11th Workshop on Discrete Choice Models

Choice-based routing problem in the context of flexible mobility on demand

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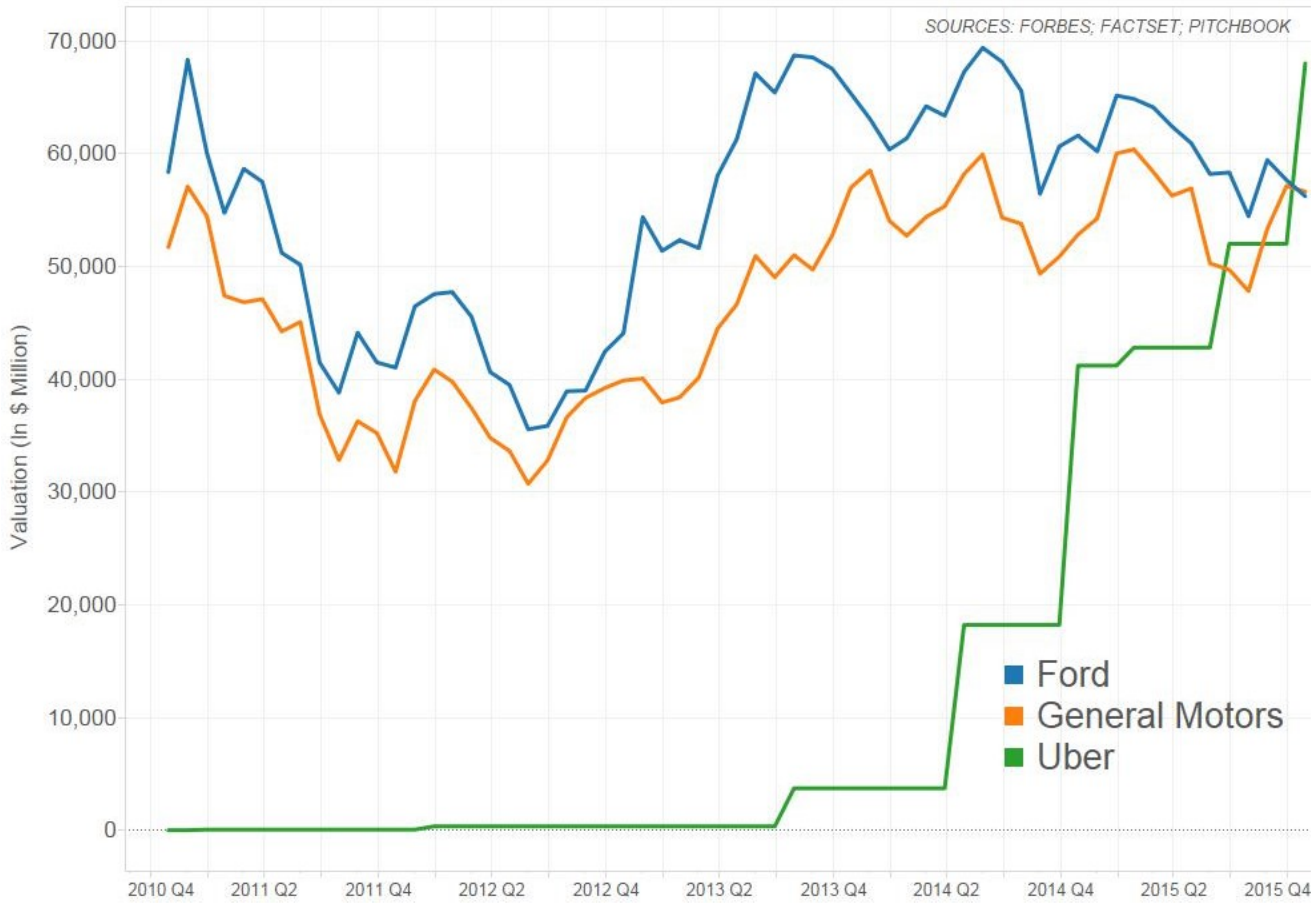
Motivation

