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

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- Data analysis
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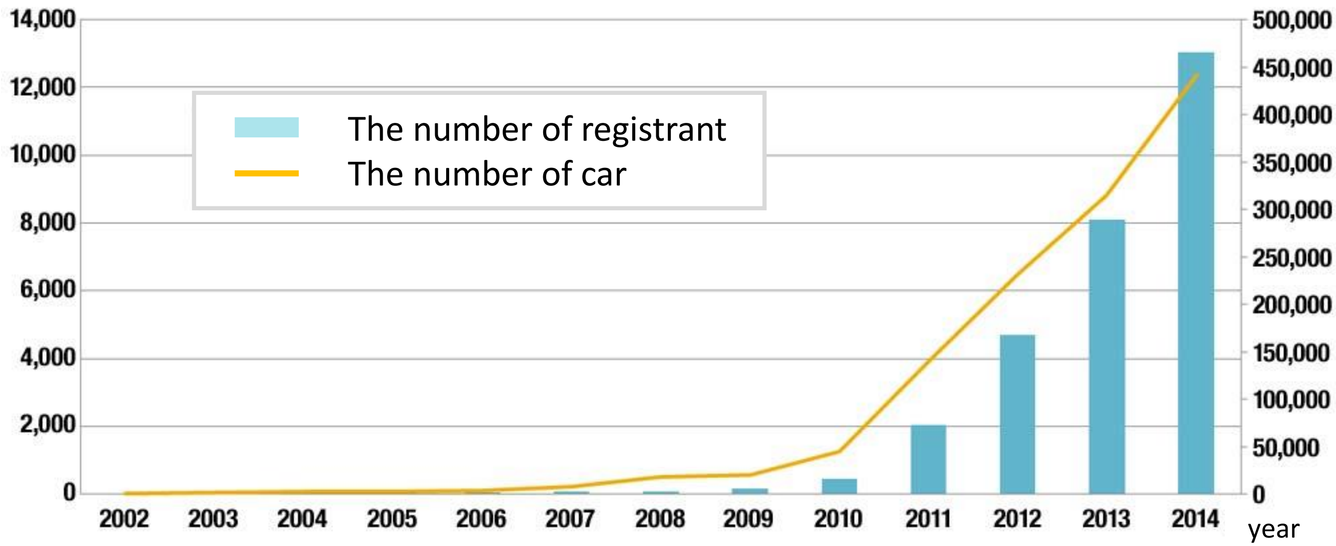
Background

