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Simulating parking for establishing parking prices

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Abstract

Urban parking prices do not reflect spatially heterogeneous parking supply and demand. We present an agent-based algorithm for establishing on-and off-street parking prices in a heterogeneous urban space that guarantee a predetermined uniform level of occupation.

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Keywords: Urban Parking; Transportation; Spatially Exlicit Modeling; Agent-Based Modeling

1. From constant to adaptive parking prices

The price of curb parking does not reflect spatial-temporal variation of demand. It is established by large urban regions and changes once in a decade. As a result, parking prices never reflect demand[1,2]. If prices are lower than necessary, then the occupation rate is always close to 100%, cruising time is horrible, the traffic is congested and the area is polluted. High prices prevent drivers' arrival to the area, force them to search for parking beyond the areas around and are evidently disadvantageous for the local economic activities.

In 2006, Donald Shoup[3] proposed to eliminate cruising by establishing parking prices that are adapted to demand and always preserve the occupancy under a threshold of 85%. That is, one of every 7 parking spots should always remain empty on every road link. It took a decade for practitioners to implement Shoup's idea of curb-parking prices adjustment to demand: In Los Angeles and San Francisco demand-responsive prices were established by street

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segments[4,5], while in Calgary and Seattle by areas of different sizes[6,7]. In all these projects parking fees were updated once in one or more months, until occupancy rates reach ca. 60 – 80%. The projects in San Francisco and Los Angeles employed ground sensors and cost millions of dollars. We propose an agent-based Nearest Pocket for Prices algorithm (NPPA) for establishing spatially varying adaptive parking prices that preserve a constant level of occupation and implement it with the freely available PARKFIT2 application (see https://www.researchgate .net/profile/Nir_Fulman).

2. Nearest Pocket for Prices Algorithm

Nearest Pocket for Prices Algorithm adjusts prices based on spatially explicit data on parking demand (usually given by buildings) and supply (usually by stops along the street links and at the parking lots). Nowadays, these data are part of a standard municipal GIS: A layer of buildings (with height attribute) is sufficient for estimating a number of households or office workers that can be considered as a proxy for parking demand, especially in case of the overnight parking, where the demand is proportional to the car ownership rate of the residents. Layers of street links (with parking permissions, if available) and of parking lots (with total capacity) are sufficient for estimating supply. A layer of statistical areas and corresponding population statistics provides information of car ownership rates that can be further disaggregated in respect to the layer of buildings. Parking places for parallel parking can be constructed, by dividing the link into parts, the length of which is equal to the average length of the car + 0.2 m on one or both sides of the street, depending on the driving directions. More information on parking permissions/restrictions and local regulation can easily be accounted for. The capacity of a parking lot can be obtained by dividing its total area into rectangles of an average car size with addition of the in-lot space for maneuver.

A layer of parking units - links and lots or, possibly larger ones, as residential neighborhoods – is necessary for applying NPPA. Its goal is to establish parking prices that preserve the occupancy O_{unit} of each parking unit below the threshold level O_{th}, $O_{unit} \leq O_{th}$. The basic assumption of the NPPA is that driver c reacts to the parking price in respect to its economic status that defines c's Minimal Perceived Price (MPP) $w_{c,mpp}$ of the nearest to the entrance to a destination (the "best") parking place.

Let us denote the price of the best parking place as F_p and the attractiveness of a parking place p at a walking distance d from the driver's c destination as $A_{c,p}(d)$. We assume that:

- $A_{c,p}(d)$ depends on p's price when $F_p > w_{c,mpp}$ only
- $A_{c,p}(d)$ decreases with d as $1/d^{\alpha}$,

and combine these assumptions as

$$A_{c,p}(d) = \min(1, w_{c,mpp}/F_p)/d^{\alpha}$$

In what follows, we also assume that for a sufficiently large walking distance $d > d_{max}$, $A_{c,p}(d) = 0$.

Below we measure distance d in units of car length, 5 m, assume that, for all drivers, $w_{c,mpp}$ is above some non-zero $w_{min,mpp}$, and that for $F_p = 0$ $A_{c,p}(d) = 1/d^{\alpha}$ In numeric experiments below we set $\alpha = 0.5$ and $d_{max} = 100$ parking spots = 500 m.

