Spatially explicit modeling of parking search as a tool for urban parking facilities and policy assessment

Nadav Levy\textsuperscript{a}, Marc Render\textsuperscript{b}, Itzhak Benenson\textsuperscript{c,}\textsuperscript{*}

\textsuperscript{a} The Porter School of Environmental Studies, Tel-Aviv University, Israel
\textsuperscript{b} AMAV Transportation and Traffic Planning Ltd., Jerusalem, Israel
\textsuperscript{c} Department of Geography and Human Environment, Tel Aviv University, Israel

\begin{abstract}

The engineering view of a measurable, supply-independent, demand for parking that can be expressed by "minimum parking codes" has been generally rejected during the last two decades and is gradually being replaced by "maximum provision" codes, limited parking development, and demand pricing. To assess new planning practices one has to estimate the drivers' reaction to proposed spatial-temporal parking limitations. The paper applies a high-resolution spatially explicit agent-based model termed "PARKAGENT" as a tool for this assessment. The model is used for evaluation of parking demand in the Diamond Exchange area in Ramat Gan, a city in the Tel Aviv metropolitan area, for estimating the effectiveness of planned parking facilities for different development scenarios in the area and assessing electronic signage system that directs drivers to vacant parking lots. The results strongly indicate the advantages of agent-based modeling over the current dominant engineering approach and show the potential benefits of using an intelligent parking guidance system.

\end{abstract}

\section{Urban parking policy revolution: from satisfying demand to regulating car usage in the city}

Parking, in the practical engineering view, is seen as a utility to be supplied based on measurable demand. For various land uses, such as a large shopping center, high tech park, or restaurants, common sense procedures based on surveys are sufficient for estimating demand. For example, parking demand generated from an office building is usually estimated based on usable floor area, factors for employees and visitors per unit of floor area, and the percentage of employees and visitors using cars to get to the office. In other cases, the number of students in a college or number of chairs in an auditorium can serve as a basis for estimating the demand for parking. The classic survey of this sort is published by the Institute of Traffic Engineers (USA) "Trip Generation Manual" now in its 9th edition. The manual contains trip generation rates for private cars for hundreds of land uses, from drive-in banks to sports stadiums. By calculating the demand for car trips at different times of the day it is possible then to calculate the parking supply needed to satisfy this demand.

In order to further standardize parking provision and avoid the need for further surveys, cities and states created parking "codes" that, similar to the surveys, set up a number of parking places to be provided by land uses. The first residential parking requirement originated in Columbus, Ohio in 1923 – one parking place per apartment. In 1939 the city of Fresno California created the first non-residential parking requirement for hospitals and hotels, in parallel to the 1939 German Reichsgaragenordnung (Order on Garages of the Third Reich) which introduced off street parking regulations to Germany and Austria (Knoflacher, 2006). A widespread adaptation of standardized parking codes started in 1950s, with the lofty goal to "alleviate or prevent traffic congestion and shortages of curbside parking places" (parking code of Pasadena, California, http://greatergreater.com/files/200802/nzoningparking.pdf). These codes specify the number of parking places per unit of a floor area, for example of a regional shopping center, local commercial areas, banks, etc. Estimating parking demand then becomes a matter of arithmetic that translates a building program to parking places to be provided for both employees and visitors according to the proposed land use.

In this standard view, a lack of parking at a facility planned in accordance with a standard type parking code indicates a need to revise the code upwards. This was the case for many years in Israel, with the minimum provision of parking for a residential unit being adjusted consistently upwards from 0.5 to 0.75 places per unit to 2.0 places in many cases today. The critical assumption of the above approach – an ability to supply unlimited amount of parking, is now obviously problematic. Besides space limitations (that can be overcome at great
expense by underground parking garages and above ground structures), it contains another, hidden, assumption that a supply of road capacity is also unconstrained, even in the critical peak periods of travel to and from work, studies and recreational trips. The latter has proved untenable even in the most car oriented North American cities. Moreover, transportation researchers noted the phenomenon of “induced demand,” namely, an unconstrained free provision of parking and road capacity increases the rate of use of both (Cervero and Hansen, 2002). This, in turn, is accompanied by an increase in average trip length, in the rate of car ownership, and in the percentage of trips made by private car thus further increasing the need for parking and road capacity. Road congestion, staggering amounts of land allocated to road space and parking, and the environmental penalty in air and noise pollution call into question the very basis of the view of transportation planning as a kind of traffic plumbing providing adequate road “pipes” and parking “reservoirs”.

Recognizing these inherent problems, transportation planners have moved away from the supply-focused view of parking to the policy driven model, which focuses on the encouraging public transportation and non-motorized transport (bicycle, walking) as the primary solution of urban mobility problem. This new attitude initially found voice in the modification of the standard parking code to require less parking in central business districts or areas with good public transport provision. A good example of the development of this approach is the new Jerusalem parking code, which establishes a maximum rather than minimum number of parking places for each land use. In areas within walking distance of existing or future mass transit lines, the maximum is severely limited, especially for employee and shopper parking (Local Masterplan #5166, 2003, amended 2007). The origins of similar policies could be seen in San Francisco in the 1970, with the implementation of the BART rapid transit system, and in 1985 limits on downtown office parking https://livablecity.org/livable-neighborhoods/parking-reform-for-a-livable-city/.

