Optimal allocation of shared parking spaces: An agent-based approach under uncertainty

Pengfei ZHAO[1], Hongzhi GUAN[2*], Kaili ZHANG[3] Lei ZHAO[4], Yan HAN[5]

[1] College of Architecture and Civil Engineering; Beijing University of Technology, No.100 Pingleyuan, Jiaotong Building 507, Chaoyang District, Beijing, China 100124; Email: zhao_pf@emails.bjut.edu.cn

[2] (Corresponding Author) College of Architecture and Civil Engineering; Beijing University of Technology, No.100 Pingleyuan, Jiaotong Building 619, Chaoyang District, Beijing, China 100124; Email: hguan@bjut.edu.cn

[3] College of Applied Sciences; Beijing University of Technology, No. 100 Pingleyuan, Science Building 0839; Email: zh_kaili@163.com

[4] College of Architecture and Civil Engineering; Beijing University of Technology, No.100 Pingleyuan, Jiaotong Building 507, Chaoyang District, Beijing, China 100124; Email: leizhao1205@163.com

[5] College of Metropolitan Transportation; Beijing University of Technology, 100 Pingleyuan, Jiaotong Building 319, Chaoyang District, Beijing, China 100124; Email: hanyan422@bjut.edu.cn

ABSTRACT

Shared parking has received considerable attention over the past decade due to its potentiality of alleviating urban parking headache through improving utilization of the existing parking resources, especially in residential zones when those residents drive their vehicles out. However, little attention has been paid to the risk that the returned residents have no parking spaces, which quite affecting residents' engagement. Based on the precondition that any resident has a parking space, the objective of this paper is to explore the potential for the shared parking spaces. Firstly, a novel reservation and allocation mechanism of shared parking was proposed. Secondly, an agent simulation model was developed to track the NP-hard problem, regarding the shared procedure as a queuing system. Finally, the optimal number of shared parking spaces was obtained through numerical tests. The result has proved that the proposed shared strategy has brought about vast improvements of both utilization and turnover rate of parking spaces, compared with the non-shared circumstances. This paper provides a novel method to the solutions of the proportion of shared parking spaces in the residential area.

Keywords: Traffic demand management and control; Urban parking, Parking lot shared; Parking space allocation; Agent simulation optimization

1 INTRODUCTION

Parking has been an important issue for both city government agents and public travelers (Shao et al., 2016). Cruising for the parking spaces consumes a large amount of time, fuel and momentously ascribing to traffic congestion and environmental pollution. According to the research of (Shoup, 2006), to find an idle space to park will cost approximately 8.1 minutes. In Chicago, 48,000 tons of carbon dioxide can be generated and discharged to the environment every year during the cruising for parking spaces (Ayala et al., 2011), which extremely contributing to creating the greenhouse effect. As a result, varieties of methods have been developed from the perspectives of both demand side and the supply side tending to solve parking problem.

On the demand side, the management goal is to reduce private cars utilization. An important mean with long-term for this purpose is enhancing the constructions of public transportation system and launching cheap tickets of public transportation, increasing parking charges. After trading off the travel cost, a part of travelers' mode choice will switch from private car to public transportation (Arnott, 2014; Arnott and Inci, 2005). Recently, a major body of researches paid much attention to model traveler response to parking charge. Simićević et al. (2013) predicted the effects of introducing or changing the parking price and time limitation. Qian and Rajagopal (2014) learned travelers' parking behaviors through the real-time data collected by smartphone and GPS, and built efficient parking pricing policies. He et al. (2015) established two mode choices model based on a SP survey considered several factors which affecting parking choices.

On the supply side, a possible way to meet the parking demand is to expand the amount of parking facilities in the conventional planning methods (Guo et al., 2016). However, it is not practical in large cities in a short period due to the limitation of time, space and construction capital. Another solution is to make full use of the existing parking resources. Distinct but complementary parking patterns, such as residential parking that is generally empty in the daytime and on workdays and office parking that is generally fuller in the daytime, offer an opportunity for cities to better satisfy residents and commuters without increasing supply. As a result, the shared parking was proposed (Kenig and Hocking, 1984). To this end, varieties of methods were developed considering many factors having an effect on parking demand such as geographic condition, time variations of parking demand, money flow and so on. (Jiang et al., 2010) proposed a process and method of shared parking demand analysis and calculation under non-booking mechanism. Guo et al. (2016) regarded the shared parking spaces as the process of repurchase. It should be noted that the supplier who shared parking space is likely to face with the risk of no parking space to park. This may become an obstacle for repurchase strategy implementation. Shao et al. (2016) proposed a simple binary integer linear programming model to allocate the shared parking spaces, the demand and supply are fixed and known through reservation mechanism. However, we usually could not exactly determine our parking duration in real life, the uncertainty of parkers should be considered during the shared period.

