Research, Practice, and Future Directions of Dynamic Ridesharing

M.M. Dessouky, S. Koenig, M. Furuhata, X. Wang, H. Xu
University of Southern California
F. Ordóñez, U.Chile

Outline

- Overview
- Market Mechanism (Sven)
- Agent Systems (Maged)
- Computational and Planning Tools (Fernando)
- Conclusions and Future Work
- Freight Projects

Opportunity for Ridesharing

- According to the U.S. Department of Transportation more than 10% of the GDP is related to transportation activity
- The 2012 Urban Mobility report estimates the cost of congestion in the US to be on the order of $121 billion and 5.5 billion hours in delayed time
- There exists a significant amount of unused capacity in the transportation network
- A multi-year project funded by FHWA Exploratory Advanced Research Program Broad Agency

Project Overview

- Emerging information technologies have made available a wealth of real time and dynamic data about traffic conditions
  - GPS systems both in vehicles/phones
  - interconnected data systems
  - on-board computers

- The Transportation Market:
  - distributed system based on auction mechanisms leading to an automated negotiation of routes and prices between consumers and providers of transportation in real-time.
- Rather than just taxis and buses, anyone with a car could offer to sell their unused vehicle capacity to other riders

Make every car a taxi

Basic Ridesharing Definitions

- Ridesharing is a joint-trip of more than two participants that share a vehicle and requires coordination with respect to itineraries and time

- Unorganized ridesharing
  - Family, colleagues, neighbors
  - Hitchhiking

- Organized ridesharing
  - Matching of driver and rider
  - Can require
    - Service operators
    - Matching agencies

Slugging

Evolution of Ridesharing

- Car Sharing Club: govt organized to conserve fuel during WWII
- 3M and Chrysler provided vans for commuting during the1970 Oil Crisis
- Carpooling:
  - Drivers take turns driving
  - Supported by employers
- Spontaneous ridesharing (location)
  - Slugging (Wash D.C.)
  - Casual Carpooling (San Francisco, Houston – fixed price)
- Matching agencies emerged with Internet
  - Cost-sharing systems (Carma, Flinc)
  - Revenue maximizing systems (Uber, Sidecar, Lyft, etc)

Matching Consolidation

- Organize information flow (listing and searching)
  - Most common
  - Provide a venue to advertise rides and look for matches

- Physically consolidate demands
  - Set ridesharing routes
  - Major stops (with consolidated pickup)

- Extend matching time
  - Using GPS and mobile technologies to track and communicate with drivers
  - Dynamic/ real time ridesharing

Ridesharing Challenges and Research

- High-dimensional Matching
- Trust and Reputation
- Mechanism Design
- Cost of Ridesharing (Agent Systems)
- Institutional Design (Computational Planning Tools)

Example: High-dimensional Matching

- Ride preferences have many dimensions
  - Type of vehicle
  - Flexibility of route
  - Gender
  - Cost
  - Travel time
- Software assistants can help with
  - How to balance different criteria
  - Multiple rides for a trip
  - Transfer points
  - Which routes to take to maximize possibility of Ridesharing

Example: Trust and Reputation

- Implementation of large scale word of mouth systems (reputation systems)
  - Used in Carma, Carpool World, Goloco
    - New users
    - Bias toward positive comments (retaliation threat)
- Escrow Mechanisms
  - Intermediary that forwards payment and collects feedback
  - Issues with incentive compatability, efficiency.
- Use of Social Networking Sites (SNS)
  - Get to know the driver/rider
  - ZimRide, Carma, Carticipate

