Research on Parking Lot Selection Model Taking Secondary Parking into Account

Chengqiang Yu1*,2
1 Ocean College Of Minjiang University, Fuzhou, Fujian, 350000, China
2 Internet Innovation Research Center Of Minjiang University, Fuzhou, Fujian, 350000, China
*Corresponding author’s e-mail: 99186816@qq.com

Abstract: Parking difficulty is a common problem in a lot of cities. People often find that there is no space in the selected parking lot so they have to look for another parking lot, which makes the parking efficiency very low. In this paper, by introducing the concept of time value, a calculation method of secondary parking cost is proposed, considering the factors affecting parking saturation, and combining BP neural network to predict parking space. Then, an optimal parking selection model with minimum generalized parking cost is built, which is applied to the calculation of optimal parking choice in Fuzhou central business district. The parking lot selection model which is built in this paper will improve the parking success probability of the selected parking lot, reduce the blindness of parking lot selection, the secondary parking flow rate and the heavy traffic in the city.

1. Introduction
With the continuous development of cities in China, parking in the city has become a research hotspot in urban transportation. Scholars pay more attention to the parking guidance information system (PGIS) in order to deal with the parking problem in the city. How to select the optimal parking lot is a core part in PGIS. A lot of scholars mainly considered the factors of traffic time, parking fee and walking distance in the selection of optimal parking lot in the past. But in the actual parking situation, a good deal of drivers often encounter the situation that they need to choose a new parking lot again because there is no space in the selected parking lot, which is particularly common in the rush hour of parking in the downtown [1].

Therefore, the parking lot in Fuzhou city of Fujian province is taken as the research object in this paper to study the influencing factors of parking, consider the possibility of secondary parking search for the saturation of the parking lot and construct a parking lot selection model which can reduce the blindness of drivers in parking lot selection, make parking process more efficient and reduce the additional secondary parking traffic flow.

2. Parking process
Generally speaking, people drive as shown in figure 1 which can be divided into three stages:

- Determine candidate parking lots. Determine the $K$ candidate parking lots in a certain range near destination $D$.
- From origin to the parking lot. After Determining the preferred parking lot $A_i$ ($i \in K$) from the $K$ candidate parking lots, the driver starts from the starting point $O$ and arrives at $A_i$. If there are spare
parking space in $A_i$, the parking will be successful; if there are no parking space in $A_i$, it will need to re-select the parking lot $A_j$ ($j \in K$).

- From parking lot to destination. Walk to destination $D$ from the parking lot and the parking process is complete.

3. Analysis of parking lot selection model

3.1 Model impact factors
The primary task of the optimal parking lot selection model is to determine the impact parameters of the model. Based on the analysis of parking behavior, the main influencing factors of parking lot choice are minimum driving time $T_i$ (minutes) from origin $O$ to the parking lot $A_i$, parking fee $F_i$ (yuan) of parking lot $A_i$, parking lot $A_i$ saturation $S_i$ and minimum walking distance $L_i$ (meters) from parking lot $A_i$ to destination $D$[1].

3.2 Model objectives
In order to consider all the factors affecting parking choice, the concept of time value in economics is introduced in this paper which is directly related to income of people and makes use of the ratio of disposable income and working minutes to calculate it by referring to the methods of Production Method, Wage Method and Expense Method, etc[2].

$$V_t = \frac{I}{(365-52 \times 2) \times 8 \times 60} = \frac{I}{125280}$$  \hspace{1cm} (1)

Where $V_t$ is time value (yuan/min), $I$ is personal disposable income (yuan/year). The factors affecting parking lot selection are transformed into corresponding economic indicators as shown in table 1.
Table 1. Cost of the evaluation indexes of the preferred parking lot.

| Evaluation index | Corresponding costs                                      | Symbol code | Unit |
|------------------|----------------------------------------------------------|-------------|------|
| $T_i$            | The minimum travel time cost from starting point $O$ to parking lot $A_i$ | $C_{Ti}$    | yuan |
| $F_i$            | The parking fee of $A_i$                                 | $C_{Fi}$    | yuan |
| $S_i$            | The secondary parking cost of $A_i$                      | $C_{Si}$    | yuan |
| $L_i$            | The minimum walking time cost from parking lot $A_i$ to destination $D$ | $C_{Wi}$    | yuan |

The generalized parking cost $C_i$ of the parking lot $A_i$ can be calculated by equation (2).

$$C_i = C_{Ti} + C_{Fi} + C_{Si} + C_{Wi}$$  \hfill (2)

The goal of the parking selection model is to choose the parking lot with the lowest generalized parking cost as the optimal parking lot by comparing the generalized parking costs from the starting point to candidate parking lots.

