CPS for Moving People and Goods in Smart Cities

Petros Ioannou

University of Southern California

Los Angeles, CA, USA

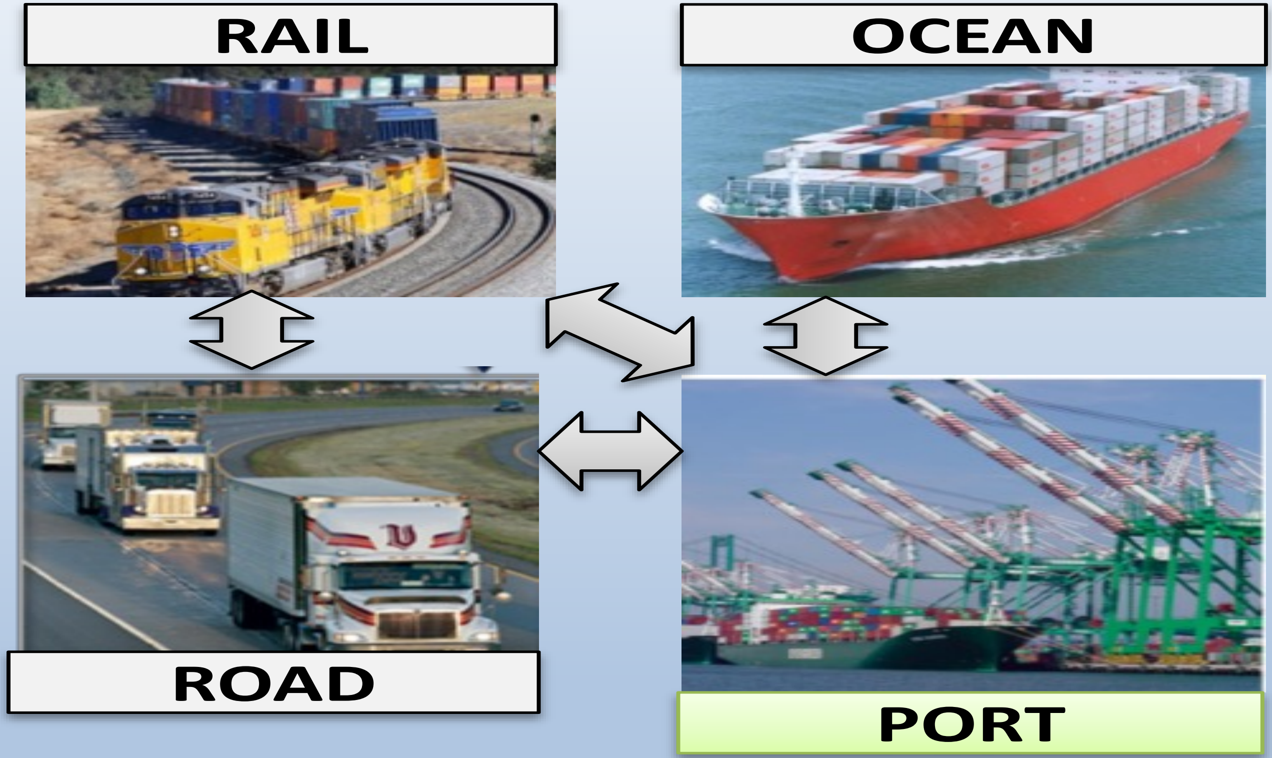
CURRENT TRANSPORTATION SYSTEM

- **Nonlinear Dynamical System of interconnected systems**
- Open Loop Most of the Time
- **Limited ineffective feedback**
- Lack of sensor data and connectivity
- Competitive environment with lack of cooperation

<u>Consequences</u>

- Congestion
- Inefficient utilization of infrastructure
- Safety
- Pollution
- Long travel times, High cost

