Online auction Designs for Traffic Intersection Operations

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Main idea

- Transportation systems normally work on a FIFO rule.
- FIFO is *the fairest rule* but may not the most efficient (efficient = maximum satisfaction from users)
- There may be an efficiency loss due to lack of use of information.
- Smartphones: elicit this private information from drivers on real time and change this FIFO rule.
- New challenges: efficiency, fairness and the role of regulation.
- Two examples: vehicle position in highway and traffic lights.

Mechanism Design

- Mechanism definition: a mechanism is a game form that induces a Bayesian game on a set of agents.

- Purpose: elicit private information from agents to reach a particular goal: efficiency or optimality.
  - Efficient mechanism: total welfare is maximized.
  - Optimal mechanism: revenue extracted from agents is maximized.

- A direct mechanism $D = (k, p)$
  - Allocation function $k: \Theta \to K$
  - Payment function $p: \Theta \to \mathbb{R}$
  - Θ is the space of players' types (private information)

Mechanism Design: Incentive Compatibility constraints

- **Incentive compatibility (IC)**: truth-telling is an equilibrium of the induced game, condition on other agents telling the truth as well.
  - Dominant Strategy Incentive Compatibility (DSIC)
  - Bayesian Incentive Compatibility (BIC)

	Economists	CS/Engineers
Use of priors	They prefer them (BIC)	Real implementability (DSIC)
Approach	Calculus based	Algorithmic
Comp. Efficiency	No primary goal	Primary goal

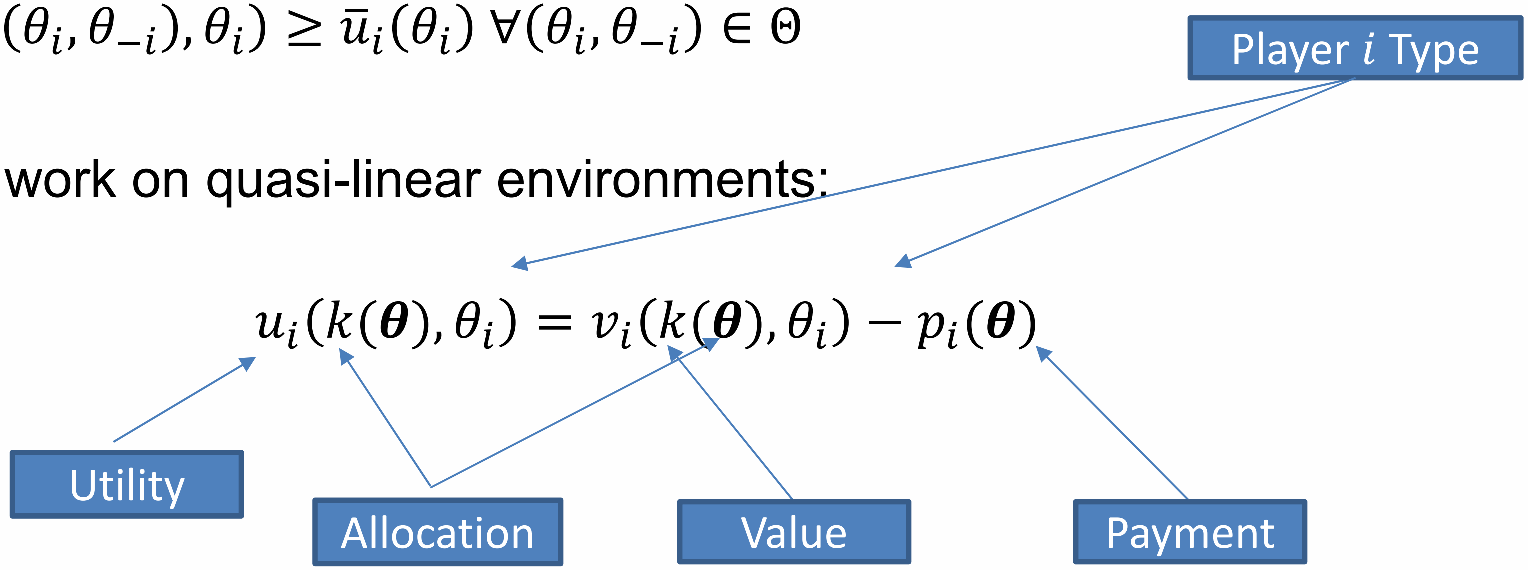
Mechanism Design: IR constraints and environments

- Individual rationality (IR): each agent, despite other agents' reports, is better off to tell the truth than stay out.

$$u_i(k(\theta_i, \theta_{-i}), \theta_i) \geq \bar{u}_i(\theta_i) \ \forall (\theta_i, \theta_{-i}) \in \Theta$$

- We'll work on quasi-linear environments:

$$u_i(k(\boldsymbol{\theta}), \theta_i) = v_i(k(\boldsymbol{\theta}), \theta_i) - p_i(\boldsymbol{\theta})$$



