Sustainable Passenger Transportation: Dynamic Ride-sharing

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Joint work with
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Motivation

- Observations
  - Congestion is a major issue in urban areas around the world
  - Congestion leads to
    - Loss of productivity
    - Wasted fuel
    - Pollution
  - Private car occupancies are low
    - Average of 1.8 for leisure trips
    - Average of 1.1 for commuting trips
Motivation

- Opportunity
  - Effective use of empty car seats can
    - Reduce congestion
    - Reduce pollution
    - Increase productivity

Enabling technology exists
- GPS-enabled mobile devices
- Mobile-to-mobile communication
- Route guidance technology

Dynamic Ride-Sharing
- Mobile-to-mobile communication
- Route guidance technology
Outline

- Introduction to dynamic ride-sharing
- Comparison with on-demand transportation
- Dynamic ride-sharing variants
- Multi-modal transit systems
- Key challenges
- Research opportunities
Dynamic ride-sharing: basics

1. Announcement of trips
2. Matching of drivers and riders
3. Execution of identified trips
4. Sharing of trip costs

Assumption: if no trip is identified, drivers and riders use their own car to reach destination
Dynamic ride-sharing: features

- Dynamic: established on short-notice
- Non-recurring trips: different from carpooling
- Automated matching: different from online notice-boards
- Independent drivers: different from taxis
- Cost-sharing: variable trip related expenses
- Prearranged: different from spontaneous, casual ride-sharing
Dynamic ride-sharing: providers

- IPhone applications:
  - Participate (Aug. ‘08)
  - Avego (Dec. ‘08)
- Google Android applications:
  - Piggyback (May ‘08)
- Web-based:
  - Zebigo, PickupPal, Nuride, Rideshark, Ridecell, Goloco, Zimride, …, etc.
What is in it for participants?

- Save costs by sharing fuel expenses and tolls
- Save time through use of HOV-lanes
- Save the planet
What is in it for providers?

- **Private**: take a cut of the participant’s cost savings

- **Public (society)**: decrease external costs of transportation: emissions, pollution, and traffic congestion
Objectives

- Participants: ↓ travel costs
- Private ride-share provider: ↓ total travel costs ⇒ ↑ cut
- Society: ↓ pollution and traffic congestion

⇒ Objectives are aligned: ↓ system-wide vehicle miles, win-win-win
Time is crucial

- Time is likely to be more constraining than out-of-distance or the number of spare seats.

- Information exchange: departure time alone may not suffice.
  - departure time flexibility?
  - travel time flexibility?
Time model

- Time window for matching
- Flexibility
- Direct travel time

- Announcement time
- Earliest departure time
- Latest departure time
- Latest arrival time
Inter-personal constraints

- smoking ↔ non-smoking
- female ↔ male
- friends ↔ strangers
- subsets of feasible ride-share partners?

⇒ integration with social networking tools!
How to divide the trip costs?

- Allocate trip costs (savings) proportional to the original trip costs?

- Financial aspects handled by provider
Related problems/literature

- Unscheduled, on-demand passenger transportation
  - ✔ Dial-a-ride
  - ✔ Taxi
  - ✔ Mobility Allowance Shuttle Transport
- Carpooling
- Scheduled passenger transportation
Comparison with on-demand passenger transportation

- **Product:** door-to-door transportation
- **Capacity:** company vehicles ↔ independent private drivers
- **Revenues:** ticket price ↔ cost-sharing
- **Route:** round-trip from depot ↔ one way from driver’s origin to destination
- **Dynamics:** new requests ↔ new riders and new drivers
<table>
<thead>
<tr>
<th></th>
<th>Single rider</th>
<th>Multiple riders</th>
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<tbody>
<tr>
<td>Single driver</td>
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<tr>
<td>Multiple drivers</td>
<td>Bipartite Matching = easy</td>
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Illustrative example: Single driver – single rider

