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Route-cost-assignment with joint user and operator behavior as a many-to-many stable matching assignment game

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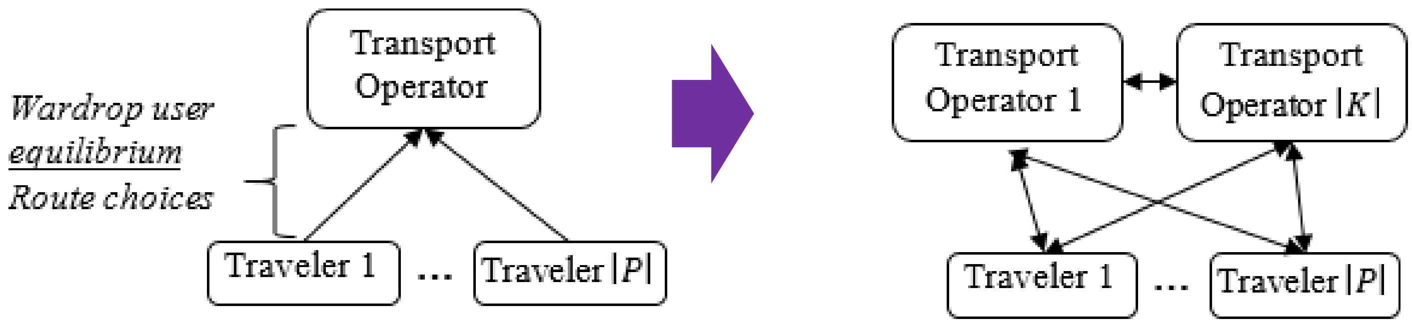
BUILT @ NYU
Behavioral Urban Informatics, Logistics, & Transport Lab

Study Purpose

- Classical traffic assignment models
  - Focused on just one side of decision makers
  - Negligence about the operator decisions

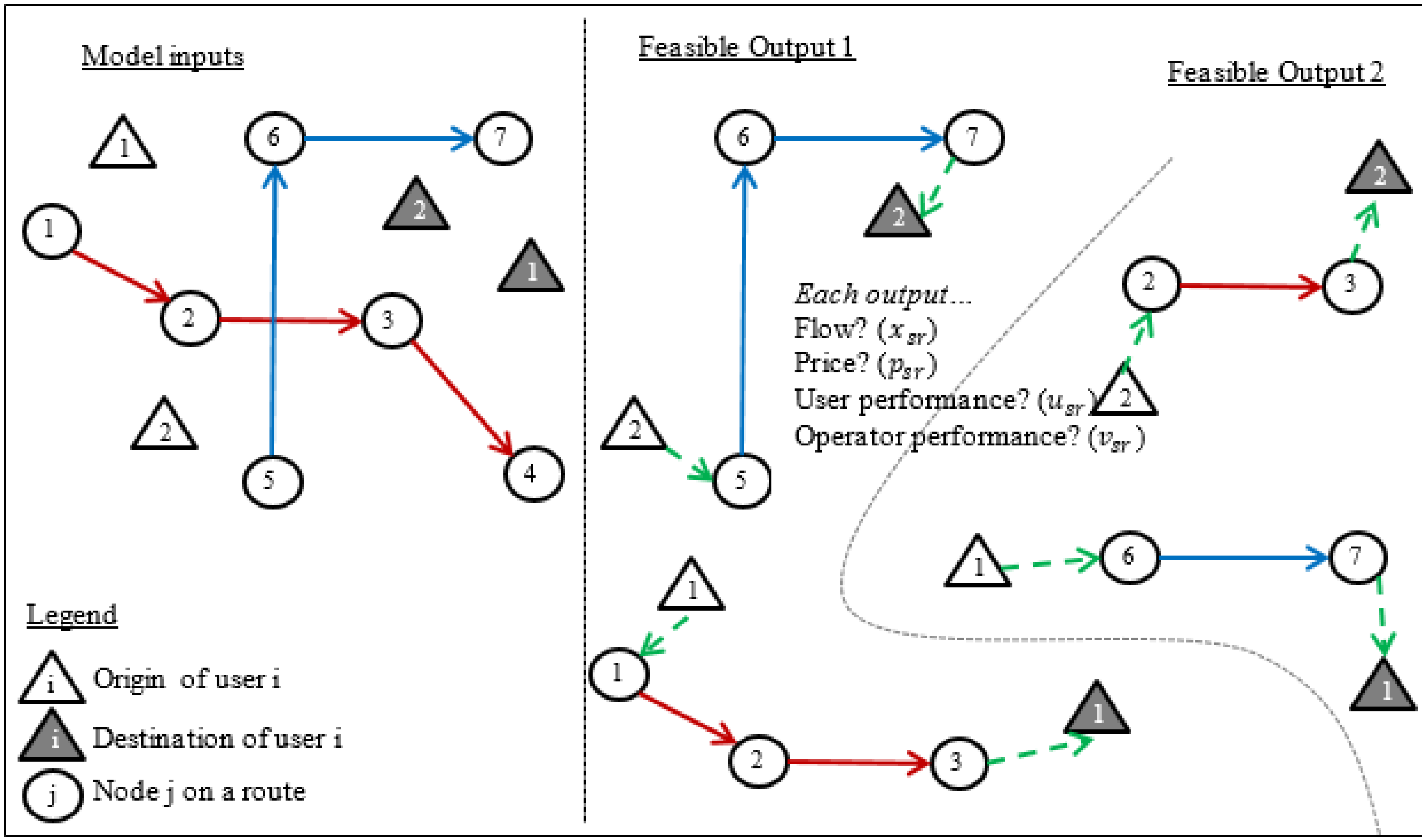
- Look at both sides of users and operators
- Operators behavior effects network flow and user decision