2.1. The Nearest Pocket Algorithm

The NPPA extends the Nearest Pocket Algorithm proposed by Levy and Benenson[8] in their PARKFIT model. As a first step we extend their algorithm for estimating the area that will be occupied at a level of O_{th} in case of a zero pricing. Let the demand for building k = 1, 2, 3, …, K be n_k. The steps of the NPA algorithm are as follows:

- Build the list of all (driver-agent, destination) pairs of length $n_1 + n_2 + n_3 + \ldots + n_k$ and randomly reorder it;
- Assign m-th driver-agent c_m in the list to the closest to c_m's destination parking spot on the unit u for which $O_u < O_{th}$; If all spots at a distance $d < d_{max}$ from c_m's destination are occupied then ignore the driver.

Parking units u, for which O_u reaches O_{th} become candidates for price increase.

2.2. Nearest Pocket for Prices Algorithm

Two basic stages of NPPA – establishment of initial price and iterative convergence to an equilibrium distribution of prices, are presented in Figure 1.

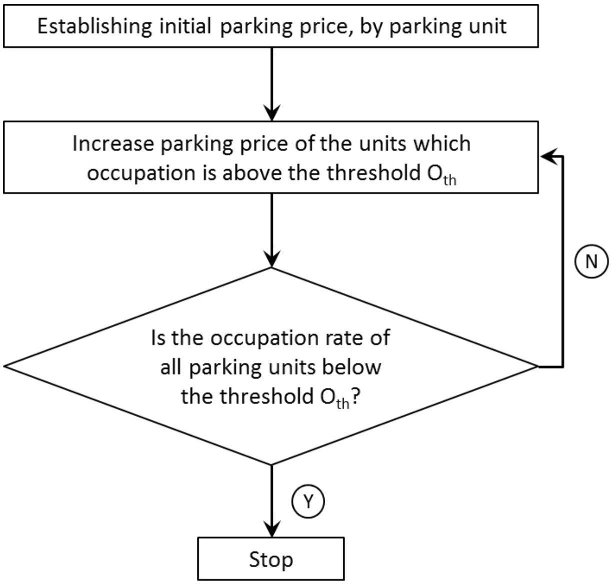


Fig. 1. Major steps of the NPAP algorithm.

Note that if the demand/supply ratio for the entire area is greater than O_{th} then we should either admit that the desired occupation rate cannot be reached or allow to some of the driver agents to give up on parking. We implement the second alternative and assume that a driver can skip parking when the attractiveness of the available parking place is low. Formally, we assume that the probability g_c that a driver-agent c will skip parking in the area is non-zero if the attractiveness of the best currently available parking place for c is below the threshold attractiveness A_{th}.

$$g_c(A_{c,best}) = \begin{cases} 0, & A_{c,best} > A_{th} \\ 1 - \exp(\gamma * (1 - A_{th} / A_{c,best})), & A_{c,best} \le A_{th} \end{cases}$$

where $A_{c,best}$ is the attractiveness of the best of currently available to c parking places, and γ is a parameter.

In computational experiments we employ $\alpha = 0.5$ and d_{max} = 100 parking spots = 500m, $A_{th} = 0.1$ and $\gamma = 0.1$.

Initial parking prices $F_{u,initial}$, by units u, are established based on applying Nearest Pocket Algorithm for 100% occupancy (Figure 2.a). At the second stage of the Nearest Pocket for Pricing Algorithm, the prices F_u on yet excessively occupied parking units are increased until the average occupation rate there does not exceed O_{th}. The algorithm applied at the iteration is presented in Figure 2.b.

The rate x of the price increase (bottom block in Figure 2.b) is a parameter, and, basically, higher values of x result in faster convergence to the equilibrium pattern. However, for high x, this can result in fluctuations of the patterns. Below we apply x = 0.05, for which no fluctuations have been observed; the number of iterations necessary for convergence was always below 60.

