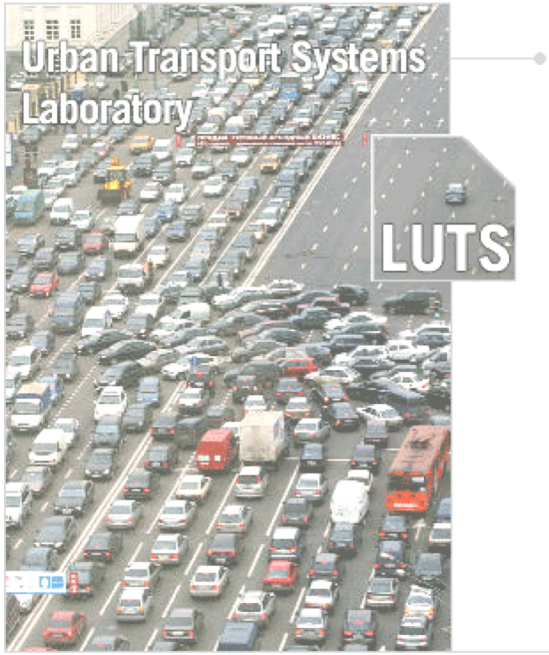

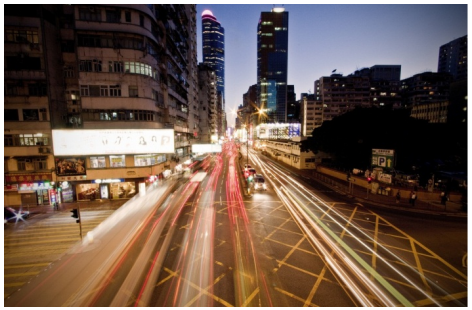

CIV-455: Transport economics

Modeling and Optimization of multimodal urban networks with MFD

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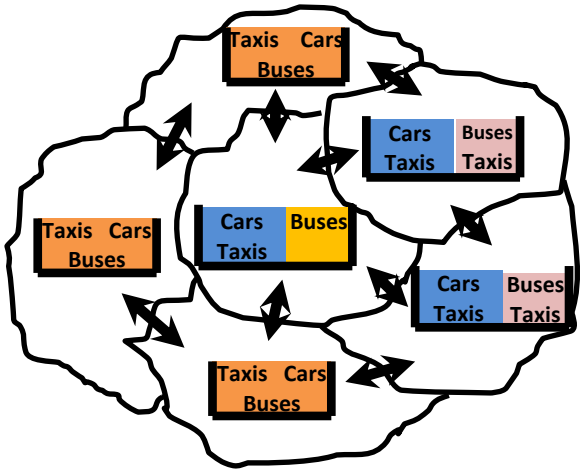
EPFL ENAC
ENVIRONNEMENT NATUREL, ARCHITECTURAL ET CONSTRUIT

LUTS

M³ : Multimodal Modeling and Management

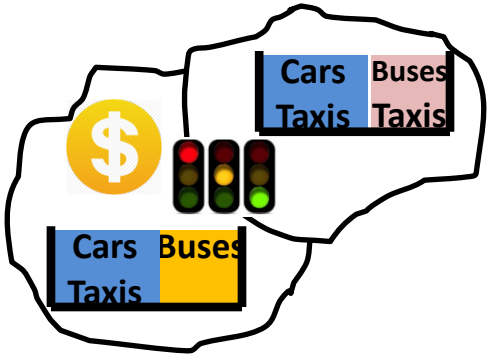
Multimodal & Management

Modal competition
Passenger mobility

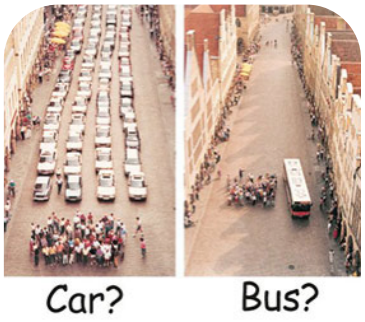


Space competition

Mode conflict



Smart controls



Passenger measures

Parking limitation

Outline

Develop network traffic models and control approaches to increase mobility and multimodality

