Exploring en-route parking type and parking-search route choice: decision making framework and survey design

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Abstract
This paper describes the first phase of an on-going research investigating the joint choice of parking type, parking facility and cruising-for-parking route. The importance of this issue derives from the significant share of cruising-for-parking traffic in urban areas, the relevance of parking policies as travel demand management tools, the growing interest in parking guidance information systems, and the need for representing parking-search behavior in traffic assignment and micro-simulation models. This paper addresses two main topics. First, the development of a methodological framework is introduced, including a behavioral model, its mathematical representation and the variable specification. Second, the design of a two-wave field survey accompanies the framework, with the aim of revealing the determinants of cruising-for-parking by retrieving both self-reported and GPS data. This paper concludes with a trajectory for the research completion and a discussion of data collection challenges yet to be addressed.

1 Introduction
Cruising-for-parking traffic comprises a significant share of the total traffic volume, with average figures equal to 30-50% of the total traffic volume in major city centers across world regions (Arnott and Inci, 2006; Shoup, 2006). Although data regarding the actual societal costs imposed by cruising-for-parking traffic are scarce (Arnott and Inci, 2006), existing evidence indicates that cruising-for-parking traffic bears severe economic and environmental implications in urban areas due to the additional travel time related to parking-search behavior. In fact, surveys conducted in Europe before the turn of the century show that 25-40% of the travel time and distance to central urban areas is attributed to parking-search (Bonsall and Palmer, 2004). According to studies conducted in several major cities (Shoup, 2006), the average parking-search time is evaluated to be eight minutes on average. Hence, reducing parking-search time could lead to significant gains in terms of time and production, traffic flow, fuel consumption, pollutant and noise emissions. In addition, cruising-for-parking traffic is possibly related to traffic safety, as a recent study shows that damage-only accidents are 20% higher in urban streets with on-street parking relative to other streets (Marshall et al., 2008).
The literature regarding discrete choice modeling of parking choice behavior is voluminous and can be partitioned into three main research streams.

The first stream is motivated by the need for examining the ability of parking policies to influence parking-related decisions. Consequently, the addressed issues are: choice of parking type between on-street, off-street, and illegal parking (van der Goot, 1982; Axhausen et al., 1988; Axhausen and Polak, 1991; Tekmono and Hoko, 1997; Golas et al., 2002; Sattayhatewa and Smith, 2003; Hess and Polak, 2004; Guan et al., 2005); choice among parking facilities (Lambe, 1996; van der Waerden et al., 2000; Anderson et al., 2006; Harmatuck, 2007; Van der Waerden et al., 2008); joint choice of parking type and facility (Hunt and Teply, 1993).

The second stream is intrigued by the need for analyzing the ability of parking policies to influence other trip-making decisions, and hence focuses on the linkage between parking choices and other travel choices. The addressed joint decisions are: travel mode and parking type (Bradley et al., 1993); travel mode and parking location (Hensher and King, 2001; van der Waerden et al., 2006; Chalermpong and Kittiwangchai, 2008); travel mode, destination, and time of day changes as a result of parking policy changes (Shi and Burd-Eden, 2001); travel mode, destination, and parking facility (van der Waerden et al., 2001).

The third stream is inspired by the advancement of parking guidance and information (PGI) systems and their potential to increase the usage efficiency of the parking stock, to alleviate the burden and uncertainty associated with cruising-for-parking, and to relieve traffic congestion. Consequently, the third stream seeks to explore en-route drivers’ decisions and behavioral changes in response to en-route parking information. The investigated choices are: parking-search duration, parking-search direction and parking-search difficulty (Axhausen et al., 1994; Axhausen and Polak, 1995; Thompson and Richardson, 1998; van der Waerden et al., 2002; Teng et al., 2001a); en-route revision of pre-trip parking facility choice, highway-exit choice, adaptive choice behavior and waiting time at the entrance of the parking facility (Waterson et al., 2001; van der Waerden et al., 2002; Bonsall and Palmer, 2004); choice of a parking stall inside parking facilities (van der Waerden et al., 2003; Caicedo et al., 2006); parking behavior before and after arrival to the destination (Benenson et al., 2008); choice parking information technologies for pre-trip versus en-route decisions (Teng et al., 2001b).