The Vickrey-Clarke-Groves Mechanism

The VCG mechanism is:

$$k^*(\theta) = \underset{k}{\operatorname{argmax}} \sum_i v_i(k(\theta), \theta_i)$$

$$p_i(\theta) = \sum_{j \neq i} v_j(k^*_{-i}(\theta), \theta_j) - \sum_{j \neq i} v_j(k^*(\theta), \theta_j)$$

The VCG is DSIC, ex-post IR. But problems…

1. Collusion
2. Not budget balanced
3. Shill bidding vulnerable

Introduction of current research

Problem:

- Current traffic light systems do not account for VoT heterogeneity.
- There is an efficiency loss.
- Smartphones can allow us to elicit this private information from drivers on real time.

Proposed solution:

- Value exchange traffic light system.
- Aiming to improve the efficiency of urban traffic networks, not to extract revenue from agents.

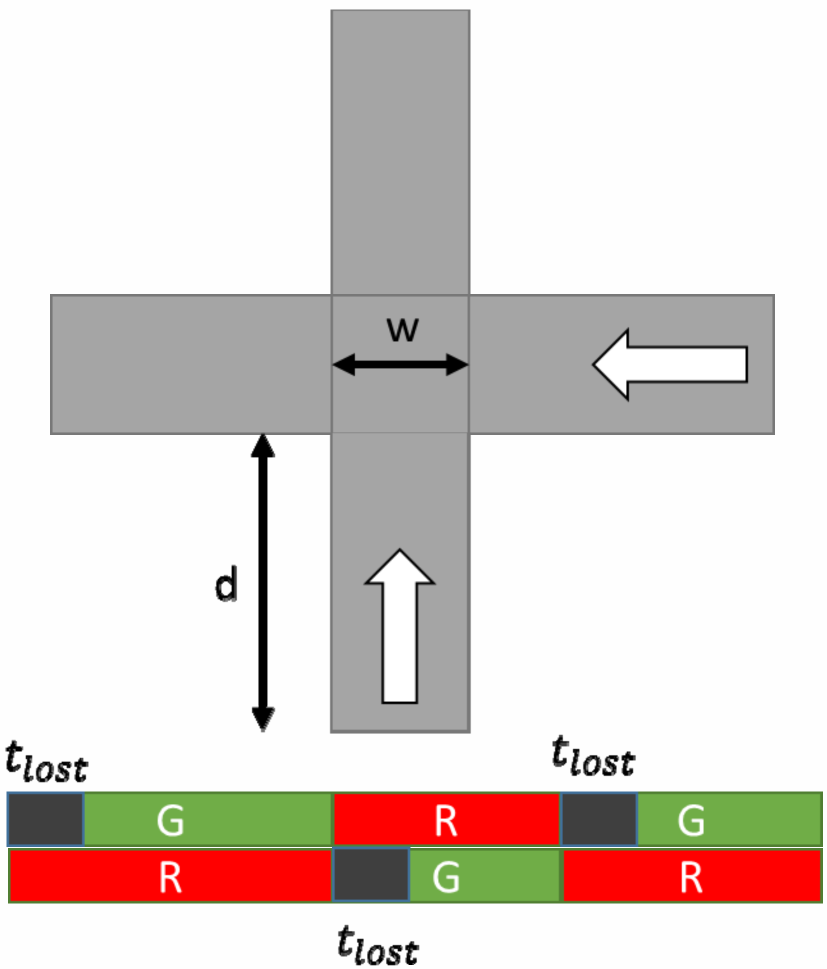
Literature review

- Mostly based on reservation systems for self-driving vehicles (Dresner and Stone, 2004) (Carlino et al., 2013)
- Simulation on large cities, or intersection scale simulation without clear theoretical-based Car Following model.
- They don't address the microeconomic aspects of intersections.
- Desired mechanism properties not thoroughly checked.
- Some research groups focused on AI protocols (Schepperle and Böhm, 2008)