Multimodal Multi-region Road Space Allocation

Three-dimensional MFD Mixed Bi-modal Networks

Multimodal Network with Limited Parking and Pricing

Special treatment of ride-pooling services

Outline

Part III

Zheng and Geroliminis (2016), *Trans. Res. Part B*

Multimodal Urban Network with Limited Parking and Pricing

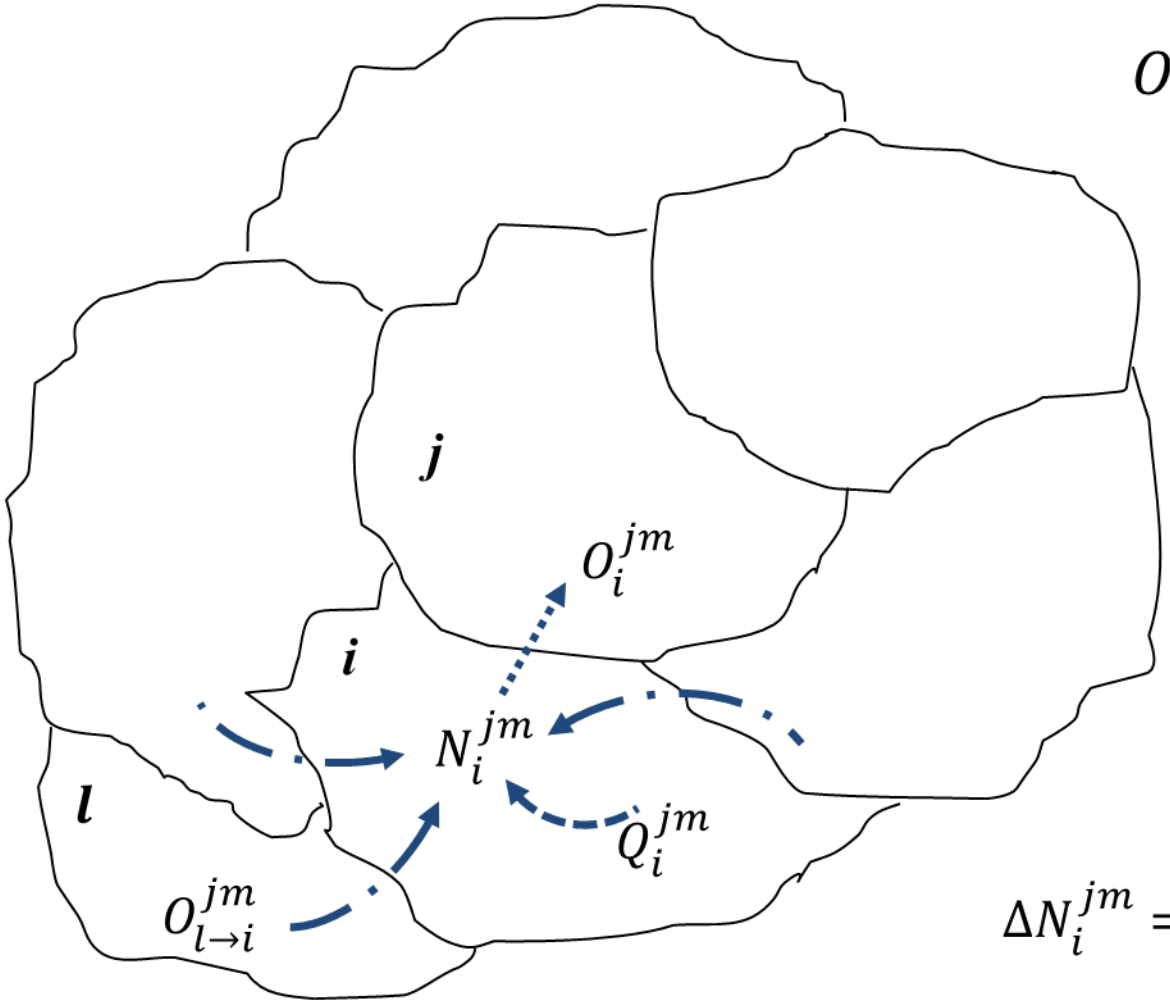
Motivations:

