MODELING THE COMBINED CHOICE OF ENTRANCE AND PARKING IN ENCLOSED BUSINESS AREAS

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ABSTRACT

This paper described a study concerning car drivers' entrance and parking choice in the context of business areas. For employees of the Eindhoven University of Technology a combined entrance and parking choice model is presented. It appears that the most optimal structure of the nested logit model consists of entrance choice at the highest level and parking choice at the lowest level. With a McFaddens' pseudo R-squared value of 0.336 the model performs quite well. The choice of entrance is significantly influenced by the distance between entrance and workplace, location of the entrance vis-à-vis the workplace, and the direction when leaving the campus area. The choice of parking is significantly influenced by the number of parking spaces, the available type of vegetation surrounding the parking, the distance between entrance and parking, and the distance between parking and workplace. All effects are as expected.

Keywords: Parking, entrance, Business areas, nested logit

INTRODUCTION

To fulfill modern business requirements many business areas are currently redeveloped. This also holds for university campus areas. Existing buildings are demolished or renewed and new buildings are constructed. Changes in area layout and building content might change the use of surrounding infrastructure in business areas. The infrastructure consists of both roads and parking facilities. When the workplace of a car driver changes the car driver might change his/her entrance and/or parking choice. In addition, the car driver might use a new route between entrance and parking resulting in changed traffic flows across the business area. In the past, little attention has been paid to changes in the distribution of cars across available roads and parking facilities especially when it concerns business areas.

The paper describes a model that can be used to asses the effects of planning measures on car drivers' combined choice of entrance and parking. The research question that is addressed in this paper is: *'What characteristics of the car driver, entrance and parking facilities influence a car driver's entrance and parking choice in the context of business areas?'* The model is an extension of a model earlier presented by Van der Waerden *et al* (2008). The extension consisted of the inclusion of the entrance choice and on-street parking facilities in the model.

The model is developed for the campus of the Eindhoven University of Technology (Figure 1). A variety of organizations is located on the campus including the university, a college, several research institutes and some private consultancies. The campus is an enclosed business area that can be entered through three different entrances. After entering the area, cars can be parked at one of 16 parking lots or along the roads in one of the 11 parking zones. The university board approved in 2004 a renewal plan of the campus called campus 2020. The plan includes both renewal of buildings and the construction of several new buildings. Also several changes in the road infrastructure and parking facilities are suggested such as closure of roads and extension of parking facilities.

The remainder of the paper is organized as follows. First, attention is paid to studies concerning parking choice behavior of car drivers. Next the adopted research approach is explained followed by a brief description of the data collection.

Figure 1 - Parking facilities at the campus of the Eindhoven University of Technology

PARKING CHOICE

Most previous parking studies focus on the influence of parking on various travel choices such as mode, destination, and route choice (e.g., Marsden, 2006). In the context of business areas little attention is paid to the distribution of arriving cars across available parking facilities. Two different approaches are adopted when studying the distribution of cars across available parking facilities. The first approach focuses on the supply of parking based on existing land use (e.g., Brown-West, 1996; Chui, 2005). The second approach focuses on the demand for a certain type of parking facility (e.g., Hess and Polak, 2004) or specific parking locations (e.g., Van der Waerden *et al*, 2008).

Car drivers' parking choice behavior consists of the search process of a car driver for an optimal parking facility out of a set of available parking facilities. In the past various studies on parking choice behavior are presented (e.g. Van der Goot, 1982; Hunt and Teply, 1993; Thompson and Richardson, 1998; Arnott and Rowse, 1999). Parking facilities were defined in terms of physical characteristics that are together with travel characteristics used to calculate the utility of the available parking facilities. Examples of investigated physical characteristics are capacity, fee rate, type, and duration limits.

Recently, Ji *et al* (2007) presented a two-phased model for parking choice behavior in combination with route choice behavior. In their study, they found that five important factors affect car drivers' parking choice: walking distance from parking to final destination, type of parking facility (e.g., underground parking, multilayer parking, curb parking, and off-road parking), parking fee, available parking spaces, and driving time. In the model, they only include walking distance to final destination and number of available parking spaces. The model was specified in the context of commercial areas.

