Modeling and optimization of multimodal urban networks with limited parking and dynamic pricing

UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

Prof. Nikolas Geroliminis

Urban Transport Systems Laboratory

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

ENAC School of Architecture,
Civil and Environmental Engineering

Riverside, Jan. 17th , 2015

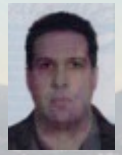
LUTS team

Nikolas Geroliminis

PostDocs

Jack Haddad (CE)

As of 5. 2013 Ass. Prof., Technion Israel



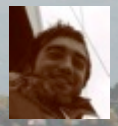
Kostas Aboudolas (EE)

As of 9. 2013 Lecturer, U of Glasgow, UK

Tasos Kouvelas (EE)

Wei Liu (CE)

PhD Students



Burak Boyaci (OR)

As of 3. 2014 Lecturer, U Lancaster, UK

Yuxuan Ji (CS)

As of 8.2014, Bloomberg, CH

Mohsen Ramezani (EE)

PhD Defense 10.2014

Nan Zheng (CE)

PhD Defense 11.2014

Reza Saeedmanesh (EE)

Mikhail Murashkin (Physics)

Raphael Lamotte (CE)

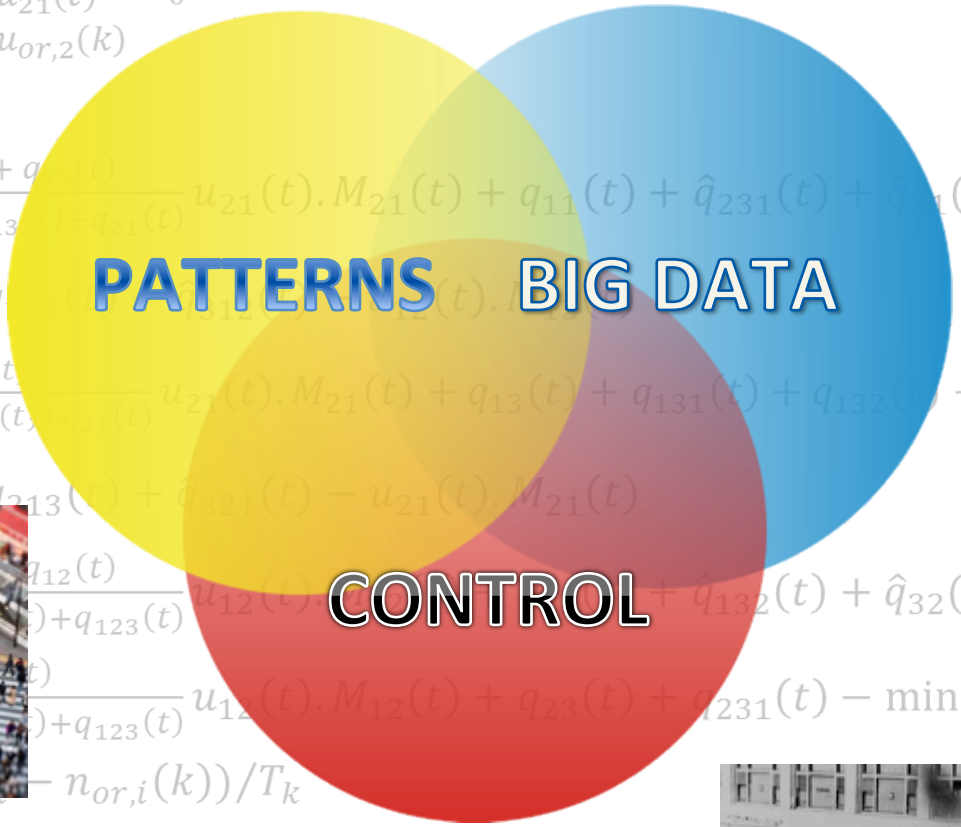
Mehmet Yildirimoglu (CE)

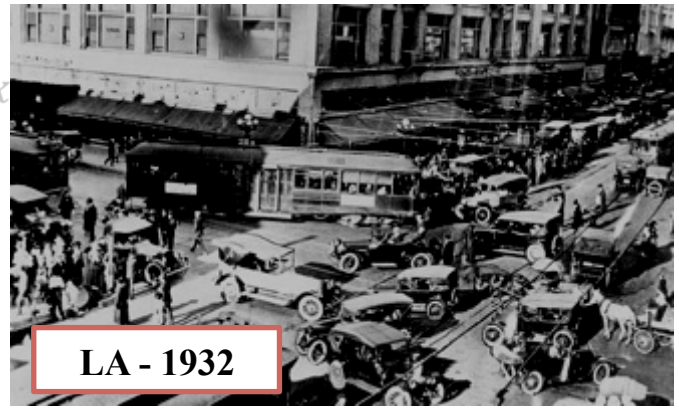







A holistic approach of mobility





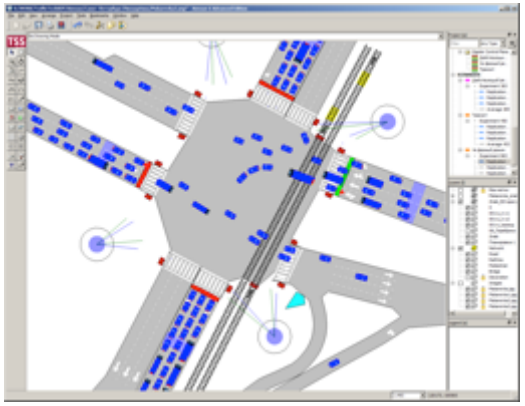
State-of-the-art: Granularity of traffic models

Fine-grained

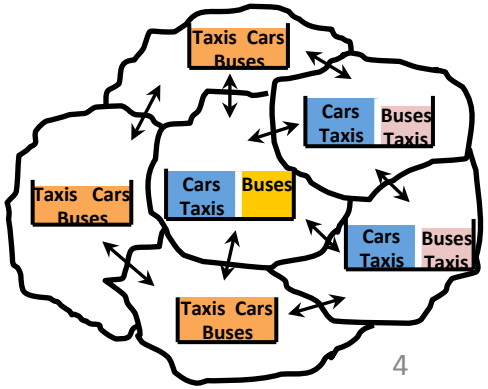
- Data intensive
- Questionable calibration
- Expensive computation
- Unreliable prediction
- Fragmented optimization

Coarse-grained

- Less accurate
- Lack dynamics
- Non-physical
- Planning oriented



traffic modeling



State-of-the-art: Traffic optimization & control

Most optimization methods for transport networks

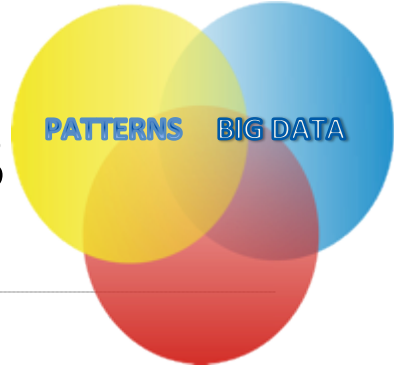
- Fragmented and uncoordinated
- Suited for toy networks with simplified dynamics
- Apply decentralized control
- Micro-simulation and scenario analysis

