A Decision-Making Model Using Machine Learning for Improving Dispatching Efficiency in Chengdu Shuangliu Airport

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Due to the increasing number of people traveling by air, the passenger flow at the airport is increasing, and the problem of passenger drop-off and pickup has a huge impact on urban traffic. The difficulty of taking a taxi at the airport is still a hot issue in the society. Aiming at the problem of optimizing the allocation of taxi resource, this paper is based on the cost-benefit analysis method to determine the factors that affect the taxi driver’s decision-making. The mathematical methods such as function equation, BP neural network algorithm, and queuing theory were used to establish a complete decision-making model for taxi drivers and an optimization model of dispatching efficiency at the airport. A conclusion has been drawn that the allocation of airport taxi resource should be arranged closely related to drivers’ revenue and the layout of airport line.

1. Introduction

With the rapid development of the transportation network, aircraft has become one of the most important means of transportation for people [1]. After getting off the plane, most passengers go to the destination in the urban area (or the surrounding area) and taxi has become one of the main means of transportation [2]. As a result, taxi dispatching at the airport has become a research issue, for improving the efficiency of picking up passengers at the departure. As reported in several contributions, improvement of transportation conditions in airport can contribute to the economy development [3, 4]. Therefore, taxi dispatching efficiency (TDE) has great significance for the development of airport economic zone.

Cost-effective analysis (CBA) is an effective method to evaluate the potential economic impact of investment choices [5, 6]. The managers should collect information related to uncertain factors in the decision-making process so that they can make the best choice [7]. By taking the multiple impacts of different choices into consideration under the background of difficult budgetary arbitrations, the CBA method makes decision-making process a quantitative analysis, providing the decision-makers with prior strategy. In 2009, Damart and Roy utilized the CBA method to evaluate the decision-making context of transport infrastructure in France and found that rationalization of public resource use and stakeholder acceptance of the choices are two elements that affects the improvement of transport infrastructure in France [6]. In 2016, Burgain et al. applied...
Complexity

Two options: Taxidriverswhodropoffpassengersattheairportwillface
taxishasbeentakenintoaccount.Secondly,thedispacthingmodel
canbeestablishedbyconsideringthedepartureplan
taxistothecity.topickuppassengers,thedriverisgiven.
theriskindexframeworkandrelatedquantitativewaysisalsoimportant[17].However,thisapproach
beendiscussed.Acomprehensiveriskevaluationapproach
influenceontheurbanareaandthefinalmodelhasbeenconstructed

to congested airport departure operations for ameliorating the
departure operations in airport [8]. Above-mentioned research used CBA for analyzing and

two options:

Error back propagation (BP) neural network is one kind of
neural network algorithms that can be applied in research
field, such as intelligent control, combinatorial optimization,
and image processing [9]. Since the late 20th century, BP
network has been widely used in the traffic engineering field.

In 2002, Mo and Su predicted the passenger volume on real-
time transit by using the neural network [10]. After that, He
et al. applied the backpropagation (BP) network to forecast
the total volume in the waterway [11]. In 2013, Yong and Tao
analyzed the demand characteristics of passenger transport-

developed a decision-making model to study dispatching
operations in airport [8]. Above-

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departure operations in airport [8]. Above-mentioned research used CBA for analyzing and

In order to establish a reasonable decision-making
model for taxi drivers, this paper uses cost-benefit analysis to
carefully differentiate the factors having impact on the
profits of waiting at airport and the profits of returning to the
city. For the benefits of drivers waiting at the airport, both
the waiting cost of the drivers and the revenue gained from
pulling passengers back to the city need to be considered.

Among them, the waiting cost of drivers is predicted by the
number of flights to port, passenger flow number, assumed
traffic flow, and other variables such as weather condition
[19]. As for the benefits of drivers returning to the urban area
to take passengers, this paper mainly considers the cost of
empty running on the way to the urban area and the revenue
from carrying passengers in the urban area. Revenue from
passengers and cost of empty running are affected by the
distance from the airport to the urban area and the distance
of different destinations in the urban area [20, 21]. Normal
distribution of the distance between the airport and the
urban area and the distance within the urban area is
modified by real-time map, so as to obtain the decision-
making model for the drivers who choose to carry pas-
sengers in the city area. Finally, by comparing the profit of
the driver waiting at the airport with the profit of the driver
going to the city to pick up passengers, the best decision of
the driver is given. The flowchart of the whole cost-benefit
analysis is shown in Figure 1:

2.2. Construction of Decision-Making Model for Taxi Drivers

2.2.1. Assumptions

(1) The behavior of the taxi driver is in line with the
"rational agent" assumption, which means that the
taxi driver always chooses the decision plan with the
greatest expected economic profits.

(2) When studying the situation of taxis picking up
passengers at the airport, it is assumed that the

2. Materials and Methods

Taxi drivers who drop off passengers at the airport will face
two options:

Option 1: go to the arrivals area and queue to get the
passengers to return to the city. Taxi drivers must go to
the designated parking lot to wait in line due to the
"first-come-first-served" basis. The length of the
waiting time depends on the number of taxis and the
number of passengers in the queue, which requires a
certain cost of time.

Option 2: return directly to the city to get the pas-
sengers in the city. Taxi drivers pay no-load fees and
may lose potential revenue from the airport.

