Demand control management for one-way car sharing system focus on the imbalance between demand and supply

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• Research background
• Introduction of one-way car sharing service in Yokohama
• Data analysis
• Numerical example : Paradox of station distribution
• Calculation of profit maximization method in simple network
• Micro simulation in real network
• Conclusion
Background

- Car sharing service was introduced to Japan as new convenient mobility in recent years.

- One-way car sharing: does not require its users to return the vehicle to the same location from which it was accessed.

- In 2014, the one-way car sharing was approved by law.

→ “in the case that we can access the situation of car by utilizing the IT”

http://business.nikkeibp.co.jp/article/topics/20140728/269323/?P=3&mds
The development of IT technology enable to on-demand transportation system.
Car sharing service in Yokohama city

Nissan and Yokohama City Launch Choimobi

First One-way Car Sharing Service with a Large Number of Ultra-compact EVs

- Number of stations: 60 (for 110 vehicles)
- Number of vehicles: 50
- Number of registrants: 14,000
- Price: 30 yen / min (basic plan)
Data property

**Probe person data**: 
- activity diary for each monitor and trajectory data by GPS
- to describe the learning effect by long-term data
- to grasp the dot base trajectory

<table>
<thead>
<tr>
<th>survey</th>
<th>Survey period</th>
<th>Number of Monitor</th>
<th>Count of trip</th>
<th>Number of GPS data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choimobi PP2013</td>
<td>2013/10/01 ～2014/03/31</td>
<td>118</td>
<td>19944</td>
<td>21553929</td>
</tr>
<tr>
<td>Choimobi PP2014</td>
<td>2014/09/01 ～2014/09/30</td>
<td>16</td>
<td>1025</td>
<td>1180192</td>
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<tr>
<td>Choimobi PP2014</td>
<td>2014/10/01～2014/10/31</td>
<td>15</td>
<td>902</td>
<td>1038377</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8 month</strong></td>
<td><strong>123</strong></td>
<td><strong>21,862</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Use result data**

- Record of use
- OD, time, the number of vehicle at each station

<table>
<thead>
<tr>
<th>Survey period</th>
<th>Number of station</th>
<th>Count of use</th>
<th>Number of user</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013/10/11～2014/09/24</td>
<td>54</td>
<td>45190</td>
<td>5910</td>
</tr>
<tr>
<td>2014/11/1～2015/6/30</td>
<td>60</td>
<td>17666</td>
<td>Over 10000</td>
</tr>
</tbody>
</table>
What is problem?

• Uneven distribution of vehicle cause the risk of unavailable service

Data collected period:
2013/10/11-2013/12/20

- Full vehicle rate: over 1/3
- No vehicle rate: over ½
- Other
What is problem?

• Imbalance between demand and supply cause the loss of opportunity cost frequently happens on the operation side when there is no reservation available for users during their required hours.
What is problem?

Paradox of station distribution

When new station established in demand concentrated area, profit may rather decrease.

Research Question

How we can reduce this imbalance and then minimize the loss of opportunity cost
Numerical example:
Paradox of station distribution

Probability of trip demand

\[ P\left(d_{ij}(t)\right) = \left(\lambda_{ij}(t)\right)^{d_{ij}(t)} \frac{\exp\left(-\lambda_{ij}(t)\right)}{\left(d_{ij}(t)!\right)} \]

Expectation value parameter of Poisson distribution

\[ \lambda_{ij}(t) = \overline{\lambda}_{ij}(t) \cdot \frac{\exp(\alpha_{ij} + \beta p_{ij}(t))}{A_{ij} + \exp(\alpha_{ij} + \beta p_{ij}(t))} \]

\( d_{ij} \): demand of trip between station \( i \) and \( j \)

\( \overline{\lambda}_{ij}(t) \): all trip between station \( i \) and \( j \)

\( p_{ij} \): price (controlled variable)

\( A_{ij}, \alpha_{ij}, \beta_{ij} \): parameter (constant)
Method of demand control

1. Reduce the number of station
   - Easy to manage
   - Decrease the advantage of one-way car sharing service that allow us to move short distance.

2. Relocation by operator
   - Surely get lid of the uneven vehicle distribution
   - Large operation cost

3. Demand incentive control by changing price
   - Trip to the high demand station: higher price
   - Trip to the low demand station: lower price
   - Demand changes by stochastic

Objective
To Formulate of the stochastic control system by the pricing strategy and propose the algorithm.
Formulation of profit maximization

- Maximize the profit by user’s use of Car sharing service

\[
\text{max } R(s(t), O(T)) = \sum_{t} r(t|s(t), o(t))
\]

Profit of time \( t \)

\[
= \sum_{t} \sum_{i,j} V_{ij}(t|s(t), o(t))p_{ij}(t|o(t))
\]

The number of trip between station \( i \) and \( j \)

The price between station \( i \) and \( j \)

\( N = \{1, ..., i, j, ..., N\} \) Set of station

\( T = \{1, ..., t, ..., T\} \) Set of time

\( c_i \) Max of parking space

\( x_i(t) \) The number of vehicle at time \( t \)

