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Ordinal Regression Model of Parking Search Time

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ABSTRACT

Parking search reduces the quality of parking service, as well as traffic network level of service, due to additionally generated traffic. Parking search also entails other negative effects, primarily ecological, social and economic. Even though the importance of this problem has been noted in the past, there is an impression that this issue has not been sufficiently researched and should be additionally analysed in order to properly understand this phenomenon. Therefore, the aim of this paper is to study the factors affecting parking search time that can be influenced through a set of parking management measures. In this paper, an ordinal regression model was developed to estimate these parameters and it was fitted using empirical data collected by interviewing drivers. Main model results show that parking occupancy has the highest impact upon the value of parking search time, indicating the significance of defining proper policies and measures aimed at reaching targeted parking occupancy. Parking frequency is the second parameter observed to be significant, demonstrating the importance of implementing proper parking information systems.

KEYWORDS

parking search; parking policy; ordinal regression model.

1. INTRODUCTION

Due to increased urbanisation, motorisation and mobility rates, as well as car dependency in general, cities worldwide have faced the problems of traffic and parking congestion, and their resolution is rather challenging for city authorities. The parking problem, defined as the imbalance between parking demand and parking supply, is most pronounced in historic centres. In these areas, parking occupancy is increasingly reaching soaring values. Because of high parking occupancy, when the driver arrives at the final destination they are not able to find a vacant parking space immediately and therefore have to continue driving. This additional travel time from the moment the search starts until a vacant parking space is found is termed parking search/cruise time.

Hence, cruising for parking increases the travel time, and thus causes additional time and money losses for the driver, but can also impact traffic safety and mental health, because it causes frustrations and feelings of uncertainty, thus undermining the trust in the city's parking and traffic management authorities. Nevertheless, the scope of negative effects of parking cruise is considerably larger and is not limited only to direct parking searchers, but is rather experienced by the society as a whole. This happens for several reasons. When a driver cruises for parking, more fuel is consumed, meaning that eventually more pollution is emitted into the environment, not only due to extra driving but also because during parking search the engine operates in less favourable modes due to low speeds and frequent stops. Furthermore, cruising vehicles boost urban traffic volumes, lowering the speed and aggravating traffic congestions. For this reason, some researchers even consider parking search a major cause of traffic congestions in central urban areas [1].

There are studies that amply illustrate the consequences of this situation. A SARECO study [1] finds that French drivers spend 70 million hours cruising for parking, which in terms of the value of time costs EUR 700 million. To this value at least additional fuel consumption costs should be added. Shoup [2] finds that in only one small business district in Los Angeles, drivers who search for parking annually travel at least the distance corresponding to 38 trips around the world, spending around 150 tons of fuel and emitting 730 tons of CO_2. In the small inner central area of Belgrade drivers need on average 3.39 minutes to find a vacant parking space in the morning peak hour, thus producing 442 kg CO_2 and 4 kg NO_x in just one hour [3].

In view of all the above, one may conclude that, generally speaking, parking in central urban areas is still not managed sufficiently well, and this results in unfavourable economic, ecological and energy effects, as well as in overall reduction of quality of life in these areas. Most experts agree that the cause of poor parking management in central areas lies in under-priced on-street parking (especially if aligned with expensive off-street/garage parking), which leads to excessive parking demand and encourages cruising on the streets. Restrictive parking policy is unpopular both among politicians (who would be held accountable) and general public (their voters) who believe parking should be abundant and free of charge. However, the importance and the necessity of parking management (including price management) as a concept to manage the quality of life through mobility management have not been sufficiently documented (especially if compared with other areas of transportation) and communicated.

This was the motive behind this paper. The paper aims to examine factors that affect parking search time, so that once these factors have been identified, adequate parking policy directions could be proposed to reduce/eliminate parking search and its accompanying negative impacts.

The paper is structured as follows: Section 2 gives a review of relevant literature that helps understand the nature of the surveyed problem. Section 3 describes the applied research methodology, i.e. the manner of required data collection. Section 4 first analyses the collected data and then, based on the collected data, develops an ordinal regressions model to predict parking search time. Section 5 summarises main conclusions and indicates future research directions.

2. LITERATURE REVIEW

Reviewing the available literature from the last century (from 1927 to 2001), Shoup [4] concludes that cruising for parking is a phenomenon present in cities worldwide for decades, if not for a whole century. In the last two decades, even though cities have already opted for sustainable development and implemented numerous transportation and parking demand management programs, applied smart and technologically advanced solutions, it seems that the parking search problem still remains. There are records even in the modern literature that drivers need to cruise on average around 5 minutes for a vacant parking space, and these vehicles account for around one quarter of urban traffic (see *Table 1*, compiled analogously to *Table 1* in Shoup [4]). Even though one may dispute the accuracy of this data because there might be an overestimation due to choice of survey area and time (parking search is often recorded at sites where and when parking search is expected), the data are still good enough to indicate the presence and importance of this problem nowadays. On the other hand, these values might as well be underestimated, because researchers focus mainly on parking users who managed to park on street, while some studies report large numbers of parking users in off-street parking lots and garages who were initially trying to park on street (see e.g. Lee et al. [5]; Simićević et al. [6]).