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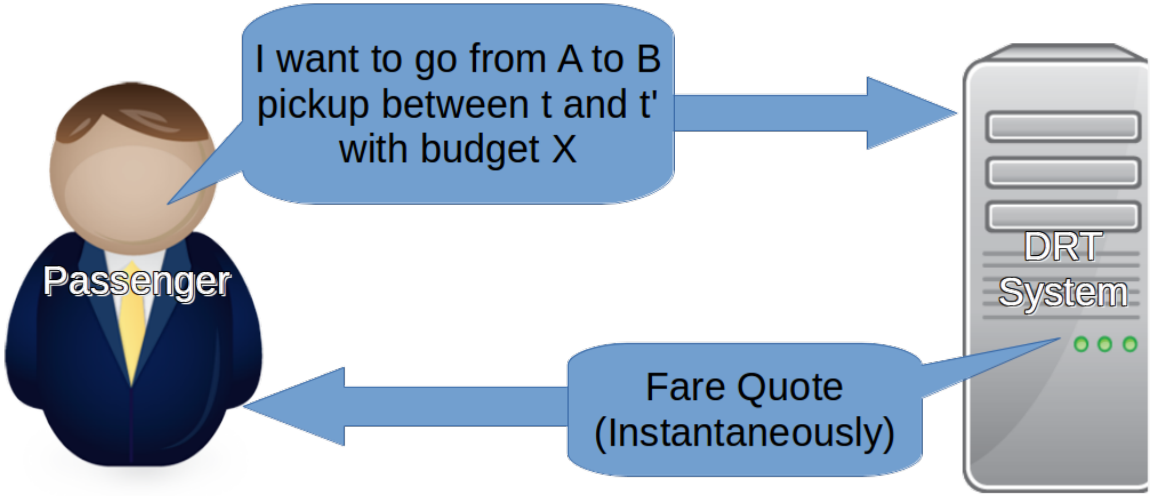
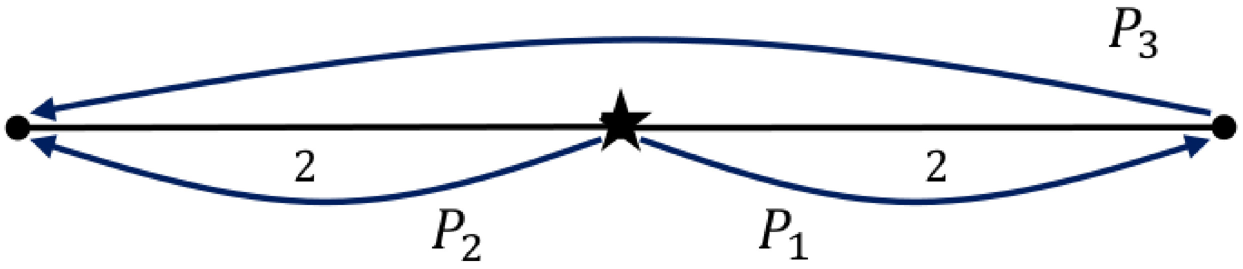
Our Setting

- Share the ride costs fairly and without any subsidies.
- Make sure passengers have no reason to drop out after accepting their fare quote.
- Motivate passengers to submit requests early. This allows the system to maximize serviced passengers.

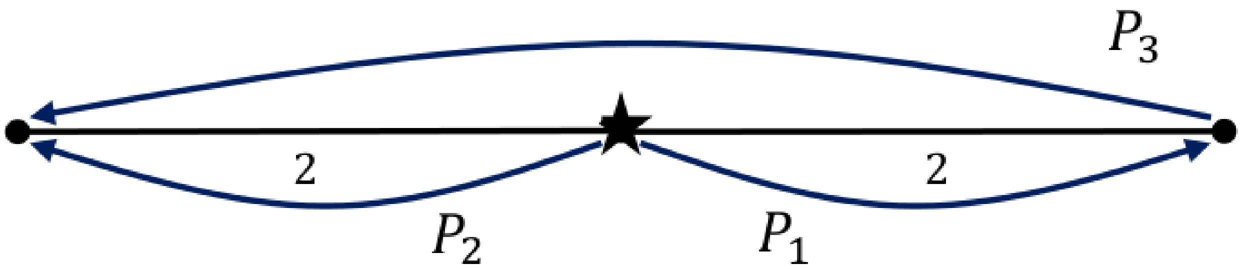


Example



	k=1	k=2	k=3
Distance	2	2	4
Total Cost	20	60	60
Marginal Cost	20	40	0
Shared Cost	?	?	?

Example

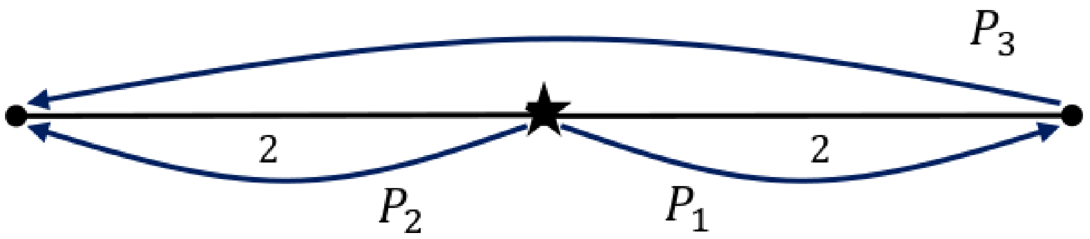


	k=1	k=2	k=3
Distance	2	2	4
Total Cost	20	60	60
Marginal Cost	20	40	0
Fixed-Fare	10	10	10
Incremental	20	40	0
Proportional	15	15	30

Desirable Properties

- **Budget balance**
  The total cost is shared by all (serviced) passengers.
- **Immediate response**
  The passengers' costs are monotonically nonincreasing (in time).
- **Online fairness**
  The costs per distance unit are monotonically nonincreasing (in passengers' arrival order).
- **Truthfulness**
  The best strategy of every passenger is to arrive truthfully (provided that all other passengers arrive truthfully and none change whether they accept).

