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An empirical agent-based model of parking behaviour

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Abstract

Today, many cities are faced with parking problems, which are only expected to become worse. Yet, there exists little empirical and theoretical knowledge on the parking behaviour of the drivers. However this knowledge is essential in order to estimate economic, social and environmental impacts of new or changing parking policies in a city.

In this paper we develop the microscopic, agent-based simulation model SUSTAPARK (SUSTAinable PARKing). At its core is a model of the parking behaviour and strategic decisions of drivers. The decision model captures reactions of the drivers to changes in the time available to them and to the local situation on the road. The model also takes into account the individual preferences of the drivers. Their main strategic decisions include aspects such as the choice between an on-street or off-street parking place, as well as choices like ‘I will make another lap around this block’ or ‘I will now look in the next side street’.

The decision rules are constructed with a parsimonious set of variables, incorporating the value of time and the willingness to cheat. The constructed model can be used to formulate parking management strategies that optimise the overall search time for and the use of parking places.

Keywords

parking strategy, agent-based modelling

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1. Introduction

Today, many cities across the world are faced with substantial parking problems. Drivers arriving with their automobiles near the location of their desired activity need to park. Usually they wish to do so near this location. Yet, with the current level of automobile usage most cities simply cannot provide enough parking spaces to meet the demand of every driver coming to the city. Worse still, the number of trips made by car is expected to rise even further, implying an even greater demand for parking and therefore larger parking problems.

In recent years, policy makers and advisory groups thought of a wide variety of measures to alleviate parking problems. An overview of such measures was made by the Victoria Transport Policy Institute [Lit2006a]. Some suggested measures are park-and-ride, carsharing, ridesharing, correct parking pricing, car-free districts, special event management… The economic, social and environmental effects and the efficacy of these measures are not known for most of the (proposed) measures. This knowledge would allow policy makers to more effectively work on solving the parking problems and the associated mobility problems.

This paper presents a behavioural model for parking developed in a project that studies the many aspects and impacts of parking. The structure of the paper is as follows: first a literature overview on parking is presented, secondly a description of the project is given to give the context of the behavioural model, and then the actual model is described. Some simulation results of the model are presented, followed by directions for further research. Lastly, we present some concluding remarks.

2. Literature overview

Parking first became a problem around 1930 when rising levels of automobile ownership made it impossible that every driver parked at the curb. Policy makers then came up with what seemed (and was) a wonderful solution at the time: minimum parking requirements. New buildings in cities were obliged to provide a minimum of on-street parking spaces. Where land was cheap, as in the United States, this resulted in a feedback loop where plentiful parking space encouraged car usage which led to more emphasis on providing parking space (contributing significantly to the phenomenon of 'urban sprawl') [Sho2005].

In the older, already densely built cities of Europe, but also in some older cities in the United States, like New York, providing plentiful off-street parking places was and is often not possible. This contributed to companies relocating to the periphery if accessibility could not be achieved by some other means, such as a well-developed public transport system [Sho2005]. It should be noted that the responsibility for parking requirements usually lies at the municipal level, leading to a wide array of parking requirements, adjusted to suit the local needs [Hea1992]. The justification for these requirements is not known or unclear. The Institute of Transportation Engineers does have a publication 'Parking Generation' [ITE2004] that forms the world's largest collection on data for parking demand at buildings of various sizes and purposes. Shoup questions the reliability of these figures and decries the misuse of them by city planners [Sho2002].

Problems associated with parking in the twenty-first century include additional congestion, emissions, noise and a decrease in the liveability of neighbourhoods as a consequence of drivers cruising for parking. Also, providing parking places means the consumption of expensive, scarce land. Parking shortages can also result in cities gaining a reputation for poor accessibility, causing shoppers, tourists and commuters to stay away and eventually businesses to leave the city.

As parking is strongly connected to other systems of a city, most notably the transportation system and land use, its 'performance' and usage spreads throughout the entire fabric of the city. Parking revenues can be used to fund street works, increase police surveillance and many other measures that increase the attractiveness of the city. A good functioning parking system is a major attraction point for a city, leading to more businesses coming to the city and therefore to more workplaces. Decreasing parking problems also means a reduction in congestion, emissions, noise and visual hindrance. It also means a reduction in the time lost searching for a parking place and an increase in the liveability of the city.

Because solutions to parking problems take time to implement, which might lead to a changed situation by the time the policy becomes operational, care should be taken that the new policies contribute to the economic, social and environmental goals of the sustainable city. Parking problems and their direct effects form only a part of the mobility and sustainability problems that cities face today. Research into and solutions for parking problems should not happen independently from the rest of the transportation system in the city.