The new paradigm “maximum parking standard” serves as a basis for establishing parking policy in many cities such as Zurich, Amsterdam and Strasbourg, which limit the amount of parking places in city centers (Kodransky and Hermann, 2011). The view of parking supply as a component of the urban transportation system is further reinforced by transportation economists, who see the employment of market forces as the most efficient arbiter of scarce parking and road resources (Shoup, 2004; Shoup, 2006; Litman, 2010). Should a market-determined price be set for either, demand would bring itself in line with supply automatically. It is now clear that increase in area’s capacity for parking is not an automatic solution, but in fact become a source of urban transportation problems (Tam and Lam, 2000).

At a country level, the new laws in Israel, Switzerland, United Kingdom and Italy (Israel Ministry of Transport, 2005; Kodransky and Hermann, 2011) also aim at limiting the amount of parking places in the cities. The assumption is that an excess demand will drive up parking prices and thus move demand to walking, biking or public transport. Other reforms, such as the imposition of property taxes on private parking areas, even if they do not charge for parking (employee parking for example) put further pressure to provide less parking or charge for its use to offset costs.

All this essentially complicates transportation planning – instead of simple mathematical calculations, estimating parking demand must account for the cost of parking and its economic justification in light of the present and future demand in the area. We also cannot be sure that population reaction to the restrictive public policy will result in increasing use of public transport and non-motorized transport in urban areas. Estimating these and other effects demands an adequate model of driver’s reactions to limits on parking supply.

This paper makes a step in this direction. To assess drivers’ reaction to the potential, yet limited, parking supply, we employ high-resolution spatially explicit dynamic agent-based PARKAGENT model and apply this model for the planning of a new parking facility in a central business area of the Tel Aviv metropolitan area. Section 2 presents a short view of the modeling of the parking search in the city with the stress on the agent-based simulation modeling; Section 3 presents the PARKAGENT model; Section 4 describes a case study of the Diamond Exchange district in the Tel-Aviv metropolitan area and the “engineering” and PARKAGENT views of the parking problem there. We discuss the obtained results in Section 5.

2. Combining optimal supply of parking facilities with simulation of cruising for parking

What is an adequate parking supply? Most parking research considers this question from an economic point of view and assumes that the driver is a rational actor who seeks to minimize the total cost of parking (Young and Thompson, 1991; Young, 2000). This view is implemented in the models based on statistical relationships between the parking demand and driver’s decision making based on the parking availability, price and currently and previously available information on parking occupation (Bates and Bradley, 1986; Polak et al., 1990; Axhausen and Polak, 1991; Khattak and Polak, 1993). The relationships employed in these models were based on stated preference experiments and accounted for the hierarchy of the traffic mode choice and type of parking (on- or off-street, etc.) and were used to estimate the effect of changes in transport and parking services on the choice of travelers’ traffic mode and parking type and location (Young and Taylor, 1991).

Shoup’s model (2005) aims at optimizing parking prices by considering equally priced on- and off-street parking and estimates the amount of parking that results in zero cruising (Shoup, 2005). However, the model does not account for the distance between the parking place and the destination: if parking lots are far from the destination, drivers will yet prefer to cruise in order to find unoccupied and close on-street parking. Calthrop and Proost (2006) suggest that street parking should be priced equivalent to the marginal cost of providing an additional off-street space, while Arnott and Inci (2006) in their “bathtub model” investigate the relation between on-street parking, parking price and traffic congestion in the city accounting for the walking time from the parking place to the destination. Further studies of Arnott and co-authors (Arnott and Inci, 2010; Arnott and Rowe, 2013; Arnott, 2014) demonstrate that pricing can be an effective and adequate tool of parking policy that causes reduction of cruising while preserving high levels of parking occupancy. The bathtub model makes it possible to recognize underpriced curb parking and establish the price level that will result in minimal potential cruising. Higher parking fees will raise municipality revenue while causing no harm to local businesses since all parking places are still occupied. Arnott (2013) also demonstrates how parking capacity and pricing should be simultaneously adjusted to minimize cruising.

All above models focus on the equilibrium ratio of parking demand and supply and the question is what should be this equilibrium and how it can be maintained in practice. This view of the parking supply, popularized by Shoup (2006), aims at 85% occupation level by prices varying in space or during the day, a rate at which cruising behavior is minimized. Levy et al. (2013) show that the 85% level can be raised to 92–93%. However, this ratio varies in time and space and its value at a certain location is very sensitive to the parking situation over the surrounding area. To account for this, we need a high-resolution and dynamic view
of parking patterns that directly takes into account parking search and choice and the spatial distribution of urban parking demand and supply. These dynamic models of parking are as of yet very few. Harris and Dessouky (1997) present a model that maximizes the efficiency of a new parking permission tag system, in Miami University's parking lots. Thompson and Richardson (1998) simulate the parking search during driving within an urban neighborhood between off- and on-street parking. They demonstrate that instantaneously varying parking conditions disable a driver’s ability to shorten cruising time based on the information accumulated during the current search or during previous attempts to park in the area. A dynamic view of parking search generates new approaches to parking management, such as pricing by drivers’ origin or in respect to parking location (D’Acierno et al., 2006; Anderson and de Palma, 2004). A comprehensive review on the early stages of dynamic parking modeling and important ideas that were implemented in the micro- and macroscopic models like PARKSIS and MONSTER can be found in work by Young and Taylor (1991). Recent research focuses on agent-based simulation of the parking search behavior (Benenson et al., 2008; Gallo et al., 2011; Waraich and Axhausen, 2012; Levy et al., 2013). In this research, we follow this line and apply PARKAGENT agent-based simulation model (Benenson et al., 2008; Levy et al., 2013) as a decision-making tool. We apply PARKAGENT for studying a popular planning problem: estimating the effects of planned parking facilities on the parking situation in the area characterized by high parking demand.