Lam *et al* (2006) present a time-dependent network equilibrium model that simultaneously considers a traveler's choice of departure time, route, parking location, and parking duration in road networks with multiple user classes and multiple parking facilities. They found that parking behavior is significantly affected by travel demand, walking distance, parking capacity, and parking charge. In a numerical study, Lam *et al* (2006) found some differences in the usage of parking facilities (duration, turnover, occupancy, and revenues) between static and time-dependent models. More research is needed to explore these differences.

Harmatuck (2007) presented a parking location choice model for the campus of the University of Wisconsin-Madison. The parking choices are extracted from employees' preference lists. To apply for a parking permit, employees have to rank four parking facilities. In most cases the highest ranked parking location will be offered to the employee. Therefore, the highest ranked parking facility is considered as parking choice that is related to the variables prices, distance, priority index, and capacity. The study of Harmatuck shows that all investigated variables significantly influence the employees' parking choice behavior.

RESEARCH APPROACH

On request of the University board Van der Waerden *et al* (2008) started in 2004 a study on parking choice behavior at the university campus. The first step in the study was the development of a simple parking choice model. The developed model related the choice of a parking facility to several physical characteristics of the parking facility, the location of the most used area entrance, and the distance between parking and the workplace of the car driver. The model only included parking lots. It appears that the choice of parking facility depends on its size, the presence of maneuver space, the right-of-way when leaving the parking, and the location vis-à-vis the workplace. The next step of the study was to include on-street parking facilities (Figure 2), the choice of entrance in the model, and to test additional of characteristics the parking facilities. To achieve this goal a new study was set up in 2008.

Figure 2 - On-street parking at the university campus

To get insight into car drivers' combined entrance and parking choice behavior the following research approach is adopted. First, an internet based questionnaire was developed concerning car drivers' travel behavior. The questionnaire consisted of questions regarding car drivers' entrance and parking choice, work place, and residential location. Car drivers can use one of the three entrances of the campus area: West, South, and East. Next, the car driver can choose to park the car at one of the 16 parking lots (see Figure 3, coding A until S), or along the roads. All on-street parking spaces are grouped into 11 so-called parking zones. The questionnaire was supplemented by questions concerning the car drivers' current parking behavior (arrival time, parking duration), adaptive parking choice, and evaluation of the parking situation.