Even though its importance is quite evident nowadays, parking cruise has long been disregarded as a source of traffic congestions. However, lately more and more authors deal with this issue and intensively study the causes leading to parking search and parameters behind it, in order to reduce the actual parking search and consequently all its side effects through such parameters.

Actual progress in understanding this problem will greatly depend on the quality of empirical research, therefore, the matter of applicable research methodologies plays a major role. In their review paper, Brooke et al. [21] specify different methodological approaches implemented at the moment, analysing their specific advantages and disadvantages. These authors observe that parking search time may be researched by means of independent survey methods, such as “park and visit“, “vehicle following“ and GPS data use, as well as by means of dependent survey methods. The latter methods are still most frequently in use, especially “on-street interview surveys conducted as drivers depart from or return to their vehicles” [21]. A disadvantage of this approach is the fact that collected data represent stated (subjective) values that are not necessarily true. However, this disadvantage is mitigated in “before and after studies” that require trends and relations between the established trends to be identified, rather than their absolute values. In any case, a simple research methodology, low costs of research and the possibility to provide a representative sample are the advantages that still keep this method favourable amongst researchers. Another significant advantage of interviewing drivers

Table 1 – Evidence on cruising for parking in XXI century

Year	City	Search time (min)	Share in traffic flow (%)	Source
2005	Los Angeles	3.3	/	Shoup [4]
2006	New York	/	28	Schaller Consulting [7]
2006	Cities in Netherlands	0.6	30	Van Ommeren et al. [8]
2007	New York	/	45	Transportation Alternatives [9]
2008	New York	3.8	/	Transportation Alternatives [10]
2011	San Francisco	1.3	/	Alemi et al. [11]
2011	Belgrade	3.4	/	Simićević et al. [12]
2011	Barcelona	/	18	Ruh [13]
2012	Turnhout	1.3	/	van der Waerden et al. [14]
2013	Brisbane	13.1	/	Lee et al. [5]
2014	Nottingham, Leicester, Derby & Lincoln	1.7	/	Brooke et al. [15]
2015	Brisbane	14.6	/	Lee et al. [5]
2017	Stuttgart	/	15	Hampshire & Shoup [16]
2017	Bristol	2.3	/	Jones et al. [17]
2018	Ann Arbor	7.7	/	Yan et al. [18]
2020	Ningbo	6.0	/	Zhu et al. [19]
2020	Ann Arbor & San Francisco	3.0	6	Weinberger et al. [20]
Average		4.8	23.7	

is the fact that it enables researchers to collect, in addition to data on parking search time, other (revealed and stated) data which can be useful in parking search behaviour understanding.

It has long been recognised and intuitively evident that the main cause of parking search is the high parking occupancy. The lower the occupancy (i.e. the more vacant parking spaces), the shorter the parking search time. Therefore, the first parking search models were created by correlating search time or search distance exclusively with parking occupancy (see e.g. Gur and Beimborn [22]; Bradley [23]). Consequently, Shoup [4] suggests that targeted on-street parking occupancy should be 85% (i.e. every seventh space should be vacant) in order to eliminate cruising for parking.

However, cruising for parking is a far more complex problem than initially recognised. Later studies show that in addition to parking occupancy at the moment when the vehicle arrives, driver's knowledge, habits, priorities, etc. play an important role in parking search behaviour. Brooke et al. [21] recognise individual characteristics as potential parking search influencing factors. This may include the following: trip, personal, socio-demographic and socio-economic characteristics. Moreover, these authors note that one should also consider the conditions and physical and functional parking characteristics, the applied parking policy and how successfully it is applied (parking enforcement), technological advances (such as Parking Guidance and Information System) and other circumstances (such as weather conditions).

Table 2 provides an overview of factors researched overtime, the influence of which upon parking search time has been confirmed. As aforementioned, the table shows that at the beginning the focus was exclusively on individual parking characteristics, primarily occupancy, and then the parking price (which, as is well known, directly affects the occupancy). However, over time, the complexity of cruising has been increasingly recognised, and in parallel more and more parameters have been included in research, not only parking characteristics, but also individual and in particular travel characteristics.

Table 2 – Overview of parameters confirmed to be important for parking search time

References	Parking characteristics					Individual characteristics				Travel characteristics					
	Occupancy	Price	Duration	Frequency	Turnover	Income	Gender	Experience	Search strategy	Main motive	Arrival time	Travel time/distance	Walking time/distance	Traffic volume	Vehicle occupancy
Gur and Beimborn [22]	X														
Bradley [23]	X														
Arnott et al. [24]		X													
Van Ommerenet al. [8]			X			X				X	X	X			
Pierce and Shoup [25]		X													
Van Ommeren and Russo [26]		X													
Arnott et al. [27]		X													
Brooke [28]		X									X	X	X		
Brooke et al. [15]		X		X						X	X	X	X		
Simićević et al. [3]	X								X						
Assemi et al. [29]	X	X	X	X	X					X	X	X		X	
Qin et al. [30]	X		X			X	X	X		X		X	X		X

To illustrate the above, we will briefly describe several selected studies.

