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Optimized Travel Menus with a Flexible Mobility on Demand System

Bilge Atasoy, **Takuro Ikeda**, Moshe Ben-Akiva

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CASPT

Massachusetts Institute of Technology

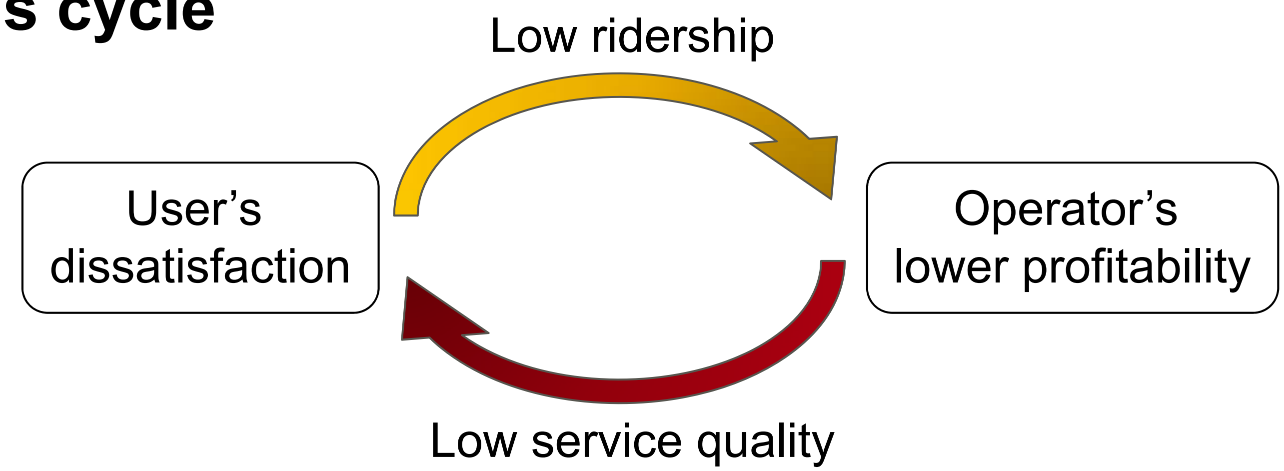
Agenda

- Motivation and background
- Flexible Mobility on Demand (FMOD) system
  - Concepts
  - Modeling Framework
- Simulation experiments
  - Myopic model v.s. Look-ahead model
- Summary and future directions

Motivation and background

- **Conventional public transportation services** are not personalized.
  - Fixed route, Fixed schedule, Low frequency etc.
- Most people cannot afford to use **taxi service** on a daily basis.

