A Simple Complex Phenomenon of Urban Parking

Itzhak Benenson, Nir Fulman

Geosimulation and Spatial Analysis Lab,

Department Of Geography, Porter School of the Environment and Earth Science, Tel Aviv University

bennya@tauex.tau.ac.il, https://www.geosimlab.org/

CIM CosY Lunch Seminar, 23-Apr-2019, Uppsala University

Parking is a long lasting urban blight

- Cruising for parking is the last leg of the car-based trip
- Cruising is linked to many urban externalities:
  - Congestion, air pollution and noise, loss of space, social inequity
- Parking has mostly been left to engineers to solve supply/operational issues by building lots

Cruising for parking may reach 30% of urban traffic in the city centers

Common belief, attributed to Donald Shoup: To avoid cruising we need 15% (1 of 7) of parking spots to remain free all the time

Deterministic model of cruising for parking

Parameters

Arrivals

a cars/min

Departure rate

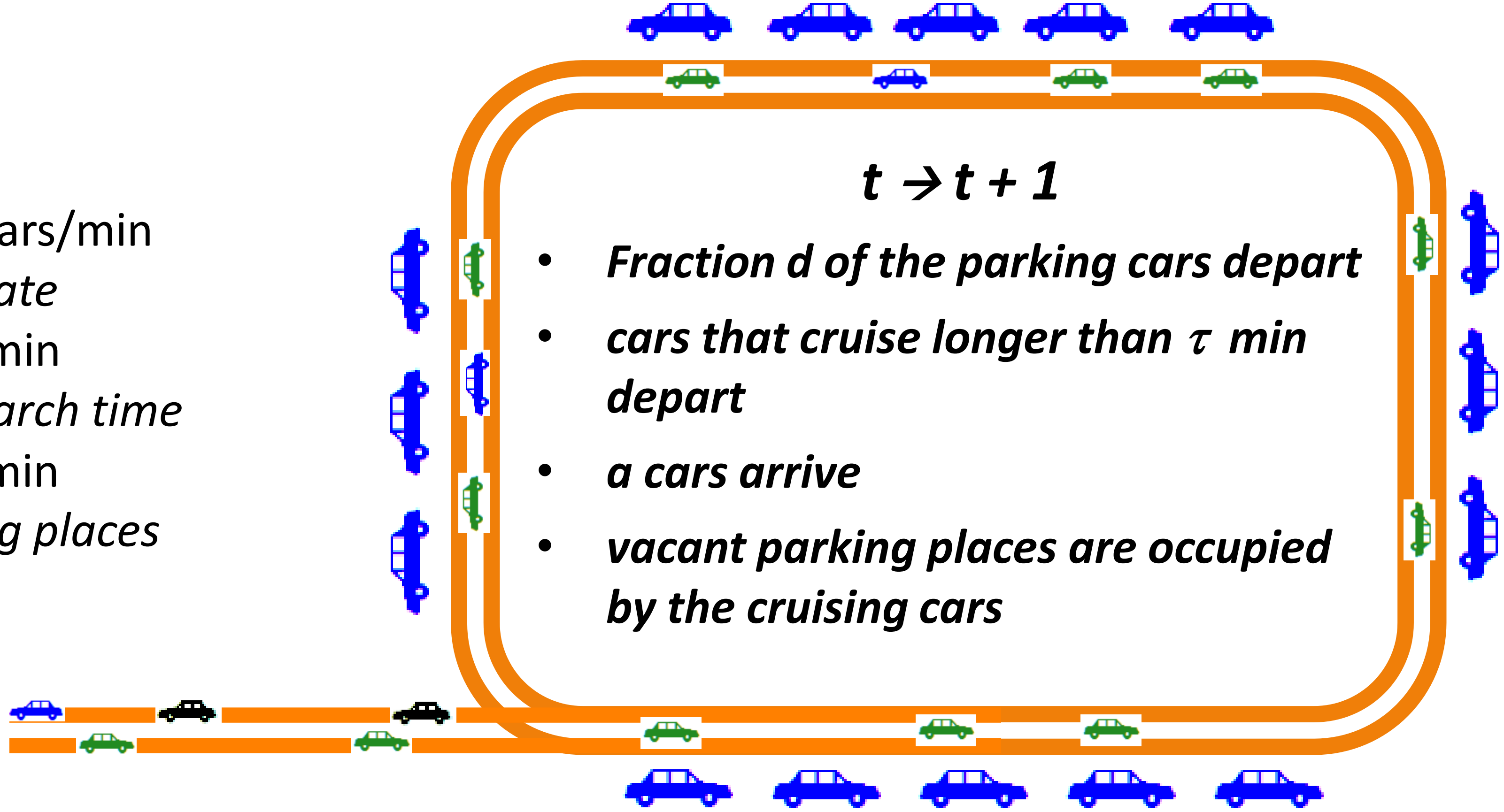
d/min

Maximal search time

τ min

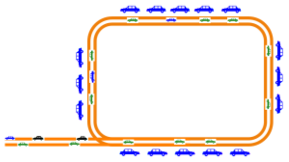
Total parking places

R



Initial conditions: *All parking places are occupied*

Deterministic model of cruising for parking



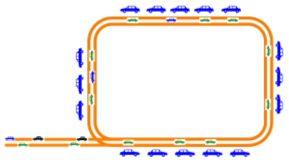
- State of the system $\boldsymbol{M(t)} = \langle M_0(t), M_1(t), \ldots M_{\tau\text{-}1}(t)\rangle$,

  $M_\mu(t)$ is the numbers of cars cruising for $\boldsymbol{\mu}$ minutes

- Total number of cruising cars $N(t) = M_0(t) + M_1(t) + \ldots + M_{\tau\text{-}1}(t)$
- $O(t)$ – Number of occupied parking places
- $F(t)$ - Cars that failed to find a parking place
- $p(t)$ - probability to park

  $p(t) = min\{1, [number\ of\ free\ places]/[number\ of\ cruising\ cars]\}$

Deterministic model of cruising for parking



Parameters

Arrivals

 ***a*** cars/min

Departure rate

 ***d***/min

Maximal search time

 τ min

Total parking places

R

O(t) – Number of occupied parking places

F(t) - Cars that failed to find a parking place

p(t) - probability to park

The dynamics of ***M(t)***, *O(t)* and *F(t)*:

$$M_0(t + 1) = a$$

$$M_1(t + 1) = M_0(t)*[1 – p(t)]$$

$$\ldots$$

$$M_{\tau-1}(t + 1) = M_{\tau-2}(t)*[1 – p(t)]$$

$$F(t + 1) = F(t) + M_{\tau-1}(t)*[1 – p(t)]$$

$$O(t + 1) = \min\{(1 – d)*O(t) + N(t), R\}$$

Auxiliary equation to estimate parameters at t

$$N(t) = M_0(t) + M_1(t) + \ldots + M_{\tau-2}(t) + M_{\tau-1}(t)$$

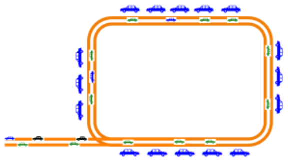
$$p(t) = \min\{1, f(\varepsilon, \mu)/N(t)\} \cong \min\{1, (R – (1 – d)*O(t))/N(t)\}$$

ε - *average number of free places per link,*

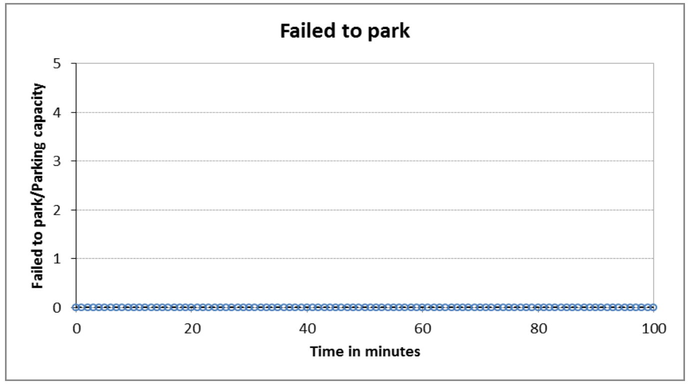
μ - *average number of cruising cars per link*

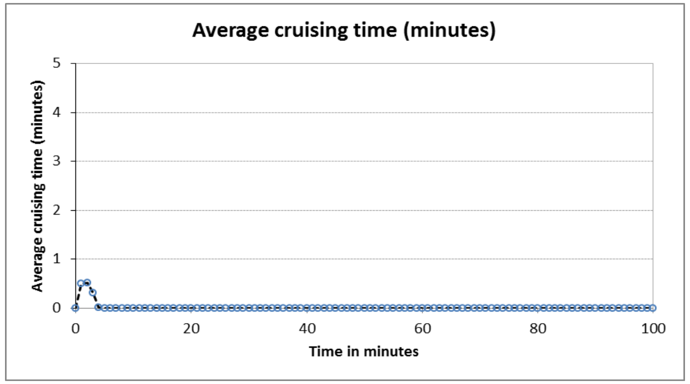
**N. Levy, K. Martens, I. Benenson, 2013, Transportmetrica A, 9 (9), 773–797*

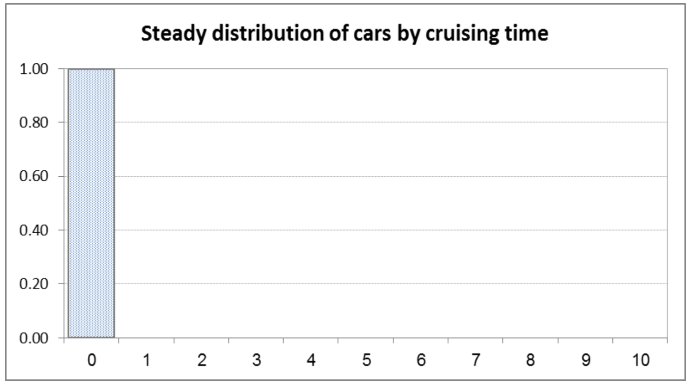
Deterministic model of cruising for parking



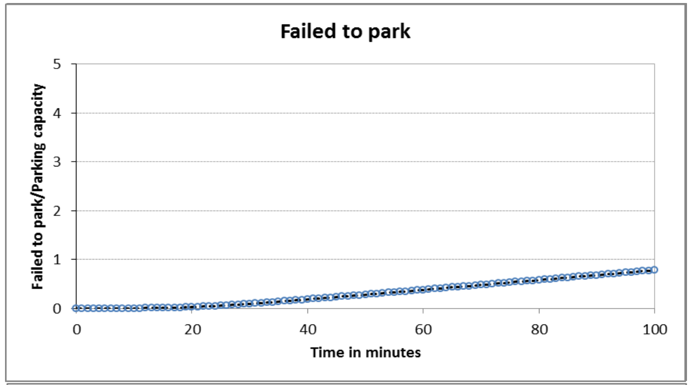
Arrivals: 4/min
Dep. rate: 0.05
Capacity: 100

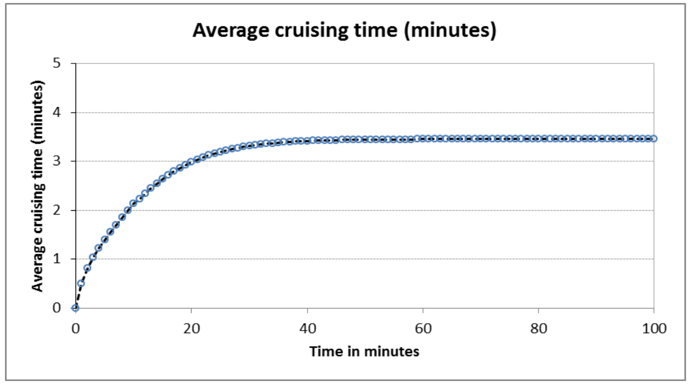


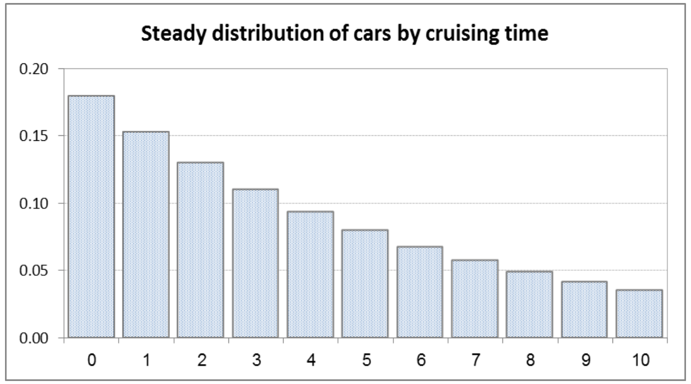




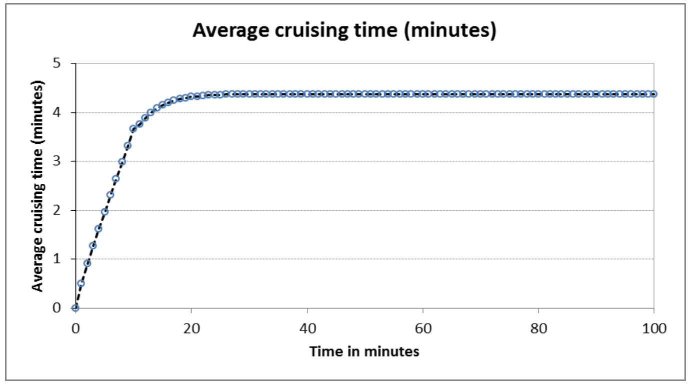
Arrivals: 6/min
Dep. rate: 0.05
Capacity: 100

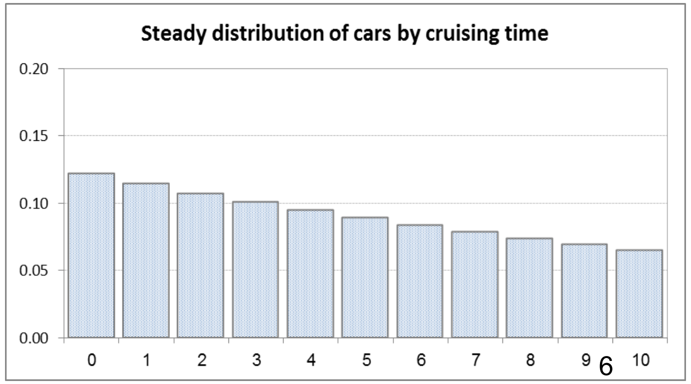




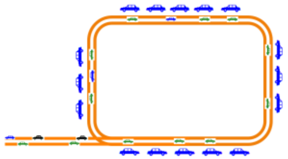


Arrivals: 10/min
Dep. rate: 0.05
Capacity: 100





Deterministic model of cruising for parking: Conclusions



- Parking search is either easy or takes a long time
- Drivers’ reaction or regulator’s intervention may reduce the number of arriving cars and result in basic alteration of parking dynamics.

