GPS DATA AND CAR DRIVERS' PARKING SEARCH BEHAVIOR IN THE CITY OF TURNHOUT, BELGIUM

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Abstract

This paper describes an exploratory study regarding parking search behavior. Based on GPS tracks of 97 car trips, the temporal and spatial components of parking search behavior are investigated in more detail. The data collection took place in November 2012 in the city of Turnhout, Belgium. The paper presents the way the data collection has been organized, the way the data have been analyzed, and some findings of the study.

It appears that GPS tracking can be used to investigate both the temporal and spatial aspects of parking search behavior. The average parking search time found in this study is 1 minute and 18 seconds (approximately 14 percent of the total travel time). The use of street segments for parking is influenced by distance to the city center, distance to nearest parking facility, presence of shops, and parking tariffs.

Keywords: GPS, Parking Search, Behavior, TransCAD, GIS Ostrava 2014

INTRODUCTION

The increase in car use has resulted into an increase in are heavily congested streets, especially in and around the central business district and shopping areas. Previous studies have shown that a considerable share of cars in these streets is searching for a free parking space (e.g. Shoup, 2006; Van Ommeren *et al.*, 2012). Due to a decrease in available parking spaces, the searching for parking will likely increase in the future with several accompanying effects such as a decrease of accessibility and attractiveness of destinations. For transport planners and decision makers, reliable information about parking search behavior is therefore important when assessing the accessibility of destinations and environmental effects of traffic in central business districts and shopping areas.

In the past, most studies focused on the number of cars searching for a free space. To date, little attention has been paid to search time and the kind of streets car drivers use while searching (e.g., Kaplan & Bekhor, 2011). To the extent attention has been paid to parking search time, the duration of search is mainly based on car drivers' assessment of time (e.g., Van Ommeren *et al.*, 2012). This study aims at getting more detailed insights into both the temporal and spatial aspects of car drivers' parking search behavior based on empirical data. The research is still in the phase of exploration of data collection and analyses methods. The study is an extension of a previous study in which the use of GPS to investigate car drivers' parking search behavior was explored (Van der Waerden *et al.*, 2012).

The remainder of the paper is organized as follows. First, a brief overview is given of existing insights and adopted approaches regarding (modeling of) parking search behavior. Next, the adopted research approach is outlined. This section is followed by a brief description of the data collection process. The findings of the data collection are described in section 4. The paper ends with the conclusions and some recommendations for future research.

PARKING SEARCH BEHAVIOR

When car drivers approach their final destination, they start to look for a free parking place. This last part of a car trip is defined as car drivers' parking search behavior (e.g., Shoup, 2006). Basically, parking search behavior consists of two components: a temporal (time used for searching) and a spatial (streets used for searching) component. Both components influence the accessibility and the livability of areas. Especially in dense inner-city areas, the presence of parking search traffic influences the accessibility by car and the livability of visitors and residents negatively. This is one of the reasons that serious attention is paid to the issue of parking search behavior, both by local authorities and researchers. Spitaels *et al.* (2009) give a detailed overview of several behavioral aspects that are related to car drivers' in parking search behavior.

Previous studies could be divided into two groups: studies with a focus on empirical insights and studies with a focus on model development. A recent study regarding empirical insights is presented by Van Ommeren *et al.* (2012). Based on the Dutch National Travel Survey (MON) for the years 2005-2007, they found that the average cruising time is 36 seconds per car trip, that cruising time increases with travel and parking duration, and that cruising has a distinctive pattern across the day. The average cruising time is totally different from the times Shoup (2006) presented in his work (ranging from 3.5 to 14 minutes). Waraich *et al.* (2012) already indicated that 'the parking strategy evaluation procedure of the previous parking search models delivers systematically too high search times'.

The second group of related studies concerns studies in which parking search models are developed (for a literature review see Young 2008; Benenson et al., 2008; Kaplan & Bekhor, 2011). The studies focus on extensions of network based assignment models (e.g., Gallo et al., 2011) or agent-based models (e.g., Benenson *et al.*, 2008; Waraich *et al.*, 2012; Guo *et al.*, 2013). The models aim to investigate:

- The impact of cruising for parking on traffic congestion (Gallo *et al.*, 2011);
- The environmental costs of parking search process (Guo *et al.*, 2013);
- The generation of distributions of key values like search time, walking distance, and parking costs over different drivers groups (Benenson *et al.*, 2008).

