PARKAGENT
A model of parking search and parking in the city

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Samenvatting

PARKAGENT – Een simulatiemodel voor parkeren en parkeerzoekgedrag in steden

Door de dalende kosten van autobezit en tegelijkertijd de inkomensstijging van huishoudens, zien we meer en meer auto's in het straatbeeld in Westerse steden en de rest van de wereld. Daar tegenover staat dat het parkeeraanbod, voornamelijk in het centrum van steden, groeit met een nadrukkelijk lagere coëfficiënt. Dit heeft tot gevolg dat individuele automobilisten te kampen hebben met een parkeerplaatsen tekort in het stadscentrum, vooral tijdens piekuren als forenzen, bezoekers en bewoners een parkeerplaats zoeken. Dit resulteert vaak in situaties waar zoekverkeer ontstaat, zeker als het aantal parkeerplaatsen en de prijzen niet in verhouding staan tot de vraag.

Schattingen wijzen uit dat het aandeel voertuigen dat op zoek is naar een parkeerplaats in stadscentra kan oplopen tot 30-40% van het totale verkeer, met een gemiddelde van 10-15%. Door het oplossen van parkeerproblemen, en dus het terugdringen van zoekverkeer, zijn het niet alleen de automobilisten die hiervan profiteren. Dit betekent namelijk een daling in het verkeersniveau in stadscentra met als gevolg minder luchtvervuiling, geluidsoverlast en een hogere verkeersveiligheid in het stadscentrum voor bewoners en bezoekers.

PARKAGENT is een geografisch, agent-based model van zoekgedrag en keuze met betrekking tot parkeren in stadscentra. Het combineert modellering met uitgebreide GIS-databases. Met behulp van GIS-gegevens van stadscentra, laat PARKAGENT een gedetailleerd beeld zien van parkeergedrag van automobilisten en is het mogelijk uitgebreide analyses te maken op lokaal en globaal niveau. PARKAGENT is een agent-based model, wat betekent dat elke automobilist in het model wordt weergegeven als een zelfstandige agent, met een eigen bestemming, rijgedrag en parkeervoorkeuren.

Steden zullen meer en meer de balans moeten zoeken tussen aanbod en vraag naar parkeerplaatsen in het centrum en drukke kantoorlocaties. PARKAGENT, een geosimulatie model voor parkeergedrag in steden, kan besluitvormers helpen om beleidsalternatieven te onderzoeken op gevolgen voor automobilisten, bewoners en de schatkist. Het is zodoende de perfecte tool om een efficiënt en eerlijk parkeerbeleid te ontwikkelen.

1. Why do we model parking?

As real, inflation-corrected, cost of car ownership and use decrease and household incomes increase, more and more cars enter cities, both in Western countries and all over the world. In contrast, parking supply, especially in city centers, grows at an essentially lower rate. As a result, individual drivers find themselves facing a structural parking shortage in the city center, especially during peak hours, when commuters, visitors and residents are in search for parking. This situation often results in *cruising for parking*, especially if parking prices and locations are not tuned to parking demand.

Cruising for parking is a well-known phenomenon (R Arnott & Inci, 2006; D. Shoup, 2006); however, its aggregates effects are still under-investigated. Estimates of the share of cars cruising for parking reach 30-40% of overall traffic in city centers, with an average of about 10-15%. Solving parking problems and thus reducing cruising would therefore not only benefit drivers. It would also mean a drop in traffic levels in city centers and, hence, less air and noise pollution and increased traffic safety for city center residents and visitors. In order to effectively eliminate cruising, we need deeper understanding of the cruising phenomenon, that is, of the interrelationship between individual driver behavior and collective parking dynamics. This, in turn, requires a model that is able to simulate driver behavior and enables analyzing the collective effects.

