Research on pricing strategy in urban parking management

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Abstract. At present, many cities in China have a serious shortage of parking spaces, and it is necessary to find ways to alleviate this problem, including ways to make full use of limited parking resources, such as formulating dynamic pricing strategies. In this paper, the roadside parking with high turnover rate and high mobility in static traffic is selected as the research object. The classic bottleneck model is used to establish the roadside parking bottleneck model (OSPB) to study the dynamic pricing of roadside parking stations during peak hours. Based on the model comprehensively considering the time when the vehicle arrives at the parking station, the geographic location of the station and many other factors, the dynamic charging problem of roadside parking stations during peak parking hours is studied to improve the efficiency of parking space utilization. This model expands the application of the bottleneck model in static traffic, and in practice uses a large amount of historical parking data to verify the model.

1. Introduction
China's car ownership has grown very rapidly. The growth rate of parking berths is slower than the growth rate of car, which cause most large-sized and medium-sized cities face a high parking demand with a few parking berth problem.

In order to solve this problem, many scholars tried to find a solution from both the perspective of meeting existing parking demand and reducing parking demand. Merriman believes that it’s worth to increase parking spaces on both sides of road in term of insufficient parking spaces near the Chicago train station. Lin Yonghua proposed the idea of establishing a Stereo garage to increase parking spaces. Fabusuyi et al. changed the parking rate to affect the demand of parking spaces by calculating the price elasticity of parking demand. Jos N et al. tried to find the factors affecting the length of the cruising time, they found that the length of the parking time and driving time were positively correlated with the length of the cruising, driver's income was negatively correlated with the length of the cruising.

This paper tries to establish a “on-street parking model” with reference to the “Bottleneck model”, aims to find out a new charging strategy for the parking which integrate arrive time of the car and the location of the parking lot together. The new charging strategy is expected to maximize social benefits through reduce or eliminate cruising time during peak hours, and let more travelers to park in off-street parking lots or use public transportation.

2. Model establishment

2.1. Classic Bottleneck model
The basic model of this paper refers to the classic bottleneck model proposed by Vickrey, the schematic diagram of the model is shown in Figure 1. It is assumed that there is a highway (OD)
connecting the living area and the working area, the commuters work through this road every morning. Queuing is inevitable due to the limited capacity of the road section B, some people set off early in order to arrive at the destination on time, and they arrived early the best arrival time, some people set off later, because the queued at the bottleneck that they arrived later than the best time. We definite early arrived time and later time as delay time cost. By establishing a model, the traveler's delay time cost is converted into road charges, and the queuing at the bottleneck would reduced or eliminated.

![Figure 1. Classic bottleneck model icon.](image)

If we replaced the capacity of the bottleneck section in dynamic traffic by the capacity of the road parking lot, replaced the queue waiting time by cruising time on the street, we can expand out the “on-street parking model” from the Bottleneck model.

### 2.2. On-street parking model

This paper committed to research the parking behavior of drivers who eventually park their cars on the street. We definite early arrived time and later time as delay time cost. The unit time parking cost is calculated from the moment when the driver generates the parking intention. The model’s symbols are listed in Table 1, set $0 < \beta < \alpha < \gamma$.

**Table 1. Symbols used in the model.**

| Symbol | Significance                                      | Symbol | Significance                                      |
|--------|---------------------------------------------------|--------|---------------------------------------------------|
| $\alpha$ | The unit time cost of cruising on street         | $S$    | The total number of parking spaces                |
| $\beta$ | The time cost of early arrival                    | $C$    | The unit time parking fee in equilibrium          |
| $\gamma$ | The unit time cost of early arrival               | $t_0$  | Earliest arrival time                             |
| $t$   | The arrive time                                   | $t_e$  | Latest arrival time                               |
| $T(t)$ | The length of time for cruising at time $t$ arrives | $t^*$  | The ideal time entering parking lot               |
| $C(t)$ | The total unit cost of parking at time $t$ arrives | $t_n$  | The ideal arrival time                            |
| $D(t)$ | Number of cars cruising on the street             | $p$    | Parking lot original unit time cost               |
| $r_0(t)$ | The number of vehicles entering the parking lot at time $t$ varies with time | $\tau$  | The length of parking time                        |
| $r_1(t)$ | The number of vehicles leaving at time $t$ varies with time | $\bar{\tau}$ | Average parking time                             |
| $r_2(t)$ | The number of vehicles leaving at time $t$ varies with time | $|t|$  | The peak period of parking                        |

The assumptions of the model as follows:

1. During the entire peak period of parking, the parking station operates at full capacity every hour, ignoring the situation that the parking space is less than one hour free.
2. Charging has not changed the peak period of parking, the cost of the system's master plan delay time remains unchanged, but the total time to find a parking space is the shortest.
3. Assuming that the urban area is spatially isotropic and stable, the driver's destination is evenly distributed on both sides of the road. It is believed that with the help of the parking guidance system, the information is clear enough, the driver is rational enough and can choose the parking space with the smallest walking distance from the destination, so the walking cost is negligible.