The number of flights arriving in a certain period of time
and the number of vehicles already in the parking lot are
certain information that the drivers can observe. Usually, the
drivers' decision is related to his personal experience, such as
the number of flights arriving in a certain time period and
the number of possible passengers [18]. If passengers want
to take a taxi after getting off the plane, they have to queue up at
the designated parking lot and get a ride in order. The airport
taxi management staff is responsible to quantificationally
release taxis into the parking lot and arrange a certain
number of passengers to board.

In order to establish a reasonable decision-making
model for taxi drivers, this paper uses cost-benefit analysis to
carefully differentiate the factors having impact on the
profits of waiting at airport and the profits of returning to the
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2.1. Construction of Decision-Making Model for Taxi Drivers

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"rational agent" assumption, which means that the
taxi driver always chooses the decision plan with the
greatest expected economic profits.

(2) When studying the situation of taxis picking up
passengers at the airport, it is assumed that the
number of passengers is always bigger than 1, which means that the taxis drivers are always able to receive passengers at the airport.

(3) When passengers take a taxi at the airport, it is assumed that the traffic volume is always equal to or greater than 0, which means that the passengers may get the taxi in the parking lot without wait, or they may need to wait for some time before getting on a taxi.

(4) The one-way income obtained by taxi drivers waiting at the airport is greater than the one-way income obtained by carrying passengers in urban area.

(5) The revenue and cost of taxi drivers to take passengers are only related to the carrying distance, fare, fuel cost, which have no relationship with the location.

(6) The distance from the airport to the city and within the city area is of normal distribution.

(7) The charge of taxi service is the same during the day and night.

(8) All taxis are refueled with gasoline No. 92 (a fuel used in China).

2.1.2. Notation Explanation. Explanation for notations are presented in Table 1.

2.2. Establishment of Decision-Making Model for Taxi Drivers. First of all, this paper considers that the main factors affecting the passenger flow of a parking lot at an airport in China are: (1) passenger flow at the airport; (2) flight number at the airport; (3) weather condition; (4) impact of holidays such as Saturday and Sunday. Because the impact of weather condition and vacation are hard to be quantified, the first two factors are mainly considered.

2.2.1. Number of Passengers in the Parking Lot. According to the influencing factors of the parking lot passenger volume: (1) the passenger flow at the airport; (2) the number of arrivals at the airport and the function relationship between the parking lot passenger volume and the influencing factors have been obtained using the BP neural network:

\[ N_C = f_{\text{network}}(x_i), \]  

where \( x_i \) represents the influencing factor of the passenger volume of the parking lot.

2.2.2. Passengers’ Waiting Time in the Parking Lot. Consider the influencing factors of taxi driver waiting time:

(1) The number of passengers in the parking lot
(2) The parking lot traffic flow

A mathematical relationship between passenger waiting time and passenger volume in the parking lot can be expressed by

\[ t_C = (N_C - 1)t_0 + N_C \cdot t_1, \]  

where \( N_C \) is the number of passengers waiting in line in the parking lot, \( t_0 \) is the time gap between when the last taxi has just been picked up and the next taxi in the parking lot is taken, and \( t_1 \) is the passengers’ boarding time.

2.2.3. Taxi Driver’s Waiting Time in the Parking Lot. Considering the assumption that the taxi drivers are always able to receive passengers in the parking lot, the mathematical relationship between the taxi drivers’ waiting time and the passengers’ waiting time can be expressed as follows [22]:

\[ \text{Driver's decision} \]

\[ \text{Profit of returning to the city} \]

\[ \text{Cost of empty running} \]

\[ \text{Distance from airport to city} \]

\[ \text{Distance of picking up passengers from airport to the city} \]

\[ \text{Revenue from passenger} \]

\[ \text{Waiting time} \]

\[ \text{Waiting cost} \]

\[ \text{Waiting profit} \]

\[ \text{Number of passengers in the parking lot in airport} \]

\[ \text{Number of taxis in the parking lot in the airport} \]

\[ \text{Figure 1: Cost-benefit analysis chart.} \]
\[
(t_C)^{n_n} (t_D)^{n_2} = K, 0 \leq n_1 \leq 1, 0 \leq n_2 \leq 1,
\]
\[
K = \frac{1}{A^{(N_C)^{1/2-n_1} (N_D)^{1/2-n_2},}}
\]
\[
A = a_0 (\phi)^{n_1},
\]

where \(a_0, n_0, n_1, n_2\) are the coefficients affected by the location of the airport, \(\phi\) is the coefficient affected by the size of the airport, and \(N_C\) and \(N_D\) represent the number of passengers and taxis in the airport parking lot at a certain moment. When the airport is determined, the values of \(a_0, n_0, n_1, n_2, \phi\) and the number of passengers and drivers at the airport parking lot at a certain time can be determined, so that the taxi drivers’ waiting time in the parking lot can be calculated as
\[
t_D = \left( \frac{(N_C)_{1/2-n_1} (N_D)_{1/2-n_2}}{a_0 (\phi)^{n_1} \cdot (t_C)^{n_2}} \right)^{1/n_2}.
\]

2.2.4. Taxi Drivers’ Waiting Cost. Because the taxi driver’s waiting cost is equal to the income of the taxi driver returning to the urban area directly in the same time [23], the relationship between the cost of waiting time and waiting time can be expressed as
\[
C_{\text{wait}} = E \cdot t_D,
\]
where \(E\) is the expected earnings per hour when the driver is waiting and \(t_D\) is the expected time of the driver in the parking lot.