The current study focuses on investigating en-route cruising-for-parking behavior with a discrete choice approach. In particular, the current paper focuses on proposing a behavioral modeling framework that encompasses the combined choice of parking type, parking facility, and driving route during the search for a parking place. Notably, efforts for modeling en-route cruising-for-parking behavior include an aggregate supply-demand equilibrium approach (e.g., Arnott and Inci, 2006; Arnott and Rowse, 2009) and an agent-based heuristic approach (e.g., Benenson et al., 2008). The current study adds to these efforts by providing a framework that enables to analyze the relationship between individual characteristics and cruising-for-parking behavior at the disaggregate level. The importance of this study derives from the necessity to develop a disaggregate model that captures cruising-for-parking behavior in order to explore the impact of parking-related policies as tools for travel demand management in congested urban areas. In addition, the model can contribute to enhancing the representation of cruising-for-parking traffic in both
traffic assignment and micro-simulation models such as PARKIT (e.g., Bonsall and Palmer, 2004) and PARKAGENT (e.g., Martens and Benenson, 2008). Consequently, such model would serve as a planning tool for transportation network management in general, and for investigating the influence of parking policies and PGI systems on cruising-for-parking behavior in particular.

This paper describes the first phase of the current on-going research and is organized as follows. Section 2 presents the development of a methodological framework for the joint modeling of parking place and route search. Section 3 describes the design of a two-wave field survey design that accompanies the framework with the aim of unveiling the determinants of route choice while cruising-for-parking by retrieving both self-reported and GPS data. Section 4 concludes the paper with the trajectory for the completion of the current research.

2 Methodology

2.1 Behavioral framework

The current research proposes an integrated framework that represents en-route cruising-for-parking, given that a certain trip is conducted as planned, namely without a change in the pre-travel choices of activity location and daily period, and that a parking choice is made, namely without abortion of the trip. The framework describes a series of joint decisions consisting of (i) determination of a parking-search starting-point upon arrival within a certain distance to the destination, (ii) choice of parking type, (iii) selection of parking facility, and (iv) parking-search route choice. The framework is illustrated in Figure 1.

Based on the car drivers' activity at the destination, time of day of the trip, and direction of approaching the destination, an initial decision of parking type is made at the parking-search starting point. Namely, at the parking-search starting point drivers may choose between searching for on-street parking and using an off-street parking facility. Upon the selection of on-street parking, drivers plan a parking-search route subject to vehicle size and spatiotemporal constraints until they find a vacant parking space satisfying the vehicle size constraint. Drivers may reconsider their decision and park off-street in case that no vacant space is found within their spatiotemporal constraints. Upon the selection of off-street parking, drivers choose among available parking facilities located within a certain radius from the destination. The choice of off-street parking facility changes the actual destination of the trip from the location of the activity to the location of the parking facility and consequently influences the chosen route at the parking-search starting point. In case that the parking facility is unavailable (e.g., full, closed, or too expensive), drivers may reevaluate their previous decision and choose to drive to a different off-street parking facility or to try to park on-street.

Notably, the hypothesized parking-search route choice mechanisms differ according to the chosen parking type.

In the case that a decision is made to park off-street, drivers engage in a sequence of parking facility choice followed by route choice to the chosen parking facility. Upon the choice of a parking facility, the route is merely the mean to arrive from the parking-search
starting point to the parking facility. Consequently, drivers who decide to park off-street would attempt to maximize their utility by choosing an efficient route in terms of travel time. Naturally, shorter routes, non-congested routes and routes with little delay due to parking activity would be preferred by off-street parkers.

In the case that a decision is made to park on-street, drivers decide upon the parking-search starting point and then develop a search route in the vicinity of their destination until they find an available parking space, subject to vehicle size and parking-search spatiotemporal constraints (e.g., parking-search time, number of turns). The hypothesized development of a parking-search route comprises of a global and a local search behavior. The global parking-search gradient, namely the general direction for the development of the parking-search route, is determined by drivers according to the angle between the direction of the movement and the direction of the destination, the proximity to the destination, and the personal perceptions regarding parking availability and parking turn-over rates. Naturally, routes with greater parking opportunities and intensive parking activity would be preferred by on-street parkers. By repeated evaluation of the driving course and adjustments according to the parking-search gradient, drivers direct their vehicle with the
aim of finding favorable parking locations in terms of proximity to the destination, parking availability and turn-over. Given a general parking-search gradient, the local parking-search behavior is hypothesized to be a myopic run-and-tumble search mechanism due to the uncertainty involved with the parking prospects that lie ahead. Namely, while cruising-for-parking, drivers randomly choose the driving search direction (i.e., right, left, through) at each intersection, hoping to "stumble" over parking opportunities. Notably, while cruising-for-parking, drivers compare available parking opportunities to future prospects for seemingly better parking opportunities, thus leading to longer parking search routes and more erratic behavior. Finally, drivers may decide to repeat previous movements and revisit previous streets by driving in loops, thus exhibiting a myopic search behavior, seemingly "forgetting" the direction in which they are driving.