4. Optimal parking lot selection modelling

4.1. Number of candidate parking lots $K$

Walking distance from parking lot to destination is the most important factor affecting drivers' choice of parking lot. The maximum tolerable pedestrian distance from the parking lot to the destination is 300 meters. Parking lots beyond 300 meters will not be included in the parking choice by drivers[1]. Therefore, taking the parking lot within the radius of 300 meters as the candidate parking lot with the destination as the center, the total number of candidate parking lots is $K$, and then the candidate parking lot $A_i (i \in K)$ is determined.

4.2. Minimum travel time cost $C_{Ti}$

According to the BPR impedance function model proposed by the Federal Highway Administration of the United States, the driving time of each road in the road network can be calculated by equation (3).

$$t_{im} = t_{im}^0 \left[1 + \alpha \left(\frac{q_{im}}{C_{im}}\right)^\beta\right]$$  \hfill (3)

The shortest road from the starting point to the parking lot $i$ can be calculated by Dijkstra algorithm and the shortest travel time $T_i$:

$$T_i = \sum_{m=1}^{M} t_{im}^0 \left[1 + \alpha \left(\frac{q_{im}}{C_{im}}\right)^\beta\right]$$  \hfill (4)

from the starting point to the parking lot $A_i$ can be calculated, where $M$ is the set of sections on the shortest path from the starting point to the parking lot $A_i$. If the relevant data of the road section is missing, the value of $T_i$ can also be determined by using the shortest driving time calculated by application software such as Baidu map and Gaode map. The cost of Minimum travel time from driver to parking lot driving time to parking lot $A_i$ can be calculated by equation (5).

$$C_{Ti} = V_i \cdot T_i$$  \hfill (5)

4.3. Parking fee $C_{Fi}$

The parking fee is mainly determined by the charging standard of target parking lot and parking time. There are obvious differences in parking charge standards because of the location, type and competent department of parking facilities, and the current parking charge standards mainly include "time charge"
and "time progressive charge" [3]. The fixed charge standard shall be adopted according to the number of times the vehicle is parked in the parking lot; Progressive charging system is based on different parking hours, different parking fees, usually measured by the hour, cost cumulative increase, can set the highest upper limit. After the parking time and the target parking lot are determined, the parking fee for parking in the target parking lot is determined.

4.4. Minimum walking time Cost $C_{Wi}$

The walking time cost from the parking lot $A_i$ to the destination $D$ can be calculated by

$$C_{Wi} = V_w \cdot T_{Wi}, \quad (6)$$
$$T_{Wi} = \frac{L_i}{V_w}, \quad (7)$$

where $L_i$ is the distance from the parking lot $A_i$ to the destination $D$, $V_w$ is the walking speed and available at 83.33 m/min. Baidu map, Gaode map and other application software can also be used to calculate the shortest walking time to determine $D$.

4.5. Secondary Parking cost $C_{Si}$

As the driver arrives at the preferred parking lot $A_i$, if $A_i$ is saturated, he needs to find the other parking lot $A_j$ ($j \in K$). Drivers are always more likely to choose the parking lot near $A_i$ and with low parking saturation as the next parking lot, so the candidate parking lot with low parking saturation is more likely to be selected with less travel time from the preferred parking lot. In this paper, the multinomial Logit model is used to describe the probability $P_{ij}$ of each parking lot $A_j$ ($j \neq i, j \in K$) being selected, and $P_{ij}$ is calculated by

$$P_{ij} = \frac{\alpha_{ij} \cdot e^{-\alpha_{ij}}}{\sum_{n=1}^{K} (\alpha_{in} \cdot e^{-\alpha_{in}})}, \quad \alpha_{ij} = \begin{cases} 1, & j \neq i \\ 0, & j = i \end{cases}, \quad \alpha_{in} = \begin{cases} 1, & n \neq i \\ 0, & n = i \end{cases} \quad (i, j, n \in K), \quad (8)$$

where $\theta$ is a parameter to be calibrated. Based on past experience and specific circumstances, $\theta$ can be set as 3.20. $U_{ij}$ is the utility function of the parking lot $j$ chosen by the driver from the parking lot $A_i$, which can be calculated by equation (9)[4, 5, 6].