Introduction

- Mobility as a service
  - conventional fixed route transit
  - flexible transit
  - Rideshare
  - Carshare
  - Microtransit
  - Ridesourcing
- Important to forecast
  - Failure or success depend on cost sharing
    - Kutsuplus in Helsinki
    - Car2Go in San Diego

Problem Illustration



Problem Description

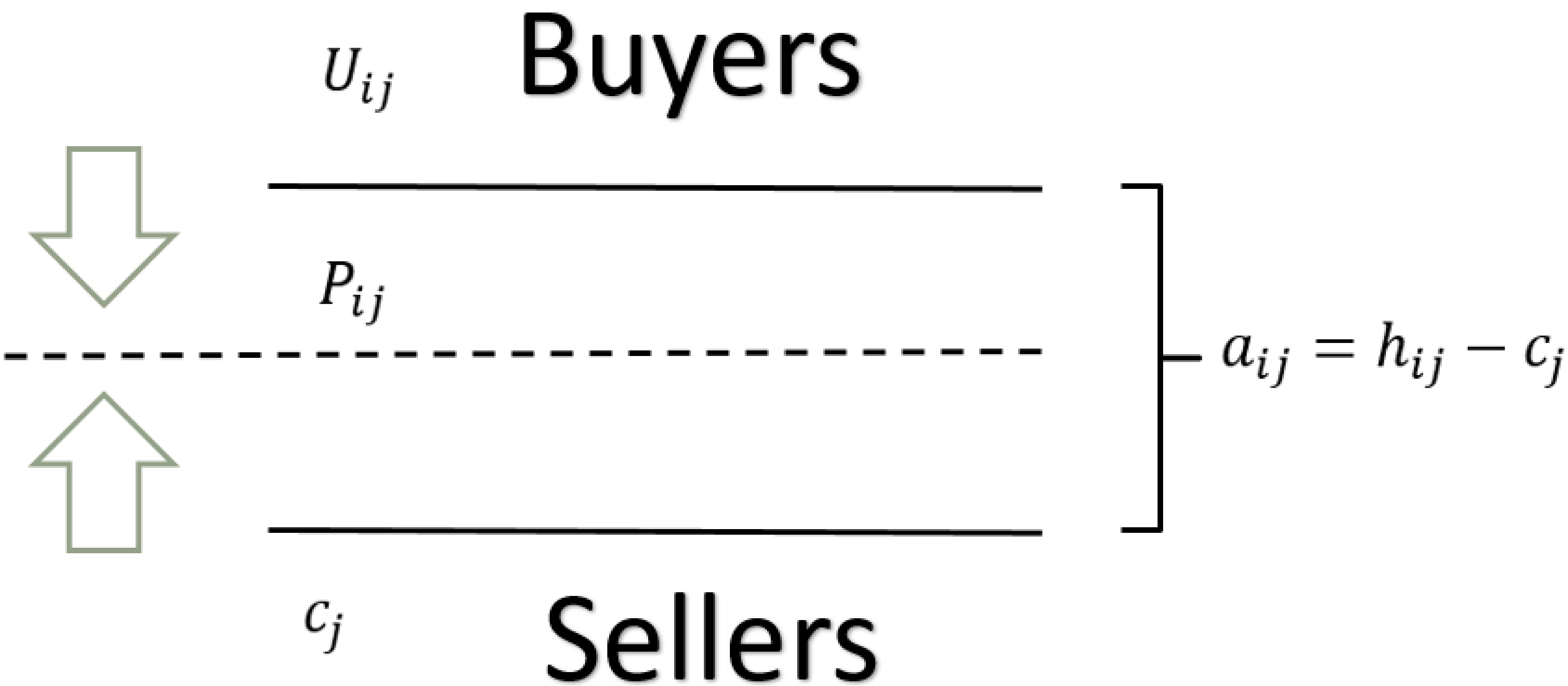
- Travelers choice depends on cost allocation decisions
  - Fare
  - Wait time, Access time, Detour time, Reservation time
  - Fare splitting, Capacity reliability, Credit/discount for switching pickup/drop-off location