The weight of the general parking-search gradient versus the myopic and erratic local search in cruising-for-parking behavior is related to the drivers' familiarity with the road network, drivers' parking skills, the level of congestion, the parking scarcity, the parking turn-over rates and the availability of PGI systems.

Figure 2 illustrates the difference between the parking-search routes linked to off-street and on-street parking with a simple example. Consider two drivers who decide to travel for shopping purposes during the afternoon peak hour to point A, which is located in the central business district (CBD) of the city of Tel-Aviv. The first driver decides to park off-street, and hence chooses between two nearby parking facilities. Upon choosing the underground parking facility located on Brener Street, possibly due to its greater proximity to the destination, the driver chooses the shortest path to the facility from the parking-search starting point, in agreement with the traffic direction. The second driver decides to park on-street and hence starts to develop a parking-search route from the parking-search starting point. The driver starts driving directly towards the destination, but fails to find an available parking space. Following, the driver performs a series of maneuvers consisting of attempts to find a parking place based on previous experience, and attempts to adjust the global parking-search gradient according to the direction of the destination. Eventually, the driver finds parking on Brener Street. Notably, although the final parking place of the two drivers is in close proximity, their chosen routes greatly differ in terms of length, time, road hierarchy, directness (number of turns) and formation of loops.

Figure 2. Example of a parking-search route for off-street and on-street parkers
2.2 Model formulation

The hypothesized cruising-for-parking model representing the joint decision of parking type, parking facility and parking-search route is illustrated in figure 3. The first decision is a binary decision related to parking type, namely drivers decide whether to park on-street or to park off-street in a parking facility. In the case that a decision is made to park on-street, drivers drive around along a viable parking-search route until they find an available parking place. In the case that drivers park off-street, they choose among parking facilities and then choose among the routes leading from the parking-search starting point to the parking facility.

![Figure 3. Cruising-for-parking model structure](image)

2.2.1 Parking type choice

Drivers' preferences regarding the binary choice of parking type are possibly related to individual characteristic, trip attributes and the overall utility expected from on-street and off-street parking. Consequently, the probability of driver \( n \) choosing off-street parking is represented according to a binary logit model as follows:

\[
P_{ni} = \frac{\exp(\beta_z 'Z_{ni} + \delta_i 'T_{ni} + \lambda_i I_{ni})}{\exp(\beta_z 'Z_{ni} + \delta_i 'T_{ni} + \lambda_i I_{ni}) + \exp(\beta_z 'Z_{nj} + \delta_j 'T_{nj} + \lambda_j I_{nj})}
\]

(1)

where alternatives \( i \) and \( j \) represent respectively off-street and on-street parking, \( Z_{ni} \) and \( T_{nj} \) are respectively vectors of individual characteristics and trip attributes relevant for choosing alternative \( i \), \( I_{ni} \) and \( I_{nj} \) are the inclusive values respectively rendered from the off-street joint choice of parking facility and route and the on-street parking-search route choice. \( \beta_z, \delta_i, \lambda_i \) and \( \lambda_j \) are vectors of parameters to be estimated.
2.2.2 Off-street parking facility and route choice

The choice of parking facility is possibly related to the characteristics of the facility and to the utility derived from driving from the parking-search starting point to the parking facility. Hence, the probability \( P_{nf}^* \) of driver \( n \) choosing parking facility \( f^* \) can be described as a multinomial logit model as follows:

\[
P_{nf}^* = \frac{\exp \left( \beta_y Y_{nf}^* + \lambda_f I_{nf}^* \right)}{\sum_{f \in F} \exp \left( \beta_y Y_{nf} + \lambda_f I_{nf} \right)}
\]

where \( Y_{nf} \) is a vector of parking facility attributes and \( I_{nf} \) is the inclusive value rendered from the route choice to parking facility \( f \). Notably, the parking facility characteristics may vary across respondents due to discounted fares (e.g., city residents, mobility-impaired drivers) or the availability of reserved parking. \( \beta_y \) and \( \lambda_f \) are vectors of parameters to be estimated.