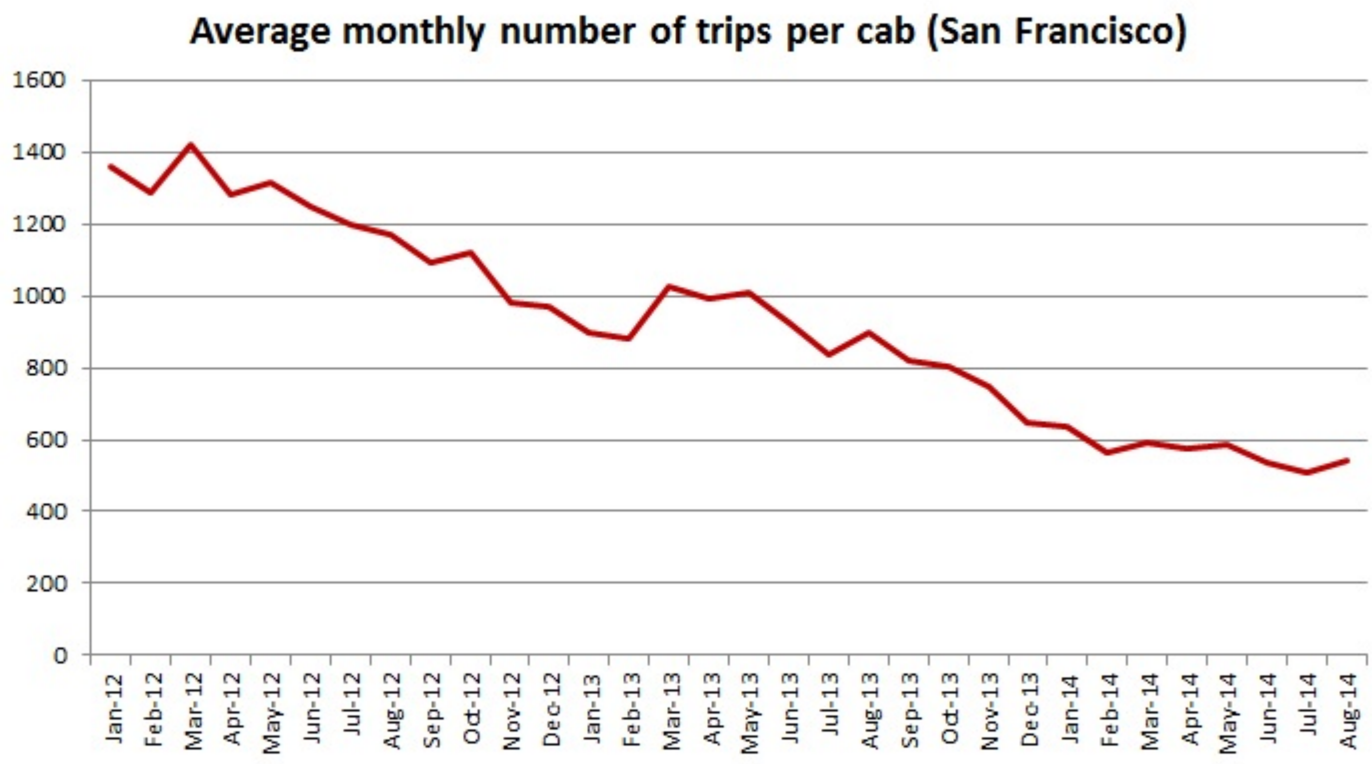

SOURCES: FORBES; FACTSET; PITCHBOOK
Valuation (In $ Million)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2010 Q4
2011 Q2
2011 Q4
2012 Q2
2012 Q4
2013 Q2
2013 Q4
2014 Q2
2014 Q4
2015 Q2
2015 Q4
Ford
General Motors
Uber

Motivation

Silverstein, 2014, calculates the fares for a sample trip of 5 miles in 10 minutes under car speed of 30MPH with no waiting time.

	Uber	Taxi +20% Tip	Taxi / Uber
New York	17.75	18.60	1.0
Philadelphia	15.25	17.04	1.1
Portland	15.05	18.00	1.2
Cleveland	13.00	16.74	1.3
Dallas	10.30	13.50	1.3
Miami	13.25	17.40	1.3
Indianapolis	11.65	15.60	1.3
Phoenix	11.00	15.00	1.4
Minneapolis	12.15	17.10	1.4
Baltimore	10.75	15.66	1.5
Columbus	10.20	15.42	1.5
Denver	10.35	16.50	1.6
Detroit	12.30	19.80	1.6
Seattle	11.70	19.20	1.6
San Francisco	12.30	20.70	1.7
Chicago	9.50	16.80	1.8
Boston	11.10	19.92	1.8
Atlanta	10.00	18.00	1.8
Houston	9.00	16.50	1.8
San Diego	11.35	21.36	1.9
Los Angeles	9.40	19.62	2.1

Motivation



Source: http://bruegel.org/2014/09/the-economics-of-uber/

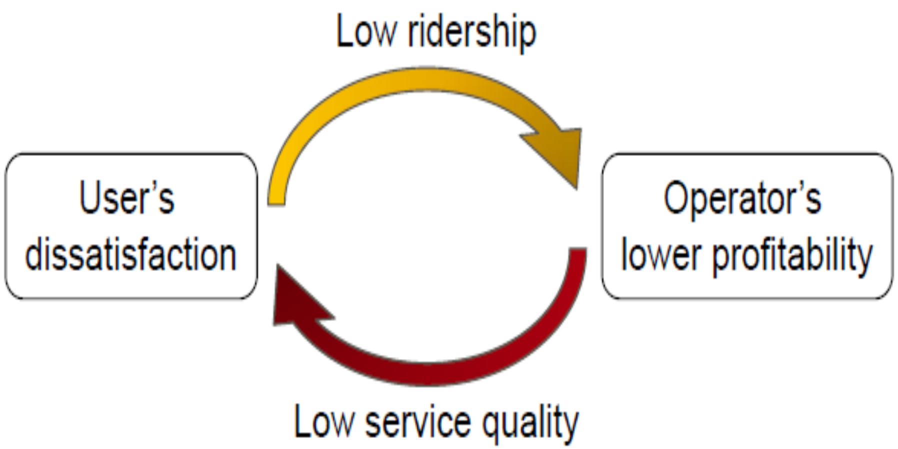
Motivation

Conventional public transportation services are not personalized.

Fixed route, Fixed schedule, Low frequency etc.

Most people cannot afford using taxi service on a daily basis.

Personalized transportation services using mobile apps are emerging Uber, Lyft, GrabTaxi.

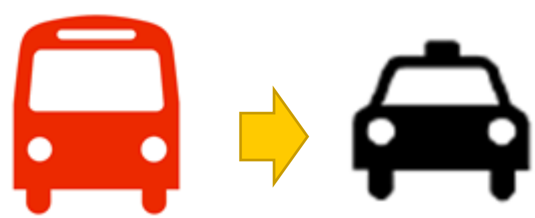


Problem definition

<u>How to increase operator profit and user satisfaction?</u>

Flexibility to demand fluctuations is necessary.
Currently, due to lack of the flexibility:

Off-peak:
=> Drivers cannot find passengers
On-peak:
=> Passengers cannot find drivers.
Some passengers may give up taking public transportation.
=> Operator lose revenue opportunity.



What is FMOD?