Despite the relevance of the issues raised by parking problems and the fact that the average automobile is parked 95% of a day (or about 23 hours each day), scientific interest in parking and its economic, social and environmental aspects has been intermittent at best, and certainly low in comparison to the attention topics such as road pricing have received. One reason road pricing is more interesting from a theoretical point of view is that it can be used to influence a much larger group of externalities than parking policies can [Mar2006]. In recent years interest in parking has increased, as shown by the publication of books by Litman [Lit2006b] and Shoup [Sho2005] and the publication of a special issue of Transport Policy on parking. This issue contains, among other articles, a good review of the current literature on parking policies [Mar2006] and an article on cruising for parking [Sho2006].

There exists little empirical knowledge of the parking behaviour of drivers. For example, it is not known how many drivers in cities are cruising for parking, let alone how this number varies during the day or what the relation, if any, is with the local circumstances. Journalists frequently city a figure of about 30 percent, a figure that likely originated from the research in the United States of Shoup. However, this figure is an average over multiple studies that often produced widely differing results and took place in a time span of more than 70 years [Sho2006]. As Shoup himself notes [Sho2005], these studies are probably not very good and likely underestimate the amount of cruising for parking. The circumstances surrounding parking, such as traffic volume and the availability of parking places, changed substantially in this time. Also, the study locations cannot be considered to have been free of bias. The comparability of these studies with each other and the representativity of their results is therefore doubtful. Still, these studies do indicate that cruising for parking can contribute substantially to traffic in the city.

Theoretical research into parking was performed mostly in the field of economics. Most authors consider parking pricing as a means either to internalise search externalities or to set an optimal price if road use is underpriced. The most advanced of these models include on-street and off-street parking and traffic congestion [Cal2002, Arn2007]. Older models consider only one or two of these aspects [Cal2004]. The aggregate, macro-economic methods applied can be criticised, however. They mostly ignore the local nature of parking and the heterogeneity in purpose and characteristics of the driver coming to the city. They also assume that the government has perfect instruments, while ignoring the high cost of (necessary) enforcement for on-street parking. While parking policy is often intended to lessen car pressure by indirectly encouraging non-car modes of transport [Mar2006], no attention seems to have been paid to this aspect in the economic literature.

In the economic models that take congestion on the road network of a city into account, it is not clear what is meant by a ‘congested’ street network. The conventional definition of congestion is that the travel time on the road is higher than what is normal for that road. However, in transportation engineering it is known that traffic in a city is almost fully determined by delays at crossroads and intersections [Mae2006]. If parking is taken into account, additional delays are caused by drivers looking to park and drivers parking or unparking. It is therefore not at all clear what congestion means in a city, as the primary cause of delays is an inherent part of the normal travel time.

In the field of traffic engineering parking has gathered some interest also. An overview of the research in this field can be found in [You2000]. The most notable contribution was the PARKSIM model of Thompson and Young [You1986, You1987a, You1987b], which models in great detail the behaviour of parkers in parking lots and is intended to aid in the design of new parking lots. Young [You2000] distinguishes 5 types of parking models, namely parking-design models, parking-allocation models, parking-search models (both in parking lots and in a street network), parking-choice models and parking-interaction models. He concluded that in all of these types of models more emphasis should be placed on the assessment of urban parking policies and the behavioural response of parkers to them.

We conclude this literature overview with a quote from Marsden [Mar2006]: "We do not understand nearly enough about how individuals respond to parking policy interventions nor how these responses interact with local circumstances, the availability of alternative transport modes or alternative destinations. A continued failure to take on the research challenges in this area will surely see increased degradation of the residential environment and further imbalances in supply and demand in a variety of locations for work, shopping and leisure trips. Parking policy may not be theoretically appealing but it is practically essential." The following section describes a project intended to improve the understanding of parking and to allow the simulation of parking policies.

3. SUSTAPARK project summary

SUSTAPARK is a project in which various parking and mobility policies are researched and modelled. One of the main objectives of the project is the development of a city-level model for parking. This model and its results are intended to support policy makers in their decisions concerning parking and mobility. Such aspects include the optimal parking fee, the determination of the parking needs at a location and the impact of a new parking garage. From the beginning of the project it was decided that special attention would be paid to on-street parking (also known as curb parking) and its related aspects. An important aspect of on-street parking is the search behaviour of a driver looking to park on-street. To properly model this, an agent-based approach was chosen.

