	Symbol	The numerical
Average distance traveled by airport passengers	μ_j	34
The distance from the airport to the nearest landmark	$jmax$	12
Speed limit on city highways	$vmax$	120
Average speed in city center	$vmin$	29.4
The distance between the airport and the edge of the city as the crow flies	L	30
The distance from the airport to the center as the crow flies	r	50

Table 3: Traffic data of Shanghai

Data description	The taxi gets gas mileage per kilometer	Fuel prices	Taxi charging standard
Symbol	y_h	y_j	$ZK(S)$
The numerical	0.07	7.09	See the function

Table 4: Taxi revenue model

First, calculate the waiting time at the airport. According to the data in the above table, it can be known that the time interval of each flight is $int = 1.82$, that is, when the data is generated randomly in [0,1.82] as the interval between adjacent flights, $zmax = 550$, $zmin = 124$, μ_z=295. Therefore, σ_z is set to be 60, that is

$$S_z \sim \mathrm{N}(295, 60) \tag{21}$$

At the same time, combined with the data, we can know

$$P = \begin{cases} S_Z * 0.832 * 0.45, & \text{During the day time} \\ S_Z * 0.832 * 0.15, & \text{During the night time} \end{cases} \tag{22}$$

that is,

$$\begin{cases} P \sim N(110, 23), & \text{During the day time} \\ P \sim N(37, 7), & \text{During the night time} \end{cases} \tag{23}$$

In order to approximate the value of $c_1 + 2 * c_2 + 3 * c_3 + 4 * c_4$ tend to A, random Numbers are generated with A medium probability of 1-100. When the number belongs to [1,60], set the number of passengers on the bus as 1; when it belongs to [61,92], set the number of passengers on the bus as 2; when it belongs to [93,98], set the number of passengers on the bus as 3; when it belongs to [99,100], set the number of passengers on the bus as 4. Set the number of vehicles waiting in the "storage pool" as (0,50), and the simulation results are as follows.

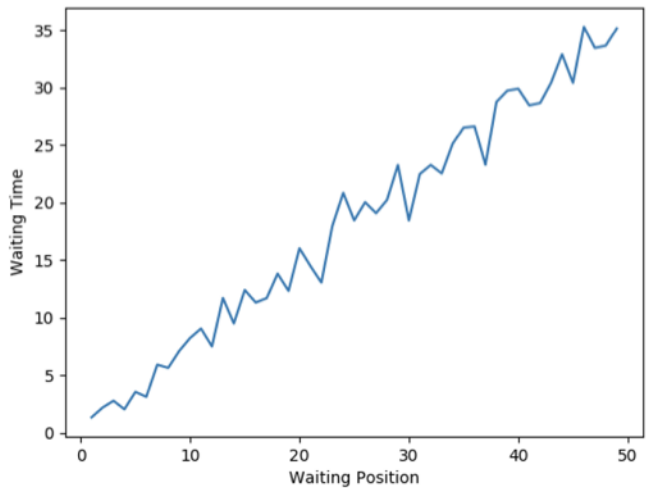


Figure 7: Airport queuing time simulation

According to the "3σ" principle of normal distribution and the distance between the average journey distance of airport passengers and the nearest landmark building in the table, the most probable normal distribution that S_j obeys in the 3.3 passenger journey path model is $N(34, 12)$. In order to determine the function expression of taxi driving speed: $v = a - be^{cd}$, taking the speed limit of urban expressway in the table as the driving speed of taxi at the airport and the average speed of downtown Shanghai as the driving speed of taxi at the downtown, the boundary condition can be used to solve the parameter value, namely, the specific speed function can be expressed as: $\mathrm{v} = 24.27 + 4.77e^{0.1d}$

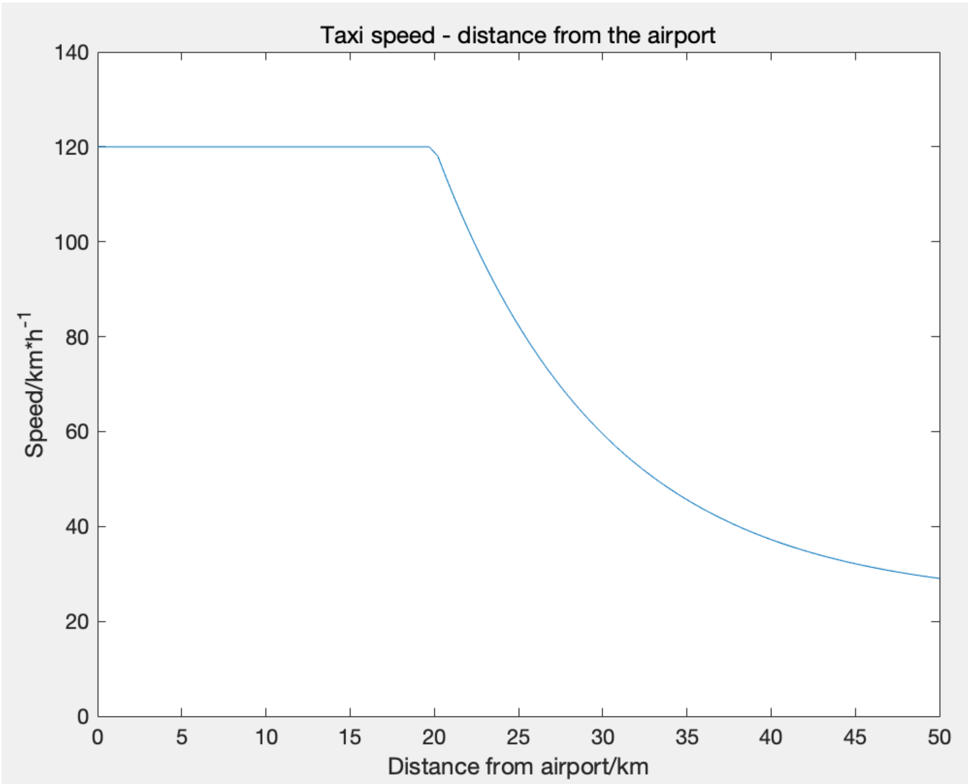


Figure 8: Taxi speed - distance from the airport diagram

Then the travel distance-operation time model can be converted into a function of travel speed

$$T_{j1} = \begin{cases} \int_0^{s_j} \frac{dS\mathrm{d}}{v} & s_j \leq L \\ \int_0^{30} \frac{dS\mathrm{d}}{v} + \int_{30}^{S\mathrm{d}} \frac{dS\mathrm{d}}{v} & S_j > L \end{cases} \tag{24}$$

Sd can be given by the cosine theorem

$$\mathrm{Sd} = \sqrt{30^2 + (S_j - 30)^2 - 2 * 30 * (S_j - 30)\cos\alpha} \tag{25}$$

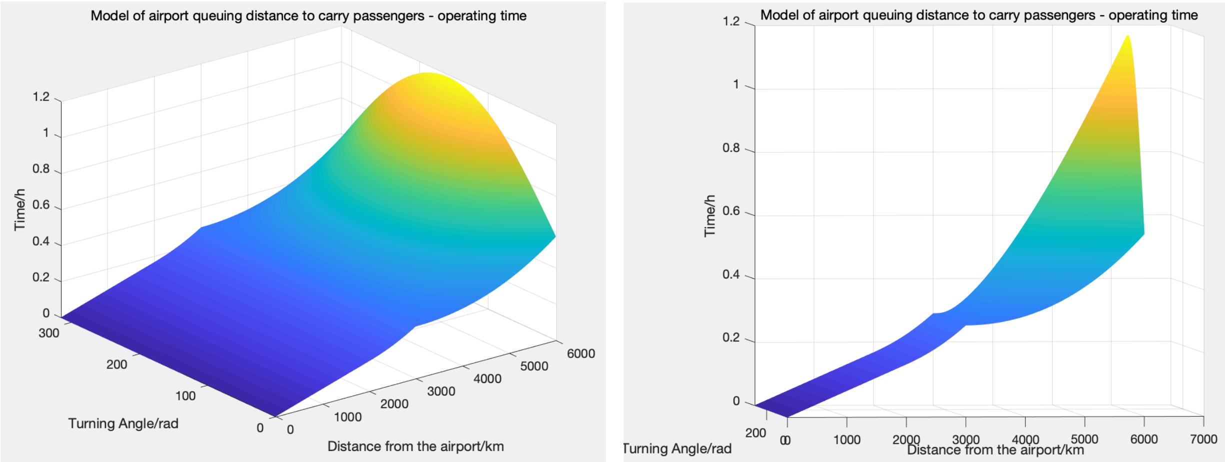


Figure 9: Model of airport queuing distance to carry passengers - operating time

According to relevant regulations of PVG taxi, the taxi pricing standard is "daytime (5:00-23:00) starting price: 14 yuan / 3km, 3-15km unit price: 2.5 yuan/km, and over 15km: 3.6 yuan/km.At night (23:00- 5:00 the next day), the starting price is 18 yuan /3 km, the unit price of 3-15 km is 3.1 yuan/km, and the unit price of over 15 km is 4.7 yuan/km ". That is, $Z_k(S)$ can be expressed as a piecewise function set [5]:

$$Z_k(S) = \begin{cases} 14 & \mathrm{S} \leq 3\mathrm{H} \; and \; \mathrm{T} \in [5:00-23:00] \\ 14 + 2.5(S-3) & 3 < \mathrm{S} \leq 15\mathrm{H} \; and \; \mathrm{T} \in [5:00-23:00] \\ 44 + 3.6(S-15) & 15 < \mathrm{SH} \; and \; \mathrm{T} \in [5:00-23:00] \\ 18 & \mathrm{S} \leq 3\mathrm{H} \; and \; \mathrm{T} \in [23:00-5:00] \\ 18 + 3.1(S-3) & 3 < \mathrm{S} \leq 15\mathrm{H} \; and \; \mathrm{T} \in [23:00-5:00] \\ 55.2 + 4.7(S-15) & 15 < \mathrm{SH} \; and \; \mathrm{T} \in [23:00-5:00] \end{cases} \tag{26}$$