Flexible Mobility on Demand

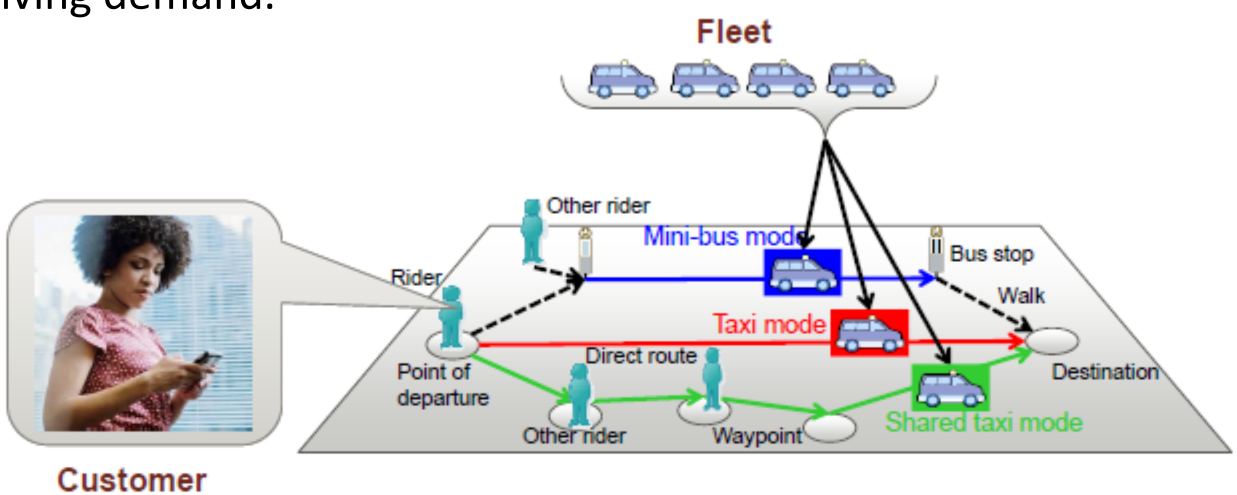
- Real-time system
- Flexibility to demand fluctuations

Concepts

- Dynamic allocation of vehicle to service modes
- Optimized travel menus are offered to the customer

Dynamic allocation of vehicle to service modes

- Same vehicle is dynamically reassigned to different service modes according to the evolving demand.