Using data from the national data base, Van Ommerenet al. [8] established that average public parking search time in the Netherlands is 36 seconds. Among the influential factors, they show that income has a negative impact upon parking search time, which coincides with the assumption that users with higher income value their time more. Further, parking search time is much higher for parking purposes "leisure" and in particular "shopping" if compared to "work". The reason behind this, on the one hand, lies in different values we assign to time for the "work" parking purpose compared to other parking purposes, and on the other hand, on the parking occupancy at the moment of search. Additionally, longer travel time and parking duration also increase parking search time. The impact of car occupancy upon parking search time has not been determined.

Brooke et al. [15] use a multilevel model to make important findings under parking search time research. Input data required to fit the model were obtained by interviewing parking users. The authors correlate the parking price and parking search time, showing that as the prices increase, parking search time rises. In addition, the longer the travel time, the longer the parking search time. The same applies to duration of walking from the parking space to the final destination. Furthermore, it is observed that parking search time is affected by the period of the day when the parking demand occurs. Arrivals later during the day lead to longer parking search times in comparison to morning hours. Parking frequency is recognised as an influential factor. It is established that parking users who rarely come to a specific parking and those who come for the first time tend to search for parking longer in comparison to frequent parking users in that area.

Simićević et al. [3] interview parking users in the central area in Belgrade and establish that, apart from the expected impact of parking occupancy on the search time, parking search strategy, described as "the set of behavioural rules adopted by the driver to find a parking space", has a fundamental importance. These findings served to propose parking policy interventions (i.e. to redefine parking prices) and demonstrated the effects of proposed measures upon reduced parking search time and consequently lower fuel consumption and harmful gas emissions.

In order to describe the impact of different factors upon parking search time, Assemi et al. [29] survey users in the central business district of Brisbane. In addition to data collected through the survey, the authors also collected data on parking characteristics, tariff systems on nearby parking capacities and traffic flow data. A multi-nominal logit model was used to identify negative correlation between the frequency of travel and parking search time. It was shown that drivers who parked less often at the considered on-street sections searched longer for a vacant space. This study also confirms the relation between parking search time and parking occupancy. These authors arrive to an interesting finding which differs from similar papers: there is a negative correlation between the traffic volume and parking search time. The authors explain that this is due to the fact that drivers avoid coming to the central business district of Brisbane during peak hours.

3. SURVEY METHODOLOGY

The aim of this survey was to collect data required to develop a logit regression model to identify parameters that considerably impact parking search time. In doing so, we implemented the methodology that is transferable to other urban areas, because it takes into account local specificities and individual user characteristics.

Data were collected in a field survey conducted in the central urban area of Valjevo (Serbia). The survey was carried out during 3 week days in September 2017 in the period when parking was the most intensive (from 7 a.m. to 5 p.m.). The survey was conducted by students of the Faculty of Transport and Traffic Engineering from Belgrade.

Area of survey (Section 3.1) and parameters selected for survey and the method of survey (Section 3.2) are presented hereinafter.

3.1 Area of survey

As above mentioned, the survey was conducted in the central area of Valjevo. Valjevo is located in the western part of Serbia, only 69 km of Belgrade, the capital of Serbia. Because of its favourable position to important travel routes, over time the city developed into one of the most important Serbian cities and is now deemed as administrative, economic and culture centre of this part of the country. According to the results of the latest census from 2011, Valjevo had 90,312 inhabitants [31].

Citizens of Valjevo make on average 3.3 movements per day. Movements are mostly realised using a passenger car (37%) and non-motorised modes: walking (30%) and riding bicycles (20%), while the share of public transportation in the transportation mode distribution is only around 7% [32].

In the central area of Valjevo there are 1,945 public parking spaces, majority of which (79%) are located on street, while a smaller portion refers to off-street parking (21%). There are no public parking garages yet. A restrictive parking regime has been applied at these parking spaces for more than a decade, and the same measures apply on both parking types. There are two parking zones: the Red Zone, where parking is limited to 3 hours and costs €0.3 per commenced hour and the Blue Zone where there is no time limit, and it costs €0.19 per commenced hour or €0.83 per day. In addition to the above, it is also possible to buy monthly parking subscriptions with prices ranging from €10.1 do €12.7, while residents are entitled to buy parking permits (2.5 €/month). This inadequate tariff system contributed to the fact that, most of the time, parking occupancy levels are higher than 85%, which is especially true for the Blue Zone. On the other hand, due to poor parking enforcement, illegal parking is evident throughout the day, even in periods when parking spaces are underused.