In this paper, we propose a new parking spaces reservation mechanism where the parking reservationists don't need to confirm their exact parking durations. Further an agent-based simulation approach (ASA) is used to track the parking spaces allocation problem which is a NP-hard problem.

The paper is organized as follows. In section 2, we introduce the shared evolution process and allocation mechanism of parking spaces. In Section 3, we demonstrate the agent-based simulation model including parameters setting. In section 4, the simulation results are analyzed. Conclusions follow in Section 5.

2 DESIGN OF SHARED EVOLUTION PROCESS AND ALLOCATION MECHANISM OF PARKING SPACES

2.1 Designing of shared process of parking spaces

To analyze the shared parking problem, the following three basic assumptions are set (Xu et al., 2016): a) some of the residents are willing to share their parking spaces (denoted as O-users) to other motorists who working at adjacent locations (denoted as P-users); b) the O-users will drive their cars out early and come back at dusk; c) all P-users only have the access of booking and parking to all the parking spaces, without ownership. To intuitively show the shared process, a staged and hierarchical shared parking spaces model is established to (see Figure 1). The phases are divided into non-shared phase and shared phase and the layers are classified into phase layer, booking access allocation layer and status of parking spaces layer from the bottom to up.

In order to ensure that all returned O-users have parking spaces, some parking spaces should be reserved only for O-users during shared phase (denoted as VIPPSs), and the remainder will be shared with both the O-users and P-users (denoted as GPSs). For O-users, they can book the VIPPSs at any time within day. For P-users, they can just book the GPSs during the open phase by providing information of starting parking time, and leave the GPSs before the time point of T_s.

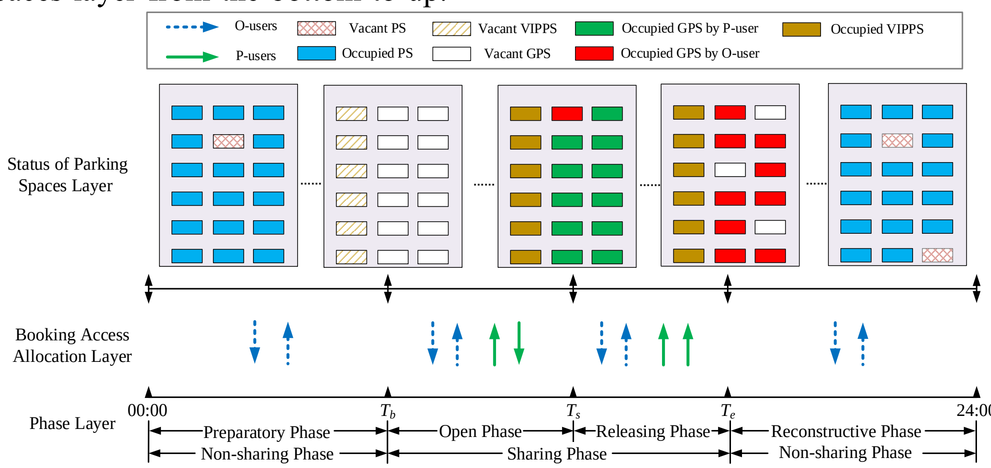

Figure 1. Evolution process of shared parking spaces within day.

Note: T_b, T_s and T_e respectively present the beginning time point of the shard parking spaces, the timing point that stops P-users entering the shared parking spaces and the deadline of permissible parking for P-users.

2.2 Allocation mechanism of the shared parking spaces during reserving

Figure 2 demonstrates the allocation process of shared parking spaces. Initially, all P-users and all O-users should obtain the parking right by reservation, but when the optimal allocation is obtained, all the O-user do not need to reservation anymore. They can get in and out of the parking lot at any time. For all the P-users, they still need to reserve the parking spaces to park.

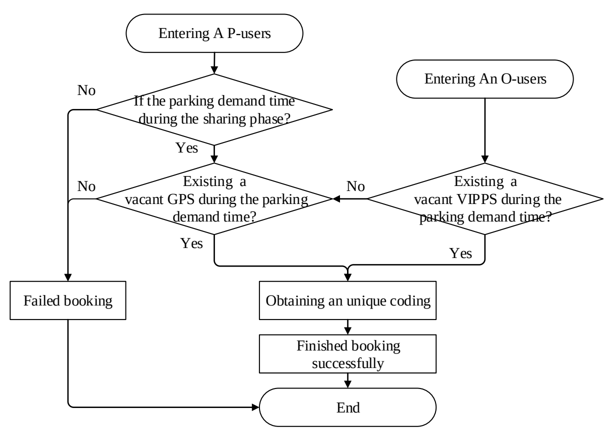

Figure 2. Allocation mechanism of shared parking spaces during booking.

