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

Rick Zhang
PI: Prof. Marco Pavone

Autonomous Systems Laboratory
Department of Aeronautics & Astronautics
Stanford University

2014 Stanford Aero/Astro Industrial Affiliates Meeting
April 29, 2014
Challenges facing urban mobility

- Urban population will double by 2050, mostly in existing cities!
- Over 3 trillion urban miles driven in the US each year
- Current trends in urban mobility are unsustainable!

Potential Solutions
Challenges facing urban mobility

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Applications for Aviation

- Commuter aviation/regional airlines
- Local aerial tour/rental
Shortcomings of Car Sharing

Car sharing systems become *unbalanced*

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**Don't use Car2go if you have an appointment and need a car at a certain time. Three times I've booked with them via phone and online, and three times the car was NO WHERE TO BE FOUND. What's even worse was when I called to complain and ask for assistance, their British customer service agents blew it big time to pointing me to other cars THAT WERE NOT THERE. Last time I used them I had to go online to search for myself after one of their agents told me there wasn't a car close-by for me to rent. Turns out, he was wrong. There was a car close by, all he had to do was look. Their prices are inflated for this kind of CRAPPY service. I will avoid using them in the future.**

**I can never find one when I need it the most EVER.**

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**Great idea, but there are some really easy to fix flaws that abound (the fact that they have not been fixed means that Car2Go either doesn't have the resources, or is completely inept). The biggest problem I've experienced occurs when someone parks one of the cars in a parking lot that is inaccessible to the public, either because you need an ID card, or straight up in someone's garage. Having to criminally trespass to get a vehicle isn't really worth it... Another problem is a little more difficult to fix, due to unpredictability of usage patterns, but occurs when there isn't a car within a mile of your location. If you have to walk more than 20-30 minutes to find one, that's not very convenient either. Car2Go also doesn't just cost $35 a minute. There are lots of other phantom fees attached. Since you aren't told how long or how much your trip cost upon completion, these fees can sneak up on you when you check your bank balance. Overall, great idea, but they clearly need more employees to address some of these issues.**
Autonomous Mobility-on-Demand

Research Objectives

Car Sharing + Vehicle Autonomy

Objectives:

- Develop a stochastic model of an autonomous MOD system that not only offers insight into system performance but also allows the synthesis of control policies
- Study rebalancing algorithms and evaluate the potential benefits of autonomous MOD systems
Closed 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:

$$\pi_i = \sum_j \pi_j p_{ji}$$

Stationary Distribution:

$$\Pr(x_1, ..., x_N) = \frac{1}{G(m)} \prod_{j=1}^{N} \pi_j^x \prod_{k=1}^{x_j} \mu_j(k)^{-1}$$

Relative Utilization:

$$\gamma_i = \frac{\pi_i}{\mu_i(1)} = \frac{\pi_i}{\lambda_i}$$

Availability:

$$A_i(m) = \frac{\gamma_i G(m - 1)}{G(m)}$$
**Optimal Rebalancing**

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

**Balanced System Parameters**

$$\tilde{\lambda}_i = \lambda_i + \psi_i$$

$$\tilde{p}_{ij} = p_{ij} \frac{\lambda_i}{\tilde{\lambda}_i} + \frac{\psi_i}{\tilde{\lambda}_i} \alpha_{ij}$$

**Rebalancing Condition**

$$A_i = A_j \leftrightarrow \gamma_i = \gamma_j$$
NYC Case Study

- 439,950 taxi trips within Manhattan on March 1, 2012
- 100 stations
- Simulation performed using a real-time rebalancing algorithm
Impact on Congestion

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

**Without Rebalancing**

**With Rebalancing**

- [Image of a network diagram with nodes and arrows indicating traffic flows.]

- [Graph showing the relationship between congestion and rebalancing metrics.]

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**Motivation**

**Research**

**Objectives**

**Model**

**Optimal Rebalancing**

**NYC Study**

**Congestion**
Thank You!

Rick Zhang

rickz@Stanford.edu