2.2.5. Taxi Drivers’ Profit of Waiting in the Parking Lot. Calculating the driver’s income from waiting in the parking lot minus the waiting cost, the waiting income of the driver at the airport parking lot can be expressed as
\[
R_{\text{wait}} = (D_D - d) \cdot f + F - D_D \cdot f_o - E \cdot t_D,
\]
where \(D_D\) is the distance between the airport and the city, \(d\) is the mileage of taxi starting price, \(f\) is the fare per kilometre after the mileage exceeds \(d\), \(f_o\) is the fuel cost per kilometre of taxi, and \(F\) is the starting price.

2.2.6. Taxi Drivers’ Profit of Directly Returning to the City. By calculating the driver’s income from carrying passengers in the urban area minus the empty running cost of driving to the urban area, the corresponding profit can be derived. Considering the different distance, when the distance is less than \(d\), the profit can be expressed as
\[
R_{\text{go}} = k(F - d_D \cdot f_o) - D_D \cdot f_o,
\]

When the distance is greater than \(d\), the profit can be expressed as
\[
R_{\text{go}} = k((d_D - d) \cdot f + F - d_D \cdot f_o) - D_D \cdot f_o,
\]

where \(k\) is the number of taxi drivers’ successfully taking passengers in the urban area per hour. Finally, the decision-making model for taxi drivers is derived by comparing the value of the income from waiting in the airport parking lot and returning to the city directly.

When \(R_{\text{wait}} > R_{\text{go}}\), the taxi driver should choose to wait in the parking lot.

When \(R_{\text{wait}} < R_{\text{go}}\), the taxi driver should choose to return to the city to pick up passengers directly.

When \(R_{\text{wait}} = R_{\text{go}}\), the taxi driver should choose to wait in the parking lot or return to the city to pick up passengers directly.

2.3. Quantitative Analysis. It is now assumed that the number of passengers waiting in the parking lot is 50, the number of taxis is 20, and the airport correlation coefficients \(a_0 = 1, n_0 = 0.5, n_1 = n_2 = 0.25, \phi = 60\). The passenger carrying distance in the district is 12 kilometres, and the passenger carrying distance in the urban area is 4 kilometres. The data are related to taxi fare \(k = 2, F = 9, f_o = 0.6, f = 2,\) and \(d = 2\). Then, a scenario analysis can be performed and give a driver’s decision in the current situation. Based on known conditions, passengers’ waiting times are
\[
t_C = (n - 1)t_0 + t_1 = (50 - 1) \times 30 + 50 \times 60 = 4470 \text{ s} = 1.242 \text{ h}.
\]

The driver’s waiting time is
\[
t_D = \left( \frac{\left(N_C\right)^{1/2-n_1} \left(N_D\right)^{1/2-n_2}}{a_0 (\phi)^{n_1} \cdot \left(t_C\right)^{n_2}} \right)^{1/n_2} = \left( \frac{50^{0.25} \times 20^{0.25}}{60^{0.5} \times 1.242^{0.25}} \right)^{4} = 0.224 \text{ h}.
\]

The driver’s waiting profit is
\[
R_{\text{wait}} = (D_D - d) \cdot f + F - D_D \cdot f_o - E \cdot t_D,
\]
\[
R_{\text{wait}} = (12 - 2) \times 2 + 9 - 12 \times 0.6 - 15 \times 0.224 = 18.44 \text{ yuan}.
\]

The driver’s profit from returning to urban area directly is
\[
R_{\text{go}} = k((d_D - d) \cdot f + F - d_D \cdot f_o) - D_D \cdot f_o,
\]
\[
R_{\text{go}} = 2 \times ((4 - 2) \times 2 + 9 - 4 \times 0.6) - 12 \times 0.6 = 14 \text{ yuan} < 18.44 \text{ yuan}.
\]

Therefore, under the current circumstances, the driver should choose to wait in the parking lot at the airport.

3. Results and Discussion

3.1. Applying the Decision-Making Model for Taxi Drivers to Practical Condition. The relevant data of taxis in Chengdu on a certain day have been collected. By combining the model established to simulate the condition, the rationality of the model and its dependence on relevant factors are analyzed by combining the BP neural network.
By querying relevant information, we get the information shown in Table 2.

By looking up the relevant data of the Chengdu Shuangliu Airport, this paper uses the BP neural network algorithm, as shown in Figures 2–4, to construct a correlation model of the number of flights, the passenger flow number, the number of passengers in the parking lot, and the number of taxis in the parking lot for one day:

\[ Y_{\text{predict}} = \text{sim}(\text{network1, } x_{\text{predict}}). \]  

According to this relationship model, a specific set of time points is selected, and the corresponding number of passengers and the number of taxis in the parking lot have been outputted, and further data analysis is performed on the model to verify the rationality of the model and find the dependence of related factors.