- Cruising-for-parking and delay
- Parking choices: on-street vs. garage
- Dynamic parking pricing
- System-optimal pricing and competition

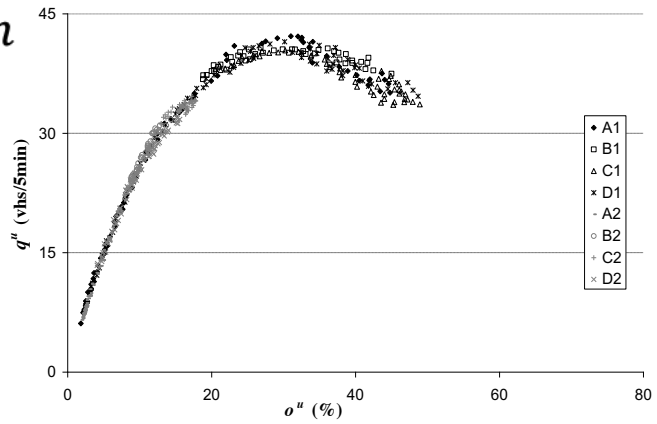
Limited downtown parking in SF

Real-time parking info

System dynamics – General representation



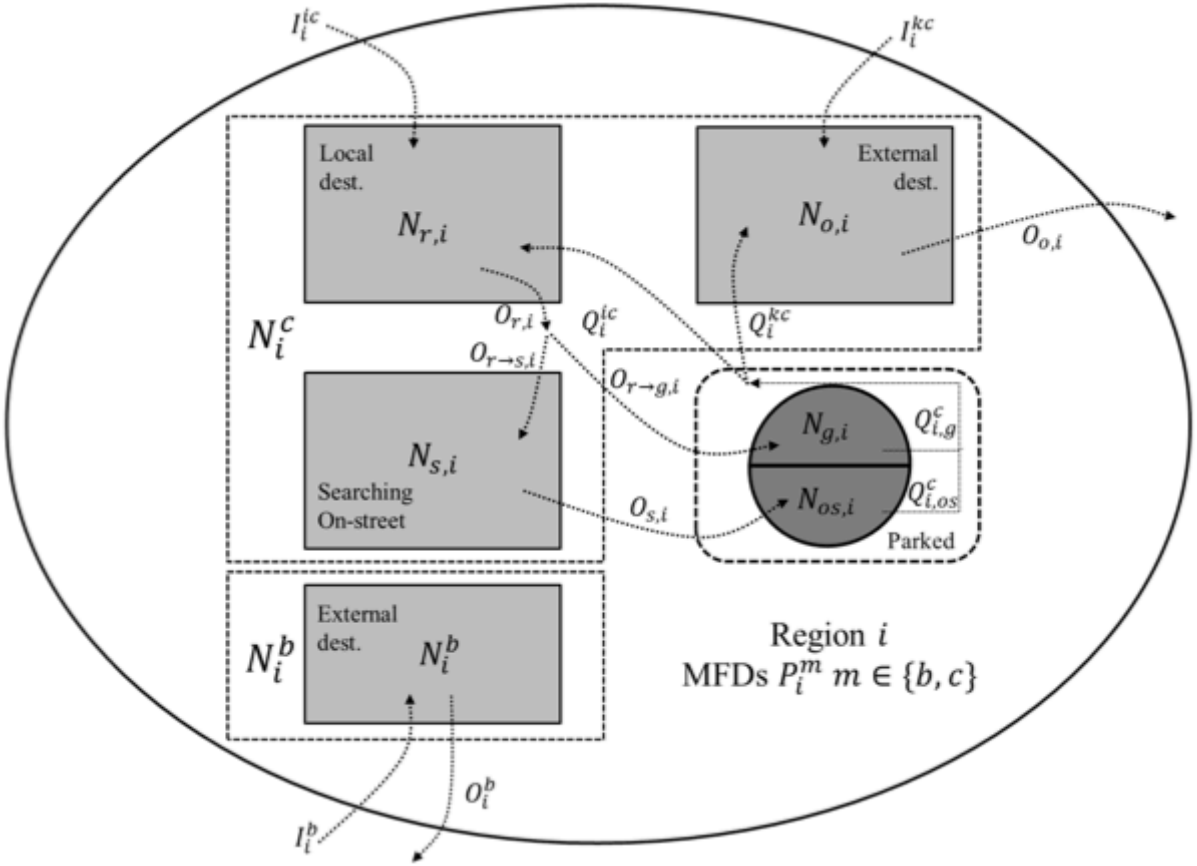
O_i^m



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

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

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

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

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

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

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

Methodology – Bi-modal with parking choices

- The disutility of traveling from region i to final destination region k