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

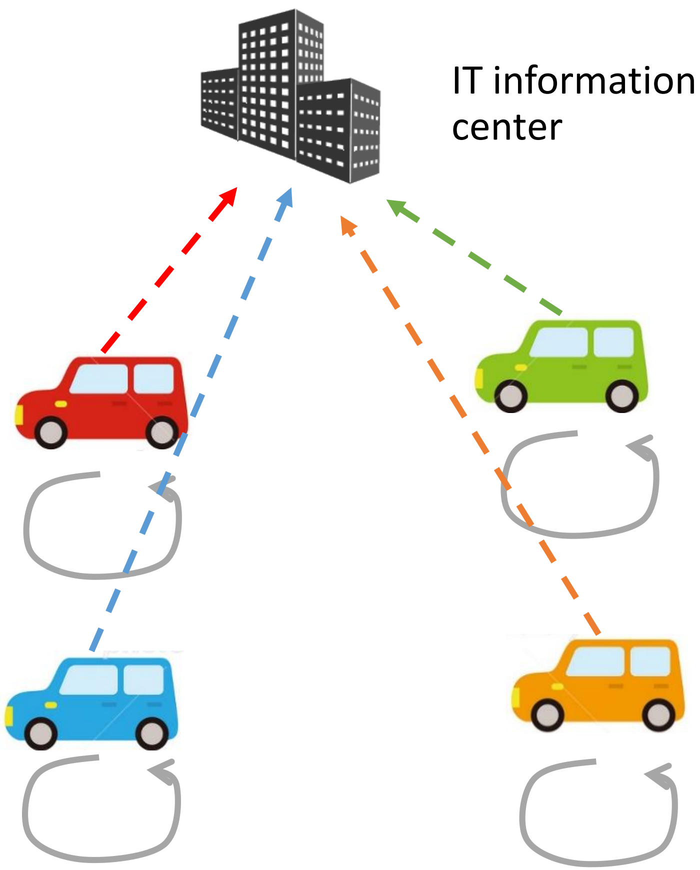


http://business.nikkeibp.co.jp/article/topics/20140728/269323/?P=3&mds

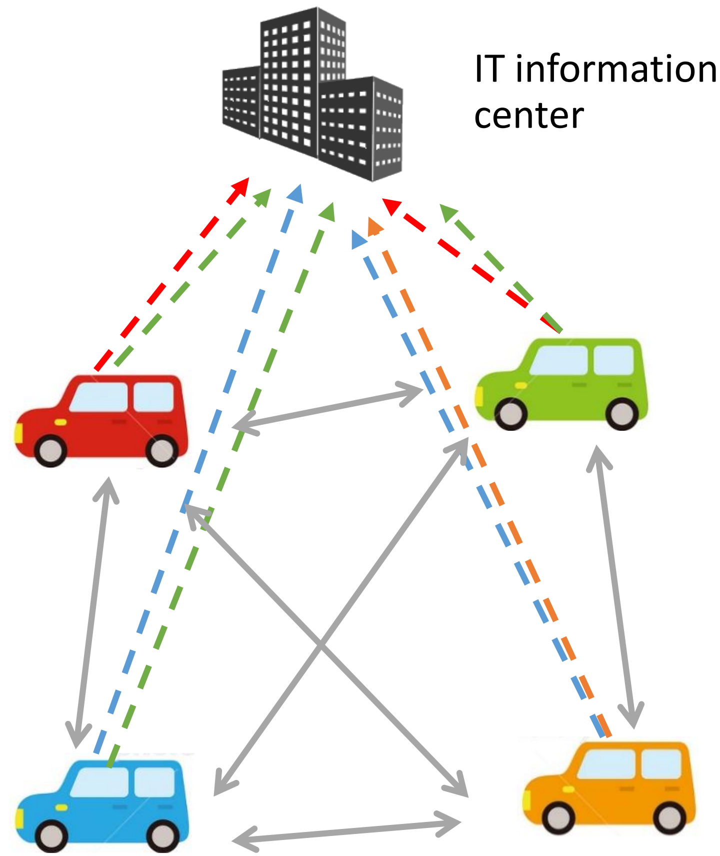
- One-way car sharing : does not require its users to return the vehicle to the same location from which it was accessed.
- In 2014, the one-way car sharing was approved by law.
  →"in the case that we can access the situation of car by utilizing the IT"

Background

Round trip Car Sharing



One-way Car Sharing



Movement of vehicle

Information of situation of each vehicle

The development of IT technology enable to on-demand transportation system

Car sharing service in Yokohama city

an and Yokohama City Launch Choimobi
st One-way C
-compact EV

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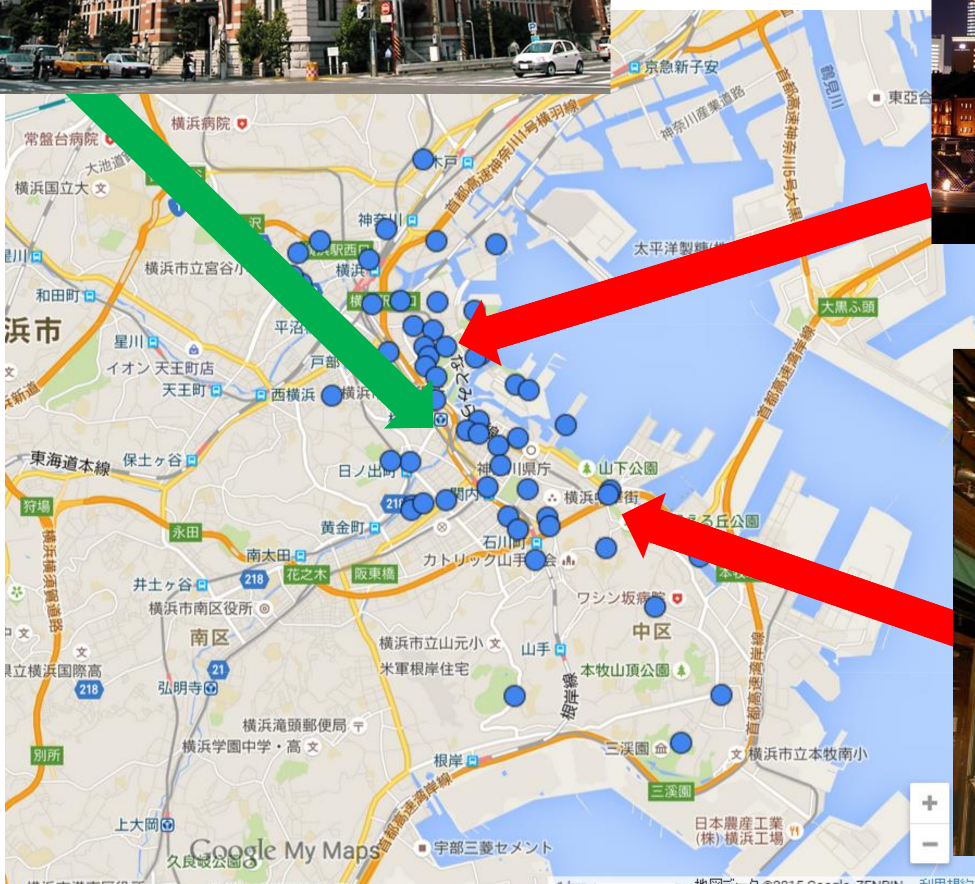
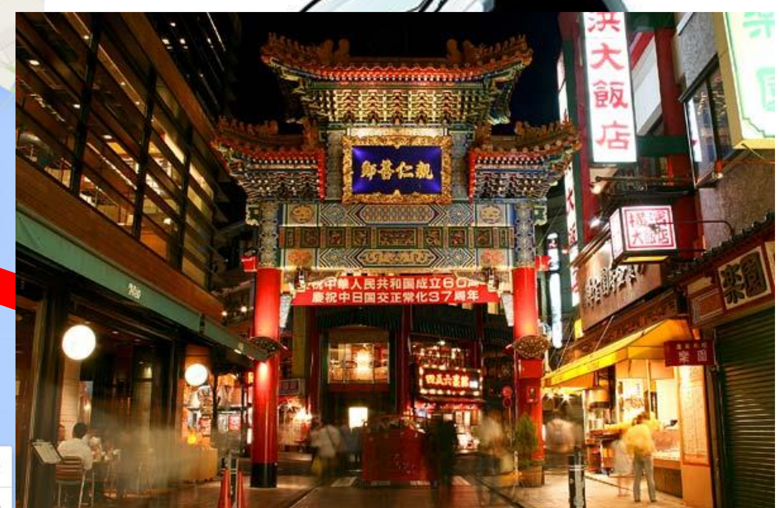