Cost allocation	Cost transfer	Example systems
Fare	User → Operator	Public transit, taxi, on-demand ridesharing, vehicle sharing
Wait time	Operator → User	Public transit, taxi, on-demand ridesharing
Access time	Operator → User	Public transit, vehicle sharing
Detour time	User → User	Public transit, on-demand ridesharing
Reservation time	Operator → User	Vehicle sharing, on-demand ridesharing
Capacity reliability	Operator → User	Public transit, vehicle sharing
Credit/discount for switching pickup/drop-off location	Operator → User	Public transit, on-demand ridesharing, vehicle sharing
Fare splitting	User → User	Public transit, on-demand ridesharing

- Focus on both sides (users and operators)
  - understanding beyond the route choices of travelers

- Assignment model framework
  - Based on stable matching

Assignment Game



Transportation applications of Game Theory

- Non-cooperative game:
  - Harker (1988), Zhou et al. (2005), Anshelevich et al. (2008)

- Cooperative game:
  - Matsubayashi et al. (2005): **Air Transportation**
  - Agraval & Ergun (2008): **Network Flow**
  - Hernandez & Peeta (2014), Hezarkhani & Slikker (2016): **Freight**
  - Wang & Erera (2014), Dai & Chen (2015), Wolfson & Lin (2017): **Ridesharing**
  - Rosenthal (2017): **Transit**
  - Aghajani & Kalantar (2017), Chen(INFORMS 2017): **Parking Management**

Proposed Model

R set of operators

S set of users

$a_{sr} = \max\{0, U_{sr} - t_{sr}\}$ Payoff value for matching btw s and r

C_r operating cost of route r

x_{sr} the number of users s that are matched to route r

$A_r \subseteq A$ disjoint sets of segments of route r

$$\max \sum_{s\in S}\sum_{r\in R} a_{sr}x_{sr}$$

s.t.

$$\sum_{r\in R} x_{sr} \le q_s \qquad \forall s \in S/\{k\}$$

$$\sum_{s\in S/\{k\}} \delta_{asr}x_{sr} \le w_a \qquad \forall a \in A_r, r \in \mathrm{R}$$