### Table 1: Explanation for notations.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_i )</td>
<td>Factor of number of passengers in the parking lot</td>
</tr>
<tr>
<td>( t_C )</td>
<td>Passenger’s waiting time</td>
</tr>
<tr>
<td>( t_D )</td>
<td>Driver’s waiting time in the parking lot</td>
</tr>
<tr>
<td>( t_0 )</td>
<td>Difference between the time taking the last taxi to pick up a passenger and the time taking the next taxi to pick up a passenger in the parking lot</td>
</tr>
<tr>
<td>( t_1 )</td>
<td>Boarding time of passengers</td>
</tr>
<tr>
<td>( n )</td>
<td>Number of passengers who are waiting for taxis</td>
</tr>
<tr>
<td>( n_1 )</td>
<td>Airport position coefficient 1</td>
</tr>
<tr>
<td>( n_2 )</td>
<td>Airport position coefficient 2</td>
</tr>
<tr>
<td>( K )</td>
<td>Waiting time coefficient</td>
</tr>
<tr>
<td>( A )</td>
<td>Airport size eigenvalue</td>
</tr>
<tr>
<td>( N_C )</td>
<td>Number of passengers in the parking lot at some point</td>
</tr>
<tr>
<td>( N_D )</td>
<td>Number of taxis in the parking lot at some point</td>
</tr>
<tr>
<td>( a_0 )</td>
<td>Airport position coefficient 3</td>
</tr>
<tr>
<td>( \phi )</td>
<td>Airport terminal size coefficient</td>
</tr>
<tr>
<td>( n_3 )</td>
<td>Airport position coefficient 4</td>
</tr>
<tr>
<td>( C_{\text{wait}} )</td>
<td>Driver’s waiting cost</td>
</tr>
<tr>
<td>( E )</td>
<td>Expected revenue per hour while the driver waits</td>
</tr>
<tr>
<td>( K_{\text{wait}} )</td>
<td>Driver’s waiting revenue in the parking lot</td>
</tr>
<tr>
<td>( D_D )</td>
<td>Distance a driver picking up passengers from airport to city</td>
</tr>
<tr>
<td>( d )</td>
<td>Mileage of taxi starting price</td>
</tr>
<tr>
<td>( f )</td>
<td>The fare per kilometre beyond the starting mileage</td>
</tr>
<tr>
<td>( F )</td>
<td>Taxi starting price</td>
</tr>
<tr>
<td>( f_o )</td>
<td>Fuel cost per kilometre of taxi</td>
</tr>
<tr>
<td>( R_{go} )</td>
<td>Revenue for drivers returning directly to the city to pick up passengers</td>
</tr>
<tr>
<td>( d_D )</td>
<td>Distance of picking up passengers in the city</td>
</tr>
<tr>
<td>( k )</td>
<td>Successful times of taxi drivers in picking up passengers per hour in the city</td>
</tr>
<tr>
<td>( R_{DP} )</td>
<td>Priority of a taxi</td>
</tr>
<tr>
<td>( t_0^i )</td>
<td>Passenger boarding time in line ( i )</td>
</tr>
<tr>
<td>( t_j^i )</td>
<td>Waiting time of the ( j )th taxi in line ( i ) at some point</td>
</tr>
<tr>
<td>( p_i )</td>
<td>Priority of the first taxi in line ( i )</td>
</tr>
<tr>
<td>( g_i )</td>
<td>Probability of choosing the first taxi in line ( i )</td>
</tr>
<tr>
<td>( g_i )</td>
<td>Relative weight for line ( i )</td>
</tr>
<tr>
<td>( r_i )</td>
<td>Standardized relative weights for nonempty line ( i )</td>
</tr>
</tbody>
</table>

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#### 3.2. Sensitive Analysis of First Stage.

By selecting the time point set, the number of passengers and taxis in the parking lot of the Chengdu Shuangliu Airport has been obtained in this paper: 18, 4; 41, 13; 41, 33; 57, 27; 57, 37; 57, 47; 83, 34; 83, 44; 95, 42. According to the decision-making model for taxi drivers established above and calculated through Matlab, the corresponding passenger waiting time value, taxi driver waiting time value, profit of taxi drivers’ waiting in the parking lot and directly returning to the urban area can be derived, as shown in Table 3:

According to the heat map of Baidu map and the crowd distribution map, the possible destinations for taxi drivers from the airport are selected, and the probability of going to the destination is simulated by the heat map [26], as shown in Figure 5.

From this, the normal distribution relationship between probability of the passengers going to the destination and the distance from airport to the city (or from one place to the destination in the city) have been obtained. The average carrying distance from the airport to the urban area is 11.54 and the standard deviation is 2.27 and the average distance within the city is 4 and the standard deviation is 1.1, as shown in Figure 6.

The rationality and correlation of the practical data acquired from the Shuangliu Airport can be analyzed by the established decision-making model for taxi drivers:

(1) By comparing the value of passenger waiting time, it can be found that the passengers’ waiting time
increases with the growing number of passengers in the parking lot and does not change with the increasing number of taxis in the parking lot. This result is reasonable, because the number of taxis in the parking lot has always been sufficient, so there will not be a shortage of taxis, which will not affect the waiting time of passengers. Meanwhile, the queuing and waiting mechanism makes it reasonable for the waiting time of passengers to rise as the number of passengers in the parking lot increases.

