Control of Robotic Mobility-on-Demand Systems: A Queueing-Theoretical Perspective

Rick Zhang and Marco Pavone
Autonomous Systems Laboratory, Stanford University

Jackson Network Model
Modeled from the vehicles’ point of view
- $m$ vehicles, $n$ stations
- $\lambda_i$ - arrival rate of passengers
- $p_{ij}$ - routing probabilities
- $T_{ij}$ - travel times

Traffic Equations:
$$\pi_i = \sum_j \pi_j p_{ij}$$

Stationary Distribution:
$$\Pr(x_1, \ldots, x_n) = \frac{1}{G(m)} \prod_{j=1}^n \frac{\pi_j}{\mu_j(1)}^{x_j} \mu_j(k)^{-1}$$

Relative Utilization:
$$\gamma_i = \frac{\pi_i}{\mu_i(1)}$$

Vehicle Availability:
$$A_i(m) = \frac{1}{G(m - 1)} G(m)$$

Optimal Rebalancing
- Rebalancing-promoting policy using “virtual” passengers with arrival rate $\psi_i$ and routing probabilities $a_{ij}$
- Optimal rebalancing can be formulated and solved as a linear program
- $A_i$ computed using mean value analysis

Balanced System Parameters
- $\lambda_i = \lambda_i + \psi_i$
- $\bar{p}_{ij} = p_{ij} + \gamma_i \lambda_i$

Rebalancing Condition
$$A_j = A_j \iff \gamma_j = \gamma_i$$

Autonomous Mobility-on-Demand
Enable sustainable urban personal mobility through autonomous driving and system-level coordination of autonomous vehicles

Motivation
- Over 3 trillion urban miles driven annually in the U.S.
- Urban world population will double by 2050, mostly in existing cities

Potential Benefits of autonomous MOD
- Higher vehicle utilization, reduced urban parking infrastructure requirement, reduced cost and emissions, and increased safety

Impact on Congestion
Rebalancing increases the number of vehicles on the road. Does it increase congestion as well?

Without Rebalancing
With Rebalancing

With intelligent routing, congestion may not be negatively impacted

Case Study: New York City
- Over 13,000 Taxis in New York City, 85% in Manhattan
- 439,950 taxi trips within Manhattan on March 1, 2012
- Replaced all taxis with an autonomous MOD system with 100 stations
- Simulation performed using a real-time rebalancing algorithm

Contact: Rick Zhang (rickz@stanford.edu), Marco Pavone (pavone@stanford.edu)