Parking reality: Spatio-Temporal Heterogeneity

Local aspects (driver's behavior, conditions at a destination)

- Parking demand, parking supply, and drivers' behavior are essentially heterogeneous, in space and in time
- They are defines by many factors: land-use, population, type (on/off-street) and location of parking, price, distance to destination, control

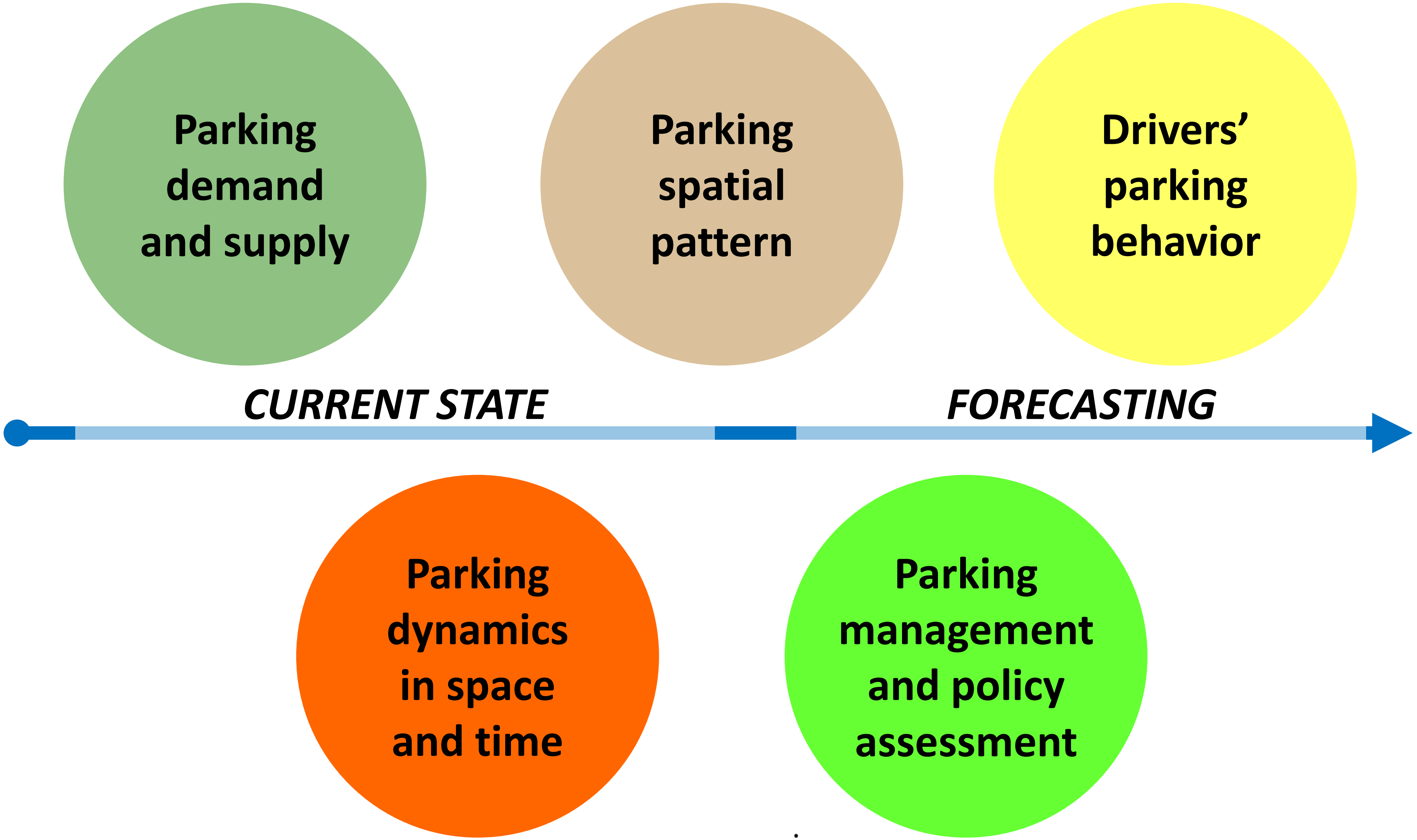
Global and long-term aspects (urban parking policy)

- Parking supply and, sometimes, demand, are defined by the city
- Drivers may be enforced to think of parking when planning a trip

Parking planning (future transportation)

- What will be travelers' mode choice in the future?
- What is parking demand for the autonomous cars?

COMPONENTS OF PARKING REALITY



GIS + Aerial photos + Population Census

URBAN GIS, AERIAL PHOTOS

DEMAND

Night:

Households*(Car ownership rate)

Day:

Households' turnover + Office area/20 + Shops' turnover

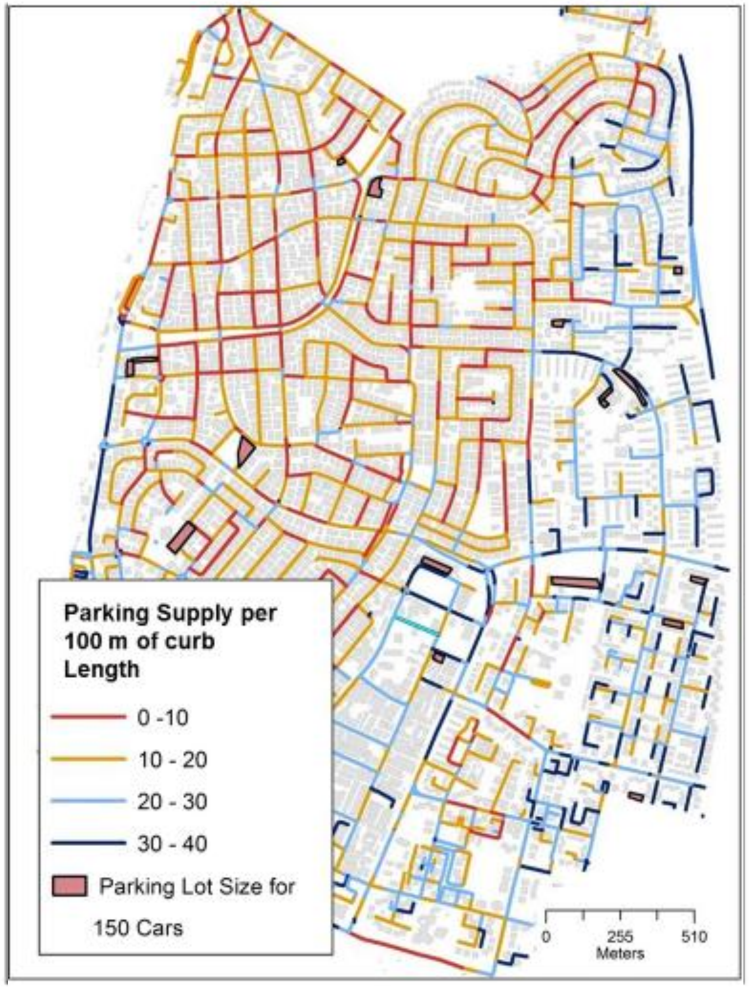
SUPPLY

Curb:

(Street length)/5 - Prohibited spots

Lots:

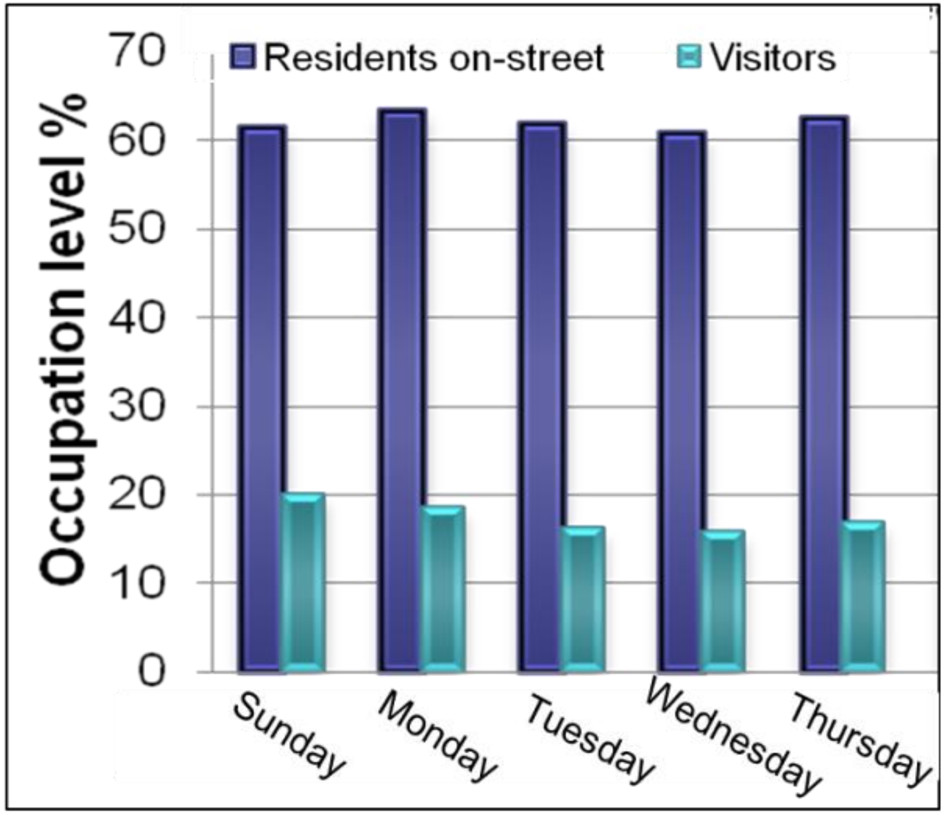
(Lot floor area)/12 (5*1.5 ~ 8m^2 car + 4m^2 pass)



**Levy, N., Benenson, I, 2015, Journal of Transport Geography, 46, 220–231*

Parking turnover: Field surveys in Basel neighborhood, TLV

For the same day of the week and hour of the day: The variation in the parameters of parking pattern is very low



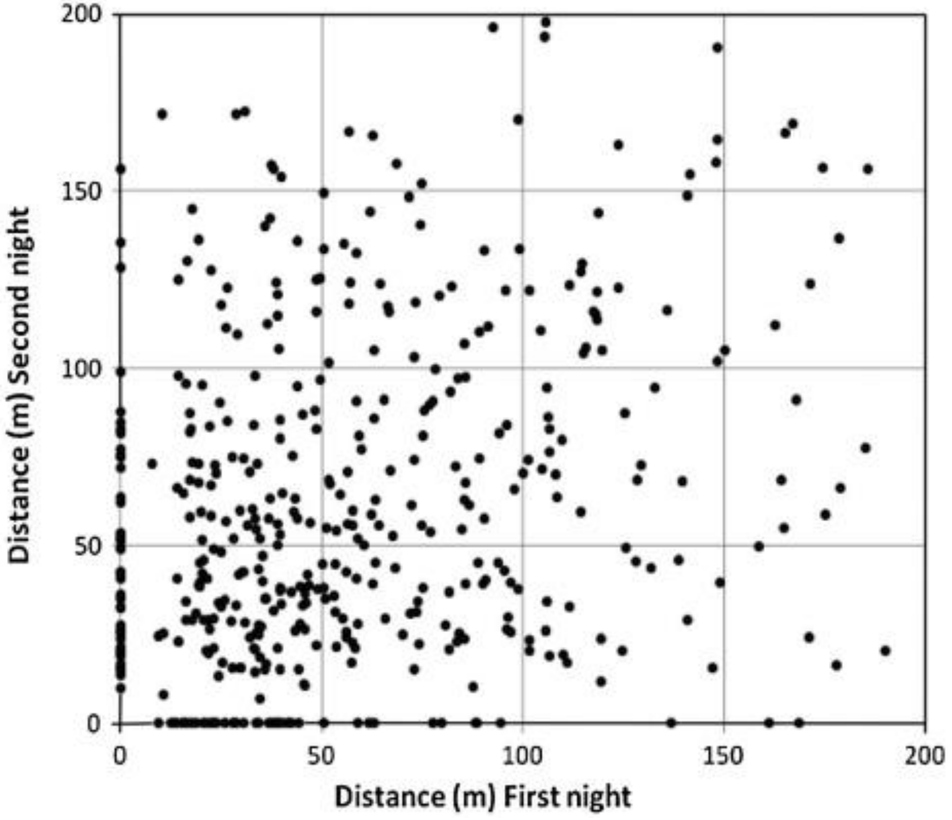
Residents		Visitors	
Average occupancy (weekdays)	STD	Average occupancy (weekdays)	STD
61.8%	0.94%	17.4%	1.77%

N. Levy, K. Martens, I. Benenson, 2013, Transportmetrica A, 9 (9), 773–797

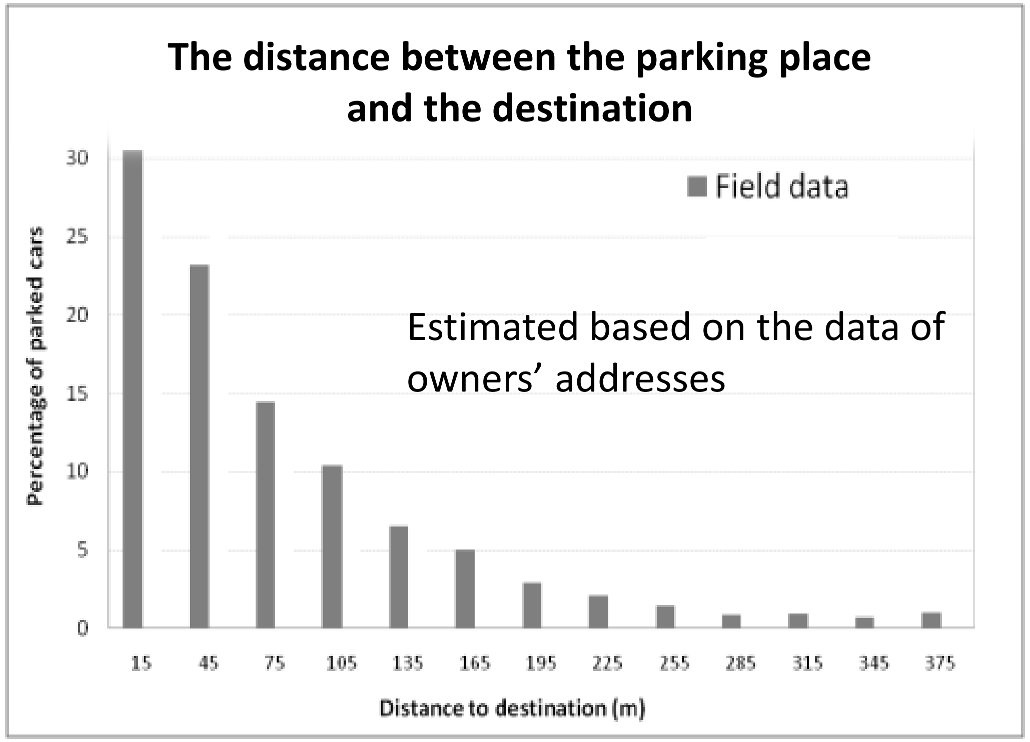
Parking demand and supply

Parking spatial pattern

Destination-parking place distance: Field surveys in Basel neighborhood, TLV



We possess reliable estimates of the parking demand, supply, spatial patterns, and turnover



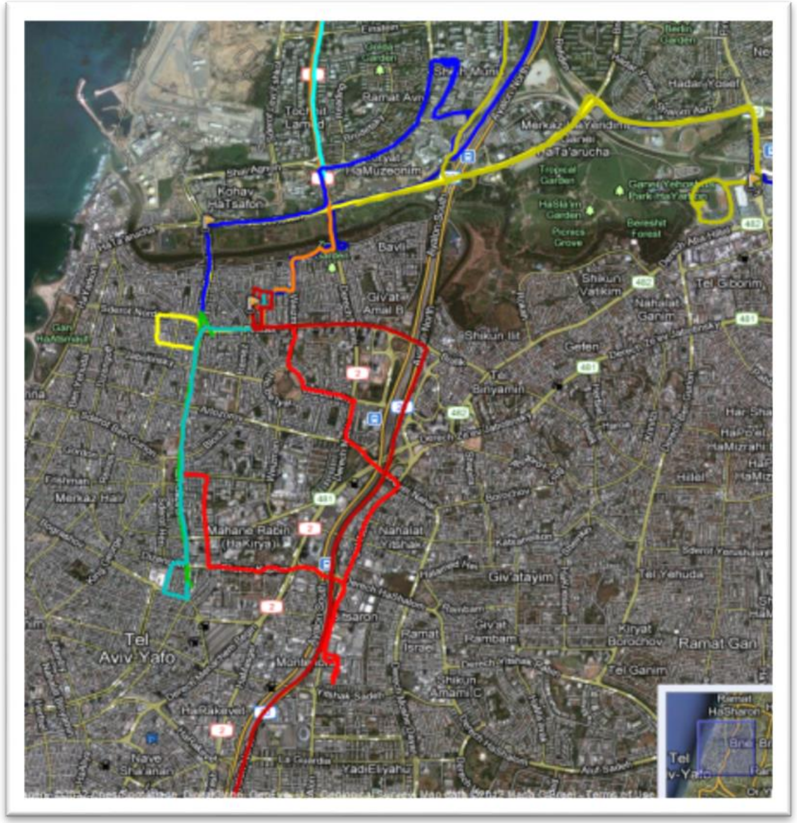
Levy, N., Benenson, I, 2015, Journal of Transport Geography, 46, 220–231