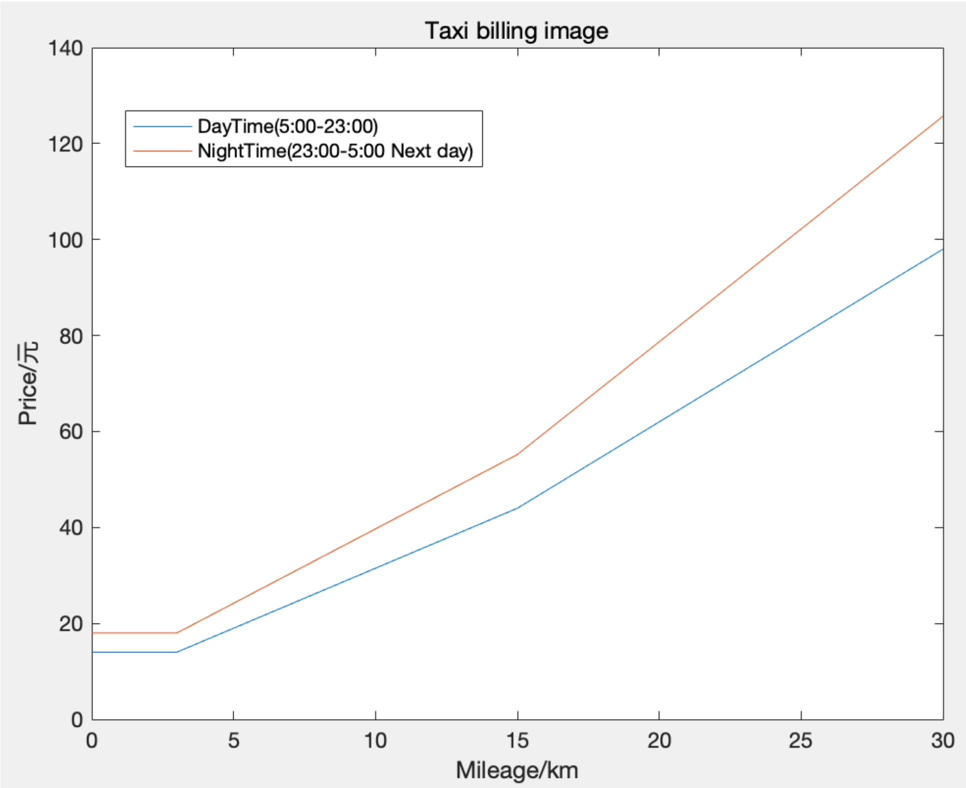


Figure 10: Taxi billing chart

To sum up, the net income in the settlement period of the taxi queuing for passengers at the airport can be selected

$$M_{j1} = Z_k\left(S_j\right) - S_j * Y_h * Y_j = Z_k\left(S_j\right) - 0.049S_j \tag{27}$$

4.1.3 Direct empty return urban passenger carrying model

For empty return to urban passenger model directly, to get the final income decision model, not only need to "4.1.2 airport queues passenger decision model to determine some of the existing models or data, in addition also need to determine the return empty downtown mileage model, passenger travel mileage obey normal distribution, the car empty rate model and the distance - operating time. According to the "3σ" principle of normal distribution and combining the mean travel distance of passengers in the downtown with the starting price in the taxi pricing table, the most probable normal distribution that S_s obeys in the 3.3 passenger driving track model is $N(6.9, 1.3)$; to determine the return urban empty driving distance model is to determine the core function - the three parameters of the growth curve function. Application "occurrence stage, change speed is relatively slow; Development stage, change speed is accelerated; the mature stage, the change speed also tends to slow "characteristic and the golden section thought, Three points (0,0), (50*0.618, $P_rmax/2$), (50P_rmax) were selected as the feature points of the function. At the same time, considering that the passenger flow gap between morning peak and evening peak has an impact on the passenger carrying probability of taxi, P_rmax is assigned to 0.95, 0.92 and 0.89 in the morning peak, evening peak and flat peak respectively, so the passenger carrying probability –

Logistic function can be obtained

$$P_r = \begin{cases} \frac{1}{1+175.90*0.760^x} - 0.06 & \mathrm{T} \in [7:00-9:00] \\ \frac{1}{1+91.079*0.789x} - 0.011 & \mathrm{T} \in [17:30-19:30] \\ \frac{1}{1+59.149*0.809x} - 0.017 & \mathrm{T} \in [19:30-7:00] \cap [9:00-17:30] \end{cases} \tag{28}$$

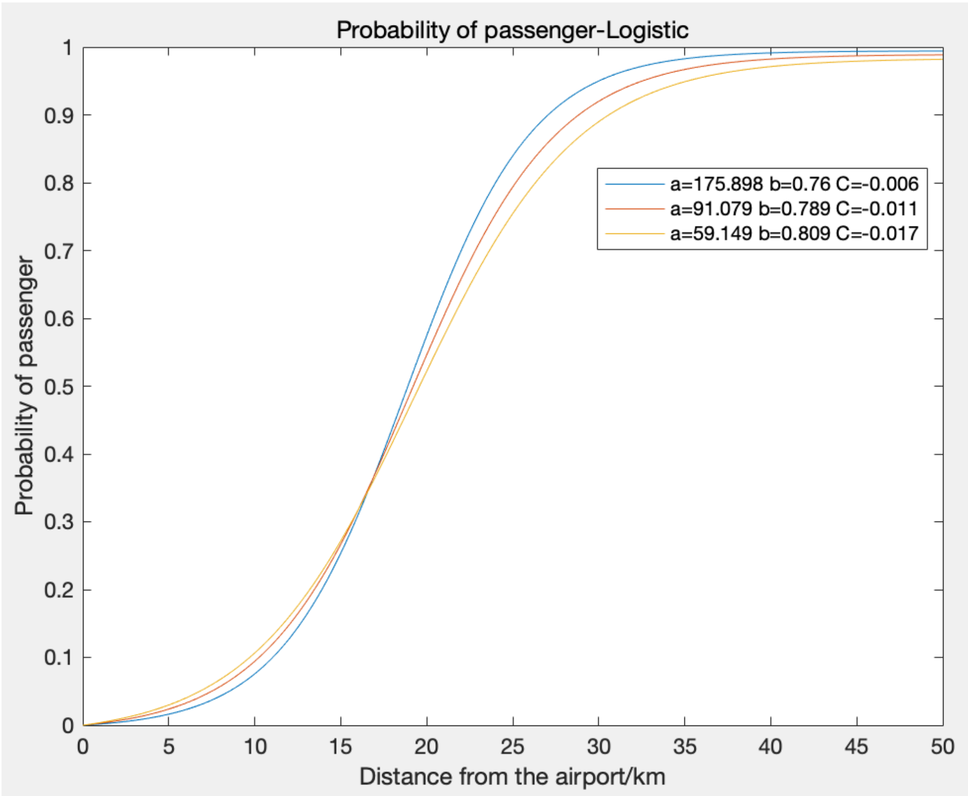


Figure 11: Passenger carrying probability -Logistic graph

With the help of passenger carrying probability – Logistic function, the driving distance – operating time model of direct empty-return to urban areas for passenger carrying can be determined as

$$T_{sI} = \int_0^{\ln b\left(\frac{k-0.85}{0.85ak}\right)} \frac{d\mathrm{Sd}}{v} + \sum_{i=2}^{I} \int_{Po_i}^{Po_{i+1}} \frac{d\mathrm{Sd}}{v} \tag{29}$$

Where, the probability of a, b and k carrying passengers – the parameter values of Logistic function under different conditions.