3. PARKAGENT: an agent-based spatially explicit model of parking search

PARKAGENT is a multi-agent spatially explicit model of parking search. It was developed for analyzing parking dynamics, assessing parking policies and evaluating parking solutions (Benenson et al., 2008; Martens et al., 2010; Levy et al., 2013). PARKAGENT is an ArcGIS application that simulates parking behavior of an unlimited number of driver-agents who simultaneously search for parking and park over any urban area, up to an entire city. Each driver agent has his own destination. In the case of an urban residential neighborhood, each building is a destination for its residents; in a large shopping mall, the destination is common for numerous drivers. During the parking search, every driver agent is aware of his current location on the road and, if a parking place is available nearby, decides, based on the distance between the current location and the destination, his personal parameters and the parameters of the parking place, whether to park or continue the search. PARKAGENT uses standard layers of the Municipal Geographical Information Systems (GIS) data to account for the road structure, traffic limitations and parking facilities. These layers are recently available in a standard format in the majority of the developed countries and accordingly PARKAGENT can be easily adjusted to different urban environments.

Typical dataset of the PARKAGENT includes:

- A layer of street segments that including the entrances to and exits from parking lots/garages. Based on this layer, PARKAGENT constructs a layer of on-street parking places. These places are created on both sides of the street at a distance between each other that is equal to the average length of a car in a particular country plus 0.5 m, an average gap between two parked cars. For Israel, we employ in this paper a distance of 5 m. These theoretically constructed parking places may in fact be physically impossible for parking, prohibited for all or for some drivers during the entire day or part of it, free of charge or priced. All these characteristics are assigned to every parking place (usually according to the information available from the other layers of the municipal GIS, as a layer of parking zones, records of parking surveys, or reports from parking inspectors).

- A layer of destinations, usually represented by building outlines. PARKAGENT considers destinations as points, and in this way the layer of building entrances, if available, serves as the basic source for building the layer of destinations. If building entrances are not available, PARKAGENT uses building centroids as destinations. Other destinations include parks and other urban facilities that are not buildings. Each destination is characterized by the number of drivers who seek to arrive there, by the hours of the day.

- A layer of parking lots/garages-a polygon layer of the parking lots and multi-storied garages each characterized by a polygon (parking lot or garage structure outline), the amount of parking places at every floor, and price. Based on this layer, PARKAGENT constructs the layer of off-street parking places. For a multi-storied garage, the number of parking places is constructed at the same location in accordance with the number of floors in the garage.

Additionally PARKAGENT is able to simulate parking control (not considered in this paper). If this option is activated, a layer of parking inspectors’ routes needs to be implemented.
Fig. 1 presents PARKAGENT’s layers of street segments, buildings as destinations, on-street parking places, and parking lots.

The figure presents a part of the PARKAGENT map screen with a parking lot, an entrance to it and the area of ∼300 × 200 m² around. The vacant parking places are represented by points; occupied parking places are represented by cars. Cars of different colors represent different groups of driver agents. At the entrance to the parking lot, two cars are in the queue to enter the lot.

3.1. Drivers’ parking search behavior

PARKAGENT distinguishes between four groups of drivers: residents, commuters, customers and visitors. Each group has its own average behavior and characteristics, such as a set of possible destinations (shopping mall/office building/residence), average willingness to search for free parking, average willingness to pay for parking, average parking duration. Individual driver’s characteristics are assigned according to the driver agent type’s parameter distribution.

The number of the driver agents starting the search during a certain hour of a day is defined in advance, based on the number of employees and visitors in the area. Arrival time of the agent is distributed uniformly during the hour.

Each driver agent starts a parking search at a distance of 500 m from his destination. The model considers an agent’s actions at a time resolution of 1 s.

During model operation, a driver agent can be in one of four main states:

1. Searching for on-street and off-street parking on the way to his destination.
2. Searching for on-street and off-street parking after missing his destination.
3. Parking.
4. Vacating the parking place and leaving the system.

The most important for our planning applications are the first two stages of the parking search. In the state of parking, an agent is idle and just counts the parking time and fees, while in the state of vacating an agent just drives out of the system.

Let us describe the parking search algorithm (stages 1 and 2) in more detail.

3.1.1. On-street search

The model driver agent is assigned the type and, depending on the type, the destination and maximal time of the on-street parking search. The agent starts his parking search at a distance of 500 m to the destination and, on his way to his destination, decreases the speed to 12 km/h (Benenson et al., 2008). The model user can choose between two algorithms of driving towards a destination: the shortest path according to the Dijkstra algorithm and the heuristic algorithm (Benenson et al., 2008; Levy et al., 2013) that assumes that at each junction the driver agent chooses a street segment, which at its end is closest to the driver’s destination. Based on local parking characteristics we consider in this paper the situation of free on-street and charged off-street parking.