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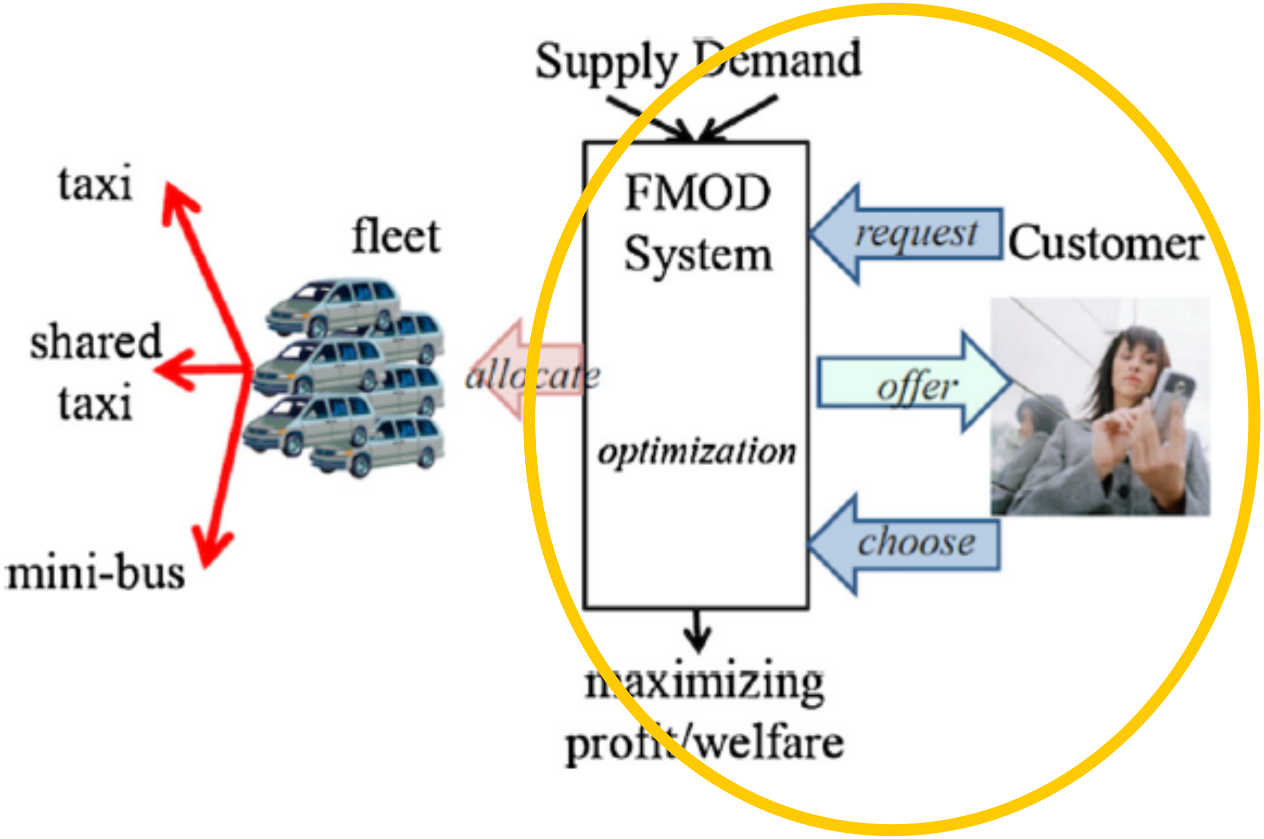
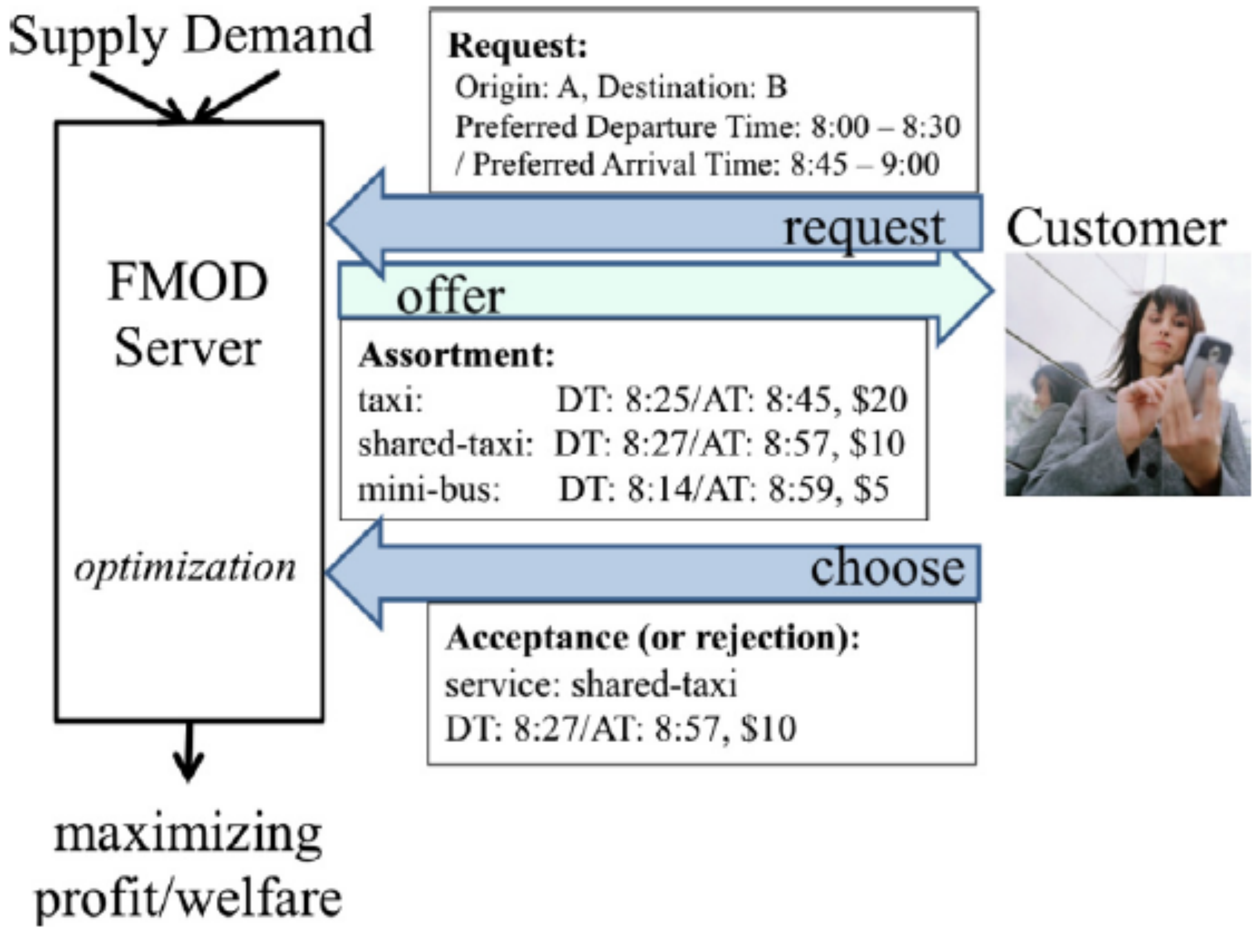
FMOD



Supply
Demand
taxi
shared taxi
mini-bus
fleet
allocate
FMOD System
optimization
request
Customer
offer
choose
maximizing profit/welfare

FMOD


Supply Demand
FMOD Server
optimization
maximizing profit/welfare
Request:
Origin: A, Destination: B
Preferred Departure Time: 8:00 – 8:30
/ Preferred Arrival Time: 8:45 – 9:00
request
Customer
offer
Assortment:
taxi: DT: 8:25/AT: 8:45, $20
shared-taxi: DT: 8:27/AT: 8:57, $10
mini-bus: DT: 8:14/AT: 8:59, $5
choose
Acceptance (or rejection):
service: shared-taxi
DT: 8:27/AT: 8:57, $10

Modes of transport

- Serves a single passenger at a time
- Provides door-to-door service
- No fix location for pickup and delivery
- Fastest alternative
- Highest fare.

Taxi

Modes of transport

- Multiple passengers in the same vehicle
- Provides door-to-door service
- Arbitrary locations for pickup and delivery
- Travel time may increase due to the pick-up and drop-off of other passengers.