Transportation System for Moving Goods and People is complex

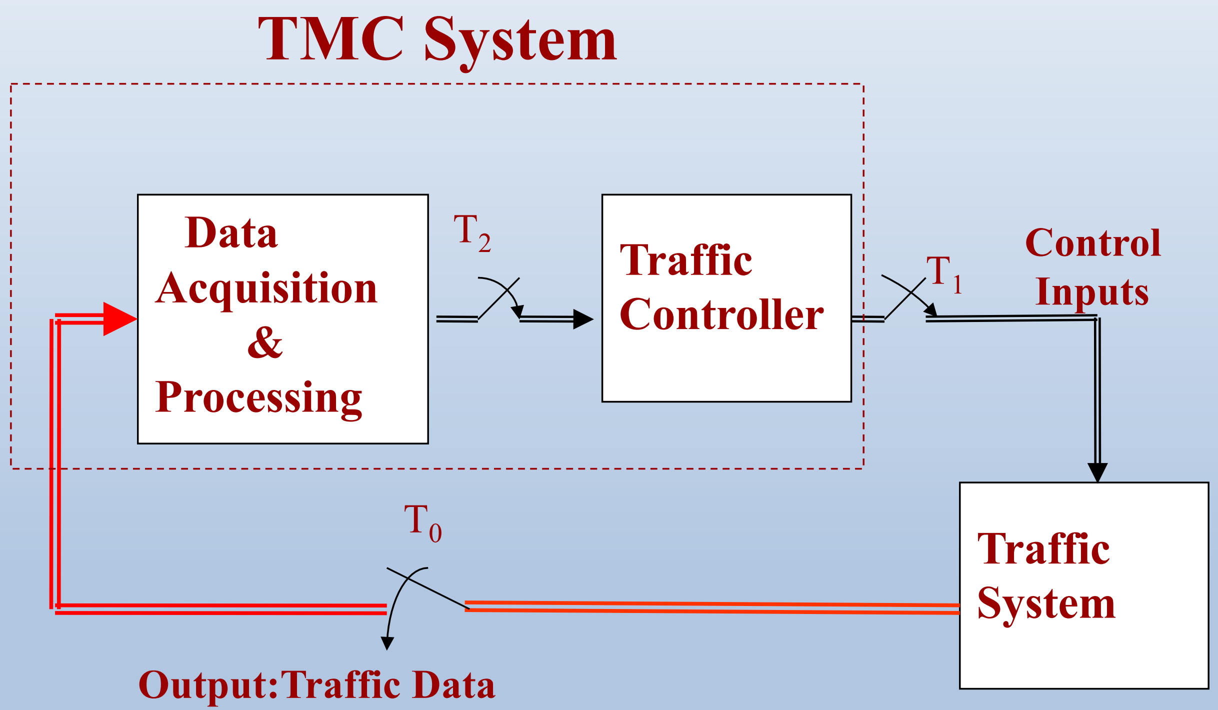


CONNECTIVITY

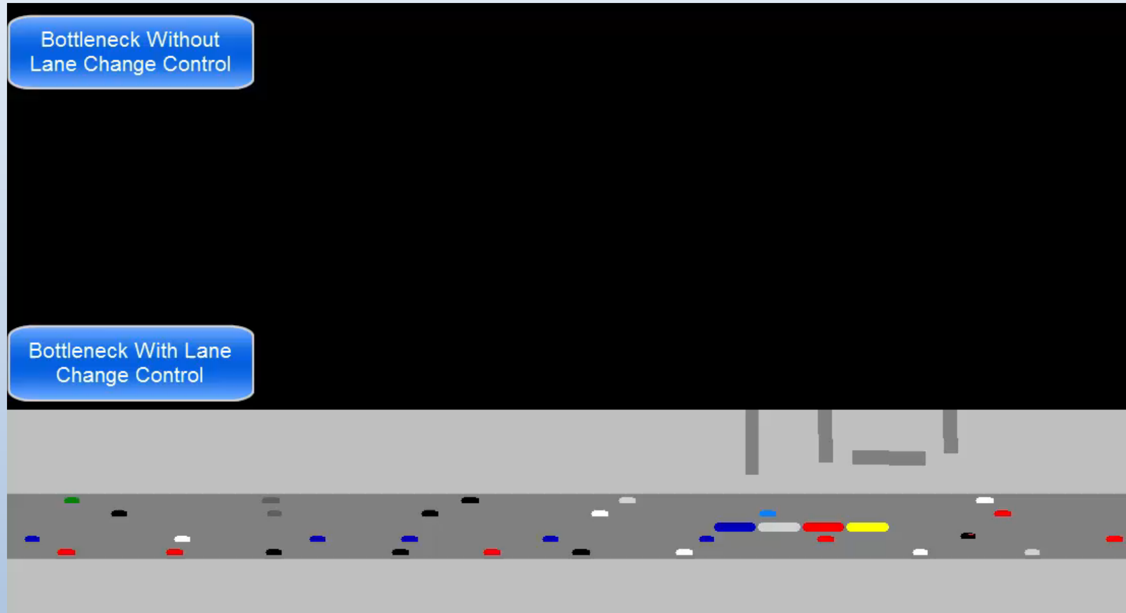
- System level traffic management and control requires data and information that can be provided by connectivity (VtoV and Vto I)
- **A revolution in the efficiency of transportation system**
- Connectivity will remove many uncertainties and current random phenomena and inaccurate predictions will be replaced by more accurate ones e.g Incident detection
- **Ability to design far more accurate and effective traffic management and traffic control systems**
- Motivate coordination and extensive use of optimization for optimum decisions and operations
- **Autonomous Vehicles need to integrated in this system not just operate as isolated robots**
- Win-win situations as a result of cooperation

