Queues and Network Control for Urban Traffic Systems

Workshop on Control for Networked Transportation Systems
July 8 2019

USC Viterbi School of Engineering

Ketan Savla
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University of Southern California

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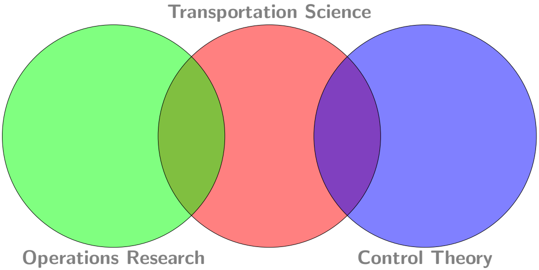
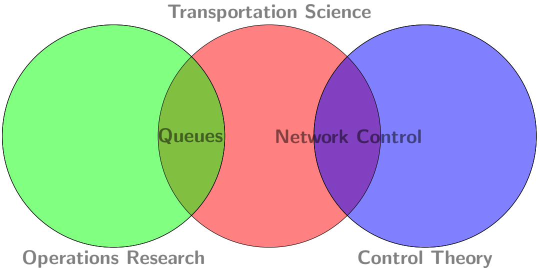
Thanks to NSF EPCN and DCSD, CALTRANS

Overview


Transportation Science
Operations Research
Control Theory

Overview



- Symbiosis between transportation and systems sciences

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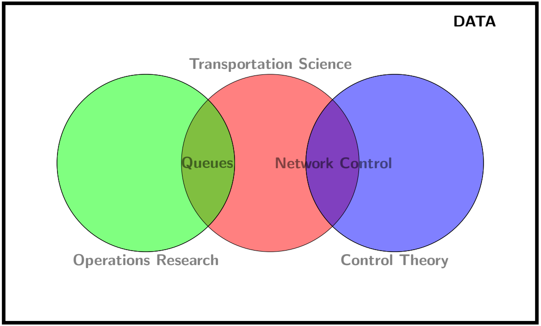
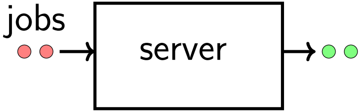


- Symbiosis between transportation and systems sciences
- Tight integration essential for efficient use of data

Transportation Queues



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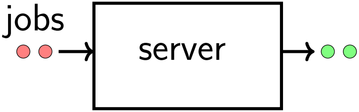

mobility on demand

- jobs: pickup/delivery requests
- server: vehicle fleet

signalized intersection

- jobs: vehicles
- server: intersection

freeway (w/ CAVs)

- jobs: vehicles
- server: freeway infrastructure

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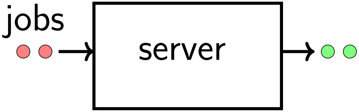

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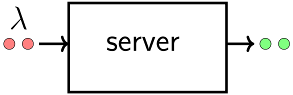
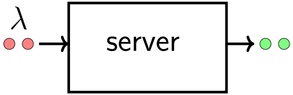
Service paradigms determined by automation and control

Performance Evaluation



capacity? **wait time**?

Performance Evaluation



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Constant Service Rate

$$\lambda - \underbrace{c}_{\text{service rate}} = \text{queue growth rate}$$

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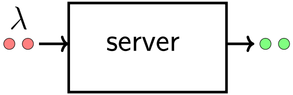

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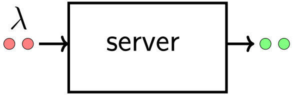

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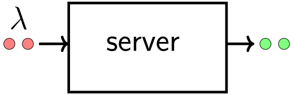

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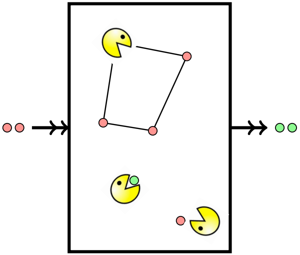
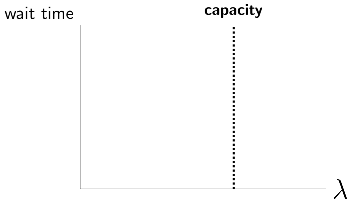


$c \equiv c(\text{queue length})$

State Dependent Transportation Queues



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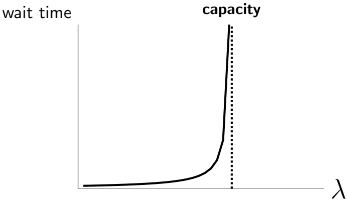

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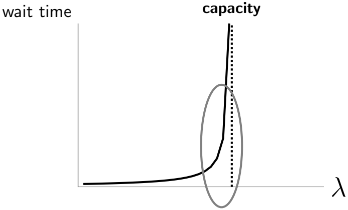

