Dynamic Pricing Strategies for High Occupancy/Toll (HOT) Lanes

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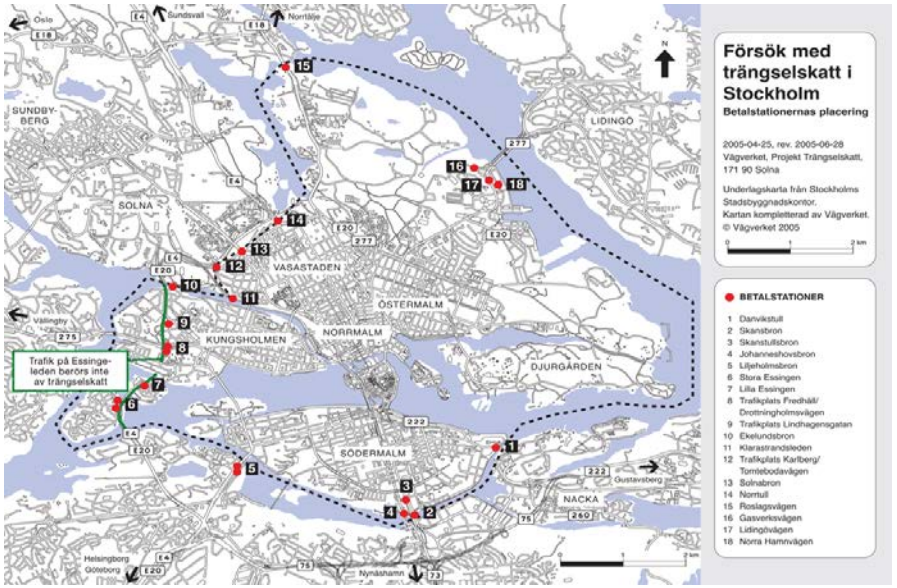
Congestion Pricing

- **The basic concept has been around for over 80 years (e.g., Pigou, 1920)**
  - **Internalize the negative externality of a trip by charging up to the full cost that the trip imposes to the society**
  - **Use tolls to provide incentives for users to change their travel behaviors to reduce traffic congestion, enhance system performance and improve social welfare**

Congestion Pricing Practice

- **Cordon or Area-based Pricing**
  - **e.g., Singapore, Oslo, London and Stockholm**



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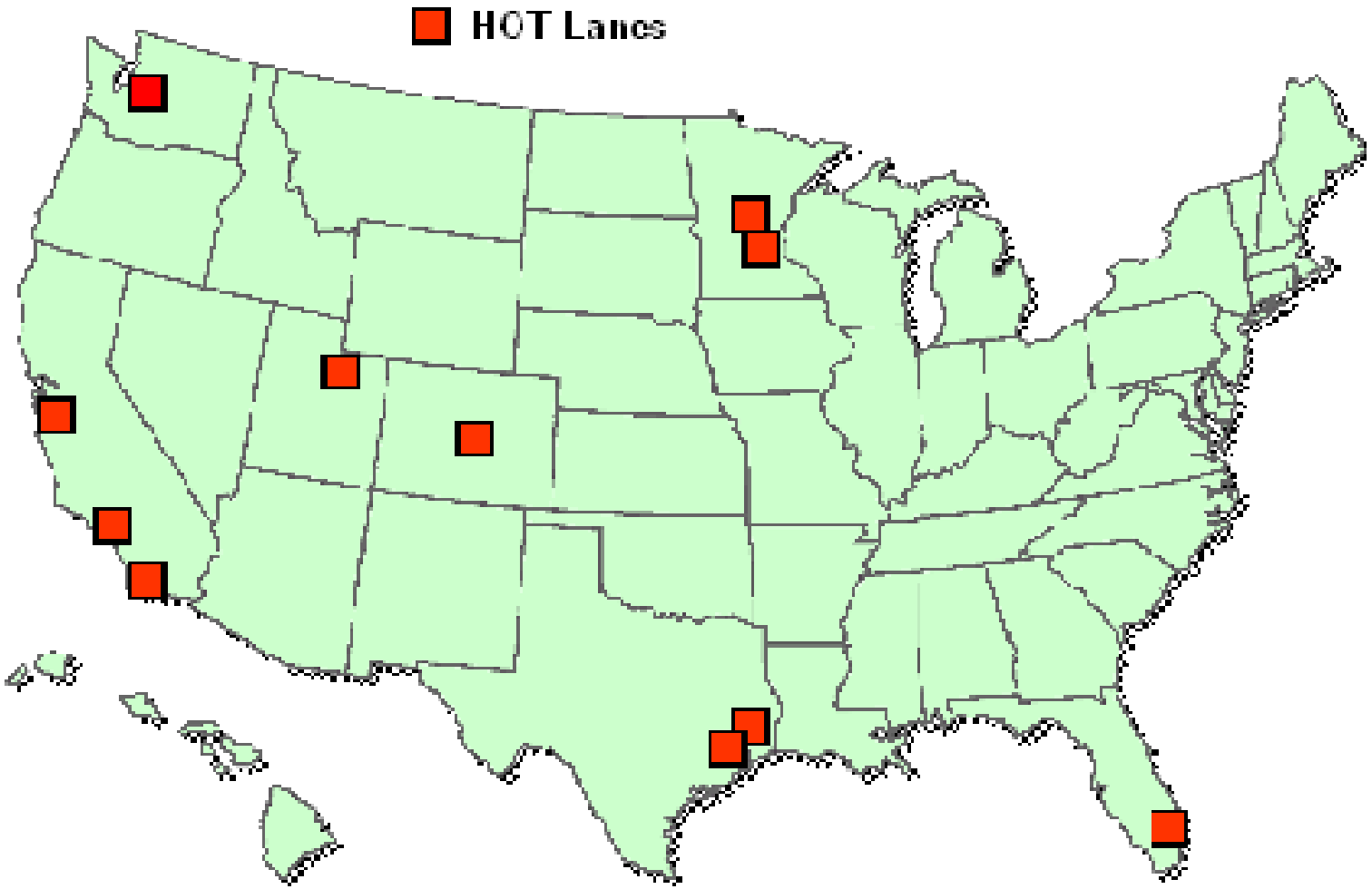
High Occupancy/Toll (HOT) Lanes