$$\sum_{s\in S/\{k\}} x_{sr} \le M(1 - x_{kr}) \qquad \forall r \in R$$

$$x_{sr} \in \mathbb{Z}_+ \qquad \forall s \in S/\{k\}, r \in R$$

$$x_{kr} \in \{0,1\} \qquad r \in R$$

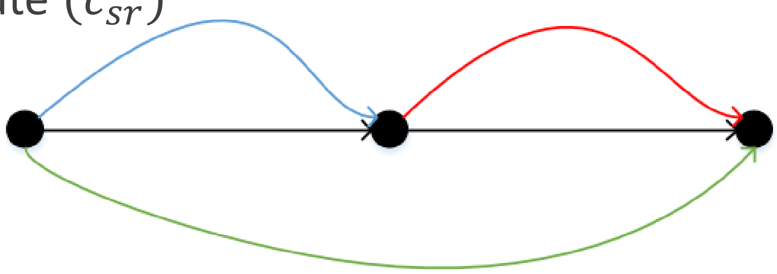
Summary of Differences

- Pay off values

$$a_{sr} = max\{0, U_{sr} - t_{sr} - c_{sr}\}$$

$$a_{sr} = \max\{0, U_{sr} - t_{sr}\}$$

- Routes has operating cost of C_r, cost of route will be divided between the users of that route (c_{sr})
- Capacity is segment level



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Computational Experiments

- 4-node example
  - with demand 1, without capacity
  - with demand 5, capacity 2
  - $C_r = 5 + 0.5 \times |A_r|$

- NYC taxi, with capacity 3

Example

- 4-node network
  - Scenario 1
    - $w_{a \in A_r} \to \infty$

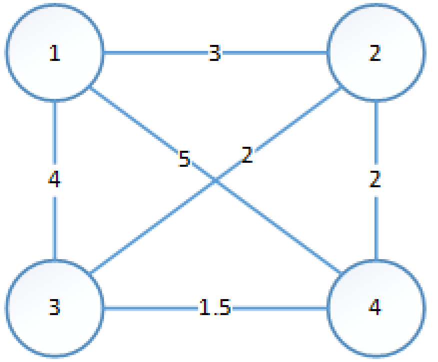


Table 3c. Ticket prices in user-optimal allocation mechanism

Optimal Solution	Route	Links of route	Cost of route	User						Operator revenue
				(1,2)	(1,3)	(2,3)	(3,2)	(4,1)	(4,2)	
X	9	1 – 2 – 3	5.5	1.83	1.83	1.83				5.5
	42	3 – 4 – 2 – 1	6				2	2	2	6
X'	21	3 – 4 – 2	5.5				1.83		1.83	5.5
	51	4 – 1 – 2 – 3	6	2	2	2		2		6
X''	26	4 – 3 – 2	5.5				1.83		1.83	5.5
	51	4 – 1 – 2 – 3	6	2	2	2	2	2		6

Example

- 4-node network
  - Scenario 2
    - $w_{a \in A_r} = 2$
    - $q_{s \in S \setminus \{k\}} = 5$

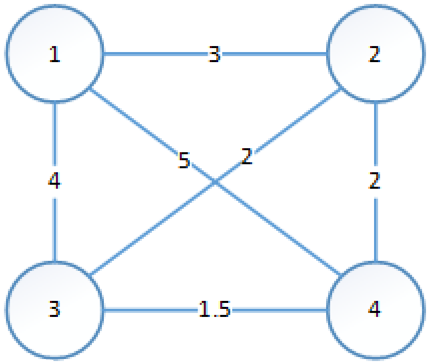


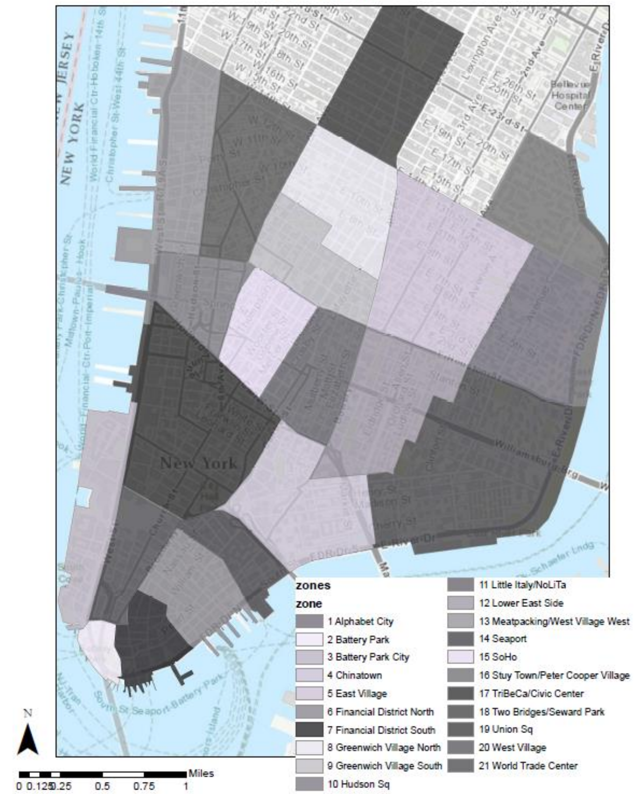
Table 4c. Ticket prices in operator-optimal allocation mechanism