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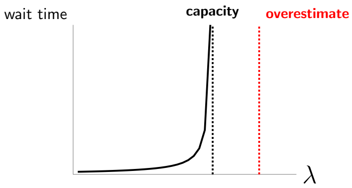

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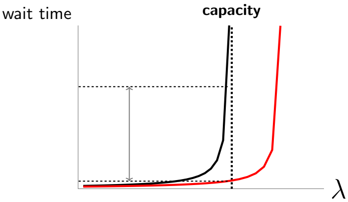

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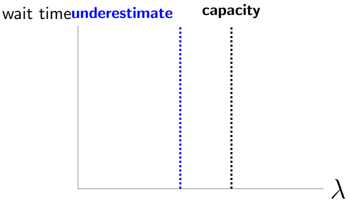

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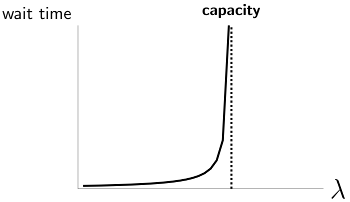

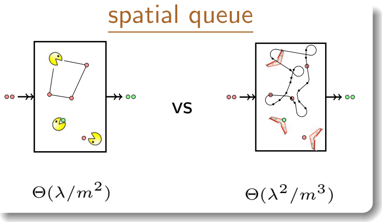

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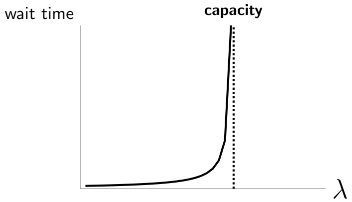
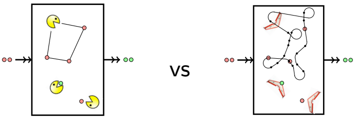
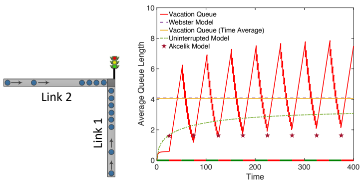


spatial queue



$\Theta(\lambda/m^2)$ $\Theta(\lambda^2/m^3)$

vacation queue



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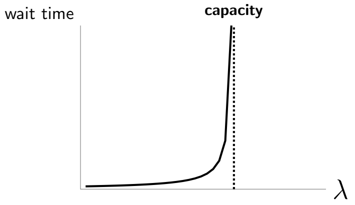

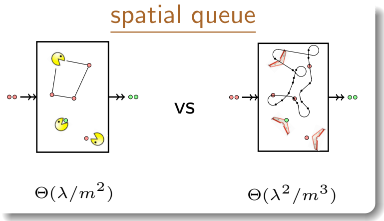

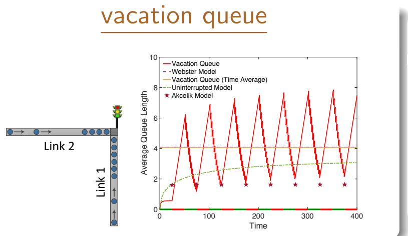

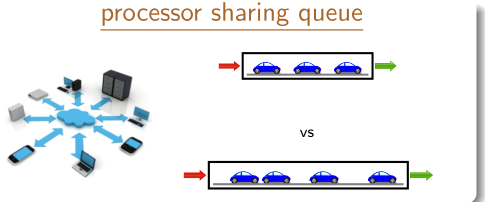

Current Notions of Capacity

Traffic Capacity [Highway Capacity Manual]

- "... maximum number of vehicles that can pass **a given point** ... (assuming) no influence from downstream traffic operation ..."

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$c - f$: local robustness

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Current capacity notions are local

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$$\downarrow$$

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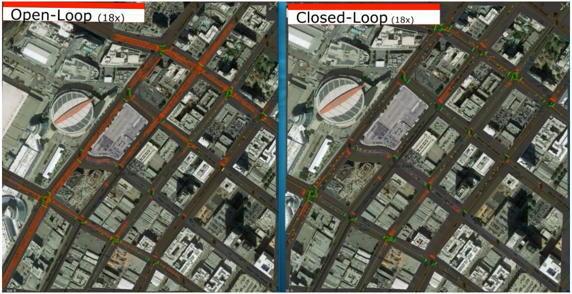
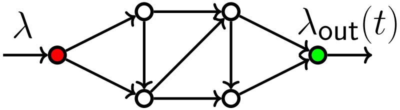
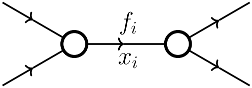
Towards Network Capacity

$$\text{network capacity} : (\{c_i\}, \text{physical constraints}, \text{control})$$