The inclusive value derived from the joint choice of off-street parking facility and route from the parking-search starting point to the parking facility is expressed as follows:

\[
I_n = \ln \sum_{f \in F} \exp \left( \frac{(\beta_y Y_{nf}^* + \lambda_f I_{nf}^*)}{\lambda_f} \right)
\]

Drivers on their way to the parking facility are assumed to maximize their utility by choosing the most efficient route to the parking facility (e.g., minimizing travel time, balancing between travel time and the prospect to find on-street parking). Consequently, the probability of driver \( n \) selecting route \( r^* \) can be expressed as a path size correction logit model (Bovy et al., 2008) that accommodates correlation across alternatives while maintaining the simple Logit structure:

\[
P_{nr}^* = \frac{\exp \left( \beta_x X_{nr} + \beta_{PSC} PSC_{nr}^* \right)}{\sum_{r \in R} \exp \left( \beta_x X_{nr} + \beta_{PSC} PSC_{nr} \right)}
\]

\[
PSC_{nr}^* = \sum_{a \in \Gamma^*_r} \left( \frac{L_a}{L_r^*} \ln \sum_{r} \delta_{ar} \right)
\]

where \( X_{nr} \) is a vector of attributes for route \( r \), \( PSC_{nr}^* \) is the path size correction of route \( r^* \), \( \beta_x \) is a vector or utility parameters, \( \beta_{PSC} \) is a parameter that relates the correction to the utilities, \( L_r^* \) is the length of route \( r^* \), \( L_a \) is the length of link \( a \), \( \Gamma^*_r \) is the set of links belonging to route \( r^* \), and \( \delta_{ar} \) is equal to one if route \( r \) uses links \( a \) and zero otherwise.

Notably, as drivers are assumed to choose among efficient routes to the parking facility, the proposed choice set formation relies on deterministic path generation techniques such as k-shortest paths, labelling approach, link elimination and link penalty (see review by Prato, 2009). Choice set generation by k-shortest paths is plausible for off-street parkers who do not reconsider on-street parking on their way to the parking facility and hence seek to minimize their inconvenience due to the travel time from the parking-search starting point to the parking facility. The labelling approach is relevant since drivers may have different objectives in their route choice to the parking facility. Specifically,
some drivers may seek to minimize their travel time, while others may maintain the hope of on-street parking by driving through streets with intensive parking activity. Finally, link elimination and link penalty are considered since drivers may choose to avoid certain streets while searching for the shortest path, for example due to street hierarchy, traffic direction, parking intensity (e.g., capacity and turn-over rates).

The inclusive value derived from the route choice to the parking facility $f$ is expressed as follows:

$$I_{nf} = \ln \sum_{r \in S_f} \exp\left[\left( \beta_\cdot X_{nr} + \beta_{PSC} PSC_{nr} \right) / \lambda_f \right]$$

where $S_f$ is the set of routes that lead from the parking-search starting point to parking facility $f$. Notably, the inclusive value for route choice to the parking facility varies across drivers due to differences in the parking-search starting point.

### 2.2.3 On-street parking facility and route choice

The model formulation for on-street parking assumes that, in the absence of information regarding available on-street parking stalls and their location, drivers can only choose the route along which they hope to find an available parking place. Due to the vast number of theoretically possible parking-search routes, limitations on cognitive data processing, and parking-search time constraint, a semi-compensatory route choice model (Kaplan and Prato, 2010) seems the most suitable for representing parking-search route choice:

$$P_n(r^* \mid G_n) = P_n(r^* \mid C_n) P_n(C_n \mid G_n)$$

where $P_n(r^* \mid C_n)$ is the probability of choosing route $r^*$ from the viable route set $C_n$ and $P_n(C_n \mid G_n)$ is the probability of choosing set $C_n$ from the possible set of alternatives $G_n$.

As mentioned in the behavioral framework, the hypothesized parking-search behavior consists of an erratic run-and-tumble behavior in which drivers randomly choose their next maneuver at every intersection, subject to a global parking-search gradient guided by location of the destination, drivers’ perceptions regarding parking availability and turn-over rates. During the parking-search process, drivers may decide to revisit previous streets by driving in loops, thus exhibiting a myopic search behavior. Consequently, the biased random walk algorithm (Frejinger et al., 2009) is suitable to represent the formation of the realm of possible routes $G_n$ for on-street parking-search. The biased random walk proposes to connect origin and destination of a trip by drawing link sequences according to the probability of extracting link $L_{h,s}$ from the set $E_h$ of links exiting the generic node $h$ (Frejinger et al., 2009):

$$P(L_{h,s} \mid E_h, b_1, b_2) = \frac{\omega(L_{h,s} \mid E_h, b_1, b_2)}{\sum_{L_{h,k} \in E_h} \omega(L_{h,k} \mid E_h, b_1, b_2)}$$

where $\omega(L_{h,k} \mid E_h, b_1, b_2)$ is the weight of each link $L_{h,k}$ connecting two generic nodes $h$ and $k$, and $b_1$ and $b_2$ are parameters of the Kumaraswamy distributions of the weights. The parameters $b_1$ and $b_2$ are assumed equal to 1 for the purposes of biasing the sequences of links toward the shortest path, limiting the number of alternatives generated in a large-size network, and considering the optimal value indicated by Frejinger et al. (2009). For each
driver \( n \), the master set \( G_n \) corresponds to the unique routes resulting from \( D \) algorithm iterations.