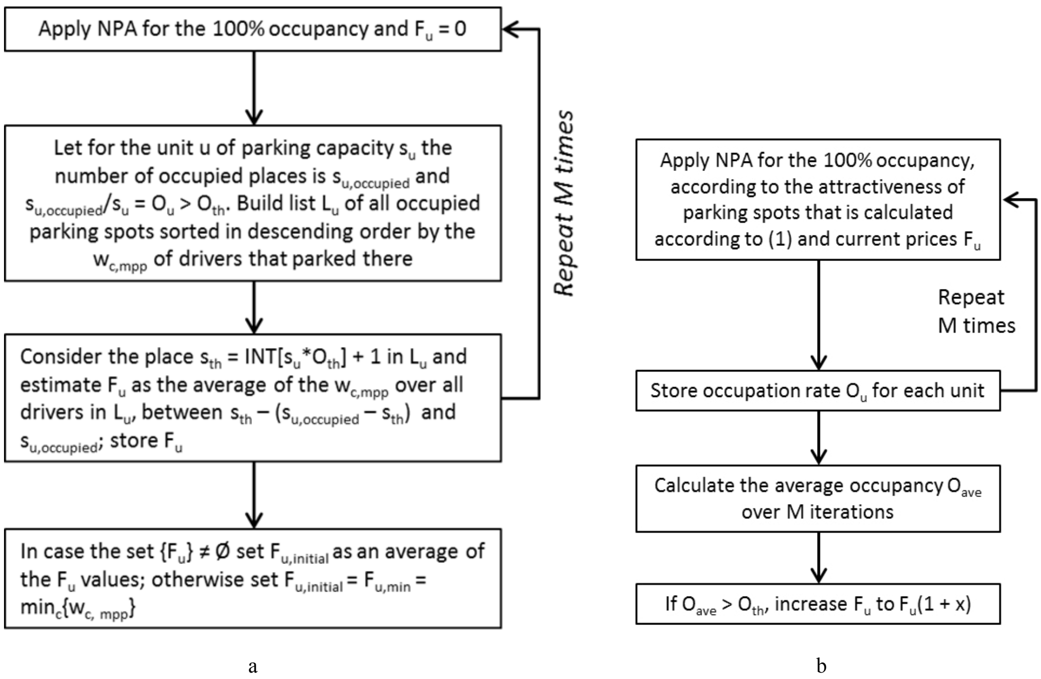


Fig. 2. Two stages of the NPPA algorithm: (a) establishing initial prices and (b) iterative increase of prices.

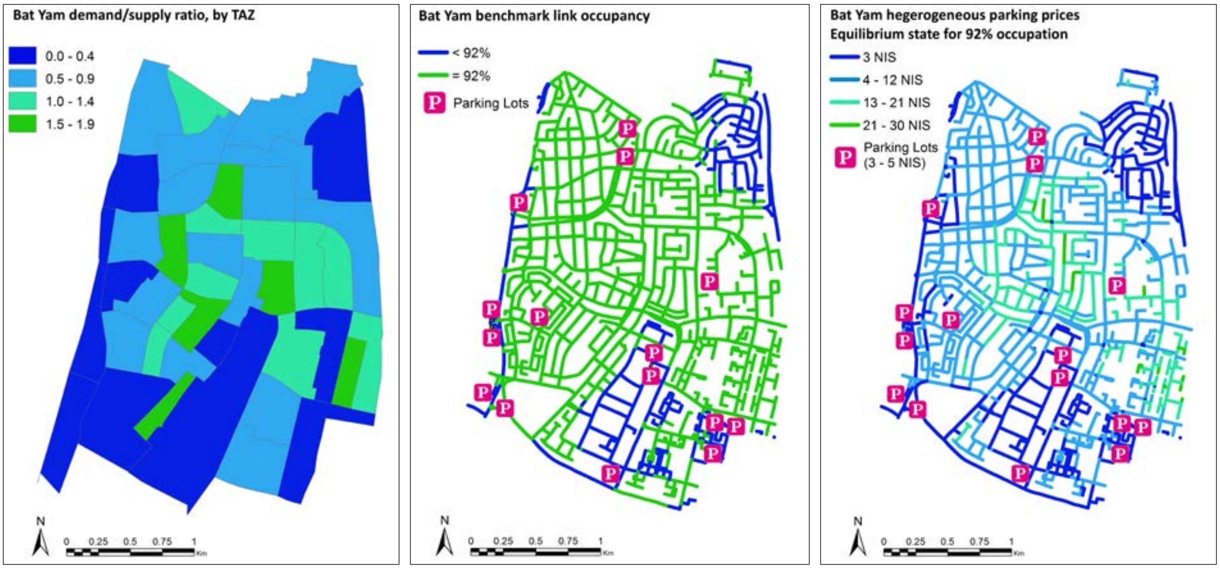
3. NPPA application

According to the Israeli Bureau of statistics, in 2010 population of the Bat-Yam city, Israel was about 130,000, total car ownership about 35,000, total number of buildings 3300 and total number of apartments 51,000. We base our NPPA application on these data and the data of Bat-Yam municipal GIS that contains layers of streets with traffic direction, buildings with building height, and parking lots. Below, we consider "parking price" as fees paid by a driver for the entire period of parking. This view fits best to the residents' payment for overnight parking.