$$U_{ij} = \frac{\sigma_T \cdot t_{ij}}{60} + \sigma_S \cdot S_{ij} \quad (9)$$

where $S_{ij}$ is the saturation of parking lot $A_j$ after $T_{ij}$ period, which can be predicted by BP neural network algorithm; $t_{ij}$ is the shortest driving time from the parking lot $A_i$ to another parking lot $A_j$, can be calculated with reference to $T_{ij}$; $\sigma_T$ is the weighting coefficient of travel time and $\sigma_S$ is the weighting coefficient of parking saturation. In this paper, $\sigma_T$ is set as 0.5 and $\sigma_S$ is set as 0.5, based on that the travel time and parking saturation have the same effect on the model. Then the secondary parking cost of $A_i$ can be calculated by equation (10).

$$C_{Si} = V_w \cdot S_{ii} \cdot \sum_{j=1}^{K} (p_{ij} \cdot t_{ij}) \quad (10)$$

4.6. Optimal parking lot selection model

The objective of the model is to select the parking lot with the lowest generalized parking cost among all the candidate parking lots, so the objective function of the model can be calculated by equation (10).
Mathematical model of optimal parking lot selection can be build based on equation (1) to equation (11).

\[
\min(C_i) = \min(C_{Fi} + C_{Wi} + C_{Si})
\]

\[
\min(C_i) = \min \left( V_i \cdot T_i + C_{Fi} + V_i \cdot T_{Wi} + V_i \cdot S_{ij} \cdot \sum_{j=1}^{K} (p_{ij} \cdot t_{ij}) \right)
\]

\[
\left\{ \begin{array}{l}
V_i = \frac{I}{125280} \\
T_i = \sum_{m=1}^{M} t_{im}^0 \left[ 1 + \alpha \left( \frac{q_{im}}{C_{im}} \right)^{\beta} \right] \\
p_{ij} = \frac{\alpha_{ij} \cdot e^{-\alpha_{ij}}}{\sum_{n=1}^{N} (\alpha_{in} \cdot e^{-\alpha_{in}})} \\
U_{ij} = \frac{\sigma_T \cdot t_{ij} + \sigma_S \cdot S_{ij}}{60} \\
\alpha_{ij} = \begin{cases} 
1, & j \neq i \\
0, & j = i
\end{cases} \\
\alpha_{ik} = \begin{cases} 
1, & n \neq i \\
0, & n = i
\end{cases} \\
T_{Wi} = \frac{L_i}{V_w} \\
i = 1,2,\cdots, K; j = 1,2,\cdots, K; n = 1,2,\cdots, K
\right\}
\]

5. Example analysis

Based on Fuzhou urban road network, this paper calculates the optimal parking lot from the origin \(O\), Fuzhou Education Institute Subsidiary Middle School, to the destination \(D\), Fuzhou Dongjiekou China Telecom Building. The personal income of a driver is set as 100,000 yuan per year. According to equation (1), the time value \(V_i\) is 0.798 yuan per minute.

5.1. Determine candidate parking lots

Taking the destination China Telecom Building as the center and taking 300m as the radius to determine the candidate parking lots: the underground parking lot of Oriental Department Store \((A_1)\), the underground parking lot of Dongbai Group \((A_2)\) and the underground parking lot of Grand Ocean Department Store \((A_3)\), as shown in figure 2, therefore \(K = 3\).
5.2. The minimum travel time

Baidu Map APP is used to calculate the minimum travel time $T_i$ (as shown in table 2) from starting point $O$ to $A_i$ and minimum travel time $t_{ij}$ between each candidate parking lot, as shown in table 3.