- **A type of managed lanes that allows lower-occupancy vehicles to pay to gain access, but free for high-occupancy vehicles**
- **One form of congestion pricing**
- **First conceived of by Elliott (1976)* and then advocated by Fielding and Klein (1993)**
- **The term "HOT Lanes" first suggested by Fred Laurence Williams at FTA in 1992**
- **First implemented in the U.S. in 1995 (SR91, CA)**

***Source:** http://www.claremontmckenna.edu/govt/welliott/discoveries.htm

Current Practices



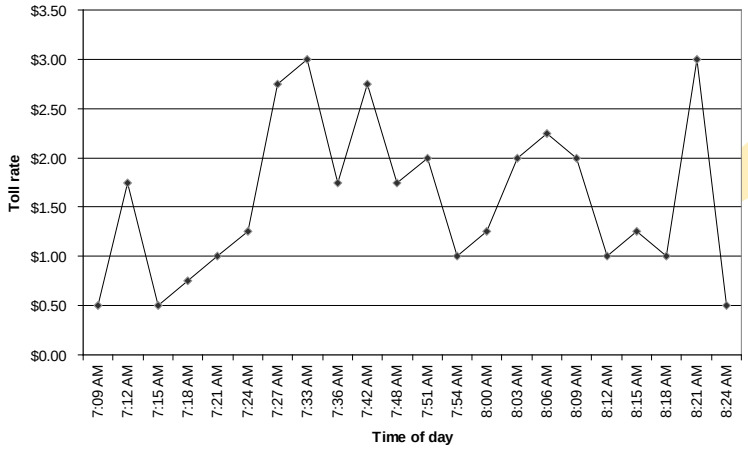
95 Express in Florida

Opened to traffic on July 11, 2008 and tolling started December 5, 2008 and January 15, 2010 for the northbound and southbound respectively

Pricing Strategies for HOT Lanes

- **Objectives**
  - **Provide a superior uncongested level of service on the HOT lanes while maximizing the throughput rate of the freeway (FHWA, 2003)**
- **Key Question**
  - **What is the right price to charge?**
- **Dynamic Pricing of HOT Lanes**
  - **Toll varies as often as every a few minutes in response to real-time traffic condition**

Dynamic Pricing



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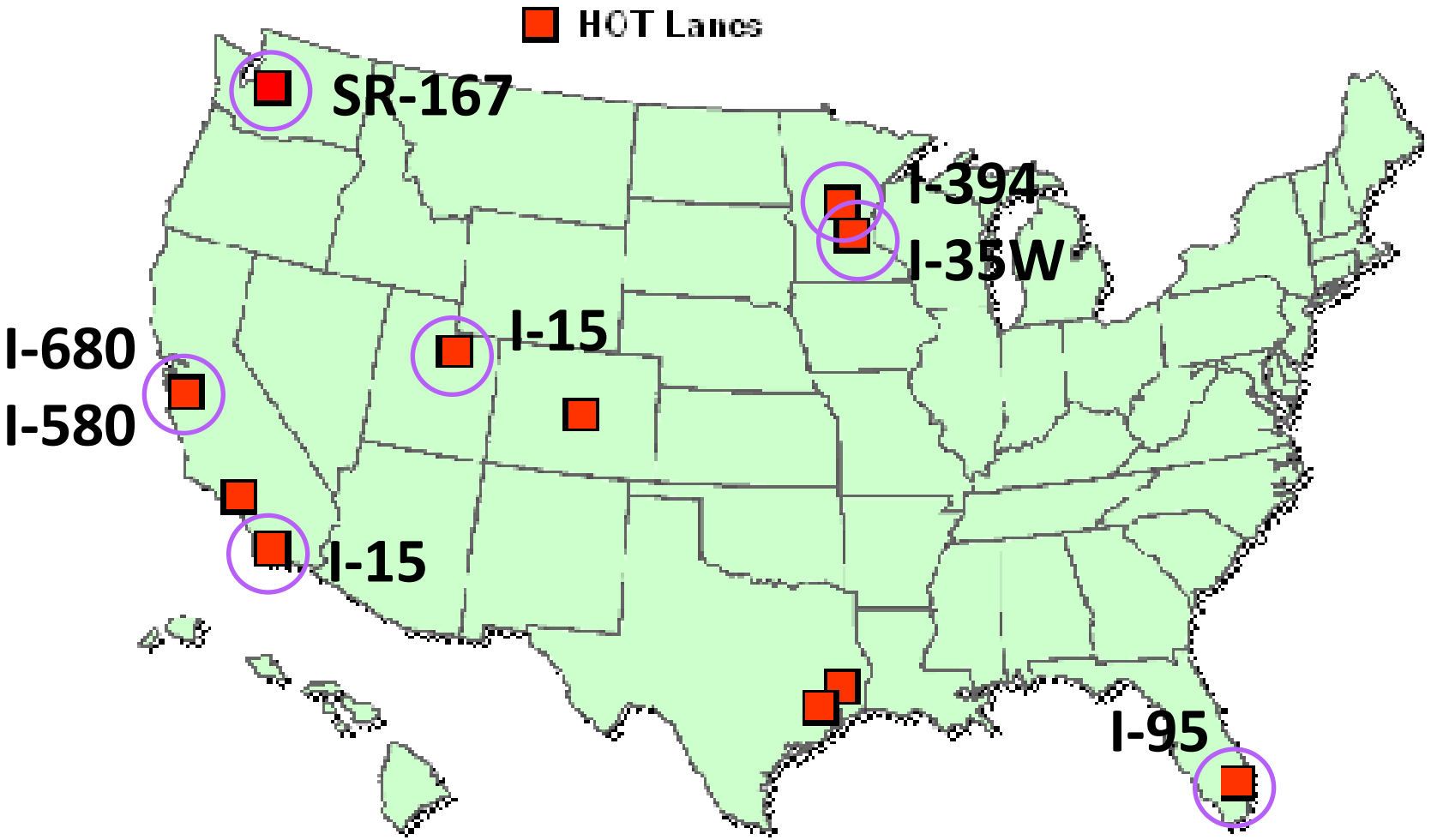
Dynamic Pricing of HOT Lanes