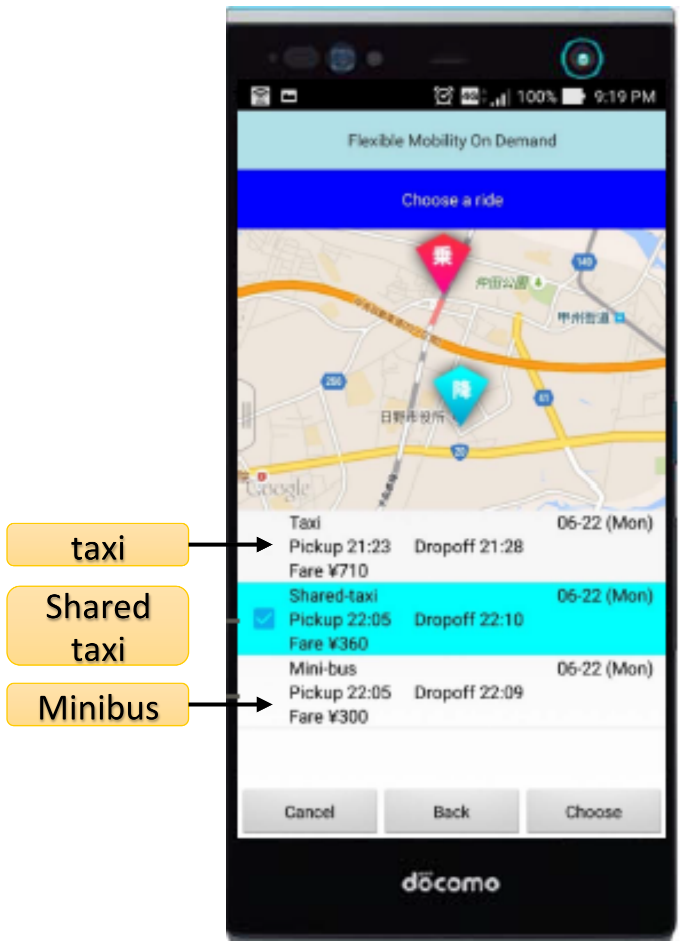
Shared Taxi

Modes of transport

Mini bus

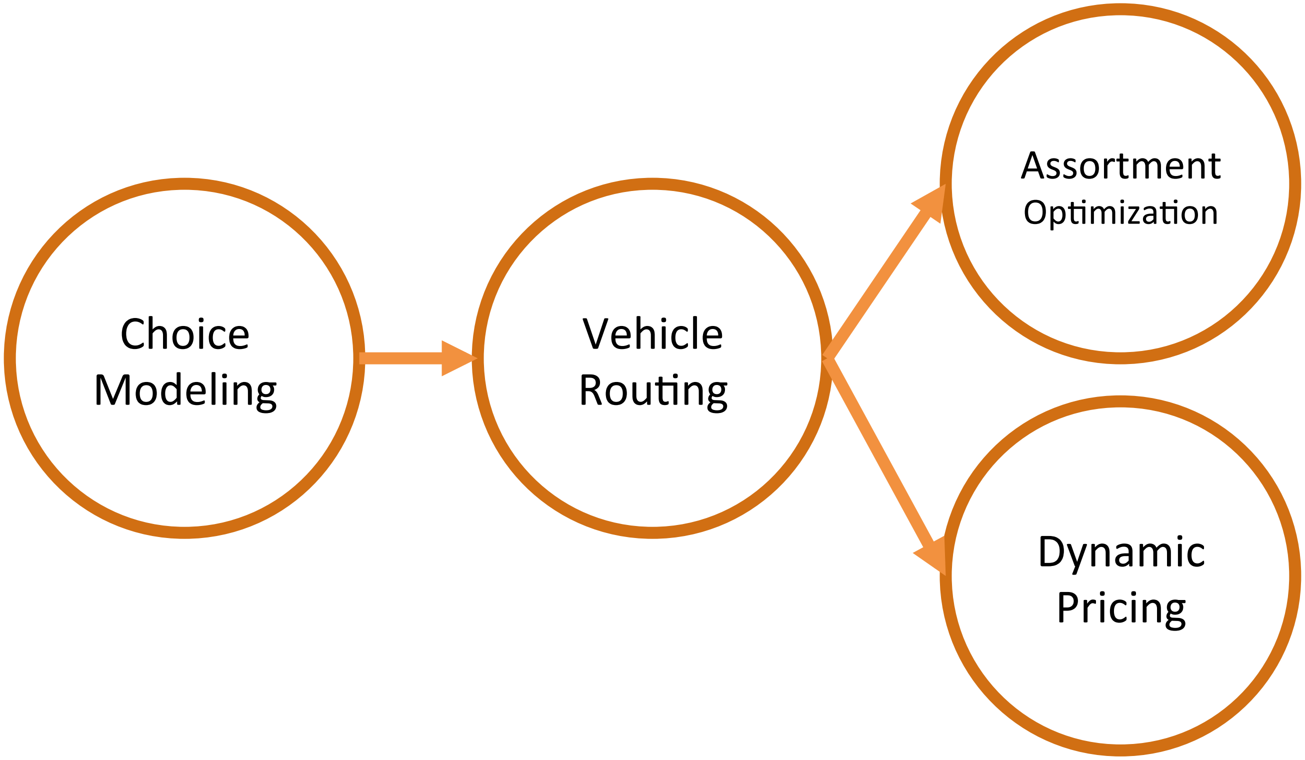
- Fixed routes
- Pick-up / drop-off locations are predetermined
- Adapted schedule for passengers similar to the shared-taxi

FMOD app



taxi
Shared taxi
Minibus
100% 9:19 PM
Flexible Mobility On Demand
Choose a ride
Taxi 06-22 (Mon)
Pickup 21:23 Dropoff 21:28
Fare ¥710
Shared-taxi 06-22 (Mon)
Pickup 22:05 Dropoff 22:10
Fare ¥360
Mini-bus 06-22 (Mon)
Pickup 22:05 Dropoff 22:09
Fare ¥300
Cancel
Back
Choose
docomo

Integrated choice-based optimization framework



Simulation (Sequential framework)