An agent is the central concept of the framework of agent-based modelling. An agent is generally defined as a software entity that can take autonomous decisions, interact with its environment and other agents and displays initiative and is goal-oriented. In the SUSTAPARK model each agent represents an actual person who has a desire for transport in or into the city. This means that in simulations of larger cities the agents can become very numerous. Each agent is able to enter a vehicle (only cars are available in the current version of the model) and drive in this vehicle towards his destination. Walking or other modes of transportation are currently not modelled.

Because the search to park of an individual is a phenomenon on a local level, a microscopic modelling approach was chosen for the physical movements of the cars. A microscopic approach also integrates more naturally with an agent-based approach than a macroscopic approach. The microscopic simulation methodology adopted was that of the cellular automaton, in which time and space are discretised. By dividing the individual road lanes into cells with a certain width and length a representation of the real street network is obtained that is still understandable and computationally fast.

The SUSTAPARK model itself is a simulator of the decisions that persons take concerning their mobility throughout the day. Since the search for parking of an individual is a phenomenon on a local level, it was chosen to simulate the streets and the traffic in cities with a cellular automaton. A cellular automaton is a simulation technique in which space is discretised in cells and time is discretised in time steps. This technique has the advantage over continuous approaches of computational efficiency while maintaining a sufficient degree of accuracy [Mae2006]. In the SUSTAPARK model the individual road lanes are divided along their length in cells such that a representation of the road network is obtained. To this street network on-street parking places, parking garages and locations can be attached.

The agents in this model want to be at certain locations at certain times, providing the motive for transportation. Depending upon characteristics of the agents themselves, the different transport modes available and the desired destination the agents make a choice regarding the mode of transportation and, if the car was chosen as the transportation means, the intended parking location or strategy to look for one. In the case of on-street parking, the model contains an elaborate modelling of the way people look for a parking place. This part of the model is based on behavioural research.

The SUSTAPARK model runs a simulation for an entire day and collects various statistics regarding parking and mobility in the city. Through the setting of various policy-related variables scenarios can be analysed and policy makers can use it assess the impacts of various policies.

The model is implemented in the JAVA programming language and reads in the required spatial information (e.g. the street network) from data in ArcGIS format. This spatial data is nowadays available from most cities. Data for the calibration of the model parameters is being gathered during the behavioural research (which is still ongoing as of the time of writing). The model is being tested on the city of Leuven in Belgium.