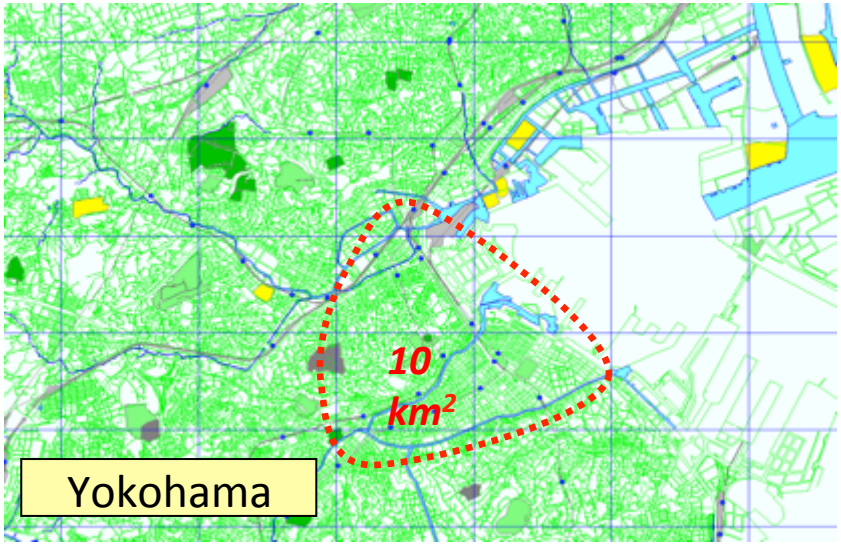
Cairo

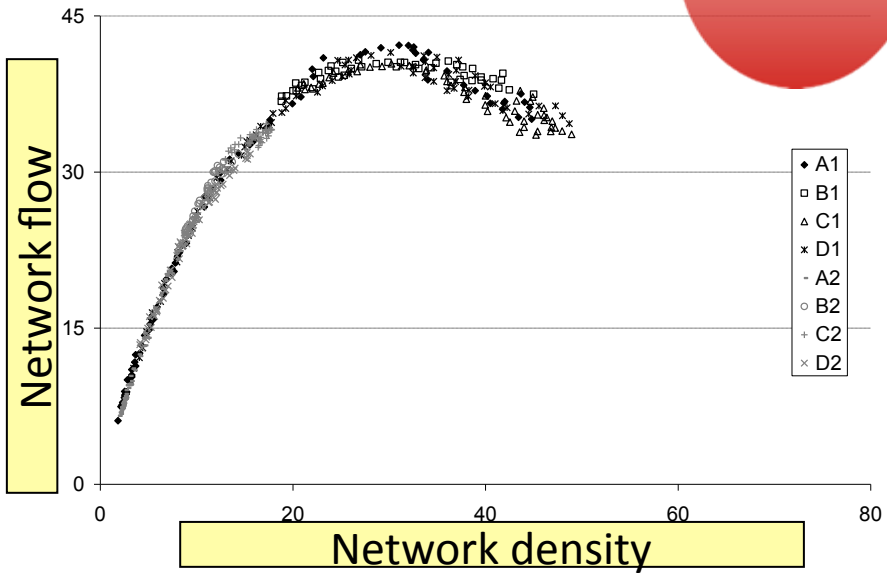
Bangkok

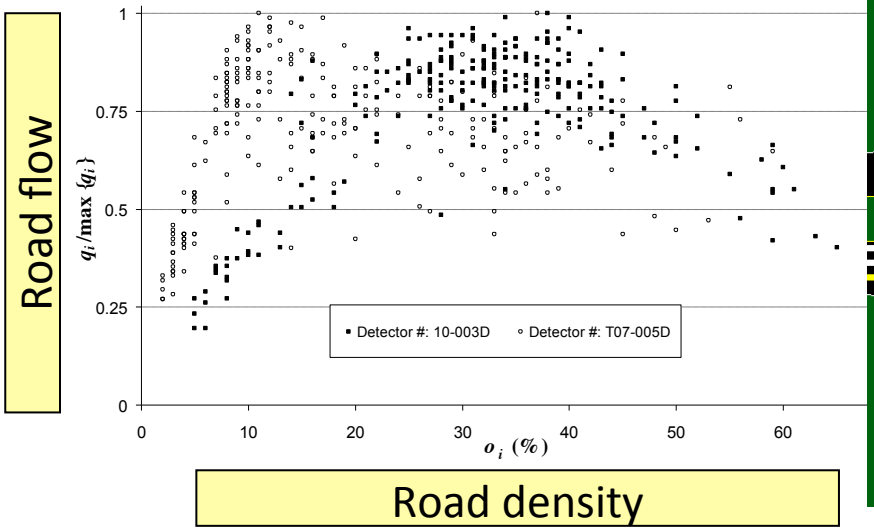
Paris

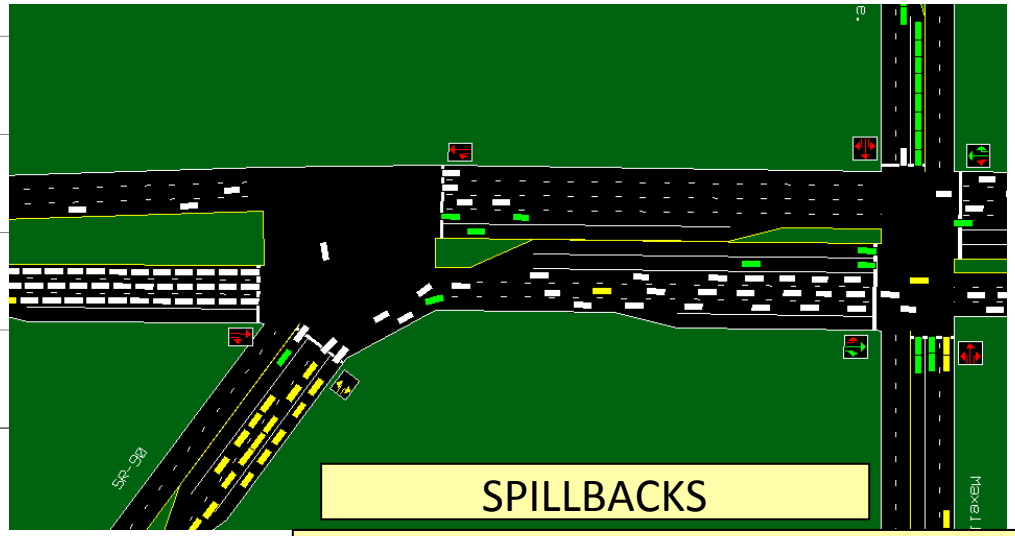
Network congestion observations





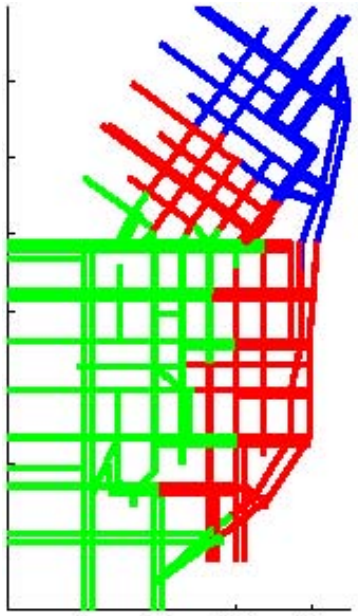


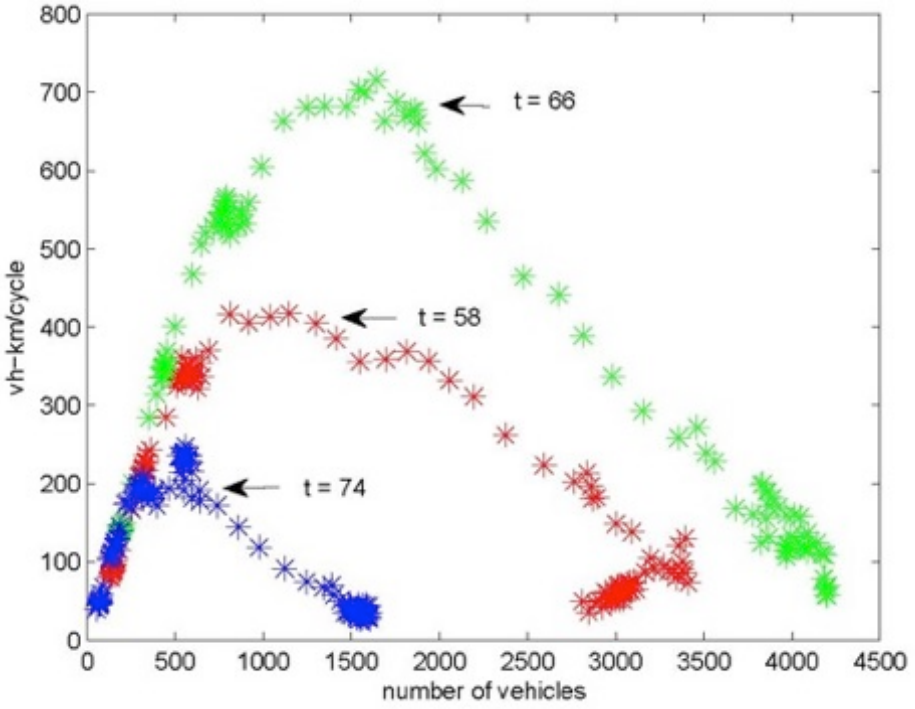




Geroliminis and Daganzo (2008) – Trans. Res. Part B

Clustering – Congestion Dynamics





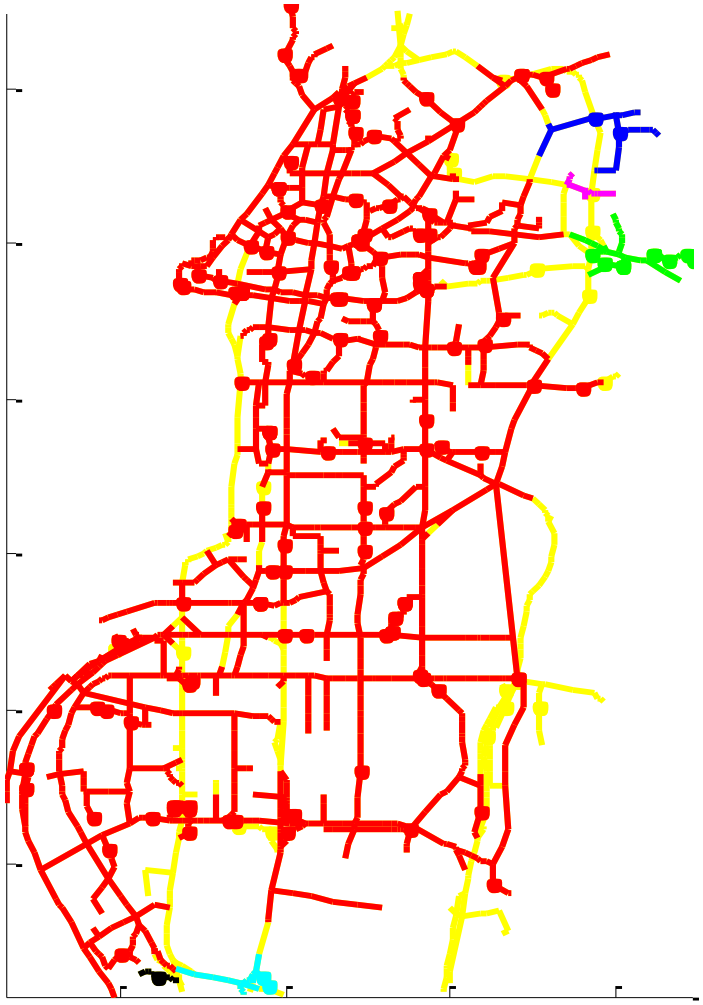