$$\begin{cases} \sum_{j \in i \to k} TT_c^j + p_{os}^k + T_{cru}^k & \text{- Car} \begin{cases} \text{on-street (limited)} \\ \text{garage} \end{cases} \\ \sum_{j \in i \to k} TT_c^j + p_g^k & \\ \sum_{j \in i \to k} TT_b^j + c_b^j & \text{- Bus} \end{cases}$$

- Nested Logit mode choice split

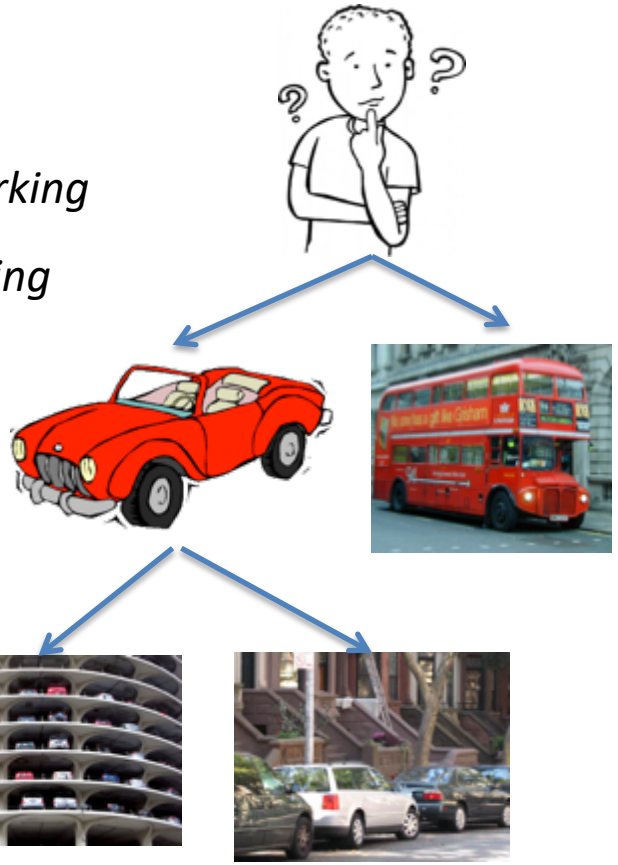
TT_m^j: travel time of using mode m in region j
p_x^k : the parking price of using parking facility x at the final destination region k
T_{cru}^k : the cruising time for on-street parking at the final destination region k
c_b^j : other disutility of using bus in region j

(time index t is omitted)

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

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

On-Street parking share :