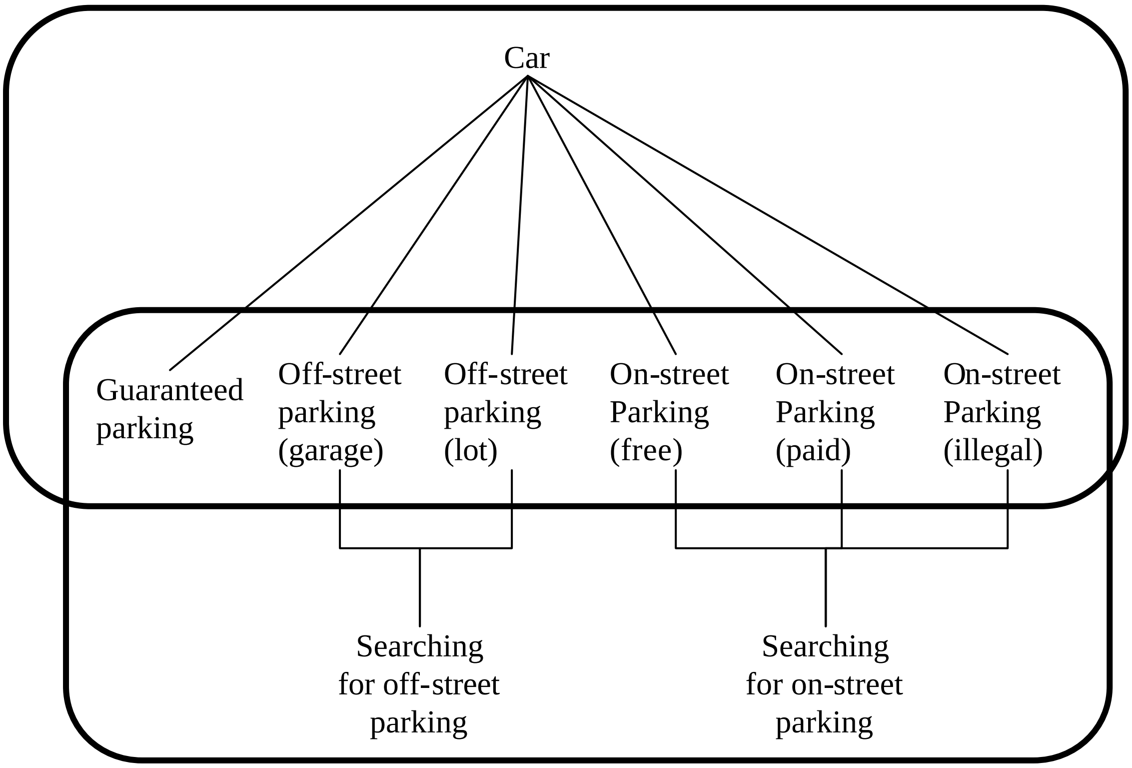

Figure 1: Part of the choice tree of the behavioural component. The two boxes indicate the 2 separate model parts; the upper box contains the model that determines the initial parking strategy, the lower box indicates the model that is used to find a parking place.

4. Parking behaviour model

4.1 Determinants of parking behaviour

Through literature study and interviews several variables were identified to be of potential relevance for the parking behaviour of persons. Unfortunately, in our project only a limited budget is available for data collection. The available datasets on parking, i.e. that link parking behaviour to personal characteristics, are few and far between. Because of this lack of data it is not possible to use all of the variables listed below. It should also be noted that some of the variables listed below are difficult to measure in practice.

- Price of the parking place: aside from supply constraints, the price of a parking place is the main policy instrument available to steer the behaviour of drivers.
- Income: income is strongly correlated to the willingness to pay for several aspects of parking and to the value of time. Therefore it should not enter the behavioural choice models directly.

- Value of time: in choosing a parking strategy, a driver will take his expected travel time into account. This is modelled through the value of time, which can be depend upon the trip purpose and can be different depending upon the activity (e.g. walking, driving, searching, waiting…).
- Trip purpose: It is well known in the field of transportation research that the choices people make regarding transportation are strongly dependent upon the purpose of the trip they want to make. The same dependency is expected for parking.
- Guaranteed parking: if a driver knows he has a parking place available somewhere (provided by his employer, for example) then he has no need to look for an on-street or off-street parking place.
- Occupancy ratio: In some areas of a city a driver might expect that there is only a low chance of finding a parking place around a specific time. The driver might choose to avoid a long expected search time or the risk of not finding a parking place and instead choose another means of transport or parking.
- Parking capacity: the driver could take into account the amount of parking places in an area, both on-street and off-street. For feasibility reasons, drivers are assumed to have full knowledge. This is thought to be a reasonable assumption as the percentage of drivers who are truly new to a city is thought to be very low. Furthermore, a driver will, through the usage of representative activity schedules, always look for parking in the same areas. This implies that on a local scale the assumption will hold.
- Turnover rate: on-street parking places are rarely occupied by the same vehicle for the entire day and even not for a large part of the day. In the city centres there is a fairly high turnover rate as drivers park and unpark, which makes the strategy of circling around the block worthwhile.
- Alternative-specific constants: Regardless of the amount of variables in a model, there will always be unobserved factors. These can be captured through the use of alternative-specific constants. A constant for each type of parking will be included, with one constant taken to be the reference level. An example from practice of an unobserved factor is the bias against parking in an (underground) parking garage that many drivers have.
- Travel time: The expected travel time will be dependent upon many factors, but for parking the proportion of the time spent on parking in relation to the total travel time is one of the more relevant attributes.

- Search time: The time that a driver has spent searching for a parking place or expects to spend on searching for one. The driver will be less willing to spend time on searching, if his value of time and/or the occupancy ratio are low.
- Remaining time: If a driver has a limited time budget, if he has an appointment, for example, then he will keep a close eye on the time that he has still available.
- Switching distance: The distance from his destination at which a driver starts to look for an on-street parking place. Further behavioural research into parking will learn whether a switching distance or a switching time is the most appropriate.
- Fine and fining probability: on-street parking policies relying on drivers paying the right price necessitate enforcement of these policies (it is assumed that drivers always pay the correct price for off-street parking). Drivers might therefore choose on-street parking if they value the expected fine (fining probability times the actual fine) to be low.

Some of these variables will be more relevant for the search for an on-street parking place, others will be more determining for the initial choice between on-street and off-street parking. If possible, attention should be given to the interactions and correlations between the variables, especially when they are included in discrete choice models.

