Empowered Consumers for Efficiency in Urban Mobility

Anuradha Annaswamy

Active-adaptive Control Laboratory
Massachusetts Institute of Technology

Joint Work with Thao Phan, Yue Guan, Eric Tseng, Diana Yanakiev, and Hao Zhou

Sponsors: NSF, Ford

Outline

- Urban Mobility – a paradigm shift
- Empowered Consumers & Transactive Control
  - An Introduction
- Towards Efficiency
  - Examples: Dynamic Tolls; Dynamic Routing and Pricing for Shuttles
  - Socio-technical modeling & Model-based Design
- Summary

Urban Mobility

Urban challenges

- Pollution
- Traffic Congestion
- Urban Stresses
- Aging demographics

Digital Advances

- Edge intelligence
- Cloud Computing
- Multicore Computing

Efficiency in Urban Mobility

New paradigms

- Self-driving cars
- Connected cars
- Shared Mobility

Empowered Consumers + Transactive Control

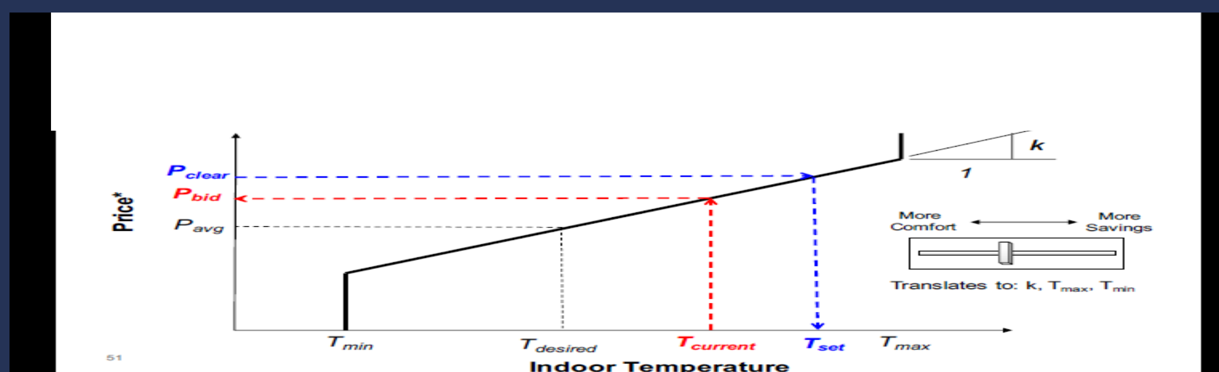
Efficient Resource Utilization

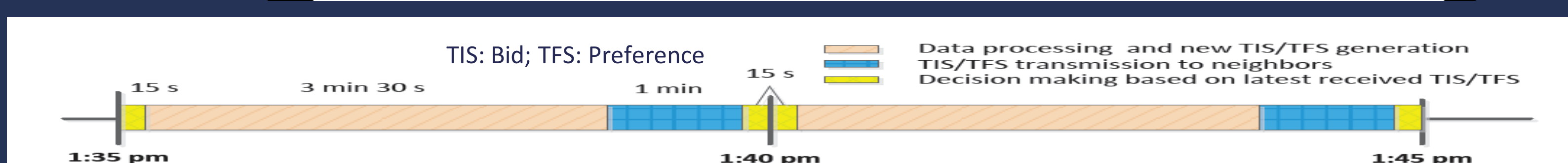
Highway Occupancy
Shuttle Occupancy
Parking spaces
Taxis

Empowered Drivers/Riders

Transactive Control

A mechanism through which system- and component-level decisions are made through economic **transactions** between the components of the system, in conjunction with or in lieu of traditional controls





Pacific Northwest Demonstration Project

What:

