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GIS-based method for assessing city parking patterns

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ABSTRACT

Every car trip ends with a parking search and parking. However, current transportation research still lacks practical tools and methodologies to analyze parking needs and dynamics, which cannot be adequately performed at an aggregate level. This paper presents PARKFIT, a novel algorithm for estimating city parking patterns that is based on a spatially explicit high-resolution view of the inherently heterogeneous urban parking demand and supply. Using high-resolution data obtainable from most municipal GIS, we apply PARKFIT to evaluate the fit between overnight parking demand and parking capacity in the city of Bat Yam, both currently and within the framework of the Bat Yam 2030 transportation master plan. We then analyze PARKFIT's capabilities and limitations, and supply PARKFIT as a free ArcGIS-based software.

1. The problem of estimating parking capacity in heterogeneous city

Parking management is an underdeveloped transportation subject. Until very recently, most of the car transportation research investigated trips between the origin and destination and did not consider parking as a specific component of a trip. Land-use planners and decision-makers could not avoid dealing with parking planning, but did that on their own, with limited research to rely on. As a result, until the mid-1990s, the prevailing view was that the growing car ownership should be accompanied by a proportional growth of parking supply (Willson, 2013).

During the last two decades, the situation has been changing. City authorities finally understood that they cannot continue expanding their parking facilities, and the paradigm of "maximal parking supply" that uses limitations to parking to encourage people to use public transport has become dominant (Kodransky and Hermann, 2011). No matter how parking limitations are imposed – by means of spatial restrictions, or price, the consequences of these limitations are complex (Shiftan, 2002; Shiftan and Golani, 2005; Vaca and Kuzmyak, 2005; Litman, 2011). Increasing parking fees over wide areas causes, usually, strong public criticism, while local changes just encourage drivers to search for parking further away from the desired destination, thus shifting parking congestion to areas where the parking situation was considered balanced. Therefore, assessing the influence of existing or planned constraints and regulations on parking availability demands accounting for the high-resolution heterogeneity of the urban parking space. This heterogeneity is often ignored by planners and their manuals that are still based on aggregate measures of demand and supply (Willson, 2013).

Both parking demand and supply vary in space and in time and are defined by the turnover, traffic limitations, drivers' preferences and their knowledge about local parking facilities. Understanding and estimating the intensity and location of gaps between parking demand and supply are critically important elements in analyzing parking patterns. A variety of academic research is using models to investigate the complexity of parking problems and suggests ways to improve parking dynamics.

The majority of parking models investigate the relation between parking demand and parking fees. Economic models focus on the equilibrium state of the parking pattern. Shoup (2005, 2006) argues that on-street parking is underpriced, and suggests regulating its availability by varying the fees, with the aim of maintaining an occupation rate of 87.5% (one parking place of eight is free). According to Shoup's model, this will provide a search time of close to zero. Calthrop and Proost (2006) suggest eliminating the competition between on- and off-street parking market by raising on-street parking fees to match off-street fees. Arnott and Inci (2006) incorporate in their model the congestion caused by parking search and demonstrate how this congestion can be eliminated by increasing parking prices. Anderson and de Palma (2004) suggest making the price of on-street parking dependent on the local demand, and suggest a model for defining parking fees for a

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specific location. They investigate how fees should vary in space to regulate the spatial distribution of demand. D'Acierno et al. (2006) propose a less traditional view – drivers arriving from areas characterized by low public transportation accessibly would pay less than drivers arriving from areas of high public transportation accessibility. This pricing scheme, according to D'Acierno et al. (2006), will result in a decrease in travel time and improve accessibility. Arnott and Inci (2006) relate between parking prices and road congestion, and propose regulating the price of on-street parking based on the value of the road space that is used for parking.

Spatially explicit simulation models aim at understanding the dynamics of parking patterns. Thompson and Richardson (1998) simulate a driver's choice between on- and off-street parking within a neighborhood of two-way streets, and demonstrate that the driver's decisions while searching for parking, result in non-optimal search behavior. Gallo et al. (2011) explicitly represent road network and parking facilities to study the effects of drivers' parking preferences and cruising on the traffic in the area. Their model estimates the correlation between the increase in the parking occupation rate and the level of road congestion. However, Li et al. (2007) present a conceptually similar model that includes public transport in addition to private cars, demonstrating that the relation between parking supply and the level of road congestion is more complex and in some cases the increase in parking supply can induce increased congestion. Recently, we proposed tackling the problem of predicting parking dynamics in a city with PARKAGENT, a spatially explicit, high-resolution simulation model of parking search (Benenson et al., 2008; Martens et al, 2010; Levy et al., 2013; Levy et al., 2015). The urban space is presented in PARKAGENT at a resolution of parking places, and every autonomous agent behaves as a driver that searches for parking in the vicinity of its destination, taking into account its knowledge of the area, time budget, and willingness to pay. The driver agent reacts to the traffic conditions within the search area, the parking situation, and the behavior of other drivers. PARKAGENT provides fundamental dependencies of the parking search time and distance between the parking place and destination on the occupation rate and turnover. We will exploit these dependencies obtained in PARKAGENT when analyzing the results of this paper.

