Dynamic Ridesharing

M.M. Dessouky, University of Southern California
F. Ordóñez, Universidad de Chile

- Engineering Tomorrow’s Transportation Market

DOT-FHWA

M.M. Dessouky, S. Koenig, F. Ordóñez

M. Furuhata, X. Wang, H. Xu, K. Daniel, L. Cohen

Opportunity for Ridesharing

- According to the U.S. Department of Transportation more than 10% of the GDP is related to transportation activity

- The 2015 Urban Mobility report estimates the cost of congestion in the US to be on the order of $160 billion and 7 billion hours in delayed time

- 87% of all trips occur in a personal vehicle
  38% of all trips are single occupant (NHTS)

Project Overview

- New information technologies => a wealth of real time and dynamic data about traffic conditions
  - GPS systems both in vehicles/phones
  - interconnected data systems
  - on-board computers

- Engineering Tomorrow's Transportation Market:
  - distributed system transportation market where consumers and providers of transportation negotiate route and prices in real-time.
- 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
  - Slugging
- Organized ridesharing
  - Matching of driver and rider, requires
    - Service operators
    - Matching agencies
  - Cost-sharing systems (Carma, Flinc)
  - Revenue maximizing systems/e-hailing (Uber, Sidecar, Lyft, etc)

Ridesharing Challenges and Research

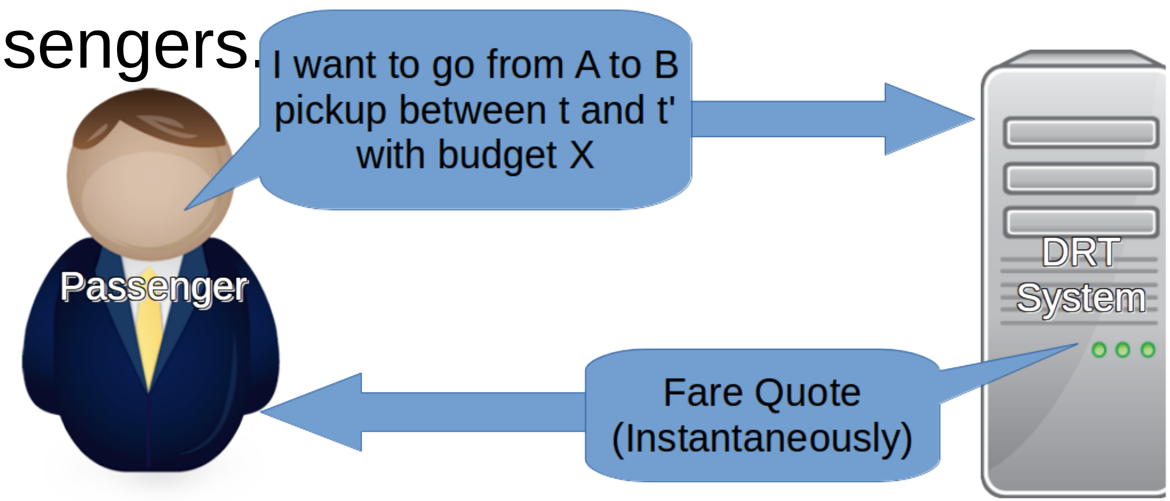
- High-dimensional Matching
- Trust and Reputation
- Mechanism Design
- Cost of Ridesharing
- Institutional Design