A variety of publications shows that the use of GPS tracking data becomes more popular to collect travel related data (e.g, Papinski *et al.*, 2009; Gong, *et al.*, 2012; Lin & Hsu, 2013). The data is easy to collect, accurate, and detailed (e.g., Stopher, 2008). Also in the context of parking search behavior, GPS tracking is a useful means of data collection (e.g., Kaplan & Bekhor, 2011; Van der Waerden *et al.*, 2012). The experiences with the use of GPS tracking to identify parking search behavior are still limited.

RESEARCH APPROACH AND DATA COLLECTION

To get insight into car drivers' parking search behavior the following research approach has been adopted. First, a city was selected according to requirements defined by Kaplan & Bekhor (2011). Next, participants were recruited who plan to make several trips by car to the centre of the selected city. All participants received a GPS logger and were asked to turn on the logger when driving with their car to the city center of the selected city. In this study the 'i-Blue 747A+ GPS recorder' was used. Every 3 seconds, the recorder stores its (horizontal and vertical) position, the day and time of day, and the number of satellites involved in the registration. For technical details of this recorder see http://blinkgadget.blogspot.com/2010/10/kode-produk-747a.html. The logger is easily to set and the data is easily to retrieve using for example the software 'DataLog' (www.datalog.de). The spatial data are stored, analyzed, and presented using the Geographic Information System TransCAD 6.0 (www.caliper.com).

In additions, the participants were invited to filled out a small questionnaire consisting of some questions regarding personal characteristics (gender, age, familiarity with the city, and possession of parking card) and for each trip some specific characteristics (type of car used during the trip, orientation on specific parking facility before leaving home, and trip purpose).

The study was carried out in the city of Turnhout, a small city in the North of Belgium (Figure 1). The city meets the four basic requirements set by Kaplan & Bekhor (2011): (i) area should be characterized by high activity generation and limited parking supply; (ii) area should offer a selection of off-street and on-street parking opportunities; (iii) area should attract both local and non-local visitors, and (iv) area should be bounded by natural and/or street network boundaries.

Fig. 1. Study area: Turnhout, Belgium (source: Google Maps)

The city's road network consists of 531 street segments (links between two intersections). On 85 percent of the street segments on-street parking is allowed. In total, 7 street segments can be used as entrance of a parking facility. The parking tariffs for on-street parking range from 0.00 (Free) to 2.00 euro per hour. On almost 50 percent of the road segments parking is free. Most streets (approximately 80 percent) are two direction streets. Approximately 90 percent of the road segments include one or more residences. All these streets are designed as local roads. On almost 15 percent of the road segments one or more shops are present.

The data collection took place in November 2012. In total, 15 persons participated in the field study describing 97 trips (Figure 2). The small number of participants was mainly caused by limited time and money resources. Unfortunately, the respondents are not equally distributed across the included personal characteristic levels: gender (60 percent women, 40 percent men); age groups (46 percent younger than 36 years, 54 percent older than 35 years); and familiarity with the city (74 percent well to very well, 26 percent limited to poor). Regarding the trip purpose it appears that 36 percent of the trips were work related trips, 27 percent shopping trips, 19 percent leisure trips, and 18 percent other (like picking up or dropping of persons).

To determine the 'search' part of a trip the following approach is applied. The approach is based on experiences from previous empirical studies (Van der Waerden *et al.*, 2012). The best method found until now, starts at the arrival time of the car and includes information concerning average speed (over different observations) and acceleration or deceleration of the car ('speed change'). The search for an optimal average travel speed is done by 'trial and error', minimizing the number of incorrect predictions (compared to real world observations of parking search behavior). The starting point of searching is set when the average speed is below 23 kilometers per hour (measured over 5 time periods) and the speed difference is less than 5 kilometers per hour as observed in the GPS data.

