Optimal Ride Service For All: Users, Service Providers, and Society

Award #1931827 Starting date: Aug 12, 2019

PIs: Sean Qian and Costa Samaras (Carnegie Mellon University), Bo Zeng (University of Pittsburgh)

How can public agencies work with Uber/Lyft to improve transportation network efficiency and equity?

Challenge.

- Transportation systems face increasing **congestion, emissions, energy use, and infrastructure deterioration.**
- Existing solutions mitigate social costs with incentives.
- Current strategies are **often difficult to design, costly to implement, and inequitable.**

Scientific Impact.

- Proposes a joint technical and social framework to price ride-sharing toward social good.
- Integrates traveler's behavior and service-provider's behavior on the network.
- Provides a novel optimization/control model of infrastructure pricing

Solution.

- Wanted: an **inexpensive**, **effective**, and **fair** incentive system for **demand control** with **voluntary participation**.
- **Ride-sharing services** offer novel opportunities to align travel behavior with **social objectives** and **benefit all stakeholders**.
- This research **investigates**, **pilots** and **validates** a theoretical, modeling and computational **framework** for leveraging a small **fraction of shared passenger vehicles** to **improve system-wide performance**, with a seamless and **inexpensive integration** of a **system of incentives** regarding travelers' choice of departure times, routes, pooling and pick-up/drop-off curbs.

Broader Impact:

- Improves understanding of how public right-of-way and ride-sharing can be leveraged for social good.
- Planners and policymakers need new tools to understand the impact of coordinated fleets.
- Findings and methods will be incorporated into graduate courses.

This research supports **improved**

- Individuals travel experience
- Service provider's revenue
- Social welfare on the road network.

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Objectives

Connected and autonomous technologies have enabled **ad hoc fleets** which may be easily **coordinated over the internet** to optimize **a fleet-level objective**.

This behavior is **neither user-optimal nor system optimal**. We investigate **the impact of fleet optimal routing** on other road users and network efficiency.

Fleet Optimal Route Choice

Fleet vehicles choose routes to **minimize total fleet travel time**

$$z^{\text{fleet}} = \sum_a \boldsymbol{x}^{\text{fleet}} \boldsymbol{t}(\boldsymbol{x}^{\text{fleet}} + \boldsymbol{x}^{\text{other}})$$

while non-fleet vehicles act individually to **minimize their own travel time**. The system reaches a **mixed equilibrium** at **x**.

$$\langle \dot{\boldsymbol{t}}(\boldsymbol{x}^{\text{fleet}}, \boldsymbol{x}^{\text{other}}), \boldsymbol{y}^{\text{fleet}} - \boldsymbol{x}^{\text{fleet}} \rangle \geq 0 \ \forall \boldsymbol{y}^{\text{fleet}}$$

$$\langle \boldsymbol{t}(\boldsymbol{x}^{\text{fleet}} + \boldsymbol{x}^{\text{other}}), \boldsymbol{y}^{\text{other}} - \boldsymbol{x}^{\text{other}} \rangle \geq 0 \ \forall \boldsymbol{y}^{\text{other}}$$

This **mixed equilibrium** reduces to user equilibrium and system optimal at its extremes.

0% fleet ← Mixed equilibrium → 100% fleet

User Equilibrium — System Optimal

Research Plan

Refine theoretical understanding

- Establish intuitive conditions under which mixed equilibrium is better/worse than user equilibrium.
- Determine the smallest fleet size required to achieve system optimal flow in several real-world road networks.

Construct policy interventions

- Formulate a pricing/incentive scheme for fleets to push the network toward system optimal flow.
- Solve the resulting mathematical program with equilibrium constraints (MPEC) on several real-world road networks.

Construct Real-time pricing

- Solve optimal policy in a stochastic dynamic network with real-time demand and pricing.

Key Findings

- Mixed equilibrium can be efficiently computed given fleet and individual traveler demand.
- At certain fleet sizes, fleet optimal routing may **increase system cost**.
- A sufficient condition is identified under which mixed equilibrium **improves system cost** over user equilibrium.
- The smallest fleet size to achieve system optimal cost, the **Critical Fleet Size**, is found via a mixed integer program.
- On the Sioux Falls network, the critical fleet size is found to be ~35% of the total demand.

Future Work

- Investigate system cost as a function of fleet penetration in several real-world networks
- Investigate critical links and origin destination pairs in system optimal achieving mixed equilibrium.