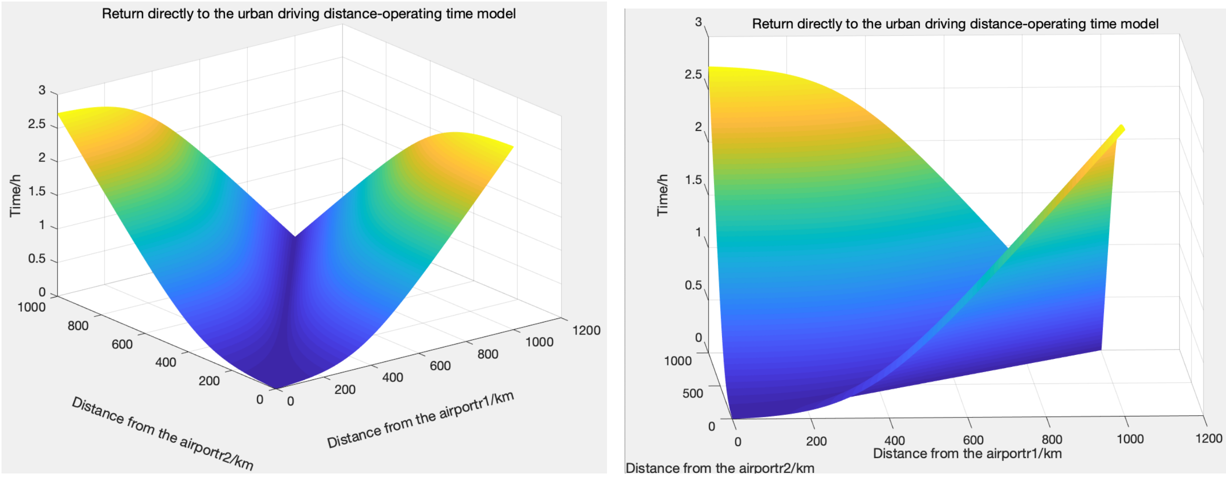


Figure 12: Return directly to the downtown area: range-run time model diagram

For empty loading rate and the function relationship between the distance from the city center, the model based on gis software ArcGIS, using 2007 Shanghai taxi GPS data sets with OpenStreetMap provided by Shanghai road network, the PVG to the center area of the road network and GPS taxi data set intersection tabulation, may go to thePVG to Shanghai central area of the empty loading rate - the road distribution table.According to the data in the table, the average empty load rate of taxi in each street in this part of the region is obtained, and then the average empty load rate of taxi in this part of the region is displayed to the corresponding road. Then, the distribution map of empty load rate – road between pudong airport and part of central Shanghai can be obtained, and each small area with low empty load rate is highlighted.

After mathematical fitting of the no-load ratio of the road along the line between PVG and Shanghai center, it is found that the no-load ratio and the distance from PVG are approximately inversely proportional. Then $K_{sd} = \frac{4.78}{sd} + 0.044$ can be calculated according to the distance between the road and the airport $sd \in [5, 50]$ and the value range of empty load rate $K_{sd} \in [14\%, 100\%]$.

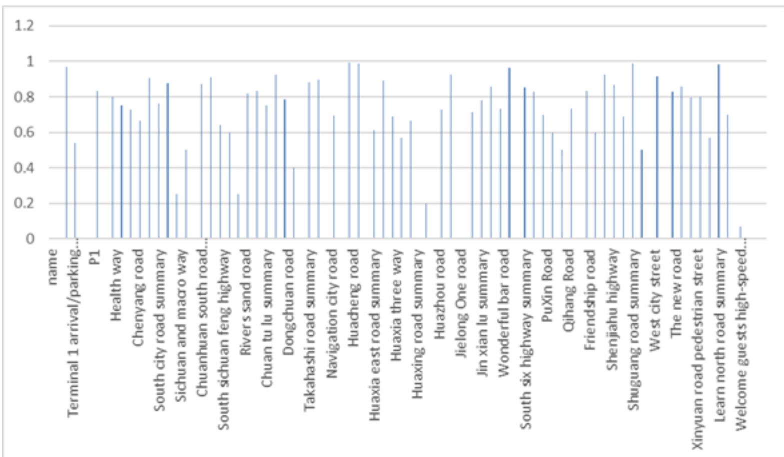


Figure 13: Statistics table of empty driving rate of some roads in Shanghai

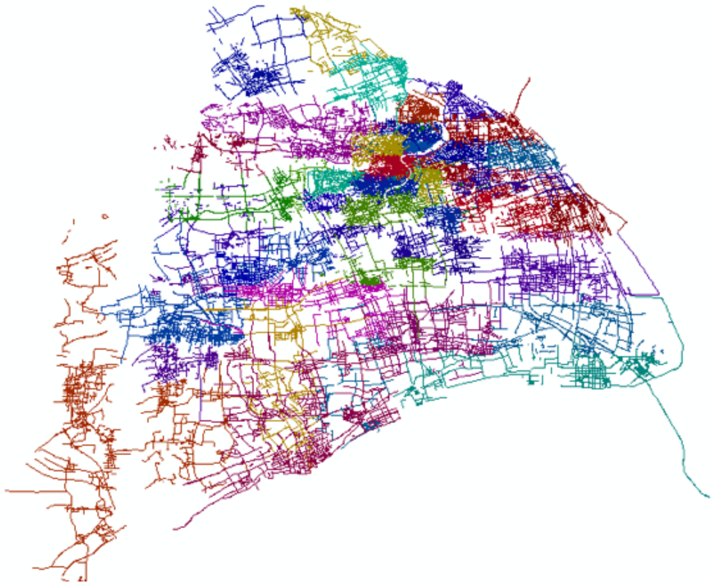


Figure 14: Shanghai road network

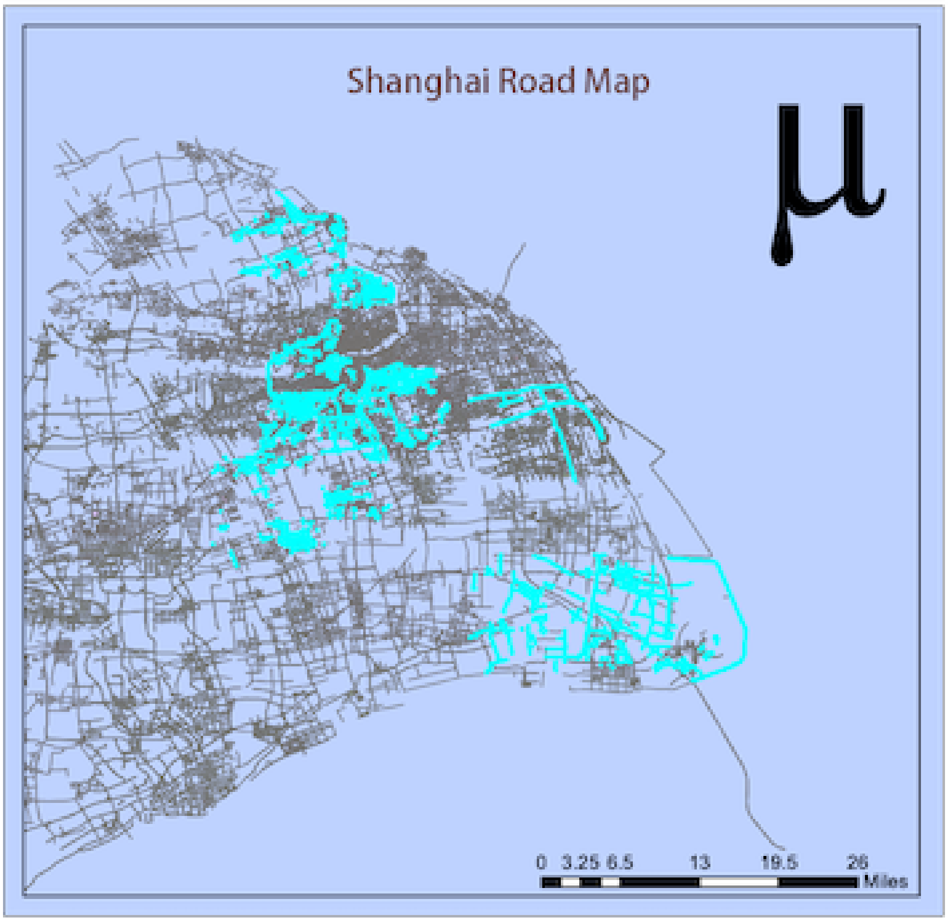


Figure 15: Shanghai road network

4.2 Model solution and decision selection

Taking M_{j1} as the Z axis, T_{j1} as the X axis and S_j as the Y axis in the 4.1.2 airport passenger queuing decision model, a three-dimensional schematic diagram of the net revenue decision model is generated by MATLAB , as shown in Figure 16. Given a certain operating mileage S_j the operating time will have a non-zero minimum value, so the schematic diagram is a defective surface near the X-axis. When S_j is small, M_{j1} grows slowly; with the constant increase of S_j, M_{j1} enters a fast growing range, and the final slope is small and the extreme value tends to be stable.

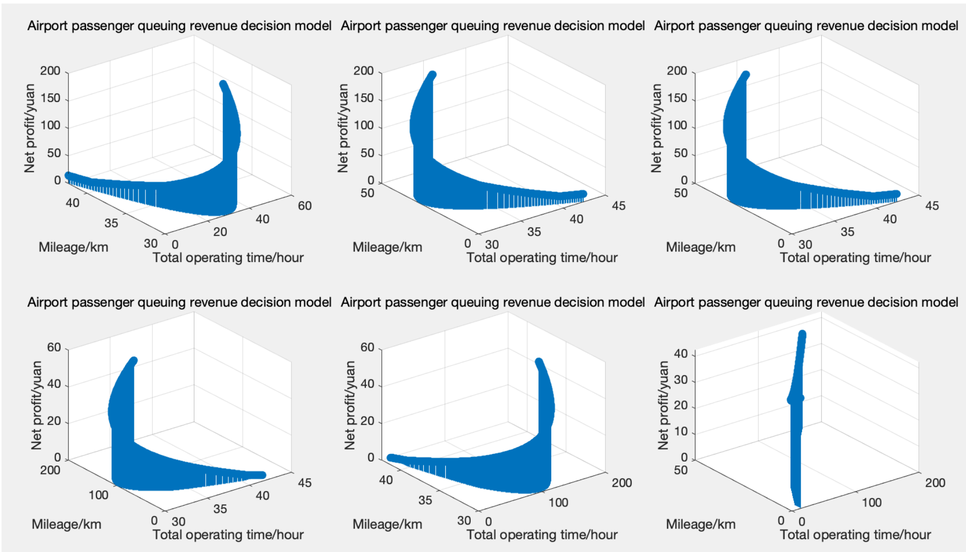


Figure 16: Airport passenger queuing revenue decision model

In terms of function expression, operation time T_{j1} has a great correlation with operation mileage S_j, so the two curved surfaces are projected onto nearly two intersecting curves on YZ plane, which also indicates that the net income model under the two decisions is more dependent on the total operation mileage than the operation time.