(2) By comparing the value of taxi driver waiting time, the waiting time of taxi drivers grows with the increasing number of passengers in the parking lot and also increases with the number of taxis in the parking lot. And the impact of the number of taxis in the parking lot on the taxi driver’s waiting time is greater than the impact of the number of passengers. Such result is reasonable because the increase in the number of passengers in the parking lot and the increase in the number of taxis will increase the load in the airport and raise the waiting time for taxi drivers. At the same time, the number of taxis has a greater impact on the driver’s waiting time, because the taxi drivers also need to wait in line for a pickup. Therefore, the number of taxis will directly affect the waiting time for taxi drivers in the parking lot. Relatively speaking, the impact of the number of passengers on the waiting time for taxi drivers is small.

(3) By comparing the waiting income of taxi drivers with the choice of returning to urban area, it can be revealed that when the carrying distance is chosen as the maximum probability is reached \(D_D = 11.54, d_D = 4\), the taxi drivers’ waiting income will change with the changes in the number of passengers and taxis in the parking lot, and the income of taxi drivers returning directly to the city will not change. This is because the driver’s waiting income is closely related to the waiting time of the driver, and the waiting time is affected by the number of passengers and the

<table>
<thead>
<tr>
<th>Variable definition</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal area at Chengdu Shuangliu International Airport</td>
<td>50</td>
<td>Million square meter</td>
</tr>
<tr>
<td>Average queue time for taxi drivers in the parking lot</td>
<td>2</td>
<td>Hour</td>
</tr>
<tr>
<td>Waiting time for passengers in line</td>
<td>20</td>
<td>Minute</td>
</tr>
<tr>
<td>Boarding time for passengers</td>
<td>60</td>
<td>Second</td>
</tr>
<tr>
<td>Fuel consumption of taxi</td>
<td>0.1</td>
<td>Liter/kilometre</td>
</tr>
<tr>
<td>Airport position coefficient 1</td>
<td>0.25</td>
<td>Dmnl</td>
</tr>
<tr>
<td>Airport position coefficient 2</td>
<td>0.25</td>
<td>Dmnl</td>
</tr>
<tr>
<td>Airport position coefficient 3</td>
<td>1</td>
<td>Dmnl</td>
</tr>
<tr>
<td>Airport position coefficient 4</td>
<td>0.5</td>
<td>Dmnl</td>
</tr>
<tr>
<td>Mileage of taxi starting price</td>
<td>2 [25]</td>
<td>Kilometre</td>
</tr>
<tr>
<td>Taxi starting price</td>
<td>9 [22]</td>
<td>Yuan</td>
</tr>
<tr>
<td>Fuel cost per kilometre of taxi</td>
<td>0.667</td>
<td>Yuan</td>
</tr>
<tr>
<td>Successful times of taxi drivers in picking up passengers per hour in the city</td>
<td>2</td>
<td>Times</td>
</tr>
<tr>
<td>Expected revenue per hour while the driver waits</td>
<td>10</td>
<td>Yuan</td>
</tr>
<tr>
<td>Difference between the time taking the last taxi to pick up a passenger and the time taking the next taxi to pick up a passenger in the parking lot</td>
<td>30</td>
<td>Second</td>
</tr>
</tbody>
</table>

Table 2: Coefficient value of the decision-making model for taxi drivers.

![Diagram](image)

**Figure 2: BP network flow diagram.**
number of taxis. The income of drivers who drive directly to the urban area is only affected by the carrying distance from the airport to the urban area and within the urban area. When the values of $D_D$ and $d_D$ that affect the passenger distance remained the same, drivers’ earnings will not be affected.

(4) At the same time, for the taxi driver’s waiting income, compare the number of passengers with the number of taxis dataset (41, 33; 41, 37; 57, 37; 57, 47). When the number of passengers in the parking lot remains unchanged, the driver’s waiting income decreases as the number of taxis in the parking lot increases. Considering that the larger the number of taxi drivers in the parking lot, the greater the waiting cost of taxi drivers, therefore the rationality of this result can be verified by reducing the waiting income of drivers. When the number of passengers and taxis is (57, 47), it can be found that the driver’s waiting income at this time is 12.6287 yuan, which is very close to the average income of the driver who directly goes to the city to pick passengers. Based on the mathematical relationship of the BP neural network established in Matlab, the number of passengers and taxis is (57, 49), and the driver’s waiting income at this time is 11.87 yuan, which is slightly larger than the average income of the drivers going to the city, which means that when the number of passengers is stable at 57 and the number of taxis in the parking lot is greater than 49, the drivers should choose to return to the city to pick up passengers directly.

(5) Furthermore, comparing the number of passengers and the number of taxis data set (41, 33; 57, 37; 83, 34), it can be revealed that when the number of taxis stabilizes, the driver’s waiting income increases with the declining number of passengers. Considering that when the number of passengers increases, the waiting cost of the driver increases, therefore the validity of this result can be verified by reducing the waiting income of the driver. When the number of passengers and taxis is (83, 34), it can be found that the driver’s income at this time is 11.87 yuan, which is approximately equal to the average income of the driver who directly goes to the city. It indicates that when the number of taxis is at around 34 and the number of passengers is greater than 83, the drivers should choose to return directly to the city to pick up passengers. According to the calculation of Matlab, the relationship between the product of the number of passengers and the traffic volume and the drivers’ profit can be derived from Table 4.

