# A spatially explicit model for establishing adaptive parking prices

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## Abstract

Urban parking prices do not reflect spatially heterogeneous parking supply and demand. We present a spatially explicit model for establishing on-and off-street parking prices in a heterogeneous urban space that guarantee a predetermined uniform level of occupancy.

**Keywords:** Urban Parking; Spatially Explicit Modelling

# 1. From constant to adaptive parking prices

Typically, the price of curb parking does not reflect demand (Arnott and Inci, 2006; Shoup, 2006). If prices are lower than necessary, then the occupation rate is always close to 100%, cruising time is long and the traffic is congested. High prices prevent drivers' arrival to the area and are disadvantageous for the local economic activities.

In 2006, Donald Shoup proposed to eliminate cruising by establishing parking prices that are adapted to demand and always preserve the occupancy under a threshold of 85%. A decade later, practitioners began implementing Shoup's idea of curb-parking prices adjustment to demand: In Los Angeles and San Francisco demand-responsive prices were established by street segments (LADOT, 2016; SFMTA, 2016), while in Calgary and Seattle by areas of different sizes (CPA, 2011; SDOT, 2016). In all these projects parking fees are updated, 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 a spatially explicit Nearest Pocket for Parking Algorithm (NPPA) for establishing adaptive parking prices that preserve a constant level of occupation and implement it with the freely available PARKFIT2 software (see https://www.researchgate.net/profile/Nir_Fulman).

# 2. Nearest Pocket for Parking Algorithm

NPPA adjusts prices based on spatially explicit data that 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 easily translated into parking demand. Layers of street links (with parking permissions) and parking lots (with total capacity) are sufficient for estimating supply.

NPPA deals with the layer of parking "units" - links, lots or larger residential neighbourhoods. Its goal is to establish units' parking prices that preserve the occupancy $O_{unit}$ of each unit below the threshold level $O_{thr}$, $O_{unit} \leq O_{thr}$. The basic assumption of the NPPA is that a driver does not react to very low prices and driver's c economic status defines Minimal Perceived Price (MPP) $w_{c,mpp}$ that demands driver's reaction.

Let us denote the price of the parking spot as $F_p$ and the attractiveness of a parking spot 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 assume that for a sufficiently large walking distance $d > d_{max}$, $A_{c,p}(d) = 0$ and measure distance d in units of car length (5 m). We also assume that, for all drivers c, $w_{c,mpp} > 0$, and that for $F_p = 0$, $A_{c,p}(d) = 1/d^{\alpha}$. In numeric experiments we use $\alpha = 0.5$ and $d_{max} = 100$ (500 m).

## 2.1. Recognizing parking units where prices should be adjusted

The NPPA extends the Nearest Pocket Algorithm (NPA) of Levy and Benenson (2015). As a first step, we apply NPA to estimate the area that will be occupied at a level of $O_{thr}$ in case of $F_p = 0$.
Let the demand for building k = 1, 2, 3, …, K be $n_k$:

- Build the list of all (driver-agent, destination) pairs, of the $n_1 + n_2 + n_3 + \ldots + n_k$ length, 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 $O_u < O_{thr}$; If all spots at a distance $d < d_{max}$ from $c_m$'s destination are occupied then ignore $c_m$.

Parking units u, for which $O_u$ reaches $O_{thr}$, are candidates for price adjustment.

## 2.2. Establishing price pattern

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

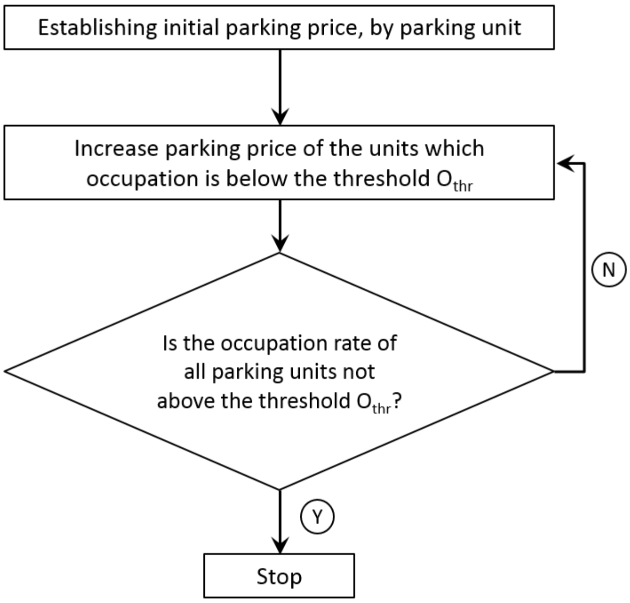



Figure 1: Major steps of the NPPA algorithm.