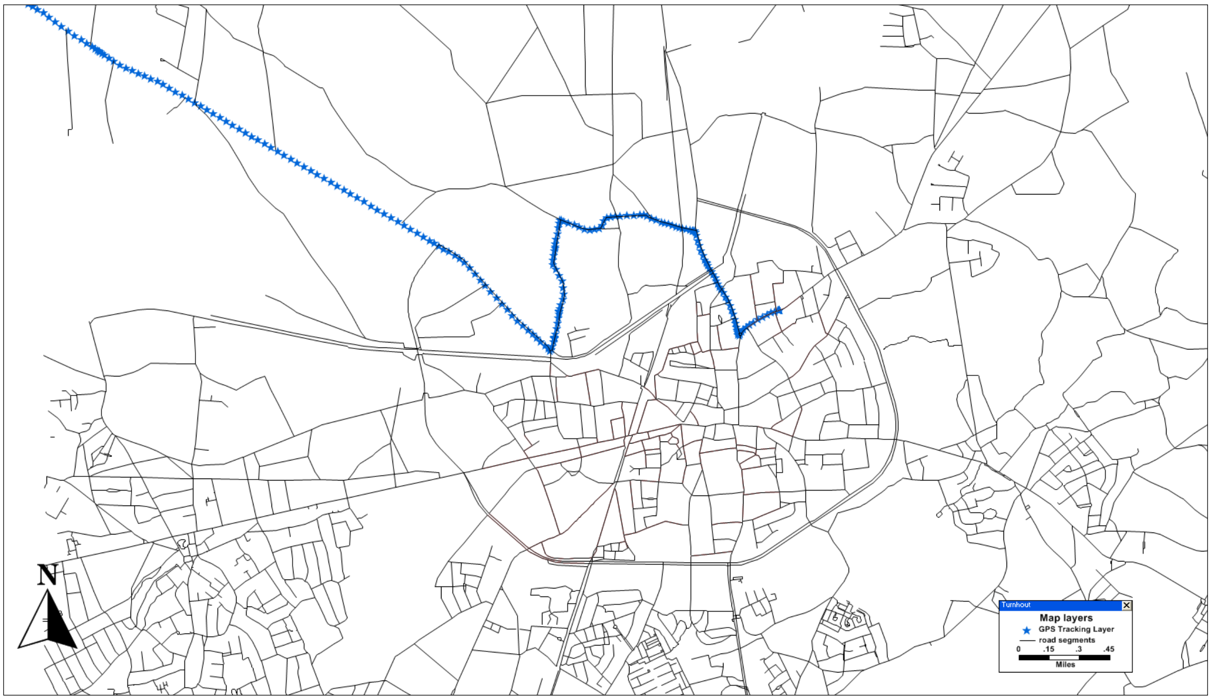

Fig. 2. Presentation of GPS tracking data on the street network of Turnhout

ANALYSES

The GPS information is stored in a (comma separated value - csv) data file (Table 1) produced by the program DataLog. The program generates a data file with several columns including time period (date and time), position of observation (latitude, longitude, and height), and vertical and horizontal accuracy (PDOP, HDOP, and VDOP, NSAT). The columns ‘Latitude’, ‘Longitude’, and ‘Speed’ are used in this study. In Table 1, the yellow box indicates the start of the search process.