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

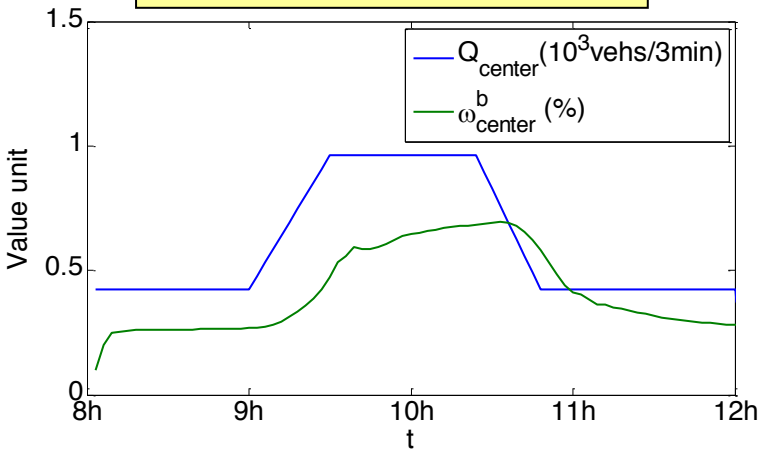
$$t' = t + TT_c$$

Pricing Schemes

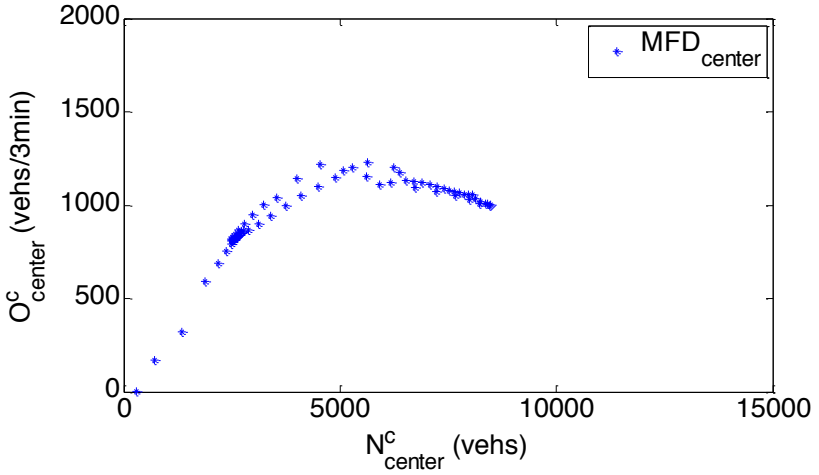
- Pbasic: constant garage pricing, on-street parking is free
- P1: Optimal constant garage and on-street pricing
- P2: myopic traffic-responsive pricing
- P3: System Optimum Pricing
- P4: Pricing competition between on-street and garage

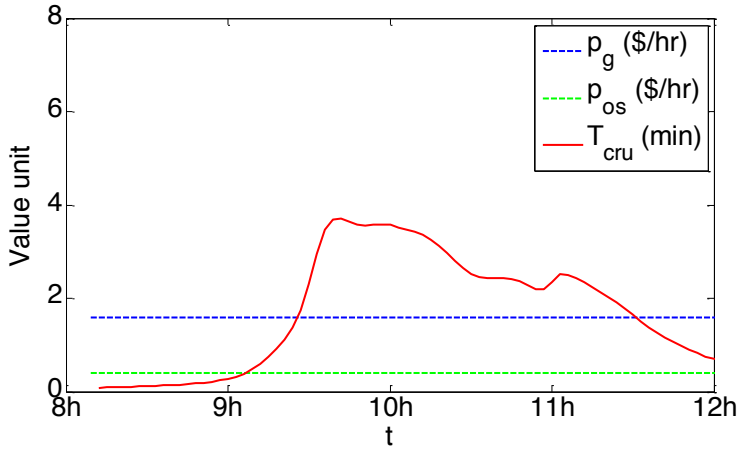
System performance: flat-rate pricing (P1)