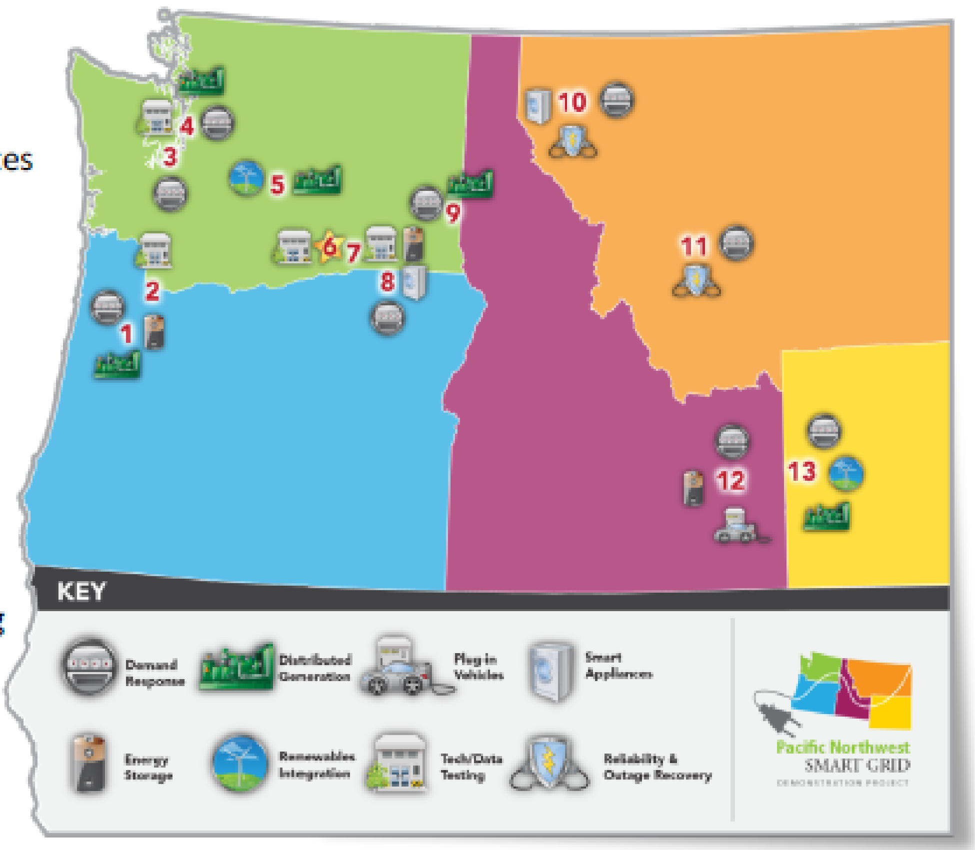
- \$178M, ARRA-funded, 5-year demonstration
- 60,000 metered customers in 5 states

Why:

- Quantify costs and benefits
- Develop communications protocol
- Develop standards
- Facilitate integration of wind and other renewables

Who:

Led by Battelle and partners including BPA, 11 utilities, 2 universities, and 5 vendors



Reference: Courtesy Jakob Stoustrup, Tutorial, American Control Conference, 2016

TOWARDS EFFICIENCY IN URBAN MOBILITY

- Examples
- Modeling
- Model-based Transactive Control

Motivation: Alleviate Traffic Congestion

Beijing

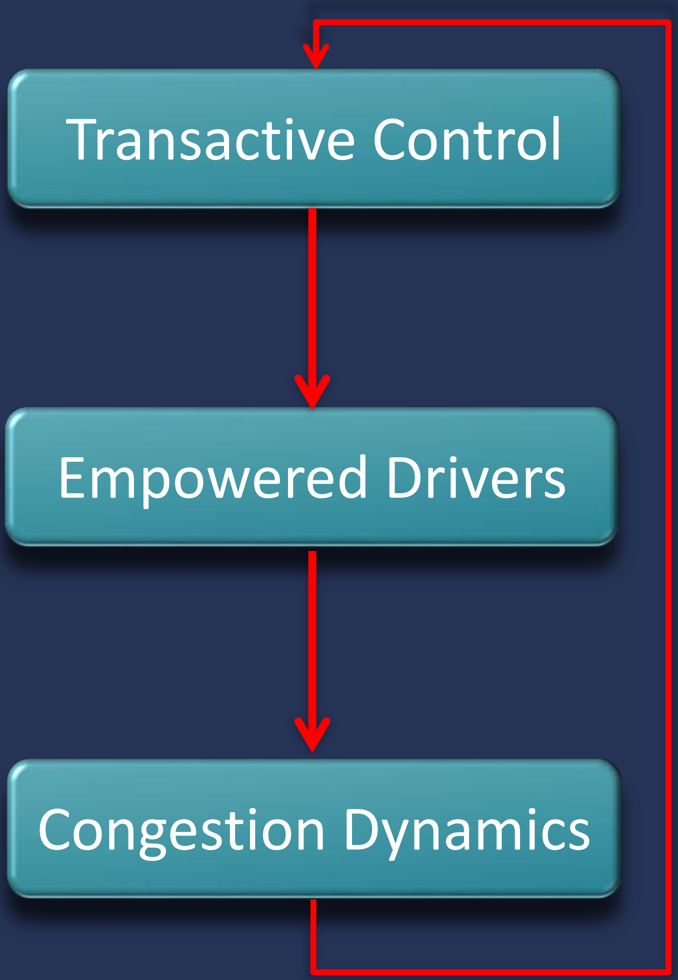
Other Means:

- Use of real-time traffic information (on-road sensors or cellphone signals)
- Informed consumers: in-car (onboard displays or smartphones) or on-road (posted signs)
- Coordinated planning: optimized traffic re-routing

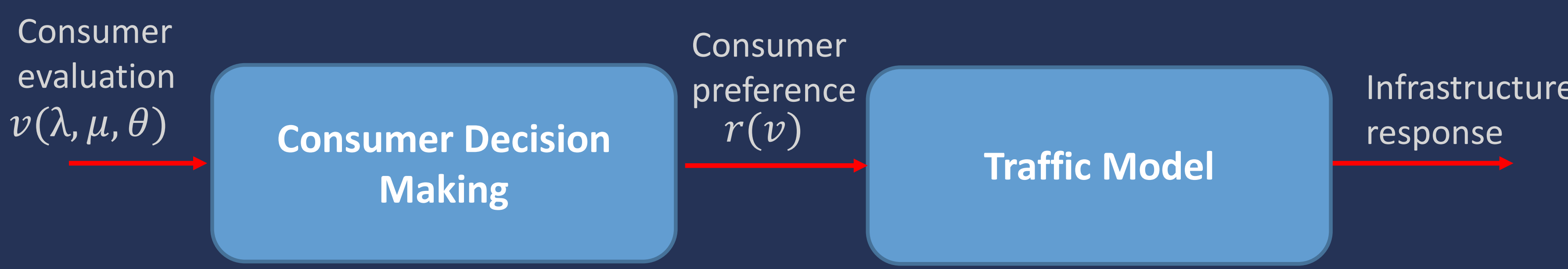
Congestion Reduction w/Toll Pricing

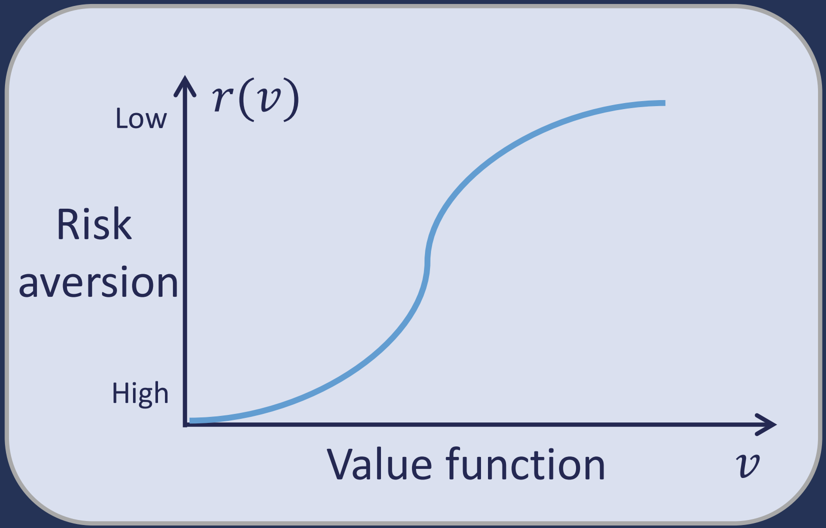
- Motivate drivers towards and away from certain roads with targeted congestion pricing
- Fixed but variable with time of day
  - Stockholm, NYC/NJ, CA, FL
- Dynamic (dependent on measured traffic conditions)
  - Minneapolis, Seattle, Virginia, Georgia, Los Angeles

Empowered Consumers and Urban Mobility



Complete Socio-Technical Model



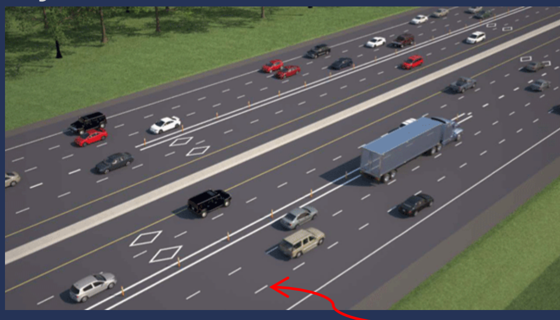


- Accumulator model
- Value function: Cost and time savings
- Logistic function – population model