Problem configuration

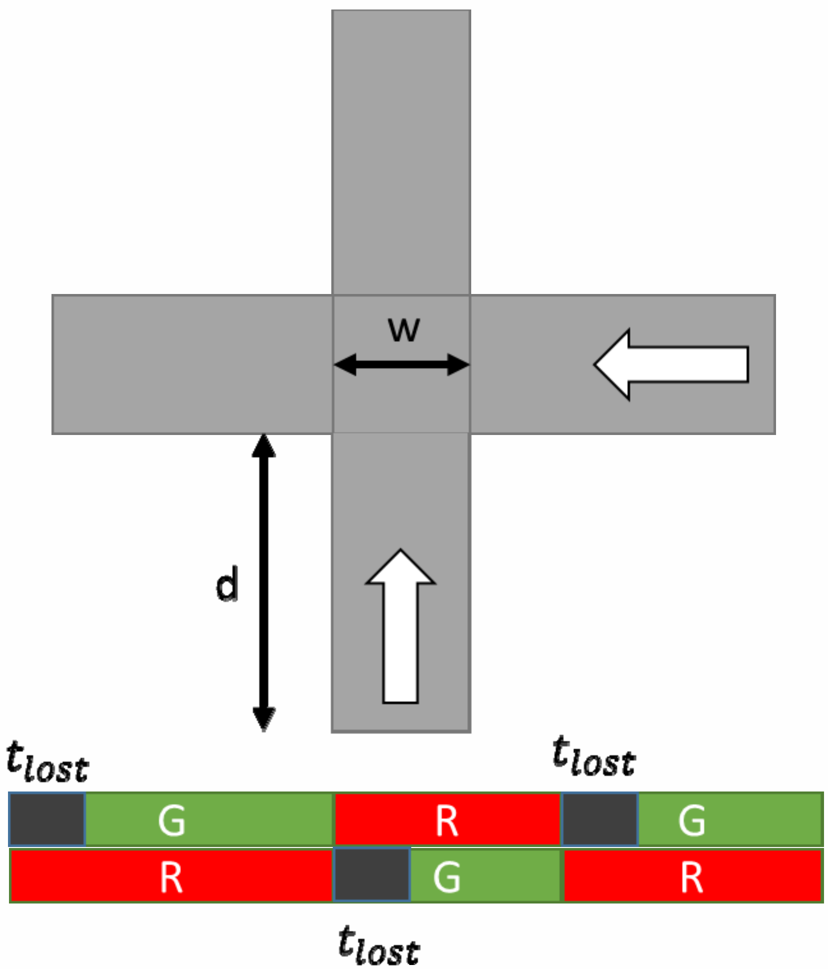
- Mechanism modelling of a single isolated intersection.
- Cycle-free traffic light.
- VCG mechanism.
- Allocations are phases (winning approach + phase duration).
- Coded on MATLAB.

Problem configuration (I)



- 2 phase one-way intersection
- The mechanism knows about players after being close than $d = 500ft$. Approaching speed = 40mph.
- Intersection has a width $w = 120ft$.
- There is a t_{lost} at every start of GREEN.
- Vehicle trajectories modelled through Newell's CFM.
- The bidding agents are the two approaches

Problem configuration (II)

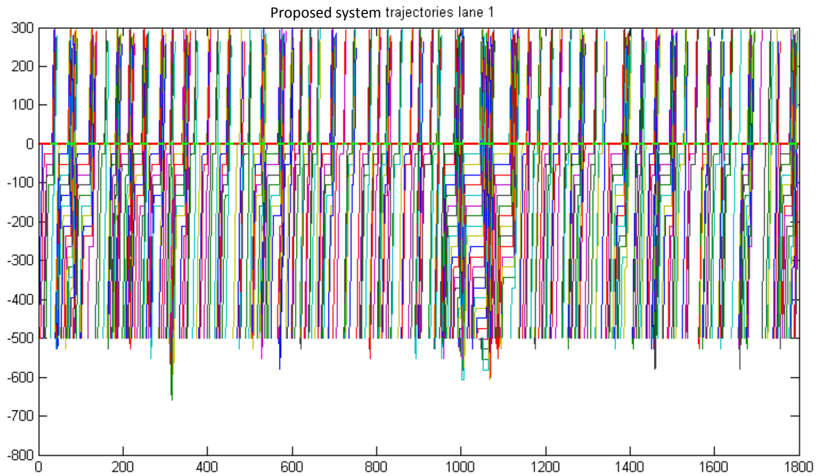


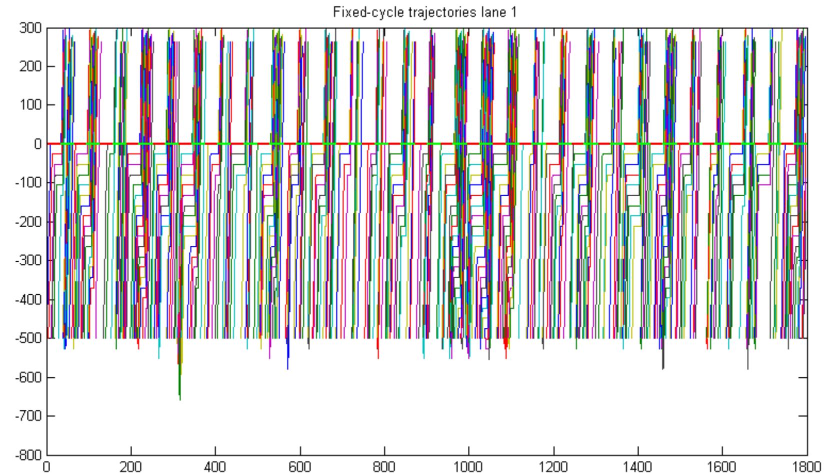
- First step: decide winning approach k^*
- $k^* = \operatorname{argmin}\{ c_1^{win} + c_2^{lose}, c_1^{lose} + c_2^{win}\}$
- $c_l^{win} = \sum_{i \in I} \theta_i ttime_i^{(l\ wins)}$
- $c_l^{lose} = \sum_{i \in I} \theta_i ttime_i^{(l\ loses)}$
- Next phase and prices are decided at the end of the current phase.
- Length of next outcome: time required for the winning approach cars to safely cross the intersection.
- $p_l(\boldsymbol{\theta}) = \sum_{j \neq l} v_j(k_{-l}^*(\boldsymbol{\theta})) - \sum_{j \neq l} v_j(k^*(\boldsymbol{\theta}))$
- Then the price per approach is divided by the number of drivers in that approach.