According to the figure, when the operating mileage is relatively small, the net income decision model of direct emptying returning to the urban passenger carrying model is better. That is to say, it is more worthy for taxi drivers to choose the direct emptying returning to the urban passenger carrying model when it takes a long time for the taxi to pick up a passenger with a small operating mileage after it takes a long time. The question of how long it takes for a taxi to queue up at an airport to receive compensation from a passenger with a smaller operating mileage will be discussed in question 4. However, when the operating mileage is long, the decision to queue up at the airport to carry passengers shows an absolute advantage.Most of the destinations are in the farther urban areas and the mileage is considerable. Therefore, it can be seen from the above that most taxi drivers will choose the airport with higher expected net income to queue up to pick up passengers after sending passengers to the airport; this is also very close to the situation in real life, so the model has a higher rationality.

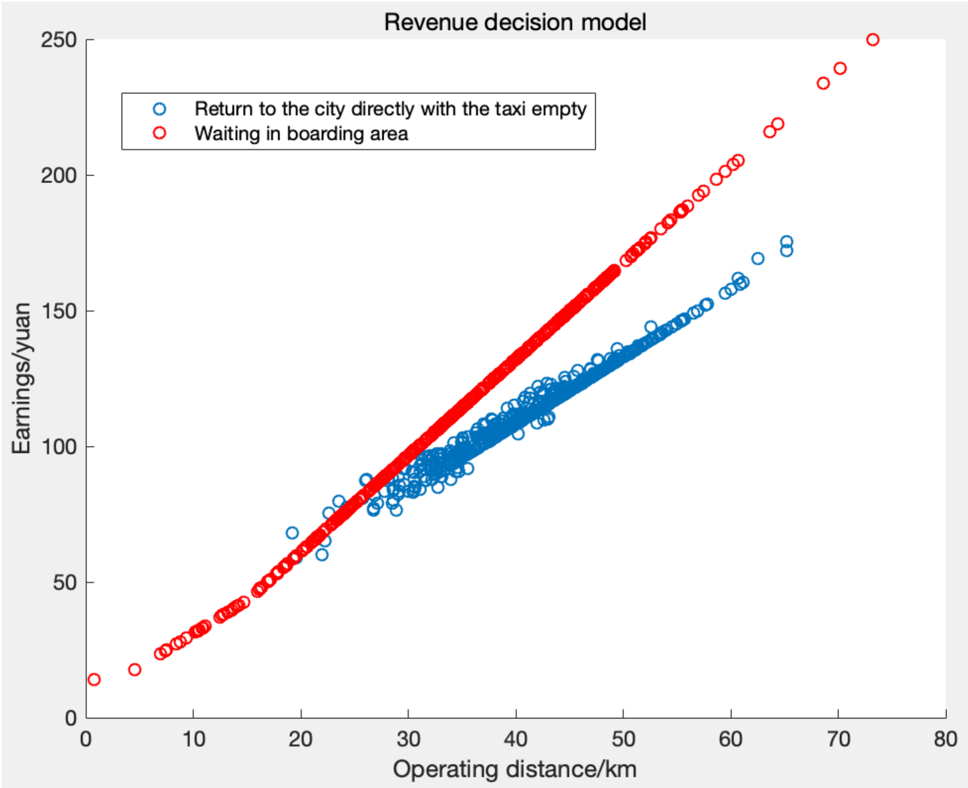


Figure 17: Revenue decision model

5 The Model of Part III

5.1 Analysis on the management mode of taxi boarding area

As can be seen from the question, the "boarding area" of the airport has two parallel lanes, and there are several applicable management modes of the pick-up area:

- Mode 1: one lane is used as the parking area and the other lane is used as the crossing road, and passengers get on the side of the parking area away from the crossing road, as shown in Figure 18.

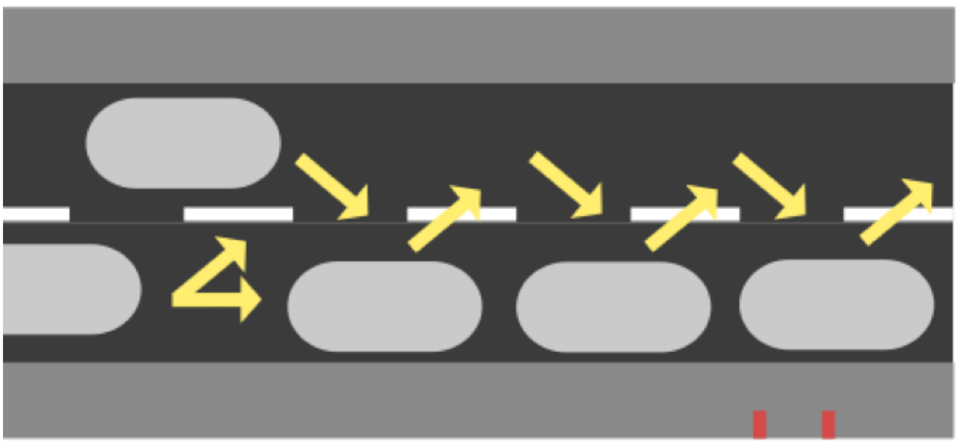


Figure 18: Passenger area management mode 1 schematic diagram

After entering the "boarding area", the taxi stops in the parking area, and after receiving passengers, the taxi can change its path to leave through the road. Whenever there is a vacancy in the parking area, the vehicle behind will make up for it.Due to the fact that each taxi enters and leaves the parking space independently, it is easy to influence each other. In addition to the pick-up time, it will also face an increase in the avoidance time for other taxis to enter and leave the parking space, resulting in low efficiency. At the same time, the model is not adopted for security reasons.

- Mode 2: both lanes are divided into a section as the parking area. Vehicles enter the parking area in batches, and all passengers get on the same side of the road. In other words, passengers can choose any taxi in the parking area on the two lanes, as shown in Figure 19.

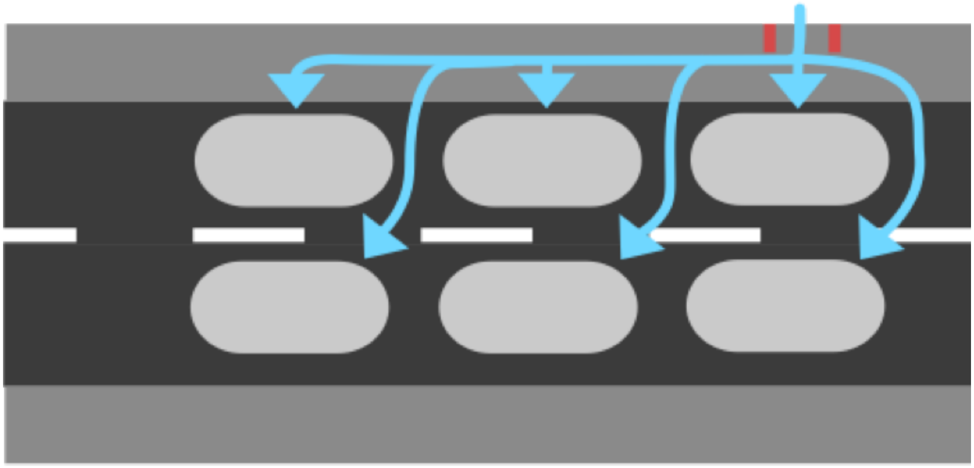


Figure 19: Passenger area management mode 2 schematic diagram

- Mode 3: both lanes are divided into one section as the parking area. Vehicles enter the parking area in batches, but passengers get on the vehicles in two batches from both sides of the road. In other words, passengers can only choose the taxi in the parking area closer to themselves, and the two roads run separately, as shown in Figure 20.

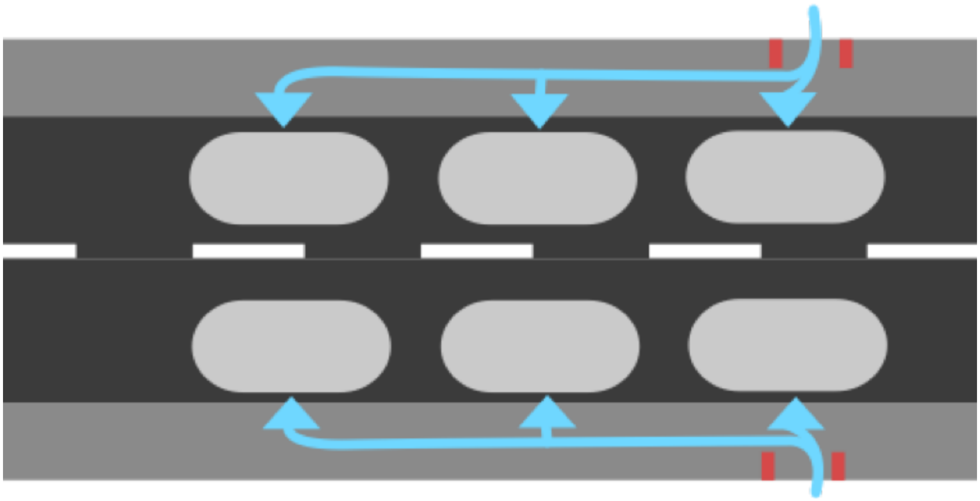


Figure 20: Passenger area management mode 3 schematic diagram

Mode 2 and mode 3 adopt the same parking zone division method, the only difference is whether the two roads work independently. In order to ensure passengers, when a passenger enters the parking area, all taxis in the parking area are not allowed to start driving. Under the regulation, considering that it takes longer for passengers to travel to the farther lane, the Shared waiting time of all two-lane taxis in mode 2 will be longer than that in mode 1.Therefore, this paper chooses mode 3 as the management mode of taxi pick-up area.