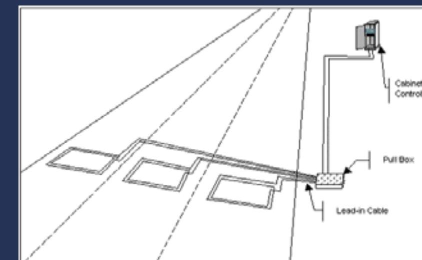
Model validation

MnPASS (Minneapolis) benchmark: in operation since 2005

dynamic toll lanes



zero toll lanes

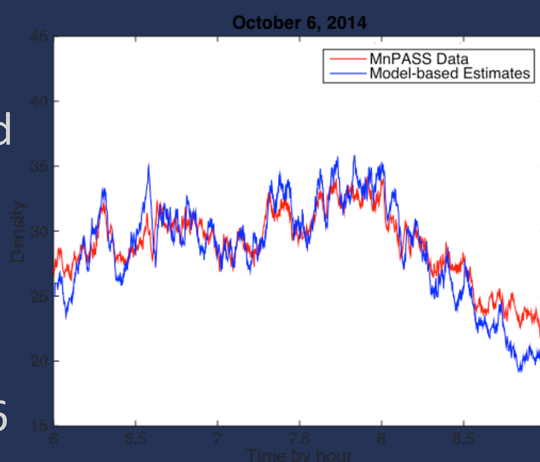


- Sensor: Inductive loop detector
- Both the traffic volume and traffic speed are measured.
- Empirically designed toll prices so as to maintain 50mph

