Optimizing the menu of travel options for a Flexible Mobility on Demand System *FMOD*

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November 12, 2014

INFORMS Annual Meeting

Massachusetts Institute of Technology

FUJITSU

Agenda

- Motivation and background
- Concept of FMOD
- Modeling framework
- Simulation experiments
- Conclusions and future directions

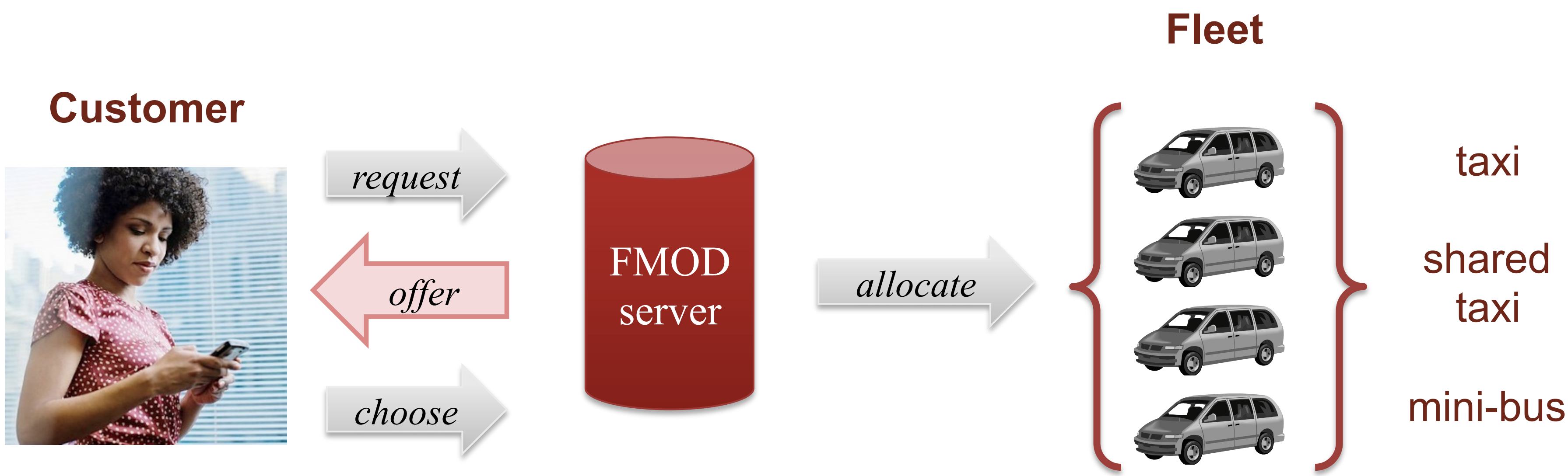
Motivation and background

- Personalized services using smartphone apps are emerging for taxi:
  - Uber, Lyft, SideCar, GoMyWay, etc.

- Why not apply similar technologies to also DRT and fixed route public transportation?

Concept of FMOD

- **Real-time** transportation system
- **Personalized** demand responsive system that gives the traveler an **optimized menu**
- **Dynamic allocation** of vehicles to services



Concept of FMOD (cont.)

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

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

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

Concept of FMOD (cont.)

Supply Demand

FMOD Server

optimization

Request:
Origin: A, Destination: B
Preferred Departure Time: 8:00 – 8:30
/ Preferred Arrival Time: 8:45 – 9:00

request

offer

Offer:

taxi:	DT: 8:25/AT: 8:45, $20
shared-taxi:	DT: 8:27/AT: 8:57, $10 as the 4th passenger
mini-bus:	DT: 8:14/AT: 8:59, $5 as the 6th passenger

choose

Choice:
service: shared-taxi
DT: 8:27/AT: 8:57, $10

Modeling framework

- **Product** $p_{n,m,l}$
  - A service (m) on a vehicle (n) departing at a certain time period (l)
- **Feasible product** $p_{n,m,l} \in F$
  - A product that satisfies the capacity and scheduling constraints
    - Vehicle capacity
    - Existing schedule
    - Preferred time window
      - Maximum schedule delay
- **Offer**
  - A list of feasible products presented to the customer (max 1 product for each service)

Modeling framework (cont.)