Within the central area, the survey was conducted at selected street sections, more precisely at 128 on-street parking spaces, of which 71 were located in the Red Parking Zone and 57 in the Blue Parking Zone, see *Figure 1*. The reason behind selecting only on-street parking spaces for the survey was the fact that searching for an on-street parking space has more negative effects than queuing for parking in front of an off-street parking, and also because on-street parking spaces are dominant in this zone.

3.2 Data collection

Analysis of to-date literature (Section 2) and previous experience of the authors indicated the parameters expected to possibly have a considerable impact upon parking search time. Since these parameters are obtained from field surveys, mostly by interviewing drivers who park at the observed parking spaces, we had to take into account the limitations of this methods as well, such as the number of questions that we should ask [21] and then to additionally revise the previously selected parameters accordingly. Consequently, some parameters

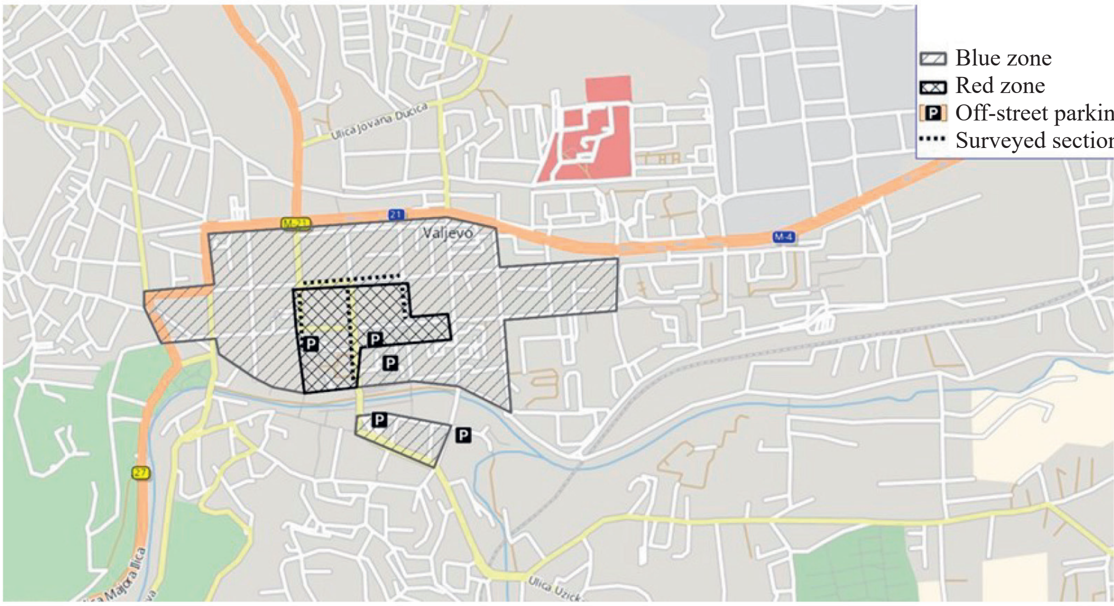

Figure 1 – Area of survey

were excluded from further consideration, because previous research in the local conditions did not confirm their significance in the parking search process, or we assumed that such parameters did not have importance due to the local context (for example, in Serbia there is not necessarily a correlation between the driver's education and income, i.e. the value of time).

In the end, we chose the following trip characteristics: arrival and departure time (which also served to establish parking duration), walking distance, parking purpose and frequency. Furthermore, since parking search behaviour is not necessarily a rational process, but sometimes depends on driver's parking service preferences, we also determined the ranking of the following parking service quality parameters: finding a vacant parking space, shorter walking distance to the final destination, lower parking charge and vehicle safety. Finally, we established the parking search manner/strategy, i.e. whether the parking user first arrives to the destination and then starts searching for parking (strategy 1) or starts searching before reaching the destination, while still driving towards the destination (strategy 2).

When it comes to driver characteristics, we selected gender and age.

All the above mentioned characteristics were established by interviewing drivers who had just parked or were leaving their parking spaces (survey template shown in Attachment 1). In addition, by combining interviews and the counting method, we arrived at the parking occupancy value in this zone when the driver was searching for parking, as this is one of the most frequently used determinants (Section 2). Namely, the survey helped us determine the arrival time, which was also taken as the time when the parking search started, while the counting method was used to determine the parking accumulation (and further, to calculate the parking occupancy) at 20-minute time sections. In doing so, we distinguished between legally and illegally parked vehicles.

As already mentioned, some of the studies correlated traffic flow parameters (flow, speed, etc.) to the time required to find a vacant parking space (Section 2). In order to investigate the impact of traffic flow conditions upon parking search time, we took vehicle flow data at 16 intersections located within the area of survey from Valjevo traffic study (Model 5 [33]), and then we related those values to the arrival time of the interviewed drivers.