Parking demand and supply

Parking spatial pattern

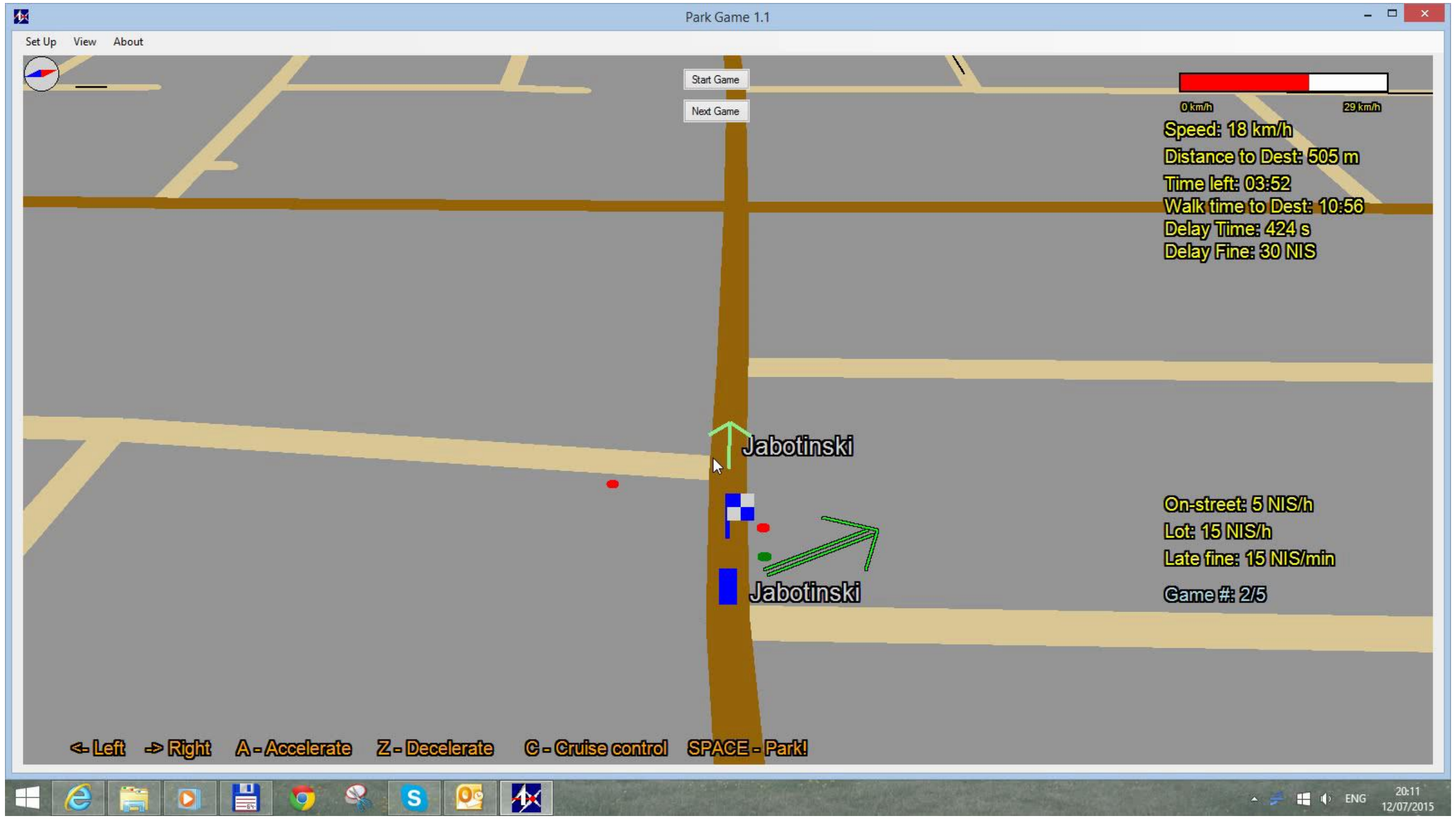
Drivers' parking search behavior

GPS logging, interviews



Driver's speed during parking search is 3 - 4 m/s (12-16 km/h)

ParkGame



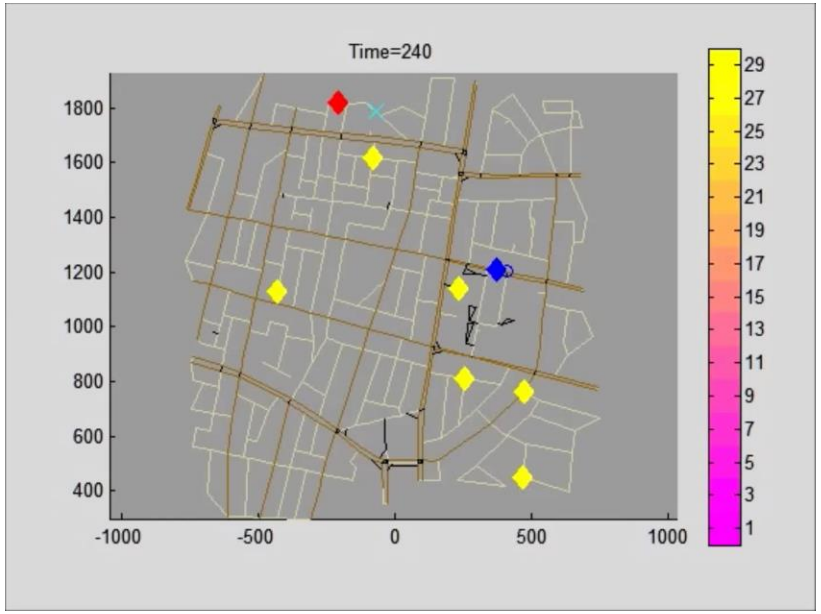
Understand cruising behaviour and the choice between curb and lot parking based on simulated cruising experience

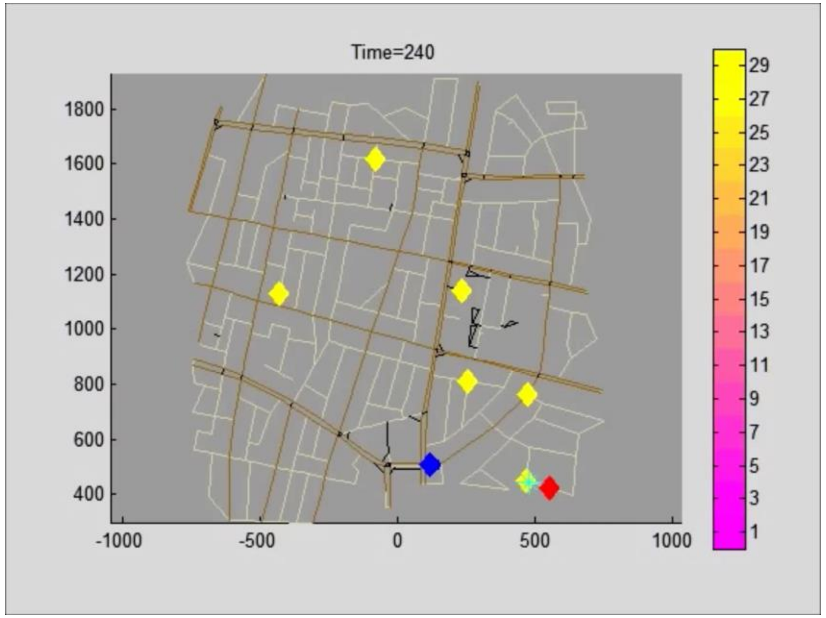
Drivers' parking behavior

ParkGame output

Driver's position and speed
are recorded every second

Time	SegmentIl	DistanceF	Free	Occupied	PType	Cruise Co	Dist. to De	Speed
240	1065280-1	0	0	3	0	OFF	428	14.4
239	1065280-1	0	0	3	0	OFF	428	14.4
238	1065280-1	0	0	3	0	OFF	428	14.4
237	1065280-1	0	0	3	0	OFF	428	14.4
236	1065280-1	0	0	3	0	OFF	428	14.4
235	1065280-1	1.28	0	3	0	OFF	429	14.4
234	1065280-1	2.56	0	3	0	OFF	430	14.4
233	1065280-1	3.52	0	3	0	OFF	431	14.4
232	1065280-1	4.8	0	3	0	OFF	433	14.6
231	1065280-1	6.13	0	3	0	OFF	434	15.8

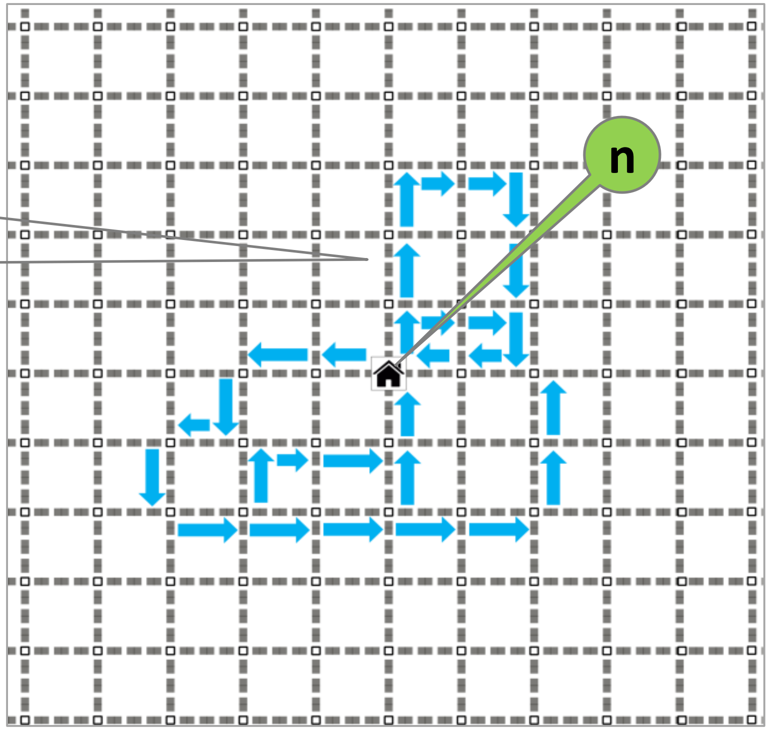


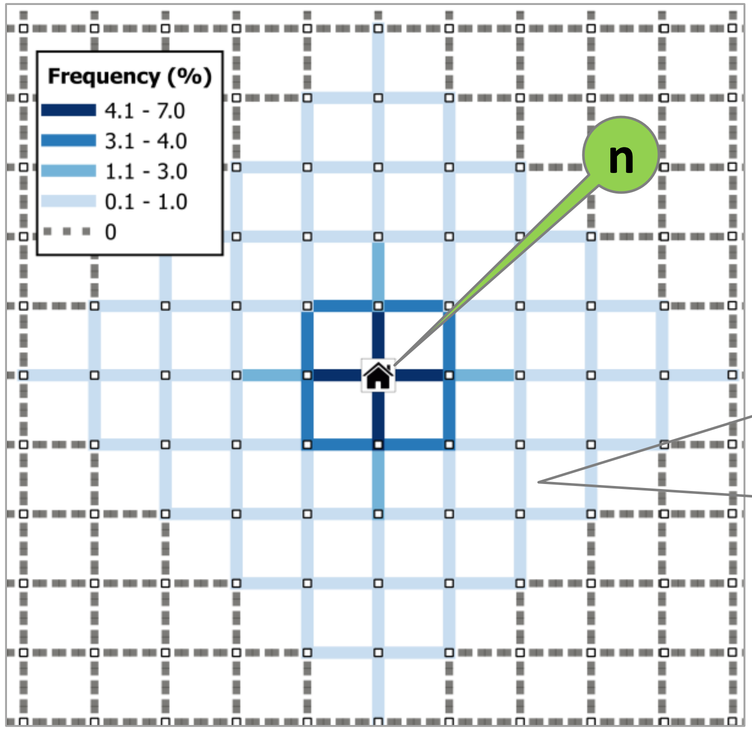


Drivers' parking behavior

ParkGame drivers’ behaviour : Biased random walk

Typical cruising trajectory





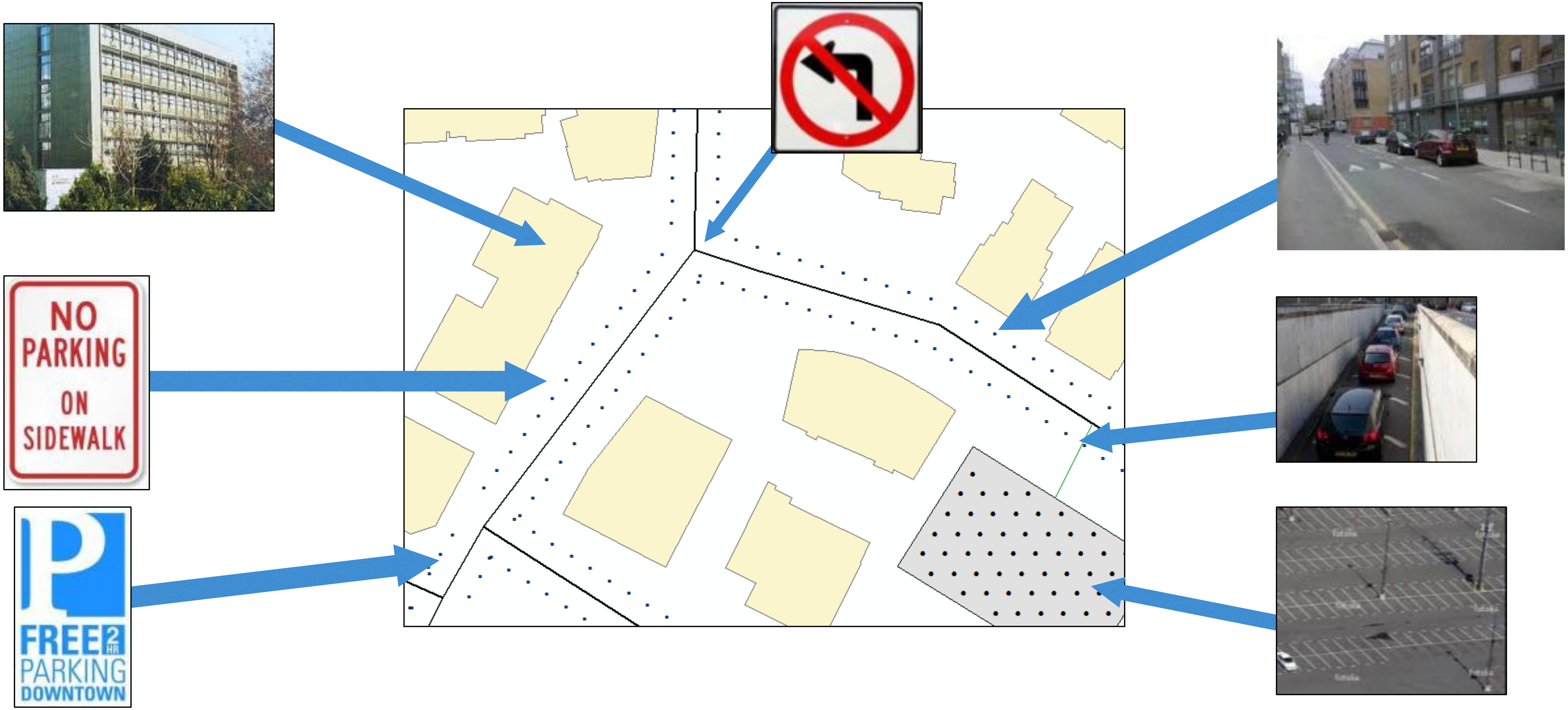
Probability $p_n(l)$ to visit a links when searching for parking near to a destination **n**