Let us stress the power of modeling for exploring complex spatial phenomena. Cruising **is** such a phenomenon – numerous drivers search for parking within an environment that is continuously changing as a result of the behavior of those same drivers. Geosimulation (Benenson & Torrens, 2004) is a tool for managing phenomena of this kind. Geosimulation models combine real-world environments through a GIS database with a modeling environment in which real-world objects are simulated. In case of parking, the GIS database contains data on infrastructure objects - roads and parking lots and the properties of these objects, like capacity, prices, and parking permission. In addition, the GIS database contains data on model agents that represent car drivers who behave, i.e., drive to their destination, search for parking, park and leave the parking place after finalizing their errands. A Geosimulation model that describes the collective of drivers driving and parking within the real-world environment provides the perfect tool to analyze and asses the impacts of alternative parking policies. As such, it provides decision-makers with invaluable knowledge about the consequences of different types of interventions and thus assists in defining a parking policy that is optimal from various perspectives.

2. A brief review of parking models

Various types of models have been developed to simulate and analyze drivers' parking behavior in urban settings. An elaborate review can be found in Young et al. (1991) and Young (2000). The models can be divided into two main groups.

The first group of models are spatially implicit and aggregate, and are mostly associated with the economic view of driver's parking behavior (e.g. Richard Arnott, 2006; Richard Arnott & Rowse, 1999; Shoup, 2006; Verhoef, Nijkamp, & Rietveld, 1995). The input of economic models to the problem of parking is in the systematic analysis of the interrelationship between parking conditions and parking policy. These models aim at specifying optimal use of parking space utilization depending on the traffic flows, departure time, modal split and so on. Necessary for the analytical investigation, the standard economic assumptions of perfectly rational and utility maximizing behavior limit the application of these models to real-world situations. For this purpose, models need to be more realistic regarding the bounded rationality of driver behavior as well as the limited knowledge of drivers regarding the continuously changing parking situation.

The second group of models consists of spatially explicit simulations of drivers' parking search and choice. The development of these models started in the 1990s, but is still in its infancy. Most of the models deal with intentionally restricted situations of, e.g. parking search within an off-street parking lot (Harris & Dessouky, 1997), along several adjacent street segments (Saltzman, 1997) or within a small grid network of two-way streets (Thompson & Richardson, 1998). Spatially explicit simulation models consider parking behavior of drivers as a sequence of drivers' responses to the actual traffic situation and, in principle, are capable of capturing the self-organizing nature of cruising dynamics. In order to apply these models to assess real-world policy scenario's, the models need substantial extension in terms of the modeled area and the types of behavioral rules.
In contrast to these models, Geosimulation has a potential to systematically assess real-world situations of many drivers simultaneously searching for on-street and off-street parking, and simultaneously entering and leaving parking places in a realistic urban environment. We implement this ability with PARKAGENT, a recently developed, geosimulation model of parking in the city.

3. The PARKAGENT model

PARKAGENT is a spatially explicit, agent-based model of parking search and choice in the city. It links modeling to full-fledged GIS databases, which are in use for an increasing number of cities around the world. In this way, PARKAGENT enables representation of driver's parking behavior in a real city and the in-depth analysis of the driver's inherently local view of the parking situation. With the Geosimulation model a new way of exploring parking dynamics, and testing repercussions of parking policies, is now possible.

3.1. Infrastructure GIS

Four components of the PARKAGENT GIS are either directly obtained from, or constructed on, the infrastructure GIS of a city, which contains the layers of:

Street network with information on roads and junctions, traffic directions, and turn restrictions. Often, the layer of streets contains information on parking permissions and fees, and even on the probability of receiving, and the height of, a parking fine.

Parking lots with information on lots' capacity and pricing.

Destinations are usually associated with the features of the layers of buildings and open spaces. The features of these layers can simultaneously have several uses, e.g. a building can be used for dwelling and for offices. In this case, each use is characterized by its capacity, which reflects the number of drivers of different types that can use this feature as a destination. For example, in a city like Tel-Aviv, where average family car ownership is close to 100%, a building's dwelling capacity of ten and workplace capacity of three means that up to ten residents can choose the building as a destination when driving home after a working day, while up to three workers can choose it as a destination when driving in the morning to the workplace.