5.2 Pick-up time model

Pick-up time refers to the time from when the last taxi of the batch was parked in the parking space and the passenger entered the parking area to when the last passenger of the batch got into the taxi. After determining the number of cars in a batch, it is reasonable to infer the number of passengers in the batch according to the historical average number of passengers in a single taxi.

$$P = AB \tag{30}$$

In the following calculation, refer to PVG and set $A = 1.5$. In order to minimize the difference between the boarding points, each boarding point is equally set on the parking area. It is also stipulated that after stepping out of the boarding point, passengers can only take the vehicles from the boarding point to the downstream neighboring boarding point. Regardless of the distance between the boarding point and the entrance and exit of the "boarding area", it is assumed that passengers will be evenly distributed to each boarding point. In order to shorten the pick-up time as far as possible, it is stipulated that the first group of passengers from each pick-up point enter the parking area and take the taxi farthest from the pick-up point (as shown in Figure 21), then the time spent is as follows:

$$t_g = (B-1) * \text{length} \,/\, (\text{E}v_p) \tag{31}$$

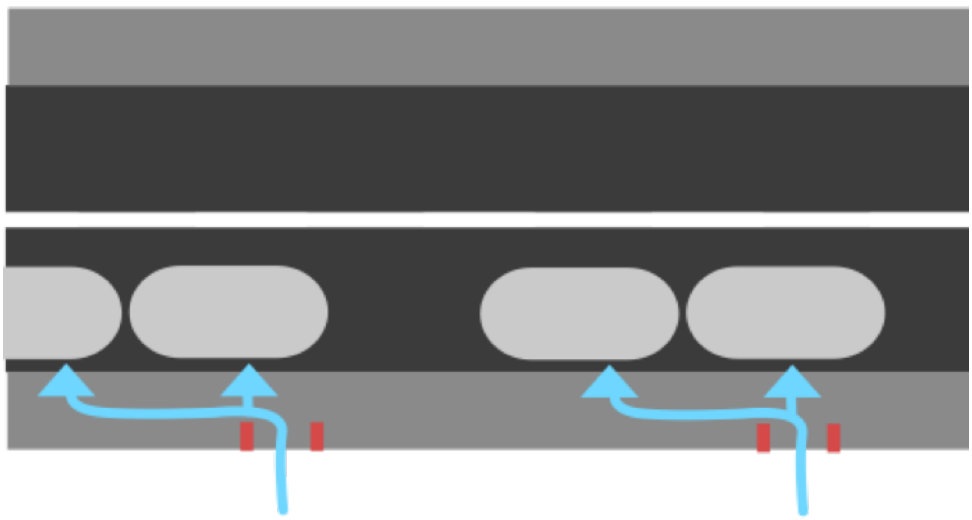


Figure 21: Provides schematic diagram of ride mode

Where, refer to the data of PVG $length = 6$. Under different travel purposes, pedestrian walking speed is different, as shown in table 5[6][6]. When the passenger team starts to release, the passenger's walking mode is more inclined to the movement of the position between two points for the purpose of transportation. Considering that the speed of carrying luggage forward will be lower than that of free walking, $v_p = 1.3$.

At the same time, the more boarding points there are, the shorter the total time for this batch of passengers to queue into the parking area.The time taken by the last passenger to queue up to walk into the parking area is as follows:

$$t_w = (P * \text{ distance }) / (\mathrm{E} v_p) \tag{32}$$

Since the distance between passengers and passengers is relatively close in the team and the walking is limited, it can be approximately assumed that the active space of passengers is a static space.[6] Most passengers waiting for a taxi at the airport carry luggage, that is, the space demand is about 0.40 0.55 [m^2/ person), and because the oval area of the human body is shown in Figure 22 on the right, $distance = 0.8$ is set here.

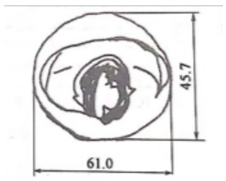


Figure 22: Body oval size in unit (cm)

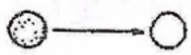
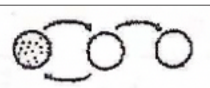
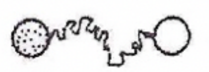
Travel purpose	graphic	Typical behavior	Walking speed(m/s)	Traffic service requirements
The movement of a position between two points for the purpose of		Commuter traffic	$1.3 \sim 2.5$	Fast pass, convenient
Movement with other behavioral goals		Shopping, go to the park	$0.7 \sim 1.3$	Comfortable, attractive space environment
The movement process is the movement for the purpose		Take a walk	$0.8 \sim 1.2$	Comfortable, attractive space environment

Table 5: Three types of typical walking purposes and walking characteristics

considerations	The traveler stood	Carry-on luggage	Feel comfortable
Space requirements	0.21	0.40-0.55	0.74-0.95

Table 6: Static space requirement

By comparing the above two equations, it can be seen that when $B > 1.25$, $t_w < t_g$.Considering the actual situation, the number of vehicles in a single batch is usually more than 2. Therefore, in the calculation, the total pick-up time is set as the sum of the time spent by the first group of passengers at each boarding point to the corresponding taxi parking space and the time spent packing up and sitting in the car.

$$t_P = t_g + t_c \tag{33}$$

Where, $t_c = 30$ according to experience

5.3 Establishment of Space-temporal trajectory model of taxi in "taking area"

Since mode 3 is adopted and the two lanes are running separately, this paper analyzes the space-temporal trajectory model of taxi in the "boarding area" for the single lane. First of all, each batch of taxis in the fleet needs to park in the parking area to pick up passengers. Each taxi must exist for a period of time and its space-time position remains unchanged. Secondly, the driving status of the taxi queuing to enter the parking area depends on the driving status of the car in front of it, and the number of parking will increase once a batch every night; due to the delay of the following mode, there will be a time difference at the time point when the front and rear vehicles switch driving states, and the time difference is related to the length of the fleet. Moreover, due to the fixed location of the parking area, the first car of each batch will stay in the space-temporal location of the first parking space in the parking area for a period of time. Similarly, the second and third cars of each batch will stay in the corresponding parking space, and the difference in the space-temporal location of each adjacent taxi is the size of the parking space. Moreover, due to the fixed location of the parking area, the first car of each batch will stay in the space-temporal location of the first parking space in the parking area for a period of time. Similarly, the second and third cars of each batch will stay in the corresponding parking space, and the difference in the space-temporal location of each adjacent taxi is the size of the parking space. The parking time of vehicles includes waiting time for all vehicles of the same batch to park in the parking area and pick-up time. Finally, the batch of cars stayed in the parking area, drove out of the "boarding area", the latter batch of cars followed by the following mode into the parking area. Lease start acceleration and braking acceleration of the vehicle is not taken into account, the approximate uniform, namely space-time path chart of each section of the slope of oblique line is the average speed of vehicles running in the "bus" area, PVG in the reference data set $\bar{v} = 8$.

Although team impact on the delay time length, on the one hand, because the team middle distance taxi anchorage areas of delay time of anchorage segment operation is affected, on the other hand because of the need to wait for all the vehicles stopped, would allow passengers to get on the bus, or in before each allow passengers to get on the car will be fixed delay time, so the only analysis between two fixed delay time, namely the next batch to anchor the delay time of the taxi. According to the study on driver characteristics, when stimulated by external factors, drivers will experience four stages of perception, recognition, decision-making and reaction, which can be quantified by perception-response time. In this model, it is assumed that the perception-response time of all drivers under normal conditions is the same as 3 seconds, but when the motorcade is too long, drivers tend to be relaxed, resulting in an increase in the perception-response time. The time that exceeds the normal perception-response time is referred to as the slack time, which is related to the distance from the driver to the first car in the fleet. The normal perception-response time and slack time constitute the delay time.

$$\begin{aligned} t_{ri} &= x/5 \\ t_{yi} &= t_n + t_{ri} \end{aligned} \tag{34}$$

Thus, the space-temporal trajectory diagram of the taxi can be obtained (schematic diagram is shown in Figure 23 below).

