INVESTIGATION OF THE DETERMINANTS OF THE MENTAL KNOWLEDGE OF PUBLIC PARKING FACILITIES

Mario Cools, [1]Local Environment Management and Analysis (LEMA), Université de Liège, Liège, Belgium, [2]Transportation Research Institute (IMOB), Hasselt University, Diepenbeek, Belgium, mario.cools@ulg.ac.be

Peter van der Waerden, Urban Planning Group, Eindhoven University of Technology, Eindhoven, the Netherlands, p.j.h.j.v.d.waerden@bwk.tue.nl

Davy Janssens, Transportation Research Institute (IMOB), Hasselt University, Diepenbeek, Belgium, davy.janssens@uhasselt.be

ABSTRACT

This paper presents a study regarding the determinants of travellers' mental knowledge of public parking facilities. The data regarding the mental knowledge were collected in the city of Hasselt, Belgium, by means of an internet-based questionnaire. In total 1007 respondents completed the questionnaire. Two different dependent variables were specified: the mental representation of parking facilities (known or not) and the identification of parking facilities (identified first or not). In addition, three different groups of determinants were included in the models: parking attributes, personal characteristics, and mental knowledge of the city. The data are analyzed using generalized estimating equations (GEE) models for binary data. The analyses show a considerable influence of the following parking attributes: type of parking facility, Park & Ride status, charged parking, number of places, and location of parking facility. Furthermore our study revealed that personal characteristics and mental knowledge of the city play a marginal role.

Keywords: mental knowledge, parking facilities, parking characteristics, GEE

INTRODUCTION

To confine the externalities of human mobility (i.e. traffic accidents, restricted accessibility of economically important locations, decreased neighbourhood liveability, social exclusion of members of society, and damage to the environment), various (transportation) policy plans have been formulated at different levels of public authority (Tormans et al., 2013). At municipality level, increasing congestion and limitation of space availability in central shopping and business areas forces municipalities to (re)develop transportation plans (Weinberger et al., 2010). These plans encompass the implementation of various policy measures – often referred to as travel demand management (TDM) measures – ranging from car related measures (e.g. one way traffic) and public transport related measures (e.g. priority at traffic lights) to bike related measures (e.g. new bike lanes).

A specific group of car related measures concerns parking measures. Parking measures influence parking demand and consequently car demand by managing the availability, location, type, size and/or price of parking lots (Golias et al., 2002; Arnott, 2006; Al-Fouzan, 2012). As parking measures are not always perceived as acceptable (see e.g. Cools et al., 2012), policy makers should embed them in a broader policy package which could include the supply of free fringe parking, and the provision of parking permits for local residents and disabled people (Rye et al., 2008; McCahill and Garrick, 2010). Moreover, the success of planning measures is especially strongly related to the familiarity of the traveller with the characteristics of the elements of the transportation system.

When a traveller wants to make a trip, he or she is confronted with different travel related choices such as choice of departure time, travel mode, route, and parking location. To make a deliberate choice, the traveller's familiarity with the attributes of the available choice alternatives plays a key role. However, travellers' familiarity with the attributes of choice alternatives is often limited. This is also the case for car drivers' familiarity with the attributes of parking facilities in CBD (Polak and Axhausen, 1990). For example, Van der Waerden and Borgers (1995) and Cools et al. (2013) found that car drivers only know a limited number of parking alternatives when visiting a shopping area. It also appears that car drivers are not familiar with existing parking problems in general (Ten Heuvelhof, 1990; Stienstra, 1999) and with the levels of different parking attributes in particular (Van der Waerden et al., 2011). In general, poor familiarity with parking facilities results into unwanted situations such as congested (overloaded) parking facilities and a number of cars searching for a free parking and, in the same time, influencing the urban traffic flows and environmental quality (Benenson et al., 2008).

The aim of the study described in this paper is to contribute to insights into car drivers' familiarity with the parking facilities in the context of shopping trips. To this end, the mental knowledge of 23 parking facilities in Hasselt, Belgium will be investigated. The main merit of this paper lies in the fact that by combining personal characteristics and attributes related to the parking facilities, this paper contributes in bridging the research gap related to driver's familiarity with parking facilities.

The remainder of the paper is organized as follows. First attention is paid to the issue of familiarity. Next, a description of the data collection and the research sample is presented, followed by the adopted analysis methodology. Consequently, the results are described and discussed. Finally, the paper ends with the conclusions.