PARKAGENT constructs the layers of *Road Cells and On-street Parking Cells* that are employed for driving and parking, respectively. *Road Cells* are constructed by dividing the streets' centerline into fragments, which length is equal to the average length of a parking place (according to the field survey, 4 m in Tel-Aviv) and are employed for representing driving. Two *Parking Cells* are set parallel to the road at a given distance of the centerline (Figure 1), and parking place attribute determines if it is physically possible to park there.

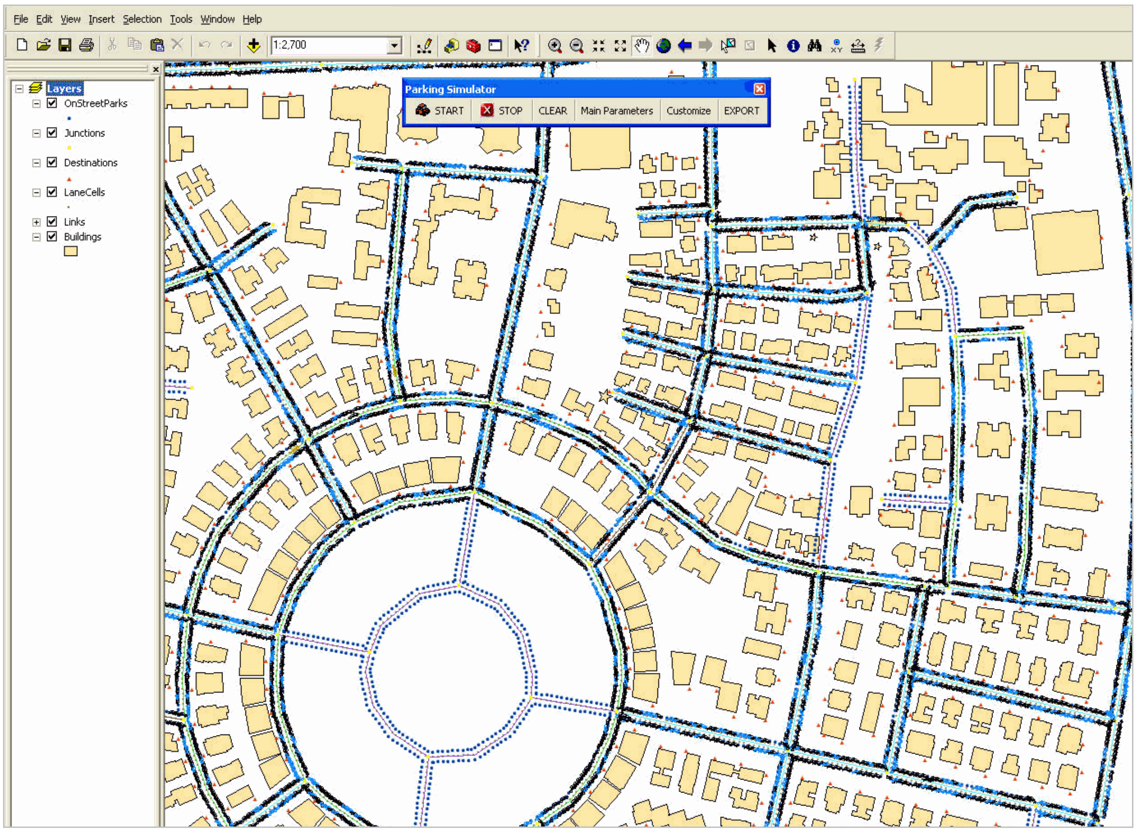


Figure 1 View of the PARKAGENT map window. Light blue points represent road cells, blue points on two sides of the street represent on-street parking places, large black points represent parked cars.

Off-street parking cells represent parking places in off-street parking facilities, based on data on parking lot capacity. In case of a multi-storey garage several cells are constructed, just one on the other.

The layers of road cells and on-street parking cells are built by PARKAGENT and the attributes of the roads are transferred to their features from the layer of streets. These are traffic directions, turn restrictions, parking permission (including 'parking not allowed'), etc.