Data property

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

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

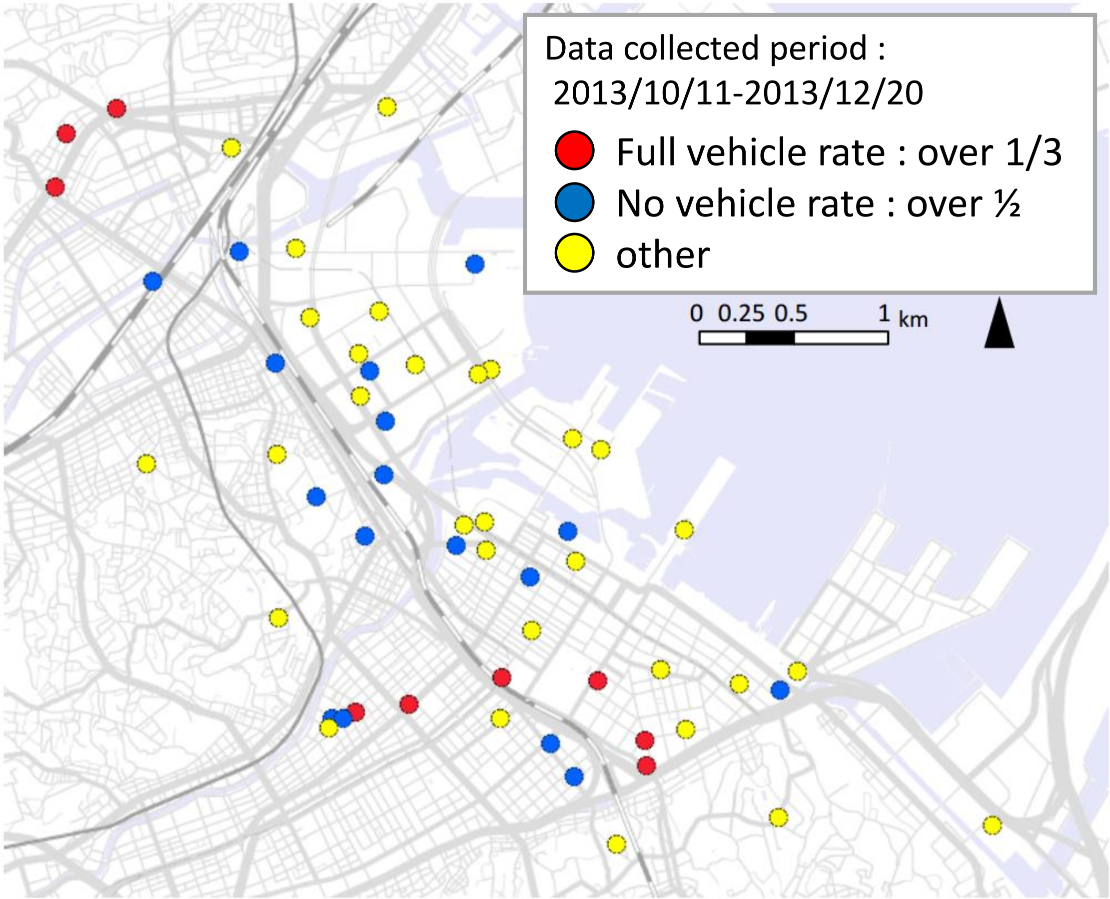
Use result data

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

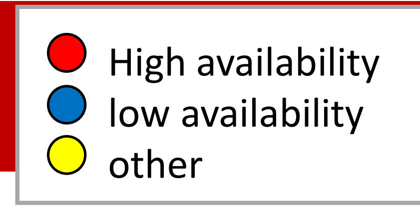
Survey period	Number of station	Count of use	Number of user
2013/10/11～2014/09/24	54	45190	5910
2014/11/1~2015/6/30	60	17666	Over 10000

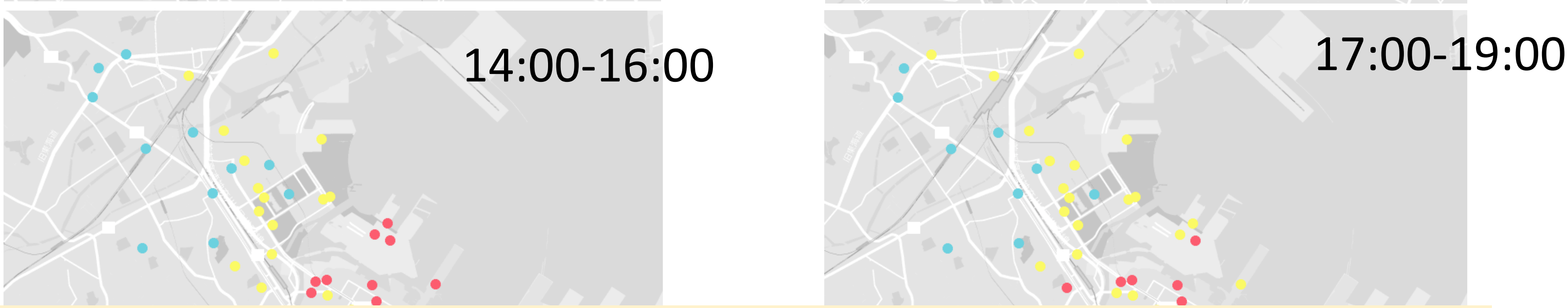
What is problem?