Driver’s behavior parameters

Decision at a previous junction	d < 100		100 ≤ d < 200		200 ≤ d < 300		d ≤ 300 < 400		d ≥ 400	
	Closer	Further	Closer	Further	Closer	Further	Closer	Further	Closer	Further
Closer	0.00	1.00	0.65	0.35	0.85	0.15	0.90	0.10	1.00	Irrelevant
Further	Irrelevant		0.00	1.00	0.80	0.20	0.85	0.15	1.00	0.00

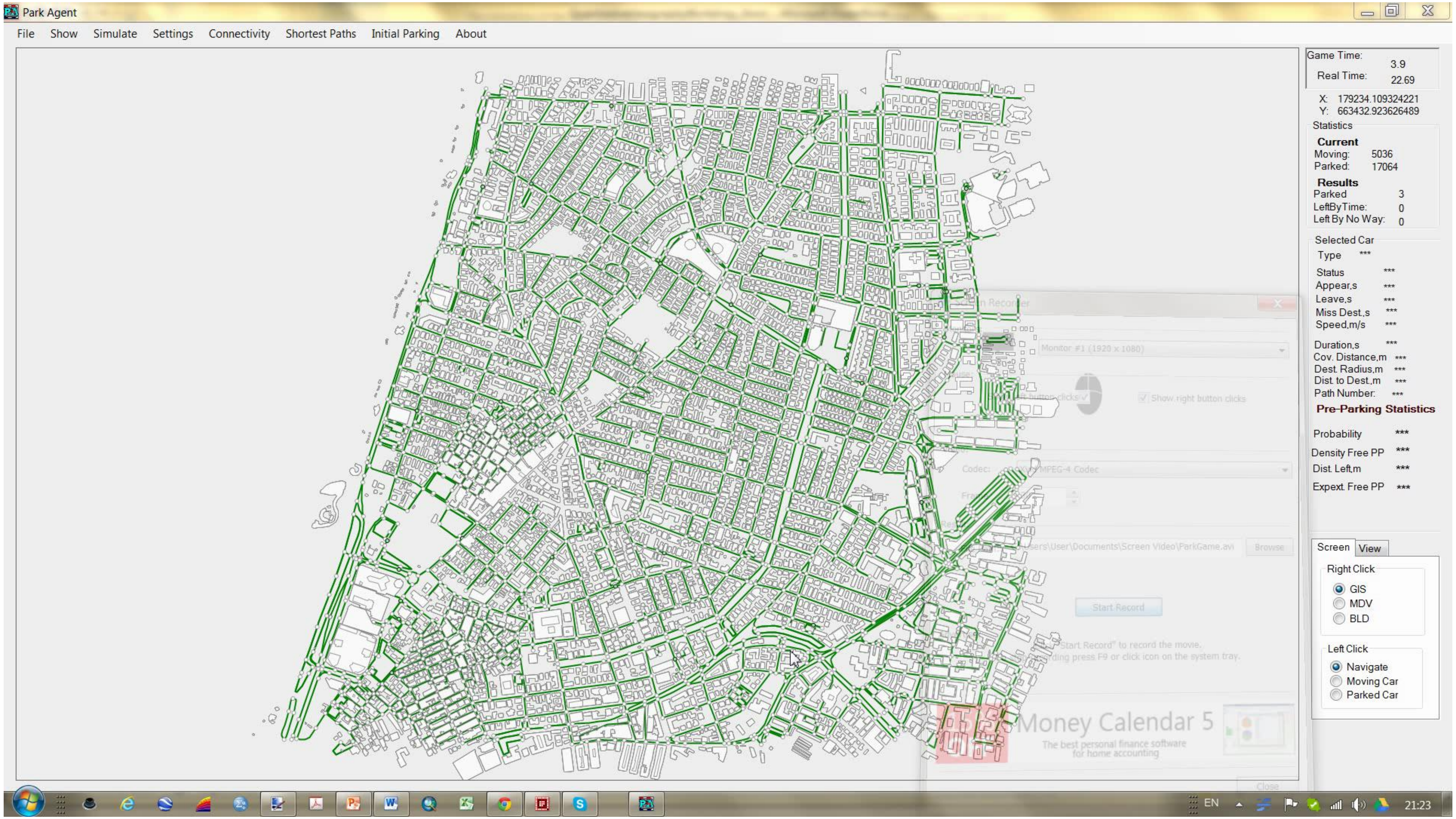
Drivers’ parking behavior

PARKAGENT - spatially explicit model of cruising for parking



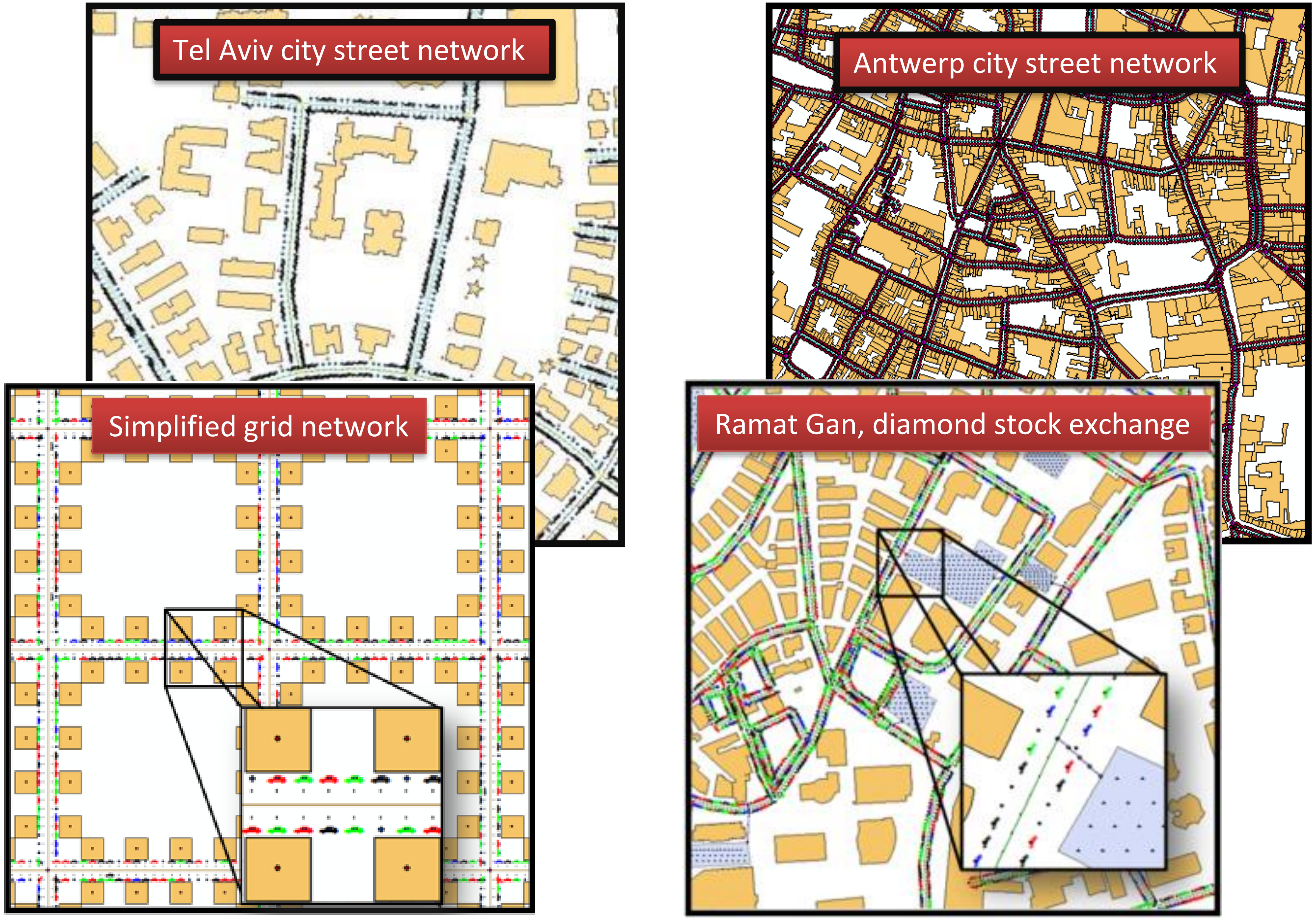
Parking dynamics in space and time

PARKAGENT: User interface



Parking dynamics in space and time

PARKAGENT: Easily adjustable to a new city



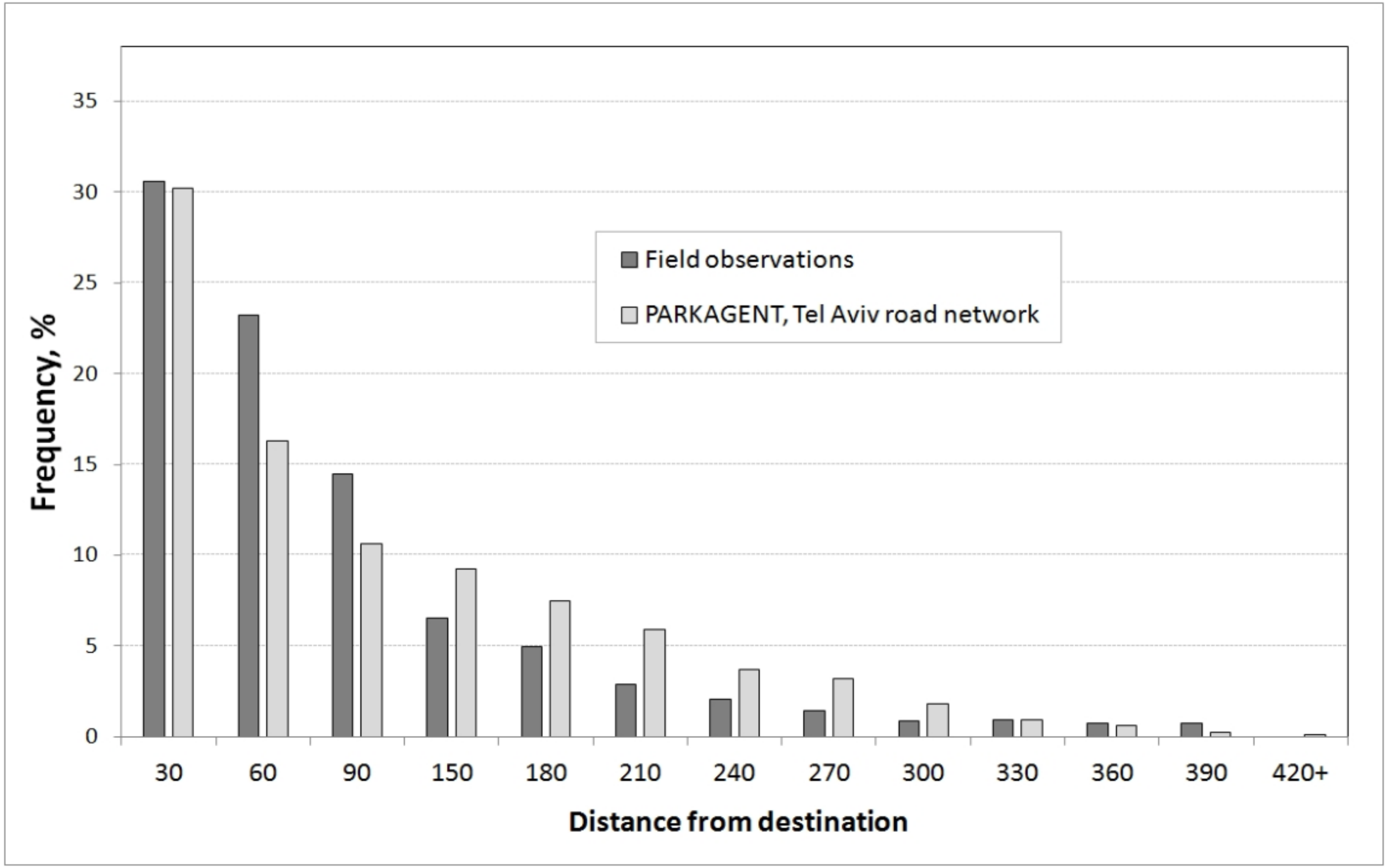
ParkAgent: Quantitative fit to the Tel Aviv data

Parameters

Parking demand: Estimated based on buildings' capacity

Spots occupied during the whole day: 40 – 80%

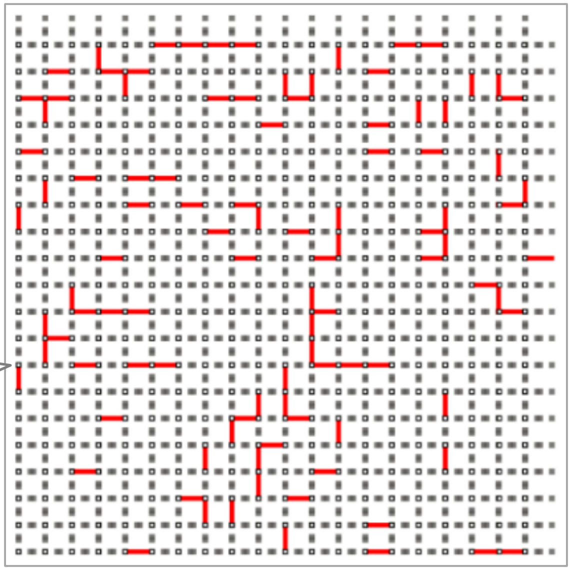
Duration of visitors' parking: Uniform, [30 min, 120 min]

