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Curb parking pricing method based on parking choice behavior

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Abstract: In order to improve the use efficiency of curb parking, a reasonable curb parking pricing is evaluated by considering individual parking choice behavior. The parking choice behavior is analyzed from micro-aspects, and the choice behavior utility function is established combining trip time, search time, waiting time, access time and parking fee. By the utility function, a probit-based parking choice behavior model is constructed. On the basis of these, the curb parking pricing model is deduced by considering the constrained conditions, and an incremental assignment algorithm of the model is also designed. Finally, the model is applied to the parking planning of Tongling city. It is pointed out that the average parking time of curb parking decreases 34%, and the average turnover rate increases 67% under the computed parking price system. The results show that the model can optimize the utilization of static traffic facilities.

Key words: curb parking; parking choice behavior; utility function; incremental assignment

Parking plays an important role in the traffic system since all vehicles require a storage location when they are not being used to transport passengers. Due to the inherent uncertainty associated with many of the attributes of public car parks, including availability and location, a high proportion of vehicles traveling within central city areas must search for a car park. Unreasonable curb parking pricing will cause an unreasonable distribution of parking vehicles. Motorists take lots of time to search for an unoccupied parking space. Parking problems accelerate the crowding of traffic and the deterioration of environmental quality in the central city. Hence, the parking pricing affecting a parking choice model and a reasonable curb parking pricing model is becoming a hotspot in the traffic field. Since Hunt first brought forward the parking choice model, the parking choice behavior model has been analyzed from parking generalized cost and parking impendence. These models can depict the parking choice behavior exactly, but cannot reflect the relationship between the parking fee and the parking choice behavior[1-3]. And the parking pricing model is constructed from macro-aspects, such as the bi-level programming model presented by An Shi, et al. with the limitation that the model cannot depict the relationship between the parking pricing and the parking choice behavior from micro-aspects[4]. Based on these, the curb parking pricing model is constructed by analyzing the parking choice and considering the constrained conditions from micro-aspects. And the incremental assignment algorithm of the model is designed.

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1 Parking Search Process

Parking choice can be considered as a search process, where drivers make a number of linked decisions based on updated knowledge gained from experience. This process consists of various stages, based on a series of decisions (see Fig. 1). Motorists examine individual car parks sequentially as they move within an urban centre. After an alternative is inspected, motorists can either select it or continue to search by traveling to another car park. The process is initiated when the first search begins. Once searching has begun, the process of inspecting and evaluating car parks commences. The decision of whether or not to accept a current car park determines if the current search is terminated or continues. After parking, the process continues when the next search is undertaken.

The decision of whether to accept the present car park determines the length of a search. If a car park is

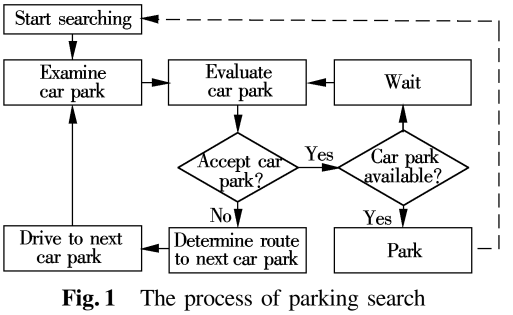

Fig. 1 The process of parking search

accepted and a space is available, the current search is terminated. This is usually well before all the feasible alternatives have been inspected. If the present alternative is rejected, search continues. This generally involves moving to a new traffic link by choosing a turning movement. The turning movement selected usually determines the next car park encountered.