NO CONTROL NO CONNECTIVITY

Traffic Management Control (TMC) System



Effect of Lane Change Control



Microscopic Simulation Result

TABLE II: Evaluation Result under Demand of 6000 veh/h

	Scenario 1			Scenario 2			Scenario 3		
	No Control	Control	Improvement	No Control	Control	Improvement	No Control	Control	Improvement
T_t (min)	18.85	16.85	10.59%	12.41	11.63	6.25%	19.84	16.69	15.89%
$\bar{s}$	11.16	1.90	83.00%	5.16	0.65	87.37%	15.46	1.74	88.75%
$\bar{c}$	4.00	3.78	5.60%	3.68	3.52	4.31%	4.61	4.21	8.60%
NOx (g/veh/mi)	1.56	1.47	5.71%	1.42	1.37	3.54%	1.58	1.50	4.95%
CO2 (g/veh/mi)	558.56	519.01	7.08%	483.37	455.16	5.84%	570.72	529.76	7.18%
Fuel (g/veh/mi)	178.65	166.02	7.07%	154.53	145.49	5.85%	182.55	169.39	7.21%
PM25 (g/veh/mi)	0.049	0.048	3.39%	0.041	0.040	3.68%	0.052	0.050	3.74%

TABLE III: Evaluation Result under Demand of 6500 veh/h

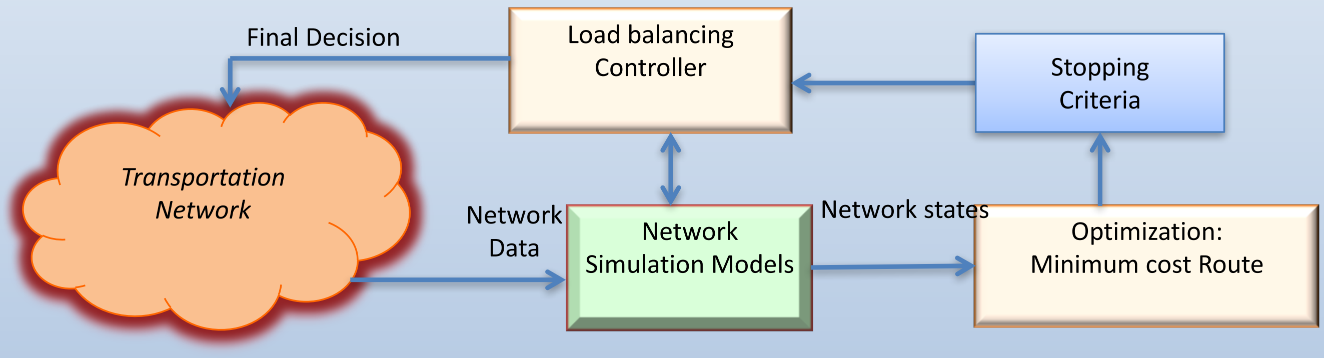
	Scenario 1			Scenario 2			Scenario 3		
	No Control	Control	Improvement	No Control	Control	Improvement	No Control	Control	Improvement
T_t (min)	20.72	16.83	18.76%	13.58	12.42	8.54%	21.25	16.55	22.13%
$\bar{s}$	12.10	1.91	84.21%	5.72	0.91	84.09%	16.12	1.83	88.65%
$\bar{c}$	4.67	4.31	7.71%	4.27	3.91	8.33%	4.58	4.10	10.48%
NOx (g/veh/mi)	1.64	1.53	6.71%	1.48	1.42	4.05%	1.58	1.50	4.95%
CO2 (g/veh/mi)	589.46	537.21	8.86%	508.13	487.18	4.12%	568.96	523.25	8.04%
Fuel (g/veh/mi)	186.78	170.31	8.82%	161.04	154.18	4.26%	182.85	168.11	8.06%
PM25 (g/veh/mi)	0.054	0.050	7.73%	0.046	0.044	4.34%	0.052	0.050	3.74%