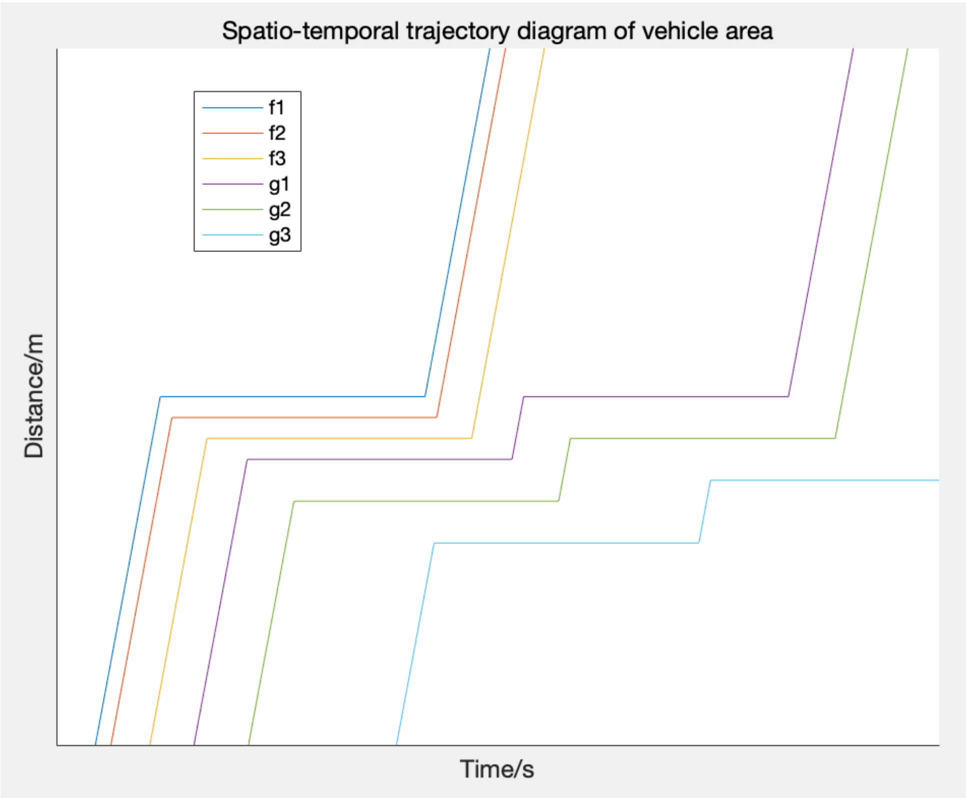


Figure 23: The spatio-temporal trajectory diagram of "ride area"

In this example, the space-temporal trajectory diagram of two batches of released vehicles is shown, in which the number of single batch of vehicles $B = 3$, and the number of boarding points $E = 2$. The functions f_1, f_2, f_3 are the space-temporal trajectory of the first batch of taxis, and the functions g_1, g_2, g_3 are the space-temporal trajectory of the second batch of taxis. The general function formula and relevant calculation of the space-temporal trajectory diagram are as follows (α is a constant that has an effect on the position of the graph but has no effect on the overall shape; the same letter is a batch, and the subscript I indicates that the car is the i-th car of the batch):

$$f_1(x) = \begin{cases} \overline{v}x + a, & x \leq 0 \\ a, & 0 < x \leq k \\ \overline{v}(x-k) + a, & x > k \end{cases} \tag{35}$$

Among them, $\mathrm{k} = (B-1) * t_n + \sum_{i=1}^{B} t_{yi} + tp^4$

$$g_1(x) = \begin{cases} f_B\left(x - t_{y1}\right) - \text{length}, & x \leq h + \frac{\text{length}}{\overline{v}} * B \\ a, & h + \frac{\text{length}}{\overline{v}} * B < x \leq h + \frac{\text{length}}{\overline{v}} * B + k' \\ \overline{v}(x-k-h) + a, x > & h + \frac{\text{length}}{\overline{v}} * B + k \end{cases} \tag{36}$$

Among them, $\mathrm{h} = t_n * \mathrm{B} + \sum_{i=1}^{B} t_{yi}$

$$g_2(x) = g_1\left(x - t_{y2}\right) - \text{ length} \tag{37}$$

5.4 Travel efficiency analysis

5.4.1 Capacity analysis of continuously arriving taxis

The continuous arrival of taxis means that the number of taxis in each batch is always fixed and there is no need for all passengers to wait. At this time, the capacity can be determined by the number of taxis that leave within the time difference between the last car parked in the parking space of two adjacent batches. Since it is a two-way parallel lane that operates independently from each other, when calculating the capacity, the capacity of single lane can be doubled to obtain the total capacity of "boarding area".

$$\text{cap} = 2 * \mathrm{B} * 3600 / \left(t_P + \sum_{i=1}^{2B-1} t_{yi} + \frac{\text{length}}{\overline{v}} * B\right) \tag{38}$$

Among them,

$$\begin{gathered} t_P = t_g + t_c \\ t_g = (B-1) * \frac{length}{\mathrm{E}v_p} \\ t_c = 30 \\ t_{ri} = x/5 \\ t_{yi} = t_n + t_{ri}^4 \end{gathered} \tag{39}$$

$$\text{cap} = 2 * \mathrm{B} * 3600 / \left((B-1) * \frac{\text{length}}{\mathrm{E}v_p} + 30 + \sum_{i=1}^{2B-1} (x/5+3) + \frac{\text{length}}{\overline{v}} * B\right) \tag{40}$$

Plug in the set value then can get

$$\text{cap} = 2 * \mathrm{B} * 3600 / \left((B-1) * \frac{6}{\mathrm{E} * 8} + 30 + \frac{6}{8} * B + \sum_{i=1}^{2B-1} (x/5+3)\right) \tag{41}$$

From the above equation, it can be seen that the capacity is only related to the number of single-lane single-batch vehicles B and the number of single-lane car entrances E, as shown in Figure 24 below.

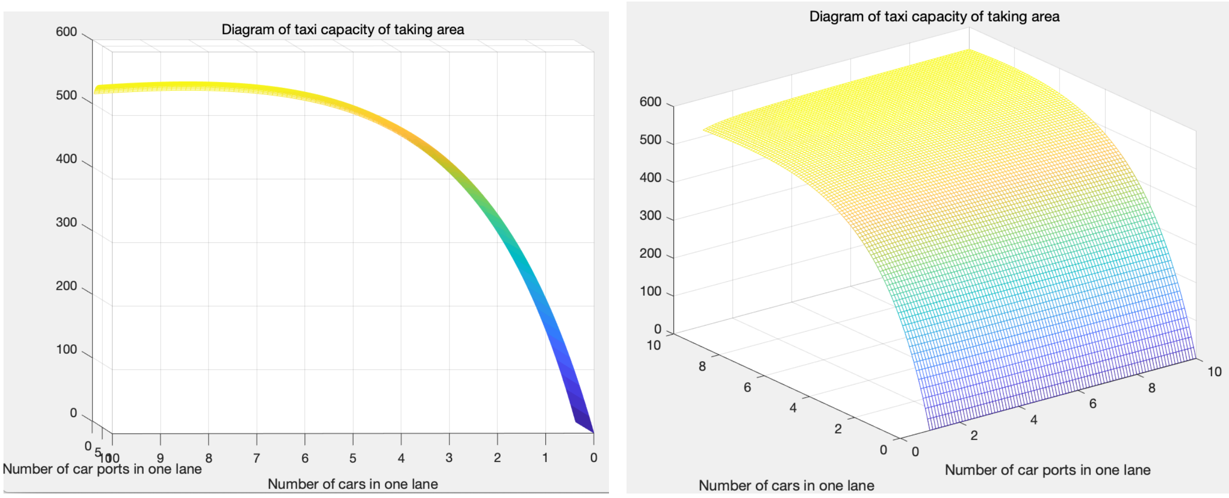


Figure 24: Map of taxi capacity of taking area

In reality, it is meaningless for the number of boarding ports in one lane to be larger than the number of single batch of taxis in one lane, and both the number of boarding ports and the number of taxis are discrete points of positive integers. Thus, table 7 below shows that when $B = 8$ and $E = 8$, the capacity is the maximum. In addition, it can be found that with the change of the number of taxis in a single batch, the capacity changes greatly. The capacity increases monotonously with the number of boarding ports, but the increase is small.

	1	2	3	4	5	6	7	8	9	10
1	212.076									
2	339.222	342.246								
3	417.391	423.529	425.615							
4	465.642	474.269	477.216	478.703						
5	494.845	505.263	508.833	510.638	511.727					
6	511.545	523.160	527.150	529.168	530.368	531.202				
7	519.855	532.207	536.455	538.605	539.903	540.772	541.394			
8	522.449	535.191	539.578	541.798	543.14	544.037	544.680	545.164		
9	521.109	533.992	538.429	540.675	542.032	542.940	543.591	544.080	544.461	
10	517.055	529.898	534.322	536.562	537.915	538.821	539.470	539.957	540.337	540.642

Table 7: List of discrete points of taxi capacity in the boarding area

5.4.2 The average arrival time of taxi was analyzed according to the negative exponential distribution

It is generally considered that when the uninterrupted traffic flow per lane is equal to or less than 500 vehicles per hour, it is practical to describe the time headway with a negative exponential table distribution.[6] assuming that the taxi arrival conforms to the negative exponential distribution, the pick-up process is regarded as a service process, and the taxi is regarded as a customer, the M/M/1 queuing model can be applied to solve. The queuing model formula of M/M/1 is as follows:

The system's service intensity is $\rho = \gamma/\mu$, where λ is the average arrival rate, μ is the average service rate;

The average time a customer stays is $W_s = 1/(\mu - \lambda)$

$\lambda = Q/3600$, where Q is hourly traffic. $\lambda = 0.083$ is set to $Q = 300$, according to the observation and description of the model provided in thetraffic engineering textbook.