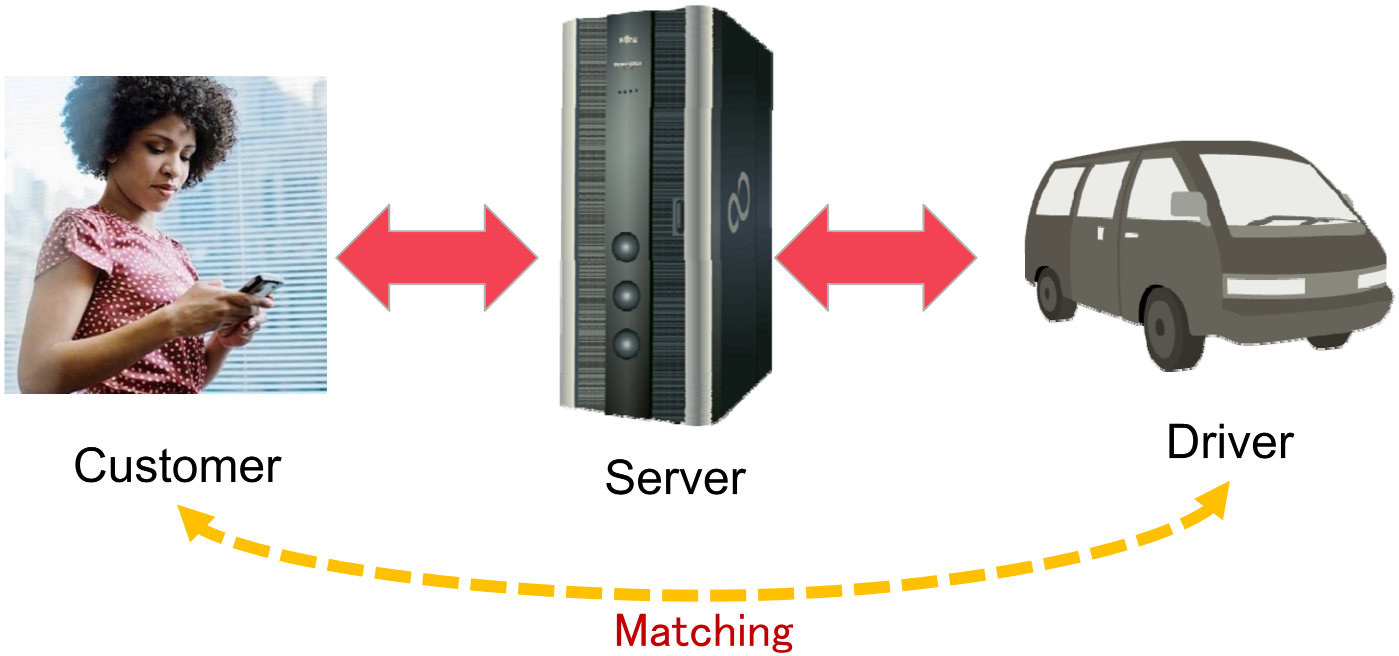
- **Vicious cycle**



- ICT has a potential to break the vicious cycle?

Motivation and background

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



- Why not apply similar technologies to **public transportation services**?
  - DRT, fixed route bus etc.

Problem

- "How to increase operator profit and user satisfaction? "

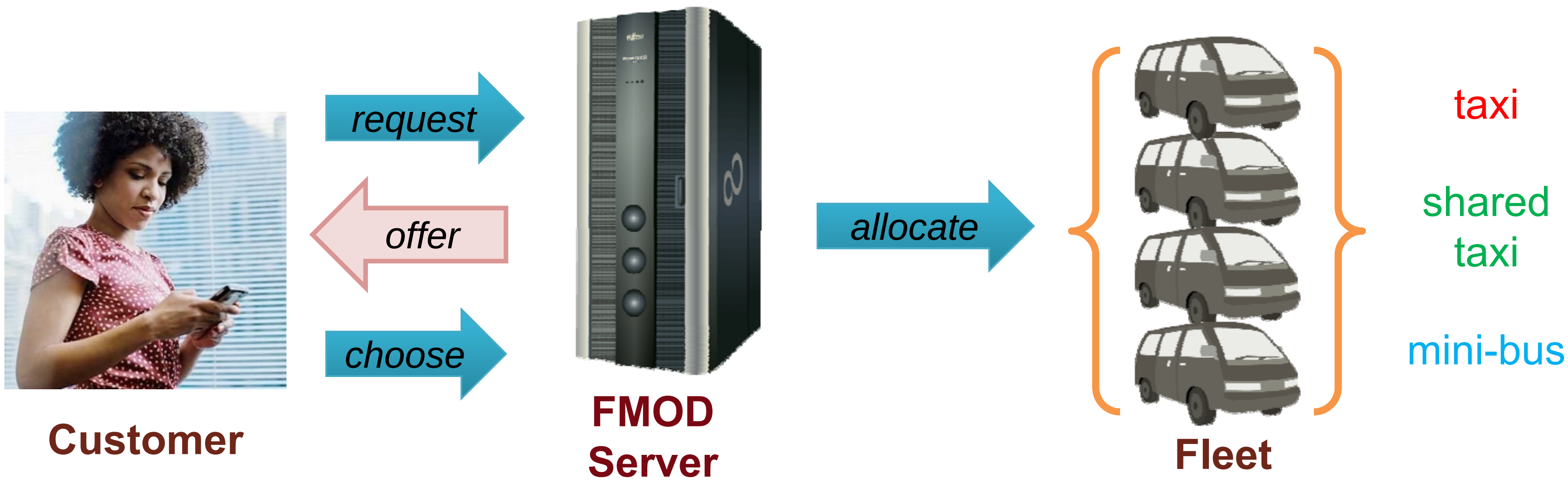
- **Flexibility** to demand fluctuations is necessary.