Demand & Mode split

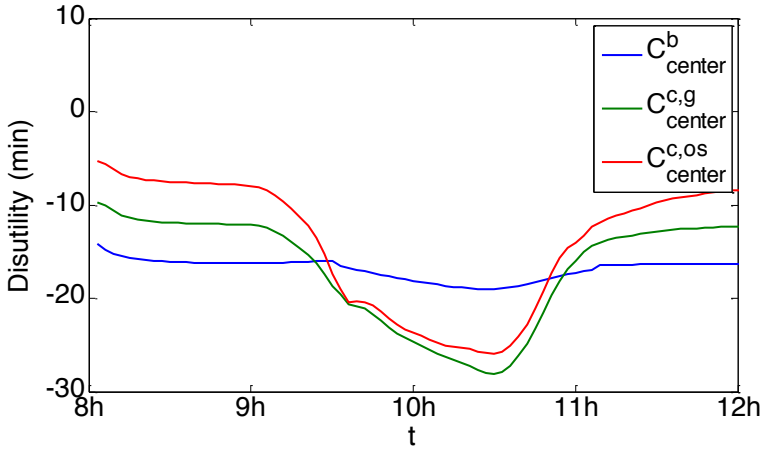


MFD center region





Fixed Pricing &
Resultant cruising time

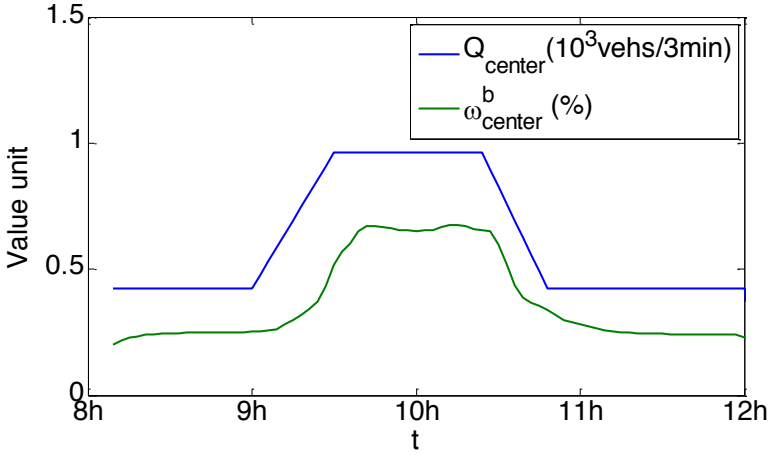


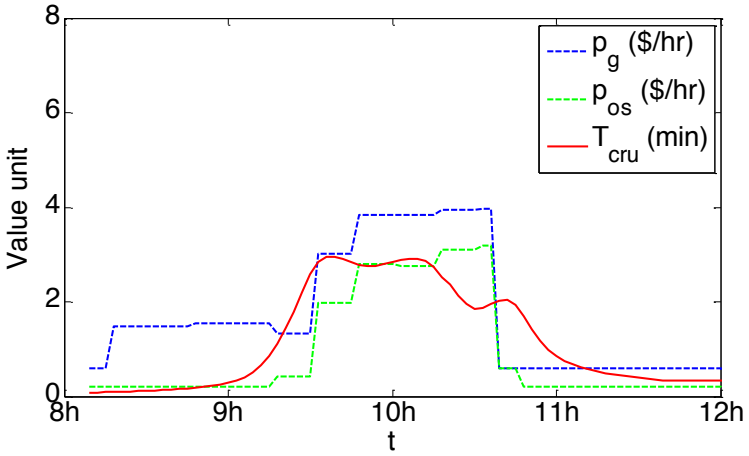
Cost per mode

System Optimum Pricing (P3)

Earlier mode shift
Higher bus share

Time-dependent Pricing &
25% less cruising time





$$\min_{p_{os}(t),p_g(t)} Z = \sum_{t,i,m} TPC_i^m(t)$$

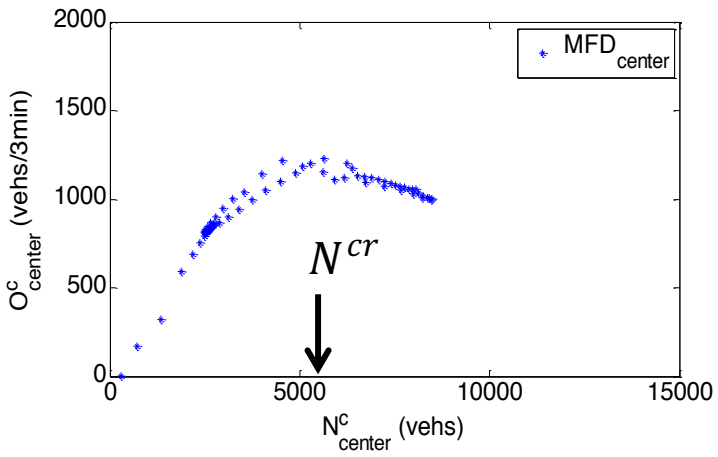
Congestion-responsive pricing (P2)