According to the definition, $1/\mu$ is the average length of each service, which can be obtained by dividing the time difference between the last car parked in the parking space of two adjacent batches by the number of taxis leaving. On the value, $\mu = cap/2$, then

$$W_S = 1/(cap/2 - \lambda) \tag{42}$$

It can be seen that the average stay time of a taxi is only related to the number of single-lane single-batch vehicles B and the number of single-lane boarding ports E, as shown in Figure 25 below.

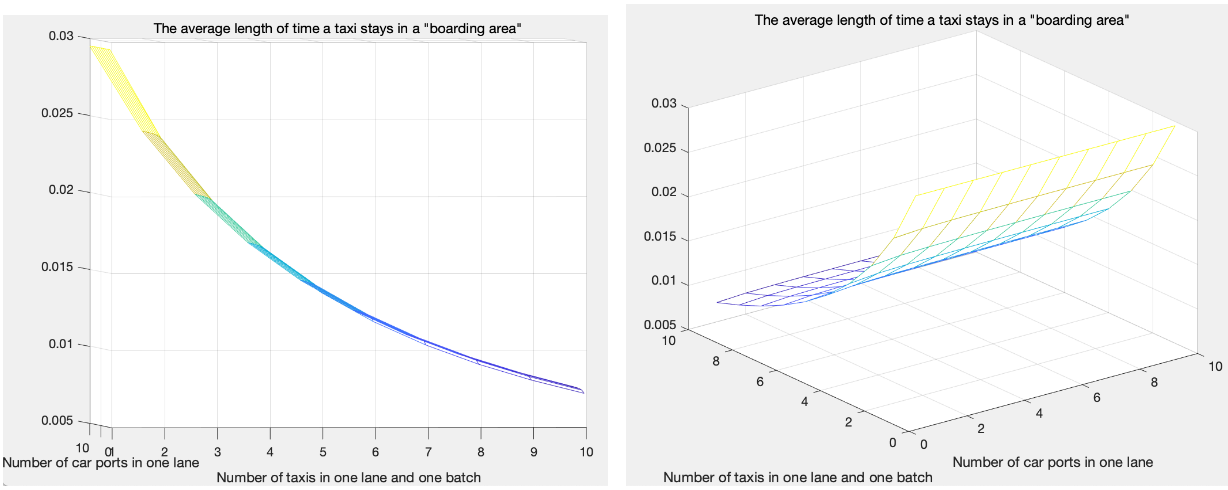


Figure 25: The average wait time for a taxi in a "boarding area"

As can be seen from the figure above, if the M/M/1 queuing model is used, assuming that the taxi arrives according to the negative exponential distribution, the more the number of taxis in one lane and one batch, the shorter the average taxi stays. This model is too ideal to be applicable to the actual situation.

6 The Model of Part IV

6.1 A model of passenger travel distance distribution in airports

According to the PVG "holding short-distance tickets, taxi mileage within 22 km and within an hour to return to enter the buffer zone" short-distance car entry standards, the operating mileage of less than 22 km is called short-distance passenger.

As can be seen from the model of passenger driving trajectory of 3.3, the travel distance of airport passengers obeys normal distribution, i.e

$$S_j \sim N(34, 12) \tag{43}$$

However, whether a passenger trip received by a taxi at the airport is a short-distance passenger ride obeys 0-1 distribution, i.e

$$\mathrm{P}\{X = k\} = p_{22}^k \left(1 - p_{22}\right)^{1-k} \tag{44}$$

Where $k = 0, 1$ and $p_2 2$ are $k = 1$, that is, the probability of carrying passengers in short distance

$$p_{22} = \int_0^{22} \frac{1}{12\sqrt{2\pi}} \exp\left(-\frac{(x-34)^2}{288}\right) = 0.1585 \tag{45}$$

The above model is in line with the current situation of "about 7,000 taxis flow in PVG every day, 15% to 20% of which undertake short-distance business", which also proves the correctness of the model of passenger driving track of 3.3 from the other side.

6.2 Taxi net revenue per unit time model

Define net income per unit time as the ratio of net income to the sum of waiting and operating time; Because the mechanism of "short-haul ticket" is to compensate the opportunity cost of the short-haul passenger taxi waiting too long in the airport car storage pool, compared with the pure use of passenger revenue or net income, taking the net income per unit time as a reference index can better reflect the compensation degree of the opportunity cost of short-haul passenger taxi.

Firstly, the simple net profit model of long-distance bus per unit time is considered. According to the income decision model based on the above branch model 3.6 and the model based on driving distance and operating time 3.5, the net income and operating time of long-distance bus can be obtained respectively, and the net income per unit time of long-distance bus is

$$M_l = \frac{M_{j1}}{T_{j1} + \Delta T} \tag{46}$$

However, the situation of short-haul bus is relatively complicated: it is assumed that the taxi with short-haul tickets will return to the airport to pick up passengers again after completing the operation task, so the taxi will continue the cycle of "short-haul operation task – return to the airport – short-haul operation task" for n times before receiving the long-distance operation task at the n+1 time. Considering that the $p_{22}^6 = 0.0001586$ is close to one in 100,000, the maximum number of times a taxi can receive a short-distance operation is set to be 6.

S_{jd} represents short-term operation task and S_{jc} represents long-term operation task;
$S_{jd} \sim N(34, 12),\ S_{jd} \leq 22, \S_{jc} \sim N(34, 12),\ S_{jc} \geq 22$

The net profit per unit time of short distance car

$$M_d = \frac{M_{jn}}{\Delta T + \sum_{i=1}^{n} \int_0^{S_{jdi}} \frac{dS\mathrm{d}}{v} + T_{j1}} \tag{47}$$

and

$$M_{jn} = \sum_{i=1}^{n} p_{22}^{n-1} \left[Z_k \left(S_{jdi} \right) - 2S_{jdi} * Y_{\mathrm{h}} * Y_j \right] + p_{22}^{n-1} \left(1 - p_{22} \right) \left[Z_k \left(S_{jc} \right) - 2S_{jc} * Y_{\mathrm{h}} * Y_j \right] \tag{48}$$

We take

$$a_1 = E \left(Z_k \left(S_{jdn} \right) - 2S_{jdn} * Y_h * Y_j \right) = Z_k \left(E \left(S_{jdn} \right) \right) - 2E \left(S_{jdn} \right) * Y_{\mathrm{h}} * Y_j \tag{49}$$

So

$$M_{jn} \sim \frac{1}{1 - p_{22}} a_1 + p_{22}^{n-1} \left(1 - p_{22} \right) \left[Z_k \left(S_{jc} \right) - 2S_{jc} * Y_{\mathrm{h}} * Y_j \right]^4 \tag{50}$$

6.3 The model solves and evaluates the compensation effect of "short-distance ticket" mechanism on short-distance taxi

This problem uses MATLAB to complete the solution of net income model per unit time and image rendering and comparison.

The first figure plots the total time function of the ten long-distance vehicles over 22 km $(S_{j1}, S_{j2}, ..., S_{j10})$ generated by the normal distribution $N(\mu_j, \sigma_j)$. The second figure is composed of a set of graphs, each of which corresponds to $n = 1, 2, 3, 4, 5, 6$ under different preconditions. Under normal distribution $N(\mu_j, \sigma_j)$, the net return per unit time of ten short-distance vehicles determined by $(S_{j1}, S_{j2}, ..., S_{j10})$ is generated.

As can be seen from the first figure, as the total operating time (waiting time) keeps increasing, the equalization of passenger income of long-distance buses becomes more and more serious. Therefore, the curve generates a very rapid decline in function value and finally stabilizes at around 20/h. It can be seen from the second figure that in the absence of "short-distance ticket" priority mechanism, the net benefit per unit time of long-distance bus is higher than that of short-distance bus, no matter long or short. That is to say, the net income of short-distance taxi is indeed lower than that of long-distance taxi, so it is necessary to give certain "priority" to some short-distance taxi that carries passengers back again. It can be seen from the third figure that under the "short-distance ticket" priority mechanism, the gap between short-distance taxi and long-distance taxi decreases as n, i.e. the number of consecutive return of short-distance taxi, increases. When $n = 3$, net income per unit time of short-distance taxi was basically equal, and even by the time of $n > 3$, the short-haul taxis had overtaken the long-haul ones at certain times. To sum up, "short-haul ticket" priority mechanism can indeed achieve the goal of balancing the benefits of waiting for taxi in the pool.