4.2 Methodology

In reality many decisions regarding transportation are taken simultaneously. It is possible to model these simultaneous choices in discrete choice theory, but taking all the possible combinations of choice alternatives then quickly results in a huge number of possible choices. Such a model is difficult to calibrate and cumbersome to use. Therefore in transportation modelling the decision taking process is often broken down into a number of sequential choice processes, with appropriate models (often nested logit models). A sequence frequently adopted is first the generation choice [Bel2006] (the decision whether to make a trip) and then consecutively the destination choice, the mode choice model, the choice of departure time and the choice of the route taken to the destination.

In the SUSTAPARK model the generation choice, the destination choice and the choice of departure time are not modelled. Further development of the model might add choice of departure time, as time-dependent parking policies can have the effect of causing a shift in the time of departure.

Instead, the trip generation, the destination and time of departure choice are determined for each agent from one of a set of possible activity schedules. Each agent is assigned such an activity schedule that describes for that agent the sequence of locations the agent wishes to be at during certain time periods. Because trip and activity choice are not part of the model, the agents are each assigned an activity schedule from a set of schedules, each of which describes a sample sequences of activities. The locations where those activities are performed are properties of the agents. The times at which an agent wishes to perform these activities are chosen by a random draw from a distribution. Each activity on a schedule has a distribution for the starting time and one for the end time, leaving enough time for transportation from one activity to the next.

A schedule covers an entire day of an agent from around 3 AM to 3 AM the next day. This allows simulating the various sources of parking demand throughout the course of a day and can be differentiated for different days of the week, such as work days and weekend days. The sample schedules and the data required for their construction are taken from previous research in Belgium on time use and activities of the households (see [Toi2001], [Toi2006], [Glo2008]). Possible types of schedules are

- commuter who comes from outside the city to work in the city.
- resident of the city who goes to work inside the city and needs to return to his home in the city in the evening.
- resident of the city who goes to work outside the city and needs to return to his home in the city in the evening.
- shopper who comes from outside the city to the city as a centre of commerce.
- entertainment seeker who comes to the city for leisure.

The time of departure is derived from the start time of the activities by adding the expected travel times and search times for a parking place.

The behaviour model in SUSTAPARK determines the mode choice and the search behaviour of drivers looking to park. The outline given in the previous part separates in two choice models, one model that determines mode choice and the intended parking strategy before the

driver starts looking for a parking place and another model that executes the parking strategy of the driver as he is looking for a parking place. This last model requires the ability to re-evaluate the current strategy and, if necessary, the change to a different strategy. For example, a driver who has unsuccessfully searched for an on-street parking place for some time might decide to go for an off-street parking place. The two models both have a part where a parking strategy is determined.
These strategy parts can have choice models with different variables, as the variables relevant for the choice of a parking place are not necessarily the same before the trip and during the actual search. It could be that e.g. the occupancy ratio is important during the parking search, but not during the pre-trip choice.

The preferred methodology for the mode choice model is a mixed multinomial logit model. This type of model allows for random taste variation, unrestricted substitution patterns and correlation in unobserved factors over time [Tra2002]. This flexibility is achieved by defining the choice probabilities as integrals of standard logit probabilities over a density of parameters. Any distribution can be chosen for the distribution of a coefficient. However, this type of model is not suitable for the project because its flexibility comes at the cost of much greater computational requirements. Due to the greater number of parameters a mixed multinomial logit model also requires a larger dataset for estimation than other choice models. The estimation and application of the models rely on simulation because the integrals over each distribution of parameters have to be evaluated each time a choice is made by an individual. While the computational requirements are acceptable in small-scale studies, they are too large for a simulation of thousands of agents [Hes2007].

Therefore, the methodology adopted is that of the nested logit model (also known as a hierarchical logit model) [Ben1973], which has closed form solutions. As argued previously, such a model allows the modelling of sequential choice processes through a tree structure where each level represents a choice. By grouping similar alternatives in ‘nests’ this type of model allows taking account of choice alternatives which are more related to each other than to other alternatives. For a detailed discussion of this type of model, see [Tra2002]. The nested logit model has been used in many models to forecast travel demand and mode choice.

The model framework as described until now takes mode choice into account. To our knowledge there has never been a study considering the combined effect mode choice and choice in parking places. Separate models for mode choice and parking choice do have been developed. Linking these models together is not straightforward and the way this will be handled in the SUSTAPARK model is still under development. The part of the model described in this paper therefore reduces to the choice of a parking strategy. The nested logit model for mode choice then simplifies to the choice of parking strategy, determined in a multinomial logit model.