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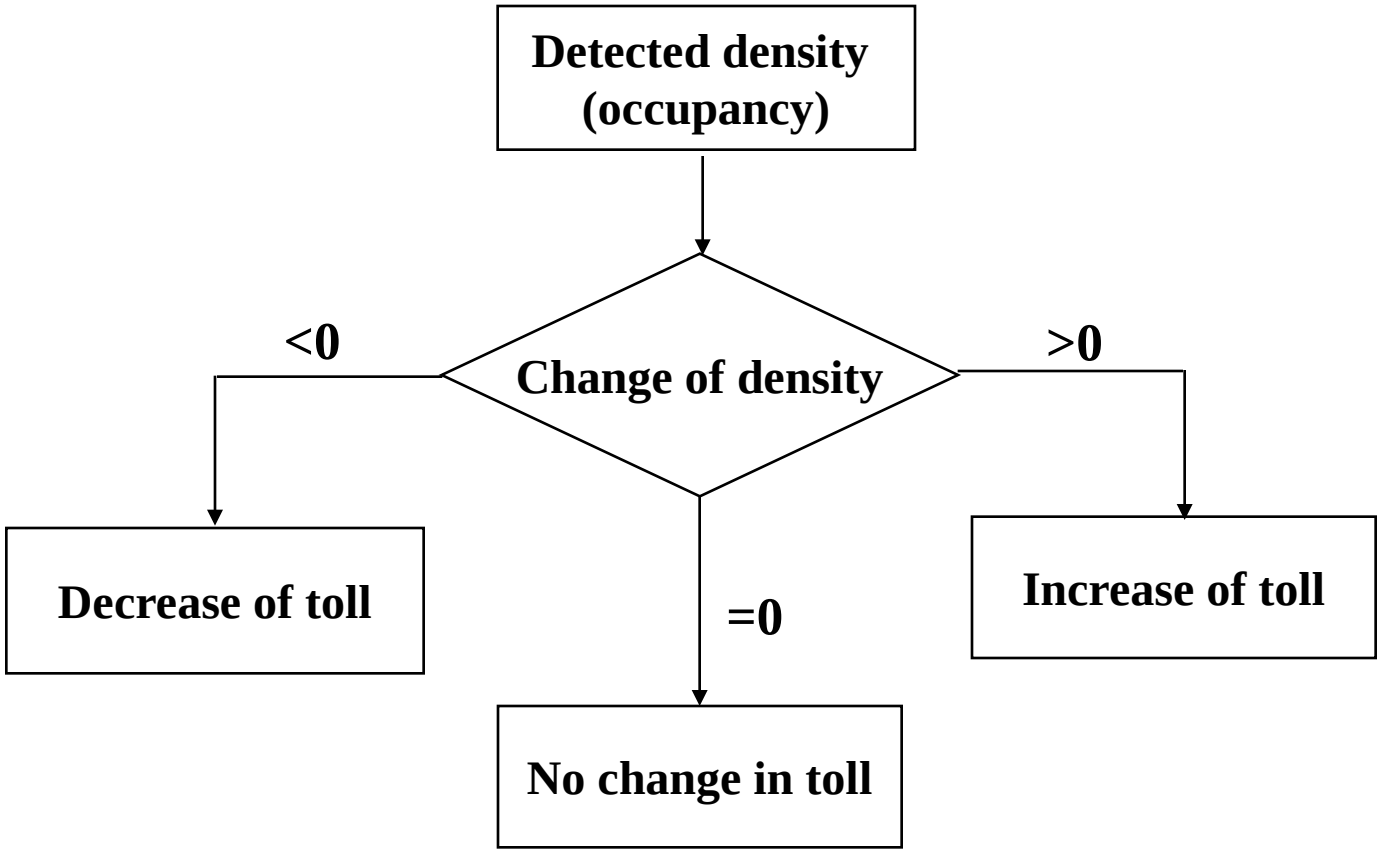
Heuristic Approach