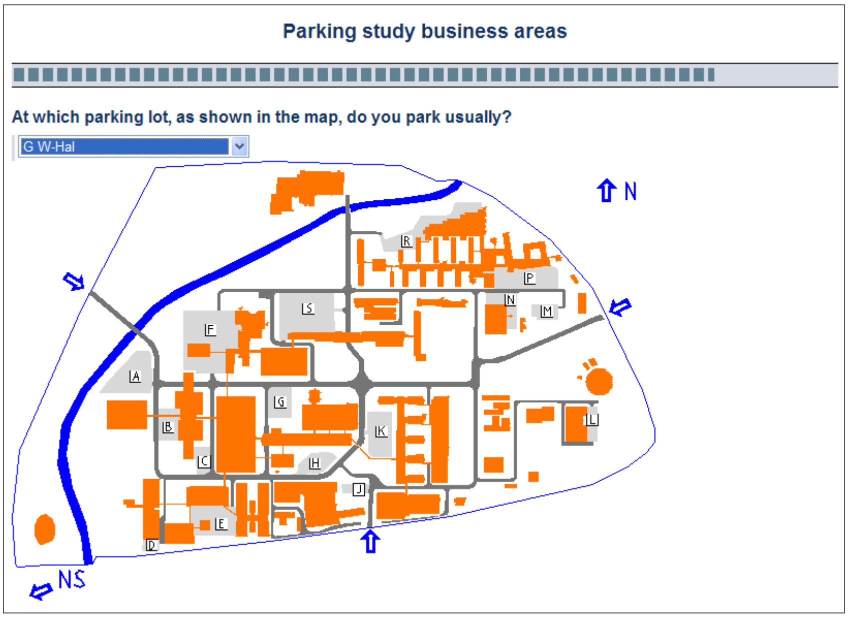

Figure 3 - Part of the internet based questionnaire, parking lots

Table 1 - Characteristics of entrances and parking facilities

Characteristics	*Levels*
Entrances	
Location vis-à-vis residential location	Positive, negative
Possible directions when leaving	Extensive, limited
Parking facilities	
Number of parking spaces	Actual number of spaces
Number of exits	Actual number of entrances/exits
Type of marking	No; continuous lines; dotted lines; lines created by colored
Presence of parking strips	bricks
Presence of trees	No; yes
Presence of vegetation	No; broad-leaved tree; conifer
Right of give away when leaving	No; bushes; grass
parking	No; yes
Smoothness of pavement	No; yes
Type of pavement	Cobblestones; asphalt; other
Presence of lighting	No; yes with protection; yes without protection
Presence of ticket machine	No; yes
Presence of barriers	No; yes
Presence of bicycle stand	No; yes
Size of parking spaces	Standard size; not standard size
Presence of extra space for	No; yes
maneuver	No; yes
Presence of footpaths	No; yes
Sight from the road	On-street; parking space; combined
Type of parking	Parallel; angle; mixed
Direction of parking	No; yes
One-way traffic	

Next, a nested logit model was selected to describe the combined entrance and parking choice behavior. The model relates the combined choice to various physical characteristics of the entrances and parking facilities (see Table 1) supplemented with distances from entrances to parking facilities and the car drivers' workplace, and from parking facilities to entrances and car driver's work place. The selection of the characteristics was based on the findings in previous studies added with several policy relevant characteristics.

THE DATA

The data used for the model estimation are gathered using an internet based questionnaire. The questionnaire contained questions regarding car drivers' entrance and parking choice. It also contained questions regarding personal characteristics (age, gender, residential location) and visiting behavior (visit frequency and final destination).

When leaving the area, car drivers were invited to participate in the study by means of an invitation card (Figure 4). The invitation card explained the purpose of the study and the web address where the questionnaire could be found. To stimulate participation, car drivers could win a diner check of 50 Euros. Approximately 2000 invitation cards were distributed at the three exits of the campus in the spring of 2008. Approximately 500 car drivers filled out the internet questionnaire. The sample covers both employees and visitors of the university or one of the other businesses at the campus.

Figure 4 - *Invitation card (in Dutch)*

DESCRIPTIVE ANALYSES

The first step of the analyses consisted of a brief description of the personal characteristics, the travel characteristics, and the parking choice behavior of the respondents. The data of 498 car drivers could be used for both the descriptive and model analyses. Table 2 presents the personal characteristics of the respondents.

Table 2 - Personal and travel related characteristics of respondents

Characteristic	*Level*	*Frequency*	*Percentage*
Gender	Male	300	60.2
	Female	198	39.8
Age	Younger than 45 years	261	52.4
	45 years and older	237	47.6
Educational level	Medium	175	35.1
	High	323	64.9
Residential location	Eindhoven	137	27.5
	Outside Eindhoven	361	72.5
Type of car driver	Employee	391	78.5
	Visitor	107	21.5
Total		498	100.0

In general, the figures in Table 2 show that the sample is what one would expect at a technical university: a large number of male car drivers, a high share of car drivers younger than 45 year of age, a high share of high educated car drivers, and most car drivers come from outside Eindhoven. As expected the number of car drivers working at the campus is considerably higher than the number of visitors.

In addition, the observed car drivers' parking choice is related to the entrance choice (Table 3). Some differences can be noticed. Car drivers who enter the campus through entrance 1 mainly park their car in parking zones 4, 6, and 10, and at parking lots 1, 6, and 16. Car drivers using entrance 2 park their car mainly in parking zones 4, 6, and 10, and at parking lots 3, 5, and 8. Finally, car drivers who enter the campus through entrance 3 park their car in parking zones 4, 10, and 11, and at parking lots 6, 14, and 16.

Table 3 - Entrance and parking choice of respondents (percentages)

	Parking zones			*Parking lots*		
Number	*Entrance 1*	*Entrance 2*	*Entrance 3*	*Entrance 1*	*Entrance 2*	*Entrance 3*
1	5.4	0.0	2.9	12.4	0.0	4.5
2	9.5	3.3	0.0	9.3	9.3	2.7
3	4.1	0.0	1.4	6.2	18.5	3.6
4	12.2	16.7	21.7	1.9	3.7	0.0
5	6.8	13.3	1.4	5.6	16.7	0.9
6	20.3	26.7	2.9	17.4	5.6	19.1
7	9.5	13.3	5.8	5.6	1.9	2.7
8	5.4	3.3	5.8	3.1	14.8	0.9
9	5.4	3.3	2.9	1.2	0.0	0.9
10	13.5	16.7	42.0	7.5	13.0	7.3
11	8.1	3.3	13.0	1.9	0.0	4.5
12	-	-	-	0.6	0.0	5.5
13	-	-	-	0.6	1.9	3.6
14	-	-	-	2.5	0.0	10.0
15	-	-	-	1.9	1.9	2.7
16	-	-	-	22.4	13.0	30.9
Total	100.0	100.0	100.0	100.0	100.0	100.0
N	74	30	69	161	54	110