Phase1. Feasible product set generation

Set of feasible products to be offered to the customer taking into account:

– Capacity constraints

– Scheduling constraints based on the request

Phase 2. Assortment optimization

Optimized list to be offered to the customer from the feasible set

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

Demand model

- A logit model in order to represent the choice probabilities for the FMOD services and the reject option
- Utility functions are defined by:
  - Price of the service
  - In-vehicle travel time
  - Out-vehicle travel time (for mini-bus)
  - Schedule delay

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

Assortment optimization model

- Myopic version (current request only)
- Maximize expected **profit**

Logit model

$$\max \sum_{n \in N} \sum_{m \in M} \sum_{l \in L} r_{n,m,l} \, \mathrm{Prob}_{n,m,l}(x)$$

- At most one product for each service

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

- Among the set of feasible products

$$x_{n,m,l} \in \{0, 1\} \qquad \forall p_{n,m,l} \in F$$

Assortment optimization model

- Formulated as a mixed integer linear problem
- Transformation with a new decision variable for choice probability

- Myopic vs dynamic

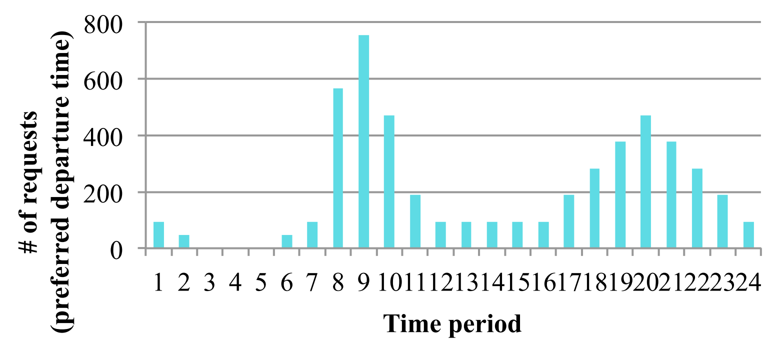
- Different versions of the model are considered:
  - maximize consumer **surplus** (logsum)
  - maximize **profit**
  - maximize profit + consumer surplus: **total benefit**

Simulation experiments
Case study

- Simulation time: 24 hours
- Network
  - Hino city in Tokyo (approx. 9km×8km)
- Supply
  - Fleet size: 60
  - Bus line: actual route
- Demand
  - 5000 requests / day
  - OD: station, hospital etc. (population density)
  - VOT: from \$6/h to \$30/h
- Fare
  - Taxi: \$5 (base) + \$0.5 (per 320m)
  - Shared-taxi: 50% of taxi fare
  - Bus: \$3 (flat)
- Operator Cost
  - \$200 / day / vehicle + \$0.2 per km

(Yellow: Bus line)