Heuristic Approach (Cont'd)

- **The above approach is similar to those implemented in practice, and has been demonstrated mostly effective in maintaining the targeted level of service**
- **It reflects the following philosophy:**
  - **"You're trying to price the toll lane and you set the price to maintain traffic volume for something like LOS-B to D. What's happening in adjoining lanes cannot be allowed to influence your price" from the CON-PRIC listserv on April 8, 2010**

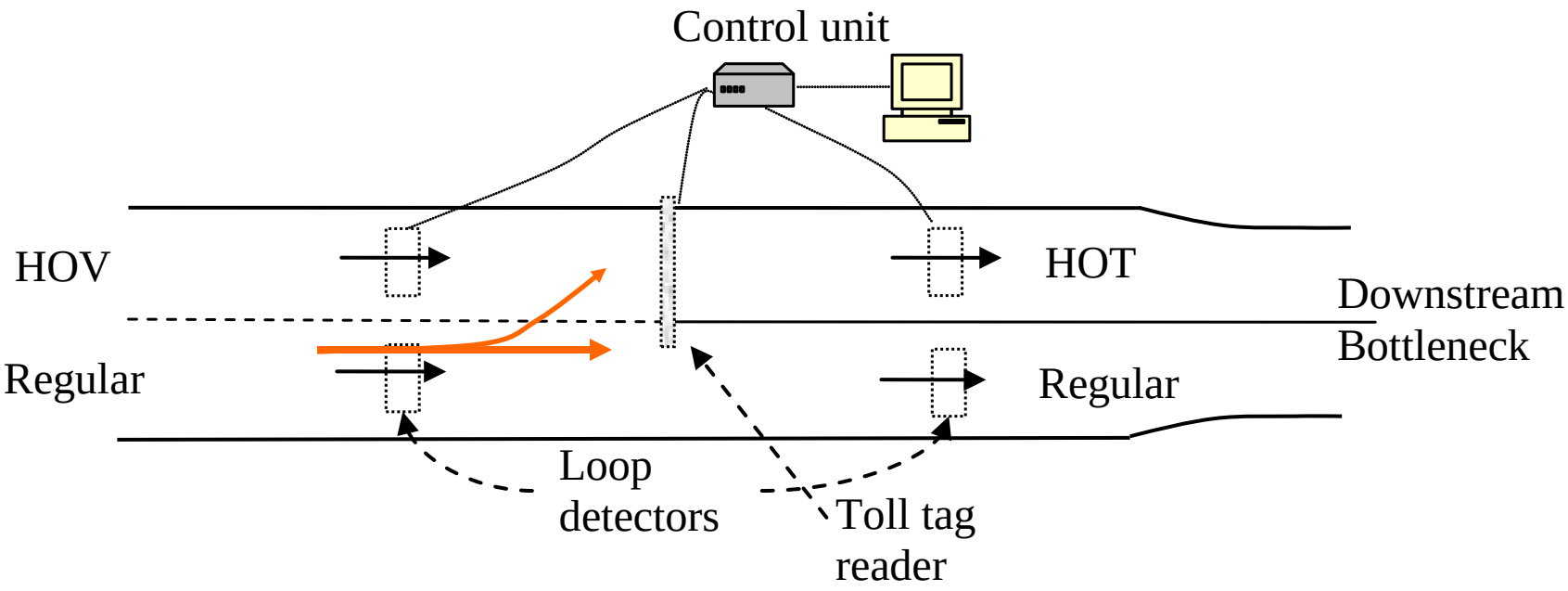
Limitation

- **The above approach may not lead to a full utilization of available capacity at HOT lanes**
- **To achieve both objectives, it is critical to monitor both the priced and unpriced lanes since the traffic conditions on those lanes will affect drivers' willingness to pay**