(6) Consider the above two situations comprehensively, we can calculate the product of the number of passengers and the number of taxis to make a judgment on the choice of the drivers. By comparing the product of the number of passengers and the number of taxis and the driver’s waiting income at the airport, it can be found that the driver’s waiting income decreases as the product of the number of passengers and taxi increases. Comparing the passenger number and taxi number data sets of (83, 34; 83, 44), it can be found that when the product of passenger number and taxi number is 2822, the driver’s waiting income is 13.61 yuan, which is greater than the average income of returning to the urban area, which is 11.83 yuan. When the product of the number of passengers and the number of taxis is 3652, the waiting income of the driver is 9.32 yuan, which is less than the average income of the driver.
### Table 3: The relationship between waiting time and diver’s revenue.

<table>
<thead>
<tr>
<th>Number of passengers in the parking lot (person)</th>
<th>Taxi flow (car)</th>
<th>Passenger’s waiting time (hour)</th>
<th>Driver’s waiting time in the parking lot (hour)</th>
<th>Driver’s waiting revenue in the parking lot (yuan)</th>
<th>Average revenue for drivers returning directly to the city to pick up passengers (yuan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>4</td>
<td>0.158</td>
<td>0.020</td>
<td>19.27</td>
<td>11.83</td>
</tr>
<tr>
<td>41</td>
<td>13</td>
<td>0.350</td>
<td>0.046</td>
<td>17.99</td>
<td>11.83</td>
</tr>
<tr>
<td>41</td>
<td>33</td>
<td>0.350</td>
<td>0.428</td>
<td>15.19</td>
<td>11.83</td>
</tr>
<tr>
<td>57</td>
<td>27</td>
<td>0.483</td>
<td>0.784</td>
<td>11.63</td>
<td>11.83</td>
</tr>
<tr>
<td>57</td>
<td>37</td>
<td>0.483</td>
<td>1.108</td>
<td>8.39</td>
<td>11.83</td>
</tr>
<tr>
<td>57</td>
<td>47</td>
<td>0.483</td>
<td>0.376</td>
<td>15.71</td>
<td>11.83</td>
</tr>
<tr>
<td>83</td>
<td>34</td>
<td>0.700</td>
<td>0.586</td>
<td>13.61</td>
<td>11.83</td>
</tr>
<tr>
<td>83</td>
<td>44</td>
<td>0.700</td>
<td>1.014</td>
<td>9.32</td>
<td>11.83</td>
</tr>
<tr>
<td>95</td>
<td>42</td>
<td>0.800</td>
<td>0.744</td>
<td>12.03</td>
<td>11.83</td>
</tr>
</tbody>
</table>

**Figure 5:** Heat map of population distribution in Chengdu.

**Figure 6:** Normal distribution of the distance.
Complexity

who returns directly to the urban area of 11.83 yuan. Therefore, it can be concluded that there is a mathematical relationship between the driver's waiting income and the product of the number of passengers and taxis corresponding to the driver’s waiting income of approximately 11.83 yuan, the driver’s choice can be judged.

(7) Further comparing the product data set of the above two cases (57, 49; 83, 34), it can be found that $57 \times 49 = 2793$ and $83 \times 34 = 2822$. So, when the product of the number of passengers and the number of taxis belongs to the range of $[2793, 2822]$, while the driver’s waiting income is within the range of $[11.61, 11.87]$. When the product value is equal to 2793, the driver’s waiting income is 11.87 yuan, which is closer to the average income of the drivers returning to the urban area, which is 11.83 yuan. So, the target product value is greater than 2793 and close to 2793. Based on this conclusion, the product value is determined to be 2800.

Therefore, after the first-stage sensitive analysis, the taxi driver’s decision is as follows.

When the product of the number of passengers and the number of taxis $NC \cdot ND$ is greater than 2800, the taxi driver should choose to return to the city to pick passengers;

When the product of the number of passengers and the number of taxis $NC \cdot ND$ is less than 2800, the taxi driver should choose to wait in the parking lot of the airport.

When the product of the number of passengers and the number of taxis $NC \cdot ND$ is equal to 2800, the taxi driver should choose to return directly to the city to pick up passengers or wait in the parking lot at the airport. And the current decision-making model for taxi drivers for taxi drivers can be written as

$$D = f_1(NC, ND),$$

where $NC$ is the number of passengers and $ND$ is the number of drivers.

### 3.3. Establishment of Optimization Model of Dispatching Efficiency

In order to obtain an ideal optimization model of dispatching efficiency, this paper introduces the highest priority taxis to carry passengers; from the perspective of taxi drivers, the management department should prefer to choose taxis with longer waiting times and higher priority taxis to carry passengers; from the perspective of passengers, the management department should choose passengers with shorter boarding times.

### 3.4. Quantitative Analysis

Now, suppose there are 20 taxis and 50 passengers waiting in the parking lot and use this model to simulate the scene, as shown in Figure 7:
should overall riding efficiency, the management department can quickly divert taxis on different routes through these measures, which not only protects the revenue of taxis but also improves the passenger’s riding efficiency.