3 MODELLING OF SIMULATION

In this section, we present an agent simulation approach for simulating the dynamic process of the shared parking lot.

3.1 Design of systematic modules

The shared parking spaces booking mechanism can be described as the queuing system (Cho et al., 2017; Gross, 2008) in which regarding the parking spaces as the server agents, and the O-users and the P-users as customer agents. Our goal is to obtain the maximum proportion of GPSs (equivalent to minimum proportion of VIPPSs) so as to maximize utilization. Due to the stochastic natures of O-users' and P-users' arriving and leaving, it is somewhat difficulty to solve analytical results (Guo et al., 2016). As a result, a Java program to construct an editable platform is developed to presenting an agent simulation algorithm (Zhang et al., 2015) for simulating dynamic parking behaviors.

3.2 Parameter design

The shared paring time is set from 8:00 a.m.(T_b) to 6:00 p.m. (T_e). Specially, the T_s is set at 5:00 p.m. The O-users will randomly return from 8:00 a.m. to 5:00 p.m., the arrival time interval obeys exponential distribution with the λ=0.04. Moreover, the O-users will intensively return from 5:00 p.m. to 6:00 p.m. with the λ=2.5 ensuring that all O-users come back before 6:00 p.m.

Similarly, the P-users will arrive randomly with two rush hours: from 8:00 a.m. to 9:00 a.m. and from 12:00 a.m. to 1:00 p.m. Their arrival time intervals respectively obey exponential distribution with the λ=2 and λ=1.8. In other simulated periods, their arrival time intervals also obey exponential distribution with the λ=0.1. To avoid the shortcoming of depicting the characteristics of P-users' departure by the traditional queuing model (e.g. M/M/c/c queuing model) (Guo et al., 2016), the parking time demands for all visiting P-users obey uniform distribution during the available parking period. The total amount of parking spaces is 100. For the reservation, the first order first service (FOFS) rule (Shao et al., 2016) was applied.

4 RESULTS AND ANALYSIS

In this section, we will present some simulation results to illustrate the essential ideas in the paper.

4.1 The optimal solution and the maximum of shared potential

Figure 3 shows the numbers of failed booking O-users with different numbers of VIPPSs. It can be seen that the numbers of failed booking O-users descend as the increasing numbers of VIPPSs. There are 24 failed O-users (in Scheme 1), then, by increasing the numbers of VIPPSs by the interval of 5, as well as reducing the numbers of GPSs by the interval of 5, the number of failed booking O-user decreases. None failed booking O-users is firstly found when the number of VIPPSs is 25. Then, the dichotomy method is applied to rapidly find the optimal solution, namely the number of VIPPSs and GPSs respectively are 21 and 79, namely the maximal proportion of shared parking spaces could be up to 79%. It should be pointed that all O-users have returned before the simulation tests end.

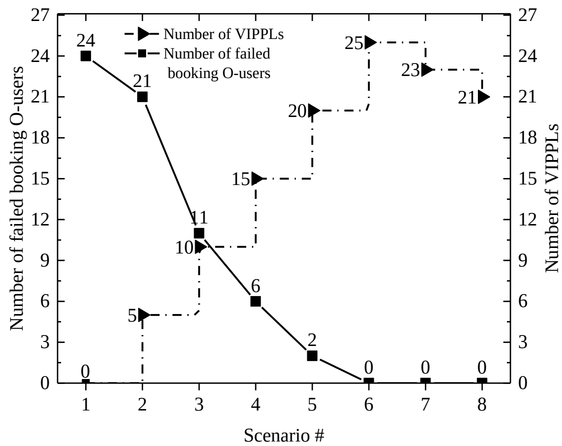

Figure 3. Process of solving shared parking spaces mechanism.

To avoid the stochastic errors, the experiments are tested additionally 500 times representing 500 days. No O-user failed parking, which verifying that the result is robust.

4.2 The utilization and turnover rate of parking spaces

Without sharing, the parking spaces are occupied only 18.9% of the daytime and there is a significant increment of 53.1% through shared strategy, see Figure 4. Meanwhile, the turnover rate increased from 1 of the non-shared scenario to 2.27 in the shared scenario.

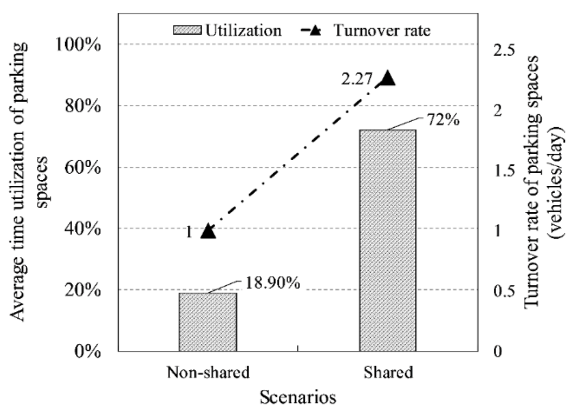

Figure 4. The comparisons of utilizations and turnover rates between the non-shared scenario and the shared scenario.