From a driver generates the parking intention to completing the parking and leaving the parking lot, the driver's unit time parking cost $C(t)$ in the whole process can be expressed as:

$$C(t) = C_1(t) + C_2(t) + C_3(t)$$

(1)
C(t) is the time cost of cruising, C2(t) is the unit time charge of the parking lot, C3(t) is the delay time cost. At time t, the cruising number D(t) is equal to the number of cars arriving minus the number of cars that have left and the number of cars that parking at the parking lot, thus D(t) can be expressed as:

$$D(t) = \int_{t}^{\infty} [r_u(u) - n_u(u)] du$$  \hspace{1cm} (2)

Cruising time function T(t) is given by:

$$T(t) = \frac{D(t)}{S}$$  \hspace{1cm} (3)

Assuming that the driver generate a parking intention at time t, the early arrival won’t late, so late time is 0, early time is t - T(t); the late arrival won’t early, so early time is 0, and the late time is t + T(t) - t; the driver who arrived at time tn meets: t + T(tn) = t. Therefore, the unit time parking cost of the earliest arriving driver can be expressed as:

$$C(t_n) = \beta \times (t - t_0) + T(t_n) + p$$  \hspace{1cm} (4)

The parking cost per unit time of the latest arriving parking person is:

$$C(t_e) = \gamma \times (t_e - t) + T(t_e) + p$$  \hspace{1cm} (5)

The unit time parking cost for a parking person arriving on time can be expressed as:

$$C(t) = T(t - t_0) + p$$  \hspace{1cm} (6)

It is known from experience that the earliest arrival and the latest arrival of the drivers’ cruising time is 0, that mean T(t_n) = T(t_e) = 0, according to the definition of t_n and the assumption of the parking cost that C(t_n) = C(t_e) = C, combine (4), (5), (6) and we will get the follow:

$$t_0 = \frac{t - \frac{p}{\beta + \gamma}}{\beta + \gamma}$$  \hspace{1cm} (7)

If we let t* as the segmentation point of time, the driver's parking cost function is:

$$C(t) = \begin{cases} \alpha T(t) + \beta (t^* - T(t)) + p & t + T(t) < t^* \\ \alpha T(t) + \gamma (t + T(t) - t^*) + p & t + T(t) > t^* \end{cases}$$  \hspace{1cm} (9)

Combine(7), (9), T(t) can be expressed as:

$$T(t) = \begin{cases} \frac{\beta}{\alpha + \beta} (t - t_0) & t \in [t_0, t_1] \\ \frac{\gamma}{\alpha + \gamma} (t - t_e) & t \in (t_e, t_2] \end{cases}$$  \hspace{1cm} (10)

From (3), D(t) can be expressed as:

$$D(t) = \frac{S \cdot T(t)}{T}$$  \hspace{1cm} (11)
Combine (2), (9), (10), (11), let each segments of the piecewise function’s first derivative be zero separately, the arrival rate function can be calculated as:

\[
\lambda(t) = \begin{cases} 
\frac{s_0}{r(a-b)} & t \in [0, t_1] \\
\frac{s_2}{r(a+\gamma)} & t \in (t_1, t_2] 
\end{cases}
\]  

After the arrival rate function is derived, a dynamic charging method for the integrated time and location can also get. As mentioned in the introduction, parking demand decreases as parking fees increase, if the newly established pricing strategy charging higher when the number of arriving cars is large, and charging lower when the number of arriving cars is small, which will effectively reduce the parking demand. Let \( P(t) \) as the charging function of the parking lot, the unit of \( t \) is hour. Combined parking time and the location of parking lot together, the new parking fee can be expressed as:

\[
P(t) = \mu \cdot r(t) + \omega \cdot p
\]  

The price of on-street parking that calculated by the model will increase during peak hours, which will lead some drivers drive off the road to off-street parking lots or choose public vehicles. The increase cars of off-street parking won’t cause it price increases because the relationship of competition. The cruising vehicles will reduce effectively if the city manager uses this model when pricing the on-street parking lot, which will promote the development of public transportation.

3. Conclusion
The model results show that the dynamic charging at the peak period can reduce the parking demand of the road to a certain extent, and encourage more travelers to choose off-street parking or choose public transportation to ease the shortage of parking spaces in the city. By changing the locating time function and the lot charging standard, the pricing strategy obtained by the model can be applied to different cities. The model converts the time cost of finding the pure loss of the parking space into the dynamic income of the parking lot, and maximizes the social benefits.

This article discusses a part of static traffic from the road parking. It is expected to reduce the on-street cruise vehicles through dynamic toll, guide some drivers to leave the road and park at the off-street parking lot. In the future, we can study how to combine dynamic traffic and static traffic together to find a relative balance point of dynamic and static traffic, and model the entire travel stop process.

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