Table 4: The relationship between passenger flow and the driver’s revenue [27].

<table>
<thead>
<tr>
<th>Number of passengers in the parking lot (person)</th>
<th>Taxi flow (car)</th>
<th>Product between number of passengers and taxi flow (Person°Car)</th>
<th>Driver’s waiting revenue in the parking lot (yuan)</th>
<th>Average revenue for drivers returning directly to the city to pick up passengers (yuan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>4</td>
<td>72</td>
<td>19.27</td>
<td>11.83</td>
</tr>
<tr>
<td>41</td>
<td>13</td>
<td>533</td>
<td>17.99</td>
<td>11.83</td>
</tr>
<tr>
<td>41</td>
<td>33</td>
<td>1353</td>
<td>15.19</td>
<td>11.83</td>
</tr>
<tr>
<td>57</td>
<td>27</td>
<td>1539</td>
<td>11.63</td>
<td>11.83</td>
</tr>
<tr>
<td>57</td>
<td>37</td>
<td>2109</td>
<td>8.39</td>
<td>11.83</td>
</tr>
<tr>
<td>57</td>
<td>47</td>
<td>2679</td>
<td>15.71</td>
<td>11.83</td>
</tr>
<tr>
<td>83</td>
<td>34</td>
<td>2822</td>
<td>13.61</td>
<td>11.83</td>
</tr>
<tr>
<td>83</td>
<td>44</td>
<td>3652</td>
<td>9.32</td>
<td>11.83</td>
</tr>
<tr>
<td>95</td>
<td>42</td>
<td>3990</td>
<td>12.03</td>
<td>11.83</td>
</tr>
</tbody>
</table>

$$t_c^1 = (50 - 1) \times 30 + 60 = 1530 \ s = 0.425 \ h,$$

$$t_D^{1,j} = \left( \frac{(50)^{0.25} \times (20)^{0.25}}{(50)^{0.5} \times (0.425)^{0.25}} \right)^4 = 0.941 \ h,$$

$$t_c^2 = (50 - 1) \times 30 + 90 = 1560 \ s = 0.433 \ h,$$

$$t_D^{2,j} = \left( \frac{(50)^{0.25} \times (20)^{0.25}}{(50)^{0.5} \times (0.433)^{0.25}} \right)^4 = 0.924 \ h,$$

$$p_1 = 1 + \frac{t_D^{1,j}}{t_c^1} = 2.21,$$

$$p_2 = 1 + \frac{t_D^{2,j}}{t_c^2} = 2.13.$$

Suppose \( p_{t_1} = 0.8, \) \( p_{t_2} = 0.8, \) \( p_{t_3} = 0.64: \)

\[
g_1 = p_{t_1} = 0.8, \\
g_2 = p_{t_2} \cdot (1 - p_{t_1}) = 0.64 \times 0.2 = 0.128, \\
g_3 = \frac{0.8 \times 2.21}{0.8 \times 2.21 + 0.128 \times 2.13} = 86.6\%, \\
g_4 = \frac{0.128 \times 2.13}{0.8 \times 2.21 + 0.128 \times 2.13} = 13.4\%. 
\]

Therefore, it can be found that the probability of the first car in the first line being selected at this time is 86.6%, while the probability of the first car in the second line being selected is only 13.4%. From such analysis, it can be concluded that the usage probability of the second line at a certain moment is much smaller than the usage probability of the first line. The reason is that passengers tend to choose the nearest line to get on the car to reduce the time required to get on the car.

Based on such conclusion, in order to maximize the overall riding efficiency, the management department should

1. increase the relevant passages to reduce the time required for passengers to get online 2 and increase the use efficiency of line 2

(2) improve the priority of taxis in line 2 so as to improve the use efficiency of line 2

With regard to granting “priority,” the further suggestions can be as follows:

1. Priority points can be added to allow returning taxis to preferentially enter these lines to take passengers so that these taxis can take a greater number of passengers per hour and increase their earnings

2. The line can be divided into a long-distance line and a short-distance line, and the passenger entrance is separated. Passengers who need to take a long-distance ride line up at the long-distance passenger line, and passengers who need a short-distance ride queue in the short-distance passenger line. The management department can quickly divert taxis on different routes through these measures, which not only protects the revenue of taxis but also improves the passenger’s riding efficiency.

Therefore, the current optimization model of dispatching efficiency can be drawn as

\[
P = f_2(t_1, t_D),
\]

where \( P \) is the dispatching priority of a taxi, \( t_1 \) is the passenger’s boarding time, and \( t_D \) is the passenger’s waiting time.

Since \( t_1 \) and \( t_D \) are dependent on the passenger number \( N_C \) and the taxi number \( N_D \), the optimization model can be further written as

\[
P = f_2(N_C, N_D).
\]

3.5. Sensitive Analysis of Second Stage. Since the previous decision-making model for taxi drivers and optimization model of dispatching efficiency are based on one day in the Chengdu Shuangliu Airport, the models lack sensitiveness analysis on the different time in a year. Therefore, to make the further sensitive analysis, weather conditions and holiday will be taken into consideration.

By selecting the passenger number of the Labour Day (blue line) in the Chengdu Shuangliu Airport, the distribution of the passenger number is shown in Figure 8 in
comparison with a normal workday (red line), where the workday is taken as the control day.