To cope with case of high demand/supply ratio over the entire area we assume that a driver can skip parking when the attractiveness of all available parking spots is low. Formally, 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 spot for c, $A_{c,best}$, is below the threshold attractiveness $A_{thr}$.

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

where $\gamma$ is a parameter. In computational experiments we employ $A_{thr} = 0.1$ and $\gamma = 0.1$.

Initial parking prices $F_{u,initial}$, by units u, are established based on applying NPA for 100% occupancy (Figure 2a). At the second stage of the NPPA, the prices $F_u$ on yet excessively occupied parking units are increased until the average occupation rate there does not exceed $O_{thr}$ (Figure 2b).

The rate x of the price increase (bottom block in Figure 2b) is a parameter, and high x may 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.

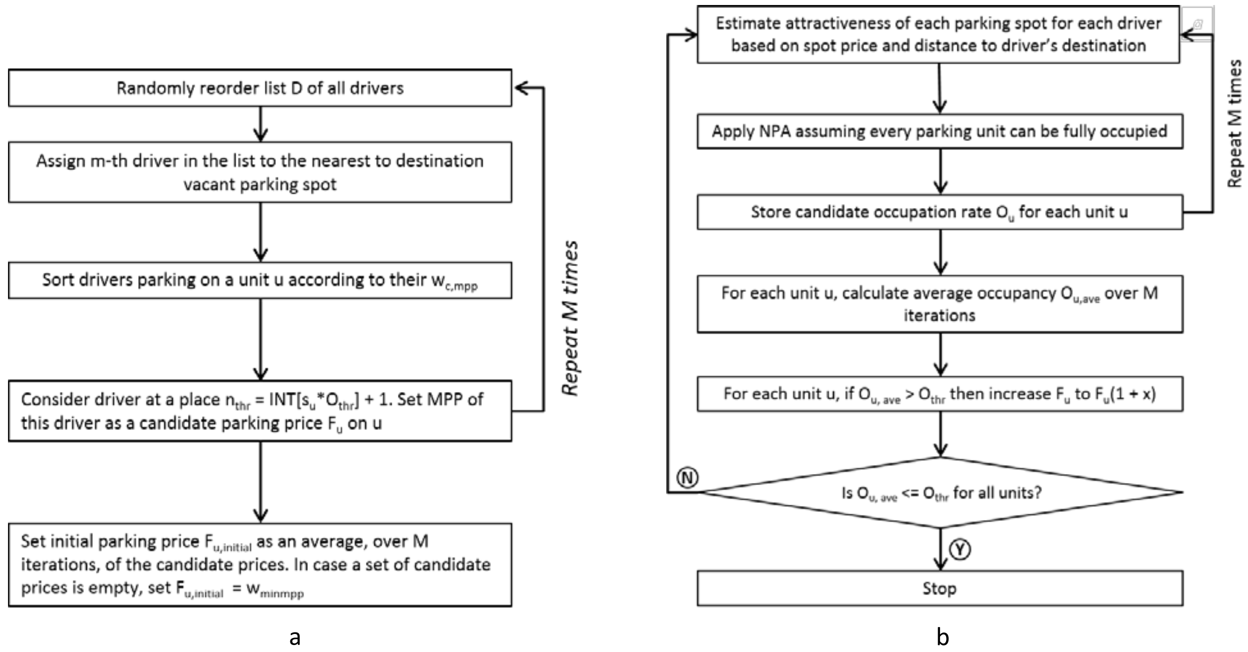



Figure 2: Two stages of the NPPA algorithm:
(a) establishment of initial prices and (b) iterative increase of prices