Ridesharing Challenges and Research

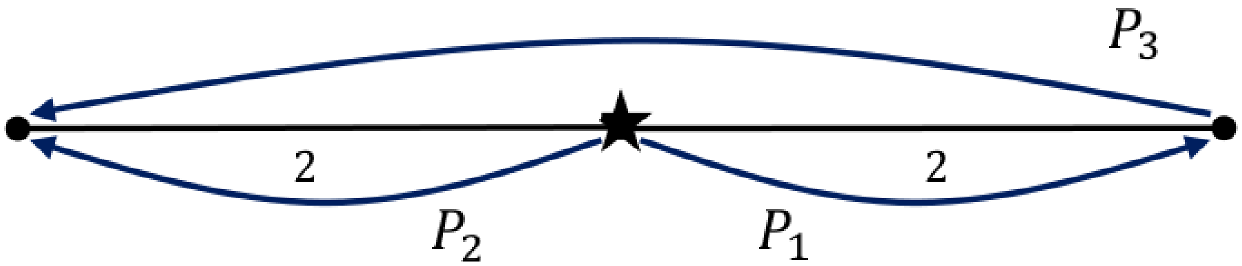
- High-dimensional Matching
- Trust and Reputation
- Mechanism Design
- Cost of Ridesharing
- Planning

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.

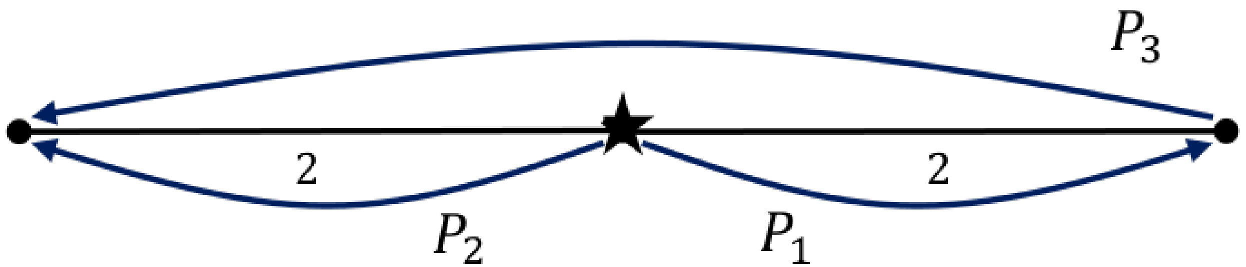


Example



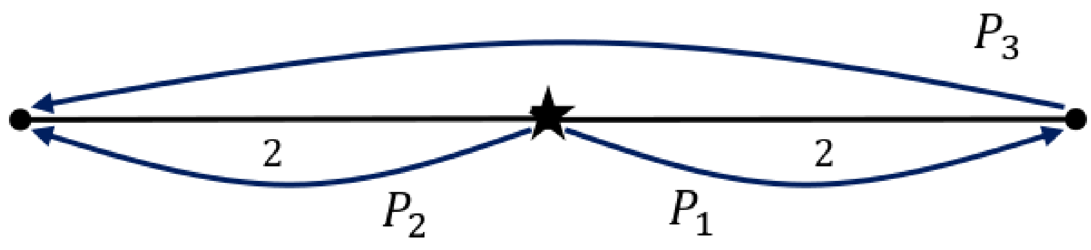
	k=1	k=2	k=3
Distance	2	2	4
Total Cost	20	60	60
Marginal Cost	20	40	0
Shared Cost	?	?	?

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



	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

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

Desirable Properties

- **Budget balance**
  The total cost is shared by all serviced passengers.
- **Immediate response**
  The passengers' costs are monotonically non-increasing (in time).
- **Online fairness**
  The costs per distance unit are monotonically non-decreasing (in passengers' arrival order).
- **Truthfulness**
  The best strategy of every passenger is to declare trip as early as possible
- **Rationality**
  Shared cost of serviced passengers <= fare limits