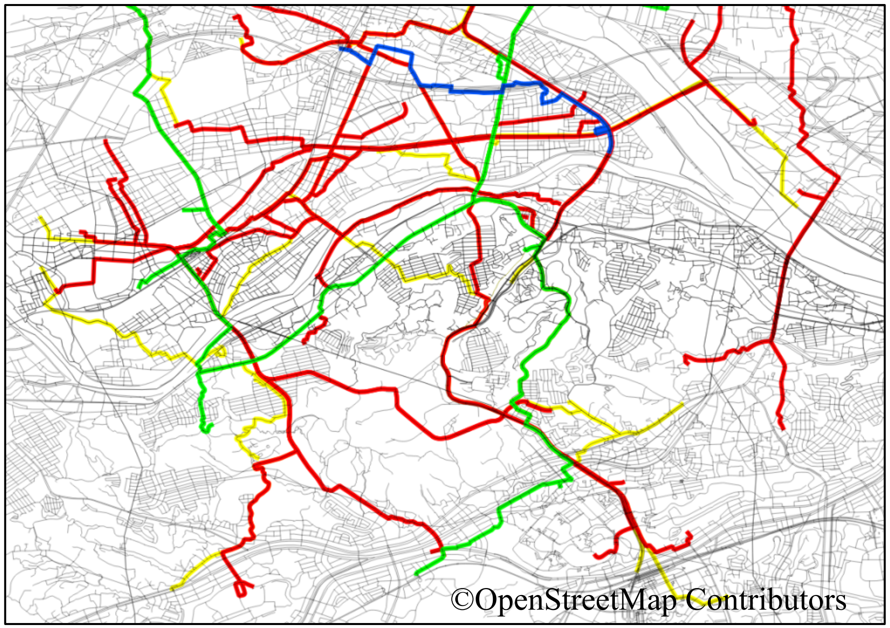
Demand



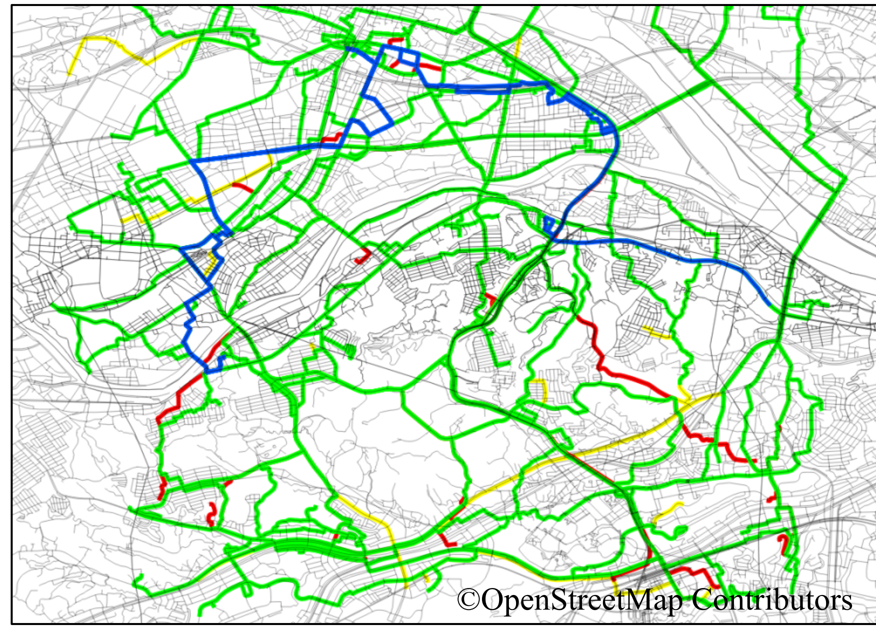
Simulation experiments

Snapshots

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



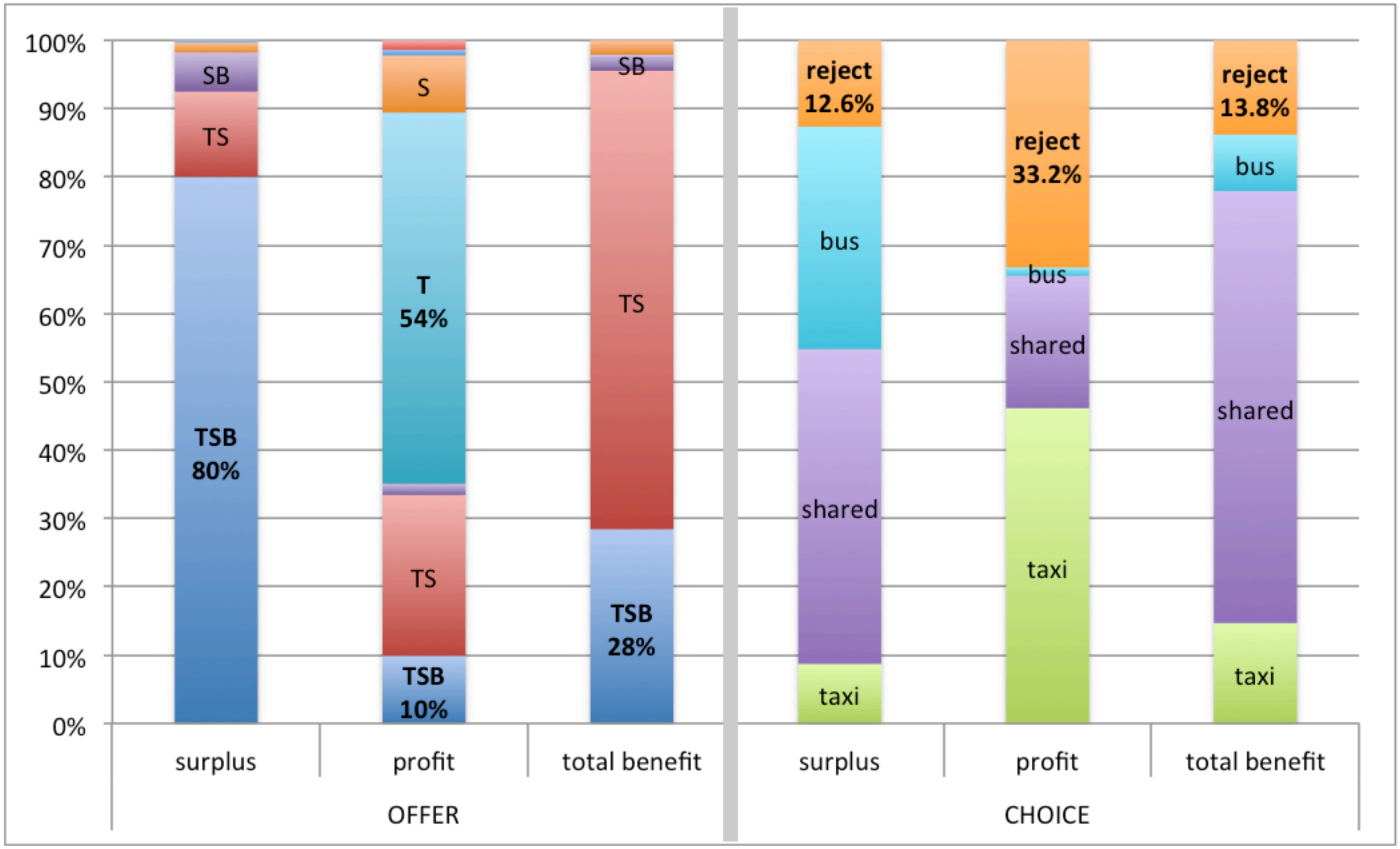
Off-peak（AM 6:00）
Taxi is dominant



Peak（AM 8:00）
Shared taxi / Mini-bus are dominant

Simulation experiments
Comparison of models

T:taxi, **S**:shared-taxi, **B**: mini-bus



Simulation experiments
Main findings

- The offer given by FMOD is significantly affected by the objective function.
- Total benefit case compared to profit maximization:
  - Significant increase in consumer surplus without much decrease in profit
- Dynamic allocation of vehicles provides significant improvements over static allocation

Conclusions and future directions

- FMOD has a potential to increase operator's profit and improve passenger satisfaction

- Ongoing and further research directions include:
  - Field test
  - Estimation of future demand
  - Real life conditions (e.g. traffic)
  - Learning the behavior of customer through repeated visits

Conclusions and future directions