2 Parking Choice Model

2.1 Parking choice utility

From a microeconomic aspect, motorists' choices are decided by the utility of the park. Motorists usually choose the park with the maximal utility. The utility correlates with the time cost and expense[5], among which, the time taken includes travel time T_m, search time T_s, waiting time T_w, and egress time T_a. The expense p is associated with park fee (see Fig. 2). Travel time includes in-vehicle travel time from the vehicles' current location to the car park as well as the time spent searching within the car park for a space. Park search time refers to the average time cost in searching for a park. Waiting time is incurred when motorists have to queue at a car park before entering a car park. Egress time depends on the walking time from the car park to the destination. The expense is related to the park, so it depends on the parking fee and the expected parking time. Time cost can be exchanged into fee cost through multiplying the time cost by the corresponding year's per person national income. Parking expense can be expressed as

$$U(T_m, T_s, T_w, T_a, p) = \alpha T_m + \beta T_s + \gamma T_w + \mu T_a + \omega p(t) + \tau_i \quad (1)$$

where $\alpha, \beta, \gamma, \mu, \omega, \tau_i$ are the utility parameters, which can be acquired by practical survey.

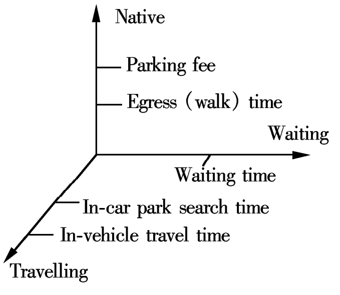

Fig. 2 Three generalized cost dimensions

1) Vehicle travel time T_m

The whole vehicle travel time includes the in-vehicle time travelling from the current position to park and the park space search time within the park. The distance between the current position and the park can be evaluated as the minimum travel time path between the current link and the link adjacent to the car park. The vehicles' average speed is associated with road impedance function, which can be calculated by the use of the BPR function. The park space search time within a park correlates with the property of the park, and the curb park space search time is usually less than off-street park space search time. The park search time within a park can be obtained by the practical survey. Therefore, the vehicle travel time can be expressed as

$$T_m = \frac{L_m}{v_m} + s_i \quad (2)$$

where L_m is the distance between the current link and the link adjacent to the car park, v_m is the vehicles' average speed, and s_i is the average park search time.

2) Parking search time T_s

The parking search time is the circumambulation time because of the unfamiliarity, and it can be evaluated with the average circumambulation distance and the average speed. The average circumambulation distance depends on the parking guidance information system, and also can be obtained from the practical survey. Therefore, the park search time can be expressed as

$$T_s = \frac{l_s}{v_s} \quad (3)$$

where l_s is the vehicle average circumambulation distance, and v_s is the average circumambulation speed.

3) Parking waiting time T_w

The parking waiting time only occurs in off-street park. Off-street parking waiting time includes waiting time, accepting service time and vehicle park time. Because the latter two factors have less difference between different off-street parks, the average queue waiting time of the k park can be obtained on the assumption that each park's accepting service time and vehicle park time remain the same[6]. The parking waiting time can be expressed as

$$T_w = \frac{(a_{wk} - c_k)^2 t_{ek}}{2 c_k a_{wk}} \quad (4)$$

where T_w is the parking waiting time, a_{wk} is the maximal parking spaces of park k, t_{ek} is the average parking time of park k, and c_k is the capacity of park k.

4) Egress time T_a

The egress time is the walking time from the car park to the final destination, which can be calculated according to the average distance from the car park to the destination and the average walking travel speed.

$$T_a = \frac{l_a}{v_a} \quad (5)$$

where l_a is the distance from the car park to the destination, and v_a is the average walking travel speed.

2.2 Parking choice model establishment

The motorists' choice behaviors are various, but they always prefer to choose the car park with maximal utility. Considering the car park distribution ecumenical situation from a probability aspect, the car park with minimal vehicle travel time, definite car park orientation, convenient parking facilities and closer distance from the car park to the destination can attract more passengers. On the other hand, the parking fee standard affects the passengers' choice of car park (see Fig. 3). Thus the user (passenger) equilibrium concept in vehicle parking is different from the user (vehicle) equilibrium concept in common road network. The latter reflects the equilibrium in travel time, the travel time varies with the degree of road congestion. The former reflects the equilibrium of parking choice under the control of parking fee besides the equilibrium of travel time and parking/waiting time, because the congestion degree has less influence on travel time.