Desirable Properties



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- ✗ Budget balance (e.g., Fixed-Fare)
- ✗ Immediate response (e.g., Proportional)
- ✗ Online fairness (e.g., Incremental)

POCS

- Proportional Online Cost-Sharing is a mechanism that provides low fare quotes to passengers directly after they submit ride requests and calculates their actual fares directly before their rides.
- POCS calculates shared-costs by:

$$cost^{t}_{\pi(k)} := \alpha_{\pi(k)} \min_{k\leq j\leq t} \max_{1\leq i\leq j} \underbrace{\frac{\sum_{l=i}^{j} mc_{\pi(l)}}{\sum_{l=i}^{j} \alpha_{\pi(l)}}}_{ccpa_{\pi(i,j)}}$$

POCS

- POCS is a mix of
  - **marginal** cost-sharing (with respect to coalitions)
  - **proportional** cost-sharing (with respect to passengers within a coalition)

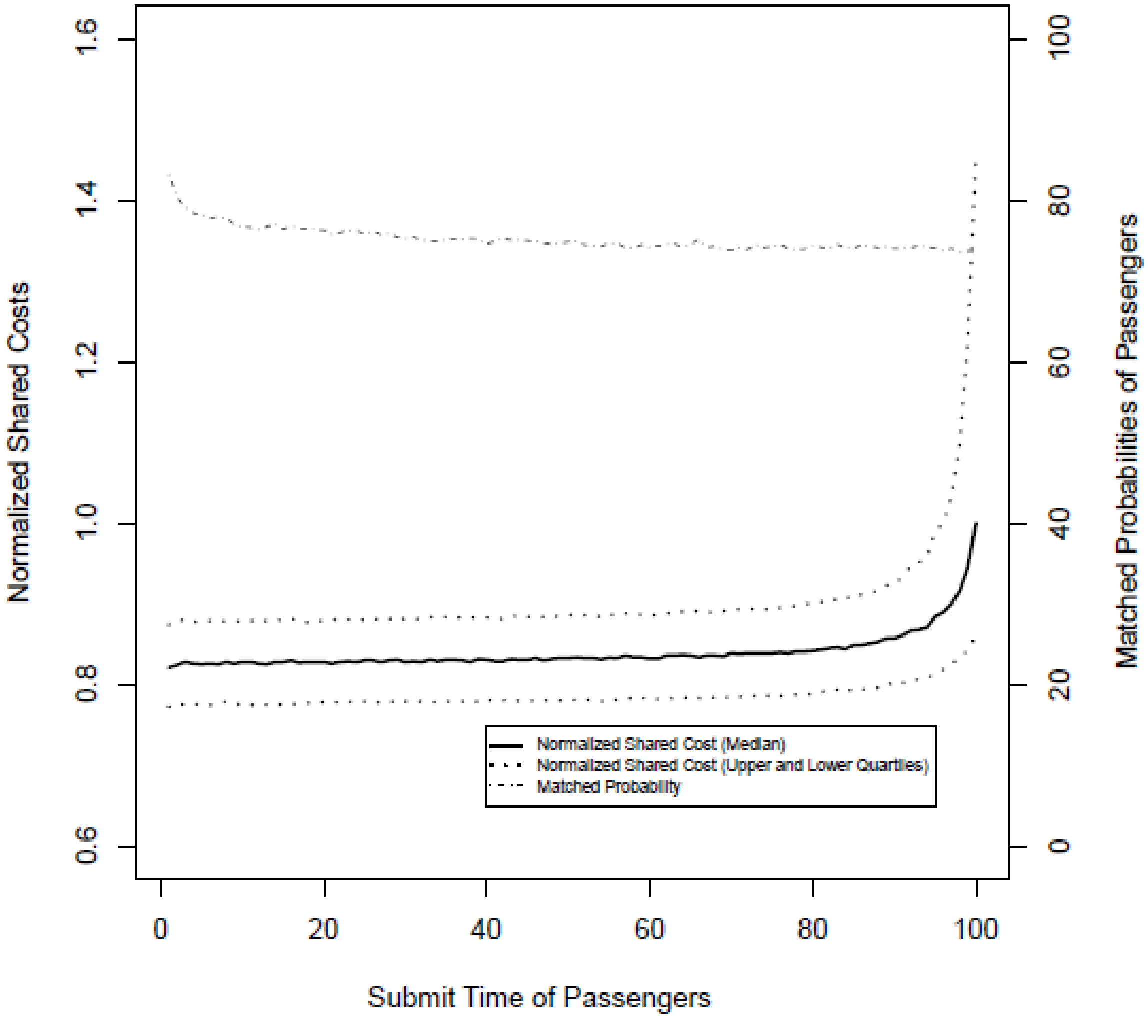
Simulation

- Transportation Market simulator
- POCS
- Vehicle routing: Insertion heuristic + Tabu search
- Demonstrate how submit time influences shared costs and matching probabilities