Basically, agent-based models are able to incorporate heterogeneous demand and supply on the one hand and drivers' parking search behavior, including reaction to prices during parking search, on the other. However, the availability of data on these two major components is different. Spatially explicit estimates of the parking demand and supply patterns are adequately represented by standard layers of the municipality GIS. Estimates of parking demand can be obtained from the buildings layer, where buildings are characterized by the number of floors and their use. The layer of street segments, characterized by road type, parking permissions, parking zone, and the layer of off-street parking lots provides information on parking supply and, often, parking fees. If the data on demand and supply is insufficient, it can be completed and verified based on aerial photos and one-time field surveys. Data on drivers' arrivals, departures, and on drivers' parking search behavior in particular, demand essential investment in field surveys and interviews and in some cases will simply not be available. This paper focuses on the problems that can be satisfactory investigated despite the lack of behavioral data. We aim at "fast and frugal" estimates of the goodness of fit between the projected parking demand and supply and develop for this purpose a simple software tool – PARKFIT that accounts for the spatial heterogeneity of the parking situation without necessitating investment in field surveys.

This paper aims at presenting and investigating PARKFIT, a method and software application. Our approach exploits standard GIS datasets that are widely available in the majority of Western municipalities, as is the case in our example application in the city of Bat Yam. The Bat Yam area is ca. 8.0 km^2, and its population of about 130,000 resides in 3300 buildings with a total of 51,000 apartments. The city has a common boundary with Tel Aviv and is located to the south to it. Part of the boundary area (close to the sea) is not populated, while the rest of the boundary is a highway that is inconvenient for crossing. At the east, the city is bounded by the wide highway. That is, for the analysis of parking processes, Bat Yam can be considered as an isolated area. In Section 2, based on Bat Yam's municipal GIS, we make the step from aggregate to high-resolution data on parking demand and supply. Section 3 introduces the PARKFIT method. Section 4 is devoted to the validation of PARKFIT and estimating its basic parameters that we consider common for similar cities. In Section 5 we apply PARKFIT for estimating Bat Yam's parking capacity nowadays and in the future, as a part of the Bat Yam 2030 transportation plan. Finally, we discuss the proposed method and results in Section 6.

2. High resolution GIS as a source of data on parking demand and supply

At the most aggregate level, the parking pattern in a specific area is defined by the ratio R of the demand D, expressed by the overall number of cars that are willing to park there, and the parking supply S, expressed by the overall number of existing parking places in the area: $R = D/S$.

If demand and supply are distributed in space uniformly, then for $R > 1$, the value of $(R - 1) * S$ is the number of parking places that the area lacks in order to accommodate all drivers wanting to park there, while for $R < 1$, $(1 - R) * S$ is the number of vacant parking places in the area.

To provide a spatial framework for this aggregate view, let us consider overnight parking in a city where each building b accommodates D_b car owners and parking is possible on street only. Let us associate each parking place to its closest building, and denote the number of parking places associated with building b, as S_b. Let the highest value of the demand-to-supply ratio $R_b = D_b/S_b$ that is observed for all buildings in the city be observed for the building b_0 and equal to $R_{b0} = D_{b0}/S_{b0}$. While R_{b0} remains below 1, the drivers in the area will easily find an overnight parking place in the vicinity of their destinations, and the overnight parking pattern will consist of non-overlapping clusters of cars around destinations of their drivers.

Starting from $R_{b0} > 1$, parking places that are associated with the buildings adjacent to b_0 will be used by drivers aiming at b_0. Those arriving late will find S_{b0} parking places occupied, and so they will park at a place associated with one of the adjacent buildings. The b_0 residents will thus cause a chain reaction (Levy et al., 2013) – some of the drivers arriving late to the destinations adjacent to b_0 will also have to park beyond the vicinity of these buildings. The phenomenon will become stronger with the increase in the number of buildings b for which $R_b > 1$, and accelerate the growths of the average parking distance to the destination (Levy et al., 2013).

We can thus conclude that in reality, where demand and supply vary over urban space and in time, the aggregate demand-to-supply ratio R is evidently insufficient. One can consider a parking supply in the city as sufficient based on a misleading aggregate value of $R < 1$ calculated over the entire city, whereas in reality the majority of the demand can be concentrated in the city center, while the majority of supply is scattered on the outskirts. Parking lots on the one hand, and office buildings that attract numerous visitors on the other, further increase the