Clusters of a city reach congestion at different times

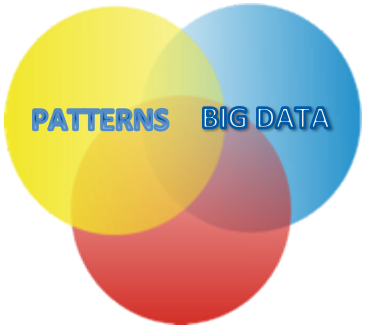
Ji and Geroliminis (2012) – Trans. Res. Part B

Congestion Propagation

Small number of critical pockets of congestion

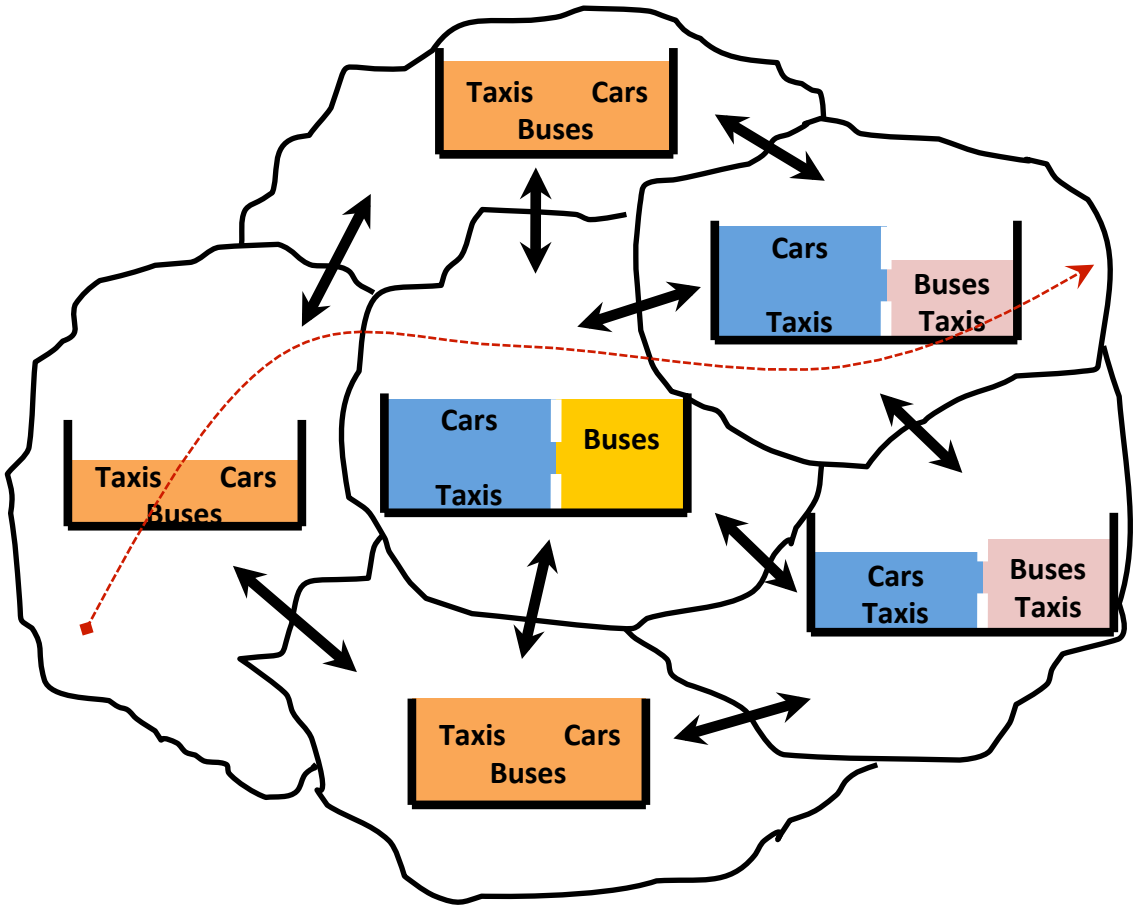
Significant Spatial correlations





20000 taxis (50M points/day) 9000 links Shenzhen 12M population

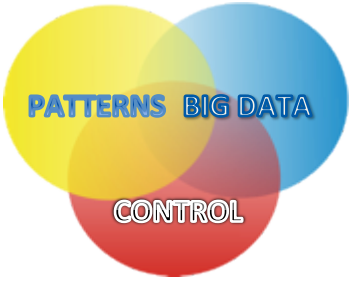
Multimodal Passenger oriented SoS Vision