3.1. Establishing overnight parking prices in the city of Bat-Yam

Parking supply in Bat-Yam consists of 27,000 curb parking places constructed based on the street layer, 17,000 dedicated parking places for residents as estimated in a field survey[8] and 1500 places in the parking lots available free of charge for the city's residents. Based on the car ownership rate, unsatisfied citizens' demand/supply ratio for overnight on- and off-street parking is (35,000 – 17,000) / (27,000 + 1500) = 0.61. However, the distribution of demand and supply is essentially non-homogeneous (Figure 3.a) and for almost a third of the city area, the demand/supply ratio is above 0.90.

After Levy et al.[9], we have applied the NPPA assuming that $O_{th} = 0.92$ - maximal possible average occupation rate for which cruising for parking is yet insignificant ($O_{th} = 0.92$ corresponds to 1 free of 12-13 parking spots). Based on the data on residents' income per TAZ, MPP = 3 NIS is assigned to the drivers of the poorest TAZ, while for the drivers residing in the other TAZ MPP is set proportionally to the ratio of their average income to that of the poorest TAZ, with a coefficient of variation CV = 20% within TAZ. The area where the prices should be established and the resulting pattern are presented in Figures 3.b and 3.c



a b c

Fig. 3. (a) Bat Yam demand/supply ratio, by TAZ; (b) area where prices should be increased, by street links and (c) equilibrium parking prices, in NIS, for 92% occupation threshold, by street links and parking lots.

3.2. Sensitivity of the Bat Yam parking price pattern to NPPA Parameters

Model parking patterns directly depend on MPP and twice higher or lower MPP evidently entail a twice higher or lower parking price of every spot in the city. In this respect, the map in Figure 3.c should be presented in terms of ratio of the equilibrium parking price to MPP (we did not do that for the clarity of presentation). Further on, to apply NPPA one has to establish two more parameters: target occupation rate O_{th} and decrement of parking attractiveness α. To guarantee zero cruising, the stakeholder may decrease O_{th} to Shoup’s 85% or even lower level, while the value of α may be dependent on the local parking habits. We thus have to know potential importance of this parameter before investing into the field surveys and questionnaires. The results clearly demonstrate that the difference between aggregate outcomes (Table 1) and prices patterns (Figure 4) obtained for different values of O_{th} and α, are relatively low. That is, urban heterogeneity is the major determinant of the equilibrium urban parking prices pattern.

Table 1: Sensitivity of NPPA outcomes to O_{th} and α ($w_{mpp,min}$ is minimal, over city drivers, value of MPP)

	α	$O_{th} = 0.9$	$O_{th} = 0.85$	$O_{th} = 0.8$
	0.6	61%	64%	67%
Percentage of links which price is higher than $w_{mpp,min}$	0.5	66%	69%	72%
	0.4	70%	74%	77%
	0.6	2.3	2.6	2.8
Average link price/$w_{mpp,min}$ ratio	0.5	2.4	2.7	3.0
	0.4	2.5	2.9	3.3
	0.6	12%	16%	20%
Percentage of drivers who give up on parking for $d_{max} = 500$ m	0.5	4%	8%	12%
	0.4	2%	5%	8%

a b c

Fig. 4. Equilibrium parking prices for α = 0.5 and (a) O_{th} = 90%, (b) O_{th} = 85% and (c) O_{th} = 80%.

4. Discussion

- We propose spatially explicit, high-resolution Nearest Pocket for Prices Algorithm (NPPA) for establishing urban parking prices.
- The level of prices suggested by the NPPA guarantees predetermined uniform occupation rate over the heterogeneous urban space.
- NPPA exploited standard municipality GIS and databases and does not require equipment for price adjustments.
- The sensitivity of the NPPA-generated equilibrium parking pattern to parameters is low.

We consider NPPA as a useful tool for establishing and assessing urban parking policy. The stakeholder can use NPPA-generated pattern as an initial high-resolution view of the parking prices that will resolve the problem of cruising in the city. Based on the NPPA maps, the stakeholders can decide on parking units that will be larger than street links, as neighborhoods or TAZ, and establish units' prices, with the NPPA, based on these units. Then, fine-tuning of parking prices that accounts for parking habits of residents (and demand field surveys) will be necessary.

Next step of the NPPA development focuses on demand that varies in time, as characteristic of daily parking. In this case, spatio-temporal dynamics of parking make it necessary to explicitly introduce the process of parking search into the NPPA algorithm. The full version of the NPPA that is developed based on the spatially explicit PARKAGENT modeling environment and its application for real world cities will be presented at the conference.

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