PARKAGENT is a generic model and can be applied to any city. It contains tools for constructing artificial street networks, which can be used for exploring the basic dynamics of the parking system. PARKAGENT is in constant development and its recent modules account for the impact of the parking drivers on through-traffic and for simulating the number of lanes, and hence the queuing behavior, at the entrance of a parking facility. Note that applications of PARKAGENT always have to be based on the results of the field surveys and estimates for a particular city or region; the latter makes its results realistic and acceptable for practitioners.

3.2. Driver agents and their behavior

PARKAGENT is an agent-based model. This means that every driver is represented as a separate autonomous agent and is assigned a specific origin, destination, form of driving and parking behavior. The simulation runs at a time resolution of one second: each second, an agent can advance zero, one or more road cells ahead, depending on its speed and whether the next cell is free, pass a junction while deciding which turn to take, occupy a free parking cell, or leave a parking place.

The driver entering the model is assigned a destination in respect to the features of the destination layer. In the current version of the model, a agent-driver "lands" randomly at a distance of 300 m from the destination and then drives towards the destination while searching for parking. If succeeding to find a parking place, the driver parks and stays at the parking place for the time that is assigned to the driver based on field data. Through-traffic is considered at an aggregate level. If slow, it decreases the speed of the driver searching for parking, while a slowly moving car searching for parking in turn reduces the speed of the through-traffic.

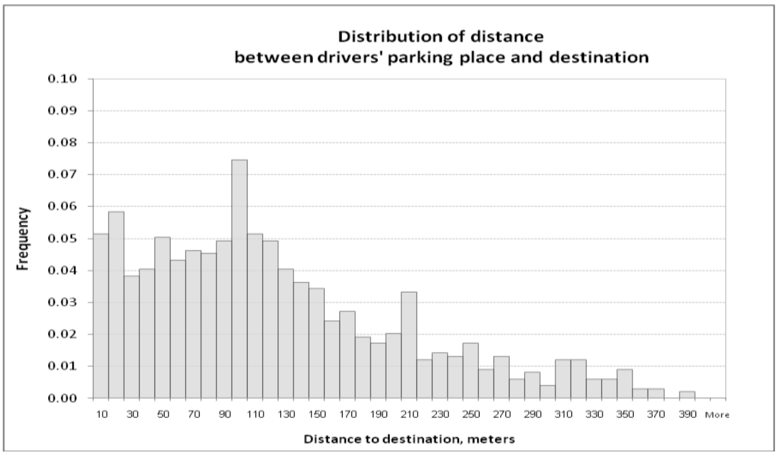
Based on Carrese et al. (2004), and our own observations while driving with drivers and recording their activities, we assume that the driving speed during the parking search does not exceed 12 km/h. PARKAGENT employs two algorithms of way-finding during driving to the destination. The first is simply the optimal (usually shortest) path between the point of landing and the destination and is characteristic of the drivers who know the area well; according to the second, at each road junction, a driver chooses the street segment which takes it closest to the destination. Following this rule, the driver usually takes a route which is close to the shortest path from the "landing" point to the destination, while in case of a complex one-way street network they can fail to approach the destination and park at some distance irrespective of parking availability. This approach can be associated with the behavior of a newcomer to a certain area.

3.3. Model output

Explicit representation of the driver agents enables both aggregate and disaggregates outputs, each at any temporal resolution. Currently, the aggregate output includes the dynamics of the number of the drivers in search of parking and of the free on-street and off-street parking places over the entire modeled area or its parts (Figure 2a). The disaggregate output encompasses, amongst others, the distribution of the time drivers spent on searching for parking and of the distance between parking place and destination (Figure 2b,c).

a)

b)