The agent, thus, prefers to park on-street.

While driving to the destination, the agent roughly estimates the remaining distance and the fraction $R(t)$ of free parking places that he passed during the last half minute (in case of uncongested traffic, this is 100 m at a speed of 12 km/h). If, during driving, the agent sees an empty parking place, he estimates, based on $R(t)$, the current number $N(t)$ of the empty on-street parking places that can be expected on the remaining trip to the destination. This estimate is given by $N(t)=D(t)+F(t)/5$, where $D(t)$ is agent’s estimate of the distance, in meters, to a destination, and $5 m$ is an average length of an interval between the cars parking on-street. If $N(t) ≥ 3$ the agent continues driving towards his destination; in case of $N(t) < 1$ the agent parks in that place; and in an intermediate case of $1 < N(t) < 3$ the agent parks with a probability $p(t)=3-N(t)/2$ or continues driving with a probability $1-p(t)$.

In a large and dense city, where there is a high demand for parking, there is a good chance the agent would not find a parking place on the way to his destination. If an agent passes the destination without finding a parking place, he starts cruising for parking within the destination’s search neighborhood. Initial radius of this neighborhood is 100 m and it grows instantaneously at a rate 30 m/min. At this stage, an agent parks at the first vacant parking place he finds.

3.1.2. Off-street search

After the accumulated time of search of free on-street parking exceeds the driver agent’s individual threshold (which can be zero), the agent is willing to park in a parking lot. In what follows, we apply the model to an area where parking fees are almost the same for every lot and, thus, the driver agent reacts to the distance between the parking lots and the destination only. Each model agent has knowledge about some parking lots within the destination’s neighborhood and from that moment on, drives to the closest known parking lot. If the driver agent reaches a lot that is fully occupied, he drives to the next closest lot, etc. If during this search, the agent comes across a vacant on-street parking place or unknown parking lot with vacant places, he parks there. If all known parking lots are full, the agent repeatedly checks known parking lots. In this paper, the agent that fails to park during 20 min forfeits the search and leaves the area.

The duration of parking depends on the driver agent’s type. The duration of parking is assigned, according to the distribution of the parking time for agents of a certain type, at the moment they start the parking search. In the version of the model that is applied in this paper, after the parking time is completed, the agent’s parking place is freed and the agent disappears from the system.

It is important to note that agents at close proximity interact and that an agent that drives just after the other agent does not advance until this is physically possible. This provides some interesting real life phenomena such as queuing outside a popular parking lot and can help provide knowledge about the size of queue required for each parking lot to prevent blockage of the adjacent road network.

4. The case study

In our case study, we applied PARKAGENT for estimating a scenario of parking infrastructure development in the Diamond Exchange business area in the Tel Aviv metropolitan area (City of Ramat Gan), Israel. Specifically, we assessed the planned Bialik parking garage in this area (Fig. 2); this assessment is a part of a report submitted to the Ramat Gan Municipality.

The Ramat Gan Diamond Exchange area is about 0.5 km² in size. It is bounded by the Ayalon Highway on the west, by Aba Hillel Street on the east, Jabotinsky Road on the south, and by Bialik Street on the north (Fig. 2).

The area has almost no residential sections and is statutorily defined as “business and light industry.” It provides jobs for approximately 30,000 employees. The parking supply in the area is divided into three types: curb parking, surface parking lots and the majority of the parking supply in underground parking lots in office buildings supplying, altogether 23,000 parking places (Table 1, Fig. 2):
Parking prices in the area are essentially uniform; at the time of the field study the price averaged about 20 NIS/h with the minimum and maximum values being 15 and 25 NIS/h respectively. This can be explained by the high density of parking lots and very short distances between them (usually, less than 50 m). A high density of parking lots makes it possible to find a parking place close to a destination and minimize walk distance. The area is considered very safe and no security issues play a role in selecting a parking location. The analysis that follows is focused on the lack of a spatial fit between demand and supply.

4.1. Characteristics of the area, transportation modes and parking demand

Parking surveys carried out in the area revealed that average parking lot vacancy during the day is 10–15% that is, current total parking supply in the area is sufficient for the current total demand.

To assess the employees’ transportation habits, parking demand and parking choice, we questioned 550 employees from 11 offices in the area about their transportation mode to get to the area and, in case they come with a car, about their parking habits (Table 2). Assuming a rough estimate of 60% private car share (Table 2), we can conclude that employee parking demand in the area is about 18,000 places.

Table 1
Parking supply in the Ramat Gan Diamond Exchange area.

<table>
<thead>
<tr>
<th>Office buildings</th>
<th>Curb</th>
<th>Surface lots</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>19,980</td>
<td>1470</td>
<td>1550</td>
<td>23,000</td>
</tr>
</tbody>
</table>

Out of the employees surveyed, 273 (ca. 50%) do not have a permanent parking place. Table 3 presents transportation means for employees that do not have a permanent parking place.