- Uneven distribution of vehicle cause the risk of unavailable service



What is problem?



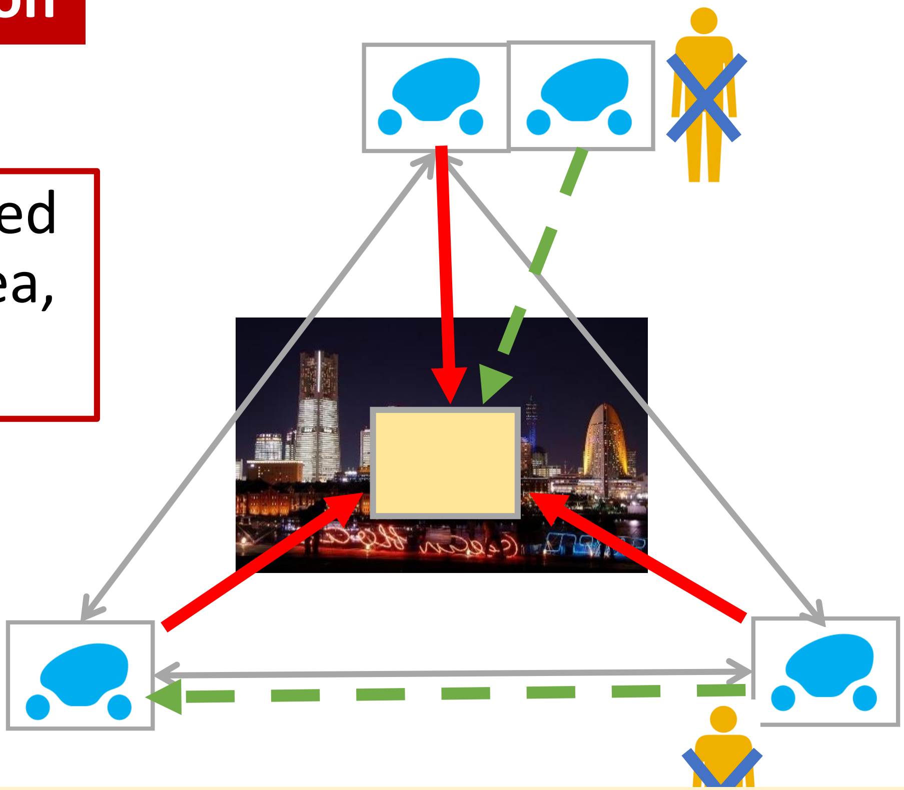


- Imbalance between demand and supply cause the loss of opportunity cost frequently happens on the operation side when there is no reservation available for users during their required hours.

What is problem?

Paradox of station distribution

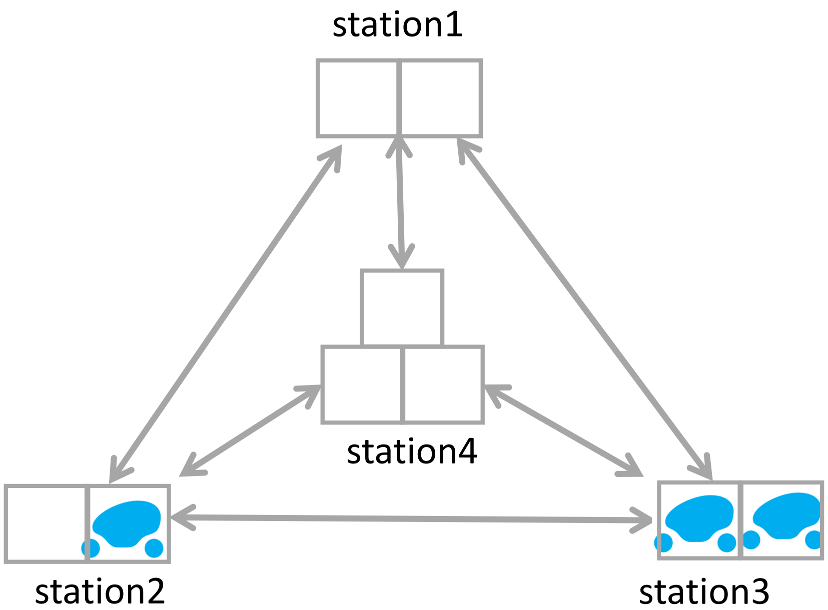
When new station established in demand concentrated area, profit may rather decrease.