Table 2. Minimum travel time from starting point to candidate parking lot.

| Origin-destination | Minimum travel time path                      | Time $T_i$ (minute) |
|--------------------|-----------------------------------------------|---------------------|
| $O \rightarrow A_1$| $O \rightarrow$ West Second Ring Road $\rightarrow$ Yangqiao Road $\rightarrow A_1$ | $T_1=13$            |
| $O \rightarrow A_2$| $O \rightarrow$ Wu Shan Road $\rightarrow$ Ba Yi Qi Road $\rightarrow A_2$ | $T_2=11$            |
| $O \rightarrow A_3$| $O \rightarrow$ Wu Shan Road $\rightarrow$ Ba Yi Qi Road $\rightarrow A_3$ | $T_3=11$            |

Table 3. Minimum travel time between each candidate parking lot.

| Origin-destination | Time $t_{ij}$ (minute) |
|--------------------|------------------------|
| $A_1 \rightarrow A_2$ | $t_{12}=2$             |
| $A_1 \rightarrow A_3$ | $t_{13}=6$             |
| $A_2 \rightarrow A_1$ | $t_{21}=2$             |
| $A_2 \rightarrow A_3$ | $t_{23}=6$             |
| $A_3 \rightarrow A_1$ | $t_{31}=5$             |
| $A_3 \rightarrow A_2$ | $t_{32}=2$             |

5.3. Parking space prediction

In order to calculate the secondary parking cost of each candidate parking lot, it is necessary to know the parking saturation $S_{ij}$ of each candidate parking lot $A_i$ after $T_i (i \in K)$. In this paper, BP neural network is used to predict $S_{ij}$ [7,8].

- Data Selection. The parking data from 12:00 on March 14, 2019 to 12:00 on March 18, 2019 are obtained through the management system of each candidate parking lot and the parking space occupancy data of the parking lot are sorted out at 5-minute intervals.

- Data normalization. By dividing the occupied parking space data calculated in the first step by the number of total parking spaces of the corresponding parking lot, the parking saturation of each candidate parking lot at 5-minute intervals can be obtained, and the data are between $[0,1]$.

- Data training. The number of neurons in the input layer is set as 6, and the number of neurons in the output layer is set as 3. That is, if $t$ is the present moment, the parking saturations at the moments of $t+5$ minutes, $t+10$ minutes and $t+15$ minutes can be predicted according to the parking saturations at the moments of $t-25$ minutes, $t-20$ minutes, $t-15$ minutes, $t-10$ minutes, $t-5$ minutes and $t$. The number of hidden layer neurons is set as 10. The network learning rate is set as 0.01, the number of iterations is set
as 1000000 and the training data are used to built BP neural network prediction models of the three candidate parking lots.

- Data prediction. Assuming that a driver is ready to depart at 16 o'clock, \( t = 16:00 \), the parking saturations of three candidate parking lots are shown in table 4 at 5-minute intervals. The data in Table 4 are substituted into the BP neural network prediction models which have been trained with historical data of candidate parking lots, and the prediction results are shown in table 5.

| Parking lot | t-25 | t-20 | t-15 | t-10 | t-5 | t   |
|-------------|------|------|------|------|-----|-----|
| \( A_1 \)   | 0.426| 0.433| 0.433| 0.426| 0.440| 0.461|
| \( A_2 \)   | 0.512| 0.504| 0.504| 0.520| 0.528| 0.520|
| \( A_3 \)   | 0.829| 0.846| 0.870| 0.878| 0.886| 0.886|

Table 4. The Parking saturations at historic times of each candidate parking lot.

| Parking lot | t+5 | t+10 | t+15 |
|-------------|-----|------|------|
| \( A_1 \)   | 0.470| 0.472| 0.480|
| \( A_2 \)   | 0.533| 0.538| 0.539|
| \( A_3 \)   | 0.816| 0.824| 0.818|

Table 5. The prediction of parking saturations.

As can be seen from table 2, \( 10 < T_i < 15 \) (i \( \in \mathbb{K} \)), the saturation prediction matrix \( S \) can be calculated by interpolation method.

\[
S = \begin{pmatrix}
S_{11} & S_{12} & S_{13} \\
S_{21} & S_{22} & S_{23} \\
S_{31} & S_{32} & S_{33}
\end{pmatrix} = \begin{pmatrix}
0.477 & 0.539 & 0.820 \\
0.474 & 0.538 & 0.823 \\
0.474 & 0.538 & 0.823
\end{pmatrix}
\]  \hspace{1cm} (13)

According to equation (8), the probability matrix \( P \) of choosing other parking lots can be calculated, when there is no parking space in the candidate parking lot.

\[
P = \begin{pmatrix}
P_{11} & P_{12} & P_{13} \\
P_{21} & P_{22} & P_{23} \\
P_{31} & P_{32} & P_{33}
\end{pmatrix} = \begin{pmatrix}
0.000 & 0.636 & 0.364 \\
0.660 & 0.000 & 0.340 \\
0.506 & 0.494 & 0.000
\end{pmatrix}
\]  \hspace{1cm} (14)