51 of the 273 employees (18.7% of those who do not have a permanent parking place and 9.3% of all employees) arrive by car and have to search for a different parking place each time they arrive to work. As part of the survey, these employees were asked to mark their current parking place on a detailed map of the area. Table 4 presents the distribution of the distances between their job location and parking calculated based on their current parking location.

Note that maximal distance to destination—about 300 m, is similar to that obtained for overnight residential parking in central Tel Aviv (Benenson et al., 2008). Extrapolating to all 30,000 employees, we find that about 3000 of them, roughly that 10% of all the employees in the business area, search and find a parking place each time they arrive to work.

Addition parking demand is created by visitors. According to the survey, about 900 visitors (i.e., 3 visitors per each 100 employees) arrive each hour to the area and stay there for an average of 2 h. That is, 6 additional parking places are needed for each 100 employees in the area, which figures to a total of 1800 parking places for 30,000 employees in the area during working hours.

The above estimates result, roughly, in a demand-to-supply ratio of 0.86: (employees demand + visitors demand)/total supply = 26,000/(18,000 + 1800) = 0.86, which is very close to 85% threshold advocated by traffic engineers (Shoup, 2005). As we recently demonstrated, the threshold can be increased even more, to 92–93%, without affecting traffic or parking dynamics. However, applied to large areas, as the Ramat Gan Diamond Exchange, this average value is misleading. This is because spatial variation in demand and supply characteristic for the high-density office areas, cause essential variation of the local demand-to-supply ratio. Drivers whose destinations are located in areas where the local demand-to-supply ratio is above 95% spend essential time for parking search and park far away from their destinations (Levy et al., 2013). Understanding of parking dynamics in the area demands high-resolution and spatially explicit estimates of the demand and supply.

The GIS layer of buildings (Fig. 1) supply the data on the building foundation area and the number of floors. This enables estimation of the number of employees and, thus, the number of drivers who aim at a building as a destination (Fig. 3). Note that according to the survey data, about 10% of the drivers do not have permanent parking place in their office building or other nearby lots.

Table 2
Transportation mode of employees (N=550).

<table>
<thead>
<tr>
<th>Private car</th>
<th>Public transportation</th>
<th>Two-wheeled</th>
<th>By foot</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
<td>26%</td>
<td>6%</td>
<td>7%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Table 3
Employees’ means of transportation (N=273).

<table>
<thead>
<tr>
<th>Private car</th>
<th>Public transportation</th>
<th>Two-wheeled</th>
<th>By foot</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>19%</td>
<td>52%</td>
<td>13%</td>
<td>14%</td>
<td>2%</td>
</tr>
</tbody>
</table>

Table 4
Parking distance (m) N=51.

<table>
<thead>
<tr>
<th>Average</th>
<th>Median</th>
<th>STD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>134.2</td>
<td>99.1</td>
<td>101.5</td>
<td>9</td>
<td>336</td>
</tr>
</tbody>
</table>
4.2. Bialik parking garage project as a solution for future parking demand

4.2.1. Future developments in the area of the diamond exchange

Future projects in the Diamond Exchange area can dramatically change the demand and supply for parking there. Currently, 10 construction projects are planned in the area for the next decade (Fig. 4), some on existing above ground parking lots. In addition to the increase in demand, this construction will reduce parking supply in the area. Some of the new projects include the construction of underground parking, but in most cases, due to the recent lowering of parking standards, the demand that they create will surpass the existing parking supply for both commuters and visitors.

According to Amav Transportation Planning Ltd., the following are accepted planning rules of thumb in Israel:

- Employee gross work space is 15 m² of built floor space
- Parking places in structures occupy a gross area of 35 m² per parking place.

Parking demand for the projects (Table 5) was calculated according to our survey results presented in Section 4.1 above:

- 60% of employees arrive to the area by private car.
- 3 visitors per every 100 employees arrive to the area and stay for 2 h, creating a demand of 6 parking places per hour.

4.2.2. Bialik underground garage as a solution for the future parking demand

The Diamond Exchange is an area of intensive development and several development projects are planned for this area, some of them in the place of existing surface parking lots. Underground parking places in the new buildings will essentially raise the cost of construction and cause additional traffic congestion in the area.

The alternative proposed by the engineers is to build an underground parking garage at one of the entrances to the area in the right of way of Bialik Street its north end (Fig. 4). The high cost of
Table 5
Planned projects and associated parking demand for the working hours.

<table>
<thead>
<tr>
<th>Project #</th>
<th>Business built area, m²</th>
<th>Employees- associated parking demand</th>
<th>Visitor associated parking demand</th>
<th>Number of planned underground parking places</th>
<th>Number of the surface parking places that are canceled by project</th>
<th>Project net added demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>37,280</td>
<td>1500</td>
<td>150</td>
<td>850</td>
<td>50</td>
<td>800</td>
</tr>
<tr>
<td>2</td>
<td>28,000</td>
<td>1120</td>
<td>110</td>
<td>700</td>
<td>0</td>
<td>530</td>
</tr>
<tr>
<td>3</td>
<td>21,400</td>
<td>850</td>
<td>85</td>
<td>360</td>
<td>0</td>
<td>575</td>
</tr>
<tr>
<td>4</td>
<td>46,000</td>
<td>1650</td>
<td>180</td>
<td>660</td>
<td>150</td>
<td>1170</td>
</tr>
<tr>
<td>5</td>
<td>16,000</td>
<td>640</td>
<td>60</td>
<td>300</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>6</td>
<td>1089</td>
<td>45</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>1000</td>
<td>40</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>45</td>
</tr>
<tr>
<td>9</td>
<td>60,000</td>
<td>2400</td>
<td>240</td>
<td>980</td>
<td>180</td>
<td>1660</td>
</tr>
<tr>
<td>10</td>
<td>21,950</td>
<td>880</td>
<td>90</td>
<td>240</td>
<td>90</td>
<td>730</td>
</tr>
</tbody>
</table>