Routing Freight in Complex Networks

- At time t all vehicles from same origin and destination are given the exact same route which is the minimum travel time based on current and past traffic information
- Result: the initially minimum travel time route gets congested and is no longer the optimum route
- There is no anticipation mechanism as the function that relates number of vehicles with overall traffic speed is nonlinear and unknown especially close to congestion operational points
- Formulation leads to a very complex optimization problem even when such functions are known

Coordination and connectivity in multimodal:
Load Balancing via Co Simulation Optimization Control Approach

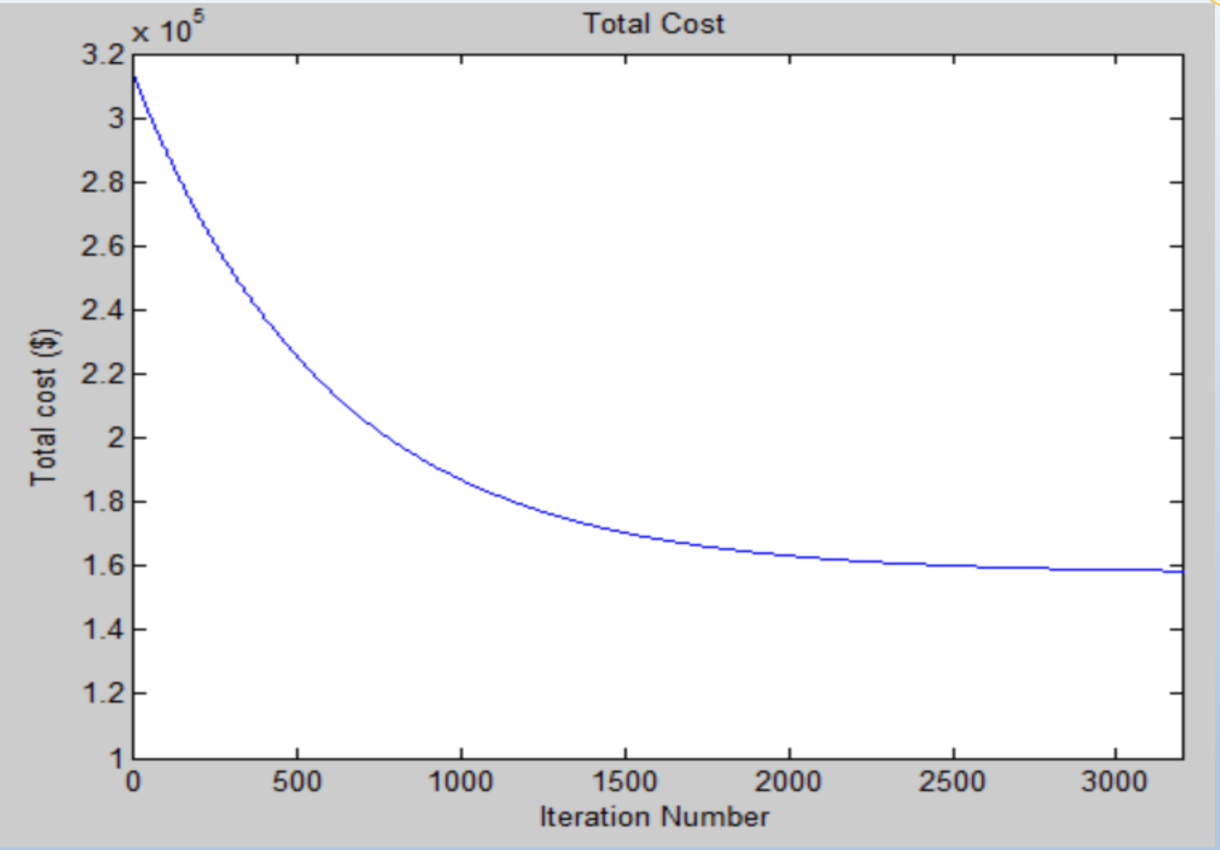
•Be pro-active than reactive



* Afshin Abadi, Petros Ioannou and Maged M. Dessouky, “Multimodal Dynamic Freight Load Balancing”, IEEE Trans. on ITS, February 2016