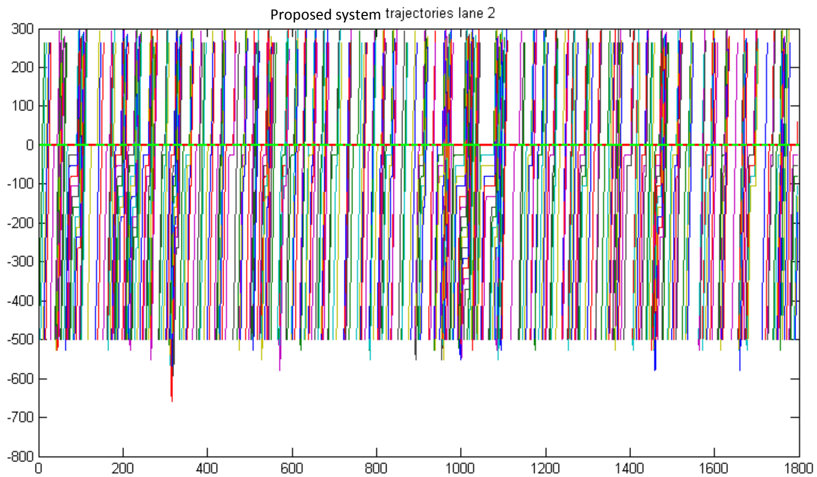
Results

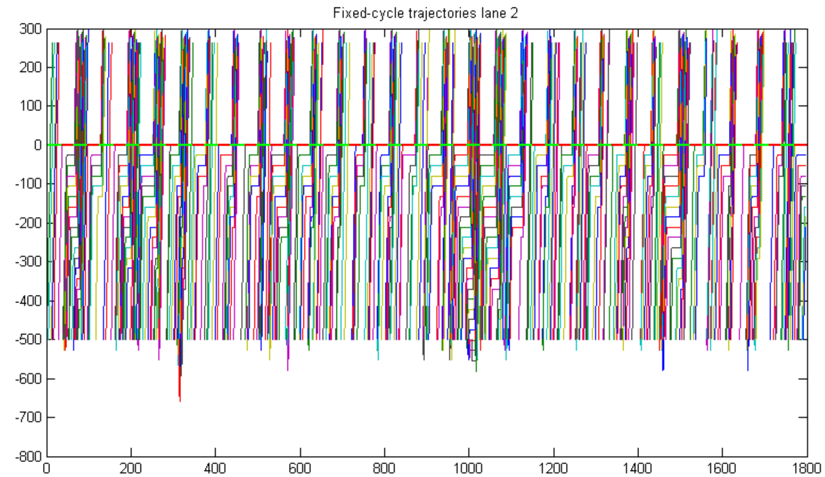
- Two different types of arrivals will be tested:
  - Uniform
  - Poisson
- Sensitivity analysis based on arrival flow, ratio of values of time per approach.
- Arrivals are symmetric (perfect conflict, worst case analysis): when flows are the same at both approaches.
- Computation of prices and agents' utilities
- Proposed system is compared to an optimal fixed-cycle traffic light
- $C = \frac{2 * t_{lost}}{\left(1 - \frac{V_C}{PHF(v/c)(3600/h_{sat})}\right)}$ $t_{lost} = 3s$ $PHF = 1$ $v/c = 1$ $h_{sat} = 2.3s$
- If calculated C is < 30, C will be set to 30s.

Results: Poisson case. Trajectories(ft & s) $\theta_2 = 20, q = 720\ veh/h$.