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

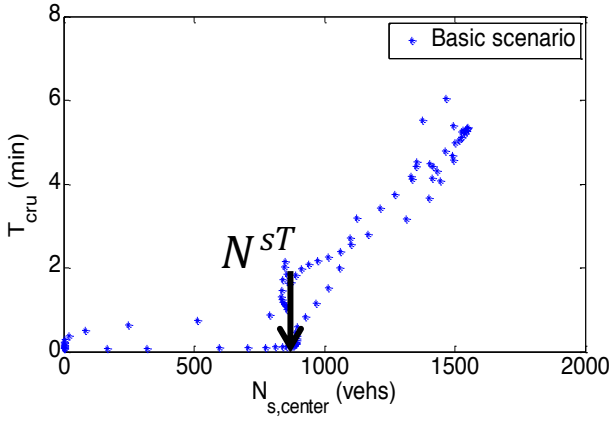
$$p_g(t+1) = p_g(t) + c_1(N^c(t) - N^{cr})$$ - Price, garage

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

MFD (center region)



Cruising time vs. searching vehicles



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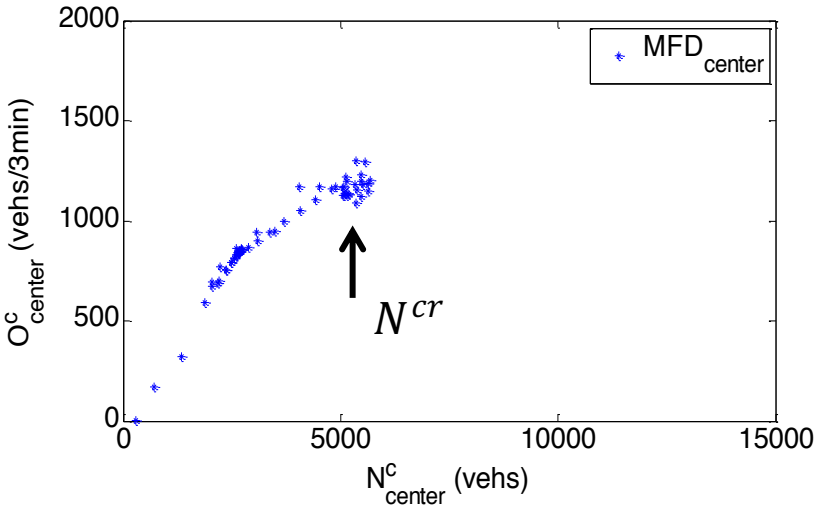
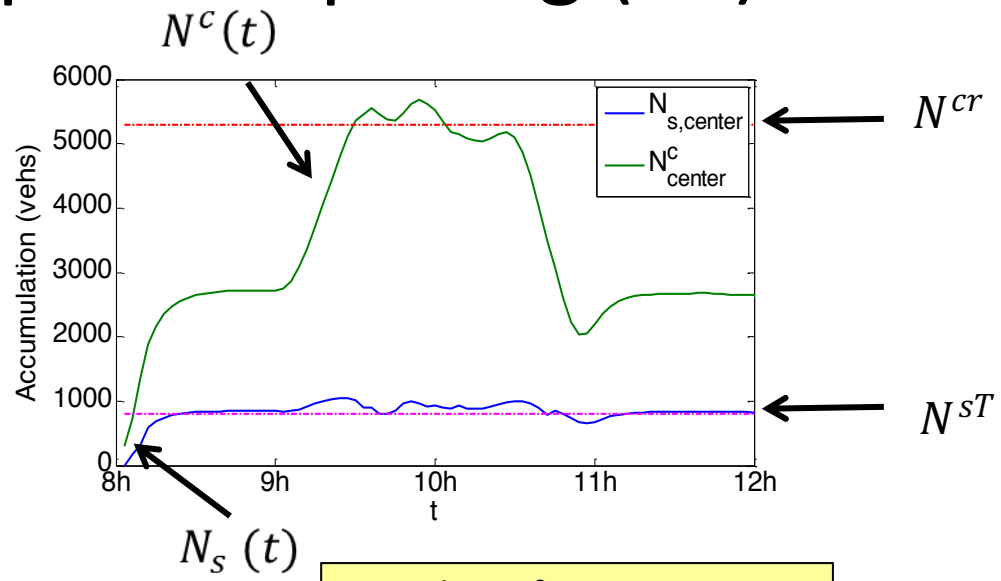
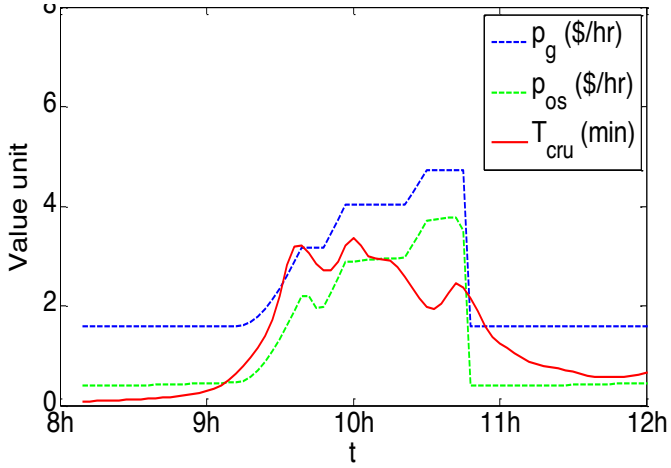
Congestion-responsive pricing (P2)