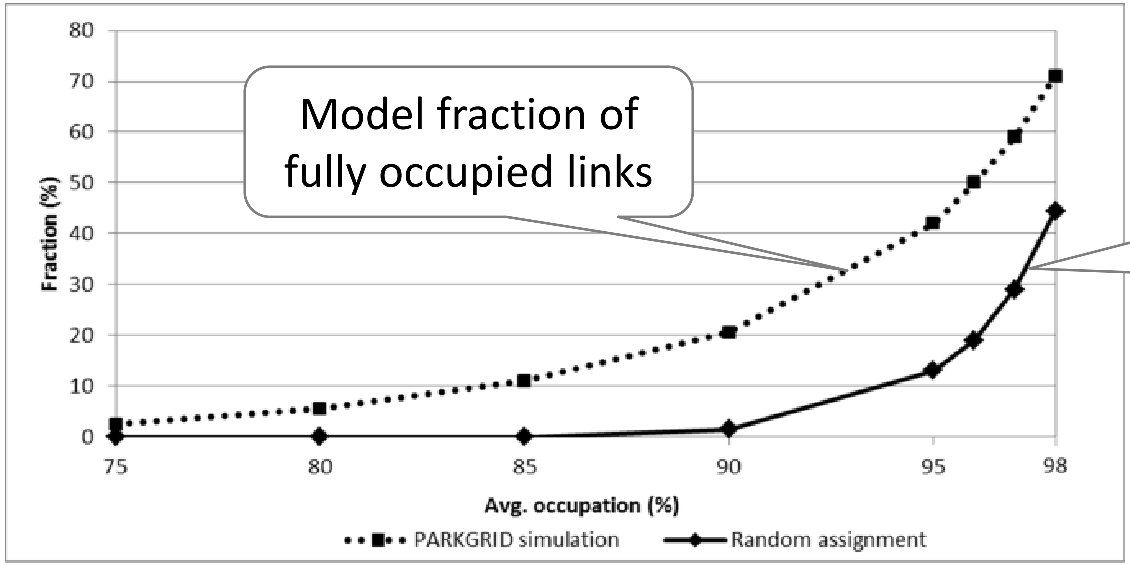


Parking dynamics in space and time

Clusters of occupied links

Average occupation rate q = 0.85

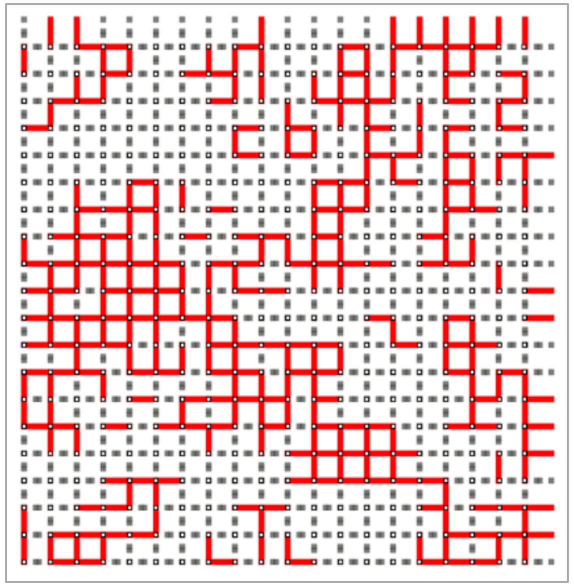


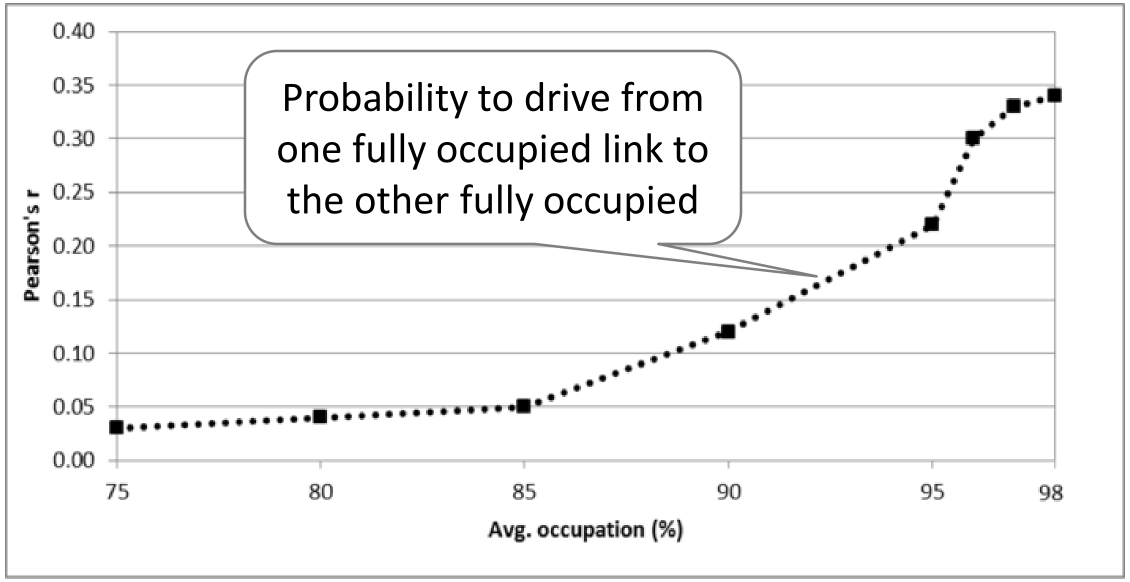


Model fraction of fully occupied links

Random occupation

Average occupation rate q = 0.95

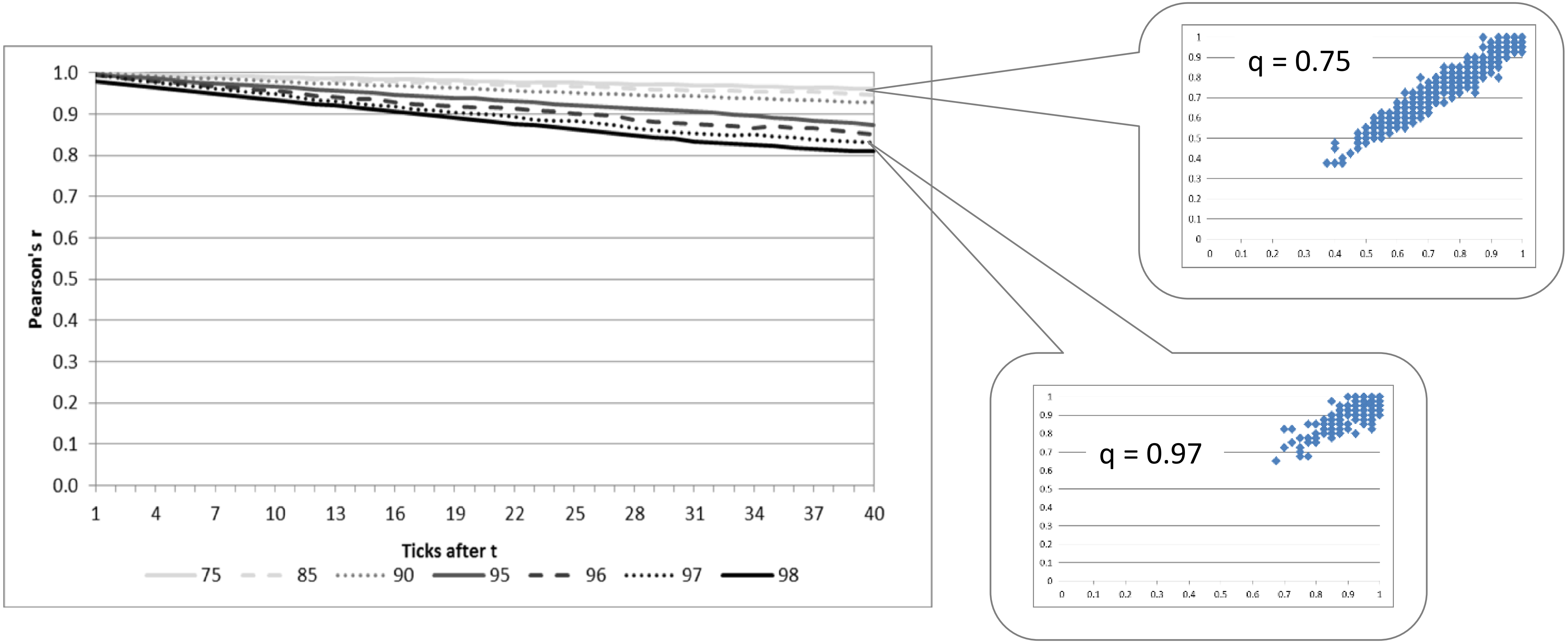




Probability to drive from one fully occupied link to the other fully occupied

Parking dynamics in space and time

Clusters do not change much during driver's search: Autocorrelation of links' occupation



Probability of a parking failure and cruising time curve

$F_{U(n)}(\tau)$ - wasted search time index

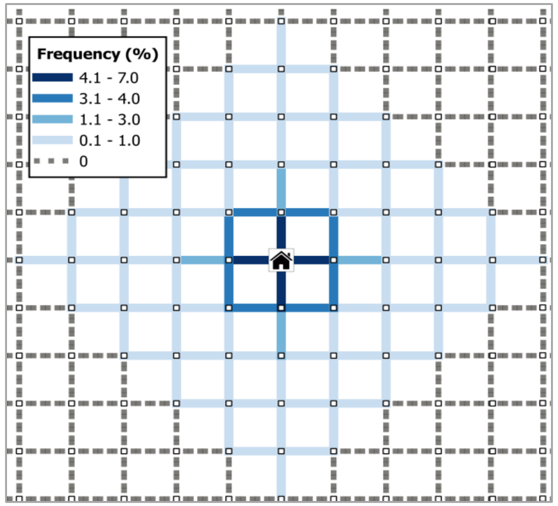
$$F_{U(n)}(\tau) = \Sigma_{l \in U(n)}\{p_n(l) \mid f_l(\tau) = 0\}$$

$p(\tau, n)$ – probability to cruise for time τ

$$F_{U(n)} = F: p(\tau, n) = (1 - F) * F^{\tau}$$

$p_n(l)$ fraction of search time wasted while traversing link l

$f_l(\tau) = 0$ iff l is fully occupied at τ



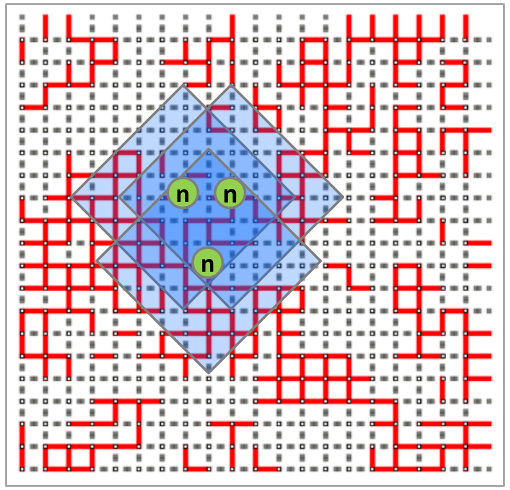
Probability $p_{failure}(F, \tau)$ of parking failure at τ for $F_{U(n)} = F \pm 0.01$

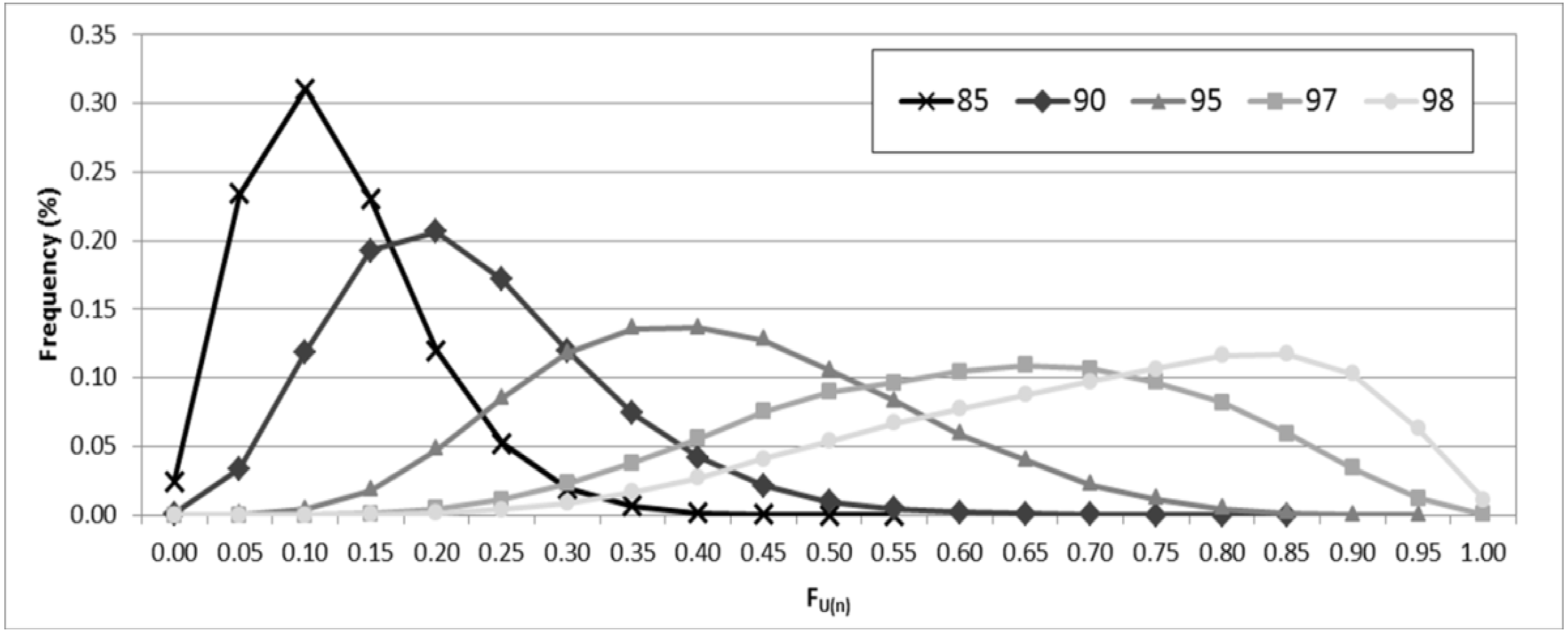
τ / F	1	3	5	7	9	Average	STD
0.05	0.05	0.07	0.04	0.05	0.06	0.053	0.0095
0.10	0.09	0.09	0.11	0.11	0.10	0.104	0.0097
0.20	0.20	0.21	0.21	0.20	0.20	0.204	0.0052
0.40	0.39	0.39	0.41	0.42	0.41	0.404	0.0117
0.60	0.59	0.61	0.60	0.60	0.62	0.607	0.0106
0.80	0.81	0.80	0.79	0.82	0.81	0.806	0.0107
0.90	0.90	0.91	0.89	0.91	0.90	0.898	0.0079
0.95	0.96	0.95	0.93	0.96	0.94	0.947	0.0095

Homogeneous area, average occupation rate q

Let $w_q(F)$ be a fraction of search neighborhoods $U(n)$ with $F_{U(n)} = F$, among search neighborhoods for all destinations n