Geroliminis and Boyaci (2012) – Tr. Res. Part B

Zheng and Geroliminis (2013) ISTTT20

A “System of Systems” Approach



CONTROL

Without affecting # trips per mode

By affecting # trips per mode

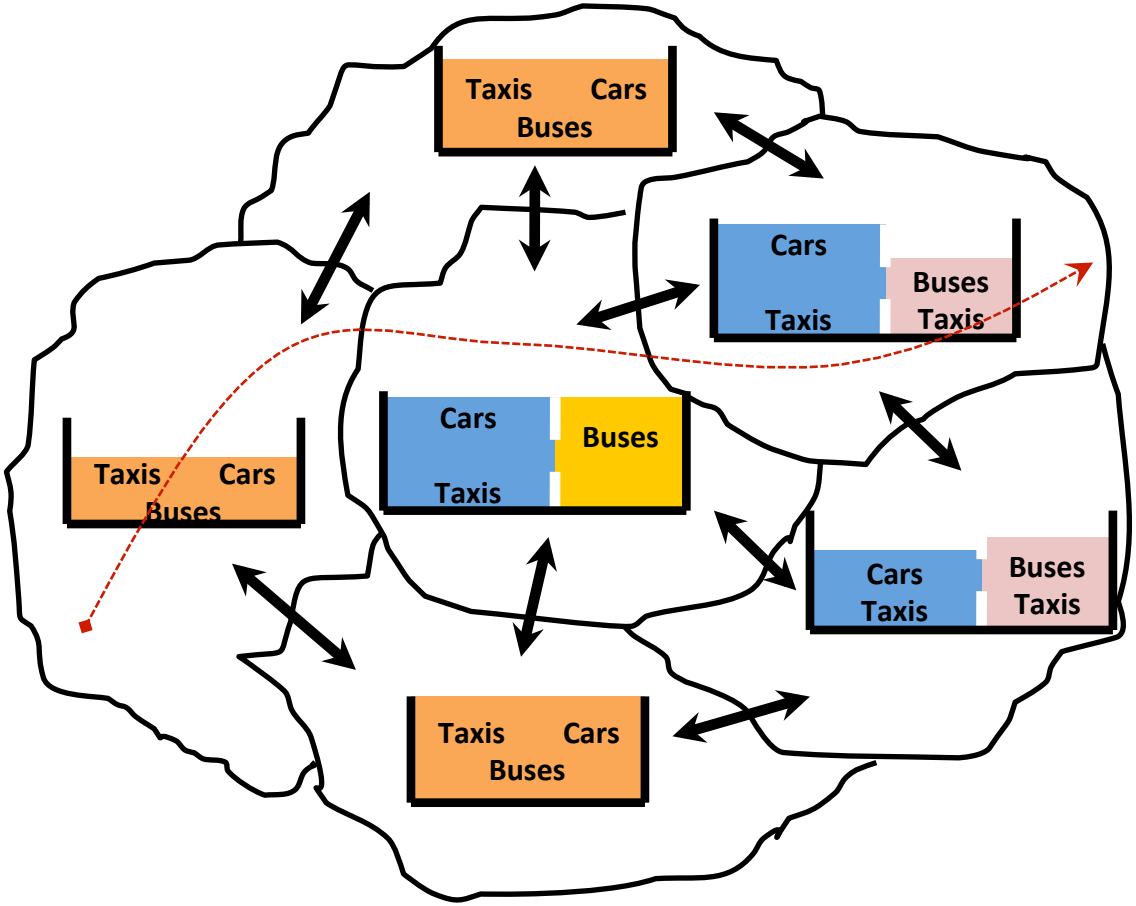
Hierarchical Signal Control

Urban Space Allocation

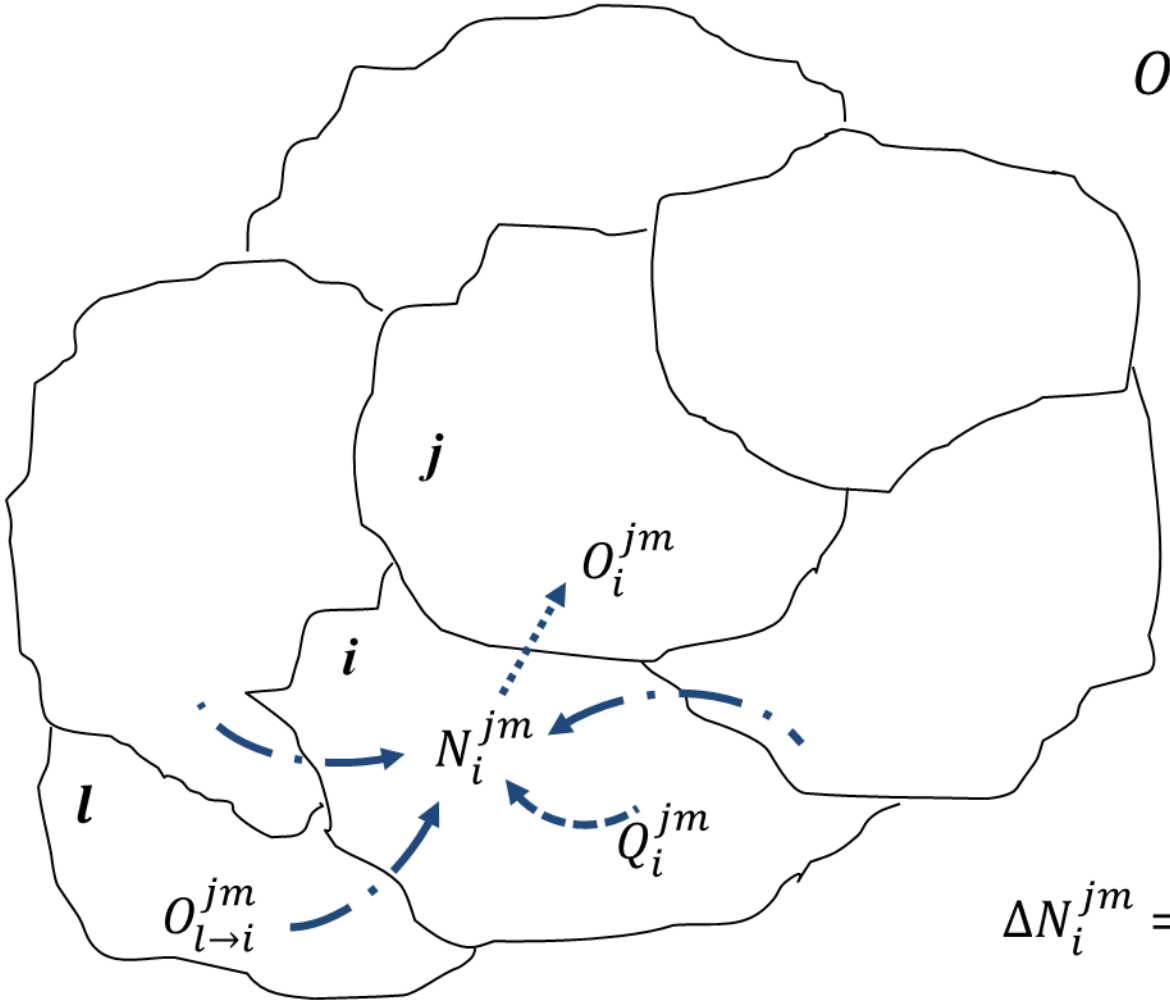
Bus Priority

Parking

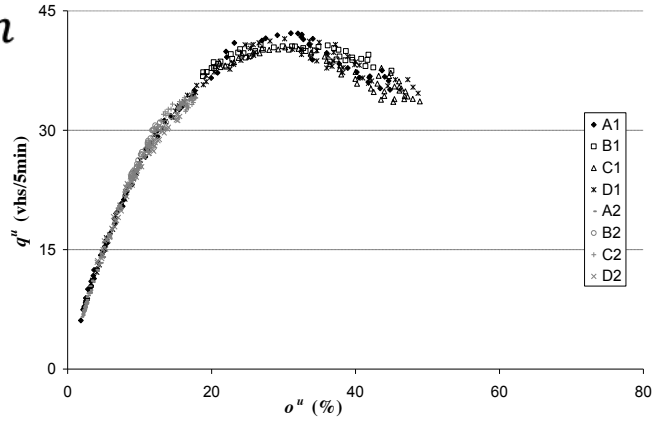
Multimodal Passenger oriented SoS Vision



System dynamics – General representation



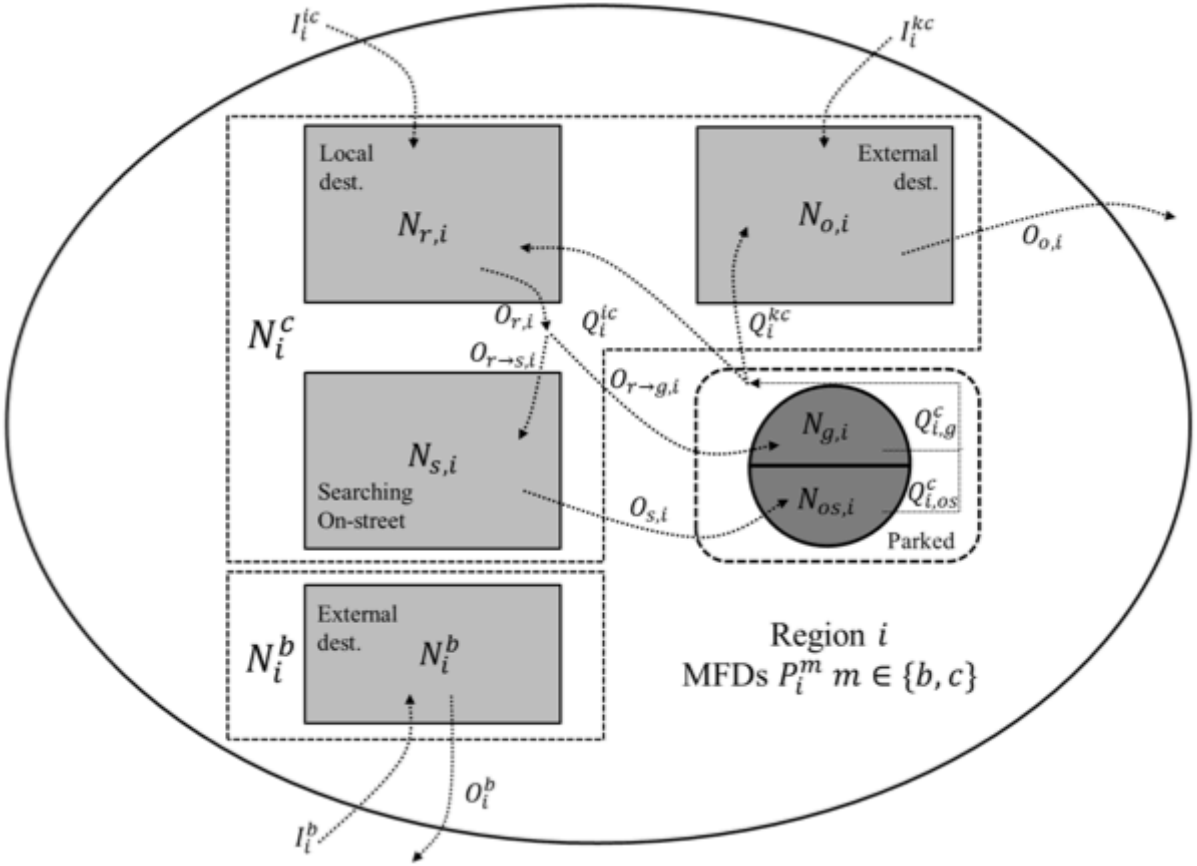
O_i^m



N_i^m

$$\Delta N_i^{jm} = Q_i^{jm} + \sum_l O_{l\to i}^{jm} - O_i^{jm}$$

Dynamics of one region with cruising



$$N_i^c(t) = \sum_x N_{x,i}(t)$$

x: vehicle activity

r: moving with internal destination

o: moving with external destination

s: cruising