$$\max \sum_{n\in N}\sum_{m\in M}\sum_{l\in L} r_{n,m,l}\,\omega_{n,m,l}$$

$$+\sum_{m\in M}\sum_{l\in L}\tilde{r}_{m,l} E[Dem_{m,l} | Dem_{m,l} \leq \tilde{z}_{m,l}]$$

$$\text{s.t.} \sum_{n\in N}\sum_{m\in M}\sum_{l\in L} \omega_{n,m,l} = 1 - \omega_{reject}$$

$$\sum_{n\in N}\sum_{l\in L} \frac{\omega_{n,m,l}}{\exp(\mu V_{n,m,l})} \leq \frac{\omega_{reject}}{\exp(\mu V_{\text{reject}})} \qquad \forall m \in M$$

$$\omega_{n,m,l} \leq 0 \qquad \forall p_{n,m,l} \notin F, n\in N, m \in M, l \in L$$

$$0 \leq \frac{\omega_{n,m,l}}{\exp(\mu V_{n,m,l})} \leq \frac{\omega_{reject}}{\exp(\mu V_{\text{reject}})} \qquad \forall n\in N, m \in M, l \in L$$

$$x_{n,m,l} \geq \omega_{n,m,l} \qquad \forall n\in N, m \in M, l \in L$$

$$\tilde{z}_{m,l} \leq \sum_{n} z_{n,m,l} \qquad \forall m \in M, l \in L$$

$$z_{n,m,l} \leq \text{Cap}_{n,m,l} - x_{n,m,l} \qquad \forall n\in N, m \in M, l \in L$$

$$x_{n,m,l} \in \{0,1\} \qquad \forall n\in N, m \in M, l \in L$$

$$z_{n,m,l} \geq 0 \qquad \forall n\in N, m \in M, l \in L$$

$$\tilde{z}_{m,l} \geq 0 \qquad \forall m \in M, l \in L$$

Thank you for your attention!