BACKGROUND

A key aspect of choice behaviour is the set of choice alternatives that is included in the choice process. In general, the individual choice set refers to the set of discrete alternatives considered by an individual, and forms a subset of the universal choice set that consists of all alternatives available to the decision maker (Bovy and Stern, 1990; Pagliara and Timmermans, 2009). In practice, the formation of choice sets is done by using heuristics or deterministic choice set generation rules (Hannes et al., 2007).
Also in the context of modelling parking choice, the choice set is important. The choice of a parking facility will be influenced by a person's familiarity with the existing parking facilities. Individuals are not necessarily familiar with all parking facilities available in a particular area and a motorist often makes an explicit utility comparison or cost-benefit trade-off before making a choice (Mehta et al., 2003). The recent developments regarding the contents and distribution of parking information will also change car drivers' familiarity with parking facilities.

Little attention has been paid to the size and composition of choice sets for parking choice behaviour. Most researchers have either assumed that choice sets contain all available parking facilities at a shopping centre or only the parking facilities individuals are familiar with (Shaffer and Anderson, 1985; Van der Waerden and Borgers, 1995; Matsumoto and Rojas, 1998; Rye et al., 2008). Only a few empirical studies of choice set composition in the context of parking have been published. In a study of car drivers' familiarity with the parking situation in a regional shopping centre, Van der Waerden and Borgers (1995) found that most car drivers are familiar with 2 or 3 parking lots. Rye et al. (2008) investigated respondents' familiarity with the parking situation in the city centre of Edinburgh. They found that 33 percent of the respondents did not know any parking facility, 48 percent indicated that they knew 1 to 8 parking facilities, while only 3 percent knew all 19 available parking facilities in the city centre. Rye et al. (2008) indicated that this lack of knowledge is likely to put pressure on the well-known parking locations. Cools et al. (2013) studied car drivers' familiarity with parking facilities at an aggregate level. They investigated the relationship between car drivers' characteristics and familiarity. In that paper, familiarity was defined in different ways: number of known car parks (per type: Charged, Free, and Park & Ride), percentage of most known type of parking facility, and percentage of at least half of certain car parks (Charged or Free) known. It appears that familiarity, at least at the aggregate level, is very heterogeneous among travels. The model estimates show that the composition of familiarity is strongly influenced by the characteristics age, education, and frequency of car use.

DATA

The study was set up for the city centre of Hasselt. Hasselt is a medium sized Belgian city that has a population of about 74,000 persons and is located in the Meuse-Rhine Euroregion. It has a main central shopping area, which is surrounded by different supporting functions such as public parking facilities. The information about the mental knowledge of public parking facilities of 1007 respondents was collected by means of an internet-based survey in 2010. The respondents were recruited by means of snowball sampling.

The familiarity to parking facilities was assessed by collecting virtual buffer data about these parking facilities as discussed in detail by Cools et al. (2013). In total, the exact location of the 23 public parking facilities (13 free car parks (green), 3 free park & ride (P&R) car parks (red), and 7 charged car parks (blue)) could have been indicated (see Figure 1). At the time of the data collection, these public parking facilities were only indicated with 'P'-signs at the location itself. No static or dynamic parking guidance system was available at that time. The majority of the charged car parks are located near the inner ring of the city. This inner ring with a diameter of about 0.8 km and a perimeter of about 2.5 km encloses the historic city centre. The structure of Hasselt with a core that acts as central business district and shopping area, surrounded by supporting functions is typical for many European cities.

Figure 1 - Public parking facilities in Hasselt

A basic description of the data is given in Table 1. The data comprises of 23,161 observations (1007 respondents times 23 parking locations). The first set of variables that are highlighted in Table 1 encompasses the parking-related attributes. The majority of parking facilities are parking terrains, and are not categorized as a park & ride facility. With respect to the distance to the CBD, one could note that the parking facilities are equally distributed. This equal spatial spread is also visible from Figure 1.