$$O_{x,i}(t) = \frac{N_{x,i}(t)}{N_i^c(t)} \cdot \frac{P_i^c(t)}{l_{x,i}}$$

$$N_{r,i}(t+1) = N_{r,i}(t) + Q_i^{ic}(t) + I_i^{ic}(t) - O_{r,i}(t) \quad (7a)$$

$$N_{s,i}(t+1) = N_{s,i}(t) + O_{r\to s,i}(t) - O_{s,i}(t) \quad (7b)$$

$$N_{o,i}(t+1) = N_{o,i}(t) + Q_i^{kc}(t) + I_i^{kc}(t) - O_{o,i}(t) \quad (7c)$$

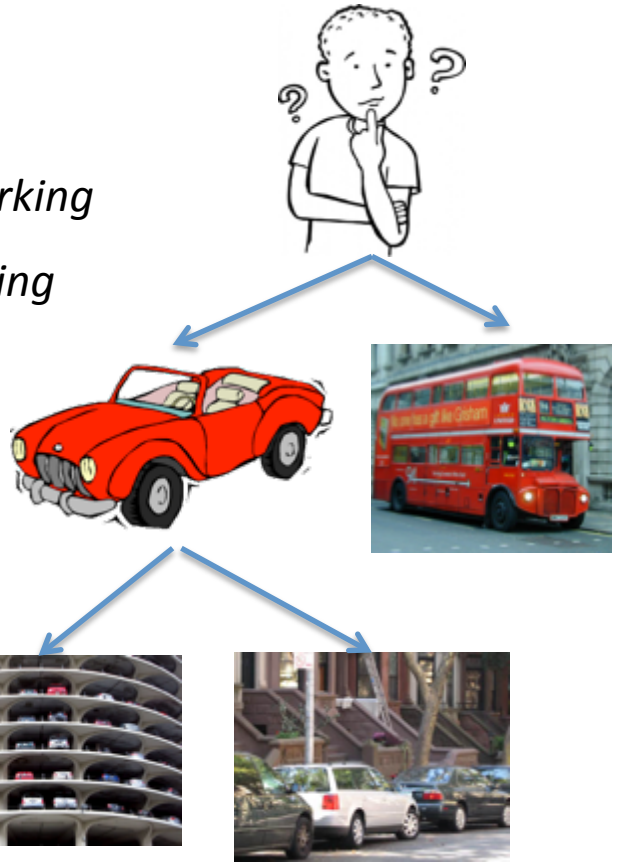
$$N_{os,i}(t+1) = N_{os,i}(t) - Q_{i,os}^c(t) + O_{s,i}(t) \quad (7d)$$

$$N_{g,i}(t+1) = N_{g,i}(t) - Q_{i,g}^c(t) + O_{r\to g,i}(t) \quad (7e)$$

Aggregated multimodal choice

- Estimated cost (mode disutility) from real-time

$$c_i^k(t) \begin{cases} \sum_{j \in i \to k} TT_c^j + p_{os}^k + T_{cru}^k & \textit{Car, on-street parking} \\ \sum_{j \in i \to k} TT_c^j + p_g^k & \textit{Car, garage parking} \\ \sum_{j \in i \to k} TT_b^j + D_b^{i \to k} + TT_{acc} & \textit{Bus} \end{cases}$$