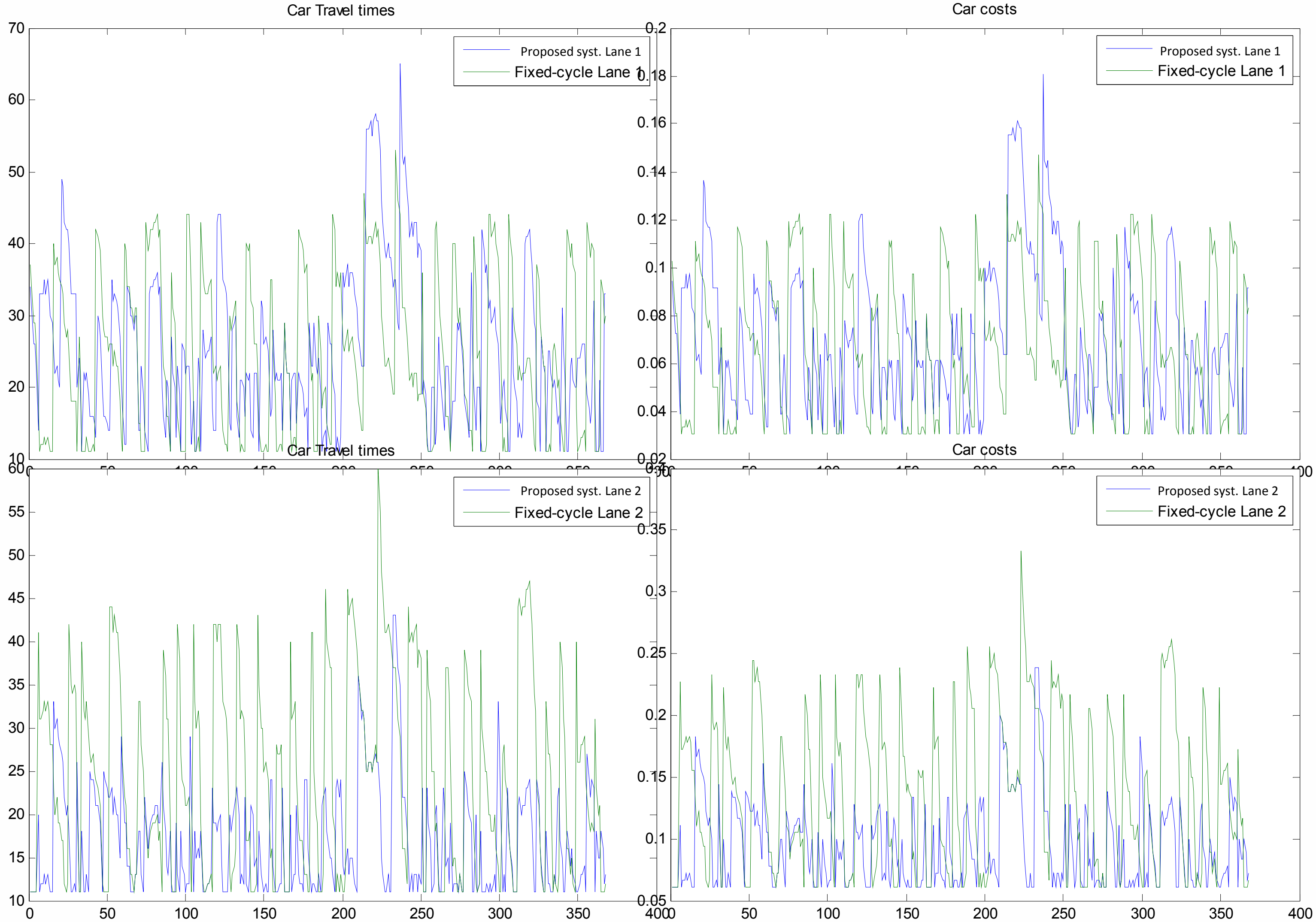






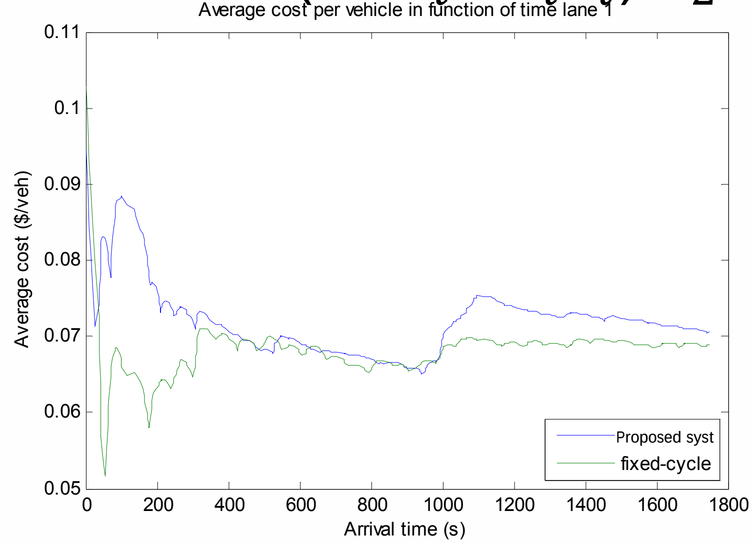


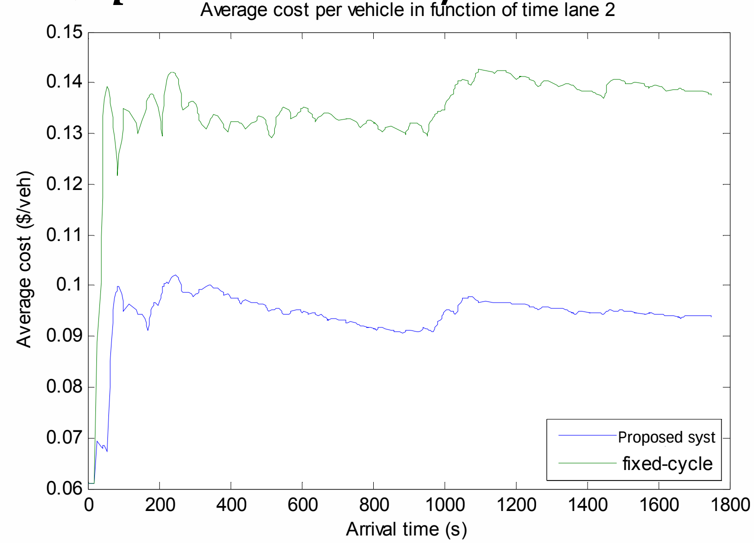
Results: Poisson case. Travel times and valuations ($cost_i = \theta_i v_i$) $\theta_2 = 20, q = 720\ veh/h$.

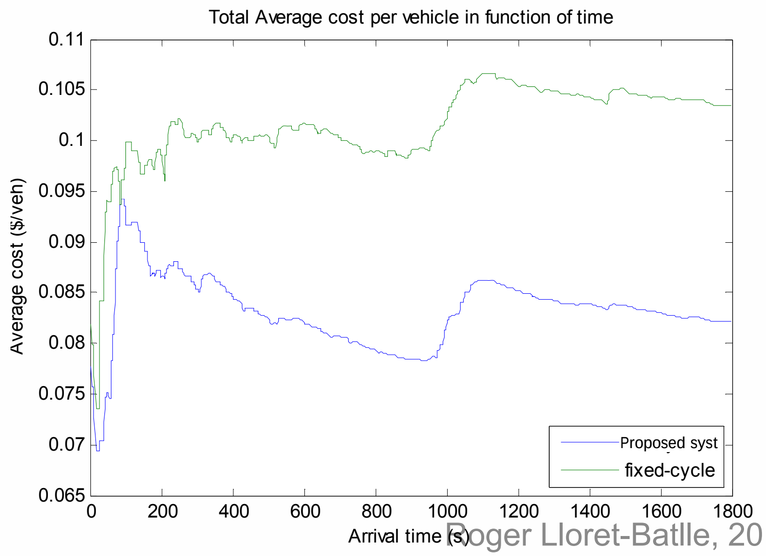


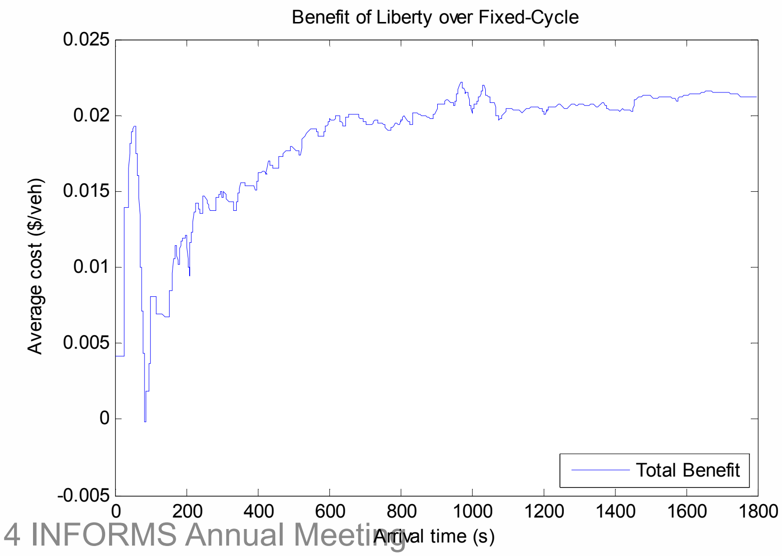
Results: Poisson case. Travel times and valuations