Potential Improvements

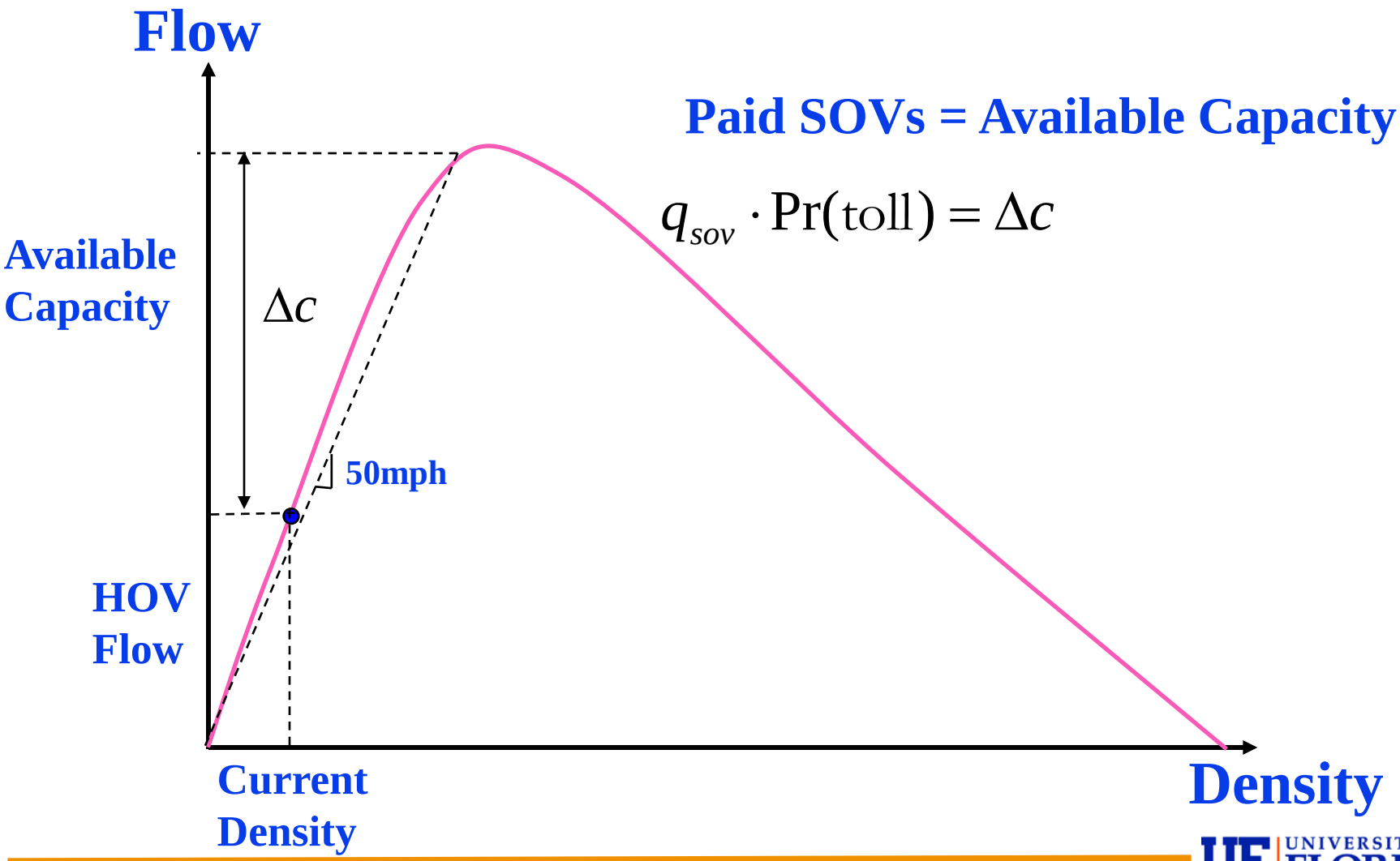
- **Adjusting the toll rate of HOT lane based on the traffic conditions on both HOT and GP lanes**
- **Displaying travel time information on DMS to help drivers to make lane-choice decision**
- **The above will allow the toll to provide a correct pricing signal on the value of traveling on HOT lane**
  - **"There is a huge disconnect with most drivers, who assume the higher tolls mean the free lanes are backed up and that if they pay they will get to go faster." - Michael Turnbell, Sun Sentinel, April 6, 2010**

Improved Pricing Approach



1. **How many SOVs should be allowed to use HOT lane?**
2. **What is the right price to attract this many SOVs?**

Fundamental Diagram



Charge a Right Price (Cont'd)

- **Lane-Choice Model**

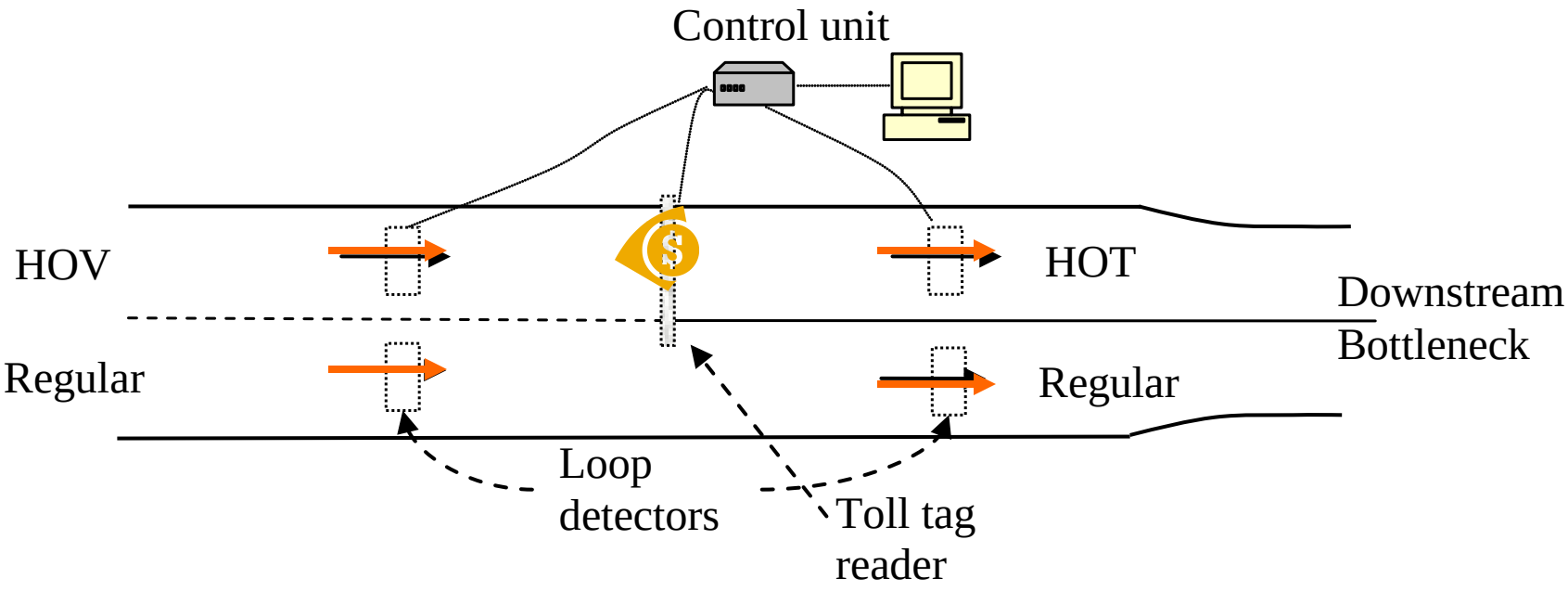
$$\Pr(\text{toll}) = \frac{1}{1+\exp\left(-\alpha \cdot \text{Travel time saving} + \beta \cdot \text{Toll} + \gamma\right)}$$