POCS

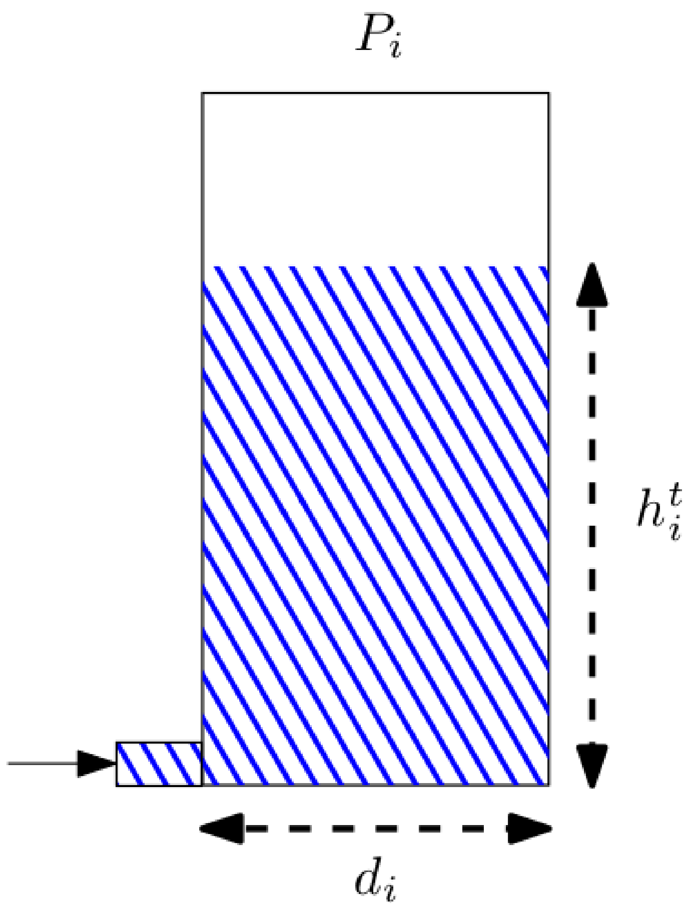
- Proportional Online Cost-Sharing is a mechanism that provides low fare quotes to passengers directly after they submit ride requests and calculates their actual fares directly before their rides.
- POCS calculates shared-costs by:

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

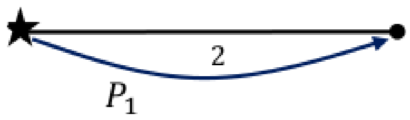
POCS

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

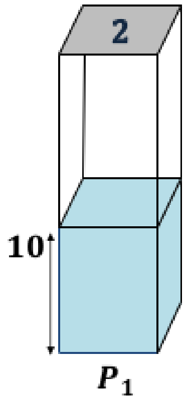
Water-Flow Analogy



Example

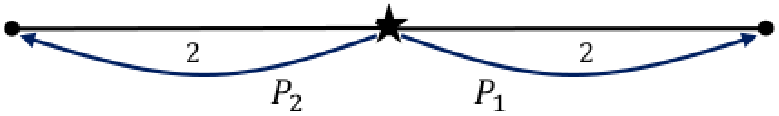


	k=1
Distance	2
Marginal Cost	20

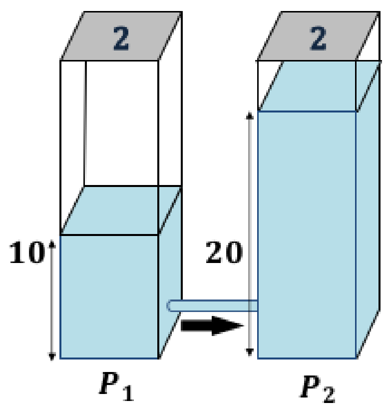


	$cost^t_{\pi(i)}$ $t = 1$
$i = 1$	20

Example

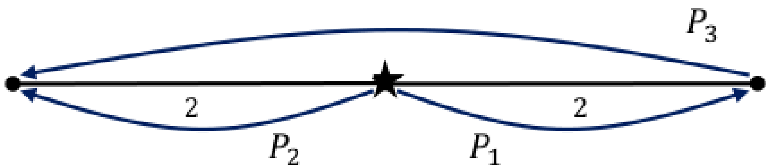


	k=1	k=2
Distance	2	2
Marginal Cost	20	40

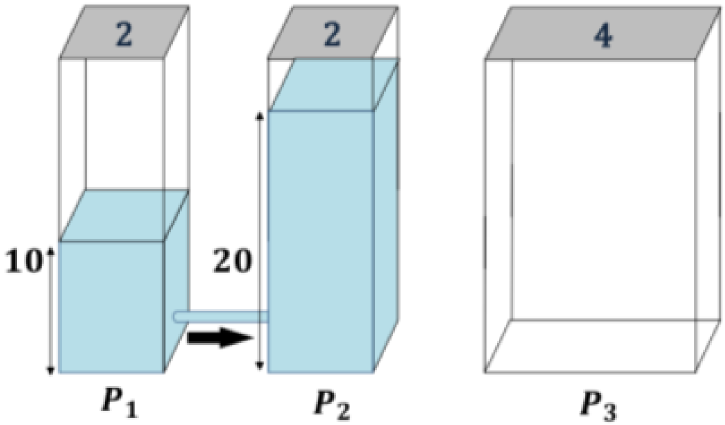


	$cost^t_{\pi(i)}$	
	$t = 1$	$t = 2$
$i = 1$	20	20
$i = 2$		40