5 CONCLUSIONS AND DISCUSSION

Aiming to improve the utilization of parking facilities of residential area during the daytime, the shared evolution process and shared parking spaces allocation were designed. In addition, in order to resolve the computational complexity resulted from the stochastic properties of parkers' arriving and departure, a Java programming agent simulator was developed, in which the characteristic parameters easily can be set up and obtain the optimal solution.

The results show that 79% of the residential parking spaces can be shared to P-users to maximize the potential of parking facilities utilization through considering the uncertainty of parking. Meanwhile, both the time utilization and the turnover rate can be significantly improved.

There are also several improvements that can be made to enhance the shared strategy in the future work. For example, we just tested a single scale of parking spaces and adopted the one distribution model to characterize the stochastic nature of parkers' arriving/departure for model simplicity. The other scales of parking spaces and different distribution models based on the empirical data for more accurate model and solution can be considered and conducted. Further, the optimal design of shared parking spaces in the mixed land-use area can be explored due to their distinct parking demands, including office, business and leisure and so on.

ACKNOWLEDGEMENT

We would like to acknowledge the financial support for this study provided by National Natural Science Foundation of China (No. 51338008 and No.51378036), the Exploration Project of BJUT's Traffic

Engineering Research (Grant No. Base2017BJUT-JTJD001) and the sixteenth Graduate Science and Technology Foundation of Beijing University of Technology (Grant No. ykj-2017-00431). We also appreciate the reviewers for their valuable suggestions and comments.

REFERENCES

Arnott, R., 2014. On the optimal target curbside parking occupancy rate ☆. *Economics of Transportation* 3, 133-144.

Arnott, R.J., Inci, E., 2005. An Integrated Model of Downtown Parking and Traffic Congestion. *Journal of Urban Economics* 60, 418-442.

Ayala, D., Wolfson, O., Xu, B., Dasgupta, B., Lin, J., 2011. Parking slot assignment games, *ACM Sigspatial International Conference on Advances in Geographic Information Systems*, pp. 299-308.

Cho, K.W., Kim, S.M., Chae, Y.M., Song, Y.U., 2017. Application of Queueing Theory to the Analysis of Changes in Outpatients' Waiting Times in Hospitals Introducing EMR. *Healthcare informatics research* 23, 35-42.

Gross, D., 2008. *Fundamentals of queueing theory*. John Wiley & Sons.

Guo, W., Zhang, Y., Xu, M., Zhang, Z., Li, L., 2016. Parking Spaces Repurchase Strategy Design via Simulation Optimization. *Journal of Intelligent Transportation Systems* 20, 255-269.

He, P., Chen, J., Zhen, J.H., Jiang, Y.H., 2015. Parking Choice Behavior for Shared Parking Based on Parking Purposes. *Applied Mechanics & Materials* 743, 439-444.

Jiang, Y.S., Peng, B., Hu, L., Dai, L.C., 2010. Study on the application of shared parking analytical thoery to mixed land use, *International Conference on Mechanic Automation and Control Engineering*, pp. 4126-4130.

Kenig, N.S., Hocking, R.J., 1984. Parking efficiency through shared parking concepts, *Innovative Strategies to Improve Urban Transportation Performance:*. ASCE, pp. 44-52.

Qian, Z., Rajagopal, R., 2014. Optimal dynamic parking pricing for morning commute considering expected cruising time. *Transportation Research Part C Emerging Technologies* 48, 468-490.

Shao, C., Yang, H., Zhang, Y., Ke, J., 2016. A Simple Reservation and Allocation Model of Shared Parking Lots. *Transportation Research Part C: Emerging Technologies* 71, 303-312.

Shoup, D.C., 2006. Cruising for Parking. *Transport Policy* 13, 479-486.

Simićević, J., Vukanović, S., Milosavljević, N., 2013. The Effect of Parking Charges and Time Limit to Car Usage and Parking Behaviour. *Transport Policy* 30, 125-131.

Xu, S.X., Cheng, M., Kong, X.T., Yang, H., Huang, G.Q., 2016. Private Parking Slot Sharing. *Transportation Research Part B: Methodological* 93, 596-617.

Zhang, W.W., Guhathakurta, S., Fang, J.Q., Zhang, G., 2015. Exploring the Impact of Shared Autonomous Vehicles on Urban Parking Demand: An Agent-Based Simulation Approach. *Sustainable Cities and Society* 19, 34-45.