- Nested-logit mode choice

Bus share : $\omega_i^b(t) = \dfrac{\exp(\tau_b \cdot C_i^b(t))}{\exp(\tau_c \cdot C_i^b(t)) + \exp(\tau_c \cdot C_i^c(t))}$

$$C_i^c(t) = \frac{1}{\beta} \cdot \left(\ln \exp\left(\beta \cdot C_i^{c,os}(t)\right) + \exp\left(\beta \cdot C_i^{c,g}(t)\right) \right)$$

On-Street parking share :

$$\omega_{os,i}^c(t') = \exp\left(\beta \cdot C_i^{c,os}(t')\right) / \left(\exp\left(\beta \cdot C_i^{c,os}(t')\right) + \exp\left(\beta \cdot C_i^{c,g}(t')\right) \right)$$

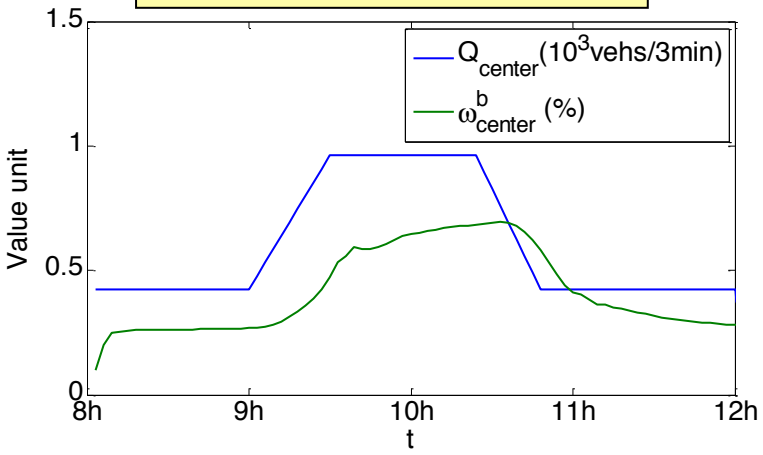
$$t' = t + TT_c$$

Pricing Schemes

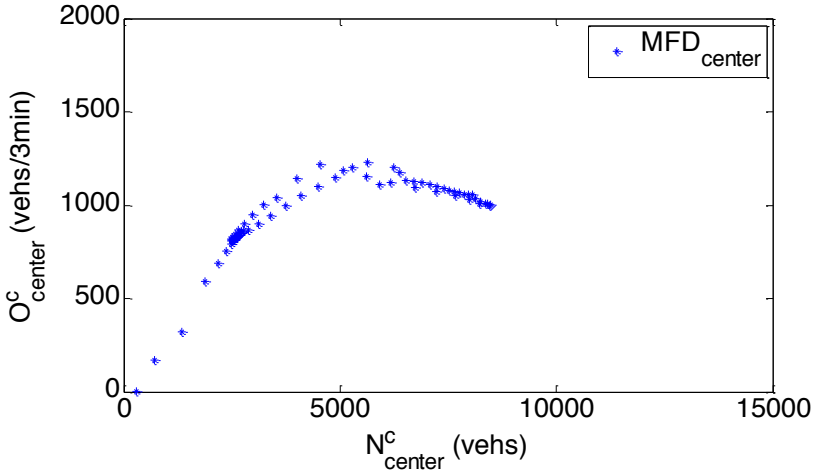
- Pbasic: constant garage pricing, on-street parking is free
- P0: Optimal constant garage and on-street pricing
- P1: System Optimum Pricing
- P2: myopic traffic-responsive pricing
- P3: Pricing competition between on-street and garage

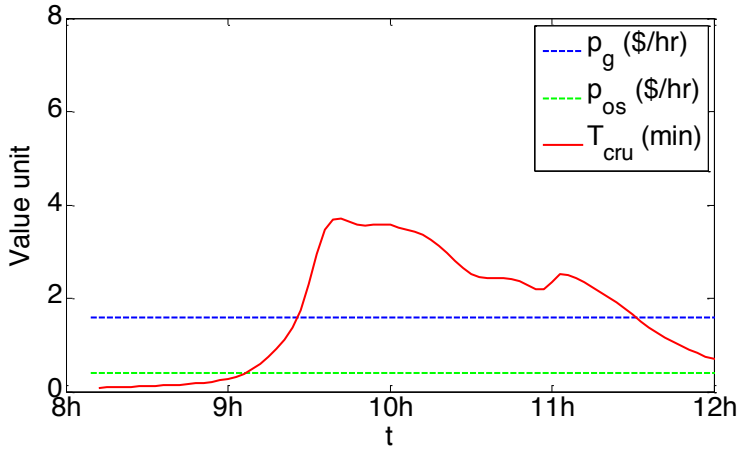
System performance: flat-rate pricing (P0)