In addition to these parameters, that represent potential independent variables in the model, we also surveyed the dependent variable – the time the drivers needed to find a vacant parking space. This value was also determined through the survey, based on the users' statements regarding the time they needed to find a vacant parking space: no parking search, up to 5 minutes, from 5 to 10 minutes or above 10 minutes. Even though determination of parking search time based on user perception may seem imprecise, this is one of the generally accepted methods to determine this value (Section 2).

4. MODELLING FRAMEWORK

Computer modelling in the form of simulations has been applied in many studies investigating the parking search time. There are far fewer empirical studies, such as ours. In comparison to other empirical studies, ours differs in the statistical techniques that are applied to obtain the output results.

Selection of a specific regression model was conditioned by the type of the dependent variable. The dependent variable (parking search time) was designed as categorical, with modalities that have a natural order, so for this reason we selected the ordinal regression model (ORM). Ordinal regression is recognised as a powerful statistical tool, as not only it compares the odds of belonging to one category with odds of belonging to another, but it also takes into account the order of categories. To date, several ordinal regression models have been developed. We chose the cumulative model (proportional odds model), which is the most commonly used model in practice.

Let Y_i, i=1,…,N, the dependent ordinal variable taking one of the J categories. Corresponding probabilities for realisation of each category at the i observation are as follows:

$$\pi_{i1} = P\left(Y_i = 1\right), \ldots, \pi_{iJ} = P\left(Y_i = J\right) \tag{1}$$

As already mentioned, ordinal variables provide additional information regarding to the relationship among dependent categories: in such cases, it is easy to see which category is "smaller" and which is "larger". Mathematical formulation of the probability of "smaller" category realisation is given below. In this context, the following cumulative probabilities (defined as described below) are crucial:

$$P\left(Y_i \leq j\right) = \pi_{i1} + \pi_{i2} + \ldots + \pi_{ij} \tag{2}$$

where j=1,…,J representing the realised category of the dependent variable.

In this model, we are interested in the odds for realisation of each single category of the dependent variable, but in such a way that we consider the ratio between the sum of probabilities for the realisation of "smaller" categories and the sum of probabilities for the realisation of categories that are "larger" than the former. If the independent variables are also included into the model, we get the following form:

$$\log\left(\frac{P\left(Y_i \leq j\right)}{P\left(Y_i > j\right)}\right) = \log\left(\frac{P\left(Y_i \leq j\right)}{1 - P\left(Y_i \leq j\right)}\right) = \beta_{0j} + \beta_{1j}x_{i1} + \beta_{2j}x_{i2} + \ldots + \beta_{Kj}x_{iK}, \quad j \in \left\{1, \ldots, J-1\right\} \tag{3}$$

where K denotes the number of independent variables, while $\beta_{0j}, \beta_{1j}, \beta_{2j}, \ldots, \beta_{Kj}$ represent the vector of parameter estimates. In this manner we calculate the odds of the realisation of category which is smaller than or equal to the j^{th} compared to the realisation of category which is larger than j^{th}.

An important assumption of this model is that coefficients $\beta_{1j}, \beta_{2j}, \ldots, \beta_{Kj}$ do not depend on the category j, but are equal for each j (1,...,J), unlike the coefficients β_{0j} that depend on the category j and vary for each of the functions (constant term).

Data collected during the field surveyed as described in detail in Section 3 were used to develop an ORM. The survey covered a sample of 190 parking users.

4.1 Data analysis

The observed sample is described in *Table 3* and *Table 4*. For each categorical variable, the tables show the frequency of the modality (n), as well as the corresponding share percentage (%). To describe continuous variables, we used the following statistical indicators: minimum value (Min), maximum value (Max), mean value (M) and the standard deviation (SD). In addition, *Table 3* and *Table 4* show the results of testing the relation between the parking search time and all other characteristics that comprise the independent variable set. Test results that were deemed important served as the basis for the assumption that the researched phenomenon did exist.

The majority of users were male (63.7%), aged between 30 and 45 (40.0%). Primary purposes for parking in this zone were private business (26.8%), followed by leisure and shopping (21.1% and 17.4%, respectively), while other parking purposes were less reported. Accordingly, parking users spent less time in the zone, 90.5% of them less than 3 hours. Almost one half of the parking users rarely parked in this zone: several times per

Table 3 – Users´ characteristics

Users' characteristics	All respondents (n=190)	P
Gender, n (%)		0.138[a]
Male	121 (63.7%)	
Female	69 (36.3%)	
Age (years), n (%)		0.692[a]
18–30	50 (26.3%)	
30–45	76 (40.0%)	
45–60	52 (27.4%)	
≥ 60	12 (6.3%)	

[a] Chi-square test ($\chi 2$); P – Statistical significance (significant when $p \leq 0.05$); n – Number of respondents