- 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.

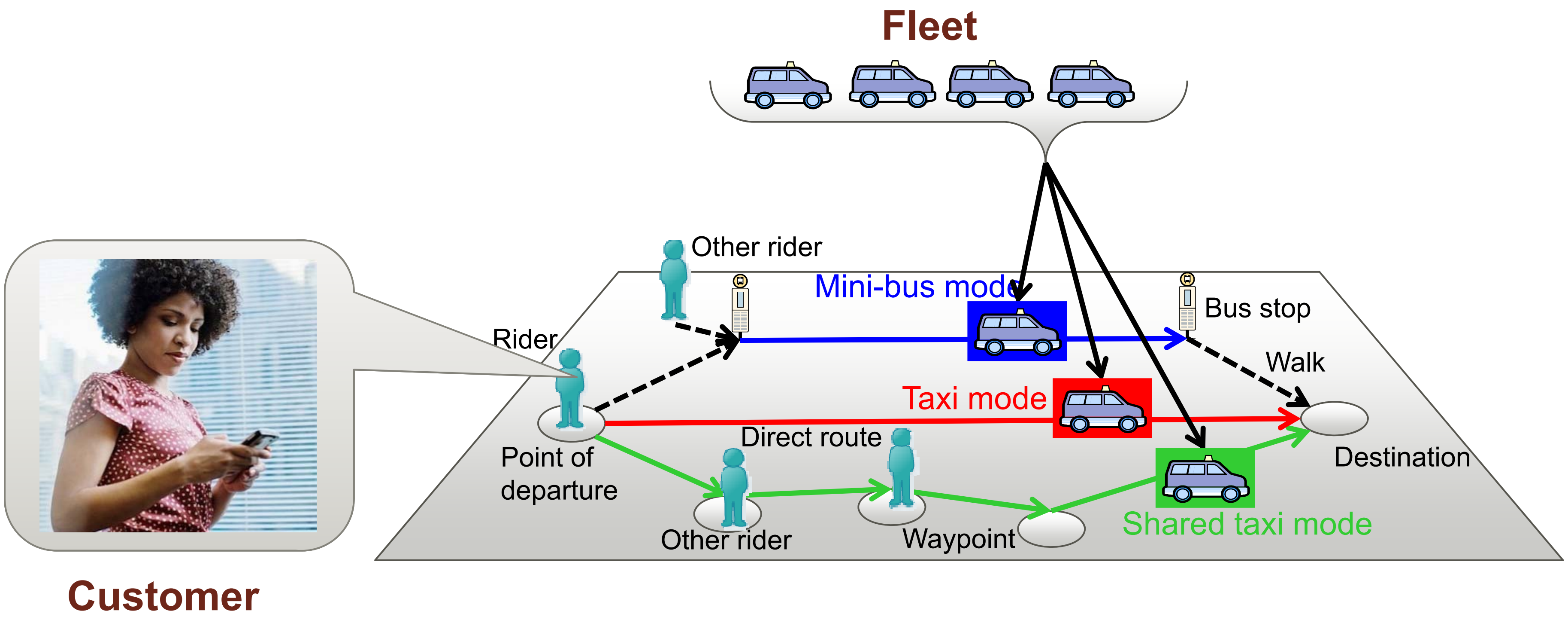
What is FMOD?