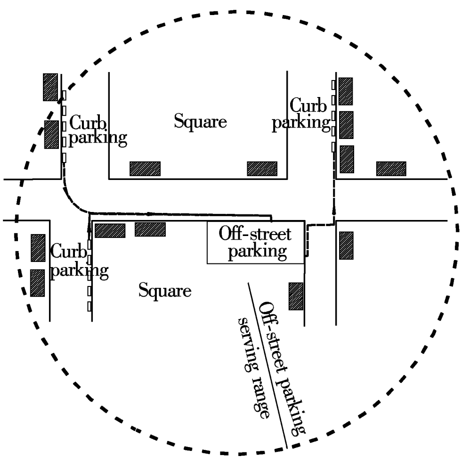

Fig. 3 Sketch map of parking choice behavior between curb parking and off-street parking

The parking choice model is brought forward based on the following reasons: Provided a group of passengers are sent out from origination r to destination d, there are n car parks around destination d. Because of the passengers' incomplete familiarity with the situation of the network and some factors being difficult to quantify, the estimation of the passengers to path impendence is a random variable. The distributing model is to calculate the number of motorists choosing each car park on the basis of studying parking choice distributing function[7].

The parking choice behavior model is constructed as

$$\left.\begin{aligned} P(k,i,j) &= \frac{\exp(aU_k(T_m,T_s,T_w,T_a,p)/\overline{U})}{\sum_{h=1}^{n}\exp(aU_h(T_m,T_s,T_w,T_a,p)/\overline{U})} \\ V(k,i,j) &= V(i,j)P(k,i,j) \end{aligned}\right\} \tag{6}$$

where $P(k,i,j)$ is the distributing rate of parking demand $V(i,j)$ in the valid car park k, $U_k(T_m,T_s,T_w,T_a,p)$ is the utility function of the valid car park k, $\overline{U}$ is the average utility of each valid car park, a is the distributing parameter, n is the number of valid car parks, and $V(k,i,j)$ is the distribution of parking demand $V(i,j)$ in the valid car park k.

3 Curb Parking Pricing Model

When a parking choice is made in the parking system formed by curb parking and off-street parking, the following two restrictions should be considered:

1) In order to ensure the high efficiency of each car park and improve the efficiency of the whole parking facilities, the status of curb parking being crowded and off-street parking being empty should be avoided. The curb parking should reserve a few empty spaces to satisfy short-time parking demand under common situations[8].

2) Curb parking and off-street parking provide services for the parking vehicles with different properties separately. The short-time parking makes use of curb parking and the long-time parking makes use of off-street parking[9].

In considering the parking choice behavior model and the constrained conditions, and on the assumption that car park k is an off-street park and car park $k+1$ is curb parking, the curb parking pricing model is established as follows:

$$\left.\begin{aligned} P(k,i,j) &= \frac{\exp(aU_k(T_m,T_s,T_w,T_a,p)/\overline{U})}{\sum_{h=1}^{m}\exp(aU_k(T_m,T_s,T_w,T_a,p)/\overline{U})} \\ V(k,i,j) &= V(i,j)P(k,i,j) \\ 0 &< \frac{V(k,i,j)}{C_k} \leqslant C_0 \leqslant 1 \\ U_k(T_m,T_s,T_w,T_a,p) &- U_{k+1}(T_m,T_s,T_w,T_a,p) \geqslant 0 \\ &t \geqslant t_{\max} \\ U_k(T_m,T_s,T_w,T_a,\mathrm{p}) &- U_{k+1}(T_m,T_s,T_w,T_a,p) \leqslant 0 \\ &t \leqslant t_{\max} \\ 0 &\leqslant P(k,i,j) \leqslant 1 \end{aligned}\right\} \tag{7}$$

where C_k is the parking space capacity of curb park k; C_0 is the saturation coefficient of curb park k, usually adopts $C_0 \leqslant 0.9$; $U_{k+1}(T_m,T_s,T_w,T_a,p)$ is off-street park $k+1$ utility value around curb park; t is the parking time; $t_{\max}$ is the curb parking time threshold (big cities adopt 1.5 h, medium or small cities adopt 2.0 h[10]), if it exceeds the threshold, prior to choosing off-street parking. Other denotations' meanings are as previous.