In addition to the parking-related attributes, Table 1 also gives insight into the personal treats of the respondents. Concerning the socio-demographic profile of the respondents, it can be seen that the sample is well balanced with regard variables such as age, gender and income.
With regard to the travel behaviour of the respondents, the frequency of visiting the city centre of Hasselt, as well as main transport mode used for these trips, with an additional focus on car use, have been queried. The large share of respondents visiting the city at least weekly is in correspondence with the large number of respondents residing in the city. A final set of person-related variables concerns some cognitive attributes such as the self-perceived mental knowledge of and way-finding capabilities in the city centre of Hasselt, as well as the degree of cosiness that the respondents award to the city centre. While reported way-finding

capabilities and perceived cosiness are high for most of the respondents, the self-perceived mental knowledge of the city centre is considerably lower.

Finally, Table 1 describes the respondents' mental knowledge of the public parking facilities. Two outcome variables have been tabulated. The first one is the knowledge of the individual parking places, i.e. the fact whether or not the parking location has been identified or not. Slightly more than one third of the public parking facilities have been identified by the respondents. The second one is the fact whether or not the particular parking facility was identified first or not (order of the identified parking facilities). Since the order of identification was stored separately for charged car parks, at maximum 2 out of the 23 parking locations could have been identified first, which corresponds to 8.7%. The fact that the overall percentage lies slightly below this value (8.34%) is due to the fact that some respondents did not identify parking locations (of a certain type).

Table I – Descriptive Statistics of the Dependent and Independent Variables

Variable	Description and Frequencies (Nominal) / Mean and Standard Deviation (Continuous)
Independent Variables: Parking related attributes	
Type	Terrain: 78.26% – Building: 21.74%
Park & Ride	Yes: 13.04% – No: 86.96%
Charged	Yes: 30.43% – No: 69.57%
Number of parking places	Mean: 294.70 – Std. Err.: 201.31
Location regarding city centre	Close: 34.78% – Small distance: 30.43% – Large distance: 34.78%
Location regarding approaching roads	Belt way/approaching road: 69.57% – Other roads: 30.43%
Independent Variables: Person-related attributes	
Gender	Female: 49.95% – Male: 50.05%
Age	Mean: 32.04 – Std. Err.: 14.77
Net household income	Low income: 15.89% – Medium-high income: 59.19% – Undisclosed: 24.93%
Highest obtained degree	None/primary/high school: 44.59% – University/university college: 55.41%
Place of residence	Hasselt: 60.68% – Elsewhere: 39.32%
Frequency of visiting city centre Hasselt	At least weekly: 59.29% – Not weekly: 40.71%
Frequency of using the car towards city centre Hasselt	Frequently: 47.57% – At most occasionally: 52.43%
Main transport mode towards city centre Hasselt	Car: 49.35% – Other: 50.65%
Mental knowledge of city centre Hasselt	Good to excellent: 55.81% – Bad to reasonable: 44.19%
Way-finding capabilities	Good to excellent: 81.73% – Bad to reasonable: 18.27%
Perceived cosiness of city centre Hasselt	Pleasant: 83.02% – Not that pleasant: 16.98%
Dependent Variables	
Mental knowledge of parking facilities	Yes: 36.45% – No: 63.55%
First identification of parking facilities	Yes: 8.34% – No: 91.66%

METHODOLOGY

As stated earlier, the main research objective of this paper is the assessment of the impact of various parking-related factors and travellers' personal traits on the mental knowledge of public parking facilities. The previous section indicated that each respondent potentially could have identified the 23 public parking facilities and that for each parking facility it was recorded whether or not the parking facility was identified as first. This implies that for each respondent, two binary variables (whether or not the public parking facility is known and whether or not the public parking facility was identified as the first) are recorded for 23 different situations and that correlation among these repeated observations cannot be disregarded. Therefore, as for instance underlined by Creemers et al. (2012), a modelling approach that takes into account correlated responses for binary data is needed.

The model adopted to fulfil this requirement is a generalized estimating equations (GEE) model for binary data with the logit link function. The mean response is modelled as a logistic regression model, which is defined as follows (Allison, 2001):

$$\log\left(\frac{\pi_i^*}{1-\pi_i^*}\right) = \theta^* + X_i^{'}\beta^*, \qquad (1)$$

where $\frac{\pi_i^*}{1-\pi_i^*}$ denotes the odds, θ^* the intercept, β^* the vector of model parameters to be estimated and X_i a vector of explanatory variables. The above equation can be rewritten to the well-known likelihood function of a binary logit model:

$$\pi_i^* = \frac{\exp(\theta^* + X_i^{'}\beta^*)}{1+\exp(\theta^* + X_i^{'}\beta^*)} \qquad (2)$$