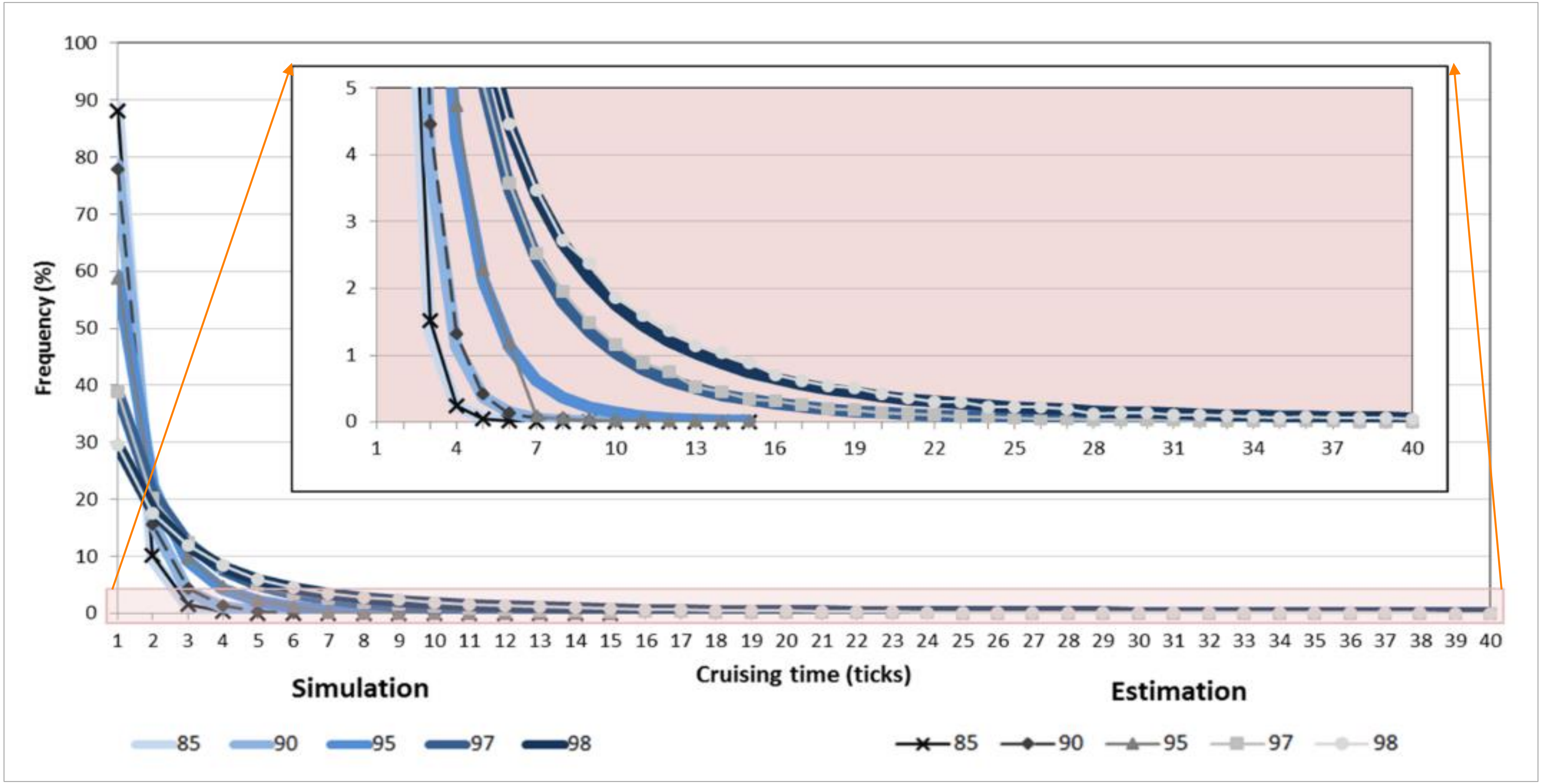
$$p_q(\tau) = \sum_F \{(1 - F) * F^{\tau-1} * w_q(F)\}$$





Parking dynamics in space and time

Simulated vs approximated $p_q(\tau)$, different occupation rates q

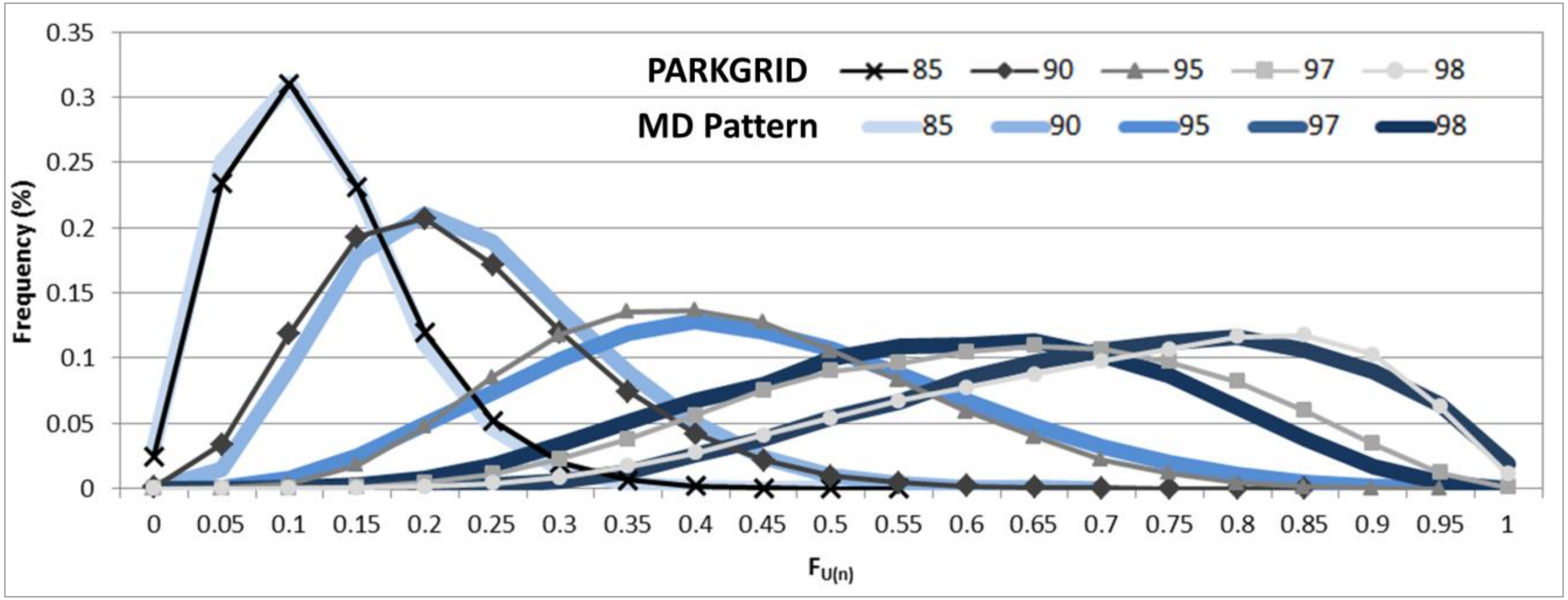


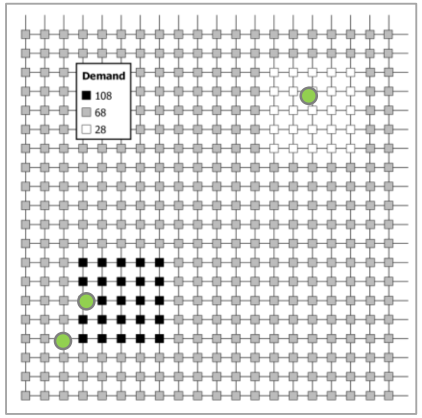
Parking dynamics in space and time

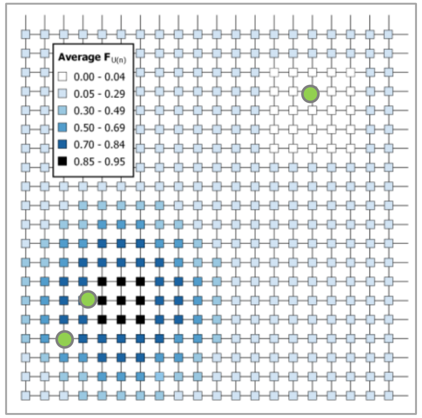
Maximally Dense (MD) parking pattern

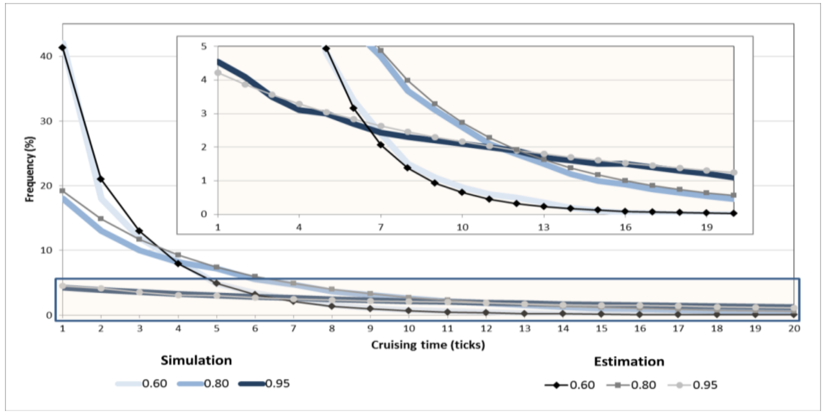
*Levy, N., Benenson, I, 2015, Journal of Transport Geography, 46, 220–231

Approximation of $w_q(F)$ distribution based on the MD pattern









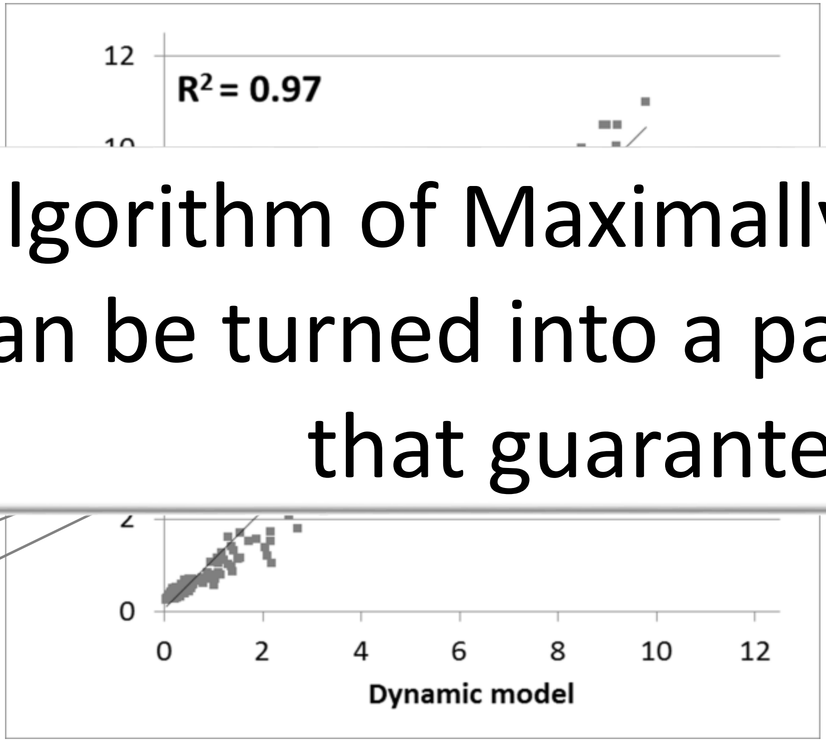
Approximation of $w_q(F)$ distribution based on the MD pattern

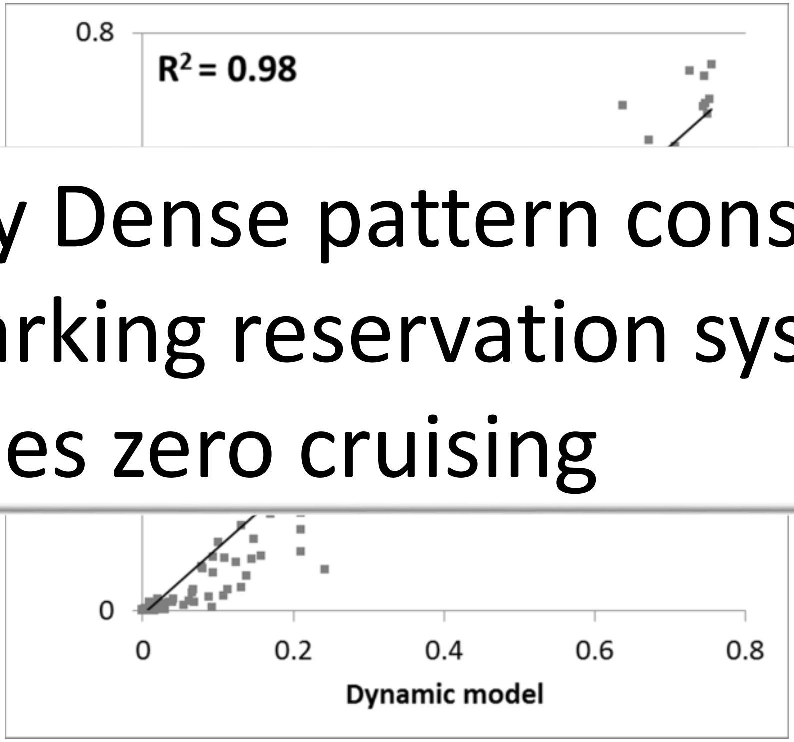
Each point
rep
de

Probability to
er
es

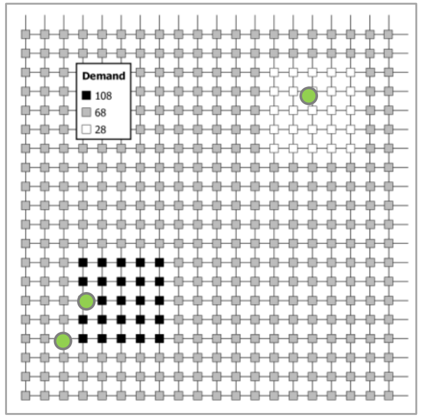
nt
ts a
on

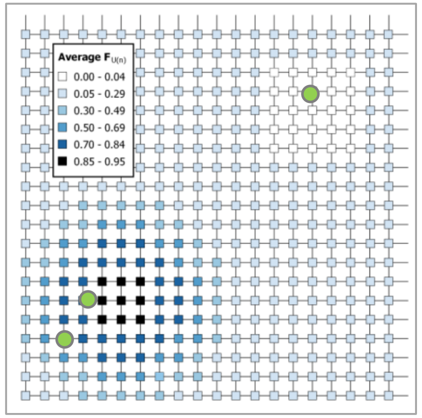
Average
search time

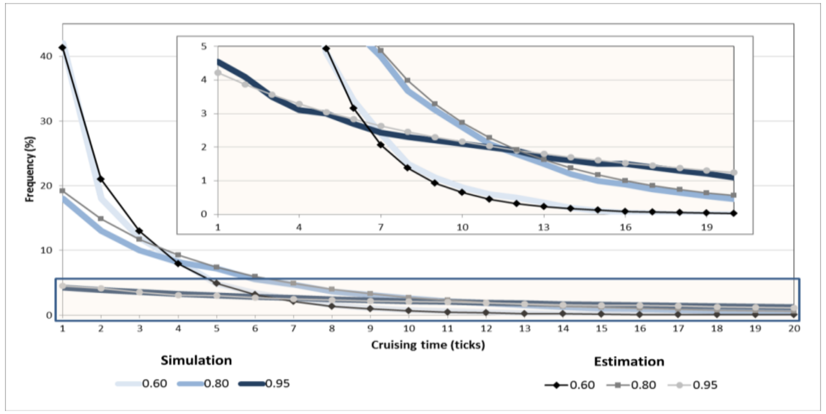




The algorithm of Maximally Dense pattern construction can be turned into a parking reservation system that guarantees zero cruising