- 3 drivers
- 2 riders
- Earliest departure / latest arrival time

- Travel time ~ travel distance
- Miles = minutes (60mph)
Announced trips
Incompatible ride-share pair: d3-r1

Time infeasible!
Incompatible ride-share pair: d1-r2

No savings!
Bipartite matching

Drivers

Riders

weight = cost savings
Bipartite matching

Drivers

d1

d2

d3

Riders

r1

r2

Solution:

d1-r1

d2-r2

weight = cost savings

weight =

cost savings
Optimal solution

17% savings in system-wide vehicle miles!
System versus user benefits

Drivers

Riders

d1  2.4  r1

2.8

2

1.4

d2  r2
d3

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User benefits
## Dynamic ride-share variants

<table>
<thead>
<tr>
<th>Single driver</th>
<th>Single rider</th>
<th>Multiple riders</th>
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<tbody>
<tr>
<td></td>
<td><strong>Easy</strong></td>
<td><strong>Difficult</strong></td>
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<tr>
<td></td>
<td><em>(Bipartite Matching)</em></td>
<td><em>(Routing)</em></td>
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<tr>
<td>Multiple drivers</td>
<td><strong>Difficult</strong></td>
<td><strong>Difficult</strong></td>
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<tr>
<td></td>
<td><em>(Transfers)</em></td>
<td><em>(Routing + Transfers)</em></td>
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Multi-modal transit systems

- Ride-sharing as feeder for public transport e.g. first and last mile to and from station
- Taxis as backup option for ride-sharing?

⇒ Multi-modal system design
What are the key challenges to implementation?
1. Reaching a critical mass

- How to ensure participation in the start-up phase when service is low?
- What kind of incentives can be offered?
- What role should (local) government and business communities play?
- What role can/should taxis play?
2. Effectively handling the dynamics

New drivers and riders continuously enter and leave the system!

- When to *commit* to a ride-share?
- What response time is *acceptable* for users?
- Should en-route matching be considered?
3. Ensuring safety and reliability

- Reputation systems: let ride-share partners rate each other!
- Reward good ratings!
- Use GPS-technology to monitor trip behavior

- Back-up options / Return trips
3. Ensuring safety and reliability

- Use social network tools to match up friends and friends-of-friends
- What kind of social networks are conducive to ride-sharing?

⇒ shape of social network
⇒ position in network, number of friends
⇒ overlap between professional and private networks
⇒ geographic density
How can the transportation-optimization community contribute?
Basic research opportunities

- **Optimization**
  - ✓ Fast matching algorithms
    - Single rider, single driver
    - Multiple riders per trip (routing)
    - Multiple drivers per trip (transfers)
  - ✓ Handling of system dynamics
    - Rolling horizon framework
  - ✓ Incentive schemes
  - ✓ Multi-modal settings (ride-sharing & public transit)

- **Simulation**
  - ✓ Create an environment to study impact of system characteristics
  - ✓ Create an environment to advice policy makers
An instance generator
A simulation environment based on traffic model data from Atlanta Regional Council
Matching technology for single rider – single driver setting
Dynamic Ride-Sharing Simulation of Metro Atlanta

- **Metro Atlanta**
  - population: 4.70 million
  - area: 4 million acres (16,000 km²)

- **Traffic Model Atlanta Regional Council**
  - 2024 Traffic Analysis Zones (TAZs)
  - # work-related round trips per day: 2.96 million
  - ~ 60% single occupancy trips
  - # O-D pairs: 2.90 million
  - max # trips per O-D pair: 881
  - min # trips per O-D pair: 0.01
Future research opportunities

- More realistic travel time settings
  - Time-dependent travel times
  - Real-time travel times

- Behavioral modeling
  - Match acceptance
  - Cancelations
  - No-shows

- Variability
  - Late driver departure
  - Late rider departure

- ...
Future research opportunities (cont.)

- Optimization
  - Centralized vs. decentralized matching
  - Buffering vs. no buffering
  - Anticipating future announcements
  - ...

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Thank You