Equation 1 shows that the estimated parameters must be interpreted as the change in the predicted logged odds for a one-unit change in the corresponding explanatory variable. The odds can be defined as the probability of an event divided by the probability of no event. In this paper, separate models are estimated for the knowledge of the public parking facilities (known or not) and for the selection (first identified or not). Thus, the probability of an event equals the likelihood of knowing a specific public parking facility in the first model, and the likelihood that a particular public parking facility was identified first in the second model. The most common way to interpret the parameter estimates is according to the odds ratios (ORs). An OR can be obtained by taking the exponent of the parameter estimate (e^{β}). If the OR is smaller (greater) than 1, it represents a decrease (increase) in the odds of an event (i.e., the public parking is known/identified first). This implies that the probability decreases (increases) significantly for every unit increase in the corresponding explanatory variable.
Parameter estimates can also be construed by examining their signs. A positive (negative) sign implies an increase (decrease) in the likelihood of an event for every increase in the corresponding explanatory variable.

GEE models take into account the correlation between different observations of the same subject (i.e., repeated answers by the same respondent) by explicitly modelling the correlation structure of the repeated observations. Correlation structures specify how observations within a subject or cluster are correlated with each other. For binary data, the correlation between the j^{th} and the k^{th} response is by definition the following (SAS Institute, 2008):

$$Corr(Y_{ij}, Y_{ik}) = \frac{\Pr(Y_{ij} = 1, Y_{ik} = 1) - \mu_{ij}\mu_{ik}}{\sqrt{\mu_{ij}(1-\mu_{ij})\mu_{ik}(1-\mu_{ik})}} \tag{3}$$

However, the above formula has one important disadvantage. The correlation is constrained to be within limits that depend in a complicated way on the means of the data. In contrast, the OR is not constrained by the means and is therefore preferred. The OR is defined as follows (SAS Institute, 2008):

$$OR(Y_{ij}, Y_{ik}) = \frac{\Pr(Y_{ij} = 1, Y_{ik} = 1)\Pr(Y_{ij} = 0, Y_{ik} = 0)}{\Pr(Y_{ij} = 1, Y_{ik} = 0)\Pr(Y_{ij} = 0, Y_{ik} = 1)} \tag{4}$$

The latter implementation of GEE is called alternating logistic regression (ALR). In general, ALR models the association between responses with log ORs instead of with correlations, as do ordinary GEE (SAS Institute, 2008).

As noted above, separate models are estimated for the knowledge of the public parking facilities (known or not) and for the selection (whether or not a specific facility was identified first or not). To build the models, forward selection was used to find the most relevant variables in the model. Forward selection adds variables to the model one at a time. At each step, each variable that was not already in the model is tested for inclusion. The most significant variable is then added to the model as long as its P-value remains below the significance level of .05. The final models were assessed for multicollinearity by using variance inflation factor values, but no problems occurred.

RESULTS

Table II presents the parameter estimates of the first model predicting the mental knowledge of the parking facilities. The dependent variable is the car driver's mental knowledge (yes or no) of parking facilities. The Table only includes only significant parameters (at least one level of an attribute with p-value < 0.000). As presented before, a positive sign implies an increase in the likelihood and a negative sign implies a decrease in the likelihood of an event for every increase in the corresponding explanatory variable.

The negative intercept, indicates that in advance, car drivers are not familiar with a parking facility. It appears that the travellers' mental knowledge of parking facilities is mainly influenced by parking attributes. The parameter α represents the common log odds ratio, under the assumption that the log odds ratio is a constant for all clusters (i.e. respondents) and pairs (i.e. pair-wise comparisons of two parking facilities). The parameters of all included parking attributes are at least for one level significant. Personal characteristics play a marginal role. Only the parameters for income and perceived mental knowledge are significant. The familiarity of car drivers *increases* when the parking facility is a building (instead of terrain), located at small or medium distance (instead of located large distance), and/or the car driver has a low or medium income level (instead of 'undisclosed' level). In contrast, the familiarity of car drivers with a parking facility *decreases* when the facility is a Park & Ride facility, a charged parking, and/or the car driver's perceived mental knowledge is very bad or mediocre. All the results are as expected.