Compared with the passenger number on the control day, it can be found that the passenger number on holiday is visibly higher than one of normal days.

Similarly, as displayed in Figure 9, by selecting one rainy day (black line) in the Shuangliu Airport, the number of passengers is lower than the one on the day with sunny day (red line), where sunny day is determined to be the control weather condition.

Based on the abovementioned observations, conclusion can be drawn that the number of passengers is sensitive to holiday and weather condition.

Roh et al. adopted the regression model to simulate the impact of snow and temperature on the highway truck traffic \cite{28} and acquired expected results. By gaining the experience from Roh’s research, this paper will apply the regression model to further simulate the effect of weather condition and holiday on the number of passengers. To simulate the effect of weather condition and holiday, each factor will be divided into five levels including the control level.

3.5.1. Weather Condition. The weather condition will be divided into sunny day (control level), light rain (level 1), heavy rain (level 2), thundershower (level 3), and snowstorm (level 4). The number of passengers can be adjusted by multiplying one weather condition factor $k_W$, and the passenger number will be $N_C \cdot k_W$. By collecting typical data from the official website of the Chengdu Shuangliu Airport on the corresponding weather conditions, the comparison between the data and the prediction can be manifested from Figure 10.

3.5.2. Holiday Condition. The holiday condition will be divided into workday (control day), weekends (level 1), holiday with 3 days to 5 days (level 2), holiday with 7 days (level 3), and holiday with over 7 days (level 4). The number of passengers can be regulated by multiplying one holiday factor $k_H$, and the

In the graphs, the red lines are the control level and the blue lines and green lines are, respectively, for original data and for predictions. From the results, it can be seen that as the weather condition gets severer, the number of passengers drops, and the predictions fit the trend of the original data, where $k_W$ equals to 3, 2.5, 2, and 1.5, respectively, for weather condition level 1, level 2, level 3, and level 4.

3.5.2. Holiday Condition. The holiday condition will be divided into workday (control day), weekends (level 1), holiday with 3 days to 5 days (level 2), holiday with 7 days (level 3), and holiday with over 7 days (level 4). The number of passengers can be regulated by multiplying one holiday factor $k_H$, and the
Figure 9: Comparison of the passenger number on control day and weather.

Figure 10: Continued.
Figure 10: Comparison between data and prediction on weather condition from level 1 to level 4.

Figure 11: Continued.
passenger number will be $N_C \cdot k_H$. By collecting typical data from the official website of the Chengdu Shuangliu Airport on the corresponding weather conditions, the comparison between the data and the prediction can be manifested from Figure 11.

In the graphs, the red lines are the control level and the blue lines and green lines are, respectively, for original data and for predictions. From the results, it can be seen that as the holiday period becomes longer, the number of passengers rises, and the predictions generally fit the original data, where $k_H$ equals to $5/6, 2/3, 5/9,$ and $2/5$, respectively, for holiday condition level 1, level 2, level 3, and level 4.

Therefore, from the discussed results, the number of passengers is sensitive to the weather condition and holiday period. Since the number of taxi drivers will be significantly influenced by the passenger number, the number of taxis will be sensitive to the weather condition and holiday period.

3.6. Final Model. Based on the previous discussions, the influence of weather condition can be deduced by a function $f_W(t)$, which depends on the time (date) $t$. And the impact of holiday period can be inferred by a function $f_D(t)$, which relies on time $t$ as well.

Then, the final taxi driver’s decision model can be derived as

$$D = f_1(N_C \cdot N_D) \cdot f_W(t) \cdot f_D(t),$$

$$D = f_1(N_C \cdot f_W \cdot f_D, N_D \cdot f_W \cdot f_D).$$

(25)

Since the number of taxis will be changed by the difference of the passenger number, the number of taxis will be a dynamic number:

$$N_{Dj} = k(D) \cdot N_{Dj-1}$$

(26)

where $k(D)$ is the influence factor caused by the change of passenger number.

And then, the final optimization model of dispatching efficiency can be obtained as

$$P = f_2(t_{ij}^j, t_{Dj}^i),$$

$$P = k(D) \cdot f_2(N_C, N_D),$$

where $P$ is the priority of a taxi at $j$ th line when the taxi number is $N_{Dj}$, and $t_{ij}^j$ is the passengers’ waiting time when the taxi number is $N_{Dj}$, and $t_{Dj}^i$ is the taxi driver’s waiting time when the taxi number is $N_{Dj}$, where

$$t_{Dj}^i = \frac{N_{Dj}}{N_{Cj} \cdot t_{Cj}^i}.$$
year so that the dispatching efficiency can be improved by taking precaution actions.

To further improve the reliability and accuracy, the decision-making model for taxi drivers can combine the relevant reliable data to get the driver’s optimal choice relatively quickly. The optimization model of dispatching efficiency can be combined with the system dynamics theory so as to cope with more complex queuing situations quickly and efficiently and obtain the most efficient dispatching efficiency.

Data Availability

Previously reported data were used to support this study and are available at http://youjia.chemcp.com/sichuan/chengdushi.html and http://www.cdtaxi.cn/ and http://www.cdairport.com/.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors’ Contributions

Y. Qian and S. Chen contribute equally to this paper.

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