- **If all parameters are known, the optimal toll can be easily calculated.**

$$\text{Toll} = \frac{\alpha}{\beta} \cdot \text{Travel time saving} - \frac{\gamma}{\beta} + \frac{1}{\beta} \ln\left(\frac{q_{sov}}{\Delta c} - 1\right)$$

- **However, the parameters are unknown, particularly:** $\frac{\alpha}{\beta} = \text{Value of Travel Time}$

Learning of Willingness-to-Pay



Learning of Willingness-to-Pay (Cont'd)

- **"Revealed-preference experiments" are being conducted every a few minutes**
- **Facing the displayed toll, drivers made their choice based on their willingness-to-pay. The choice outcomes are captured by traffic measurements**
- **Drivers' revealed willingness-to-pay can be learned by analyzing traffic measurements (flow, occupancy and speed) at limited sensor locations**

$$\text{Toll} = \frac{\alpha}{\beta} \cdot \text{Travel time saving} - \frac{\gamma}{\beta} + \frac{1}{\beta} \ln\left(\frac{q_{sov}}{\Delta c} - 1 \right)$$

Proactive Self-Learning Pricing Approach

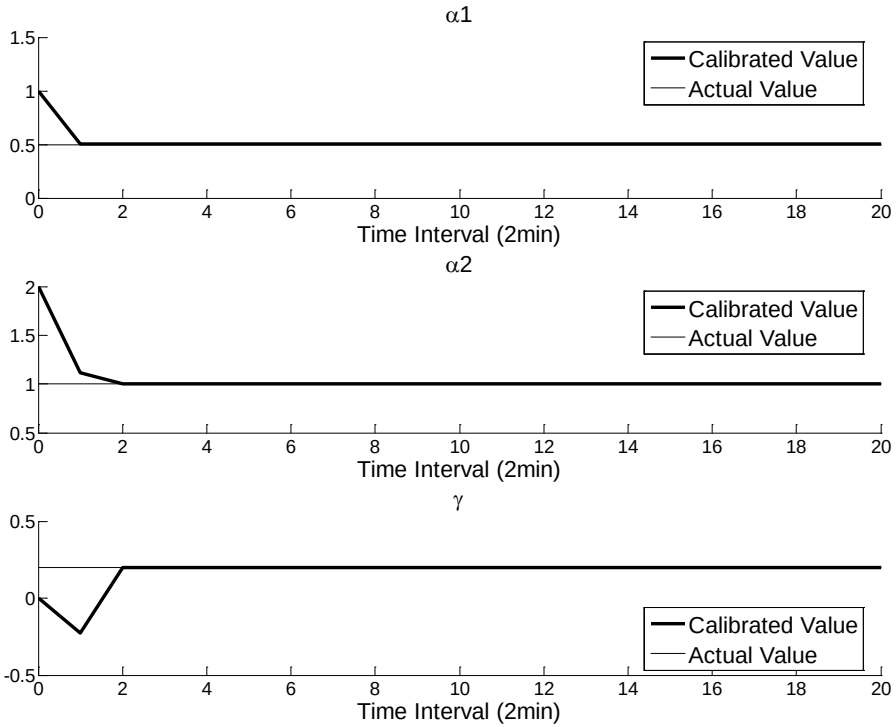
- **Data mining. Analyzing traffic measurements (flow, occupancy and speed) at limited sensor locations for:**
  - **(Revealed) willingness-to-pay learning**
  - **Demand forecast**
  - **Traffic state estimation**
- **Toll optimization to maximize throughput while ensuring**
  - **A superior level of service on HOT lanes**
  - **Incremental change of toll rate**
  - **Equity among users**