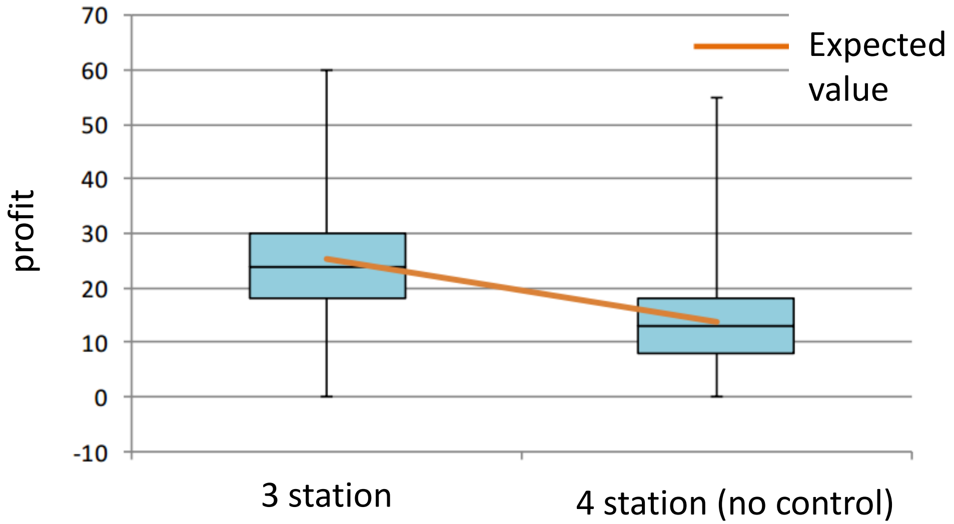


Research Question

How we can reduce this imbalance and then minimize the loss of opportunity cost

Numerical example : Paradox of station distribution





Probability of trip demand

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

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)

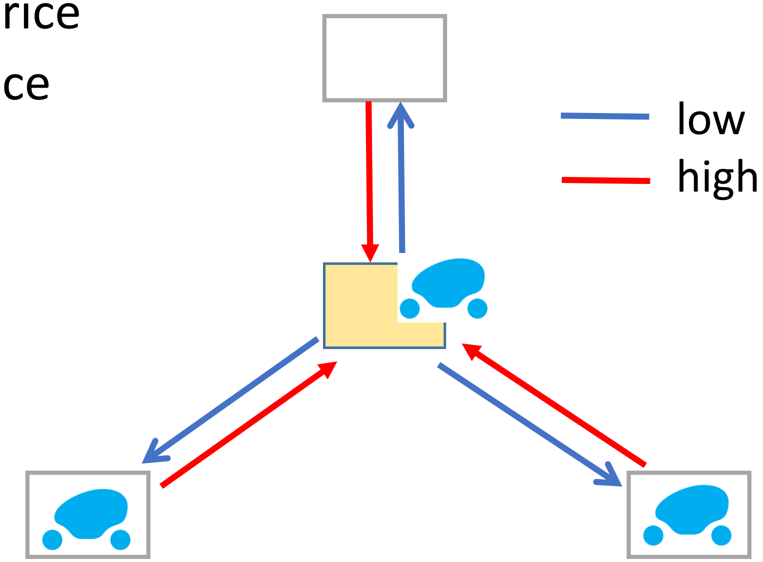
Method of demand control

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

$$\max R\big(s(t), O(T)\big) = \sum_t r(t|s(t), o(t))$$

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

$N = \{1, \dots, i, j, \dots, N\}$	Set of station
$T = \{1, \dots, t, \dots, T\}$	Set of time
c_i	Max of parking space
$x_i(t)$	The number of vehicle at time t
$s(t) = \{x_1(t), \dots, x_N(t)\}$	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

s.t.

$$\sum_i x_i = X$$ Law of the conservation of the number of vehicle

$$x_i - \sum_j v_{ij}(t) + \sum_k v_{ki}(t) \geq 0$$ Constrain of departure

$$x_i - \sum_j v_{ij}(t) + \sum_k v_{ki}(t) \geq c_i$$ Constrain of arrival

$$x_i(t+1) = x_i - \sum_j v_{ij}(t) + \sum_k v_{ki}(t)$$ The movement of vehicle

$N = \{1, \dots, i, j, \dots, N\}$	Set of station
$T = \{1, \dots, t, \dots, T\}$	Set of time
c_i	Max of parking space
$x_i(t)$	The number of vehicle at time t
$s(t) = \{x_1(t), \dots, x_N(t)\}$	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