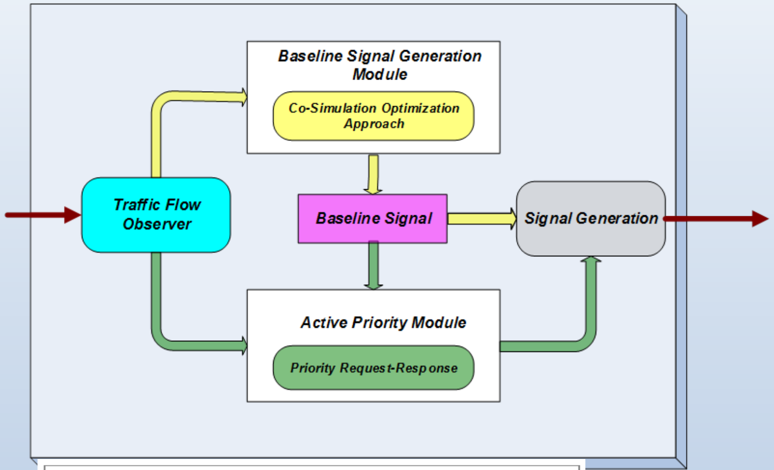
Load Balancing

- Considerable reduction in overall cost
- Raises problems of fairness to individual users
- Game theoretic problem: User optimum versus social optimum
- Incentives for participation



Traffic Light Control with Truck Priority

- **Why Truck Priority:**
  - Slower Dynamics and Larger Size
  - More Fuel Consumption and Emissions
- **Approach:**
  - Generate baseline signal which minimizes the overall delay time based on simulations (Offline)
  - Fine-tune the traffic light timing per request of truck priority in order to reduce the queue size at the intersection (Online)
- **Results:**
  - The proposed controller can improve delay time, number of stops, fuel consumption and emission for both trucks and passenger vehicles
  - The baseline signal controller which is optimized with simulations can provide significant improvement
  - Online truck priority controller can further improve the performance



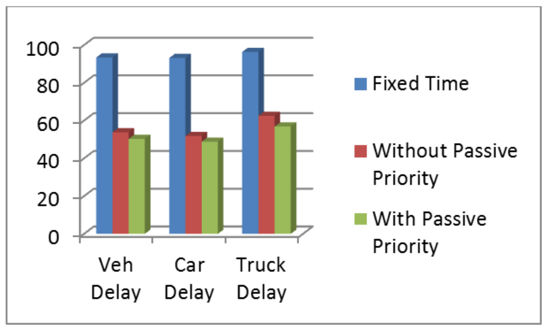
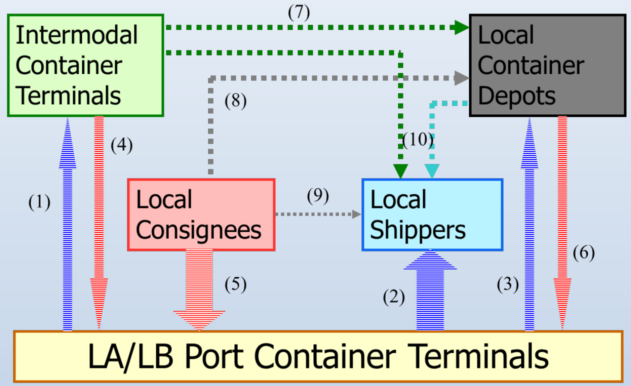


Fig. 10 Average delays for 20% truck penetration (Unit: sec).