Input flow

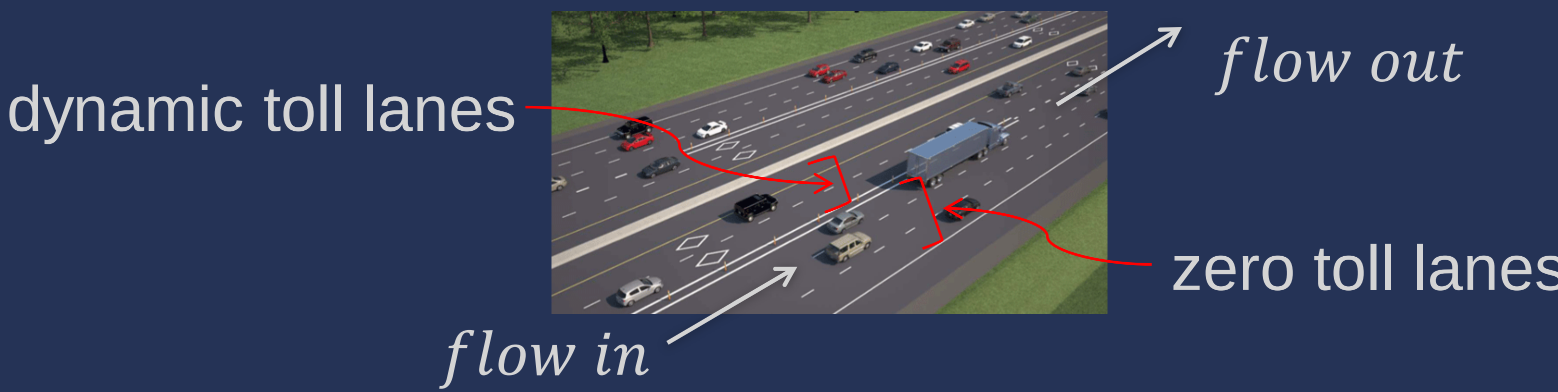
MnPASS Data → Actual density

Driver Behavior → Traffic Flow Model → Estimated density



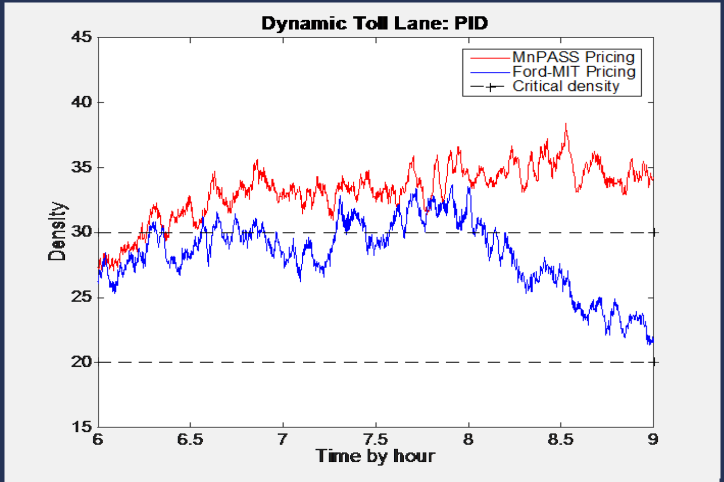
RMSE=1.6

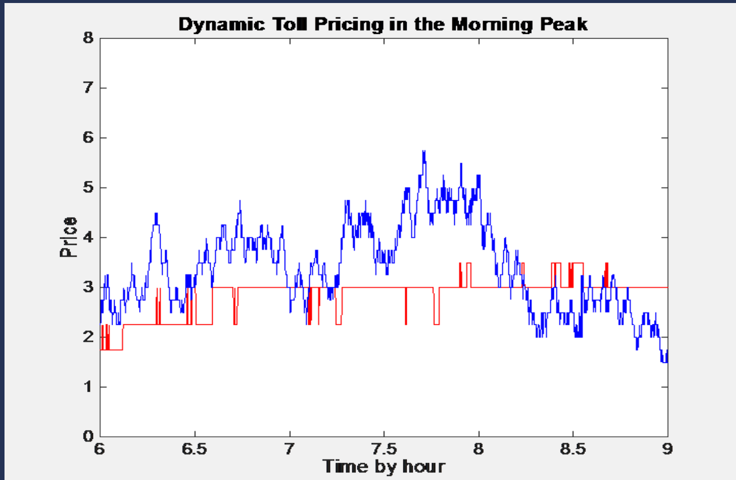
Toll-pricing controller

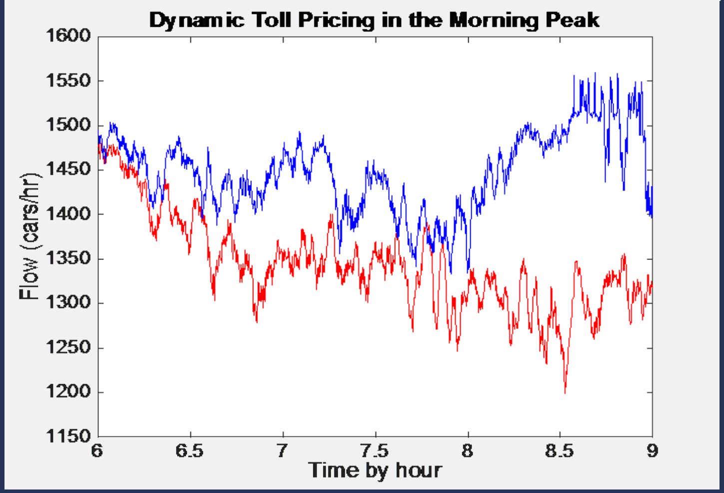