COMBINED CHOICE MODEL

To get insight into the combined choice of entrance and parking of commuters several nested logit models (NL-models) were estimated. NL-models are preferable in situations of multi-dimensional choices (Ben-Akiva and Lerman, 1985). The structure of NL-models is characterized by grouping all subsets of correlated (or similar) choices into so-called nests. Each nest is represented by a composite alternative (with an inclusive value representing the joined utility of the alternatives in that nest) which competes with the other alternatives or composites available to the individual.

In the present study, the NL-models are estimated by using the software package NLOGIT (Green, 2007). NLOGIT defines composite alternatives and individual alternatives. Associated with the composite alternatives and individual alternatives is the composite utility or inclusive value. This value synthesizes the utility of the different elemental nodes forming the structural node. The value is multiplied by the structural coefficient Theta. If utility-maximizing behavior is assumed, the NL-model is defined by the following equations. First, the probability of the structural node is defined by

$$P_j = \frac{e^{[V_j + \theta_j \cdot V'_j]}}{\sum_{i' \in J} e^{[V_{j'} + \theta_{j'} \cdot V'_{j'}]}}$$

where, P_j is the probability of structural node *j*; V_j, utility value for structural node *j*, apart from V'_j; V'_j, composite utility of the set of elemental nodes under *j*; θ_j structural coefficient for structural node *j*; *J*, set of structural nodes *J*.

The probability of elemental nodes equals

$$P_{i|j} = \frac{e^{V_i}}{\sum_{j' \in I_j} e^{V_{i'}}}$$

where, $P_{i|j}$ is the probability of elemental node *i*, given structural node *j*; V_i, utility value for elemental node *i*; I_j, set of elemental nodes given structural node *j*.

Then, the probability of choosing elemental node *i* and structural node *j* is equal to

$$P_{ji} = P_j \cdot P_{i|j}$$

The composite utility of the structural node *j* is defined as

$$V'_j = \ln\left[\sum_{i \in I_j} e^{V_i}\right]$$

Effect coding was used to represent the effects of the characteristics on the utility of an alternative. The first step of the model estimation process was to find the most optimal nesting structure. Two alternative model structures were tested: (a) parking choice as highest choice level and (b) entrance choice as highest choice level. For both model structures, a NL-model is estimated. A model structure is consistent with utility-maximizing behavior if the coefficient (Theta) of the inclusive value meets the criteria of being positive and less than or equal to 1 (Ben-Akiva and Lerman, 1985).

For the estimation of the parameters the following data of the respondents were used: parking choice, entrance choice, and work location. In addition, all parking zones and parking lots were described by using the characteristics presented in Table 1. The work location of the respondent was used to determine the distances between entrance and workplace and between parking and workplace. It was also used to determine the car driver's choice set of parking facilities. In principle all parking facilities within 400 meter of a work place are included in the car driver's choice set.

The model estimation process shows that the most optimal structure of the nested logit model consists of entrance choice at the highest level and parking choice at the lowest level (parameter of inclusive value is equal to 0.5321). With a McFaddens' pseudo R-squared value of 0.336 the model performs quite well. The choice of entrance is significantly influenced by the distance between entrance and workplace, location of the entrance vis-à-vis the workplace, and the direction when leaving the campus area. The effects of the characteristics on the utility of entrances are as expected. It appears that the utility of an entrance increases when the distance between entrance and parking decreases. The utility of an entrance increases in the case that the entrance is positively located vis-à-vis the car drivers' origin (residential location). The utility of an entrance also increases when there are more than one driving direction presence when leaving the entrance.

The choice of parking is significantly influenced by the number of parking spaces, the available type of vegetation surrounding the parking, the distance between entrance and parking, and the distance between parking and workplace. Again, all effects on the utility of parking are as expected. The utility of parking increases when the size of the parking increases and decreases when the distance between entrance and parking, and between parking and workplace increases. The absence of vegetation results into a higher utility of the parking then in the case of bushes or trees.