Table II – GEE Parameter Estimates of the Model Predicting the Mental Knowledge of the Parking Facilities

Parameter	Est.	S.E.	*z*-value	*p*-value
Intercept	-1.504	0.070	-21.5	<0.001
Type				
- Building	0.472	0.078	6.1	<0.001
- Terrain	0.000			
Park & Ride				
- Yes	-1.861	0.065	-28.7	<0.001
- No	0.000			
Charged				
- Yes	-0.623	0.063	-9.9	<0.001
- No	0.000			
Number of parking places	0.002	<0.001	28.7	<0.001
Location regarding city centre				
- Close	0.101	0.045	2.2	0.025
- Small distance	0.293	0.036	8.2	<0.001
- Large distance	0.000			
Location regarding approaching roads				
- Belt way / approaching road	0.643	0.036	17.9	<0.001
- Other roads	0.000			
Income				
- Low	0.155	0.086	1.8	0.072
- Medium-High	0.215	0.066	3.3	0.001
- Undisclosed	0.000			
Perceived mental knowledge Hasselt				
- Very bad – mediocre	-0.390	0.053	-7.4	<0.001
- Good – Very good	0.000			
Alpha	0.518	0.028	18.5	<0.001

The parameter estimates of the second model, where the dependent variable represents the fact whether the parking facility is identified first or not, are presented in Table III. It appears that the identification of parking facilities is influenced by almost all included parking attributes. Only the influence of charged parking is not significant. This means that it does not matter whether a parking facility is charged facility or not when identifying a parking facility as first facility or not. Personal characteristics do not play a role in this context.

A comparison of the parameter estimates of the two models learns that some parking attributes influence the overall mental knowledge less than the first identification of parking facilities. For example, being a Park & Ride increases the odds of familiarity with 0.15 [=exp(-1.861)] while it increases the odds with 0.08 [=exp(-2.581)] in the case of first identification of parking facilities. A similar influence if found for the location related attributes (location regarding city centre and location regarding approaching roads). In the case of the 'first identification' model charged parking does not pay a role. The same holds for the personal characteristics income level and perceived mental knowledge of Hasselt.

Table III – GEE Parameter Estimates of the Model Predicting the First Identified Parking Facilities

Parameter	Est.	S.E.	*z*-value	*p*-value
Intercept	-4.816	0.101	-47.6	<0.001
Type				
- Building	0.468	0.114	4.1	<0.001
- Terrain	0.000			
Park & Ride				
- Yes	-2.581	0.222	-11.6	<0.001
- No	0.000			
Number of parking places	0.003	<0.001	19.5	<0.001
Location regarding city centre				
- Close	-0.205	0.125	-1.6	0.101
- Small distance	0.382	0.084	4.5	<0.001
- Large distance	0.000			
Location regarding approaching roads				
- Belt way / approaching road	1.762	0.090	19.7	<0.001
- Other roads	0.000			
Alpha	-0.796	0.007	-121.1	<0.001

CONCLUSIONS

In this paper, it is shown that familiarity with parking facilities is mainly determined by characteristics of these parking facilities. The strongest effects were found for the parking characteristics Park & Ride or not, location on approaching road or not and the size of the parking facilities in terms of number of parking places. Furthermore, it is demonstrated that travellers' personal traits only play a marginal role.

The insights from this paper are valuable from transportation planning point of view. The fact that the familiarity of parking facilities is mainly determined by objective parking characteristics is clear indication that the underlying choice process is more structured. After all, Bonsall & Palmer (2004) underlined that an increased familiarity coincides a stronger structure and larger predictability. The main advantage of such a structured process is that it allows planners to more efficiently influence the multitude of travellers' choices (destination, mode, route, parking, etc.). If one is capable of accurately predicting travellers' familiarity with the parking situation in the vicinity of shopping areas is known, this information can be used when looking to the utilities of different destinations, travel modes, and route alternatives. Furthermore, it is recommended that simulation models that predict parking choice behaviour (see e.g. Benenson et al. (2008), Fries et al. (2010), Waraich and Axhausen (2012)) incorporate the contribution factors to familiarity that have been identified in this paper. After all, based on the results presented in this paper, assumptions made in such simulation models can be relaxed and adjusted. This has the potential to yield more reliable insights into the parking demand at different (known) parking locations including the location and size of the facilities.

Finally, it should be stipulated that further research should focus on the linkage between the familiarity of parking locations and the actual parking choice behaviour that is observed. To this end, the data collection should encompass the reporting of the actual choices, and a validation with on real life parking statics could further enhance the state-of-the-art.

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