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Feasible product set generation

- Insertion of a new schedule

[Schedule Block]	SB_1				SB_2		SB_3			
Service type	Shared				empty		Mini-bus			
[Stops]	s_1^1	s_2^1	s_3^1	s_4^1	s_1^2	s_2^2	s_1^3	s_2^3	s_3^3	s_4^3
Location	a	b	c	d	d	g	g	h	i	j
Arrival Time	-	9:15	9:30	9:50	-	14:40	-	15:00	15:10	15:20
Departure time	9:00	9:16	9:31	-	12:30	-	14:50	15:01	15:11	-
Boarding passengers	1	2	-	-	-	-	4,5	6,7	-	-
Alighting passengers	-	-	1	2	-	-	-	4	6	5,7

[Schedule Block]	SB_1				SB_2		SB_3		SB_4		SB_5			
Service type	Shared				empty		taxi		empty		Mini-bus			
[Stops]	s_1^1	s_2^1	s_3^1	s_4^1	s_1^2	s_2^2	s_1^3	s_2^3	s_1^4	s_2^4	s_1^5	s_2^5	s_3^5	s_4^5
Location	a	b	c	d	d	e	e	f	f	g	g	h	i	j
Arrival Time	-	9:15	9:30	9:50	-	13:00	-	13:30	-	14:40	-	15:00	15:10	15:20
Departure time	9:00	9:16	9:31	-	12:30	-	13:05	-	14:30	-	14:50	15:01	15:11	-
Boarding passengers	1	2	-	-	-	-	3	-	-	-	4,5	6,7	-	-
Alighting passengers	-	-	1	2	-	-	-	3	-	-	-	4	6	5,7

Feasible product set generation (cont.)

- Insertion to the existing schedule

[Schedule Block]	SB_1				SB_2		SB_3			
Service type	Shared				empty		Mini-bus			
[Stops]	s_1^1	s_2^1	s_3^1	s_4^1	s_1^2	s_2^2	s_1^3	s_2^3	s_3^3	s_4^3
Location	a	b	c	d	d	g	g	h	i	j
Arrival Time	-	9:15	9:30	9:50	-	14:40	-	15:00	15:10	15:20
Departure time	9:00	9:16	9:31	-	12:30	-	14:50	15:01	15:11	-
Boarding passengers	1	2	-	-	-	-	4,5	6,7	-	-
Alighting passengers	-	-	1	2	-	-	-	4	6	5,7

[Schedule Block]	SB_1						SB_2		SB_3			
Service type	Shared						empty		Mini-bus			
[Stops]	s_1^1	s_2^1	s_3^1	s_4^1	s_5^1	s_6^1	s_1^2	s_2^2	s_1^3	s_2^3	s_3^3	s_4^3
Location	a	b	c	e	d	f	d	g	g	h	i	j
Arrival Time	-	9:15	9:30	9:40	9:50	10:20	-	14:40	-	15:00	15:10	15:20
Departure time	9:00	9:16	9:31	9:41	-	-	12:30	-	14:50	15:01	15:11	-
Boarding passengers	1	2	-	3	-	-	-	-	4,5	6,7	-	-
Alighting passengers	-	-	1	-	2	3	-	-	-	4	6	5,7

Transformation of the model

$$\max \sum_{n \in N} \sum_{m \in M} \sum_{l \in L} r_{n,m,l}\, \omega_{n,m,l}$$

$$\text{s.t.} \sum_{n \in N} \sum_{m \in M} \sum_{l \in L} \omega_{n,m,l} = 1 - \omega_{reject}$$