Fig. 5. The aerial image (a) and engineering map (b) of the immediate area of the proposed garage used, according to the engineering standards, for the assessment of the Bialik garage.
construction makes a new garage of less than 500 parking places uneconomical.

The location of the new garage at the periphery of the office area is however, problematic. On the one hand, the garage can be underused: drivers just entering the area and passing a new garage can skip it in hope of finding a parking place closer to their destination, while drivers arriving by the other roads can search for long in the vicinity of their destinations and ignore the garage at the periphery. On the other hand, we are in danger of underestimating the convenience of the garage for drivers, build too small a garage or worse yet not resolve the parking problems in the area, saying nothing about lost revenue. PARKAGENT makes it possible to estimate the utilization of the Bialik garage for various construction scenarios.

4.2.3. Engineering estimates of Bialik garage effectiveness

As an initial engineering investigation, a study was made of existing buildings in the surroundings of the new parking garage and the amount of existing parking in these buildings was estimated. The immediate study area includes the area bordering Bialik Street to the north and south within walking distance of approximately 250 m from the proposed garage, as mandated in existing parking codes of the Israeli National Building and Planning Regulations, Parking Requirements, 1983, paragraph 2b (Fig. 5). This supply was compared to a calculation of the demand for parking in this area based on the “minimum parking provision” for the buildings in the impact area.

The area in Fig. 5 includes 270 housing units and 28,800 m² of existing office and commercial space. Parking codes for the area (1 per 40 m² of the office space) mandate 997 off-street parking places, of which only 440 (44%) actually exist. However when on street and surface level off street parking in undeveloped plots is included, the available parking supply grows to 900 places that is 90% of the parking requirement. Thus, when the latter parking supply is included, the gap between supply and demand drops to 100 parking places and does not justify the construction of a new garage. The future project nearby (see more on the area development projects below in the Section 4.3) demands 43 more parking places, of which only 440 (44%) actually exist. However when on street and surface level off street parking in undeveloped plots is included, the available parking supply grows to 900 places that is 90% of the parking requirement. Thus, when the latter parking supply is included, the gap between supply and demand drops to 100 parking places and does not justify the construction of a new garage. The future project nearby (see more on the area development projects below in the Section 4.3) demands 43 more parking places. Should the “traditional” method of measuring parking demand be adopted, the Bialik garage project would be dropped.

However, there are several problems, which immediately call into question the usefulness of a parking code oriented analysis:

- The existing parking supply includes yet undeveloped building lots that are now being used for parking. In the future, these lots will be developed, i.e. available parking in the area will be reduced. In parallel, the future developments themselves will create additional parking demand in the area.
- The demand for parking is based on the parking code, i.e. 1 parking place for 40 m² of gross usable space. The provision of parking at this rate is sufficient only if 75% or more of employees arrive by public transportation or non-motorized transport. This does not fit the field data, which indicates that only 40% of employees arrive without the use of a private car today. Even if the number of public transport users increases, it is unlikely to double.
- Demand is not differentiated for employees and visitors. The parking code is oriented to employee parking, while the area is a magnet for service-type offices, like lawyers and accountants who attract many visitors. This parking need is not considered in the existing code.
- Standard engineering view of the parking garage local area as ~250 m walk radius does not account for spill over of excess demand in further away areas that can directly affect the usage of the new garage.

Generalized parking code based on generalized assumptions of parking demand do not provide proper estimate of the future parking situation in the area. The decision on the Bialik parking garage construction should be based on simulating drivers’ parking behavior against various future development scenarios. These simulations should account for the drivers’ parking habits and parking behavior surveys and drivers’ competition for available parking place and cruising for parking. The latter can shift the demand farther away from the destination.

4.2.4. Diamond exchange development scenarios

A realistic view would claim that only some of the proposed projects will be constructed. In addition, the locations of some projects are quite far from the location of the proposed Bialik parking garage (Fig. 4). In this research, we consider several scenarios of area development that differ in respect to the projects selected for construction. These scenarios have been chosen by the municipality as most probable future development combinations (Table 6, Fig. 6) and are based on the current and anticipated plan approvals.

Table 6 presents localized parking supply minus demand per 100 m² for each of the scenarios.

Fig. 7 shows that the new constructions’ local demand for parking will surpass the local supply. This will evidently create a ripple effect – excessive demand will cause parking imbalance around and push the drivers who aim to park nearby to search for the parking further away (Levy et al., 2013). However, it remains unclear whether the spread of the demand will enforce sufficient number of drivers to reach Bialik garage and park there. To assess the use of Bialik garage in the future we apply PARKAGENT and simulate drivers parking search for each of the scenarios in Table 6.