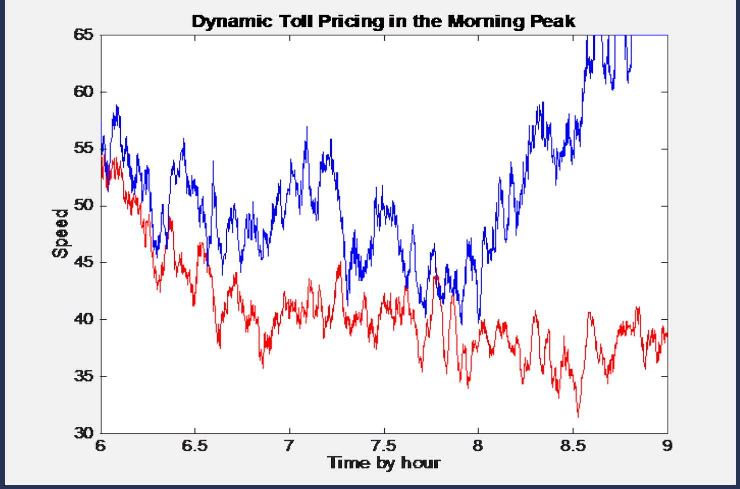
Response to High Input Flow

High input flow is introduced in the middle of the operating period to test the systems' ability to prevent congestion. Our model-based control (blue) is successful in keeping the HOT density low compared to MnPASS (red).