\( s(t) = \{x_1(t), ..., x_N(t)\} \) Distribution of vehicle at time \( t \)

\( d_{ij}(t) \) Trip demand at time \( t \)

\( v_{ij}(t) \) The number of real trip at time \( t \)

\( o(t) \) demand control at time \( t \)

\( p_{ij}(t) \in o(t) \) Price between \( i \) and \( j \) at time \( t \)
Formulation of profit maximization

\[ \sum_{i} x_i = X \quad \text{Law of the conservation of the number of vehicle} \]

\[ x_i - \sum_{j} v_{ij}(t) + \sum_{k} v_{ki}(t) \geq 0 \quad \text{Constrain of departure} \]

\[ x_i - \sum_{j} v_{ij}(t) + \sum_{k} v_{ki}(t) \geq c_i \quad \text{Constrain of arrival} \]

\[ x_i(t + 1) = x_i - \sum_{j} v_{ij}(t) + \sum_{k} v_{ki}(t) \quad \text{The movement of vehicle} \]

\[ N = \{1, ..., i, j, ..., N\} \quad \text{Set of station} \]

\[ T = \{1, ..., t, ..., T\} \quad \text{Set of time} \]

\[ c_i \quad \text{Max of parking space} \]

\[ x_i(t) \quad \text{The number of vehicle at time } t \]

\[ s(t) = \{x_1(t), ..., x_N(t)\} \quad \text{Distribution of vehicle at time } t \]

\[ d_{ij}(t) \quad \text{Trip demand at time } t \]

\[ v_{ij}(t) \quad \text{The number of real trip at time } t \]

\[ o(t) \quad \text{demand control at time } t \]

\[ p_{ij}(t) \in o(t) \quad \text{Price between } i \text{ and } j \text{ at time } t \]
Algorithm by using dynamic programming method

Dynamic programming method

Calculate an optimum control by considering a state transition of next period = Finite Markov Decision Process (Bellmann, 1957; Howard, 1960)

Optimality function

\[
\begin{align*}
  u_t(s(t)) &= \begin{cases}
    \underset{o(t)}{\max} \left[ r(t|s(t)), o(t) \right] + \sum_{s(t+1)} P(s(t+1)|s(t), o(t)) \cdot u_{t+1}(s(t+1)) & (0 < t \leq T - 1) \\
    \underset{o(T)}{\max} \{ r(T|s(T)), o(T) \} & (t = T)
  \end{cases}
\end{align*}
\]

\rightarrow \text{calculation is start from last period } T \text{ towards beforehand}

Step1: calculate \( u_T(s(T)) \) for state \( s(T) \)

Step2: calculate \( u_{T-1}(s(T-1)) \) for state \( s(T-1) \)

Step3: repeat towards the former period
Numerical example: Verify the price control effect

- Calculate double or half price for each OD

\[ r(t) \text{ is stochastic function} \]
\[ \Rightarrow \text{result of calculation are variable} \]

Solution algorithm:
- Maximize the expected value type
  \[ \Rightarrow \text{profit might decrease extreme} \]
Micro simulation

Probability of service available changes dynamic and discrete

⇒ necessary to consider availability for mode choice
Mode choice model by using PP data

**Probe Person data**: activity diary for each monitor and trajectory data by GPS

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<td>16</td>
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<td>2218469</td>
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**Use result data**

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<td>45190</td>
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</tr>
</tbody>
</table>

Mode choice model by using MNL

\[
P_{cs} = \frac{\delta_{cs} \exp(V_{cs})}{\sum_{m} \delta_{m} \exp(V_{m})}
\]

\(cs\) : car sharing

\(P_{cs}\) : probability of car sharing

\(V_{m}\) : constant term of mode \(m\)

\(\delta_{m}\) : availability of mode \(m\)

Considering availability of CS

<table>
<thead>
<tr>
<th>variables</th>
<th>parameter</th>
<th>t-value</th>
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<tbody>
<tr>
<td>specific constants(public transportation)</td>
<td>1.010</td>
<td>7.23**</td>
</tr>
<tr>
<td>Time [*10min]</td>
<td>-0.203</td>
<td>-2.06*</td>
</tr>
<tr>
<td>Cost [*100 yen]</td>
<td>-0.239</td>
<td>-8.52**</td>
</tr>
<tr>
<td>Access/egress time [min]</td>
<td>-0.028</td>
<td>-5.43**</td>
</tr>
<tr>
<td>Under 1km(walk)</td>
<td>-1.240</td>
<td>-9.56**</td>
</tr>
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</table>

number of sample 688

LL(0) -1232.731

LL(β) -716.47

\(\rho p^2\) 0.40
Application to the real network

<table>
<thead>
<tr>
<th>Simulation Scenario</th>
<th>Station interval</th>
<th>Pricing control</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>500m</td>
<td>Without</td>
</tr>
<tr>
<td>B</td>
<td>500m</td>
<td>With</td>
</tr>
<tr>
<td>C</td>
<td>100m</td>
<td>Without</td>
</tr>
<tr>
<td>D</td>
<td>100m</td>
<td>with</td>
</tr>
</tbody>
</table>