$$(cost_i = \theta_i v_i)\ \theta_2 = 20, q = 720\ veh/h.$$

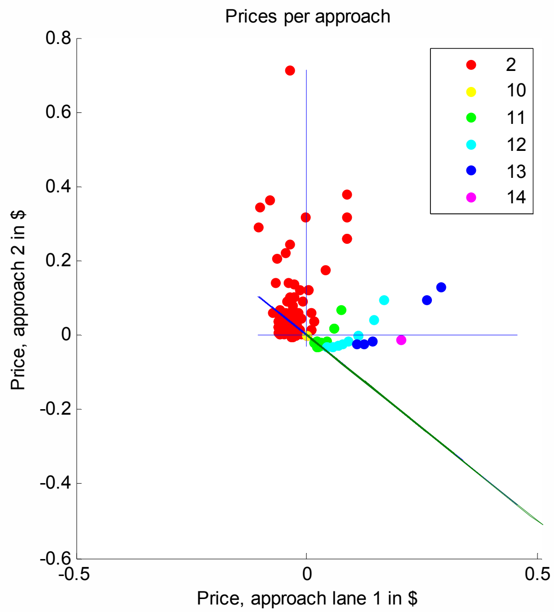


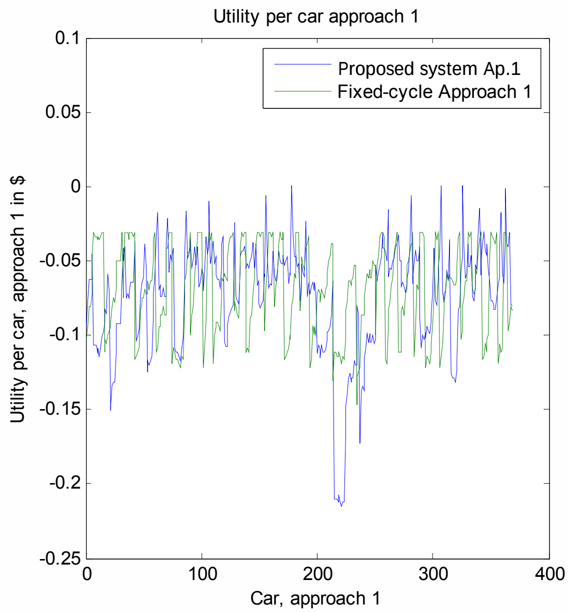


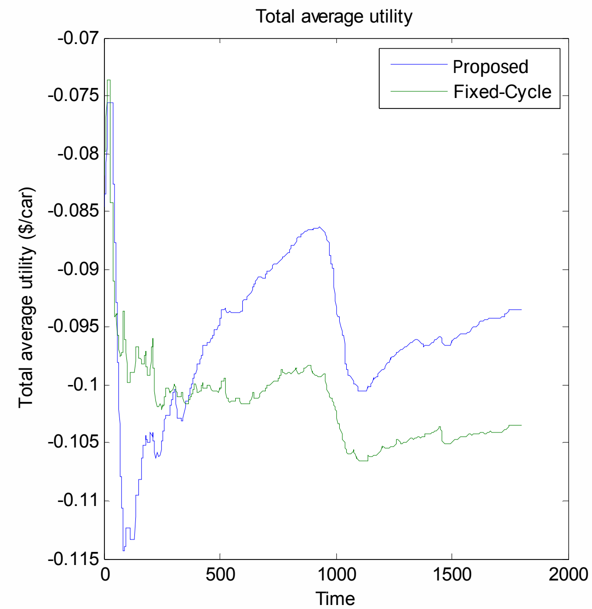


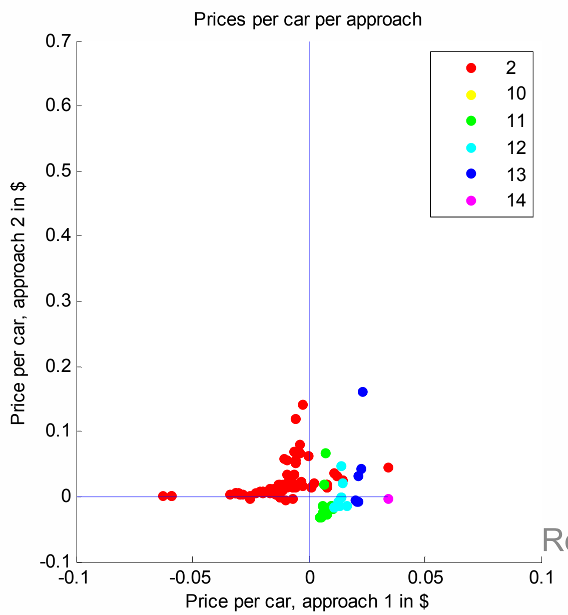


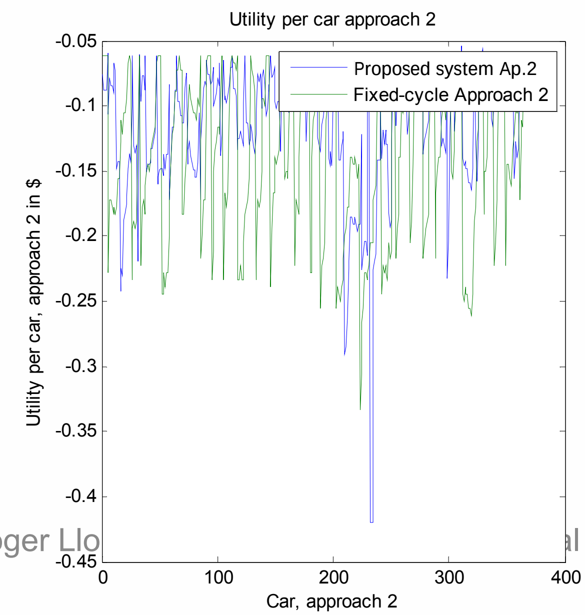
Results: Poisson case, prices and u's.