Table 4 – Trip characteristics

Trip characteristics	All respondents (n=190)	P	Trip characteristics	All respondents (n=190)	P
Trip purpose, n (%)		0.016[a]	Main parking quality parameter, n (%)		0.720[a]
Residence	12 (6.3%)		Vacant parking space	64 (33.7%)	
Shopping	33 (17.4%)		Vicinity of the destination	47 (24.7%)	
Work	11 (5.8%)		Lower parking price	52 (27.4%)	
Leisure	40 (21.1%)		Car safety	27 (14.2%)	
Business	43 (22.6%)		Parking search time (min), n (%)		/
Private business	51 (26.8%)		Without searching	109 (57.4%)	
Parking frequency, n (%)		0.089[a]	Up to 5 minutes	61 (32.1%)	
Every day	26 (13.7%)		From 5 to 10 minutes	15 (7.9%)	
Several times a week	85 (44.7%)		Over 10 minutes	5 (2.6%)	
Several times a month	63 (33.2%)		Parking search time (min), n (%)		/
More rarely	16 (8.4%)		Without searching	109 (57.4%)	
Parking duration (min), M±SD(Min–Max)	102.5±126.7	0.414[b]	Up to 5 minutes	61 (32.1%)	
	(5–1047)		Over 5 minutes	20 (10.5%)	
Parking duration, n (%)		0.212[a]	Parking search strategy, n (%)		0.000[a]
Up to 1 h	95 (50.0%)		At the final destination	103 (54.2%)	
From 1 to 2 h	64 (33.7%)		Before the final destination	87 (45.8%)	
From 2 to 3 h	13 (6.8%)		Parking occupancy, M±SD(Min–Max)	0.76±0.22	0.000[b]
Over 3 h	18 (9.5%)			(0.25-1.18)	
Walking distance (m), M±SD (Min–Max)	188.3±107.1	0.031[b]	Arrival during the peak period, n (%)		0.003[a]
	(20–800)		Yes	63 (33.2%)	
			No	127 (66.8%)	

[a] Chi-square test ($\chi 2$); [b] One-way analysis of variance (ANOVA); M±SD(Min–Max) – Mean ± Std. Deviation (Min–Max); P – Statistical significance (significant when $p \leq 0.05$); n – Number of respondents

month (33.2%) or even less frequently (8.4%). The average walking distance from the parking space to the final destination was 188 m, thus the mean walking distance is somewhat longer if compared to other cities of similar size in Serbia. When it comes to service quality parameters, for parking users the most important was to manage to find a vacant parking space at all. The second ranked parameter was the parking price, being more important for the users than the proximity of the final destination and vehicle safety.

More than one half of the users (57.4%) stated they had not searched for a vacant parking space, while slightly less than one third of the users stated they had searched for less than 5 minutes. Slightly more drivers (54.2%) employed strategy 1 when searching for parking i.e. reaching the destination first, and only then would the drivers start searching for parking.

When analysing the collected data, special attention was given to parking occupancy because of the importance of this characteristic in the context of parking search time (Section 2). The field survey determined the mean parking occupancy value of 0.76 with the standard deviation of 0.22 (*Table 3*). Maximum recorded value of 1.18 confirms there is a parking problem and indicates that the portion of illegally parked vehicles is not so small (23 vehicles were parked illegally). Therefore, in addition to the regular parking spaces, we decided to include illegal parking into the analysis, as part of the official parking supply. The primary reason to include illegal parking was the fact that it was observed that parking users were used to parking their vehicles at spaces not intended for parking, despite the fact there were vacant, regulated parking spaces available. So, the users consider such illegal spaces (where parking is not allowed) to be parking capacities and in case they find a vacant space, they do not refrain from parking there.

We tested the impact of different variants of parking occupancy in order to arrive at the best possible description of causal relations to the dependent variable. We created sets of occupancy values in comparison to spatial characteristics, and then we assigned each survey respondent with a corresponding occupancy value according to their time of arrival. We separated several variants which were used to calculate the parking occupancy: for a particular street section where the user parked, for zones formed according to the attractiveness in terms of the realised demand (ratio between the afternoon and morning accumulation), for the whole survey area and for the existing parking zones (Red and Blue). In addition, for each of the above variations we analysed only regularly parked vehicles, as well as all parked vehicles (regular and illegal parking). *Table 5* shows an overview of variance analysis (ANOVA) for different occupancy variants.

Table 5 – Variance analysis (ANOVA)

Parking occupancy scenarios	F	p
Surveyed sections (regular parking)	16.620	0.000
Surveyed sections (regular+illegal parking)	15.030	0.000
Attractiveness of the zone (regular parking)	16.376	0.000
Attractiveness of the zone (regular+illegal parking)	14.943	0.000
Total area (regular parking)	14.119	0.000
Total area (regular+illegal parking)	12.596	0.000
Parking zones (regular parking)	24.135	0.000
Parking zones (regular+illegal parking)	27.850	0.000

Calculated results confirm there is a statistically significant difference between the classes of the dependent variable – parking search time and the corresponding mean values of parking occupancy. The most fitting was the parking occupancy established depending on the parking zone where the user parked ($F=27.850$; $p<0.000$). Selection was made based on the performed univariate ordinal regression, which recognised the highest contribution coming from this occupancy variant in the explanation of the independent variable (Wald=33.664;

p<0.000). The result obtained can be explained by the fact that parking regimes differ between the parking zones (Red Zone and Blue Zone), and different regime attributes exert different impact upon the occupancy value.