Example

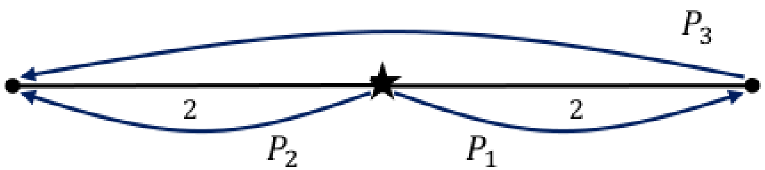


	k=1	k=2	k=3
Distance	2	2	4
Marginal Cost	20	40	0

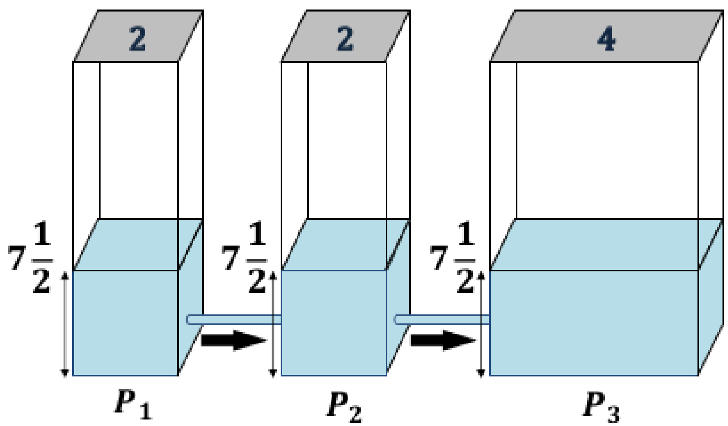


	$cost^t_{\pi(i)}$		
	$t=1$	$t=2$	$t=3$
$i=1$	20	20	15
$i=2$		40	15
$i=3$			30

Example



	k=1	k=2	k=3
Distance	2	2	4
Marginal Cost	20	40	0

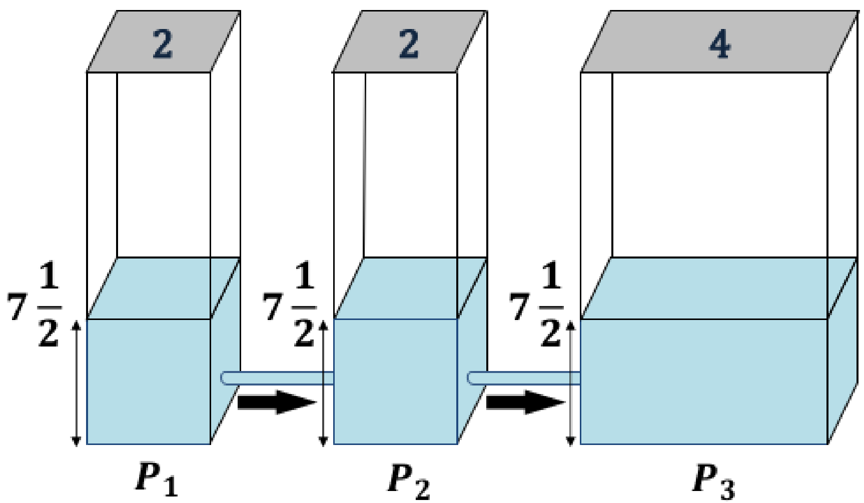


	$cost^t_{\pi(i)}$		
	$t=1$	$t=2$	$t=3$
$i=1$	20	20	15
$i=2$		40	15
$i=3$			30

POCS's Properties

- ✓ Budget balance
- ✓ Immediate response
- ✓ Online fairness

	k=1	k=2	k=3
Distance	2	2	4
Total Cost	20	60	60
Marginal Cost	20	40	0
POCS	15	15	30



