A Strategic Optimization Model for One-way Carsharing Systems

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1. Introduction

As a promising sustainable transportation mean, carsharing is receiving the increasing attention around the world. Recently, the Japanese government has presented a concept of MaaS (mobility as a service) in the 5th Science and Technology Basic Plan to promote the development of carsharing and ridesharing. Toyota is a leading corporation in providing car-sharing service and launched its own station-based one-way carsharing system "Ha:mo RIDE" in 2012 [1]. In such system, users are allowed to drop off at any stations with great flexibility, which is different from the round-trip system requiring users to return cars to their original sites. As of now, Ha:mo RIDE has been implemented in four cities in Japan, including Toyota city and Tokyo, and two overseas cities.

With the popularization of such carsharing systems, it becomes necessary to make proper strategic decision considering some long-term issues (e.g., station locations and number of vehicles). In previous study related to one-way carsharing systems, the main focus is usually the Vehicle Relocation Problem (VReP) for solving the imbalance problem in the spatial and temporal distribution of vehicles. Boyaci et al. [2] introduced a multi-objective mixed integer programming optimization and discrete event simulation framework to optimize operational decisions including vehicle and personnel relocation. Based on the Boyaci's study, Yamada et al. [3] took the features of Ha:mo RIDE into account to improve the optimization model for short-trip one-way carsharing and applied the imporved model to various cases. Soon after, Takahashi [4] determined the operational decision with a scenario model which can deal with the uncertainty of demand data. In order to verify the scenario model, some testing data is input to the selected scenario model to compare the profits and satisfied demand ratio.

Although these studies developed many methods to improve the operational efficiency of carsharing systems, few of them pay attention to the strategic decision. Therefore, a strategic optimization model (SOM) will be proposed in this study to determine number of stations, station locations, number of parking lots of each station and total number of vehicles.

2. Strategic optimization model

In this section, the model will be illustrated in detail. Similar to the scenario model proposed by Takahashi [4], different scenario data are produced to make the SOM more generalized.

2. 1 Set and indices

- $s \in SC$: scenarios
- $i \in I_s$: potential trips
- $t \in T$: time intervals
- $j \in J$: station location sites

2. 2 Parameters

- $start_i, end_i \in T$: start and end intervals of potential trip i
- $origin_i, dest_i \in J$: origin and destination of potential trip i
- M_j: maximal number of parking lots at each site j
- PC_j: cost of each parking lots with a charging pile at site j
- VC: cost of each vehicle
- α: acceptable satisfied ratio

2. 3 Decision variables

- $p_j \in \mathrm{Z}^+,\ \forall j \in J$: number of parking lots at site j
- $n_{jt}^s \in \mathrm{Z}^+,\ \forall s \in SC, j \in J, t \in T$:number of vehicles at site j at the beginning of time interval t in scenario s

- $z_i \in \{0,1\}, \forall s \in SC, i \in I_s$: binary, 1 if trip i in scenario s is served, otherwise 0
- $x_j \in \{0,1\}$, $\forall j \in J$: binary, 1 if a station is located at site j, otherwise 0
- $NV \in Z^+$: total number of vehicles prepared for the system

2. 4 Formulation

The SOM is formulated as follows.

$$minimize \sum_{j \in J} PC_j * p_j + CV * NV \quad (1)$$

Subject to:

$$n_{jt+1}^s = n_{jt}^s - \sum_{\substack{i:orgin_i=j \\ start_i=t}} z_i^s + \sum_{\substack{i:dest_i=j \\ end_i=t}} z_i^s \quad \forall s \in SC, j \in J, t \in T/\{0\} \quad (2)$$

$$p_j - n_{jt}^s \geq \sum_{\substack{i:dest_i=j \\ end_i=t}} z_i^s \quad \forall s \in SC, j \in J, t \in T \quad (3)$$

$$n_{jt}^s \geq x_j \quad \forall s \in SC, j \in J, t \in T \quad (4)$$

$$p_j \leq M_j x_j \quad \forall j \in J \quad (5)$$

$$\frac{1}{|SC|} \sum_{s \in SC} (\frac{1}{|I_s|} \sum_{i \in I_s} z_i^s) \geq \alpha \quad (6)$$

$$\sum_{j \in J} n_{j0}^s \leq NV \quad \forall s \in SC \quad (7)$$

$$n_{jt}^s \in Z^+ \quad \forall s \in SC, j \in J, t \in T \quad (8)$$

$$p_j \in Z^+ \quad \forall j \in J \quad (9)$$

$$z_i^s \in \{0,1\} \quad \forall s \in SC, i \in I_s \quad (10)$$

$$x_j \in \{0,1\} \quad \forall j \in J \quad (11)$$

$$NV \in Z^+ \quad (12)$$

The objective function (1) minimizes the total cost including parking lot cost and vehicle cost. Constraints (2) are the vehicles conservation equations for each scenario, each location site and each time interval. Constraints (3) ensure the remaining parking lots at site j in scenario s are enough for the vehicles arriving at time interval t and, at the time, ensure enough parking lots for the vehicles at site j. Constraints (4) mean some vehicles can park at site j only if a station is located there. Constraints (5) state the parking lots built at each site cannot over a maximal value. Constraint (6) makes sure the average satisfied demand ratio in all scenarios is no less than a given value. Constrain (7) means the total initial vehicle stock is no more than the number of vehicle prepared. Constrains (8)-(12) are the variable constraints.

3. Case study

Based on the data from Ha:mo RIDE in Toyota city, we conducted some experiments with SOM. The problem was solved in Gurobi Optimizer.

3. 1 Parameter setting

Currently, there are 55 stations in Toyata city and we assumed these station sites were the potential location site ignoring the existing stations. The maximal number of parking lots of each station (M_j) was the current size of each station. Instead of estimating the potential demand, we generated demand values from this use history according to a Poisson distribution and produced 80 scenarios totally. The acceptable satisfied ratio α was chosen from 0 to 1.

3. 2 Optimization results

The detailed experimental results will be shown in the presentation.

References

[1] Toyota Motor Corporation. Ha:mo, Harmonious Mobility Network, 2013
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