In addition to parking occupancy and other mentioned characteristics, it is assumed that parking search time is also affected by the traffic flow conditions [29, 34]. Traffic flow conditions and parking characteristics are multiply related. For example, the current parking occupancy dictates the distance the user has to travel in order to find a vacant parking space. The time the user needs to travel this distance depends directly on the traffic flow conditions, primarily on the speed. We used the traffic flow data to determine peak and off-peak periods during the day. Time periods when the vehicle flows in the areas of the observed intersections were intensive were marked as peak periods, so parking users were classified according to peak/off-peak period of their parking. As a result, three periods transpired as peak periods: 07:00 a.m.–08:30 a.m., 02:30 p.m.–05:00 p.m. and 06:30 p.m.–08:30 p.m. Intensive traffic demand in the morning and afternoon peak periods is related to the working hours, i.e. the time when the users come to/leave from work. On the other hand, the evening peak period occurs primarily due to leisure activities. The evening peak period is not included in the scope of our research. Data from *Table 4* show that 66.8% of the parking demand happened within off-peak hours (in terms of traffic dynamics).

4.2 Model fitting

Data collected during the field survey were grouped and sorted to serve as a basis for the model development. Data presented in Section 4.1 helped define the direction during the model fitting. Even though parking search time (the dependent variable) originally included four categories (Section 3.2), due to the low frequency of some categories we decided to regroup them, so the last two categories were integrated into a single category. Predictors were included in the model rather carefully, with due care given to the model complexity and its prediction capabilities. The goal was to create a simple model with good performances. The final model is given in *Table 6*.

Several indicators were used to evaluate the model performances. In this paper, the threshold of 0.05 for determining statistical significance has been adopted. Comparison of the model developed to the zero model which included only the constant shows that the set of independent variables reliably predicts the parking search time (χ^2=32.666; df=4; p<0.000). Pearson's chi square test was used to assess the model's goodness of fit. The result obtained (χ^2=183.771; df= 172; p<0.256) indicates that parameters included are consistent with the model, i.e. that the model is properly fitted. Parallel lines test accepts the zero hypothesis (χ^2=6.524; df=4, p<0.163) that the regression coefficients are equal for all variable categories, thus justifying the application of ORM.

Table 6 – ORM Results

Dependent variable	Variable	Parameter estimate (B)	Std. Error	Wald	Sig.	Exp(B)
Parking search time (ref. over 5 minutes)	Without searching	2.234	0.769	8.443	0.004	
	Up to 5 minutes	4.331	0.816	28.164	0.000	
	Parking occupancy	4.239	0.901	22.123	0.000	30.027
Parking frequency (ref. more rarely)	Every day	-1.612	0.710	5.146	0.023	0.188
	Several times a week	-0.942	0.527	3.195	0.074	0.395
	Several times a month	-0.892	0.542	2.706	0.100	0.417

The model distinguished two most significant parameters impacting the parking search time by the user. These are the parking occupancy at the moment of search and parking frequency.

As expected, the results show that the higher the parking occupancy in the moment of parking search, the longer the user needs to finds a vacant parking space, and vice versa. Furthermore, a negative correlation between on-street parking frequency and parking search time was revealed. This implies that drivers who park less often at the observed street sections search for a vacant parking space longer. This result is based on the fact that users who park frequently in the zone are more aware of the local conditions and have a better idea where it is possible to find a vacant parking space. The same was concluded by other authors, such as Teng et al. [35], Brooke et al. [15] and Assemi et al. [29].

In addition to the two above mentioned parameters that were included in the final model, some other parameters also were shown to be statistically significant. Specifically, the variable that defines whether the user parked in the peak/off-peak hours proved to be influential. Even though peak/off-peak periods were defined on the basis of the traffic flow characteristics, the main feature of this variable is the time component that is further on related to the parking occupancy at the time of arrival. More precisely, users who were searching for parking during off-peak periods spent more time cruising, because the maximum parking demand was around noon and in early afternoon hours (that were included in the off-peak hours). Since a logical relation between these two variables was established, we decided to exclude the time of arrival in peak/off-peak hours from the model.

A statistically significant impact upon parking search time was also identified for walking distance. As expected, it was shown that the higher the walking distance from the parking space to the final destination, the higher the parking search time. However, it is questionable whether the longer walking distance is the cause or the consequence of longer parking search time. Generally speaking, a parking user who cruises longer to find a vacant parking space is at the same time moving away from the final destination, thus increasing the walking distance. This leads to a conclusion that walking distance is actually related to parking occupancy, the impact of which is explained in the previous section.