Product $p_{n,m,l}$

A service on a vehicle departing at a certain time period

Feasible product $p_{n,m,l} \in F$

A product that satisfies the capacity and scheduling constraints

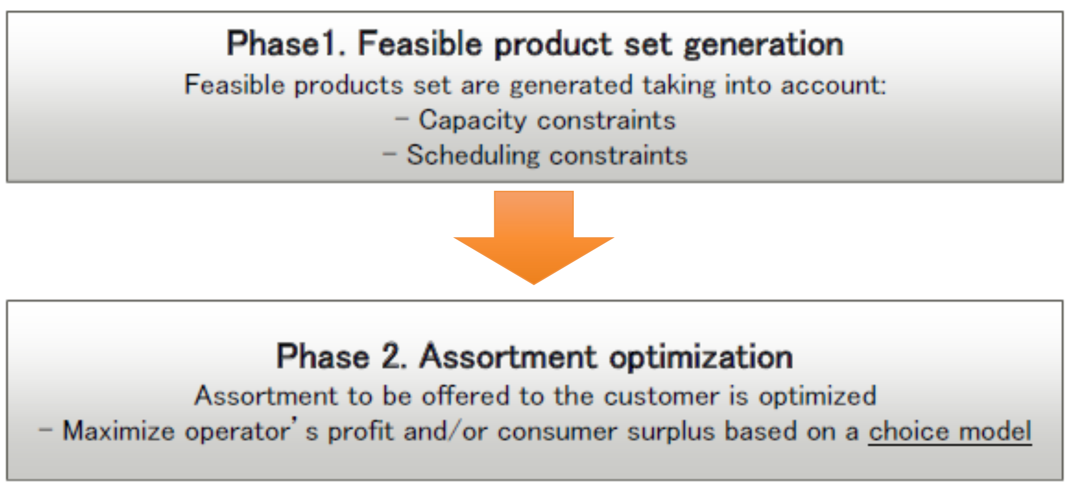
Vehicle capacity

No conflict with existing schedules

Deviation from preferred time window

Assortment

A list of feasible products on the travel menu



Ref: Atasoy, Bilge, et al. "The concept and impact analysis of a flexible mobility on demand system." *Transportation Research Part C: Emerging Technologies* 56 (2015): 373-392.

Simulation (model)

N : set of vehicles,
M : set of service modes
L : set of time periods

$X = \{x_{n,m,l} \mid x_{n,m,l} \in \{0,1\}\}$ *Decide which feasible products are included in the assortment*

$x_{n,m,l} = 0 \quad \forall p_{n,m,l} \notin F$ *Only feasible products are included*

Logit model

$$max \;\; R_{current}(X) = \sum_{n \in N} \sum_{m \in M} \sum_{l \in L} r_{n,m,l} Prob_{n,m,l}(X)$$

Expected profit from each product

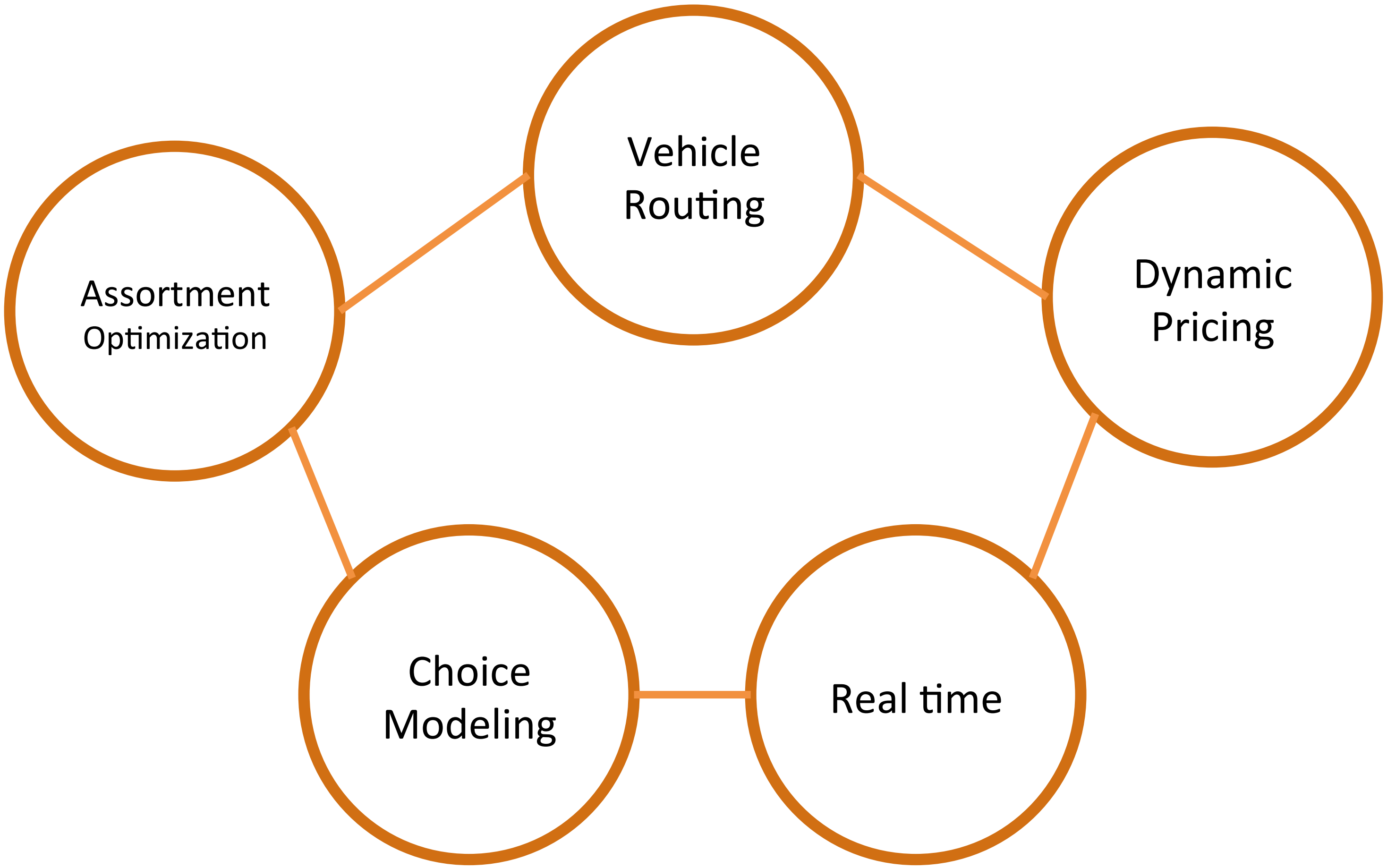
$$\text{s.t.} \;\; \sum_{n \in N} \sum_{l \in L} x_{n,m,l} = 1 \qquad \forall m \in M$$