- **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



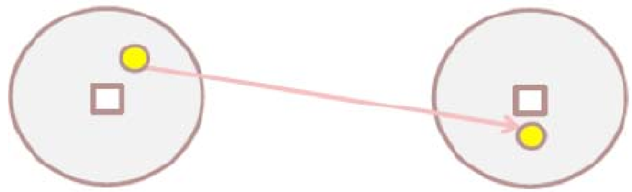
Concept of FMOD (1/2)

- **Dynamic allocation of vehicle** to service modes
  - Same vehicle is dynamically reassigned to different service modes according to the evolving demand.



Service mode

- **Taxi:** Flexible route, flexible schedule, private

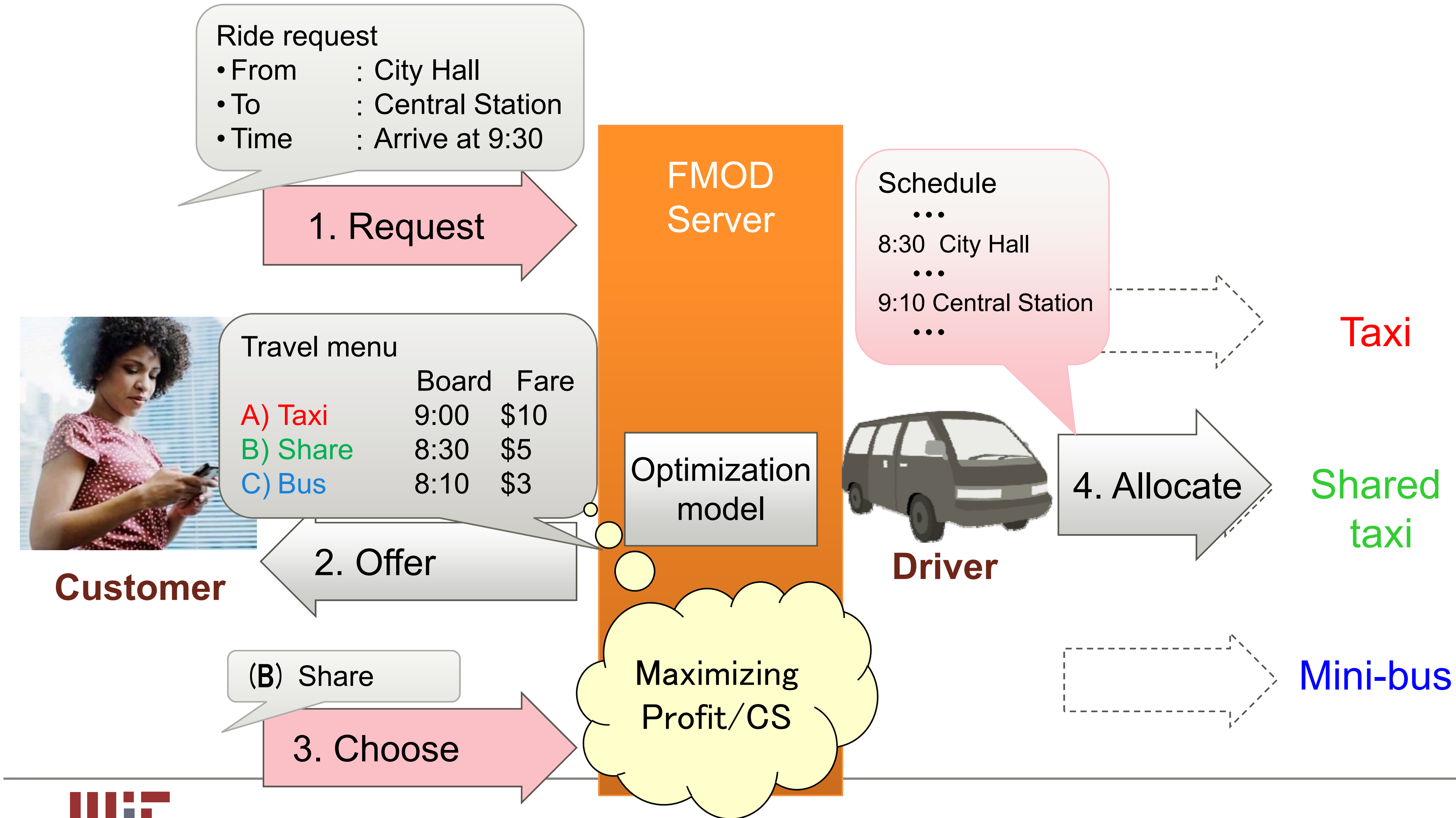


- **Shared-taxi:** Flexible route, flexible schedule, **shared**

- **Mini-bus: Fixed route**, flexible schedule, shared

Concept of FMOD (2/2)