Mathematical Techniques

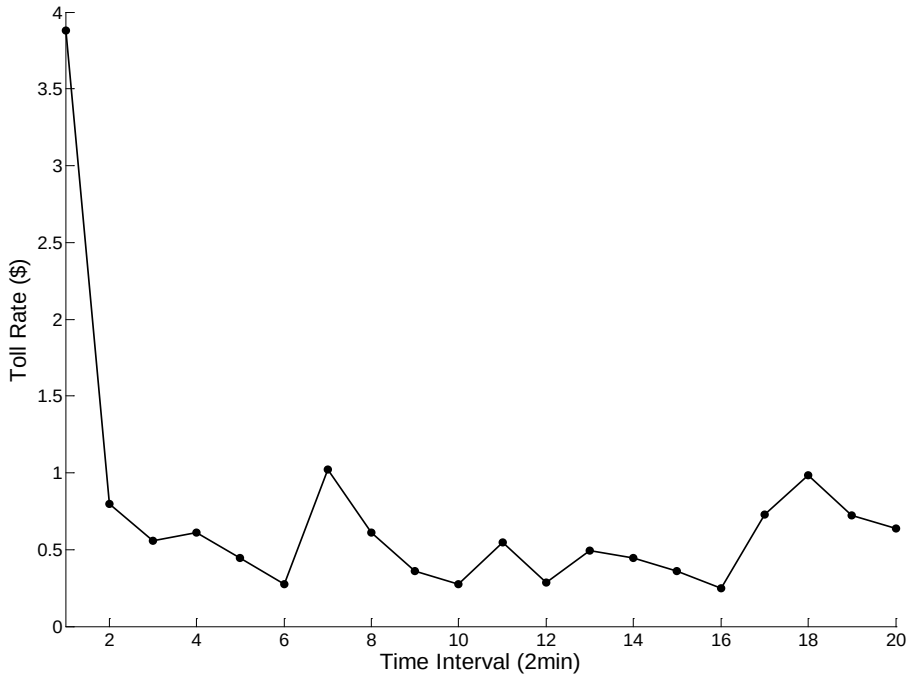
- **Data Mining**
  - **Kalman filtering for willingness-to-pay**
  - **Unscented Kalman filtering for traffic state estimation**
  - **Bayesian inference for demand forecast**
- **Toll Optimization**
  - **Rolling-horizon framework**
  - **Robust optimization to address uncertainty**