4.3. Using PARKAGENT for assessing Bialik garage facility

The attractiveness of the Bialik garage project was assessed for all six possible scenarios of area development assuming that the behavior rules of the driver agents remain as described in Section 3. The general assumptions of the assessment are based on field surveys described in Section 4.1 and are as following:

- Workers either park at the parking place provided by the employer, or have already learned a parking pattern and repeatedly use one of few optimal parking places available at the hour of arrival. We assume that visitors do not have significant experience of parking in the area and search for parking anew. In both cases therefore there is no need to include the learning process of drivers in assessing the various scenarios.
- 60% of employs arrive by car, uniformly, between 8:00 and 10:00 am and leave the area uniformly between 16:00 and 18:00 pm. A consistent fraction of these drivers have dedicated parking places close to their offices or park at the same parking lot that is always available in the morning.

Table 6. Most likelihood development combination (set up by the Ramat Gan municipality).

<table>
<thead>
<tr>
<th>Scenario #</th>
<th>Projects Added demand</th>
<th>Added parking supply</th>
<th>Parking place reduction</th>
<th>Demand-to-supply ratio for the entire Diamond Exchange area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>970</td>
<td>240</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1650</td>
<td>850</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>10, 8, 6</td>
<td>1070</td>
<td>330</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1980</td>
<td>660</td>
<td>150</td>
</tr>
<tr>
<td>5</td>
<td>8, 6, 3, 2</td>
<td>2910</td>
<td>1060</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>2640</td>
<td>1150</td>
<td>180</td>
</tr>
</tbody>
</table>
We assume that visitors arriving to the area come with the standard knowledge that the area is densely filled by off street parking facilities and to park there one has to find an available parking place at one of them.

The supply of on street and off street parking in undeveloped lots remains, as it is now, 1470 parking places or is reduced if the parking lot is used for construction.

Current pricing of parking in the area differs between on-street parking that is considerably cheaper, and off-street parking. While off-street parking lots are privately owned and can be priced individually, price equilibrium is currently reached in the area and off-street parking lots are priced very similarly throughout the area. While we admit that future plans can change current pricing of parking lots in response to changes in supply, we predict they will eventually reach equilibrium. Hence for all simulations we set parking lots (including the planned Bialik garage) to be priced equally.

Only drivers that do not have permanent parking places are simulated.

For each of the scenarios we simulated parking search in the Diamond Exchange area and, for each scenario, four key characteristics of the system: average search time, average distance to destination, number of cars parked in Bialik garage and number of cars that searched for parking longer than 10 min. Table 7 presents these characteristics:

According to the Table 7, only for scenarios 5 and 6 the expected number of occupied places in Bialik parking garage is close to the minimal economic requirements or exceeds them. At the same time, in all scenarios, a substantial number of drivers, even if finally parking in the Bialik garage or elsewhere, search for parking longer than 10 min. The major reason for agents’ cruising for parking is the lack of knowledge of occupied parking lots in conditions of 90% and higher demand-to-supply ratio (Table 6). A driver starts his parking search when arriving close to his destination, around which demand-to-supply ratio is close to or above 100%, and, thus a significant fraction of drivers start their parking search when all parking facilities that are close to the destination are fully occupied. The driver that knows about a fully occupied facility will avoid it and, in this way, exploit the search time more effectively. PARKAGENT, as an agent-based model, enables investigating the consequences of providing such knowledge to the drivers.

### 4.4. Testing an electronic signage system

Real time information on availability of parking at various lots can be provided by a simple electronic signage system. Potentially, such a system can significantly reduce cruising time and positively affect the traffic and congestion status in the area. Although dynamic signage systems are widely used (Spencer and West, 2004), we are unaware of any real life case study analyzing their effectiveness and impact on cruising time.

In order to assess the impact of a signage system, PARKAGENT was modified to imitate the simplest signage system that provides each agent a list of lots with currently available parking places when it enters the Diamond Exchange area. In the model, we assume that the agent that knows the state of lots modifies his behavior and instead of driving to the destination drives to the lot that is closest to its destination and yet not full. If this lot is already fully occupied by the time the agent arrives at it, the agent drives to the second best among those in his list, etc. The driving time between the entrance to the area and yet not full lot can take several minutes and during this period the lot can become full. However, the cruising time will be essentially reduced.

According to the PARKAGENT simulations, the signpost system reduces average parking search time about 10%. Its critical influence, however, is not on the average characteristics of the system, but on the outliers – the fraction of cars that search longer than 10 min decreases, depending on scenario, by 50–80% (Table 8).

It seems that a simple parking information system can significantly reduce cruising and, thus, not only improve parking search but also decrease congestion and improve traffic flow in the

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**Fig. 6.** Most likelihood scenarios of the Ramat Gan Diamond Exchange area as set out by the Ramat Gan municipality.
Table 7
Aggregate scenarios’ output.