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

Profit at the time t Expected at the time $t+1$

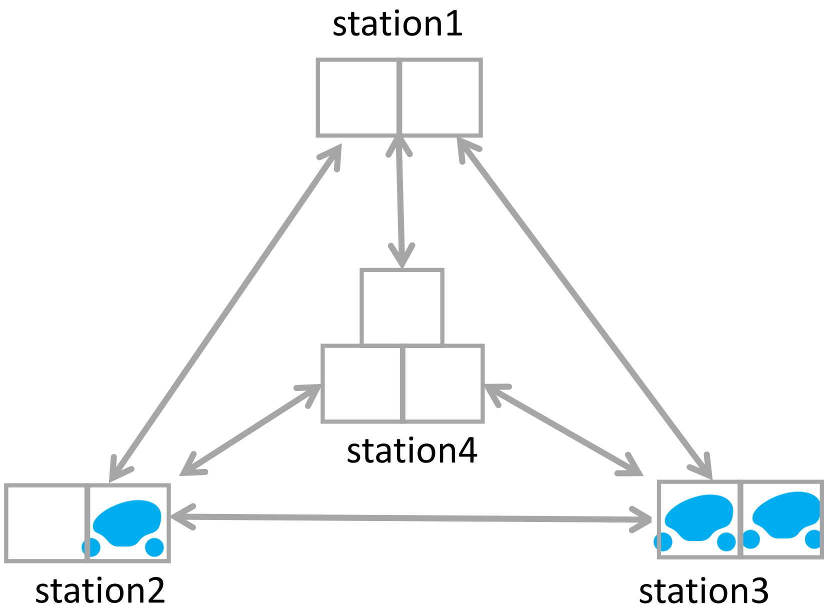
$$u_t(s(t)) = \begin{cases} \max\limits_{o(t)} \left\{ r(t|s(t)), o(t) + \sum\limits_{s(t+1)} P(s(t+1)|s(t), o(t)) \cdot u_{t+1}(s(t+1)) \right\} & (0 < t \leq T-1) \\ \max\limits_{o(T)} \{ r(T|s(T)), o(T) \} & (t = T) \end{cases}$$

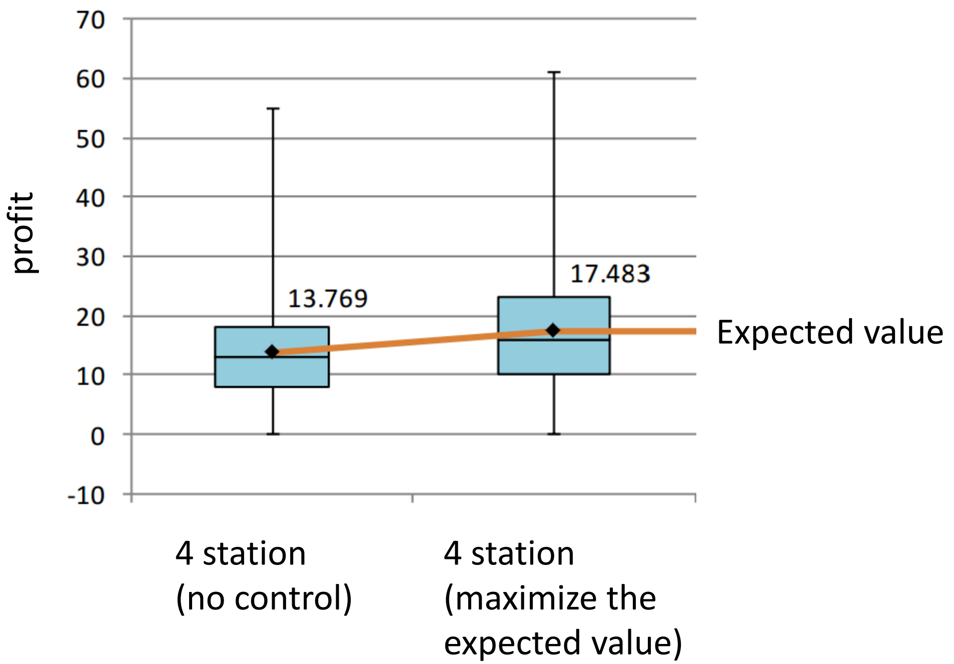
→calculation is start from last period T towards beforehand

- Step1: calculate $u_T\big(s(T)\big)$ for state $s(T)$
- Step2 : calculate $u_{T-1}\big(s(T-1)\big)$ 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