Simulation Study

- **Parameter Calibration**

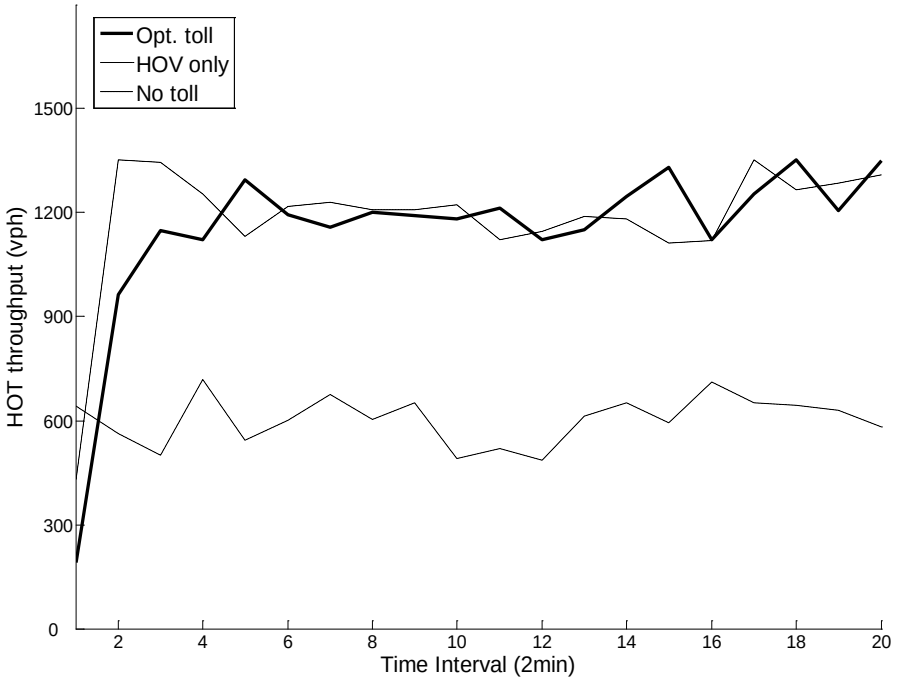


- **Optimal Toll Rates**

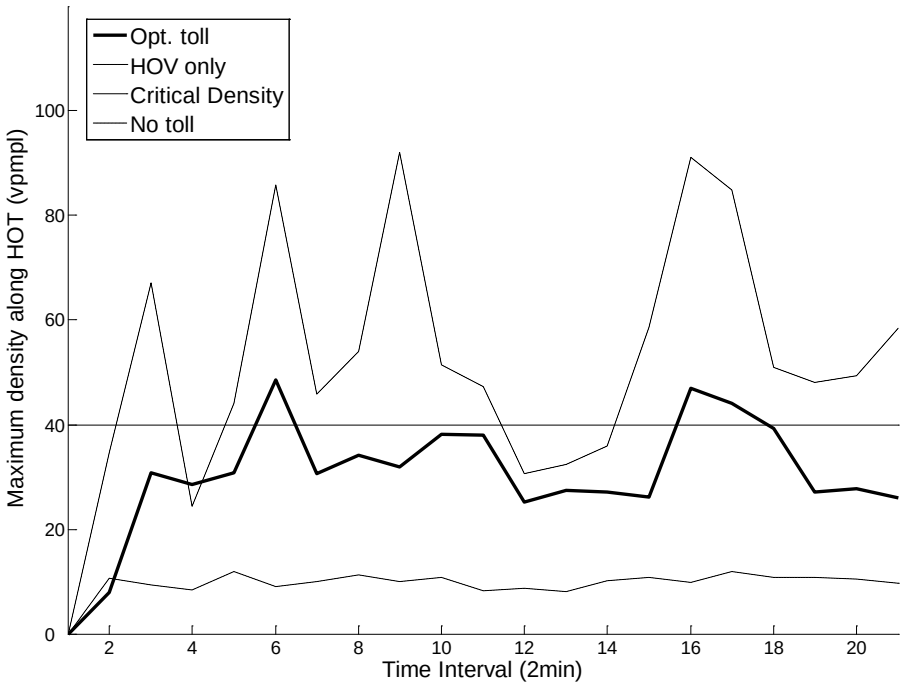


Simulation Study (Cont'd)

- **HOT Throughput**



- **HOT Density**



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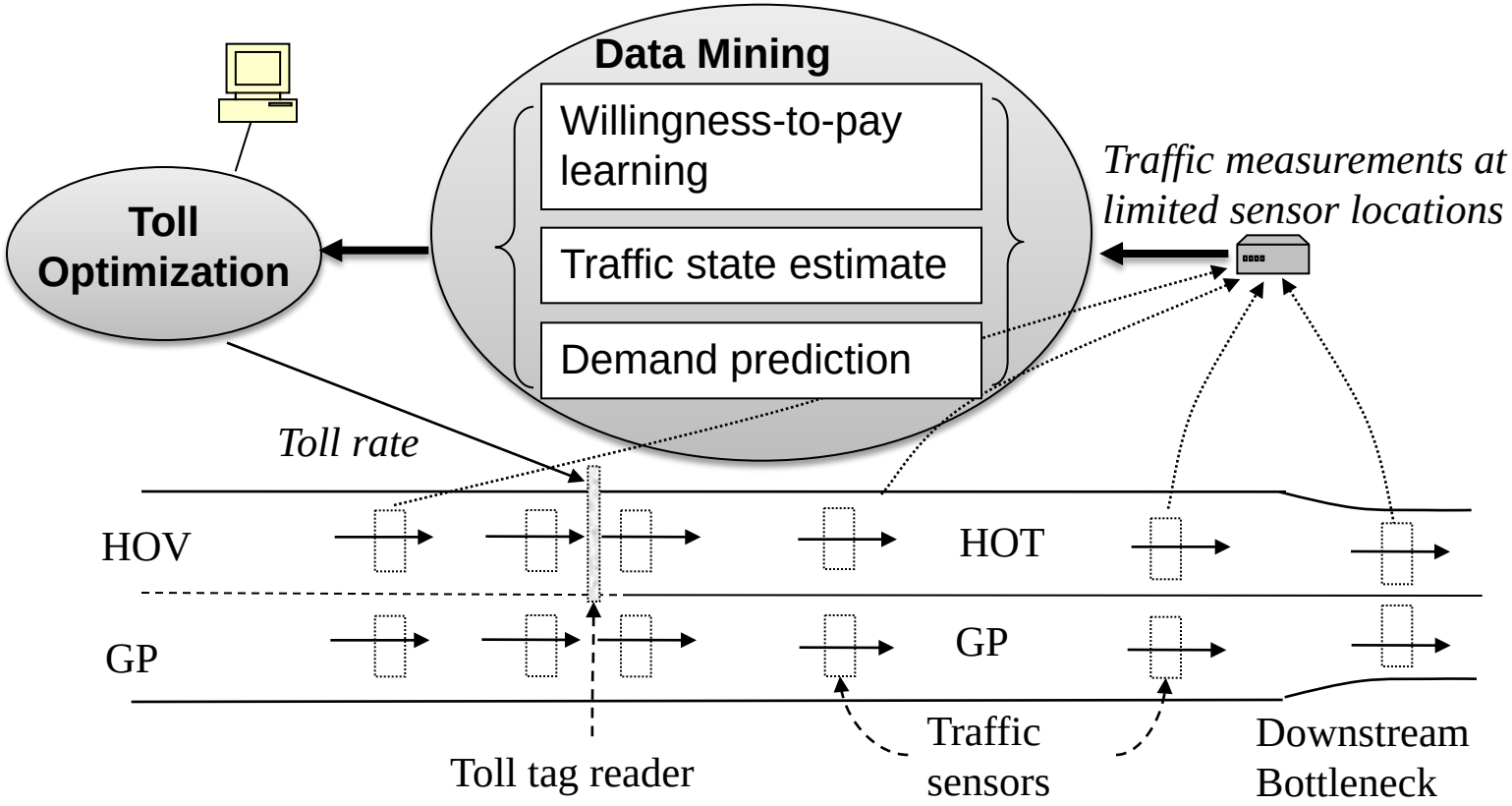
Summary



Implication

- **Transportation industry is making transition from being “data poor” to “data rich”**
- **Freeway operations can be data driven**
  - **System performance monitoring**
  - **“Hidden” facts or patterns on both the demand and supply sides can be identified**
  - **Data-driven adaptive control for efficiency, safety and reliability**

Questions?

For more information

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