5.4. Parking fee

The fee standards of the candidate parking lots are shown in table 6 through investigation.

| Parking lot | Fee standards |
|-------------|---------------|
| \( A_1 \)   | Free within 20 minutes; more than 20 minutes, 5 yuan per hour; less than one hour is charged by one hour. |
| \( A_2 \)   | Free within 20 minutes; more than 20 minutes, 5 yuan per hour; less than one hour is charged by one hour. |
| \( A_3 \)   | Free within 15 minutes; more than 15 minutes, 5 yuan per hour; less than one hour is charged by one hour. |

If the estimated parking time is set as 2 hours, the parking fee matrix \( C_F \) of the driver in each candidate parking lot can be calculated according to the fee standards in table 6.

\[
C_F = (C_{F1}, C_{F2}, C_{F3}) = (10, 10, 10)
\]  \hspace{1cm} (15)

5.5. Walking time

By Baidu Map APP, the minimum walking time matrix \( T_W \) of each candidate parking lot to the destination China Telecom Building can be calculated.
8

\[ T_w = (T_{w1}, T_{w2}, T_{w3}) = (5, 3, 2) \] (16)

5.6. Determine the optimal parking lot

The generalized parking costs from origin to the candidate parking lots can be calculated by the mathematical model (12), as shown in Table 7.

Table 7. The generalized parking costs to the candidate parking lots (yuan).

| Parking lot | \( C_{Ti} \) | \( C_{Fi} \) | \( C_{Si} \) | \( C_{Wi} \) | \( C_i \) |
|-------------|-------------|-------------|-------------|-------------|-------------|
| \( A_1 \)   | 10.377      | 10.000      | 1.315       | 3.991       | 25.683      |
| \( A_2 \)   | 8.780       | 10.000      | 1.443       | 2.395       | 22.618      |
| \( A_3 \)   | 8.780       | 10.000      | 2.310       | 1.596       | 22.687      |

As can be seen from Table 7, although \( C_{W2} \) (2.395 yuan) is 0.799 more than \( C_{W3} \) (1.596 yuan), \( C_{S2} \) (1.443 yuan) is 0.867 less than \( C_{S3} \) (2.310 yuan), that is, the risk cost of secondary parking to \( A \) parking lot is less. After combining the minimum travel time cost, parking fee, secondary parking cost and walking time cost, the generalized parking cost \( C_2 \) of the parking lot \( A_2 \) is the smallest, which is 22.618 yuan. Therefore, \( A_2 \), the underground parking lot of Dongbai Group, is the optimal parking lot. According to Table 2, the minimum travel time path from origin \( O \) to \( A_2 \) is from \( O \), Fuzhou Education Institute Subsidiary Middle School, to Wu Shan Road, then to Ba Yi Qi Road and finally to \( A_2 \).

6. Conclusion

In this paper, an optimal parking lot selection model with minimum generalized parking cost is build, which takes the parking saturation into account. The validity of the model is verified by an example calculation. The application of the model can improve the probability of successful parking of the selected target parking lot, alleviate the difficulty of parking, reduce the secondary parking flow and alleviate traffic congestion.

References

[1] Yu, C.Q. (2016) Research on underground parking behavior characteristics of Fuzhou commercial center. Journal of Hunan City University (Natural Science Edition). 26, 3:48-50.
[2] Luo, L.X. (2005) Study on the Impact of Parking Charge. Southwest Jiaotong University. 44-46.
[3] Chen, J. (2007) Urban Parking Facilities Planning Methods and Information Guidance Technology. Southeast University Press, Nanjing.
[4] Lu, H.P. (2006) Traffic Planning Theories and Methods. Tsinghua University Press, Beijing.
[5] Hongzhi Guan. (2004) Disaggregate Model--A Tool for Traffic Behavior Analysis. People's Communications Press, Beijing.
[6] Wang, W., Xu, J.Q., Yang, T. (1998) Urban Traffic Planning Theory and Its Application. Southeast University Press, Nanjing.
[7] Pan, G.Q., Cheng, Y.H. (2018) Parking Demand Forecast of Small and Medium-sized Cities Based on BP Neural Network. Highway and Automobile Transportation. 4: 26-36.
[8] Zhang, D.F. (2011) MATLAB Neural Network Programming. Chemical Industry Press, Beijing.