The structure of the choice tree is shown in figure 1. The upper box shows the model that is used to determine the parking strategy, the lower box the model used to search for a parking place in the model. The upper tree first contains a choice between slow modes, mass transit modes and the car. If the car is chosen as mode of transportation, three types of parking are available:

- Guaranteed parking means that the driver is guaranteed a parking place at his destination. This might be because he gets a parking place from his employer, owns a garage nearby or has reserved a place in some way.
- Off-street parking is parking in a parking lot or a parking garage (either below or above ground). If this option is chosen, a specific parking garage still needs to be chosen.
- On-street parking means curb side parking, including illegal parking or parking without paying the required fee. If this option is chosen, the driver knows beforehand that he will have to look for a parking place. Consequently, he will need some strategy to find an on-street parking place. The driver starts looking for his on-street parking place at a distance of about 200 m from his destination.
- Illegal parking covers both parking at a place where it is legal to park, but not paying the fee for it, and parking at place where it is not legal to park (e.g. double parking…). Illegally parked cars contribute more than other cars to visual obstruction, create unsafe situations and prevent land from being used for its intended purpose. An illegally parked car also does not pay the actual cost for his parking place, thereby passing the this cost on to the rest of society. The fraction of parked cars that is parked illegally can be quite high in some cities.

Few authors consider the aspect that enforcement of the parking fee for on-street parking is costly and requires a substantial amount of manpower. (It is assumed that off-street parking is always paid for) In some cities enforcement is strict, but in other cities enforcement is not strict, making it worthwhile to drivers to risk not paying. Policy instruments relying on drivers paying the right price should take this aspect into account when assessing the impact and revenue of a new policy. What sort of enforcement (and hence the cost of it) is necessary depends upon the policy. Electronic systems have a large investments cost and require substantial maintenance; traffic wardens need to be paid and many of them are required to get a good coverage of a city. Enforcement enters the model through the probability of fining for illegal parking (see below). In the model this probability can be made dependent upon the area of the city where a driver wishes to park. The values for the probability can either be determined from surveys in the city or from calculations based on information provided by the city itself.

Depending upon the city different choices for mass transit can be available. While bus and train are the most common, other options, such as tram or metro, might also exist. For this reason and also because the modelling of mass transit is not the primary focus of the project, mass transit and slow modes (walking, bikes) are not explicitly modelled in the cellular automaton. Instead their shares are determined from the pre-trip choice model. Because this is still in development the shares are currently determined exogenously from statistics on the modal split for passenger transport.

The model must also be capable of modelling novel parking schemes, like park-and-ride, that are different enough from the types of parking described above that they cannot be catalogued as one of them. Modelling of the success rates of these novel parking schemes is difficult, as this can only be done identifying the relevant choice attributes for these schemes and collecting data on them in a stated preference survey of sufficient scale (see, for example, [Alb2006]). These were not foreseen within our project. Therefore, the success rate of a new parking mode will need to be exogenously given in a scenario-based approach. Such a scenario does need to take into account the practical limits of a novel parking scheme. A side effect is that this also allows the evaluation of the effects of various success rates of a given policy since the model does not depend on one internally calculated success percentage.

4.3 Pre-trip choice model

For the upper model (in effect, the model for the parking type choice) we adopt the multinomial logit model of Hess and Polak [Hes2005]. The model makes a distinction between a 'work' purpose (commuting) and an 'other' purpose which captures all other trip purposes. This gives mainly differences in the willingness to pay for parking and to risk a fine. The multinomial logit model described here concerns a choice made before the trip is actually made. This means that the model deals with the values of the variables expected by the agents, not the observed values. This is an important distinction for the interpretation of the model.

Table 1: Table with the coefficients of the MNL model for the parking type choice [Hes2005].

Variable name	Work	Other
Access time [min]	-0.0513	-0.0283
Search time [min]	-0.0632	-0.0589
Egress time [min]	-0.0925	-0.0924
Parking fee [€/h]	-1.4104	-0.8267
Expected fee [€]	-1.2347	-0.4228
$I_{on\text{-}street}$	-2.7628	-0.8126
$I_{off\text{-}street\ (lot)}$	0.2830	-0.0913
$I_{off\text{-}street(garage)}$	1.0614	-0.2140
$I_{Illegal}$	-0.8833	-2.8972

The access time is the expected time to drive to the area around the destination, which is the area where the driver intends to park. The search time is the time a driver is willing to search for a parking place once he has arrived at his parking area. This will be important for on-street parking, but it could also be that the preferred off-street parking is full and that the driver has to go looking for another parking lot or parking garage. The egress time is the time a driver is willing to walk from his parking place to his actual destination. For the calculation of these times the assumption is made that the driver has full knowledge of the city, including roads, parking places and parking garages.