Table 1. Example of database produced by DataLog

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	INDEX	RCR	DATE	TIME	VALID	LATITUDE	N/S	LONGITUI	E/W	HEIGHT	SPEED	SPEED/1000	PDOP	HDOP	VDOP	NSAT (USED	DISTANCE
199	198	T	28-8-2012	8:36:48	SPS	51.361.781	N	4.858.652	E	69.094 M	59.118	59,12	1.49	0.90	1.18	9(11)	49.96 M
200	199	T	28-8-2012	8:36:51	SPS	51.361.501	N	4.859.164	E	68.279 M	56.115	56,12	1.49	0.90	1.18	9(11)	47.39 M
201	200	T	28-8-2012	8:36:54	SPS	51.361.237	N	4.859.661	E	68.326 M	53.149	53,15	1.66	0.97	1.35	8(11)	45.38 M
202	201	T	28-8-2012	8:36:57	SPS	51.360.990	N	4.860.108	E	68.556 M	46.689	46,69	1.25	0.96	0.80	8(11)	41.53 M
203	202	T	28-8-2012	8:37:00	SPS	51.360.774	N	4.860.507	E	68.710 M	43.227	43,23	1.49	0.90	1.18	9(11)	36.75 M
204	203	T	28-8-2012	8:37:03	SPS	51.360.557	N	4.860.898	E	69.236 M	44.314	44,31	1.25	0.96	0.80	8(11)	36.39 M
205	204	T	28-8-2012	8:37:06	SPS	51.360.340	N	4.861.300	E	69.135 M	44.934	44,93	1.25	0.96	0.81	8(11)	37.03 M
206	205	T	28-8-2012	8:37:09	SPS	51.360.123	N	4.861.692	E	69.070 M	43.089	43,09	1.66	0.97	1.35	8(11)	36.40 M
207	206	T	28-8-2012	8:37:12	SPS	51.359.931	N	4.862.065	E	69.415 M	38.557	38,56	1.48	0.90	1.18	9(11)	33.66 M
208	207	T	28-8-2012	8:37:15	SPS	51.359.814	N	4.862.459	E	69.497 M	37.446	37,45	1.66	0.97	1.35	8(11)	30.39 M
209	208	T	28-8-2012	8:37:18	SPS	51.359.754	N	4.862.860	E	69.065 M	30.932	30,93	1.48	0.90	1.18	9(11)	28.70 M
210	209	T	28-8-2012	8:37:21	SPS	51.359.703	N	4.863.161	E	68.556 M	23.970	23,97	1.86	1.26	1.37	8(11)	21.72 M
211	210	T	28-8-2012	8:37:24	SPS	51.359.546	N	4.863.305	E	69.869 M	21.846	21,85	1.25	0.96	0.80	8(11)	20.18 M
212	211	T	28-8-2012	8:37:27	SPS	51.359.417	N	4.863.393	E	70.229 M	18.753	18,75	1.34	1.7	0.82	7(11)	15.64 M
213	212	T	28-8-2012	8:37:30	SPS	51.359.288	N	4.863.400	E	69.877 M	14.081	14,08	1.25	0.96	0.80	8(11)	14.37 M
214	213	T	28-8-2012	8:37:33	SPS	51.359.211	N	4.863.404	E	70.400 M	8.802	8,80	1.25	0.96	0.80	8(11)	8.55 M
215	214	T	28-8-2012	8:37:36	SPS	51.359.133	N	4.863.414	E	70.611 M	14.046	14,05	1.66	0.97	1.35	8(11)	8.74 M
216	215	T	28-8-2012	8:37:39	SPS	51.359.025	N	4.863.423	E	70.524 M	13.587	13,59	1.79	1.9	1.42	7(11)	12.03 M
217	216	T	28-8-2012	8:37:42	SPS	51.358.949	N	4.863.428	E	71.099 M	3.171	3,17	2.33	1.69	1.60	6(11)	8.40 M
218	217	T	28-8-2012	8:37:45	SPS	51.358.946	N	4.863.424	E	71.834 M	159	0,16	1.34	1.7	0.82	7(11)	0.86 M
219	218	T	28-8-2012	8:37:48	SPS	51.358.947	N	4.863.425	E	71.771 M	127	0,13	1.75	1.53	0.85	6(11)	0.10 M
220	219	T	28-8-2012	8:37:51	SPS	51.358.943	N	4.863.427	E	71.717 M	4.438	4,44	1.75	1.53	0.85	6(11)	0.41 M
221	220	T	28-8-2012	8:37:54	SPS	51.358.877	N	4.863.440	E	71.640 M	12.269	12,27	1.79	1.9	1.42	7(11)	7.44 M
222	221	T	28-8-2012	8:37:57	SPS	51.358.785	N	4.863.444	E	71.833 M	10.666	10,67	1.75	1.53	0.85	7(11)	10.24 M

The data were analyzed in two different ways. First, the parking search time was investigated in more detail. Based on the observations of 97 city oriented car trips the following details can be noticed. The average car trip takes almost 14 minutes (minimum of 1 minute and maximum of 60 minutes. The average parking search time is 1 minute and 18 seconds (minimum of 0 seconds and maximum of 6 minutes and 48 seconds). Figure 3 shows the distribution (in classes) of parking search times over all 97 car trips. Approximately 50 percent of the parking search times are between 0 and 60 seconds. When this search time is related to the total travel time, it appears that on average 14 percent of the total travel time is used for parking search (minimum 0 percent and maximum of 49 percent).