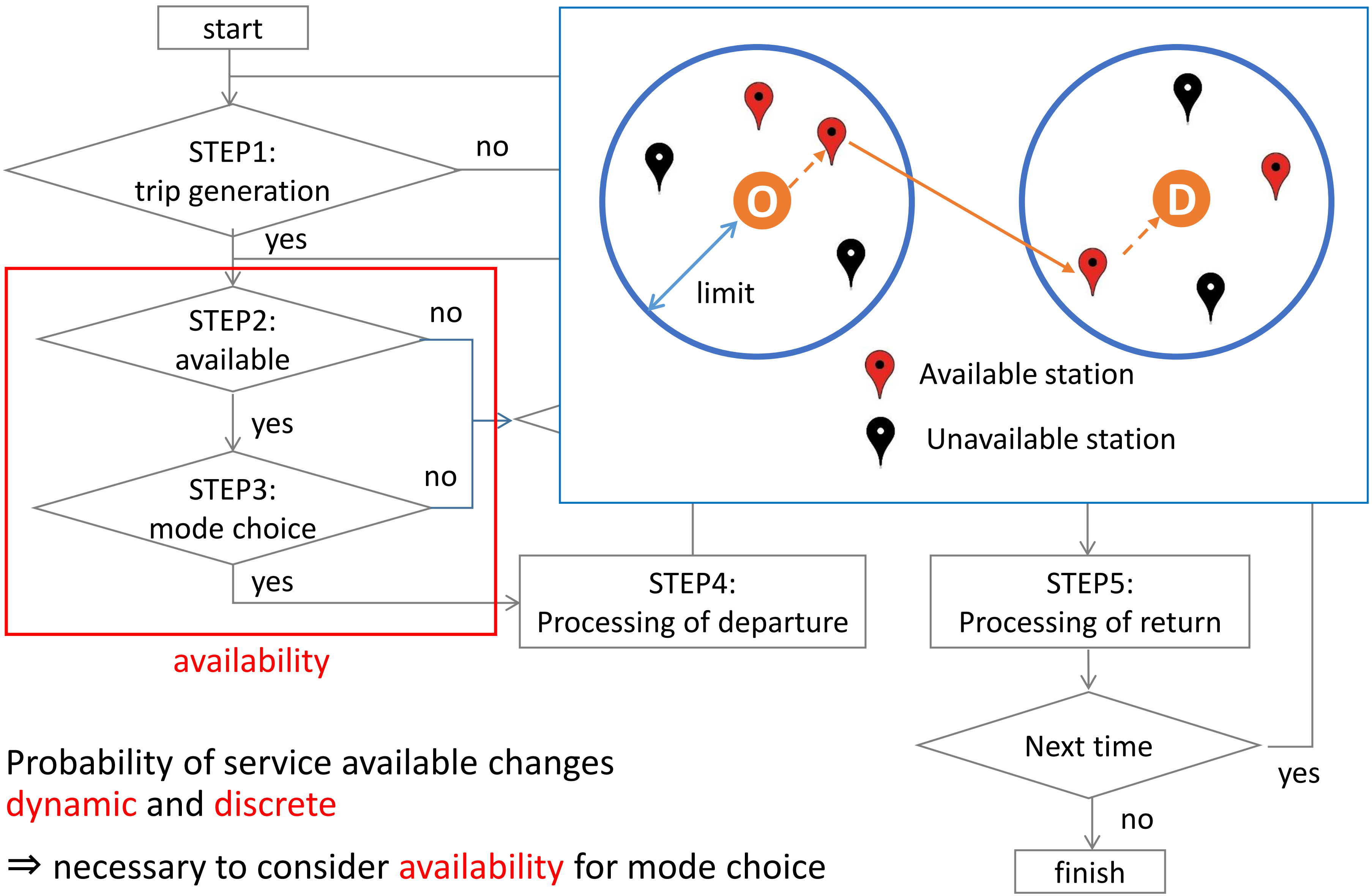


$r(t)$ is stochastic function
⇒result of calculation
are variable

Solution algorithm

- Maximize the expected value type
  ⇒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

survey	Survey period	Number of Monitor	Count of trip	Number of registrant
Choimibi PP2013 Choimobi PP2014	2013/10/01 ～2014/3/31 2014/9/1-2014/10/31	118 16	19944 1927	21553929 2218469

Use result data

Survey period	Number of station	Count of use	Number of user
2013/10/11～2014/09/24	54	45190	5910

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

δ_m: availability of mode m

Considering availability of CS

variables	parameter	t-value
specific constants(public transportation)	1.010	7.23**
Time [*10min]	-0.203	-2.06*
Cost [*100 yen]	-0.239	-8.52**
Access/egress time [min]	-0.028	-5.43**
Under 1km(walk)	-1.240	-9.56**
number of sample		688
LL(0)		-1232.731
LL(β)		-716.47
$\rho\rho 2$		0.40

Application to the real network

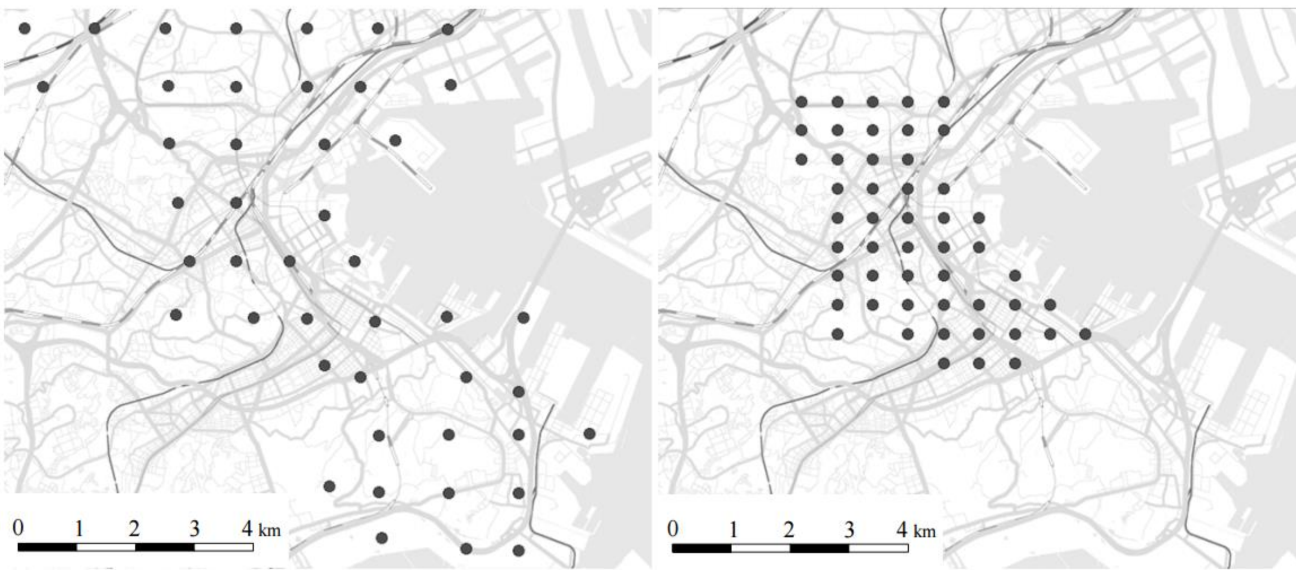
Simulation Scenario

Scenario	Station interval	Pricing control
A	500m	Without
B	500m	With
C	100m	Without
D	100m	with