Given the set of possible routes, conjunctive elimination by spatiotemporal thresholds serves to delimit the set of plausible routes to the set of viable routes. Hence, the probability of selecting consideration set \( C_n \) derives from the probability selecting combination of \( K \) constraint thresholds \( t_{kn}^* \):

\[
P_n(C_n|G_n) = P(t_{1n}^*) \cap P(t_{2n}^*) \cap \ldots \cap P(t_{kn}^*)
\]  

(9)

The relevant spatiotemporal thresholds for parking-search are search duration and number of turns. The search duration is a continuous threshold represented by a hazard model, while the number of turns is a discrete ordered threshold, represented by an ordered probit model (Kaplan and Prato, 2010). Consequently, the probability of driver \( n \) selecting the number-of-turns threshold \( t_{tn}^* \) is expressed as follows:

\[
P(\theta_{(m-1)n} < t_{tn}^* \leq \theta_{mn}) = \Phi(\theta_{(m-1)n} - \alpha_{tn}Z_{tn}) - \Phi(\theta_{mn} - \alpha_{tn}Z_{tn})
\]  

(10)

where \( \theta_{mn} \) is the parameter of the threshold category \( m \), \( Z_{tn} \) is the vector of characteristics of driver \( n \) relevant for the choice of number-of-turns threshold, \( \alpha_{tn} \) is a vector of parameters to be estimated and \( \Phi \) is the cumulative normal distribution function.

The probability of a maximum parking-search duration threshold \( t_{tn}^* \) selected by driver \( n \) is represented as follows:

\[
P(\theta_{(m-1)n} < t_{tn}^* \leq \theta_{m}) = \int_{\theta_{(m-1)n} - \alpha_{tn}Z_{tn}}^{\theta_{m} - \alpha_{tn}Z_{tn}} f(\varepsilon) d\varepsilon
\]  

(11)

where \( Z_{tn} \) is a vector of characteristics of driver \( n \) relevant for the choice of the time threshold, and \( \alpha_t \) is a vector of parameters to be estimated. The value of the parameter \( \theta_{tn} \) corresponds to the logarithm of the integrated baseline hazards and the hazard rate \( \lambda_n(\tau) \) expresses the rate at which duration is completed at time \( \tau \):

\[
\theta_{tn} = \log \int_0^{\theta_{tn}} \lambda_n(\tau) d\tau \quad \text{for } m_i = 1, \ldots, M_i
\]  

(12)

\[
\lambda_n(\tau) = \lambda_n(\tau) \exp(-\alpha_{tn}Z_{tn})
\]  

(13)

In line with Kaplan and Prato (2010), the thresholds are hypothesized to be correlated.

The hypothesized behavioral process underlying the choice among viable parking-search routes is regret minimization, namely the attempt to avoid the negative feeling of regret when the chosen alternative is outperformed by another alternative. In line with Chorus et al. (2008), regret minimization is more plausible than utility maximization when on-street cruising-for-parking is considered, since parking-search is likely not a fully compensatory process in the sense that trade-offs are only plausible for some route attributes. Specifically, when drivers search for parking, they may consider trade-offs between parking availability and parking turn-over rates, while trade-offs between travel time and parking turn-over rate are less probable. Interestingly, the random regret minimization model was found suitable for representing the choice among parking facilities (Chorus, 2010). In the current study, the random regret minimization model (Chorus, 2010) is applied to represent the probability \( P_{nr^*} \) of driver \( n \) choosing route \( r^* \) from the set of viable routes \( C_n \).
\[ P_{n^r} = \frac{\exp(-\tilde{R}_{n^r})}{\sum_{r \in C_s} \exp(-\tilde{R}_{n^r})} \]  
\[ \tilde{R}_{n^r} = \sum_{r \neq r', r \in C_s} \sum_{a \in A_{n^r}} \ln \left( 1 + \exp \left[ \beta_a \left( a_{n^r} - a_{n^r} \right) \right] \right) \]  
where $\tilde{R}_{n^r}$ is the systematic regret component, $A_{n^r}$ is a vector of attribute values for route $r$, $\beta_a$ is the regret parameter of route attribute $a$. The inclusive value of on-street parking-search route choice is expressed as follows:

\[ I_{nj} = \ln \sum_{r \neq j} \exp \left( -\tilde{R}_{n^r} / \lambda_j \right) \]  

### 2.3 Variable specification

This section describes the explanatory variables that are hypothesized to be associated with the cruising-for-parking decision sequence.