The parking fee is the amount of money the driver would have to pay for the time he spends at the parking place. This can be zero if the parking place is provided free to the driver. The expected fine is the actual fine times the expected probability of getting a ticket. In the article of Hess and Polak [Hes2005] this was separated from the parking fee because it was found that the fine was valued significantly different from the amount of money that had to be paid for the fee. Note that this fine lumps together both parking at a place where it is illegal to do so and parking at a legal place, but not paying for it, is not considered.

The other variables are alternative-specific constants, with the ‘free on-street parking’ alternative chosen as the reference level. The other dummies stand consecutively for paid on-street parking, (paid) parking in a parking lot, parking in a (multi-storey) parking garage and illegal parking. Substantial differences can be seen between the coefficients for the ‘work’ purpose and for the ‘other’ purpose. In particular, commuters seem to have a strong dislike of paid on-street parking and seem to prefer garages. For the ‘other’ purpose, the willingness to park illegally is much lower than for the ‘work’ purpose. Hess and Polak [Hes2005] note that the signs of the dummies for parking lot and parking garage of the ‘other’ purpose are wrong and should in fact be positive.

For the calculation of the expected values the assumption of full knowledge gives that the (expected) parking fee and the expected fine are the same as the true values. The access, search and egress times are determined in iterative runs of the model until they converge to stable values. This means that the for the search and egress times the average is taken of all the actual times experienced by the agents in a (small) zone of the city. For the access times the actual driving time is taken. Note that this represents traffic on a ‘normal’ i.e. without accidents or other disturbances. All these times are given a small random error to represent uncertainty.

4.4 On-street search model

As shown in figure 1, the choices in the parking choice model described above require further modelling. The process of finding an off-street or on-street parking place is complex and not straightforward to model. The methodology adopted is explained in the following paragraphs.

The approach in the paragraphs below is partly inspired by the work of Thompson and Richardson [Tho1998]. The case treated first is that of driver looking for on-street parking. The guiding principle here is that a driver desires to park as close as possible to his destination. For most part of his trip, the driver follows the route towards his destination and he is not looking for a parking place. In case the driver expects to park in a street where there are only parking places on one side of the street, the route choice should take this into account. The driver only starts searching when he gets near enough to his destination. This distance is about 200 m from his destination, measured along the roads, not as the crow flies. This assumes that the driver knows exactly where his destination is located and the street network surrounding this location. It is possible to modify this distance if the driver perceives the occupancy ratio to be low or high.

When the driver decides to start looking for a parking place, he immediately starts to look ahead some 35 metres (roughly 6 to 7 parking places on one side of the street) for free parking places. This distance is situation dependent; if the driver is tailgating, he can only see one or two places. If the driver sees a free parking place or places, in general he prefers the one closest to his destination to park. Sometimes the parking fee will be higher in some zones of the city, which might cause drivers to avoid these parking places. If the driver does not see any free parking places, he will need to make a choice as to where he will look next. In the current version of the model, a driver looking to park ignores drivers wishing to leave a parking place.

Determining where to look next for a parking place is a complicated matter. The decision process could be modelled as a series of choices, pointing in the direction of discrete choice theory. However, discrete choice theory does not offer the needed flexibility, given the multitude of situations that can be encountered in the streets of a city. Therefore an algorithm based on behavioural research was developed.

First, the driver re-evaluates the local situation and decides whether he should continue to look for on-street parking. For this, a logit similar to the one used to determine the initial search strategy is appropriate. The main difference lies in the interpretation of the parameters. The access time is now zero for on-street parking and illegal parking, since the driver already arrived at the area where he intended to park. The search time is now interpreted as the time the driver already spent searching; the higher this time becomes, the more likely a driver is to switch to a different parking strategy. The egress time increases with the distance that a driver gets removed from his destination. For the consideration of the nearest off-street alternatives the access time is still relevant, since the driver will have to drive towards it. The search time and the egress time still have the same meaning here.