Route	Links of route	Cost of route	Ticket price (1,2)	(1,3)	(2,3)	(3,2)	(4,1)	(4,2)	Operator revenue
6	4 – 2	5						5.5	5.5
7	1 – 3 – 2	5.5		3		5			8
9	1 – 2 – 3	5.5	5	2	5				12
25	4 – 1 – 2	5.5	5				5		10
26	4 – 3 – 2	5.5				5		4	9
28	4 – 2 – 3	5.5			5			5.5	10.5
49	4 – 1 – 3 – 2	6		3		5	5		13
51	4 – 1 – 2 – 3	6	5		5		5		15

NYC taxi case study

- Data:
  - Wednesday October 5th 2016 from 8AM to 8:30AM
  - the lower Manhattan region, 21 zones
  - 755 taxi trips were conducted during the study period
  - Routing:
    - $(O_f, D_f)\ ,(O_g, D_g)$
    - $\{(O_f - O_g - D_f - D_g), (O_f - O_g - D_g - D_f), (O_g - O_f -$

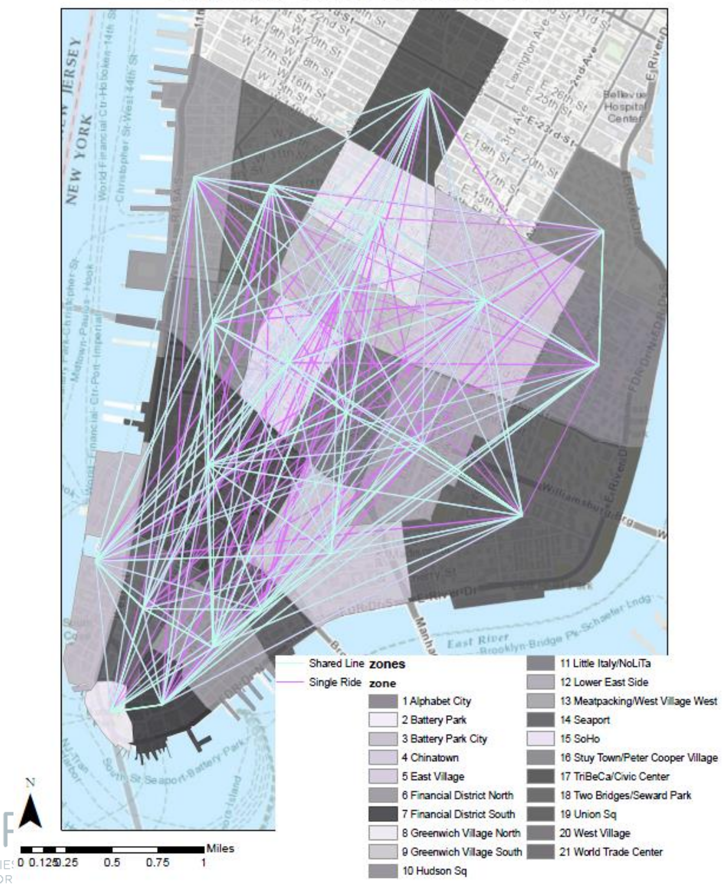
NYC Zones



Results

- Total mileage from 1996.9 miles to 1621.5 miles (31.4% decrease)
- 542 of 755 users decide to share their ride (71.8%)