The decision of parking type is hypothesized to be related to individual characteristics, trip characteristics and the overall utility expected from on-street and off-street parking. Individual characteristics include socio-economic characteristics (e.g., gender, age, income), driving experience and parking skills, time and money saving skills, parking discount availability for city residents, and parking payment method (e.g., parking meter, cellular parking service, electronic parking cards, monthly subscription at a parking facility). Trip characteristics include trip purpose, activity duration, total amount of money spent during the trip excluding parking fees, number of passengers, presence of children and weekly trip frequency. The expected utility from the choice of off-street and on-street parking is the log-sum over the alternatives included in each parking type. In general, an increase in the probability of choosing off-street parking is hypothesized to be related to (i) higher income, (ii) better time saving skills, (iii) availability of monthly subscription at a parking facility, (iv) possession of city resident discount for parking facilities, (v) higher number of passengers, (vi) presence of children, and (vii) total amount of money spent during the trip. The probability of on-street parking is expected to increase with (i) greater driving experience, (ii) better parking skills, (iii) lower income, (iv) better money saving skills, and (v) availability of cellular and electronic payment methods.

Once off-street parking is chosen, the choice between parking facilities is hypothesized to be related to the parking facility attributes and to the utility from driving from the parking-search starting point to the parking facility. The attributes of the parking facility consist of parking cost (i.e., hourly fee), and availability of discount (e.g., night, city resident), accessibility (i.e., walking time and distance) from the parking facility to the activity location, street walkability from the parking facility to the activity location (e.g., land use, street hierarchy and width, illumination and pedestrian movements), access and egress delays at both entrance and exit, structural features (e.g., underground or above ground, size and number of parking levels, maintenance and illumination), and security level (e.g., availability of electronic surveillance and security personnel, valet parking, request to turn-over the car keys). The expected utility derived from driving from the
parking-search starting point to the parking facility is the log-sum over the considered routes. In general, a greater probability to park at a parking facility is hypothesized to be associated with (i) lower costs, (ii) greater facility size, (iii) greater accessibility to the activity location, (iv) better walkability from the facility to the activity location, (v) lower access and egress delays, (vi) greater security level and (vii) ease of arrival from the parking-search starting point to the parking facility. Interaction effects are anticipated between socio-economic characteristics, structural features, security level and street walkability from the parking facility to the activity location.

Once the decision of a parking facility is made, the route choice from the parking-search starting point to the parking facility depends mainly on route attributes. The considered attributes are route length, travel time, degree of angularity with respect to the activity location, number of turns, number of signalized intersections, total waiting time at signalized intersections, road hierarchy, traffic direction, number of driving lanes, and parking turn-over rate and percent of route length with illegal parking. The route choice can also be related to individual socio-economic characteristics and latent traits such as age, gender, income, education, spatial orientation, time saving skills, network familiarity and habit. In general, a higher probability of choosing a specific route to the parking facility is assumed to be correlated with (i) shorter length and travel time, (ii) low degree of angularity, (iii) low number of turns, (iv) low number of intersections, (v) low total waiting time at signalized intersections, (vi) higher road hierarchy and (vii) greater number of lanes. Interestingly, the existence of parking activity along the route may function as a double-edge sword for drivers driving towards off-street parking facilities. Parking availability and high turn-over rate may on the one hand delay the arrival to the parking lot, while on the other hand increase drivers’ prospect to find on-street parking along the route.

In the case that on-street parking is chosen, the spatiotemporal thresholds that delimit the realm of parking-search routes to the viable choice set (e.g., parking-time search, number of turns) are related to both individual and trip characteristics. Upon the formation of the viable choice set, the choice of the preferred cruising-for-parking route depends on the route attributes that are relevant for parking-search.

Individual characteristics that influence the threshold selection consist of socio-economic characteristics and latent traits (e.g., time saving skills, need of punctuality, patience, enjoyment from driving, spatial orientation ability, familiarity with the road network, mnemonic ability and habit). In general, lower parking-search time thresholds are assumed to be related to (i) higher time saving skills, (ii) greater need of punctuality, (iii) higher patience and (iv) lower enjoyment from driving. Lower number-of-turns thresholds are hypothesized to be associated with (i) higher spatial orientation, (ii) greater network familiarity and better mnemonic ability.

The route attributes that are considered relevant for cruising-for-parking are route length, travel time, degree of angularity with respect to the activity location, number of signalized intersections, total waiting time at signalized intersections, road hierarchy, traffic direction, number of parking lanes, parking turn-over rate, parking direction relative to the sidewalk (i.e., parallel, vertical or diagonal) and percent of route length with both free and illegal parking. Higher parking-search route choice probability are assumed to be associated with (i) lower degree of angularity, (ii) lower number of signalized intersections, (iii) lower overall waiting time at signalized intersections, (iv) local, unidirectional streets with
parking on both sides, (v) higher parking turn-over rate, (vi) diagonal parking, (vii) higher percent of free parking and (viii) lower percent of illegal parking.