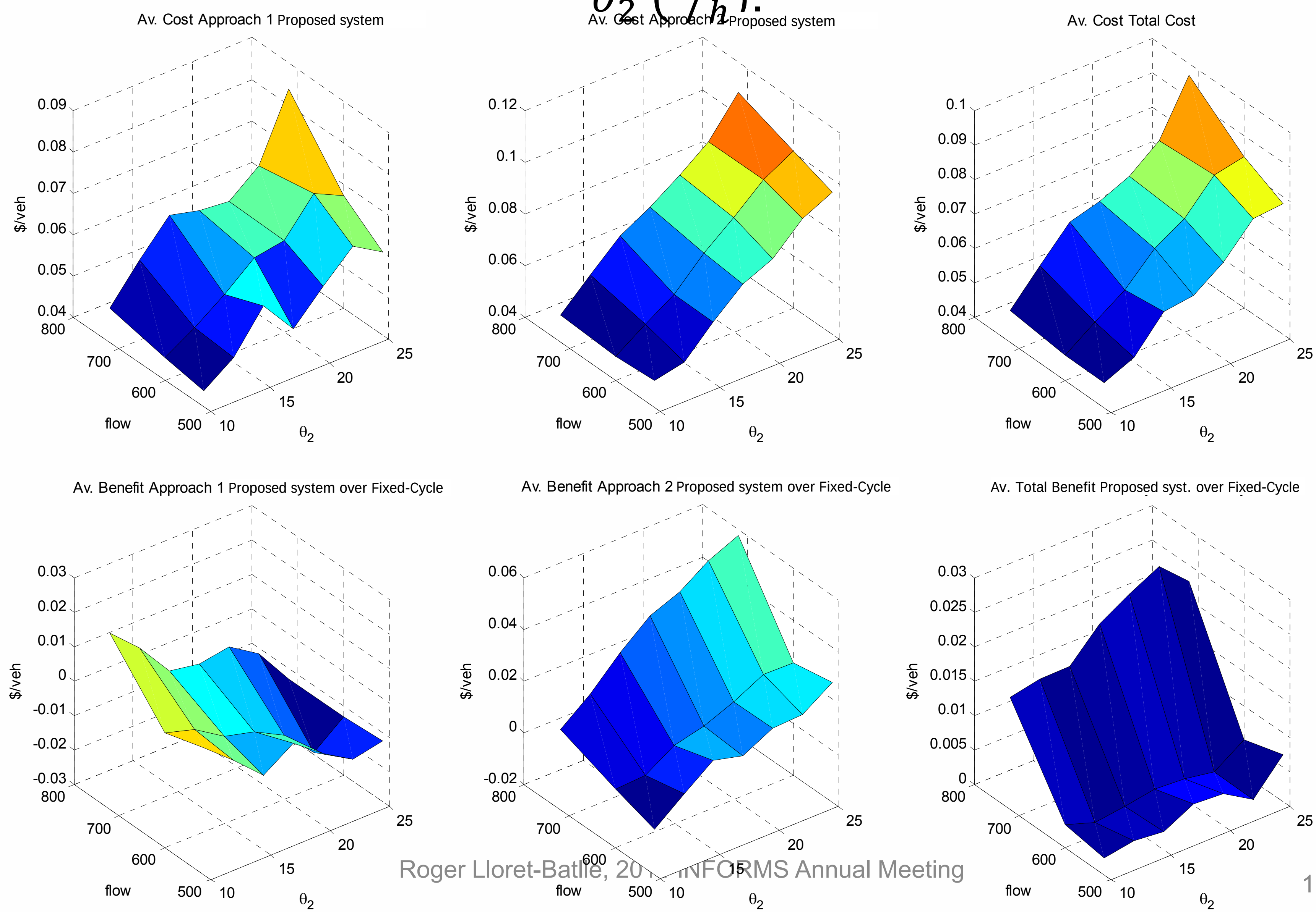








Results: Poisson case. Sensitivity analysis over $q\ (^{veh}/_{h})$ and $\theta_2\ (^{\$}/_{h})$.



Comments about results

- As it is by now, mechanism considers only future costs and not past ones.
- This can produce very long phases when there is a high difference in values of time.
- Need to refine the allocation rule.
- The outcome is shared by all the agents in the approach. How does this affects IC, IR and collusion?

Further research

1. Signal coordination. Adaptive control system on network
2. 8 phase signal. Budget balancing assessment.
3. Simulation on Irvine Triangle in Paramics (Yang, 2011)