Simulation Setting

- 11 x 11 grid city
- 10,000 runs
- 25 identical shuttles
  - Initial location: a depot
  - Capacity: 10 seats
  - Operating hour: dawn to dusk
  - Identical speed and gas mileage
- 100 non-identical passengers
  - Random OD-pair
  - Sequential request submission
  - Random drop-off time window
  - Random fare limit

Simulation Results



Summary

- POCS is a cost-sharing mechanism
- Provide fare quotes without knowledge of future arrivals
- Satisfy desirable properties
- Has an intuitive water-flow model
- Is (in some sense) unique

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Computing Cost of Ridesharing

- High Occupancy Vehicle (HOV) lanes
  - Time savings: About 36.5% of saving for HOV lanes in peak hour (LA County Metrop. Transp. Authority, 2002)
- Reduced toll rate on high occupancy vehicles
  - Cost reduction: 50% off the regular toll for California state-owned toll bridges (Bay Area Toll Authority)

- A vehicle pickup and delivery problem considering congestion
  - total distance
  - total customer ride time
  - total toll fee

Model Formulation

- Objective function

Minimize:

$$\sum_{i\epsilon N_P} \underset{\substack{\uparrow\\ \text{customer ride time}}}{\beta * (v_{n+i} - v_i)} + \sum_{(i,j)\epsilon A} (\gamma * \underset{\substack{\uparrow\\ \text{distance}}}{D_{i,j} * x_{ij}} + \underset{\substack{\uparrow\\ \text{toll cost}}}{\mu * c_{ij}}) + \sum_{(i,n+i)\epsilon A} \underset{\substack{\uparrow\\ \text{taxi}}}{\lambda * D_{i,n+i} * u_i}$$

Model Formulation

- Min $\sum_{i \epsilon N_P} \beta * (v_{n+i} - v_i) + \sum_{(i,j) \epsilon A} (\gamma * D_{i,j} * x_{ij} + \mu * c_{ij}) + \sum_{(i,n+i) \epsilon A} \lambda * D_{i,n+i} * u_i$

service all requests

$$\sum_{j \epsilon N} x_{ij} + u_i = 1 \qquad i \epsilon N \backslash \{2n+2\}$$

$$\sum_{i \epsilon N} x_{ij} + u_j = 1 \qquad j \epsilon N \backslash \{2n+1\}$$

MTZ constraints

$$v_i + t_{ij} \leq v_j + \mathrm{M}(1 - x_{ij}) \qquad i \ \epsilon N \quad j \epsilon N$$

$$E_i \leq v_i \leq L_i \qquad i \epsilon N$$

index i before j

$$b_{ki} \leq b_{kj} + (1 - x_{ij}) \qquad (i,j) \epsilon A \backslash (2n+2,2n+1) \qquad k \epsilon N \backslash \{i\}$$

no. passengers

$$z_i = G_i * (1 - u_i) + \sum_{m \epsilon N} (b_{mi} * G_m) + O * (1 - u_i) \qquad i \epsilon N$$

capacity

$$z_i \leq Ca \qquad i \epsilon N$$

time-cost/pass

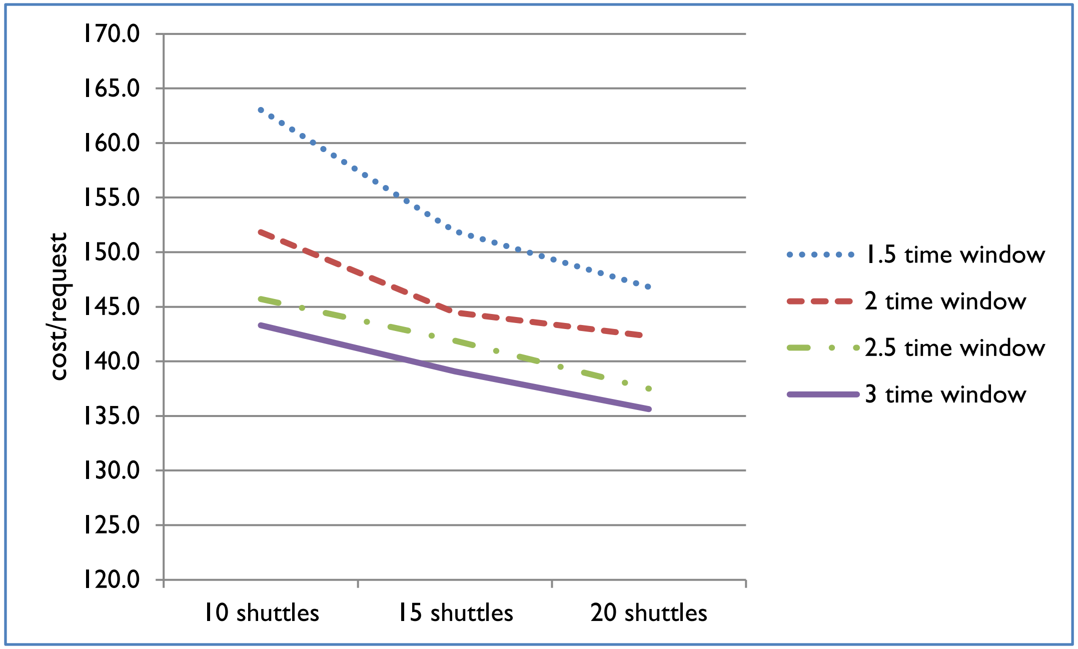
$$t_{ij} \geq T_{ijk} - |z_i - k| * M \qquad (i,j) \epsilon A \qquad k = 1,2 \ldots Ca$$