3 Data collection

This section describes the experimental design proposed for understanding en-route cruising-for-parking behavior and for estimating the proposed integrated framework for representing joint parking-search decisions. The experimental design includes the choice of a study area, as well as a survey aimed at collecting information about (i) actual parking-search behavior by travelers, and (ii) explanatory variables that are hypothesized to be associated with cruising-for-parking decisions.

3.1 Geographical scope

Based on the aforementioned criteria, two possible study areas in the Tel-Aviv metropolitan area are identified as suitable for the purpose of the current study. The geographical definition and the street view of the two study areas are presented in figure 4 and figure 5, respectively.

The selection of appropriate study areas for the purpose of gathering information related to cruising-for-parking behavior is guided by the following principles. First, relevant study areas should be characterized by high activity generation and limited parking supply, as primary conditions for the existence of cruising-for-parking behavior. Second, relevant study areas should offer a selection of off-street and on-street parking opportunities within reasonable distance from possible activity locations. Third, relevant study areas should attract both local and non-local visitors, since cruising-for-parking is hypothesized to be related to road network familiarity and spatial orientation. Last, study areas bounded by natural and road network boundaries are advantageous, since a limited area of manageable size facilitates gathering information related to parking supply and driving routes.

The first study area is the Sheinkin street compound located in the heart of Tel-Aviv, which represents a typical CBD area. This village style compound includes a mixture of residential and commercial land-use and has been one of the most popular hang-out places in Tel-Aviv during the last two decades. The compound offers an abundance of trendy dining places and shopping opportunities, and hence attracts both leisure and home-based trips.

The Sheinkin street compound is characterized by a very limited supply of off-street parking for both residential and commercial use, since most of the buildings in the area were built in the early decades of the 20th century without any consideration for parking. There are two underground parking facilities with a capacity of a few hundred parking stalls and a small illegal parking lot providing a few dozens of parking stalls. In the streets of the compound, paid on-street parking is permitted on both sides of the street with a fee of 1 Euro per hour up to three hours. In some streets, parking is permitted after 5pm on one side of the road only to local residents, while parking on the other side is permitted to both local residents and visitors.
The second study area is the Herzliya-Pituach industrial park, which represents a typical large industrial park located in the suburbs. Herzliya-Pituach, which is one of Israel’s leading high-tech industrial parks, is occupied by hundreds of Israeli and international high-tech firms, altogether employing tens of thousands of workers. Side-by-side with the high-tech companies, the industrial park includes hundreds of restaurants and coffee-shops that have become a major attraction as well. The industrial park does not include residential land-use, and hence mainly attracts habitual work and business related trips.

The Herzliya-Pituach industrial park offers an abundance of off-street parking facilities for employees and visitors. During October 2010, a survey was conducted for the purpose of the current research among the 15 leading parking facilities that are open to the general public. Most facilities are relatively new underground multi-storey facilities,
although there are a few open parking lots. The parking facilities largely differ in their size, price and available discounts to Herzliya city residents and to local employees. The size of the parking facilities ranges between 150 and 1700 parking stalls per facility. The hourly price ranges between 1 and 3 Euros for the first hour, with an additional payment of 1.6 to 3.2 Euros for additional hours and a daily price between 2 and 12 Euros. The price of a monthly parking card ranges between 60 and 130 Euros before taxes. However, prices largely differ according to the parking facility and individual characteristics (e.g., employee versus visitor, company of employment), since prices of monthly parking cards for employees are typically negotiated at the firm level between the companies and the management of the parking facility. A 50% discount for city residents is only offered at two open parking lots that are operated by the municipality of Herzliya. The Herzliya-Pituach industrial park provides also on-street parking opportunities. Paid on-street parking is available in most streets, with a fee of 1 Euro per hour and maximum duration of three hours. Free on-street parking is also available in partially developed streets on the fringe of the industrial park, although it is very scarce and difficult to find.

3.2 Survey design

The proposed experimental design for data collection includes a two-wave survey consisting of a revealed-preferences self-reported parking-search behavior survey, followed by a GPS-based field experiment. The advantage of a self-reported behavior survey lies in the ability to conduct a large-scale survey at a relatively modest cost, while its disadvantage consists in the risk of retrieving inaccurate or incomplete data due to partial memory recall. Consequently, in order to retrieve detailed information with high degree of accuracy about parking-search route choice, the survey is coupled with a GPS-based field experiment, which can be conducted only as a small-scale survey due to the high-costs and respondents’ burden.