Dynamical Network Flow





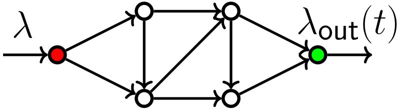
Mass Conservation

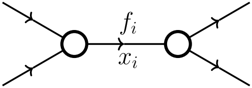
$$\dot{x} = \underbrace{\lambda + R^T(x) f(x,u)}_{\text{inflow}} - \underbrace{f(x,u)}_{\text{outflow}}$$

x_i : queue on link i

$R(x)$: routing matrix

Dynamical Network Flow





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- equilibrium x^*: $\lambda_{\text{out}}(t) = \lambda$
- existence, stability, and robustness of x^*

Distributed Feedback Control

$$\min_u \int_0^T J(x(t), u(t))\, dt$$
$$\text{subj. to} \quad \dot{x} = \text{traffic flow dynamics}$$

- $u \equiv$ ramp metering, variable speed limit, routing

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- distributed computation

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feedback: $u(x)$ [ThC02.3]

- principled distributed control
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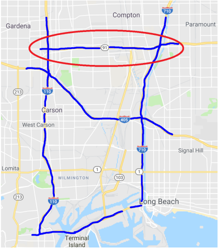
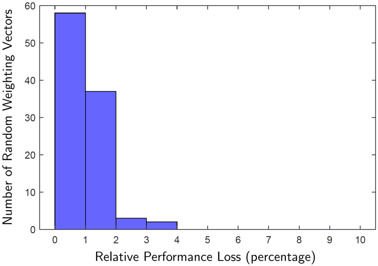
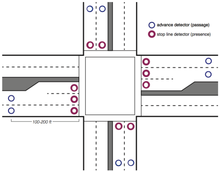




From State to Output Feedback Control



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- y: detector measurement

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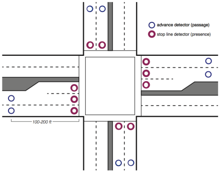

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  $y \to \hat{x} \to u(\hat{x})$

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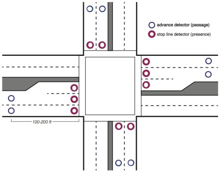

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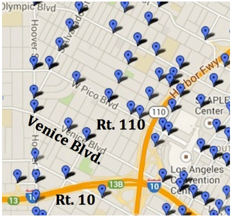

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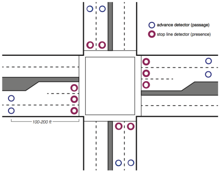

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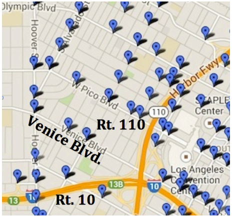

- optimal output feedback traffic signal control

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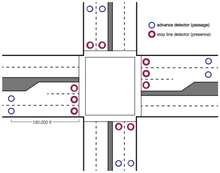

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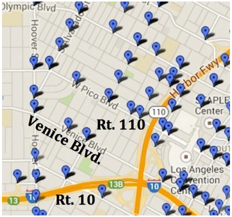

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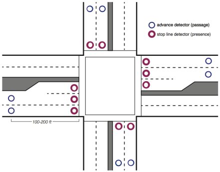

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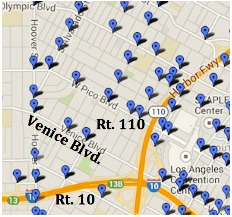

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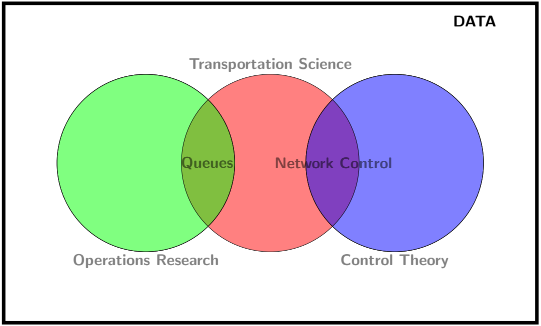
Xtelligent

Concluding Remarks



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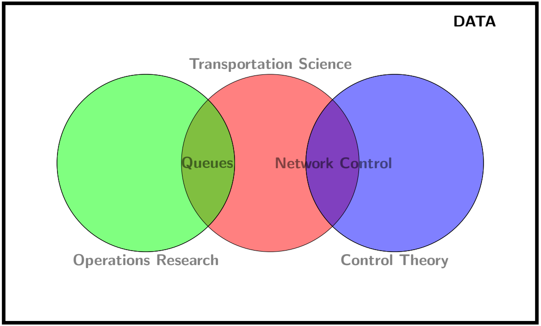

- state-dependent queues
- distributed/output feedback control for nonlinear systems
- . . .