One product is offered for each services

$r_{n,m,l}$	Profit associated with $p_{n,m,l}$
$Prob_{n,m,l}$	Choice probability $p_{n,m,l}$

Ref: Atasoy, Bilge, et al. "The concept and impact analysis of a flexible mobility on demand system." *Transportation Research Part C: Emerging Technologies* 56 (2015): 373-392.

Integrated choice-based optimization framework



Assumptions

- Integrating vehicle routing, assortment optimization and dynamic pricing.
- Flexible service providing
- Homogeneous fleet with the same capacity of 8 persons.
- Dynamic change of role among taxi and shared-taxi
- Information of the ride request:
  - Origin and destination of the requested trip
  - Preferred departure time interval or preferred arrival time
  - Number of passengers

The passenger could accept or reject the proposed option.

The the server may reject the request:

(1) there is no vehicle available to serve the customer

(2) the associated profit to the offered choices is negative

Assumptions

Arrival / departure time

A time window (in minutes) is received $\delta^P(+/-)15$

Fare

Base fare charged once

Price per kilometer (shortest path between O-D)

Three levels of price

Utility of taxi and shared taxis

$$u_{taxi} = \beta_0 P_{Base} + \beta_1 P_{Km} D + \beta_2 (TTime) + \beta_3 (SD) + \epsilon$$

$$u_{sharedtaxi} = \beta_0 P_{Base} + \beta_1 P_{Km} D + \beta_2 (MaxRideTime) + \beta_3 (SD) + \epsilon$$

Sets	
$a \in A$	Set of nodes generated for a new request (Each node represents a product)
$s \in S$	Set of services {Taxi, Shared Taxi}
P^S	Set existing pickup nodes for service S
D^S	Set of existing delivery nodes for service S
$k \in K$	set of vehicles which can be used either as a taxi or as a shared-taxi
V	Set of nodes in the graph $P^S \cup D^S \cup A \cup Depot$
V_i^+	Set of exiting arcs from the node i
V_i^-	Set of entering arc to the node i

Notations

Parameters	
C_n	Total routing cost (excluding cost associated with products) for request n
c_{ij}	Cost of traveling from node i to node j
t_{ij}	Travel time between node i and j
$[e_i, l_i]$	service time window at node i
Q	vehicle capacity
q_i	load at node i, positive value for pickup and negative value for delivery it is of quantity 1 for shared-taxi, and Q for taxi
T^{max}	maximum ride time for shared taxi
M	Large constants
u_0	Utility of no-purchase (reject) option
f_a	Charging fare associated with alternative a
v_a	Utility weight of alternative a

Variables	
p_a	The probability of selecting alternative a by customer
x_{ij}^k	Binary variable, 1 if vehicle k travels from node i to node j
w_i	Arrival time of vehicle at node i
l_i^k	Load of vehicle k at node i

$$\text{Max} \sum_{a \in A} f_a p_a - \left(\sum_{i \in V} \sum_{j \in V} \sum_{k \in K} c_{ij} x_{ij}^k\right)$$

Routing

$$\sum_{j\in V'}\sum_{k\in K} x_{ij}^k = 1 \quad (\forall i \in P\setminus\{p',p''\})$$

$$\sum_{j\in V} x_{ij}^k - \sum_{j\in V} x_{n+i,j}^k = 0 \quad (\forall i\in P, k\in K)$$

$$\sum_{i\in V} x_{ij}^k = \sum_{i\in V} x_{ji}^k \quad (\forall j\in P\cup D, k\in K)$$

Time window

$$w_j^k \geq w_i^k + t_{ij} - M1_{i,j}^k(1-x_{ij}^k) \quad (\forall i,j\in V, k\in K)$$

$$e_i \leq w_i^k \leq l_i \quad (\forall i\in V)$$

$$t_{i,n+i} \leq w_{n+i}^k - w_i^k \leq T^{max} \quad (\forall i\in P, k\in K)$$

$$w_{n+i}^k \geq w_i^k \quad (\forall i\in P, k\in K)$$

Vehicle capacity

$$v_j^k \geq v_i^k + q_i - M2_{i,j}^k(1-x_{ij}^k) \quad (\forall i,j\in V, k\in K)$$

$$\max\{0,q_i\} \leq v_i^k \leq \min\{Q, Q+q_i\} \quad (\forall i\in V, k\in K)$$

$$x_{i,j}^k \in \{0,1\} \quad (\forall i,j\in V, \forall k\in K)$$

Individual Customer behavior (routing and assortment link)

$$\sum_{l\in L}\sum_{b\in B}\sum_{s\in S}\pi_{a,l,b,s} \leq \sum_{j\in V} x_{ij}^k \quad (\forall a\in A, k\in K | a\equiv k, i\in\{p',p''\})$$

$$u_{a,l,b,s} = \beta_l^p p_{a,l}^0 + \beta^p p_a d_{a,b} + \beta_s^{tt}(tt_{i,s}^k)$$
$$(\forall a\in A, l\in L, b\in B, s\in S, k\in K | a\equiv k, i\in\{p',p''\})$$

$$\sum_{a\in A}\sum_{l\in L}\sum_{b\in B}\sum_{s\in S}\pi_{a,l,b,s} = 1-\pi_0$$

$$\sum_{l\in L}\sum_{b\in B}\sum_{s\in S}\frac{\pi_{a,l,b,s}}{\exp(u_{a,l,b,s})} \leq \frac{\pi_0}{\exp(u_0)} \quad \forall a\in A$$

$$0 \leq \frac{\pi_{a,l,b,s}}{\exp(u_{a,l,b,s})} \leq \frac{\pi_0}{\exp(u_0)} \quad (\forall a\in A, l\in L, b\in B, s\in S)$$