- **Travel menu** is optimized in order to maximize operator profit / customer surplus



Example of travel menu (Mobile app)

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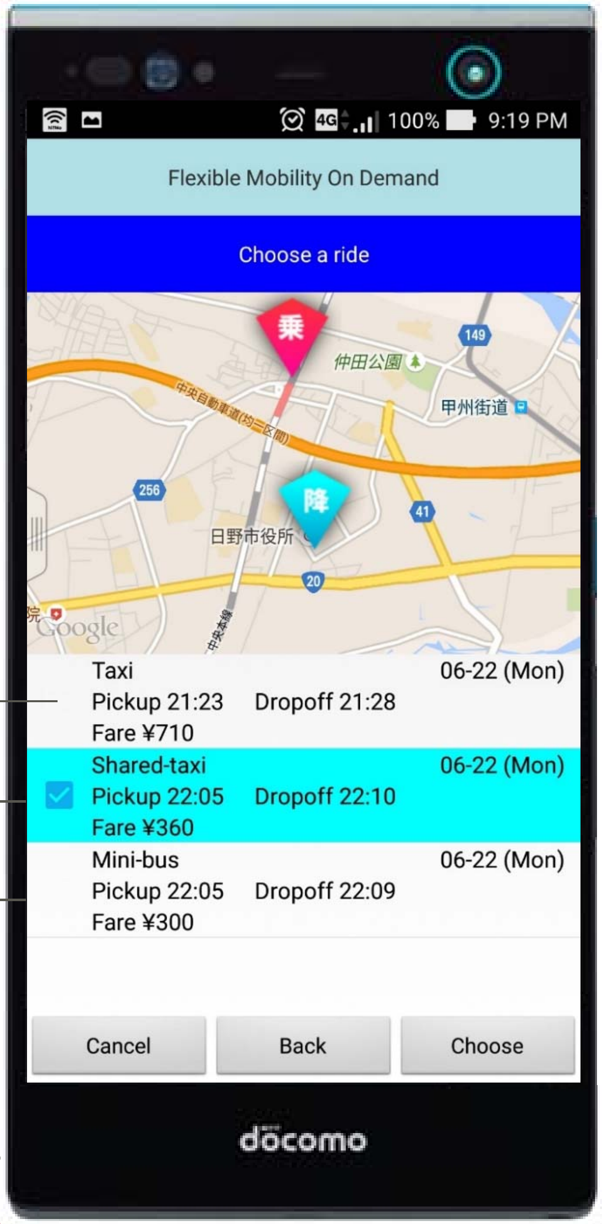
Options with different scheduled time and fare

taxi

shared-taxi

mini-bus



Dynamic allocation (Simulation)