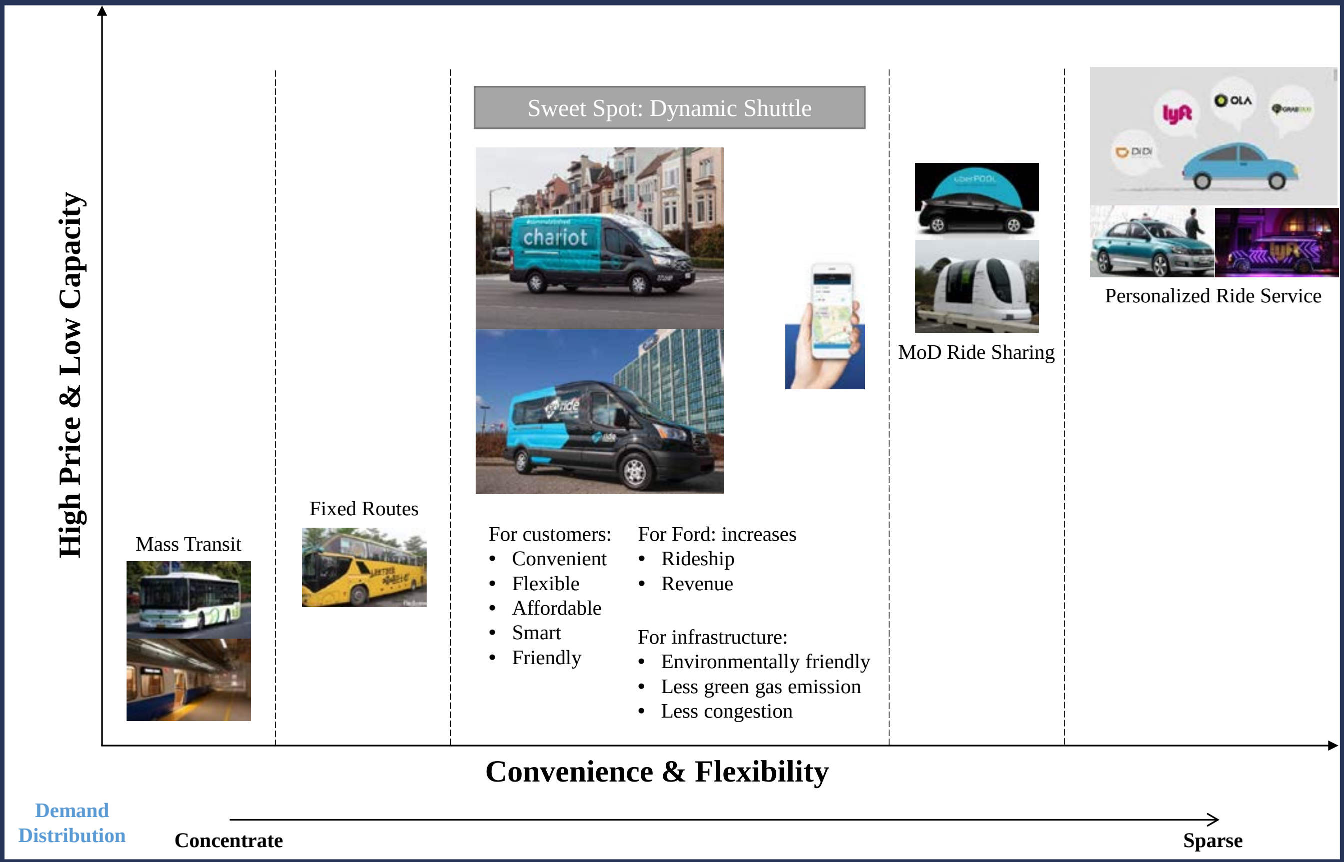






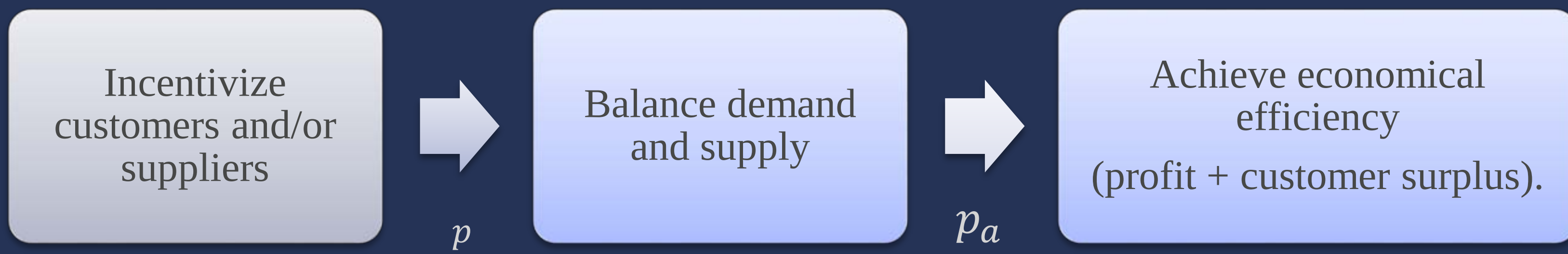
Dynamic Shuttles

Spectrum of the typical urban transportation methods



Goal: Accommodate a larger number of passengers per vehicle with flexible service experience

Transactive Control + Dynamic shuttles



- **Supply characteristics: fixed, little elasticity under short time frame**
- **Demand characteristics: large elasticity, can be incentivized instantaneously**

- **"Balance":**
  1. **Key Performance Indicators (KPIs): estimated waiting time (EWT), idle rate (IR), completion rate (CR), average revenue, …**
  2. **When demand > supply, EWT↑, IP↓, CR↓, revenue↓ and vice versa**
- **Given the route, price affects passenger's decision. The choice model maps price to probability of acceptance.**

$$U_a = \alpha + \beta_p \cdot WalkT_p + \beta_w \cdot WaitT + \beta_r \cdot RideT + \beta_d \cdot WalkT_d + \gamma \cdot p$$

$$U_d = \sigma \cdot DirectT$$

Utility of acceptance

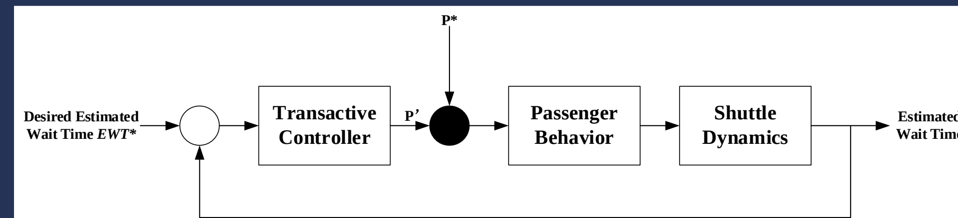
$$p_a = \frac{e^{U_a}}{e^{U_a} + e^{U_r}} = \frac{1}{1 + e^{U_r - U_a}} = \frac{1}{1 + e^{\Delta U}}$$