The self-reported survey regarding parking-search behavior will be collected via a memory jogger developed for the purpose of the current study. Survey participants will be asked to recall the most recent trip made to the designated study area. The memory jogger will allow retrieving trip characteristics (e.g., purpose, destination, number of passengers), as well as parking type and parking-search information (e.g., chosen route, driving speed, parking-search duration, parking location). A list with street names and a map will be provided to respondents in order to facilitate the mnemonic retrieval of the parking-search route. Figure 6 presents an example of the memory jogger. The memory jogger will be accompanied by a questionnaire eliciting individual information such as socio-economic characteristics and latent traits that are relevant to parking-search route choice (e.g., time saving skills, spatial orientation, memory and habits).

The proposed self-reported survey will be web-based in order to reduce operational costs, to avoid coding mistakes by the automatic recording of respondents’ answers to the survey, and to minimize disturbance to respondents’ daily activities due to schedule and location flexibility. The survey will be advertised by postcard-size leaflets distributed around the two study areas during the course of the survey in postal boxes, on parked cars and in coffee-shops.
Figure 6. Cruising-for-parking memory-jogger

The GPS-based field experiment will involve GPS devices to be carried by survey participants over a period of one day. The GPS-based survey will be accompanied by a web-based questionnaire eliciting socio-economic data, trip related information, and parking related information (i.e. parking-search starting point, intended and actual parking type and facility).

The participants in the GPS-based field experiment will be recruited among the respondents in the self-reported survey. The GPS device will enable the partition of a given route into two distinct parts: the route from the origin to the parking-search starting point, and the relevant part for the current research which is related to the search for a parking...
place. The parking-search starting point will be identified by matching the self-reported parking behavior for a particular trip with data from the GPS device regarding significant changes in speed or driving direction during the same trip. In addition, the GPS device will enable to collect other information regarding cruising-for-parking behavior such as parking-search duration, driving speed and driving pattern (e.g., acceleration, deceleration and queuing). The survey will be accompanied by a supply-side survey, since parking-search route choice is likely influenced by street characteristics such as number of parking and driving lanes, traffic direction and volume, parking capacity and parking turn-over rate. The characteristics will be retrieved from maps and street cross-sections in the designated study areas. Traffic volumes and street parking replacement rate will be surveyed on-site during the survey period.

4 Concluding remarks

This paper describes the first phase of a current on-going research aimed at investigating cruising-for-parking behavior. Specifically, the current study focuses on investigating the combined choice of parking type, parking facility and driving route during the parking-search. The developed model framework is potentially beneficial for understanding the impact of parking-related policy measures (e.g., price control, minimum and maximum parking standards) and PGI systems on parking-search behavior and its externalities (e.g., air pollution, traffic congestion). Another potential use of the model is for improving the representation of parking-search behavior in state-of-the-art traffic assignment and micro-simulation models.

The current paper addresses two main topics. First, the paper presents the development of a methodological framework that represents the joint en-route decision of parking type, place and driving route while cruising-for-parking. The methodological framework comprises a conceptual behavioral model, its mathematical representation and the specification of relevant explanatory variables. Second, the design of a two-wave field survey design accompanies the framework with the aim of unveiling the determinants of route choice while cruising-for-parking by retrieving both self-reported and GPS data.

The second phase of the research, namely the preparation of the web-based survey for self-reported parking-search behavior, is currently under development, and survey administration is expected to follow later this year. Data collection challenges that lie ahead are (i) gaining an acceptable response rate from the population and (ii) controlling for sample reliability. Gaining support from the municipal authorities Tel-Aviv and Herzeliya, for example by sending an official letter to residents and employers in the study areas, is vital for successful response rates. In addition, possible alternatives such as a prize raffle are being discussed as incentives. Alternatives are parking-related incentives (e.g., a monthly parking cards and electronic parking devices), leisure related incentives (e.g., restaurant vouchers, shopping vouchers), and their combination. Last, survey promotion under the motto "voting for parking" is considered. A possible solution for sample reliability is survey design to identify respondents by their computer IP address. Likely, respondents use their home or portable computer to complete the survey, as internet-cafés are scarce in the two study areas. Hence, more than a couple of respondents with the same IP address are not plausible. Another possible solution is to request respondents to identify
themselves by name and email address in order as a pre-condition of receiving the promised incentives.

The GPS-based field experiment will conclude the current research by providing in-depth information related to cruising-for-parking. The main challenge associated with this phase is the identification of the parking-search starting point from the GPS data. Possibly, heuristic rules that were developed on the basis of field survey data will be utilized (see Benenson et al., 2008).

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**References**