If he decides to continue looking for an off-street parking place, he will need a route to his next search location. In the model developed by Thompson and Richardson [Tho1998], this could be determined fairly simple due to the hypothetical CBD that was used being composed of square blocks. Our model has to be capable of modelling the inner areas of the European cities with their complex winding streets. Generally, a driver will search for an on-street parking place in an area around his destination with a radius that increases the longer the driver cruises looking for parking. This radius can increase to 550 m at maximum [Gan2006]. Note that actual decisions as to where to look next only need to be made at intersections and crossroads. Otherwise, a driver has no other option than to continue driving down the street he is in. The model does not allow a driver to change his driving direction in a street. This because this is often not feasible in the streets of an European city and because it is likely that the parking place will already be occupied by the time the driver has changed directions.

At an intersection, the driver can evaluate the apparent occupancy ratio in all the streets that connect to the intersection. If the occupancy ratio is substantially lower in one of the streets, the driver will chooses that street to look next for parking. This mechanism will, by its nature, quickly result in streets where the occupancy ratio is roughly equal in the immediate area of a driver. The occupancy ratio will vary across a city dependent upon the number of destinations within an area.

If the occupancy ratio is about equal in all the streets, the drivers adopts the ‘circling around the block’ strategy where he circles around the block one or more times in the hope of finding a free parking place at the block or that a place will be vacated in the time it takes him to make a tour around the block. If this fails, the driver starts looking in an area around his destination, making laps of which the radius increases the longer he cruises for parking. It should be noted that this strategy can fail, as the driver might wind up in a traffic situation where it is impossible for him to make the tour around the block he intended, due to one-way streets for example. In that case the driver tries to get back to his destination along the most expedient route available (remember that a driver is assumed to have full knowledge of the street network).

If a driver decides to go for an off-street parking place, his search strategy is different. While on-street parking can be regarded as a roughly continuous quantity spread out across the city, off-street parking is inherently discrete, constrained to the relatively few parking lots and parking garages available to the public. Following the same principles as for on-street parking, a driver initially selects a parking garage through a logit of which the most important variables are the distance from the garage to his destination, the price of the garage and the expected amount of free places in the garage. If, upon arriving at this garage, it is revealed that this garage is full, the driver reroutes to the second nearest garage and so on. If in the process of driving towards a parking garage a driver notices a free on-street parking place, he can decide to take this place, but he does not actively look for an on-street parking place.

5. Directions for further research

The model adopted for the choice of parking place adopted in this paper is a fairly simple one. As noted before, many variables could potentially have an impact on the parking choice of persons. These variables were not considered for the current choice model. This is largely caused by the sparse availability of data on the determinants of the parking choice of persons. Better research into this is needed, necessitating more and better data gathering that was possible under the current project.

Further, to function as a policy model the SUSTAPARK model needs to have a model for the modal choice of the agents. One of the main objectives of various policies related to parking is to achieve a modal shift, i.e. the encouragement of the use of other means of transport than the car in order to increase the sustainability of the transportation system and the liveability of the city. As noted higher, a model combining modal choice and parking choice on the basis of existing models is under development. A better approach would be to base this combined model on a new survey that queries respondents for their modal choice, their choice of type of parking if they choose a car and how the availability of parking and parking regimes influences the modal choice.

In recent years many parking policies and 'new' forms of car use, parking and parking management have been suggested. Actual implementations of these policies (aside from car-pooling) have been rare and little research has been done into the efficacy and popularity of these measures. To provide good advice to policy makers, a large scale study should be performed into the attitudes of the public towards these measures.

For policy-analysis on the longer term there are also interesting questions regarding the relationship between car ownership and parking supply and the relationship between the demand for mobility and the availability of affordable parking. The latter point is also connected to the activities performed in the city and hence to the economy of the city.

6. Concluding remarks

This paper described a detailed concept for a model for the behaviour of drivers needing to park. This model can be applied in the analysis of policies for the optimal usage of parking places and the reduction of the time that drivers spend looking to park. The parking behaviour of drivers is very complex and strongly dependent upon the local circumstances.

Policy makers attempting to influence parking behaviour need to find the right balance between providing enough parking at the correct price and providing not so much parking that car usage is excessively encouraged. Policy makers can employ two groups of tools: one group contains mostly pricing measures and better management of existing parking places, which can be implemented in a short time frame; the other group contains measures that have their impact in the long term and work mainly on the supply side of parking, i.e. the absolute number of parking places available.

But policy makers should keep in mind that trying to diminish the number of cars in the city should be paired with the development of and investment in alternative means of transport, both in their geographic coverage as in level of service. Otherwise, the city will become less accessible for everyone and those who need to be in the city will still come by car, causing problems in the city with their difficult to park car.

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