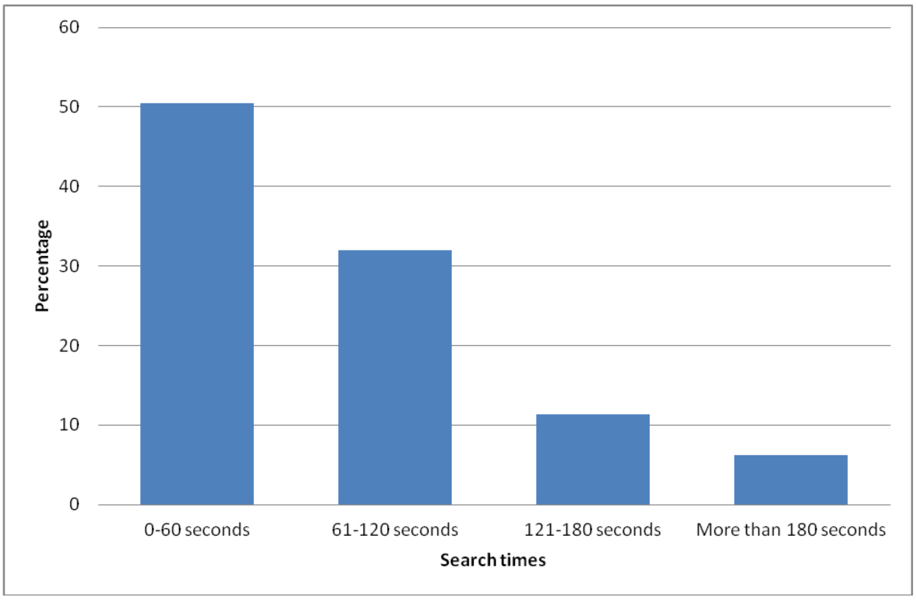

Fig. 3. Distribution of parking search times in Turnhout, Belgium

In the second part of the analyses, parking search routes and included street segments were analyzed in more detail. The GPS data were related to street segments of the urban street network using TransCAD (Figure 4). After the calculation of the number of times each street segment was used in the various parking search routes, the numbers were related to some street segment characteristics. The use of street segments is related to characteristics of the street segments using multiple regression analyses. The (logarithm of) numbers of times are used as dependent variable; while various street characteristics are used as independent variables (see Table 2).