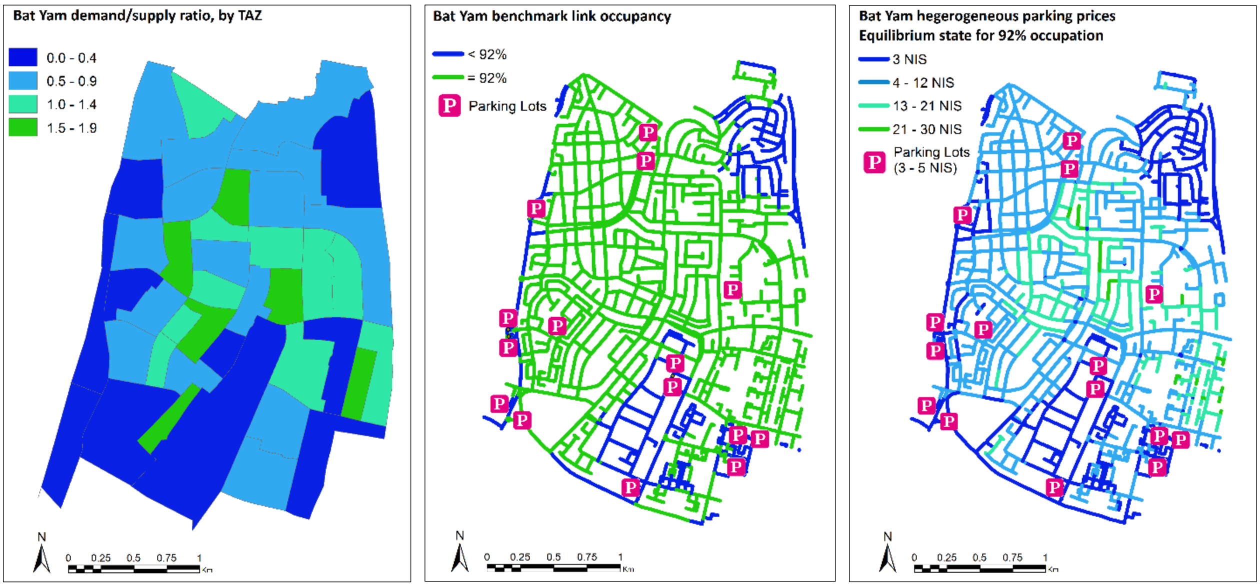
# 3. Establishing overnight parking prices the city of Bat-Yam

We have applied NPPA for establishing overnight parking prices in the city of Bat-Yam, Israel. According to the Israeli Bureau of Statistics, the city population is about 130,000, total car ownership about 35,000, total number of buildings 3300 and total number of apartments 51,000. We base 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.

Parking supply in Bat-Yam consists of 27,000 curb parking spots constructed based on the street layer, 17,500 dedicated parking spots for residents as estimated in a field survey (Levy and Benenson, 2015) and 1500 spots 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 3a) and for almost a third of the city area, the demand/supply ratio is above 0.90.

We have applied the NPPA for Bat-Yam assuming that $O_{thr}$ = 0.92 and parking units are street links. As it is demonstrated by (Levy et al., 2013), with the dynamics model of parking search this is maximal possible average occupation rate for which cruising for parking is yet insignificant (~ 40 seconds). It is worth noting that Levy et al 2013 result is highly intuitive. Indeed, for the ~5m parking space necessary for the standard European car, 92% occupation means, on average, one vacant spot per 60-70 m of the curb space. That is, on average, 92% occupation corresponds to one parking spot per street link between two junctions.

Based on the data on residents' income by Transport Analysis Zones (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 CV = 20% within TAZ. The NPPA outcomes – the part of the Bat-Yam area where prices should be adjusted and the resulting prices pattern are presented in Figures 3b, 3c




a b c

Figure 3: (a) Bat Yam demand/supply ratio, by Transport Analysis Zones (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.

## 4. Discussion

We propose spatially explicit, high-resolution Nearest Pocket for Prices Algorithm (NPPA) for establishing urban parking prices that guarantees predetermined uniform occupation rate over the heterogeneous urban space. NPPA exploited standard municipality GIS database and does not require equipment for price adjustments.

We consider NPPA as a tool for establishing and assessing urban parking policy. Stakeholders can use NPPA-generated prices pattern as an initial high-resolution view of the parking prices that will resolve the problem of cruising in the city. NPPA enables examining the effectiveness of specific policy decision, as establishing price ceiling or providing parking permits to certain groups of the drivers (e.g. veteran residents of the neighbourhood). Based on the NPPA maps, the stakeholders can decide on parking units that will be larger than street links, as neighbourhoods or Transport Analysis Zones, and establish units' prices either by re-estimate equilibrium prices, with the NPPA, based on these units, or by averaging link prices within the unit. Fine-tuning of parking prices that will account for parking habits of residents (and demand field surveys) may be then necessary.

The next step of the NPPA development that will be presented at the conference, considers demand that varies in time. It explicitly accounts for the arrivals and departures and can be applied for adjusting daily parking prices.

## 5. Acknowledgements

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