$$c_{ij} \geq C_{ijk} - |z_i - k| * M - \left(1 - x_{ij}\right) * M \qquad (i,j) \epsilon A \qquad k = 1,2 \ldots Ca$$

Simulation Parameters

- **100 requests**
- **Varied time window to be multiples of direct ride time with TW= 1.5, 2, 2.5 and 3**
- **Varied the number of drivers: 10, 15, and 20**
- **Number of people picked up per request is discrete uniform random number from 1 to 3**
- **Map: 16 by 10 grid (160 nodes, and each edge 10 kilometers)**
- **50 of the 294 randomly chosen to be toll roads ($9 fee)**
- **147 out of the remaining 244 edges contain HOV lanes (117 HOV2, and 30 HOV3)**
- **Travel time reduction per edge of 3 minutes for HOV2 and 4 minutes for HOV3**
- **Also, toll fee is waived if there are multiple people on the vehicle**

Cost/request for Different α's Using Congestion-Tabu

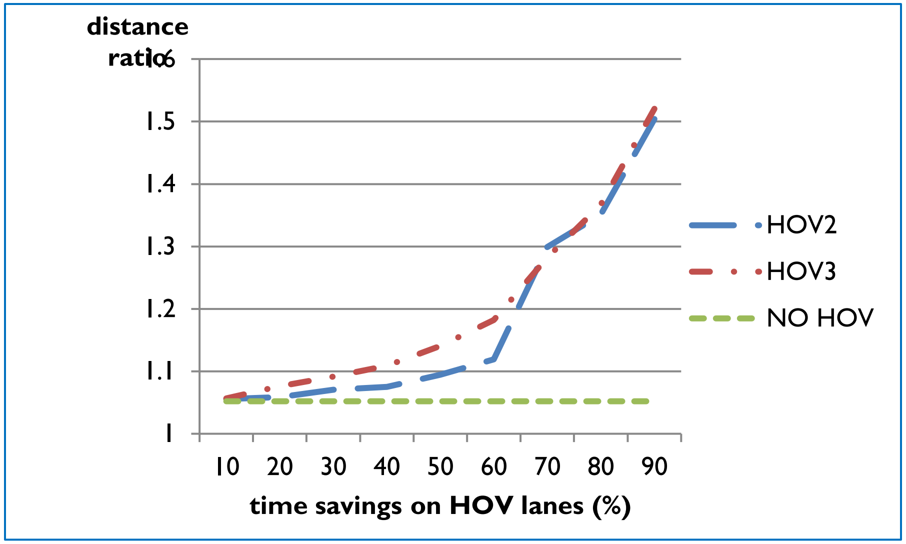


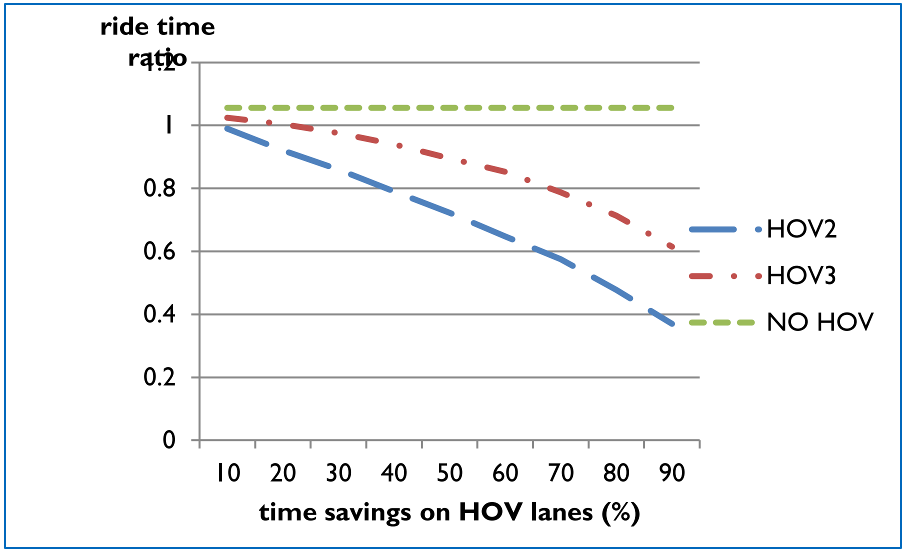
*100 requests

Ratio Comparison

$$distance\ ratio = \sum_{all\ i \in request\ set} \frac{real\ distance\ i\ travelled}{distance\ if\ i\ travel\ alone}$$