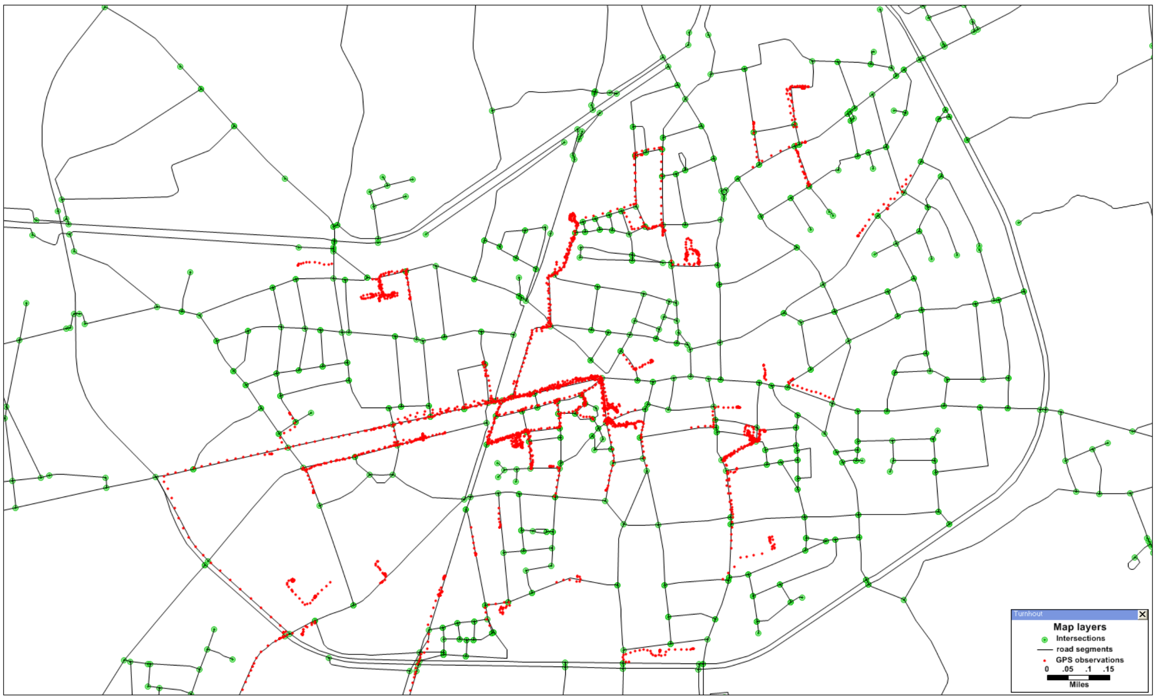

Fig. 4. Basic representation of GPS observation

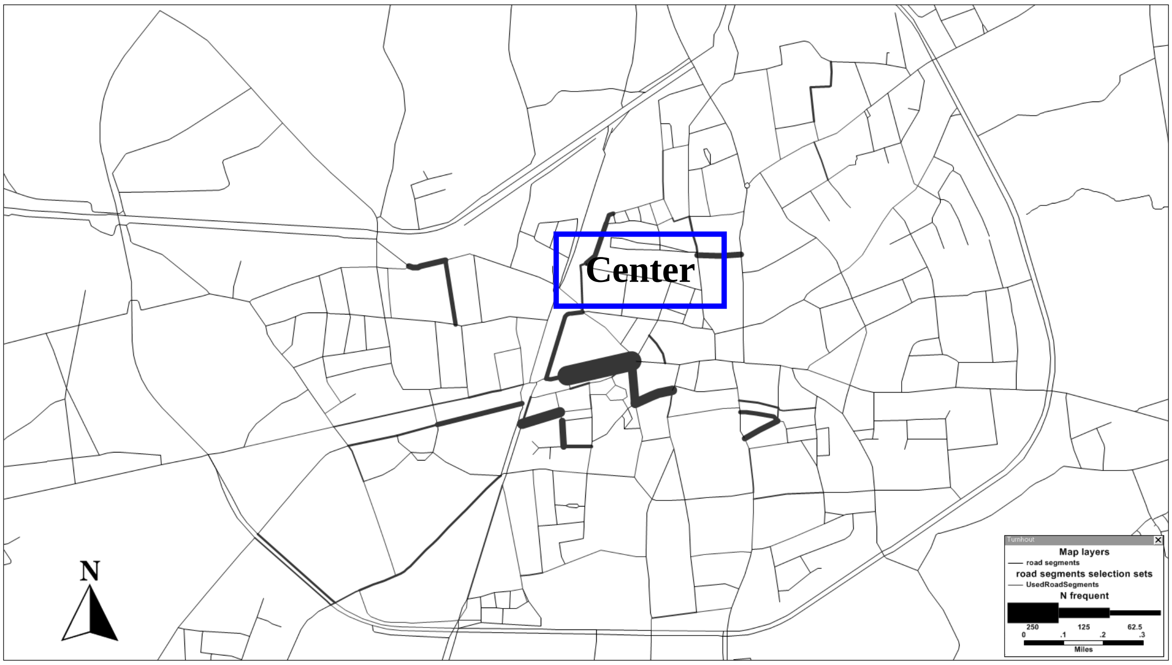

Fig. 5. Use of street segments for parking search

Figure 5 presents the number of times each street segment is used for parking search. The numbers range from 0 to 237 times. The latter street segment is close to one of the main parking facilities in the center. The figure also shows that car drivers already start to search at a considerable distance from the core of the city center.