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 (P4)

- 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 pricing competition

- ***City*** operates <u>on-street</u> parking to minimize total user cost

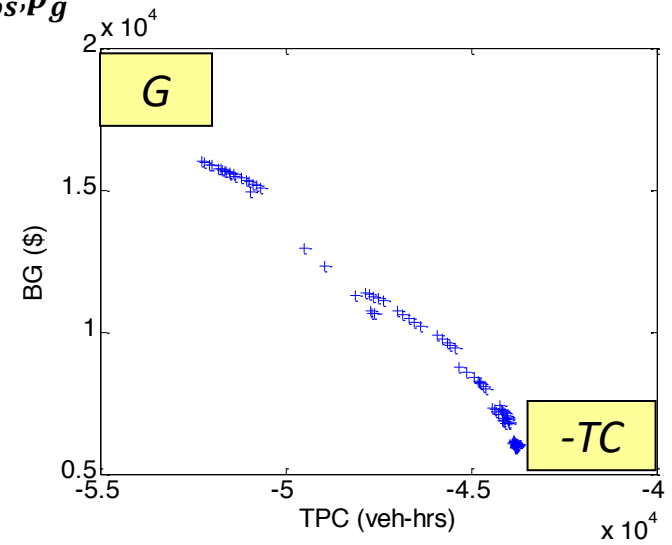
$$\min_{p_{os}^i} TC = \sum_{m,t,i}(PHT + Onstreet\ \$\$ + Garage\$\$)$$

- ***Real-estate firm*** operates <u>garage</u> parking to maximize revenue

$$\max_{p_g^i} G = \sum_{m,t,i} Garage\ \$\$$$

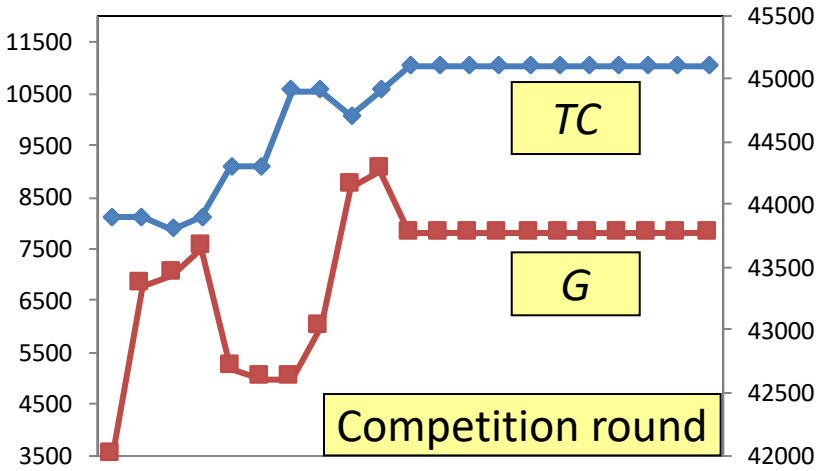
- Efficient frontier of Cooperative pricing

$$\max_{p_{os}^i, p_g^i} Z = \alpha \cdot (-TC) + (1-\alpha) \cdot G$$



- Converging behavior of Competitive pricing

A bi-level pricing adjustment



DISCUSSION

- Parking research deserves attention, as everybody needs a spot