Using the data from *Table 6* (constant terms and parameter estimates), probabilities of parking search time categories can be calculated. These equations are as follows:

$$logit\left(P_1\right) = 2.234 + 4.239k_i - 1.612f_{ed} - 0.942f_{stw} - 0.892f_{stm} \quad (4)$$

$$logit\left(P_2\right) = 4.331 + 4.239k_i - 1.612f_{ed} - 0.942f_{stw} - 0.892f_{stm} \quad (5)$$

where:
$logit(P_1)$ – the probability of not searching for parking (search time equals 0);
$logit(P_2)$ – the probability of searching for parking for less than 5 minutes;
k_i – parking occupancy at the moment of search;
f_{ed} – the user parks in the area every day (equals 1 if the statement is true, 0 otherwise);
f_{stw} – the user parks in the area several times a week (equals 1 if the statement is true, 0 otherwise);
f_{stm} – the user in the area several times a month (equals 1 if the statement is true, 0 otherwise).

5. CONCLUSION

The paper analyses the impact of certain factors upon parking search time. For this reason, we developed an ordinal logit model using empirical data collected by interviewing drivers. The proposed methodology is applicable to other cities as well, and it can be adjusted to the local context, as required. In this case, the applied methodology identified patterns of user behaviour conditioned both by their characteristics and by the traffic conditions. Specifically, it was established that parking search time is influenced mainly by the following two characteristics: parking occupancy at the moment of parking search and frequency of parking in a particular area.

We also confirmed the impact of parking occupancy at the moment of parking search upon the time required to find a vacant parking space. The lower the parking occupancy, the shorter the parking search time. This actually means that in order to reduce/eliminate parking search, good parking management is required, i.e. it is required to enforce adequate policies and measures that will result in achieving the primary, direct goal of parking management – achieving balance between parking demand and parking supply. In this respect, parking charge proved to be a useful tool, and for this reason it is often emphasised that the parking cruise problem is actually the problem of under-priced parking [4] and that prices need to be set to reach a target parking occupancy of 85 to 90% [36]. The reason for this is the fact that it is considered that at this parking occupancy users can find a vacant parking space at any time and yet, on the other hand, parking spaces remain used to an acceptable degree, because we cannot allow spaces that are generally scarce in urban areas to be used irrationally.

The second parameter the significance of which was identified by the model is the frequency of parking in a particular area. Parking frequency is closely related to the level of knowledge of local parking conditions: users who come to the central urban area by car less often are less or not at all aware of the local context, so they search for parking longer. Better provision of vacant parking information to these users should contribute to reduction of parking search time. For this purpose, Parking Guidance and Information (PGI) systems are used to inform the user in real time about vacant parking spaces. Recently such systems have been intensively introduced worldwide. If parking occupancy is high, PGI systems will not be useful to users, because they will almost always inform the user there are no vacant parking spaces. On the other hand, if parking occupancy is low, users will be able to find a vacant parking space easily and without the assistance of a PGI system. This actually brings us back to the first step, emphasising that the principal action to reduce parking search time is successful parking demand management.

Results obtained in this paper are useful for policy makers and local authorities to understand the nature and the importance of the parking cruise problem. In addition, the results indicate what directions to follow when defining a set of measures to reduce/eliminate parking search time. In this sense, the proposed methodology contributes to the decrease of congestions in urban areas. The effects of applying proper parking policies to achieve the desired parking occupancy and improved provision of vacant parking space information to parking users are manifold. Not only do these policies ensure positive effects in the parking sub-system, but they also support the implementation of urban mobility goals, primarily through better accessibility, attractiveness and quality of life in cities [37]. In addition to the social aspect, successful application of proper parking measures contributes both ecologically and economically.

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Ordinalni regresioni model vremena traženja slobodnog parking mesta

Rezime

Vožnja zbog traganja za slobodnim parking mestom smanjuje kvalitet usluge u parkiranju, ali i nivo usluge na saobraćajnoj mreži generisanjem dodatnog saobraćaja. Traganje za slobodnim mestom sa sobom nosi i druge negativne efekte, pre svega ekološke, društvene i ekonomske prirode. Iako je važnost ovog problema uočena još ranije, stiče se utisak da fenomen traženja slobodnog parking mesta još uvek nije dovoljno istražen i da su potrebne dodatne analize kako bi se njegova priroda bolje razumela. S tim u vezi, ovaj rad ima za cilj da ispita faktore koji utiču na vreme potrebno za pronalaženje slobodnog mesta, a na koje je moguće uticati skupom upravljačkih mera. U radu je za procenu parametara razvijen ordinalni logit model, koji je podešen korišćenjem empirijskih podataka prikupljenih anketiranjem vozača. Glavni rezultati modela ukazuju da zauzetost parking mesta ima najveći uticaj na dužinu vremena traženja što ukazuje na značaj definisanja politika i mera koje treba da dovedu do željene zauzetosti kapaciteta za parkiranje. Učestalost parkiranja je drugi parametar čija je značajnost uočena, što ukazuje na važnost implementacije adekvatnih sistema informisanja u parkiranju.

Ključne reči

traženje parking mesta; politika parkiranja; ordinalni regresioni model.