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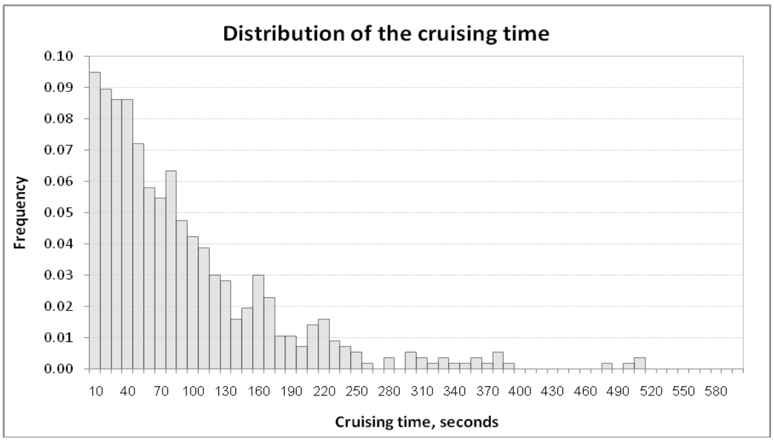


Figure 2 Typical output of PARKAGENT for the scenario for the case of 1000 cars leaving, and 1000 cars entering 1 km^2 urban area (~5000 on-street parking places). In the beginning, 98% of parking places are occupied. (a) Aggregate output – overall number of free on-street parking places and cars searching for parking over 1 km^2 of the urban area; (b) Disaggregate output - distribution of the drivers' search time and (c) Disaggregate output - distribution of distance between the drivers' parking place and the destination.

3.4. Technical Characteristics of PARKAGENT

The PARKAGENT Geosimulation model is implemented as a C#.NET ArcGIS™ extension. Its performance remains high for several thousands of drivers simultaneously searching for parking. The latter is sufficient for practical implementations in most cities.

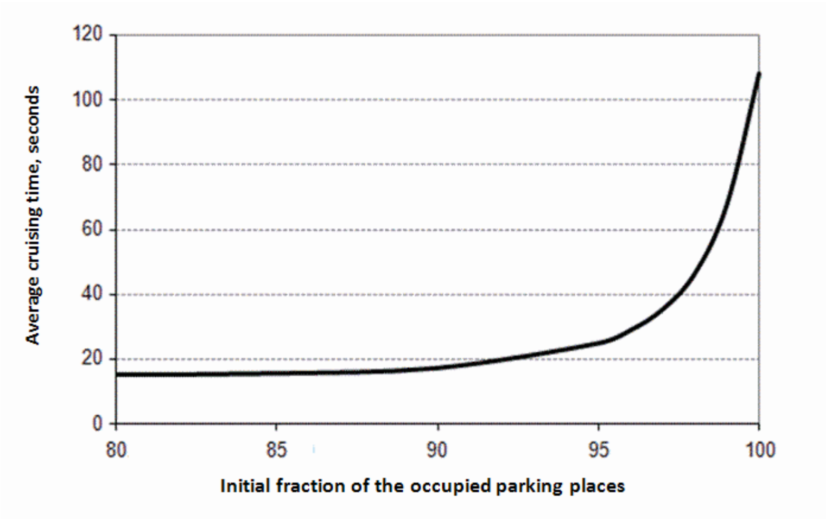
4. Applications of PARKAGENT

Can a high-resolution spatially explicit, agent-based model help decision makers, transportation experts and planners? To answer to this question positively, we are working in a few directions.

4.1. Cruising threshold

We have explored the cruising phenomenon in depth to determine what rate of parking vacancy is necessary to eliminate cruising for parking. Traffic engineers generally recommend that about 15% of all on-street – one space in every seven – should remain vacant to ensure easy ingress and egress and achieve close-to-zero levels of cruising (Shoup, 2005, p. 297). However, till today the 15% ratio has never been tested in reality or in a model. A series of simulations with PARKAGENT has generated interesting result regarding this so-called *cruising threshold*. As can be seen in Figure 3, we found that cruising is kept to a minimum level with a substantially lower share of vacant parking places. Even if 95 - 97% or parking places are occupied (i.e., 3-5% of free parking places) the average cruising time remains below half a minute. This information is critical for setting parking policy and prices. It suggests that policy makers do not have to aim for a parking occupancy rate as low as 85% in order to avoid cruising for parking, but can actually accept much higher occupancy rates. This finding can thus reduce the need for new parking facilities and/or limit the need to raise on-street parking fees.

a)