Pricing rule

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

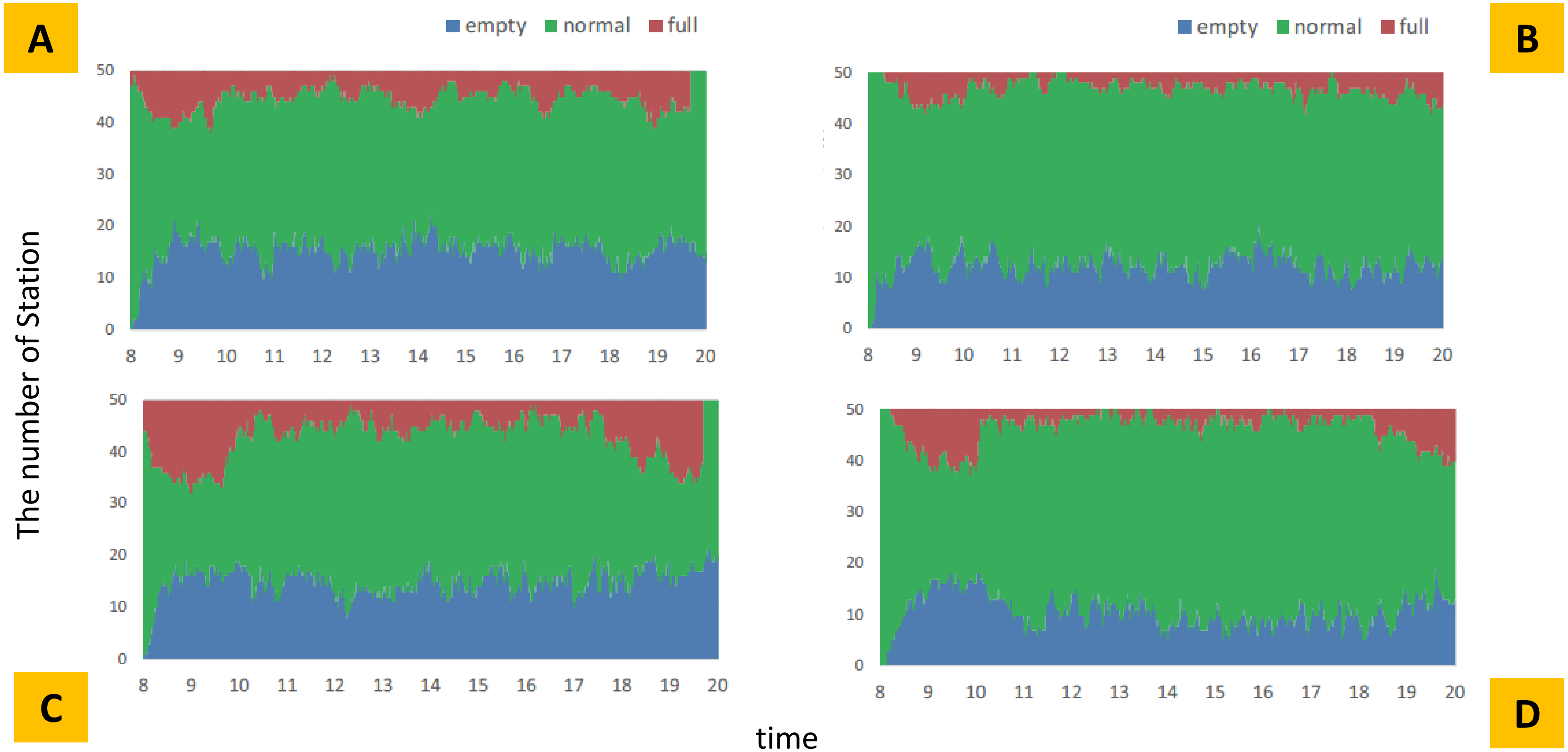
(b) Set double price(40yen/min) when vehicle make origin station full or depart station empty



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

Result of simulation

Result of Simulation			Simulation Scenario	
Scenario	Profit (yen)	Count of user	Station interval	Pricing control
A	347,260	1,709	500m	Without
B	401,390	1,862	500m	With
C	272,580	2,279	100m	Without
D	303,900	2,391	100m	with



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

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チョイモビのサービスの整理

	第一期	第二期
運用期間	2013/10/11～2014/11/1	2014/11/1～2015/9末
会員登録	2014/9/30で終了	20014/10/28
安全講習会	201/10/9	2014/10/4
車両	70台	50台
ステーション	63か所(131台分)	約60か所(約110台分)

料金設定	第一期	第二期
会員登録料	無料	1000円
10月	20 円/分（21 日まで）	－
11月		A プランまたは B プラン
12月以降	A プランまたは B プラン	

料金設定	A プラン	Bプラン
月額会費	1,000 円	－
無料利用	50 分	－
料金／分	20 円（51 分以降）	30 円