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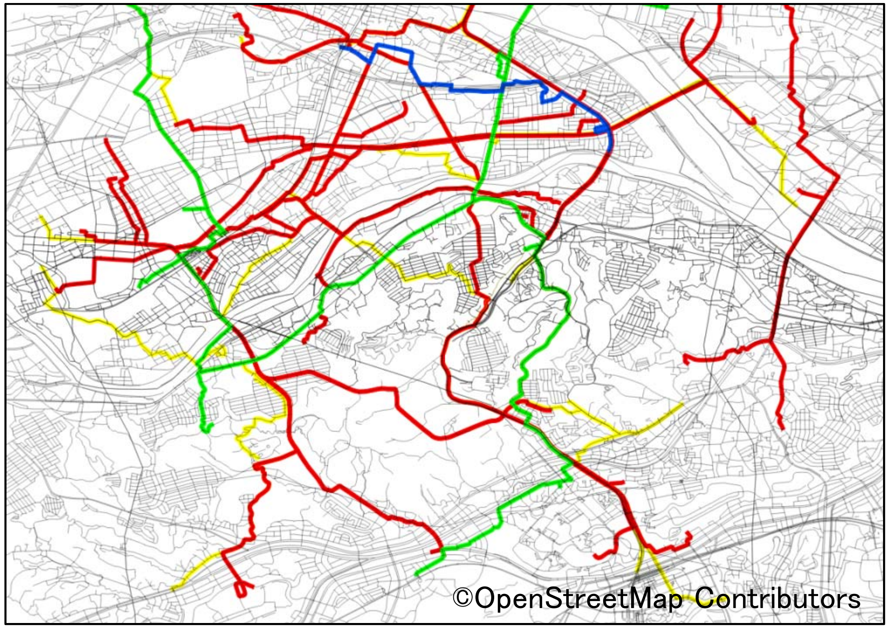
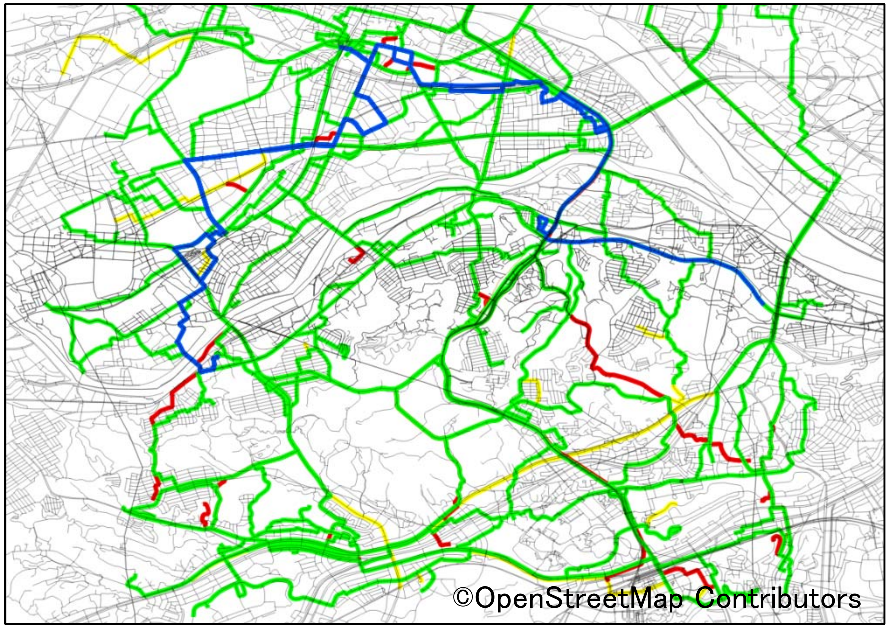
Red: Taxi, Green: Shared taxi, Blue: Mini-bus, Yellow: empty



Off-peak（AM 6:00）
Taxi mode is dominant



On-peak（AM 8:00）
Shared taxi / Mini-bus mode is dominant

Modeling framework

Product $p_{n,m,l}$

- A service ($m \in M$) on a vehicle ($n \in N$) departing at a certain time period ($l \in L$)

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

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

Modeling framework (cont.)

Phase1. Feasible product set generation

Feasible products set are generated taking into account:

– Capacity constraints

– Scheduling constraints

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Phase 2. Assortment optimization

Assortment to be offered to the customer is optimized

– Maximize operator's profit and/or consumer surplus based on a choice model

Choice model

- **Logit model** is used for estimating the choice probabilities for each product and the reject option
- **Utility functions** are defined by:
  - Price
  - In-vehicle travel time
  - Out-vehicle travel time (for mini-bus)
  - Schedule delay

$$\mathrm{Prob}_{n,m,l}(x) = \frac{x_{n,m,l} \exp\left(\mu V_{n,m,l}\right)}{\exp\left(\mu V_{\mathrm{reject}}\right) + \sum_{n' \in N} \sum_{m' \in M} \sum_{l' \in L} x_{n',m',l'} \exp\left(\mu V_{n',m',l'}\right)}$$