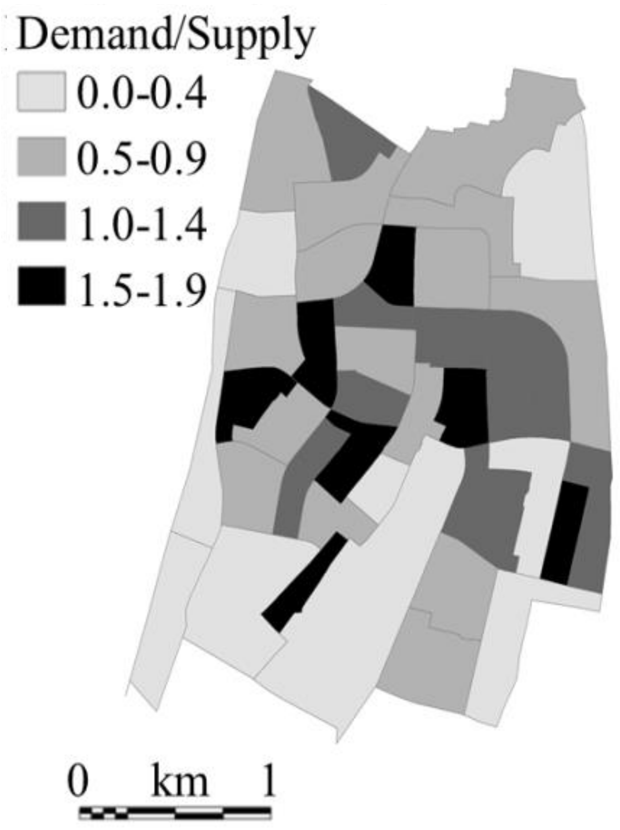




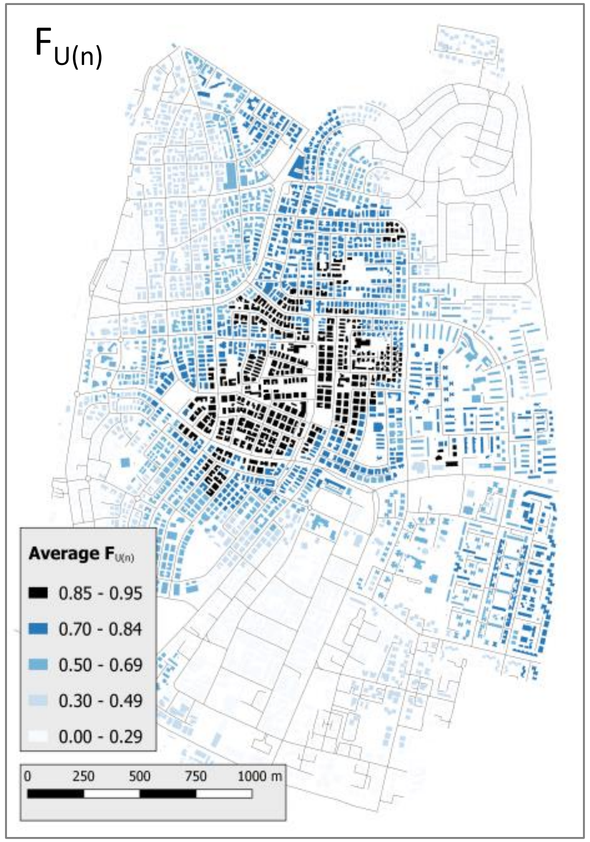
Parking dynamics in space and time

Real example: Bat Yam evening parking

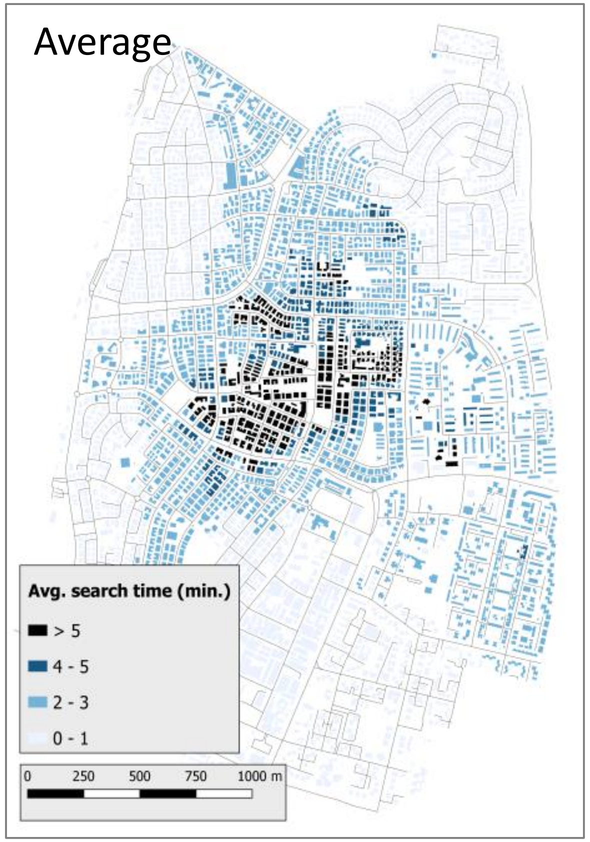
Population 130K pop; Car ownership 35K; 3.3K residential buildings with 51K apts and 17.5K dedicated parking places. Residents park for free on/off-street, visitors parking is paid equally on/off-street. Limited mixed land-uses.



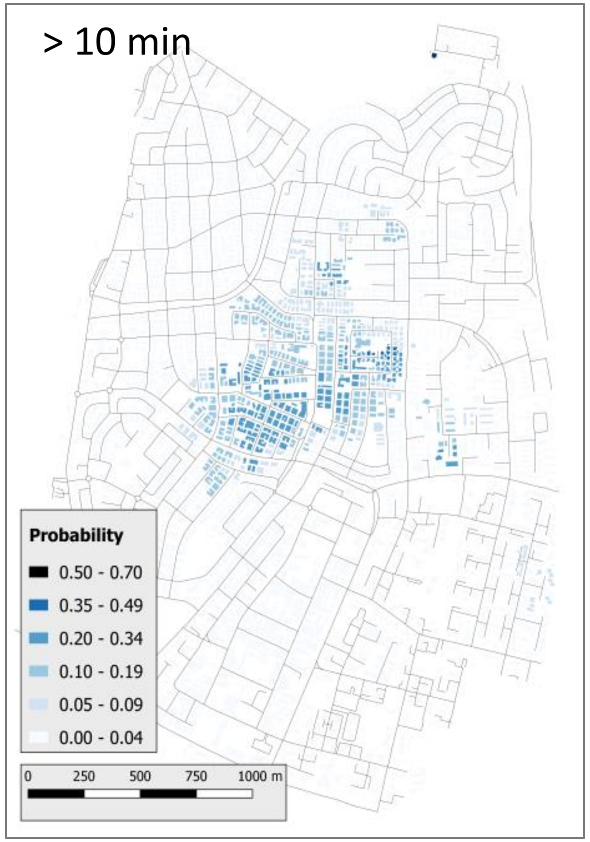
By TAZ, data aggregation



By residents' destinations (Maximally Dense pattern)



By residents' destinations (cruising time curve)



By residents' destinations (cruising time curve)

Parking management and policy assessment

Parking policy: Recent ideas

Should we adjust parking facilities in the city center to demand?

(1)Greg Marsden, The evidence base for parking policies—a review:
The research base, in many instances, does not support, or provides evidence counter to, the assumption that parking restraint makes centers less attractive.
From that on, this claim is reconfirmed many times

How to restrain cruising, then? By increasing parking prices…

(2)Donald Shoup strongly advocates *adaptive parking prices,* with an objective to preserve 1 per 7 places free. Implemented in a famous San Francisco SF-PARK experiment in 2011-2013, (3)Millard-Ball et al, 2014.

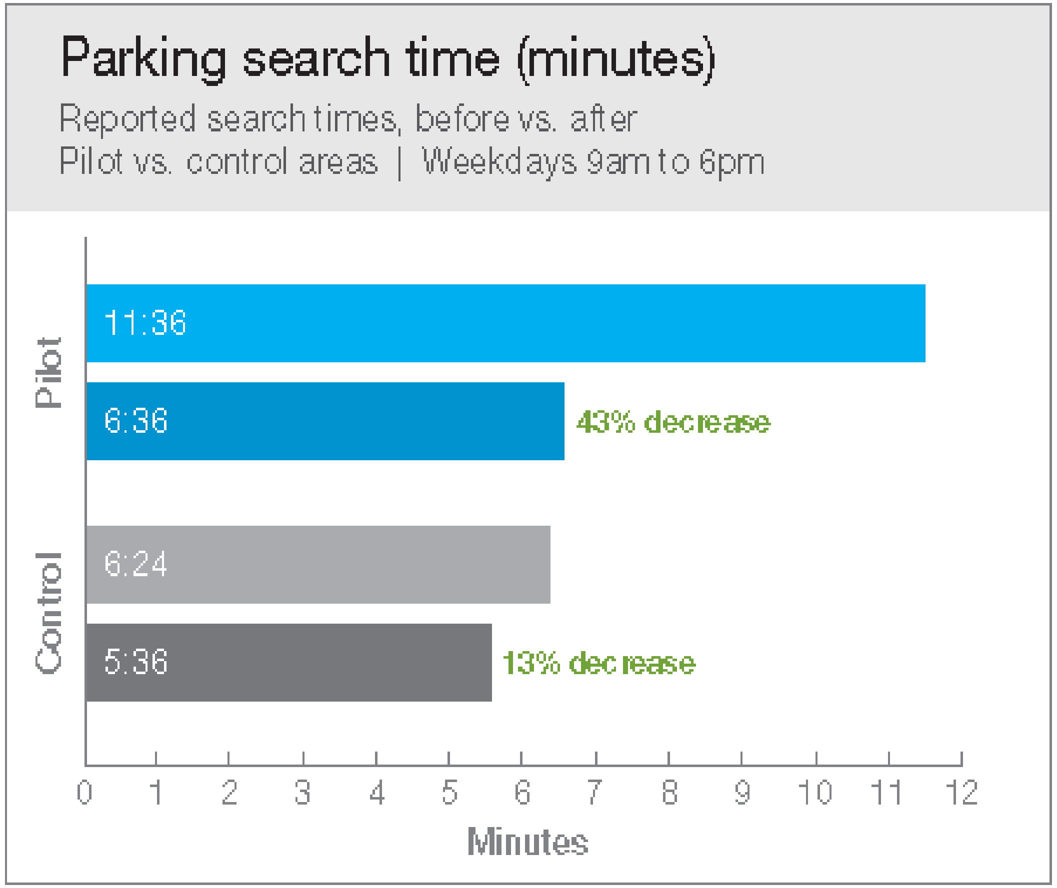
What can be positive incentive to change the transportation mode?

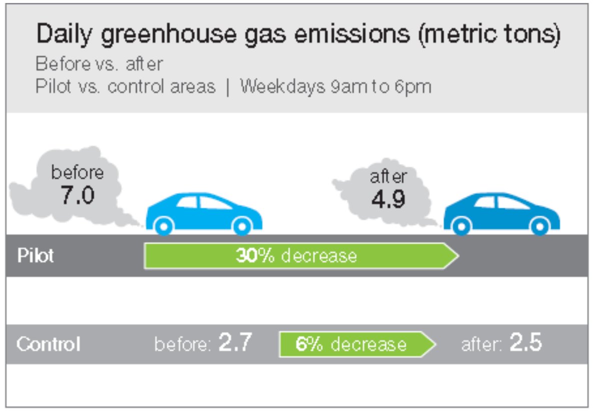
Give residents the right to sell their parking permits, (4)van Ommeren et al, 2014

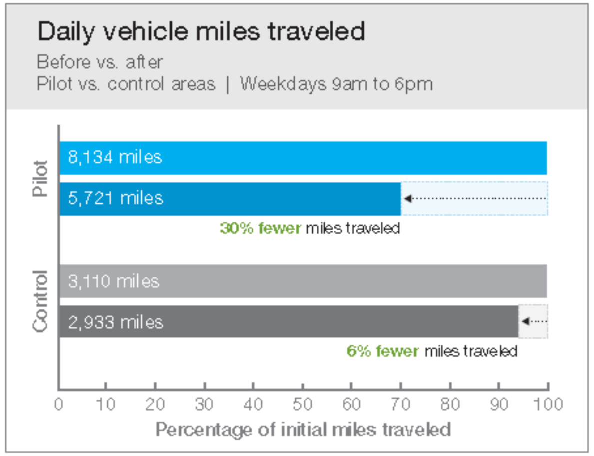
[1] G Marsden, 2006, Transport Policy 13, 447–457
[2] D. Shoup, 2004, Reg. Sci. Urban Econ. 34 (6), 753–784
[3] Millard-Ball et al, 2014 Transportation Research Part A 63, 76–92
[4] J. van Ommeren et al, 2014, Reg. Sci. Urban Econ. 45 (1) 33–44)