$$ride\ time\ ratio = \sum_{all\ i \in request\ set} \frac{real\ ride\ time\ i\ travelled}{ride\ time\ if\ i\ travel\ alone}$$

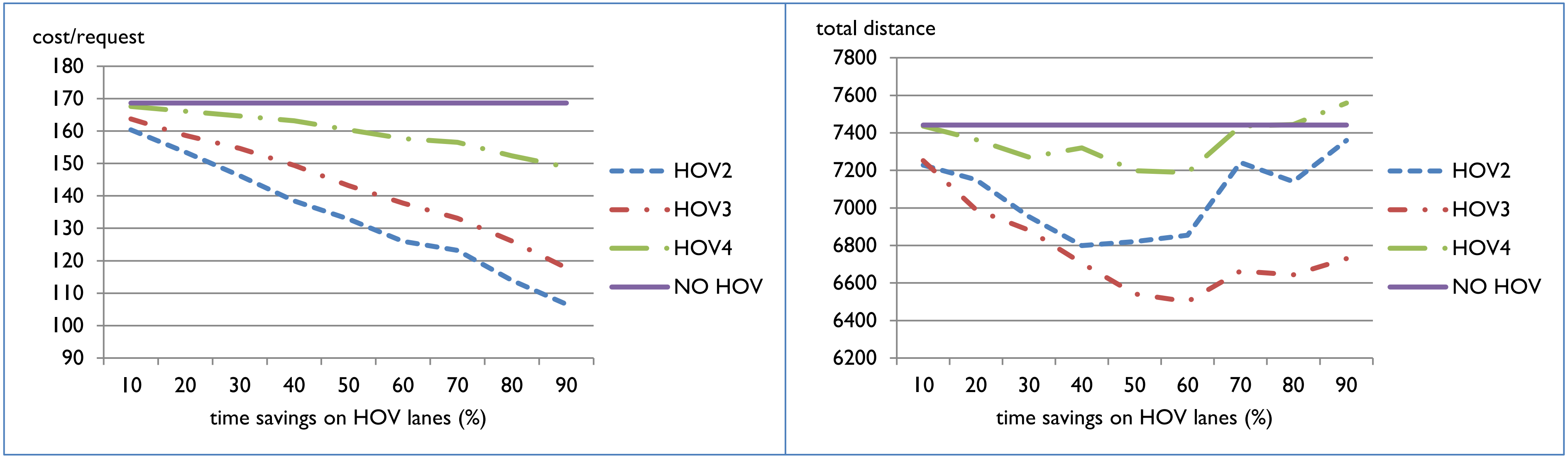




*100 requests

Value Comparison

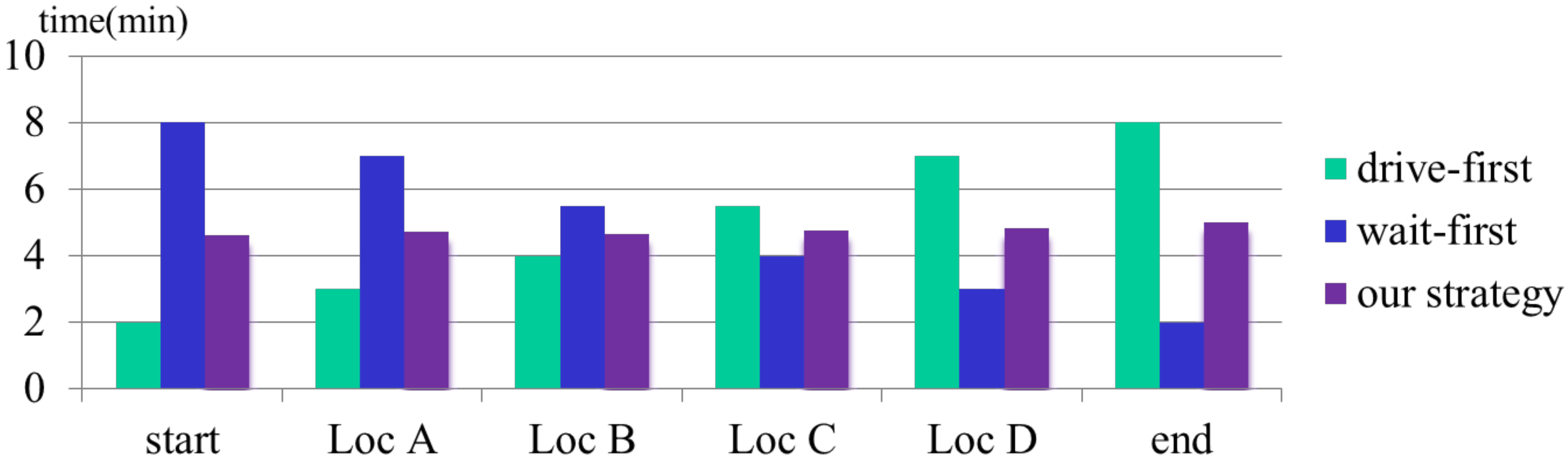
$$cost/request = \frac{objective\ cost}{total\ number\ of\ requests}$$