<table>
<thead>
<tr>
<th>Scenario #</th>
<th>Projects</th>
<th>Added demand</th>
<th>Mean search time (min)</th>
<th>Mean distance to destination (m)</th>
<th>No of occupied places in Bialik garage</th>
<th>No of cars searching for parking 10 min or longer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>730</td>
<td>5.8</td>
<td>142</td>
<td>220</td>
<td>413</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>800</td>
<td>7.8</td>
<td>150</td>
<td>348</td>
<td>321</td>
</tr>
<tr>
<td>3</td>
<td>10, 8, 6</td>
<td>830</td>
<td>5.6</td>
<td>138</td>
<td>319</td>
<td>421</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1470</td>
<td>6.2</td>
<td>123</td>
<td>304</td>
<td>710</td>
</tr>
<tr>
<td>5</td>
<td>8, 6, 3, 2</td>
<td>1200</td>
<td>5.7</td>
<td>235</td>
<td>489</td>
<td>654</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>1680</td>
<td>5.6</td>
<td>219</td>
<td>678</td>
<td>740</td>
</tr>
</tbody>
</table>

Table 8
Scenario outcomes for simulations with and without (in brackets) signage system.

<table>
<thead>
<tr>
<th>Scenario #</th>
<th>Projects</th>
<th>Search time</th>
<th>No. of cars searching longer than 10 min</th>
<th>No. of occupied places in Bialik garage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>5.2 (5.8)</td>
<td>65 (413)</td>
<td>412 (220)</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>6.6 (7.8)</td>
<td>55 (321)</td>
<td>514 (348)</td>
</tr>
<tr>
<td>3</td>
<td>10, 8, 6</td>
<td>5.4 (5.6)</td>
<td>51 (421)</td>
<td>537 (319)</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>5.5 (6.2)</td>
<td>297 (710)</td>
<td>597 (304)</td>
</tr>
<tr>
<td>5</td>
<td>8, 6, 3, 2</td>
<td>5.4 (5.7)</td>
<td>240 (654)</td>
<td>489 (489)</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>5 (5.6)</td>
<td>376 (740)</td>
<td>690 (678)</td>
</tr>
</tbody>
</table>

Fig. 7. The maps of the supply minus demand per 100 m² for the development scenarios in Table 6: (a)-(f) – scenarios 1–6.
area. Due to the large number of visitors in the area, occupancy rates depend on local real time demand and can change on a daily basis. Note that our research does not account for a potential learning process of the agents and there may be some over-estimation of the failure rate in the above results.

5. Conclusions: simulation versus the standard engineering view

The view of a measurable, supply-independent, demand for parking that can be expressed by “minimum parking codes”, has been generally rejected during last two decades. This is especially important for urban areas, where several mobility modes can be an alternative to private vehicle for the trip to work and studies. “Minimum” parking codes are gradually being replaced by “maximum provision” codes, which limit parking development.

The use of a high-resolution spatially explicit simulation model to estimate real-time parking demand seeks to address the inadequacy of a static engineering calculation of parking needs. An agent based model provides a realistic understanding of the parking dynamics in a study area and the consequences of a local shift in the demand and supply caused by new development projects. The model is capable of accounting for the exact spatial information on the amount of drivers interested in parking near the specific location and simulates the “competition” between drivers for parking in the area. In this way, we became able to estimate the effectiveness of the planned Bialik parking garage for every scenario of area development. Moreover, a high-resolution agent-based simulation model makes it possible to assess the effectiveness of the spatially distributed systems that influence parking search, for example the signage system that prevents drivers from searching for parking at the fully occupied lots.

The use of PARKAGENT model for studying future parking situation in the Diamond Exchange area in Ramat Gan provides significant arguments in favor of the spatially explicit high-resolution agent-based modeling approach in parking planning:

- At its core, a simulation model reflects real-life situations by considering individuals making decisions about parking. In contrast with the “engineering” calculation of parking demand, in the agent-based model price, availability, distance, and search time can all be factored in to the demand for parking at a proposed facility.
- The outcomes of the local surveys in regards to the on-street and off-street parking provision, price of parking, existing occupancy rates, planned parking facilities, road conditions, existing modal split, and current walking distance to parking can be utilized for the calibration and validation of the simulation model. The use of the local surveys provides a necessary link between the generalized, non site-specific parking surveys by land-use carried out in the USA and Israel to determine parking demand and the knowledge that is necessary for adequate estimate of the current and future parking situation over the studied area. The requisite surveys are necessary for creating an adequate view of parking demand, regardless of the system ultimately used; and the potential use for the simulation model provides the best background for deciding of the type and amount of the surveys.
- Parking demand is clearly influenced by a confluence of factors untouched by the traditional engineering approach, such as: parking charges; ease of access; type of parking (daily, visitor); parking availability; distance of available parking; etc. which can best be analyzed as scenarios in a simulation model based on individual choice behavior as opposed to generalized assumptions and aggregate calculations.
- The simulation model, by varying input assumptions for parking availability, arrivals, departures, traffic situation and prices, can provide a range of future scenarios. One should compare this to the standard engineering model, which can provide only one outcome based on the multipliers determined by the Ministry of Transport.

To conclude, the increased use of simulation models in general for transportation modeling is indicative of the complex and interconnected nature of transportation research today, which demands more detailed and responsive tools for use in the planning process. A simulation model for parking demand fits neatly into this trend. It is a “next generation” of planning tools for application in an increasing number of situations where detailed spatially explicit high resolution analysis is not only preferred but is required.

References