Single and Shared Taxi Rides-NYC



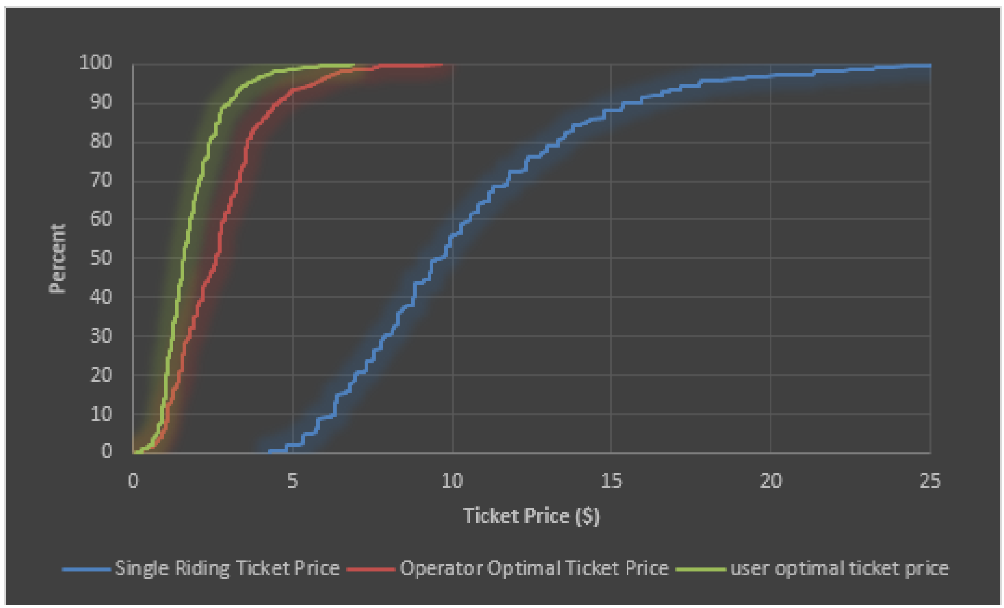


Figure 8. Ticket price percentage of users pay in three different scenario

Results

- Gap btw user and operator optimal ticket price

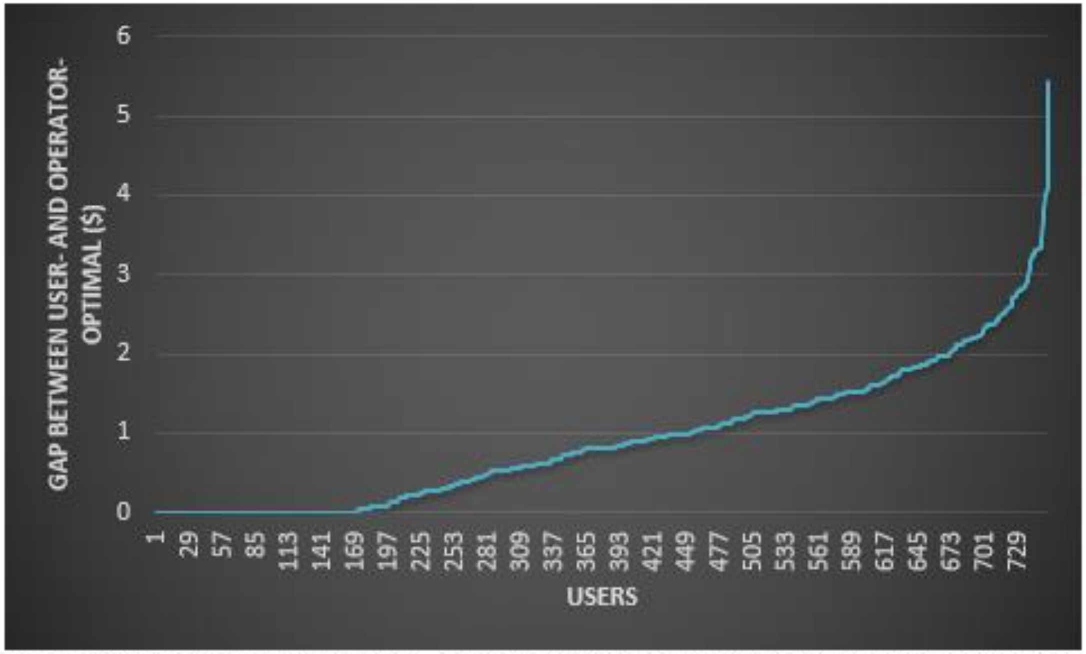
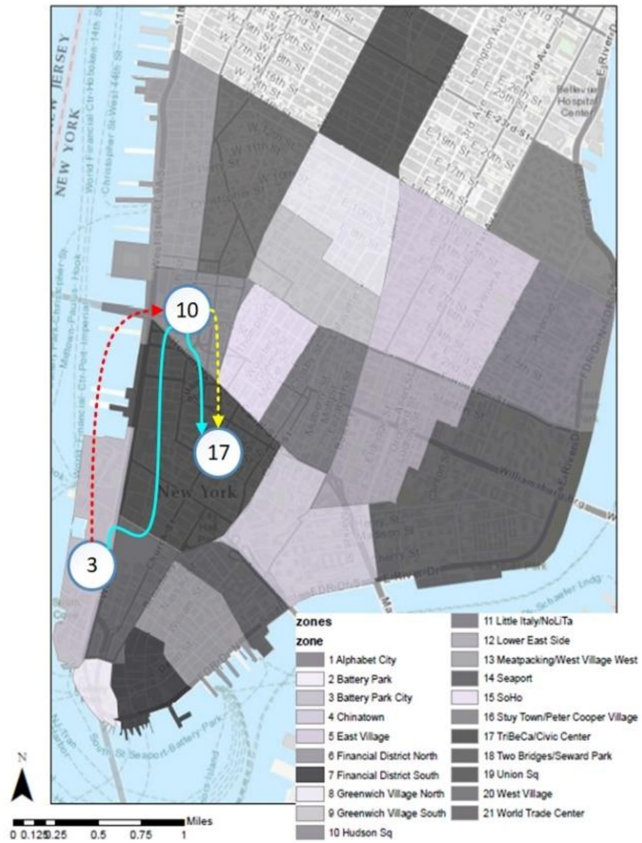