Demand & Mode split

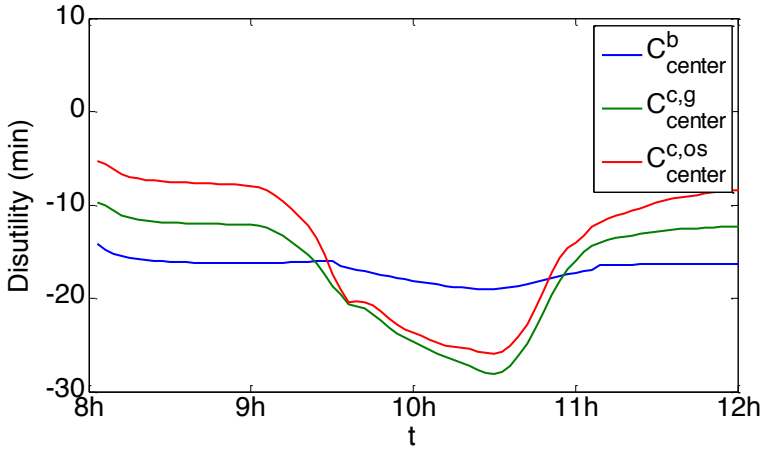


MFD center region





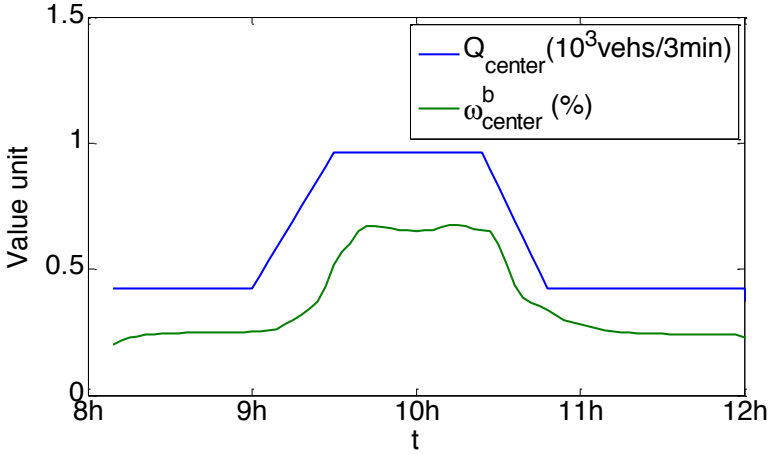
Fixed Pricing &
Resultant cruising time



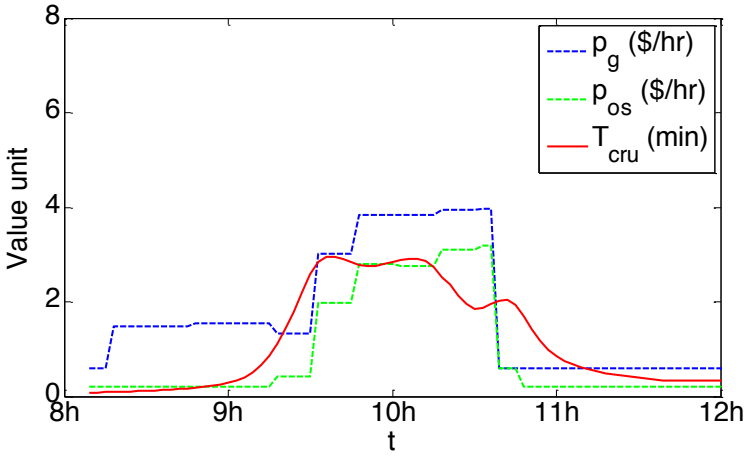
Cost per mode

System Optimum Pricing (P1):

Earlier mode shift
Higher bus share



Time-dependent Pricing &
25% less cruising time



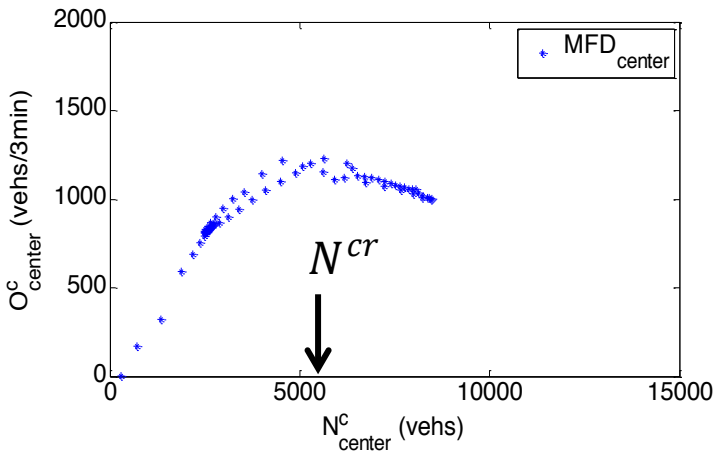
Congestion-responsive pricing (P2)

- ❑ Control objective:
- Maintain general congestion level below N^{cr}
- Maintain cruising congestion level below N^{sT}
- ❑ PI-type feedback control strategy

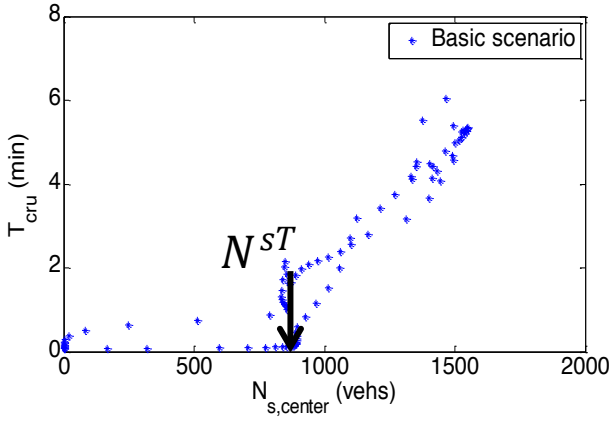
$$p_g(t+1) = p_g(t) + c_1(N^c(t) - N^{cr})$$ - Price, garage

$$p_{os}(t+1) = p_{os}(t) + c_1(N^c(t) - N^{cr}) + c_2(N_s(t) - N^{sT})$$ - Price, on-street

MFD (center region)

