第Ⅳ部門　Modeling the competition and cooperation between car-sharing and public transportation with Kyoto case study

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Introduction:

Car-sharing (CS) service has been introduced in many cities worldwide, and the emergence of this new travel mode brings changes to the society especially for public transportation (PT). The impact of car-sharing has been a controversial issue as it can bring conveniences but cause congestion at the same time. Therefore, we are aiming to investigate the competition and cooperation between car-sharing and PT, as well as develop suitable network, especially to reduce the travel cost of passengers. In this research, instead of traditional shared vehicles with drivers, we consider relocated shared autonomous vehicles.

Methodology:

The simulation is conducted based on the model used in Iacobucci and Schmöcker's research [1]. In the simulation, trip demand is integrated into nodes, and the model uses origin-destination (OD) trip demand data as inputs including OD node pairs and starting time of trips. The model uses a relocation strategy based on the research by Iacobucci et al. [2]. The simulator relocates vehicles according to the imbalance of nodes which means the difference between needed number of vehicles and available number of vehicles, aiming to transfer vehicles from nodes with positive imbalance to nodes with negative imbalance to maintain an ideal enough balance between nodes. The model employs two types of car-sharing pricing strategy, distance-specific pricing and dynamic pricing. Dynamic price is optimized to maximize the net profit (1). The optimization for relocation and dynamic pricing is performed every 10 minutes. The mode choice of each trip is based on binary logit model (2) according to the cost of each mode. Then simulator will provide car-sharing price and estimated waiting time to the passenger. If the request is accepted by passengers, model will assign vehicles to each trip. In the study of base model, alternative mode is presumed as a uniform PT network, thus in this study PT network and choice model are improved. As to the mode choice, we consider subway, bus and walking besides car-sharing. The distance between each node and the distance from each node to the closest subway stops are calculated for every single trip. Passengers can either take bus or walk from the origin/destination node to the subway stop. Accordingly, we can obtain the cost of two public transportation choices based on travel time and fare. Then the PT choice with minimal cost is selected for passengers. We test with two city scenarios, using small, abstract city and Kyoto city respectively.

Results:

The performance of the whole network is evaluated by cost for passengers and profit for car-sharing operator as well as the spatial distribution of car-sharing price and modal share. As for city with small size, we found that car-sharing can be used as a substitute for public transportation in the area far away from the PT networks. On the contrary, for relatively larger city, i.e., Kyoto city in this study, for peripheral areas price for car-sharing is high and lose advantage over PT even though it is difficult to acces PT network. In some cases, the modal share of car-sharing along PT lines is high. It is inferred that car-sharing competes

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with PT, which is undesirable from the point of view of city planners, hence some regulations can be employed such as limitation on the use of car-sharing for trips near PT lines. As to the total cost for all passengers, if car-sharing service is operated in the network, cost for passengers can be decreased. Dynamic pricing can largely reduce the total travel cost in small network while it is not beneficial for travelers in Kyoto city case compared to distance specific pricing.

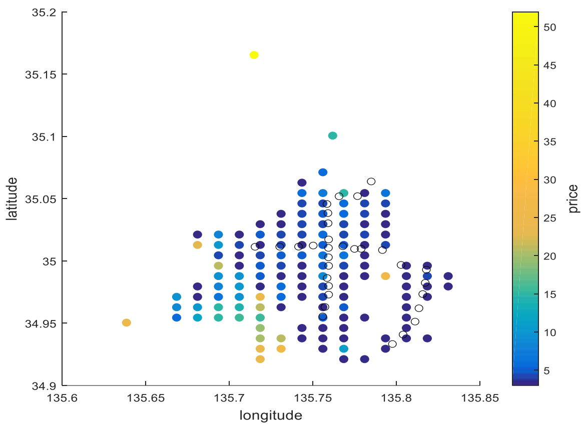

Fig 1 Distance specific price of CS for Kyoto city

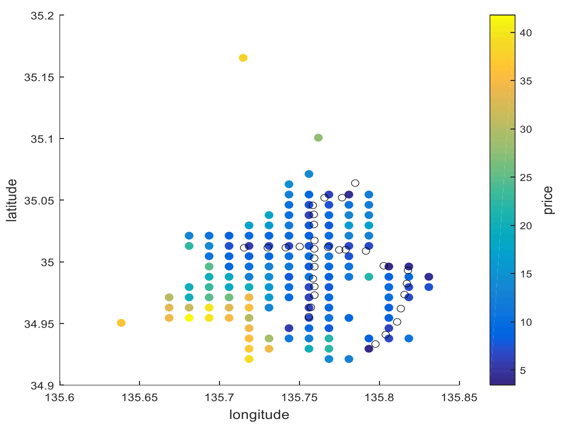

Fig 2 Dynamic price of CS for Kyoto city

Conclusion:

If a car-sharing service is introduced in the network, cost for passengers can be decreased, meaning that the car-sharing service can improve traffic network. The case studies illustrate that the benefit of car-sharing service is affected by the location and structure of the PT network. Further, the impact of pricing strategies also varies with features of the city, such as population distribution and city size. Hence, it's necessary for city planners to draw up a proper pricing regulation, in order to balance and maximize the benefits for both passengers and car-sharing operators.

Key references:

[1] R. Iacobucci , J.-D. Schmöcker, "Optimal Time and space differentiated dynamic pricing for ride hailing services," submitted in 2020.

[2] R. Iacobucci, R. Bruno , C. Boldrini, "A Multi-stage Optimisation Approach to Design Relocation Strategies in One-way Car-sharing Systems with Stackable Cars," (in review).

Appendix:

Key formulations are listed as follows.

Maximize net profit $$\max \ \sum_{i,j} b_{ij} n_{ij} d_{ij} - \sum_{i,j} r n_{ij} d_{ij} - \sum_{i,j} r_{ij} q_{ij} d_{ij} \quad (1)$$

Model choice by binary logit model $$p_C^{ij}(t) = \frac{\exp(-c_C^{ij}(t))}{\exp(-c_C^{ij}(t)) + \exp(-c_P^{ij}(t))} \quad (2)$$

b_{ij}: Dynamic price of car-sharing for the trip from node i to j	$q_{ij}(t)$: Predicted relocation flow between node i and j
n_{ij}: Predicted demand for car-sharing from node i to j	$p_C^{ij}(t)$: Probability of choosing car-sharing from node i and j in the coming time horizon t
d_{ij}: Distance between node i and j	$C_C^{ij}(t)$: Cost of car-sharing of one trip from node i to j in the coming time horizon t
r: Relocation cost of car-sharing	C_P^{ij}: Cost of public transportation of one trip