Table 4 - Estimation results of the combined entrance and parking choice model

Characteristics	*Levels*	*Parameter*	*Significance*
Parking choice			
Number of parking spaces	Number	0.0092	0.000
Presence of vegetation	No	0.2217	0.032
	Bushes	-0.2994	0.003
Distance between entrance and parking	Meters	-0.0027	0.000
Distance between parking and workplace	Meters	-0.0075	0.000
Entrance choice			
Distance between entrance and workplace	Meters	-0.0019	0.000
Location vis-à-vis residential location	Positive	0.9428	0.000
Direction when leaving	Extensive	0.1827	0.083
Theta		0.5321	0.000
General results of the estimation			
Number of coefficients		9	
Final log-likelihood		-1417.143	
Log-likelihood of model with zero coefficients		-2134.854	
Chi squared value		1435.423	
Rho-squared		0.336	

CONCLUSIONS

To get insight into car drivers parking choice at business areas a model for the combined choice of entrance and parking is developed. The model is based on the choice behavior of employees and visitors of Eindhoven University of Technology. In this context, it appears that the choice of entrance is significantly influenced by the distance between entrance and workplace, location of the entrance vis-à-vis the workplace, and the direction when leaving the campus area. The choice of parking is significantly influenced by the number of parking spaces, the available type of vegetation surrounding the parking, the distance between entrance and parking, and the distance between parking and workplace. No effect was found for other physical characteristics of the parking facilities.

The estimated model can be used to predict all effects of planning measures that can be described in term of the included characteristics. A change in the layout or the location of parking influences the car driver's choice of the parking facilities and consequently the occupancy rates of the parking facilities both on-street and off-street. Changing the employees' workplace and/or visitors' visiting location changes the use of entrance. Both changes affect the traffic flows at the campus and consequently the amount vehicle miles travelled across the campus.

REFERENCES

Arnott, R.J. and Rowse, J. (1999) Modeling Parking, *Journal of Urban Economics* **45**, 97-124.

Brown-West, O.G. (1996) An Optimization Model for Parking in the Campus Environment, *Paper presented at the 75th Annual Meeting of the Transportation Research Board,* Washington DC, USA.

Chui, H.M. (2005) A location Model for the Allocation of the Off-street Parking Facilities, *Journal of the Eastern Asia Society for Transportation Studies* **6**, 1344-1353.

Green, W.H. (2007) *NLOGIT Version 4.0: Reference Guide*, Econometric Software Inc., Plainview USA and Castle Hill, Australia.

Harmatuck, D.J. (2007) Revealed Parking Choice and the Value of Time, *Proceedings of the 86th Annual Meeting of the Transportation Research Board (CD-Rom),* Washington DC, USA.

Hess, S. and Polak, J.W. (2004), Mixed Logit estimation of parking type choice, paper presented at the 83rd Annual Meeting of the Transportation Research Board, Washington D.C.

Hunt, J. and Teply, S. (1993). A nested logit model of parking location choice*, Transportation Research B* **27,** 253-265.

Ji, Y., Deng, W., Wang, W. and Liu, G. (2007) Two-phased Parking Choice Model for Pre-trip Parking Guidance System, *Proceedings of the 86th Annual Meeting of the Transportation Research Board* (CD-Rom), Washington DC, USA.

Lam, W.H.K., Li, Z.C., Huang, H.J. and Wong, S.C. (2006) Modeling Time-Dependent Travel Problems in Road Networks with Multiple User Classes and Multiple Parking Facilities, *Transportation Research B* **40**, 368-395.

Marsden, G. (2006) The Evidence Base for Parking Policy – A Review, *Transport Policy* **13**, 447-457.

Thompson, R.G. and Richardson, A.J. (1998) A Parking Search Model, *Transportation Research A* **32**, 159-170.

Van der Goot, D. (1982) A Model to Describe the Choice of Parking Places, *Transportation Research A* **16**, 109-115.

Van der Waerden, P., Borgers, A. and Timmermans, H. (2008) Modeling Parking Choice Behavior in Business Areas, *Proceedings of the 87th Annual Meeting of the Transportation Research Board (CD-Rom),* Washington DC, USA.