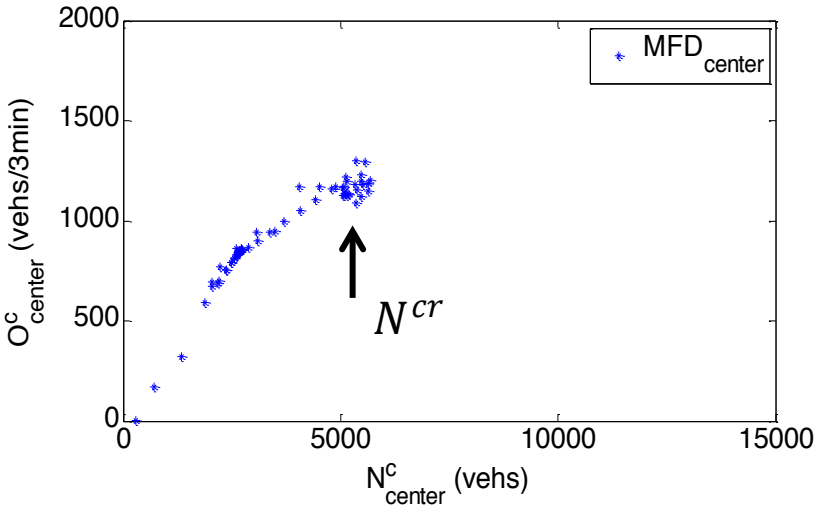


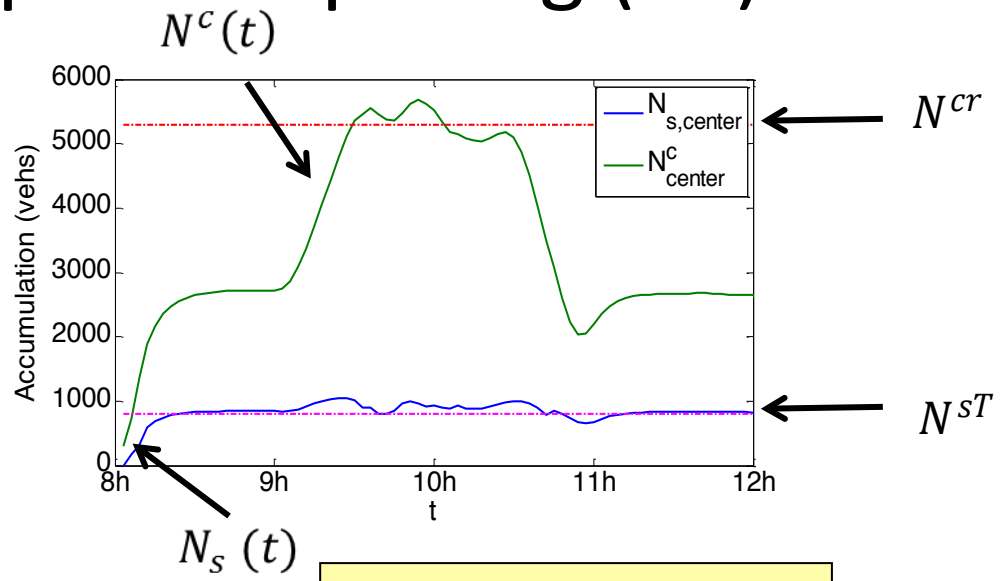
Cruising time vs. searching vehicles



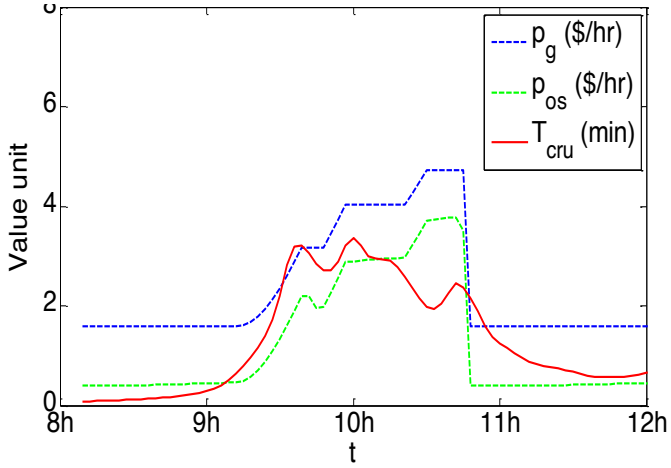
18

Congestion-responsive pricing (P2)





Number of cars over time



Pricing and cruising over time

	Saving in PHT (hrs)	Total toll (hrs)	Toll efficiency (PHT.sav/Total Toll)	Ave. cruising delay (min)
Base scenario	0	660	0	3.7
Strategy P1	1211 (2.7%)	2641	45.8%	1.9
Strategy P2	5944 (13.0%)	7207	82.5%	1.4
Strategy P3	6990 (15.5%)	5857	119.5%	1.2

Parking price competition (P3)

- Operators and objectives

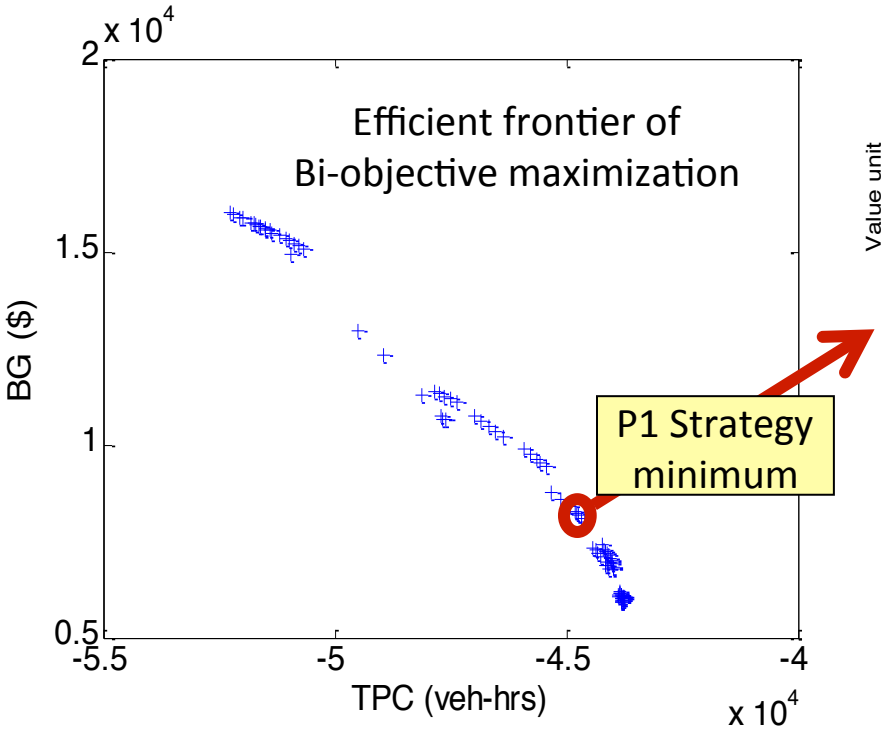
City manager : $\min_{p_{os}(t)} TPC = \sum_{t,i,m}(PHT_i^m(t) + Tos_i^c(t) + Tg_i^c(t))$

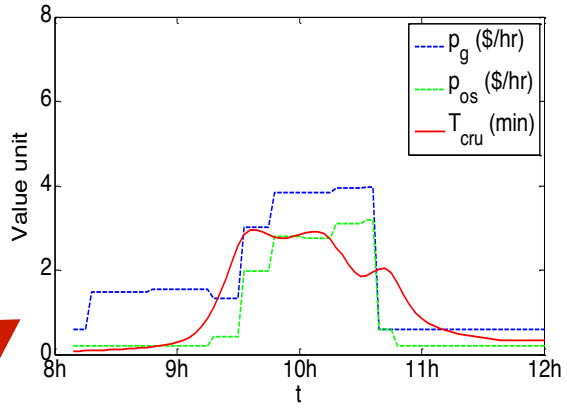
Garage company: $\max_{p_{og}(t)} BG = \sum_{t,i} Tg_i^c(t)$

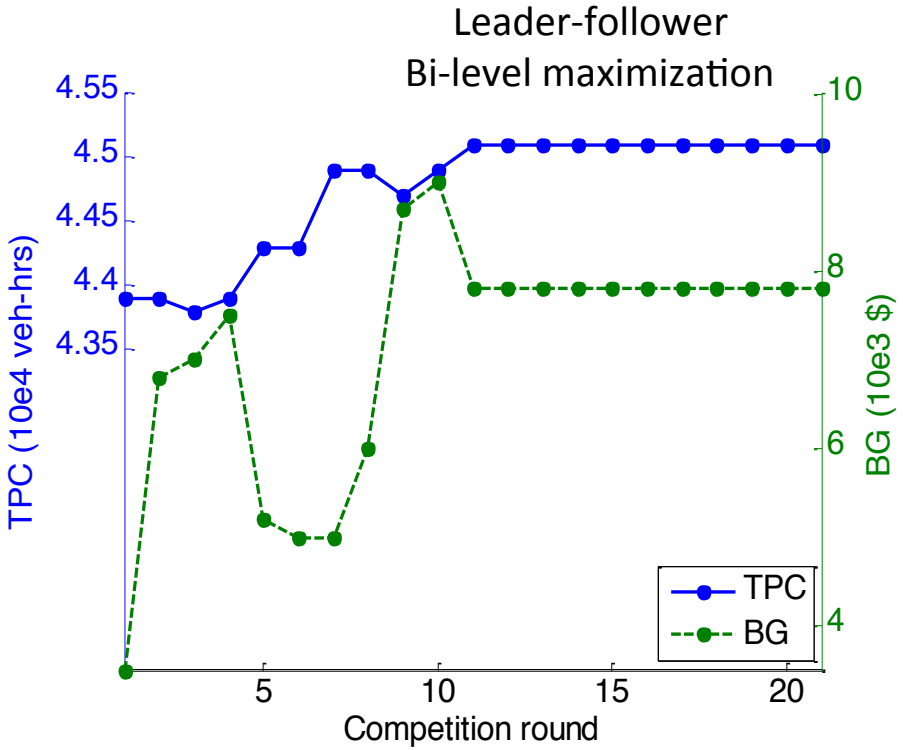
PHT: total travel time
Tos: total toll paid, on-street parking
Tg: total toll paid, garage parking

- Competition scenarios
  - Cooperation: maximize the common benefit
  - Individual maximization: change prices knowing the other's

Parking price competition – Preliminary results







RESEARCH SPONSORS

DISCUSSION

- Parking research deserves attention, as everybody needs a spot