SF-Park: the higher the demand the higher the parking price

Reduced 43% search time, 30% mileage, 30% emissions! But cost $18M…



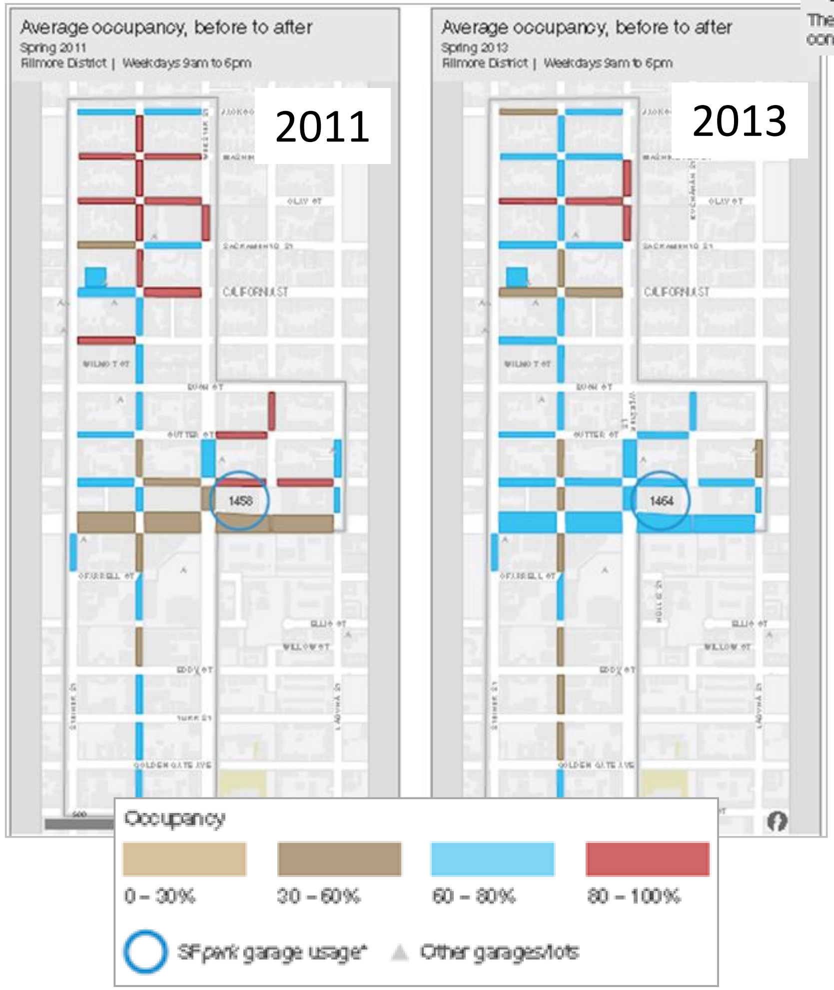




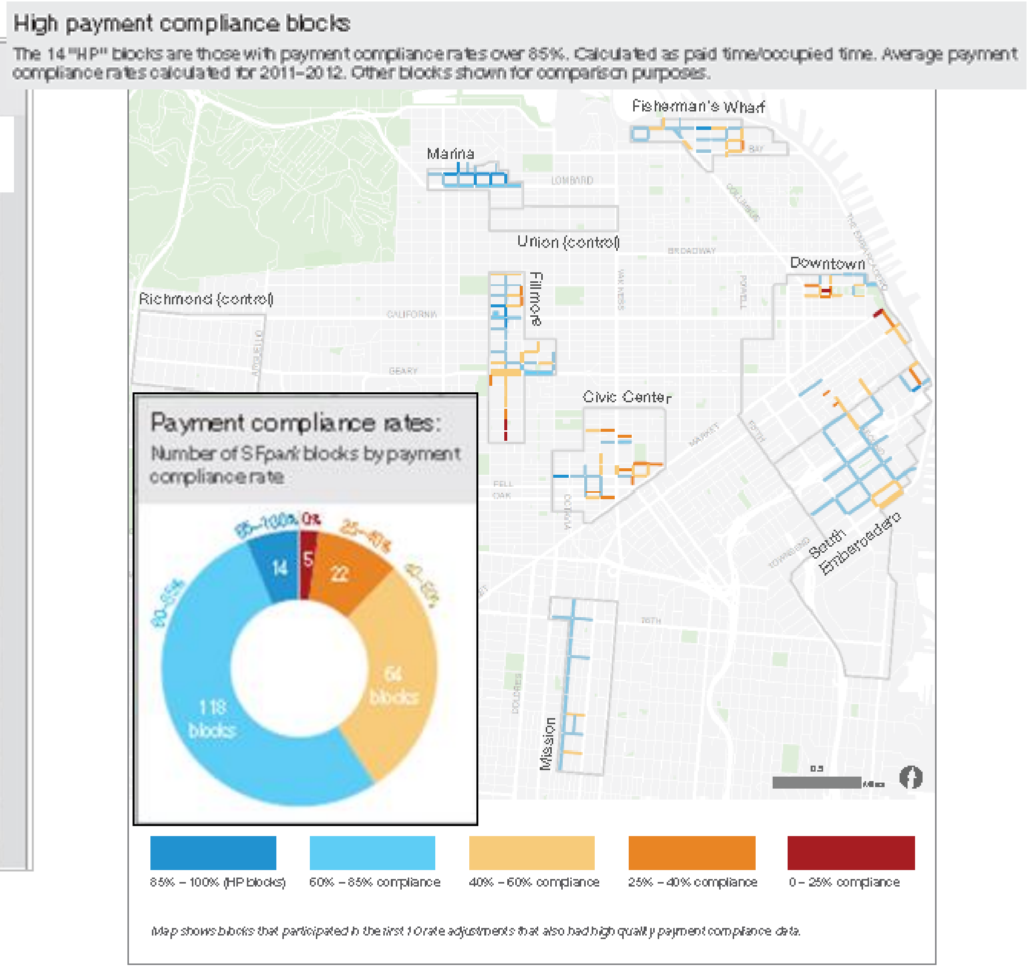
- **Millard-Ball, Adam, Rachel R. Weinberger, and Robert C. Hampshire,** Is the curb 80% full or 20% empty? Assessing the impacts of San Francisco's parking pricing experiment. *Transportation Research Part A: Policy and Practice* 63 (2014): 76-92.
- **SFMTA's evaluation of the SFpark pilot project:** http://sfpark.org/resources/docs_pilotevaluation/

Parking management and policy assessment

Parking is a heterogeneous but "smooth" phenomenon



Occupancy
before and after



Readiness to pay is
heterogeneous too

Parking management and policy assessment

Establishing adaptive parking prices

Attractiveness of a spot on a link **l** at a distance **d** from driver's **c** destination (tradeoff between walking distance and willingness to pay):

$$A_l(d) = \min(1, w_c/F_l)/d^a, a < 1$$

F_l – price of the parking place on **l**, w_c – minimal perceivable price

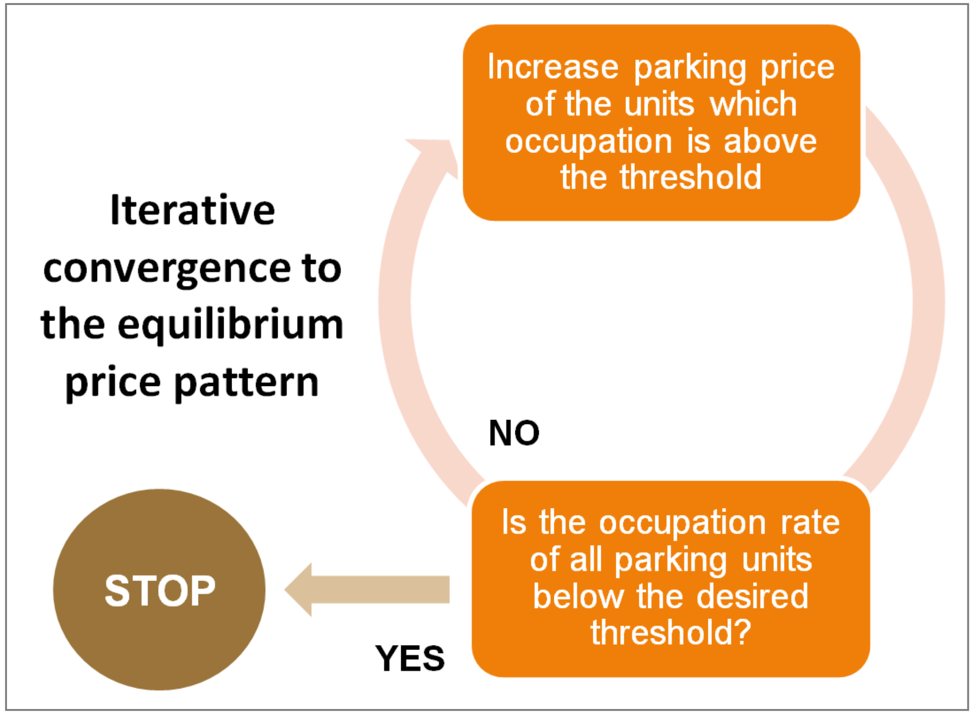
If {link **l** average occupancy $O_l > O_{threshold}$}

Then {

Increase price $F_l = F_l*(1 + x)$

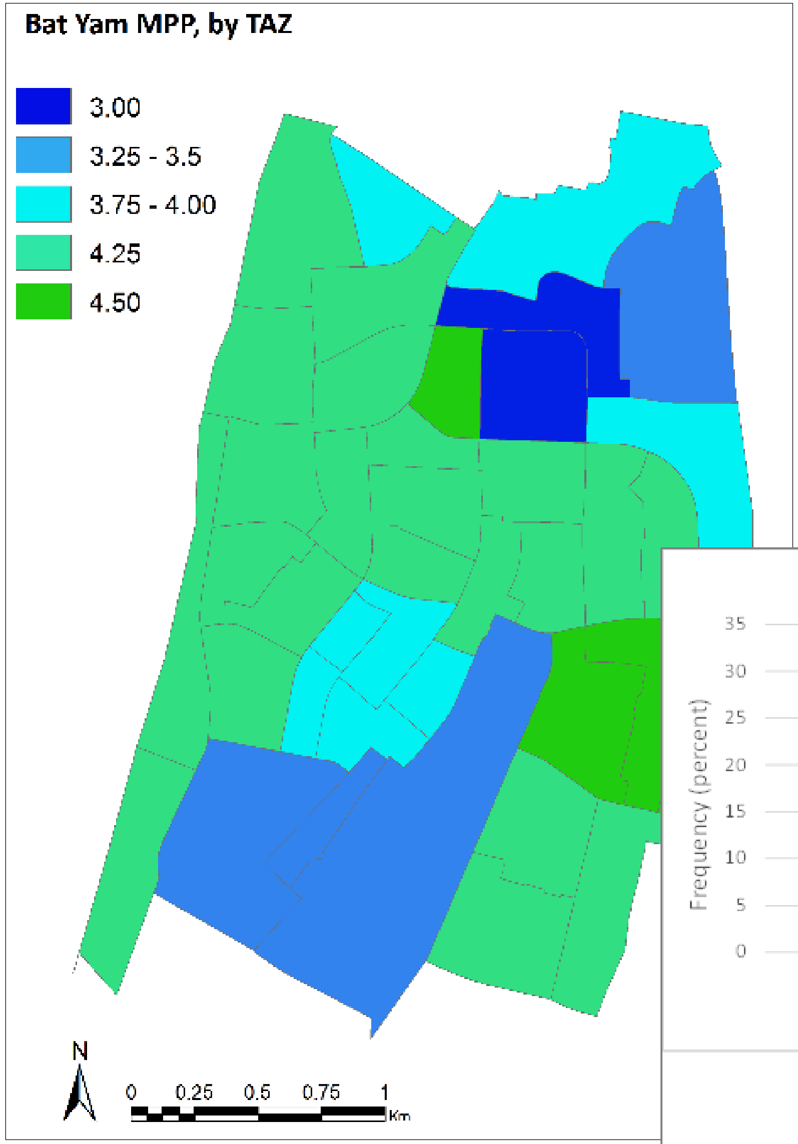
Reapply MD-pattern construction algorithm

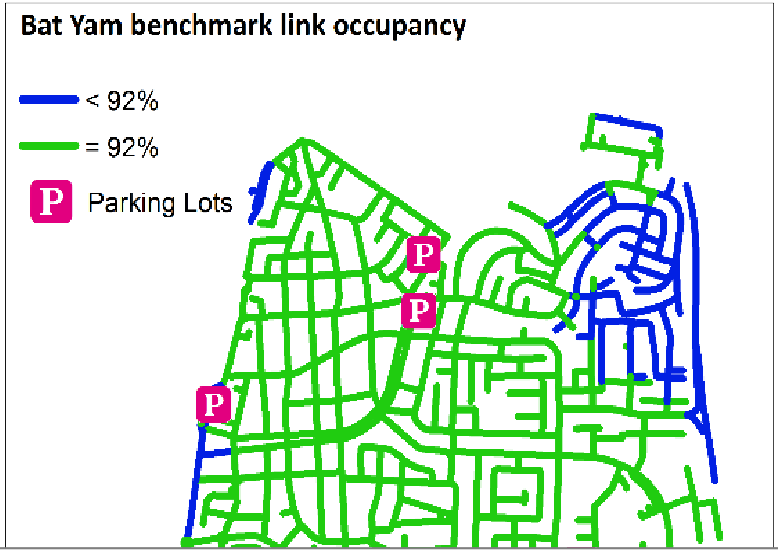
}

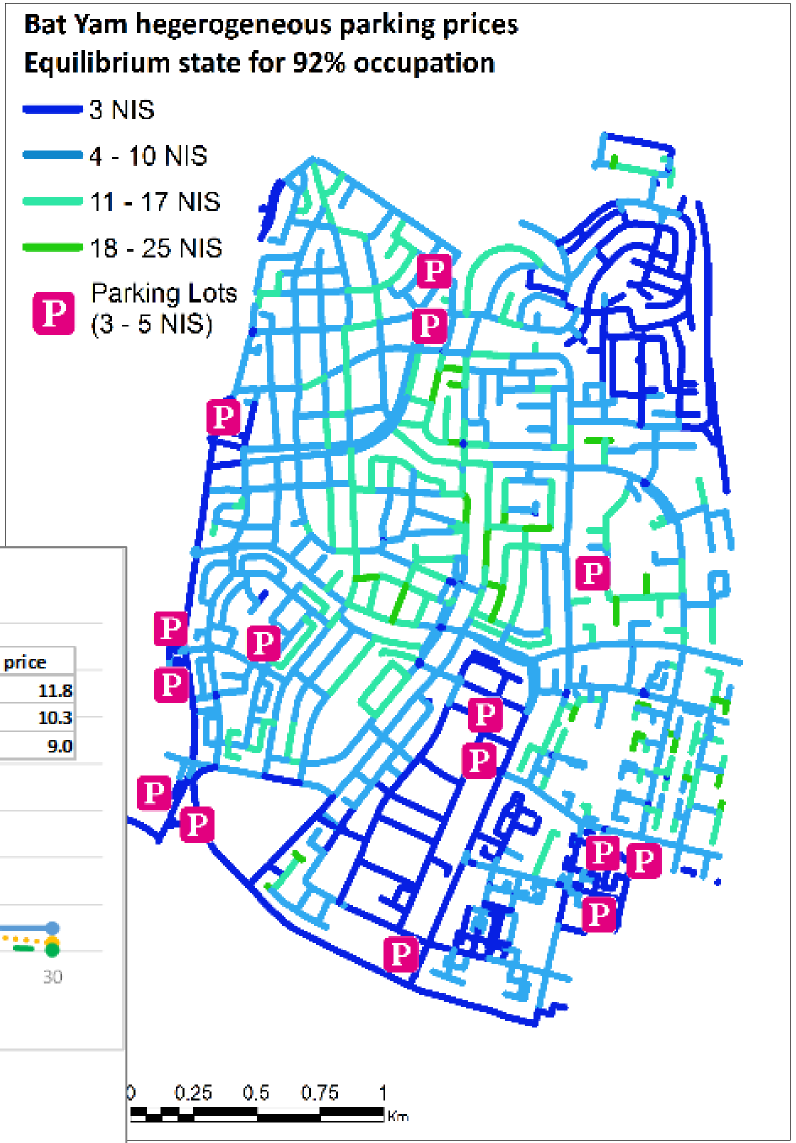


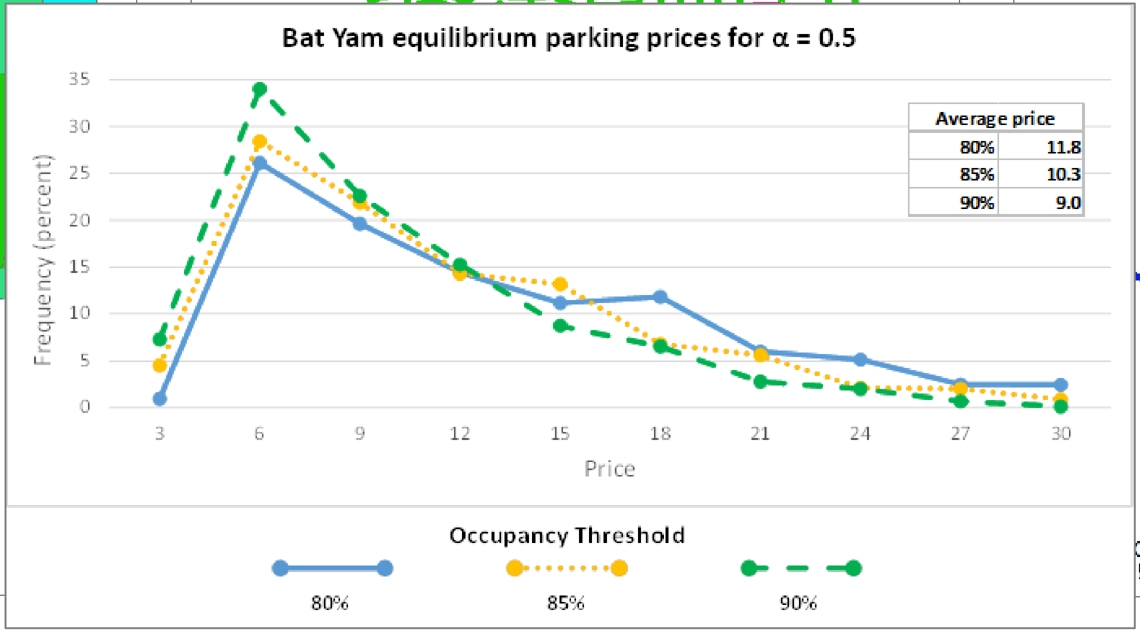
*Fulman, Benenson, 2019, Establishing Heterogeneous Parking Prices for Uniform Parking Availability for Autonomous and Human-Driven Vehicles, IEEE ITS Magazine, 11(1), 15 – 28

Adaptive parking prices for Bat Yam









Parking management and policy assessment

Simple complex problem of urban parking

Conclusions

- Parking patterns of the day/hour are repeated
- Drivers' search behavior is relatively simple and can be revealed in the lab
- Necessary for parking analysis data are readily available: GIS layers of city buildings, streets, parking lots; aggregated statistical data on car ownership
- High-resolution dynamic simulation properly repeats real-world parking patterns
- Parking search time can be estimated with static models, at any level of resolution
- Parking reservation system will guarantee zero cruising
- If reservation is impossible, adaptive parking prices will guarantee zero cruising

What else do we need for establishing urban parking policy?

Anticipating the future…

Thank you!