Assortment optimization model

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- Myopic model
  - Consider the current request only

$$max \quad R_{current}(X)$$

- Look-ahead model
  - Take into account future demand

$$max \quad R_{current}(X) + R_{future}(X)$$

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

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

Myopic model

- Maximize expected profit from current customer

Logit model

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

Expected profit from each product

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

One product is offered for each services

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

Look-ahead model

- Maximize expected profit from current customer and **expected future profit**

$$\max R_{current}(X) + \sum_{l \in L} \tilde{r}_l \tilde{z}_l$$

Expected future profit as a function of the reserved capacity

$$\text{s.t.} \quad \sum_{n \in N} \sum_{l \in L} x_{n,m,l} = 1$$

$$z_{n,m,l} \leq Cap_{n,m,l} - x_{n,m,l}$$

$$\tilde{z}_l \leq \sum_{n \in N} \sum_{m \in M} z_{n,m,l}$$

$$\tilde{z}_l \leq \Phi^{-1}{}_{Dem_l}(\tau)$$

Reserved capacity is limited by percentile of the future demand distribution

$\tilde{r}_l$	*Average future profit in time period l*
$\tilde{z}_l$	*Total reserved capacity in time period l*
$z_{n,m,l}$	*Reserved capacity of $p_{n,m,l}$*
$Cap_{n,m,l}$	*Capacity of $p_{n,m,l}$*
Dem_l	*Future demand in time period l*

Simulation Experiment - Conditions

- Network
  - Hino city in Tokyo (approx. 9km×8km)
- Simulation horizon: 4 hours
- Supply
  - Fleet size: 12 (8 seats)
  - Bus line: actual route
- Demand
  - OD: From Hino station to arbitrary location (based on population density)
- Fare
  - Taxi: $5 (base) + $0.5 (per 320m)
  - Shared-taxi: 65% of taxi fare
  - Bus: $4 (flat rate)
- Operation Cost
  - Variable cost $0.2 / km
  - Fixed cost $200 / day / vehicle

(Yellow: Bus line)

Simulation Experiment - Scenarios

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- Optimization models
  - Myopic
  - Look-ahead
- Objective function
  - Profit maximization
- Demand
  - 200, 400, 800 requests

Results

- In all cases, look-ahead model improves the profit compared to the myopic model.
- As demand increase, improvement in profit increase,

		% change in profit	% change in cons. surplus	# of served pax.	# of no-offers
200 requests	myopic	reference		170	0
	look-ahead	+2.92%	-0.55%	200(+30)	0
400 requests	myopic	reference		269	20
	look-ahead	+30.8%	+16.4%	304(+35)	7(-13)
800 requests	myopic	reference		335	145
	look-ahead	+85.8%	+2.00%	356(+21)	112(-33)

Results

- In all cases, look-ahead model accommodates more passengers compared to the myopic model

		% change in profit	% change in cons. surplus	# of served pax.	# of no-offers
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Results

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- Look-ahead model decrease the number of no-offers.

		% change in profit	% change in cons. surplus	# of served pax.	# of no-offers
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Conclusions

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- Flexible Mobility on Demand (FMOD)
  - **Dynamic allocation of vehicle** to service modes
  - **Optimized travel menus** are offered to the customer
- We have developed and compared two optimization models.
  - Myopic model, Look-ahead model
- **Look-ahead model** improves the profit and accommodates more passengers compared to the **myopic model**
  - Especially in high demand scenarios.

Future research directions

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- Test with different scenarios
  - Robustness for poor demand estimation
- Field test (Singapore, Japan etc.)
  - Dedicated + non-dedicated fleet
- Real world conditions
  - Traffic congestion, Cancelation / No show, Behind schedule
- Learning the behavior of customer through repeated usage
  - Online calibration of demand model parameters

Thank you for your attention!

ikeda.takuro@jp.fujitsu.com

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