Computational results

Alternatives:

- Two type of scheduled delay
- Two price levels
- Two types of vehicles

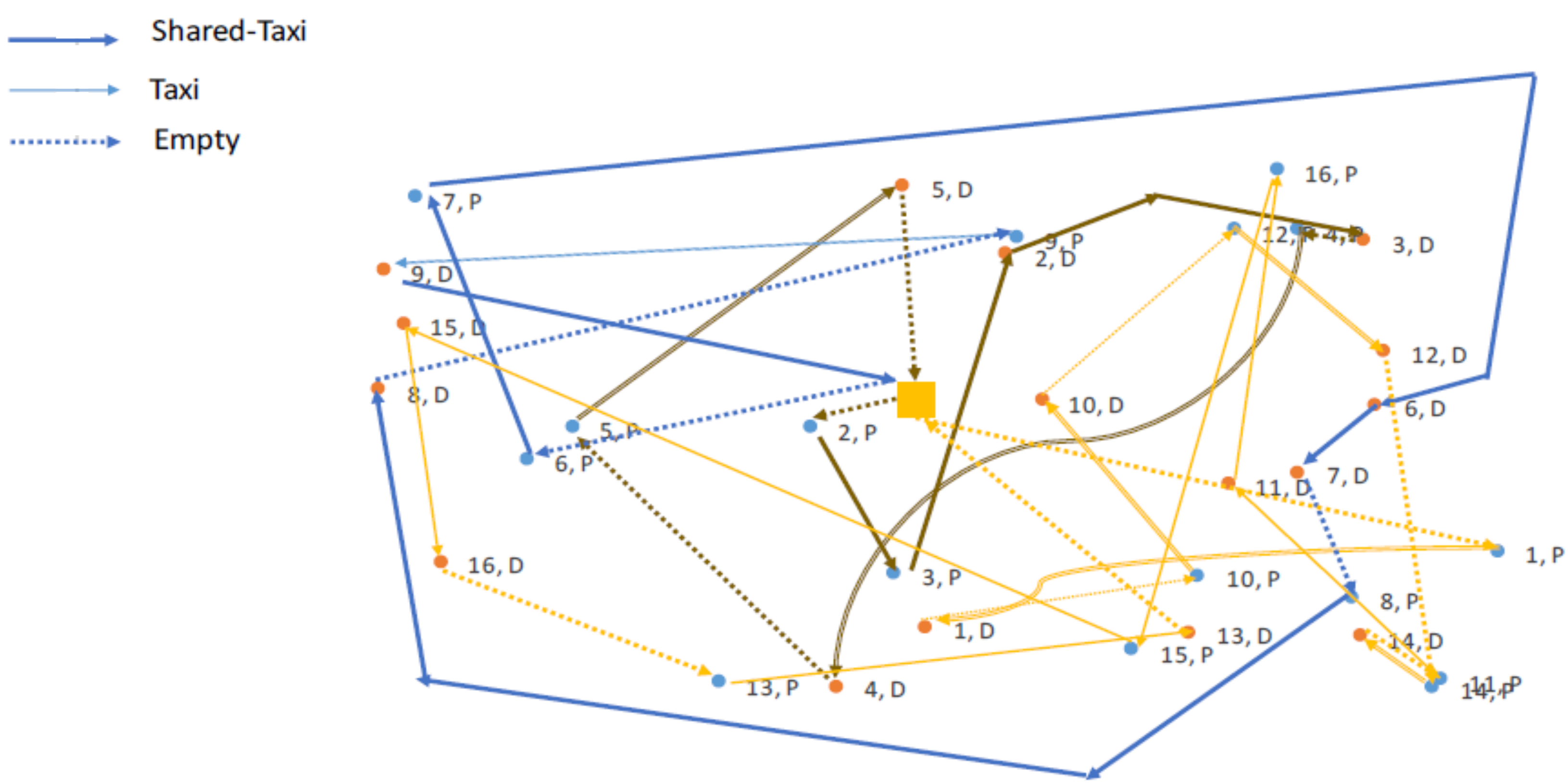
Individual based opt out included

Initial cost and per kilometer cost is different from taxi to shared taxi.

Profit is defined for the assortment.

Customer	Offer	Profit	Time	Selection
1	2,3,6	5.3	0.75	2
2	3,6	10.068	1.55	6
3	2,7	16.36	0.91	7
4	2	19.2203	0.92	2
5	3,4	8.8821	1.42	4
6	1,8	12.54	1.81	8
7	6,3	12.084	1.39	6
8	6,4	13.42	1.25	6
9	4	20.16	1.28	4
10	2,3	8.04	0.91	2
11	7	4.01	2.06	7
12	3,4	4.96	1.24	4
13	8	16.18	1.5	8
14	6,2	11.66	9.42	2
15	5,6	15.02	4.05	5

Computational results



Conclusion

- Integrated framework for FMOD
- Adding minibus in the system
- More sophisticated pricing planning
- Intelligent heuristic for large size network

Thank You

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Conclusion

$$\text{Max} \sum_{a\in A} \sum_{l\in L} \sum_{b\in B} \sum_{s\in S} \pi_{a,l,b,s}(p^0_{a,l} + p_a d_{a,b}) - \sum_{i\in V} \sum_{j\in V} \sum_{k\in K} c^k_{ij} x^k_{ij}$$