Probability of acceptance

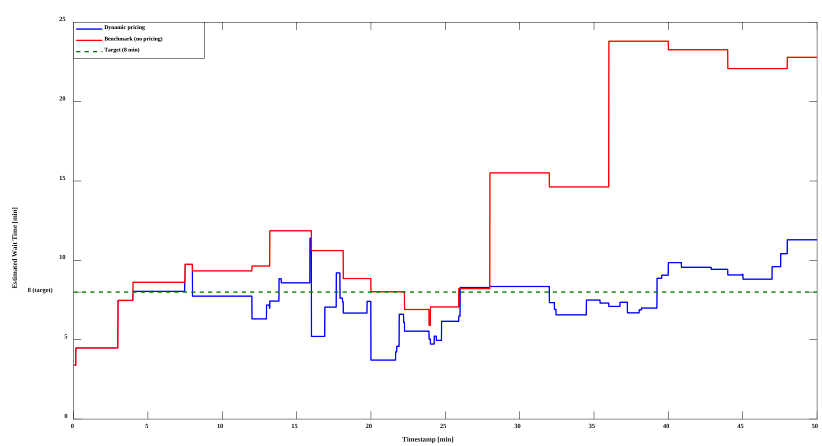
A numerical illustration

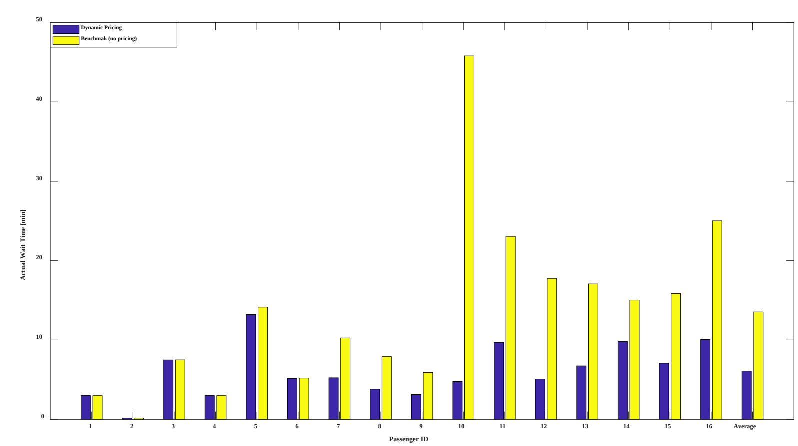
Simulation setup:

- 16 requests of real operational data from Chariot SF
- Requested pickup and drop-off locations
- Timestamps are such that there are 4 initial requests at t=0, and the other 12 arrive 4 minutes apart over a interval of 44 minutes.



$$\mathrm{prob_a} = \begin{cases} 0.9\exp(-\lambda\Delta EWT), & if\ EWT \geq EWT^* \\ & and\ \Delta EWT > 0 \\ 0.9, & otherwise \end{cases}$$





Empowered Consumers and Urban Mobility

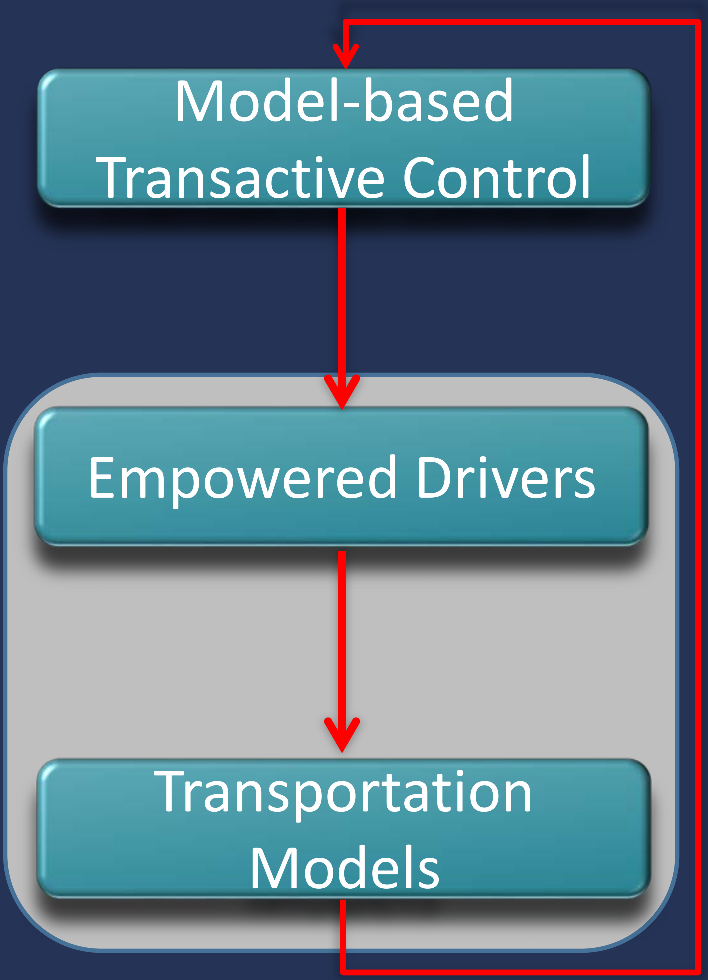
Several Challenges

- Negative externalities
- Behavioral Economics

  - Value of Decisions

. Complex technical models

- Effects of social networks



Summary

- Urban Mobility – a paradigm shift
- Empowered Consumers & Transactive Control
  - An Introduction
- Towards Efficiency
  - Examples: Dynamic Tolls; Dynamic Routing and Pricing for Shuttles
  - Socio-technical modeling & Model-based Transactive Control