*100 requests

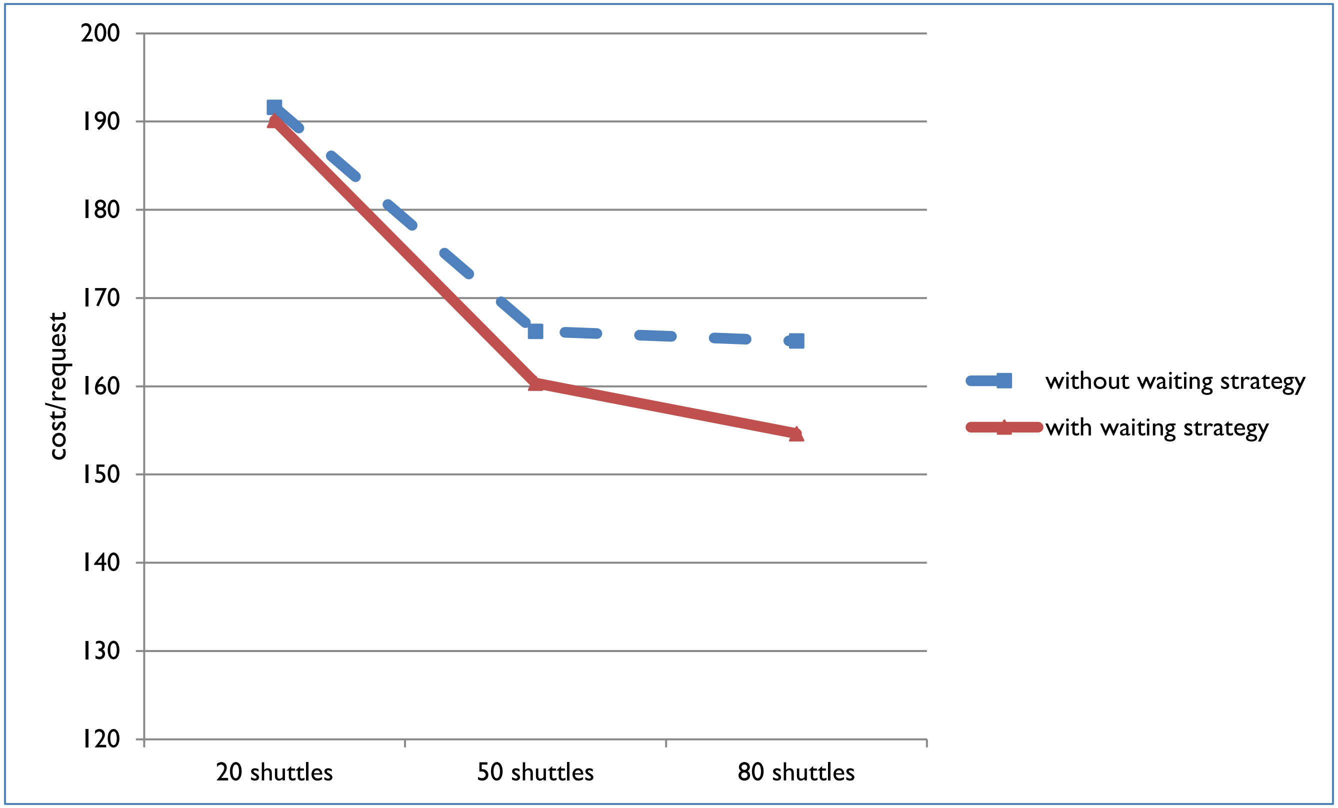
Waiting Strategy

- Drive-first waiting strategy: drive as soon as possible.
- Wait at the current location as long as it is feasible.
- Our strategy: try to evenly assign the slack time of the route to increase the possibility to serve more requests.