Coordination and Connectivity in Freight CPS for Empty Container Reuse

LA/LB Regional Empty Flows



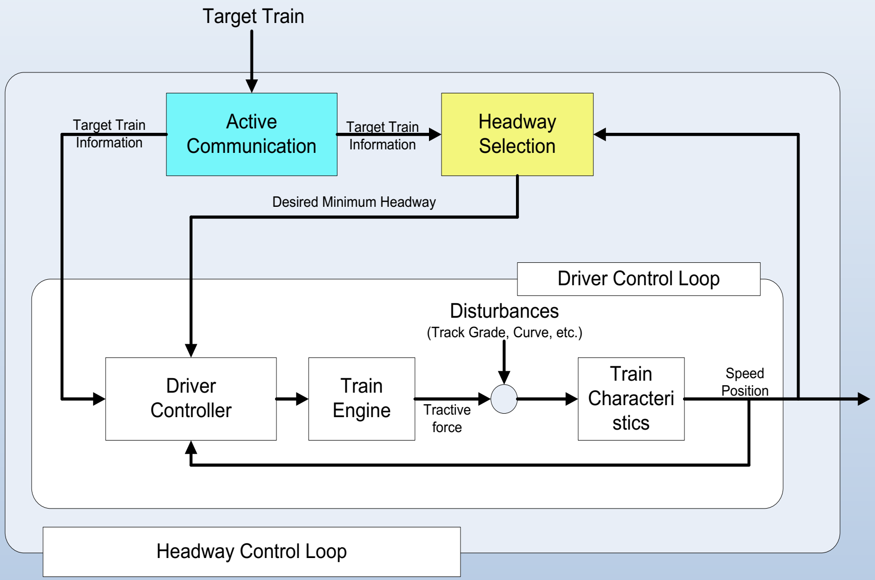
- **Study Objectives:**
  - To analytically model the empty reuse and develop optimization techniques to minimize the cost.
  - Use real data and scenario for the LA/LB area to assess benefits

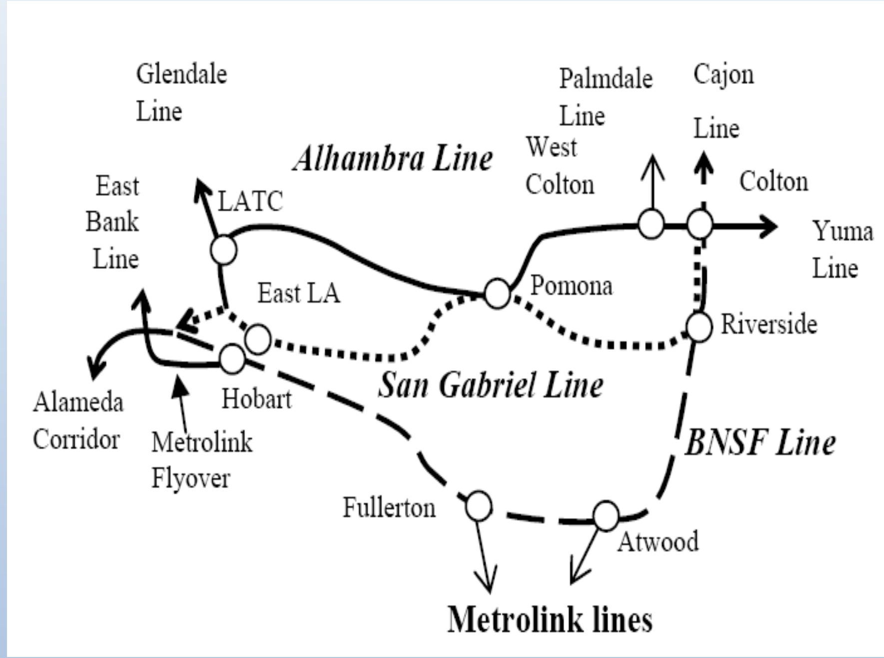
Study Findings Data :

- Empty container reuse can substantially (up to 60%) reduce the cost (travel distance) of empty movements in the LA/LB port area.
- The cost can be additionally reduced (between 5 to 40%) by allowing substitution between different types of empty containers.
- The empty reuse not only reduces truck trips to and from the LA/LB ports, but also significantly improves traffic congestion, noise and emissions around the ports.

* H. Jula, A. Chassiakos, and P. Ioannou, “Port dynamic empty container reuse,” Transportation Research – Part E, Vol. 42, No. 1, pp. 43-60, Jan. 2006

Connectivity in Positive Train Control: Dynamic Headway





*Yanbo Zhao and Petros Ioannou, “Positive Train Control with Dynamic Headway based on Active Communication System”, IEEE Trans. on ITS, 2016

Research Problems

- Connectivity will generate vital information and provide missing data that are necessary for any control and optimization design for an efficient transportation system
- New modeling techniques for control and optimization designs are needed
- The traditional simple mathematical models are not always adequate
- Real time simulation models in feedback loops may provide state estimates and predictions for control and optimization by taking advantage of fast computing power and availability of software tools
- The use of simulation models in feedback raises many interesting research problems such as proving stability, robustness, guaranteeing performance under different situations
- Conflicts between system cost and subsystem or user cost is an interesting research problem
- How to create incentives for participation in schemes that aim to optimize system performance
- Game theoretic approaches to create win win situations and eliminate adverse competitions that lead to lose-lose situations

THANK YOU