4 An Algorithm

Through considering the model's characteristics, this model is a probit-based distribution problem which contains parking choice problems first. At the same time the distribution results are confined by constrained conditions. So the model can be resolved with the use of the following algorithm.

① Initialization: establish the entire park's geometry information table.

② Define the curb parking at an original price, and then calculate the off-street park parking fee. When $t \geqslant t_{\max}$, check whether $U_k(T_m, T_s, T_w, T_a, p) - U_{k+1}(T_m, T_s, T_w, T_a, p) \geqslant 0$. If not, the curb parking pricing should be improved to satisfy the conditions. If the condition is satisfied, then check whether $U_k(T_m, T_s, T_w, T_a, p) - U_{k+1}(T_m, T_s, T_w, T_a, p) \leqslant 0$, if not, the curb parking pricing is too high, the curb parking pricing should be reduced to meet the conditions. If the conditions are met, the parking choice distribution begins.

③ Decompose the parking demand table into N parking demand tables. The course is processed using the following formulae:

$$\left.\begin{aligned} [q_{rs}^k]_{n\times n} &= [f_k q_{rs}]_{n\times n} \\ f_k &= \frac{k}{\sum_{i=1}^{N} i} = \frac{2k}{(1+N)N} \\ N &= \left|\frac{C_{\max}}{C_{\min}}\right| \\ \sum_{k=1}^{N} f_k &= 1 \end{aligned}\right\} \quad (8)$$

where $C_{\max}$, $C_{\min}$ are the maximal and minimal park capacities of the area of study, respectively; $[q_{rs}^k]_{n\times n}$ is the assigned parking demand in distribution k; f_k is the distribution proportion in distribution k.

④ Assign one parking demand table with the use of the multi-route probit-based loading model.

⑤ Recalculate every park's parking utility after each parking demand table has been assigned. Then check whether $0 < V(k, i, j)/C_k \leqslant C_0 \leqslant 1$ and when $t \geqslant t_{\max}$, whether $U_k(T_m, T_s, T_w, T_a, p) - U_{k+1}(T_m, T_s, T_w, T_a, p) \geqslant 0$. If not, the curb parking pricing needs to be improved to restart assignment according to steps ②, ③ and ④. If it satisfies the qualifications, carry on through the next parking demand table assignment.

⑥ Examine whether the entire parking demand table has been assigned completely, "no" to return step ③, and "yes" to finish the whole assignment. Here the curb parking price p_{ti} is the reasonable result.

5 Instance Applications

Take the fifth section in the center of Tongling city as a planning area to process instance application. The topology relations and present parking facilities are shown in Fig. 4. Suppose that there is a curb parking in the study area, and the No. 20 off-street park is nearby, evaluate the reasonable curb parking pricing. The capacity of the curb park is 30 and the capacity of No. 20 off-street park is 50. The parking demand in the study area is 100 vec/h.

The diameter of the study area is 500 m, and the average design parking time is 1 h. Measure the parameters according to the survey data, and carry on through