For planning purposes the individual GPS tracks could be related to characteristics of individual street segments and/or routes (a set of linked street segments). This can be done in various ways as shown in the section about (modeling) parking search behavior. For illustration purpose, in this study the use of street segments is related to attributes of the street segments using regression analyses. In the analyses, the dependent variable is the natural logarithm of the number of times a street segment is used for searching. A variety of street segment attributes are used as independent variables (Table 2). The selection of interesting variables was based on existing literature (see before) and the ease of gathering information regarding the variables. The following hypotheses were defined regarding the effects of the included variables: a <u>higher usage</u> is expected for street segments

- Larger distance from the center (final destination);
- Short distance between street segment and parking facility;
- No presence of parking facilities;
- Presence of on-street parking;
- Presence of shops or residences;
- Presence of two-way driving direction;
- Absence of dynamic parking guidance system;
- High parking tariff;
- Secondary streets.

Table 2. List of investigated street segment characteristics

Attribute	***Levels***
Walking distance between street segment and center	Meters/10
Distance between street segment and closest parking facility	Meters/10
Presence of parking lot	Yes, No
Presence of parking garage	Yes, No
Presence of on-street parking	Yes, No
Presence of houses	Yes, No
Presence of shops	Yes, No
Number of allowed driving directions	One way, Two way
Presence of dynamic parking guidance system	Yes, No
Parking tariff	Euros per hour
Street type	Primary, secondary

For a first exploration of the relationship between the use of street segments and the characteristics of street a basic linear regression model is estimated (Equation 1).

$$Ln(F+0.5)=\sum_i \beta_i \cdot X_i \quad (\mathbf{1})$$

where,

F Number of times a street segment is used for searching

X_i The *i*-th attribute of a street segment

β_i The weight (parameter) of the *i*-th attribute

After evaluating several regression models, the best performing model only includes four street segment attributes. The other attributes were removed from the analyses because of a high correlation or the absence of a significant effect (Table 3). The performance of the model is poor (based on adjusted R-square value) but still acceptable (based on F-value).

Table 3. Parameter estimates of regression analyses

Attributes	Parameters	***Significance***
Constant	-0.297	0.100
Walking distance between street segment and center	0.047	0.001
Distance between street segment and closest parking facility	-0.010	0.000
Presence of shops	0.365	0.039
Parking tariff	0.649	0.000
Goodness-of-fit:		
F-value	25.538 (sign. 0.000)	
R-square	0.163	
Adjusted R-square	0.157	

The parameters show the contribution of attributes to the number of car drivers using the street segment. A positive sign means that an increase of the attribute levels results in a higher number of searchers in the street segment, while a negative sign indicates a decrease of searchers when the attribute level increases. The positive sign for the distance indicates that car drivers start to search for a free parking space at some distance from the center (see before). If a car driver approaches a parking facility, he/she stops searching and drives immediately to the parking facility. Streets close to parking facilities are less used for searching. In streets with shops the number of searchers is higher than in streets without shops. Finally, the parameter estimate of parking tariffs shows that the higher the parking tariff the higher the number of searchers in a street.

CONCLUSIONS

The study described in this paper aims to provide more insight into the temporal and spatial aspects of car drivers' parking search behavior in central business districts and shopping areas. Special attention is paid to the collection of empirical data using GPS loggers. It appears that GPS data could be used for describe car drivers' search behavior both in terms of time and location. The approach provides information regarding search time which can be included in accessibility studies. Also detailed information becomes available regarding the use of street segments that could be used in livability studies. Young (2008) summarizes this as follows: '*Parking search models provide an ability to investigate long-term commitments to parking expenditure, the impact of parking information on route choice, the time spent in searching for a space, and the choice strategy*'.

The temporal and spatial data could be explored in more detail when more data (more trips and more car drivers) were available. The same holds for the modeling part presented in this paper. More sophisticated analyses could be explored to related search behavior to streets segments.

Future research on car drivers' parking search behavior will focus on:

- Extend the collection of empirical GPS data;
- Validate the identification of parking search behavior based on GPS data;
- Relate parking search behavior to characteristics of street segments (including traffic flows and parking occupation levels).

CONCLUSIONS

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