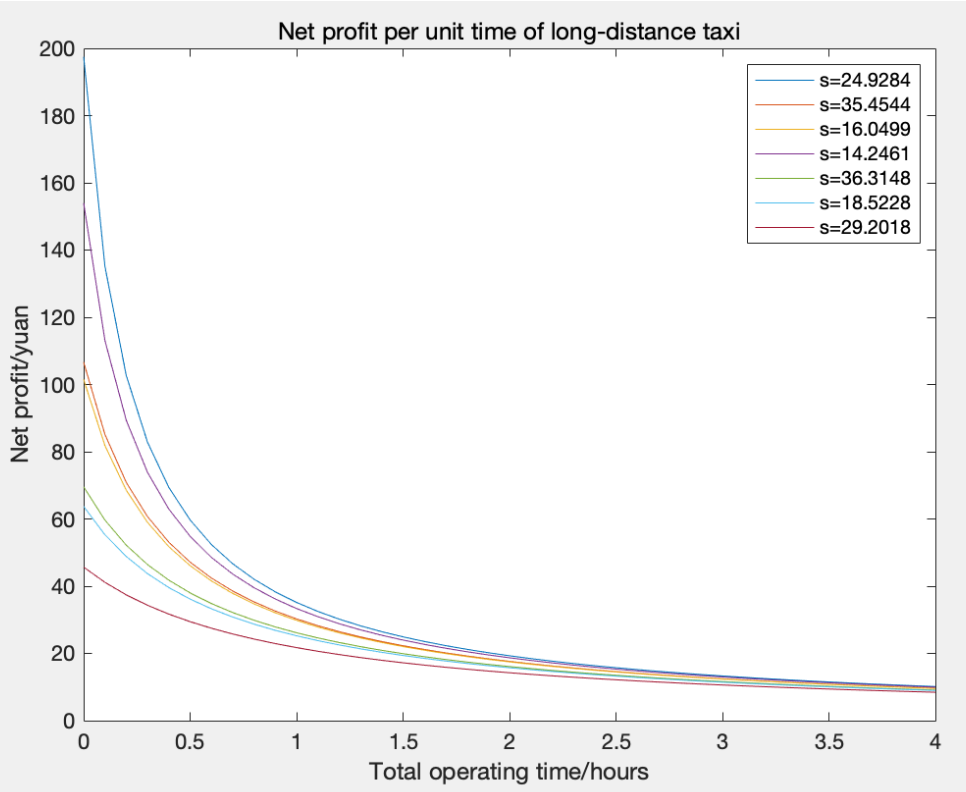


Figure 26: Net profit per unit time of long-distance taxi

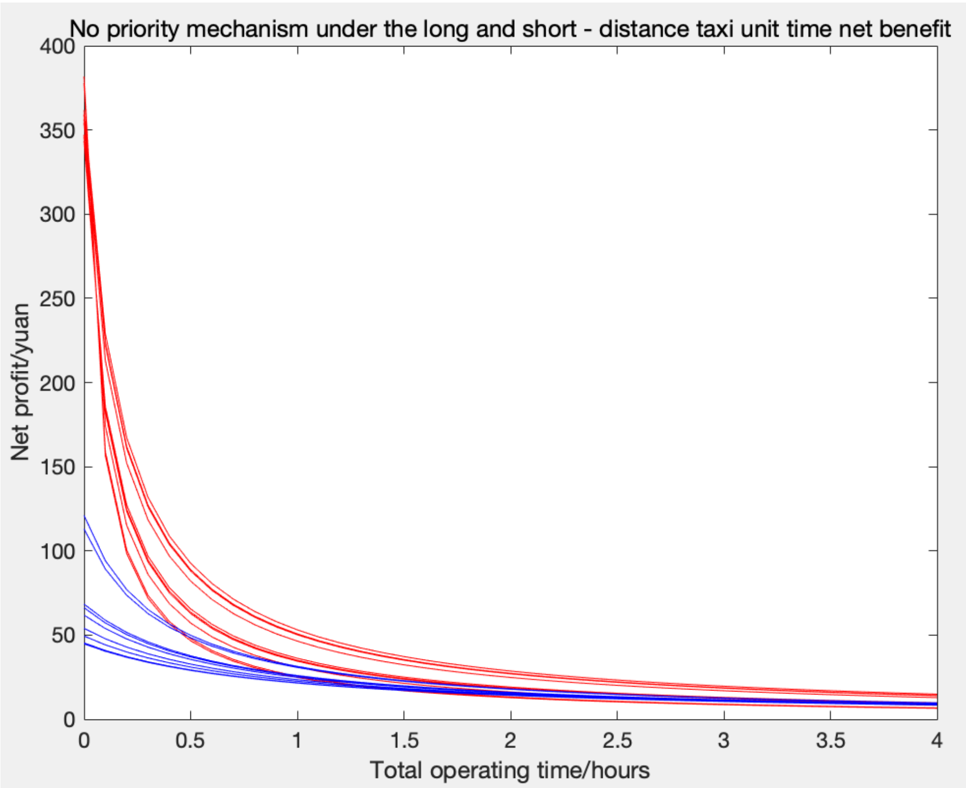


Figure 27: No priority mechanism under the long and short - distance taxi unit time net benefit

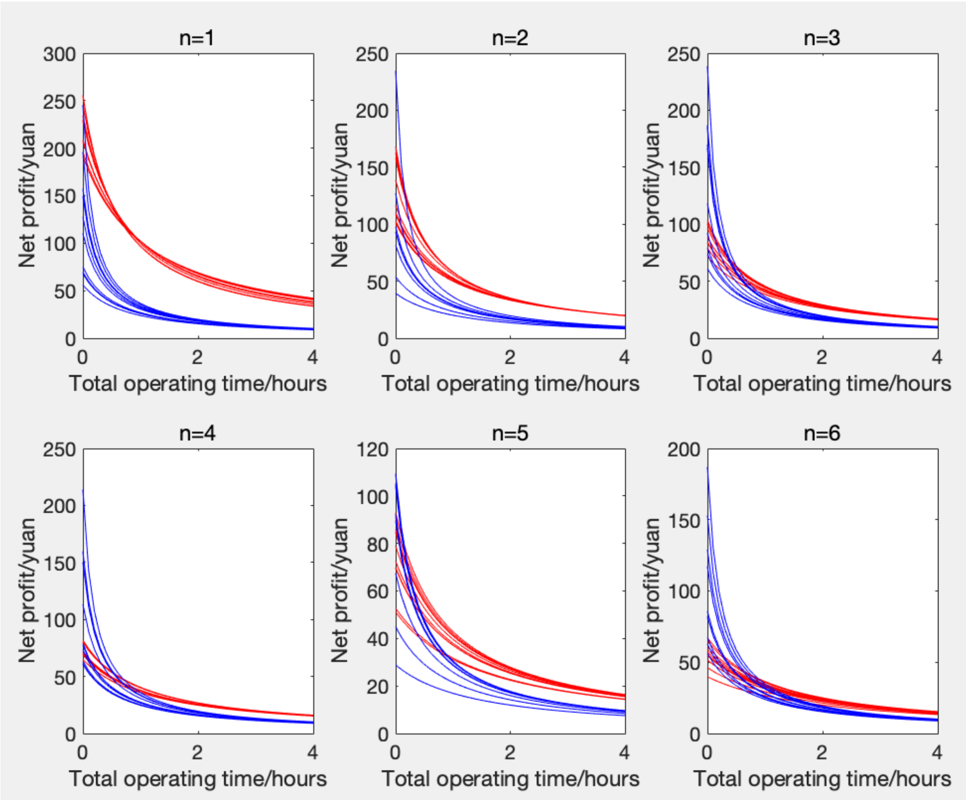


Figure 28: Comparison chart of net profit per unit time of long and short distance taxi under priority mechanism

7 Testing the model

7.1 Improvement

The results obtained from ArcGIS taxi GPS data set in question 2 can be used for further data mining and data analysis in PVG area, which can provide certain simulation basis for question 3 and question 4.

7.2 Generalize

In the third part of the problem, part of the classical theory in the traffic course is applied to make the model universal, which is of certain guiding significance for the analysis of the traffic flow in and around the airport, the taxi operation mode and the development of airport bus.

8 Conclusions

8.1 Strengths

The first problem is to take into account the factors that affect the taxi driver's various indicators, and to comprehensively consider the influence of these indicators on the subsequent operation mode of the taxi through the establishment of an abstract or specific mathematical model. When determining the no-load rate model in question 2, the taxi GPS big data and professional geographic information software ArcGIS were used to make statistics on the no-load rate of some roads in Shanghai, which effectively ensured the correctness of the established model. In problem 3, two different theories of space-temporal trajectory graph and queuing theory were used for modeling and solving, which improved the fault tolerance of the model. In question 4, the rationality of the normal distribution model in question 1 is tested by checking the proportion of short-distance vehicles.

8.2 Weaknesses

In the process of establishing the passenger driving track model in question 1, abstraction and idealization are too high. In addition to concise modeling, the highly non-linear automobile operation law is also greatly simplified. It is difficult to truly simulate the travel track of a large number of taxis. In the modeling process of queuing theory in question 3, some theoretical models that do not accord with the actual situation are applied, resulting in the modeling results not as ideal as expected.

9 Reference

[1] Liu junjuan, wang wei, xiao meidan. Study on traffic density and speed model in single-center city [J]. Journal of railway science and engineering,2011,8(01):113-117.

[2] Anonymity. Shanghai taxi GPS data sets [DB/OL].

[3] Civil Aviation Administration of China .The civil aviation industry development statistical bulletin in 2018 [EB/OL]. http://www.caac.gov.cn/XXGK/XXGK/TJSJ/201905/t20190508_196033.html, 2019-5.

[4] Li Yin. Pudong airport can increase shipments landing flights to 70 vehicles per hour at [EB/OL]. http://news.carnoc.com/list/287/287527.html, 2014-07-11

[5] Anonymity. Pudong international airport traffic [EB/OL]. https://flights.ctrip.com/booking/airport-pudong/jichangjiaotong.html, 2019-09-15

[6] Wu jiaorong. Traffic engineering [M].Beijing: people's communications press, 2018-10.
https://download.csdn.net/download/feng512275/10978231,2019-9-13.