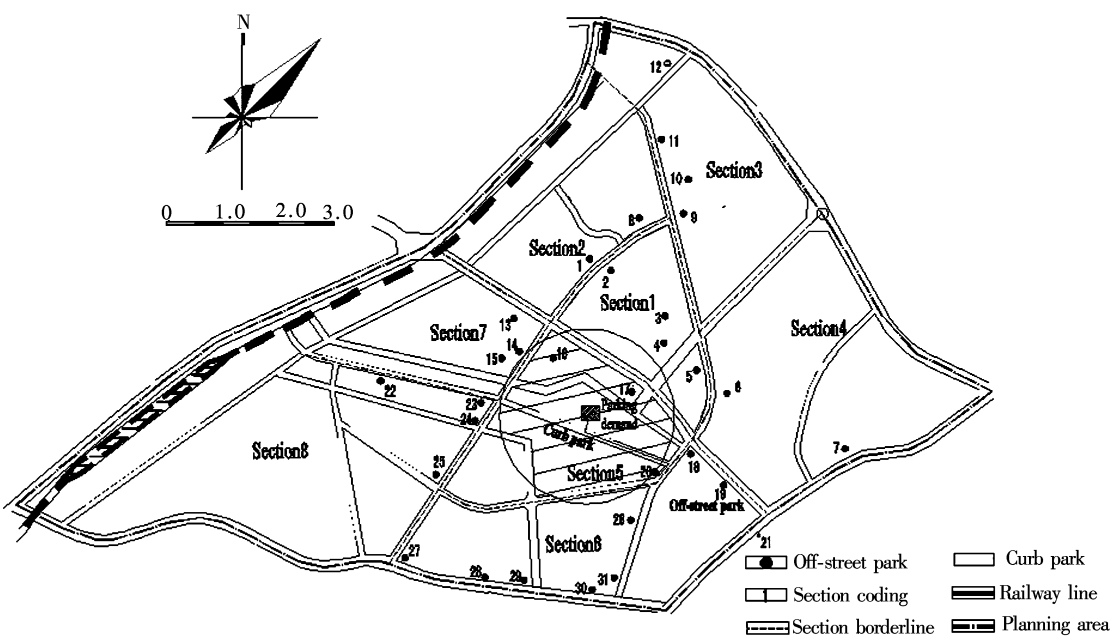

Fig. 4 Reasonable curb parking pricing example sketch map

the computation according to the instance's idiographic scheme and the model algorithm. The results are shown in Tab. 1.

Tab. 1 Computation results of reasonable curb parking pricing

Parameters	Average velocity of curb parking/(vec·h^{-1})	Curb parking saturation	Curb parking reasonable price/(yuan·h^{-1})
Result	3.5	0.9	5

Through the field survey, the average velocity of curb parking is 2.1 vec/h and the curb park saturation exceeds 95% according to the present price system in Tongling city. When the curb parking pricing is changed to the optimal results, the average parking time of curb parking decreases 34% and the average velocity of curb parking increases 67%. It shows that the utilization of parking facilities has been optimized and the model can provide a strong theory and technical support for the planning scheme.

6 Conclusion

By analyzing vehicle parking choice behavior from a micro-view, this paper evaluates the present parking choice combined with the motorists' trip costs, native costs and waiting costs. On the basis of these, the motorists' probit-based choosing model is established. The curb parking pricing model is constructed considering the parking choice restraints, and then the algorithm of the model is analyzed. Finally, the instance of the curb parking pricing model is given. The instance indicates that the model can insure practicability and reliability. Due to the complexity of the parking system constituted by curb parking and off-street parking, the more comprehensive factors in the parking choice model should be considered in future research.

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基于停车选择行为的路内停车定价方法

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摘要: 为了提高整个城市停车场的使用效率,在考虑个体停车选择行为的基础上,确定合理的路内停车定价. 采用微观上分析车辆停放的选择过程,结合车辆停放者的行程时间、停车场搜索时间、停车等待时间、出口时间和停车场自身费用建立当前停车场的选择效用函数,通过效用函数建立了车辆停放者的概率选择模型,通过考虑停车选择的约束条件,在提高整个停车设施使用效率的前提下建立路内停车定价模型,并设计了容量加载方法作为求解模型的算法. 通过铜陵市实例验证,计算的停车价格体系使路内停车平均停放时间降低了34%,周转率提高了67%,结果显示该模型能有效优化静态交通设施资源的利用.

关键词: 路内停车;停放选择;效用函数;容量加载
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