Figure 9. Sorted gap between user- and operator-optimal pricing under shared taxi policy.

Results

- Let's look closer
  - (3,10), (10,17) and (10,17)

NYC Zones



Results for one coalition

Table 5. Pricing of users (1,2) and (1,7) in single and ridesharing taxi riding

	Path	Results		Users (3,10)	Users (10,17)	Users (10,17)
Single taxi riding	$1 \to 6$	*Travel time (min)*		8		
		Ticket price (\$)		7.55		
		User profit (\$)		0		
		Operator profit (\$) (ticket price − operation cost)		5.57		
	$5 \to 1$	*Travel time (min)*			11	
		Ticket price (\$)			7.50	
		User profit (\$)			0	
		Operator profit (\$) (ticket price − operation cost)			5.52	
	$5 \to 6$	*Travel time (min)*				11
		Ticket price (\$)				7.85
		User profit (\$)				0
		Operator profit (\$) (ticket price − operation cost)				5.87
Ridesharing taxi riding	$1 \to 2 \to 7$	*Travel time (min)*		8	11	11
		Ticket price (\$)	*User optimal*	$b + 1.32$	$b+1.32$	$b + 1.32$
			Operator optimal	$b + 1.98$	$b + 1.98$	$b + 1.98$
		User profit (\$)	*User optimal*	$9.43 - b$	$10.58 - b$	$10.93 - b$
			Operator optimal	$8.77 - b$	$9.92 - b$	$10.27 - b$
		Operator profit (\$) (ticket price − operation cost)	*User optimal*	$3b$		
			Operator optimal	$1.98 + 3b$		

Conclusions

- First model to formally address both user and operator behavior
- Identify the types of cost allocation possible for designing new cost sharing mechanisms for different mobility systems
- Identify the challenges of considering segment capacity and congestion effects for future research
- Cost sharing policies instead of in advance cost sharing policies
- Matching part of demand to routes (Flow)

Acknowledgments

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Citation

- Rasulkhani, S., Chow, J.Y.J., 2018. Route-cost-assignment with joint user and operator behavior as a many-to-one stable matching assignment game. In: 97th Annual Meeting of the TRB, working paper available at https://arxiv.org/abs/1711.11230.

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Questions?