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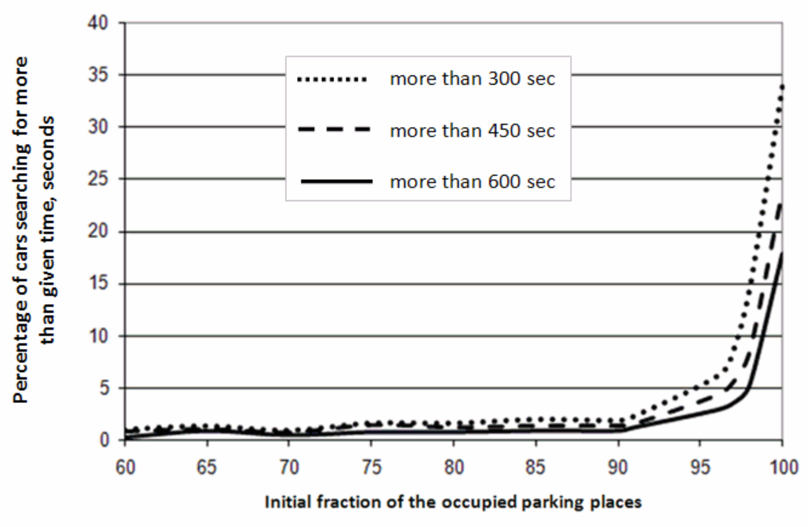

Figure 3 PARKAGENT analysis of cruising threshold as dependent on the density of occupied parking places. Typical output of PARKAGENT for the scenario for the case of 1000 cars leaving, and 1000 cars entering 1 km^2 urban area (~5000 on-street parking places) as dependent on the initial fraction of the occupied parking places: (a) Average cruising time; (b) Percentage of cars cruising more than given time.

4.2. One large parking lot or several smaller ones

A municipality that wants to improve parking conditions for visitors in the daytime and for residents at night is usually faced with the problem of garage size. The choice for one large garage implies that a large share of drivers will face a substantial walking distance to their destination and may also imply cruising, as drivers may prefer on-street parking close to the destination over off-street parking. Several small garages, on the other hand, may provide a higher level of service to the driver, but are more expensive to build and operate and may also induce cruising among drivers during peak times as the chances of a fully occupied parking facility increase.

PARKAGENT makes it possible to compare these aspects. For the case of the Tel-Aviv center, where the experimentally estimated average demand/supply ratio remains 105-110% both at night and in the daytime (i.e., some of the arriving drivers have to park far away from their destinations outside the study area), we have compared parking search dynamics in case one large garage of 1,000 parking places would added in the center of the area versus the case of four lots of 250 places distributed over the area (Figure 4). The analysis with PARKAGENT demonstrates that the number of drivers who would search for more than 10 minutes in case of one parking garage is about 400-450, while in case of four small parking lots this number decreases to 250-300. That is, smaller plots cause less cruising for parking.

Figure 4 Possible location of the (a) one large parking garage and (b) four smaller parking lots of 1/4th capacity. Typical dimensions of the parking lots service area are shown.

4.3. Construction of an underground parking lot

Recently, we have been asked to employ PARKAGENT to assess the necessity and effects of an underground parking facility in the Central Business District of the Tel Aviv metropolitan area. This highly dense urban area undergoes constant development, and the municipal plan is to construct a parking garage of up to 800 places under the main street of the area to compensate for the loss of small off-street parking lots and to generally improve parking availability in the area. After surveying parking supply and parking dynamics in the area, we will employ PARKAGENT for simulating different developing scenarios and estimating their consequences on the parking dynamics. The full study of the situation demands an additional component of PARKAGENT, namely, the detailed representation of the entrances, which is evidently necessary for assessing possible congestion there. This component is currently under development.

5. Conclusion

Cities increasingly have to balance supply of, and demand for, parking, in their inner cities as well as around major employment centers. PARKAGENT, a geosimulation model of parking search in the city, can help decision-makers explore policy alternatives and identify the impacts for drivers, residents, and the city’s coffers. As such it provides a perfect tool to develop efficient and fair parking policies.

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