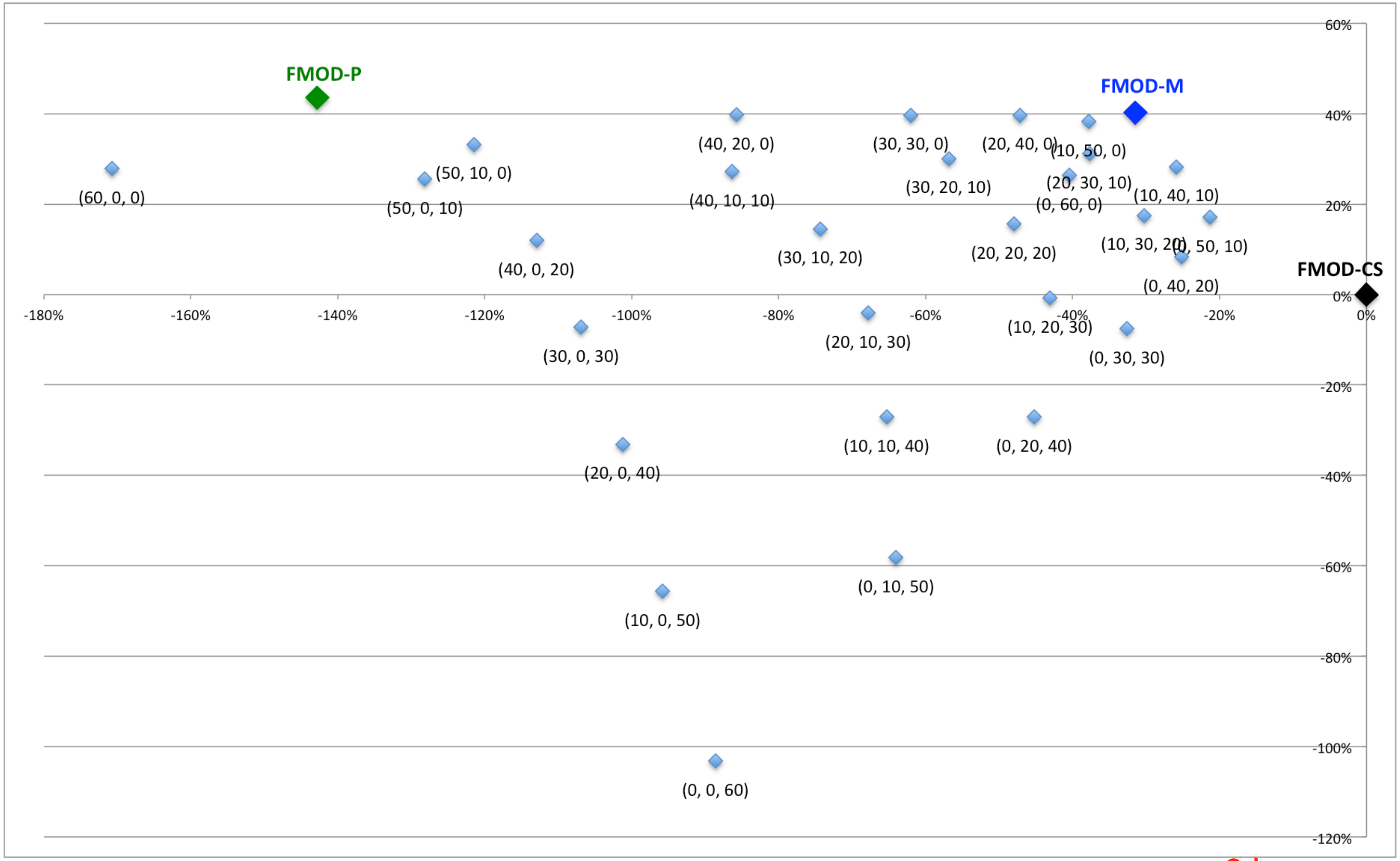
$$\sum_{n \in N} \sum_{l \in L} \frac{\omega_{n,m,l}}{\exp\left(\mu V_{n,m,l}\right)} \leq \frac{\omega_{reject}}{\exp\left(\mu V_{\text{reject}}\right)} \qquad \forall m \in M$$

$$0 \leq \frac{\omega_{n,m,l}}{\exp\left(\mu V_{n,m,l}\right)} \leq \frac{\omega_{reject}}{\exp\left(\mu V_{\text{reject}}\right)} \qquad \forall p_{n,m,l} \in F$$

Additional simulation results

Added value of dynamic allocation

x-axis: % change in consumer surplus with respect to FMOD-CS
y-axis: % profit in profit compared to FMOD-CS



Dynamic programming

- Dynamic programming Bellman equation:

$$J_c(S_c) = \max_{x \in F_c} \{E[R_c(x)] + E[J_{c+1}(S_{c+1})]\}$$

state

All feasible assortments in stage c under state S_c

- where expected profit is:

$$E[R_c(x)] = \sum_{n \in N} \sum_{m \in M} \sum_{l \in L} r_{n,m,l} \, \text{Prob}_{n,m,l}(x)$$

- For each possible choice of the customer the state will be updated differently for the next customer.

Dynamic programming (cont.)

- The dynamic programming equation can be solved with the reference point being the last customer:
  - Given the feasible set of products we know what we will offer to the last customer: we will offer the best product we have at hand!

$$J_C(S_C) = \max_{x \in F_C} \{E[R_C(x)]\}$$

Dynamic programming (cont.)

- The recursive function can be demonstrated as below
  - We know what we will decide at the last stage (last customer request)
  - The recursive function will enable to store the best decisions at each state for all possible feasible set of products

```
function MAXPROFIT(c, S_c)
    if c==C then
        return E[R_C(x)]
    else
        return E[R_c(x)] + MAXPROFIT(c + 1, S_{c+1})
    end if
end function
```