**Pricing rule**

(a) Set half price (10 yen/min) when vehicle ahead to the empty station or depart from full station

(b) Set double price (40 yen/min) when vehicle make origin station full or depart station empty

Distribution of station (left: 500m interval, right: 100m interval)
# Result of Simulation

## Result of Simulation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Profit (yen)</th>
<th>Count of user</th>
<th>Station interval</th>
<th>Pricing control</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>347,260</td>
<td>1,709</td>
<td>500m</td>
<td>Without</td>
</tr>
<tr>
<td>B</td>
<td>401,390</td>
<td>1,862</td>
<td>500m</td>
<td>With</td>
</tr>
<tr>
<td>C</td>
<td>272,580</td>
<td>2,279</td>
<td>100m</td>
<td>Without</td>
</tr>
<tr>
<td>D</td>
<td>303,900</td>
<td>2,391</td>
<td>100m</td>
<td>with</td>
</tr>
</tbody>
</table>

## Simulation Scenario

- **A**: Scenarios A and B show the effect of pricing control on profit and user count. Scenario A, with a profit of 347,260 yen and a count of 1,709 users, compares to Scenario B, which has a profit of 401,390 yen and a count of 1,862 users. The difference in profit and user count could be due to the different pricing control strategies. Scenario A uses a 500m station interval without pricing control, while Scenario B uses a 500m station interval with pricing control. The results suggest that pricing control can potentially increase profit and user count.

- **B**: Scenarios C and D show the impact of station interval and pricing control on profit and user count. Scenario C, with a profit of 272,580 yen and a count of 2,279 users, has a 100m station interval without pricing control. Scenario D, with a profit of 303,900 yen and a count of 2,391 users, has a 100m station interval with pricing control. The results indicate that a shorter station interval (100m) and pricing control can lead to increased profit and user count.

## Graphs

### A

![Graph A](image)

The graph shows the number of stations over time for Scenario A. The blue line represents empty stations, the green line represents normal stations, and the red line represents full stations. The graph suggests a trend where the number of empty stations decreases over time, indicating a higher demand for stations.

### B

![Graph B](image)

The graph shows the number of stations over time for Scenario B. The graph indicates a similar trend as Scenario A, with a decrease in empty stations over time, suggesting a higher demand for stations with pricing control.

### C

![Graph C](image)

The graph shows the number of stations over time for Scenario C. The graph indicates a trend where the number of empty stations decreases over time, suggesting a higher demand for stations with a shorter station interval.

### D

![Graph D](image)

The graph shows the number of stations over time for Scenario D. The graph indicates a similar trend as Scenario C, with a decrease in empty stations over time, suggesting a higher demand for stations with a shorter station interval and pricing control.
Conclusion

Summary

• Propose the algorithm and formulation regarding to the stochastic control with pricing strategy deal with loss of opportunity caused by uneven station distribution.
  →enable to control considering the stochastic transition of system

• Evaluate the pricing strategy in the Yokohama network by constructing the micro simulation based on the Use result data.
  →enable to consider availability of CS

Future works

• Elaboration and sophistication of Micro simulation and activity model
• Verify the profit maximization in the real network.
• Examine the scenario for simulation ..... And so on
Reference

• Nissan, choimobi

• http://www.nissan-global.com/EN/NEWS/2013/_STORY/131010-02-e.html


• Thomson, J., M., Great Cities and their Traffic, Gollancz, London.


• Ciari, F., Dobler, C., and Axhausen, K., Modeling one-way shared vehicle systems: an agent-based approach, paper presented at 13th International Conference on Travel Behaviour Research, Toronto, July 2012.


チョイモビのサービスの整理

| 運用期間 | 会員登録 | 安全講習会 | 車両 | 施設
|---------|---------|---------|------|---------|
| 2013/10/11～2014/11/1 | 2014/9/30で終了 | 201/10/9 | 70台 | 63か所（131台分）
| 2014/11/1～2015/9月 | 20014/10/28 | 2014/10/4 | 50台 | 約60か所（約110台分）

<table>
<thead>
<tr>
<th>料金設定</th>
<th>第一期</th>
<th>第二期</th>
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<tr>
<td>会員登録料</td>
<td>無料</td>
<td>1000円</td>
</tr>
<tr>
<td>10月 11月</td>
<td>20円/分（21日まで）</td>
<td>-</td>
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<tr>
<td>12月以降</td>
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<td>AプランまたはBプラン</td>
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<table>
<thead>
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<th>Bプラン</th>
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<td>-</td>
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<tr>
<td>無料利用料金</td>
<td>50分</td>
<td>-</td>
</tr>
<tr>
<td>料金/分</td>
<td>20円（51分以降）</td>
<td>30円</td>
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