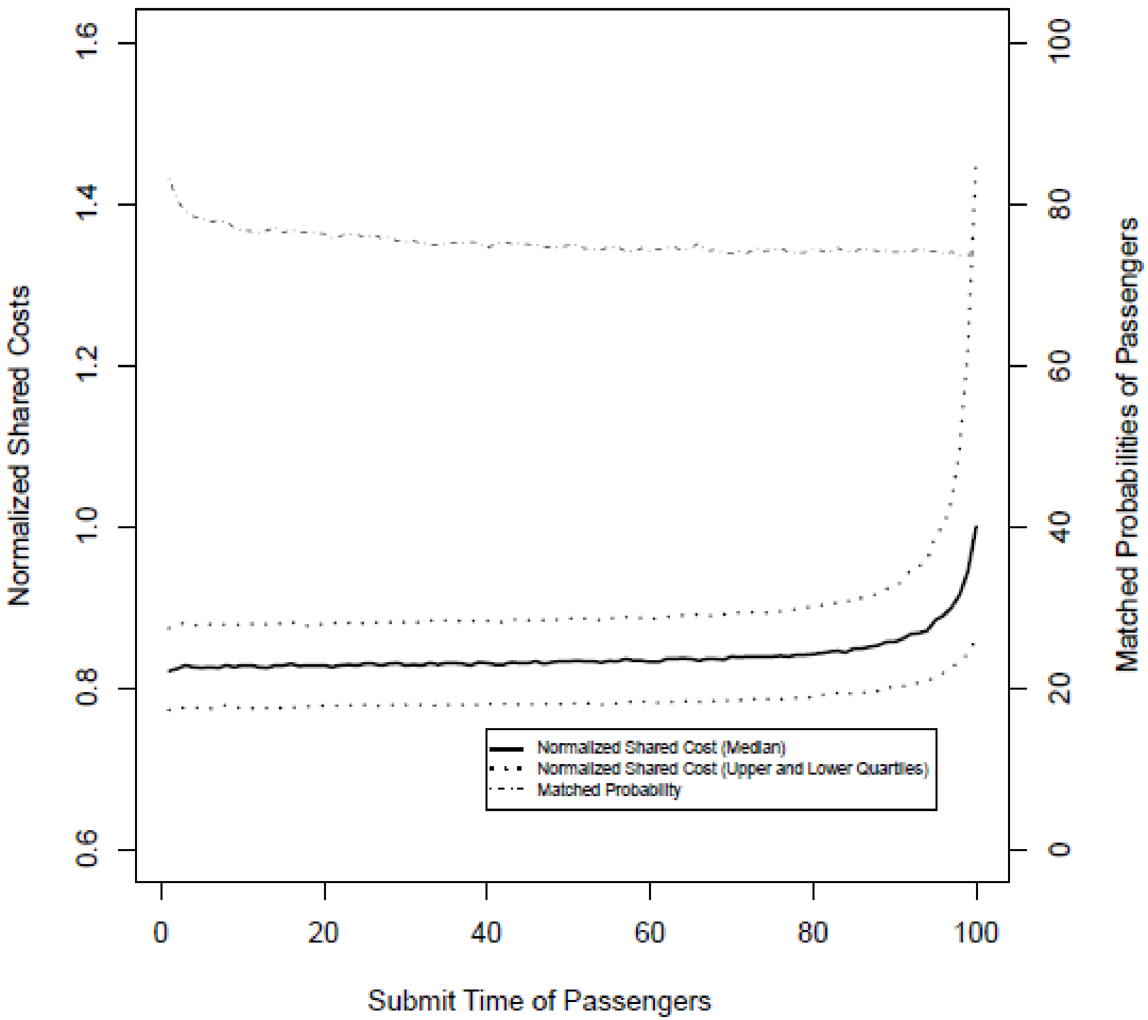
POCS's Uniqueness

- POCS is a mechanism that satisfies these properties and always minimizes the fare quotes of newly arriving passengers.

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



Simulation Results

- Benefit to delay ride request?

Scenario	Number Shuttles	Time Window	Number Runs	Situation Improves	No Change	Situation Worsens	
						Not Drop.Out	Drop.Out
1	2	3.0	33,116	11%	32%	24%	33 %
2	2	4.0	37,047	15%	31%	39%	15 %
3	10	3.0	36,975	16%	31%	51%	2 %
4	10	4.0	37,911	17%	29%	51%	3 %

Conclusions

- POCS mechanism induces
  - online fairness, immediate response, individual rationality, budget balance and ex-post incentive compatibility
- How to adapt if computing travel cost approximately
- Dynamic POCS

Ridesharing Challenges and Research

- High-dimensional Matching
- Trust and Reputation
- Mechanism Design
- Cost of Ridesharing
- Planning

Model Formulation

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

service all requests $\sum_{j \in N} x_{ij} + u_i = 1 \quad i \in N \backslash \{2n+2\}$

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

MTZ constraints $v_i + t_{ij} \le v_j + M(1 - x_{ij}) \quad i \in N \quad j \in N$

$E_i \le v_i \le L_i \quad i \in N$

index i before j $b_{ki} \le b_{kj} + (1 - x_{ij}) \quad (i,j) \in A \backslash (2n+2, 2n+1) \quad k \in N \backslash \{i\}$

no. passangers $z_i = G_i * (1 - u_i) + \sum_{m \in N} (b_{mi} * G_m) + O * (1 - u_i) \quad i \in N$

capacity $z_i \le Ca \quad i \in N$

time-cost/pass $t_{ij} \ge T_{ijk} - |z_i - k| * M \quad (i,j) \in A \quad k = 1,2 \ldots Ca$

$c_{ij} \ge C_{ijk} - |z_i - k| * M - (1 - x_{ij}) * M \quad (i,j) \in A \quad k = 1,2 \ldots Ca$

Model 1 Formulation

- *Elastic demand TAP with ridesharing prices*

$$\min \quad \sum_a \int_0^{y_a} tt_a(s)\,\mathrm{d}s - \sum_k \int_0^{\delta_k} \Lambda_k(t \qquad)\,\mathrm{d}t$$

$$\text{s.t.} \quad \mathbf{N}x^k - \mathbf{\Delta}_k \delta_k = 0, \quad \forall k$$

$$\sum_k x_a^k - y_a = 0, \forall a$$

$$x_a^k \geq 0, \forall a, \forall k$$

Travel cost $tt_a(s) = t_a\left(1 + \rho\left(\frac{s}{c_a}\right)^4\right)$

Utility $\Lambda_k(\delta_k \qquad) = \alpha \qquad - \beta\delta_k$

Supply function

Demand function