Dynamic Case

Comparison of cost/request between with and without waiting strategy



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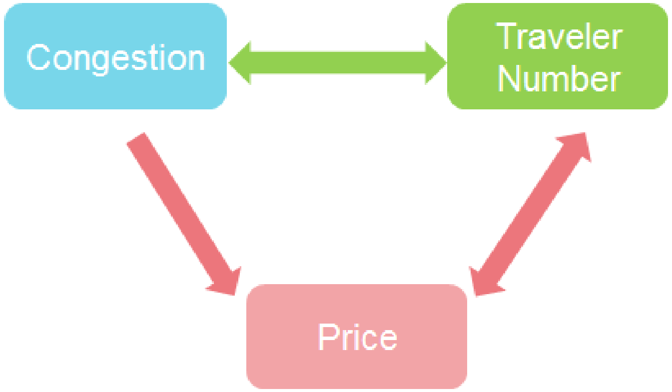
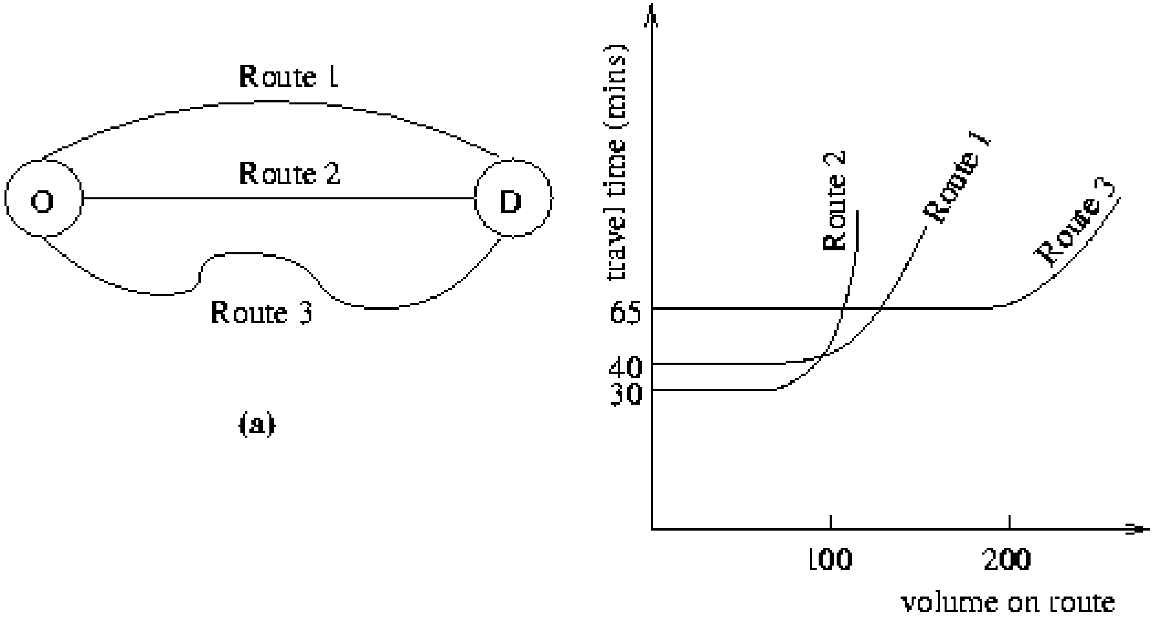
Example: Institutional Design

- How to support ridesharing
- Costs involved vs benefit
- Traffic assignment with ridesharing
  - Ridesharing brings new features to TAP
    - The cost/price of ridesharing is determined by the number of people participating
    - The offer for shared rides (capacity of transportation mode) varies with congestion and price.



Computational and Planning Tools

- Traffic Equilibrium
  - Assume every passenger wants to minimize own travel time
  - Passengers on the transportation market have a travel time, cost, but cause minimal additional congestion



(a)

Computational and Planning Tools

- Modified equilibrium models:
  - OD pair split between driver and riders
  - more congestion → more attractive to be a rider
  - more riders → reduce congestion
  - there is an equilibrium price for transportation market
- Two versions
  - Model 1: ridesharing between same OD pair, elastic demand, no capacity.
  - Model 2: ridesharing between all OD pairs, constant demand, vehicle capacity.

- How parameters modify traffic equilibrium?

Conclusion

- Goals:
- Make good decisions
- In real time
- For selfish participants
- In a market with a huge number of other participants
- Under uncertainty and incomplete information

- Requires an integrated approach:
- Distributed optimization
- Agents and user-interfaces
- Computation of large scale equilibria
- Planning under uncertainty

Freight Projects: Transportation Sharing

- National Science Foundation, Supply Chain Consolidation and Cooperation in the Agriculture Industry

- AQMD, Freight Load Balancing and Efficiencies in Alternative Fuel Modes

- National Science Foundation, CPS: Synergy: Load Balancing for Multimodal Freight Transportation

- Metrans, An Online Cost Allocation Model for Horizontal Supply Chains