Transportation Research Part B 109 (2018) 40–69

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

Shared parking problem: A novel truthful double auction mechanism approach

Haohan Xiao, Meng Xu*, Ziyou Gao

State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing 100044, China

ARTICLE INFO

Article history:
Received 2 August 2017
Revised 10 January 2018
Accepted 11 January 2018

Keywords:
Shared parking
Auction mechanism design
Slot allocation rule
Transaction payment rule
Incentive compatibility

ABSTRACT

Considering a parking platform with multiple slot demanders and multiple slot suppliers, this paper addresses two truthful double auction mechanisms for shared parking problem, where the demanders targeted by the proposed mechanisms are with flexible schedules and for non-work activities, and the suppliers are with the typical daily 'driving go out early and come back at dusk' pattern. To provide flexible match schemes and increase the trading scale, we allow "all-or-nothing" principle for demanders and "one-to-many" principle for suppliers. Based on the parking slot allocation rule and the transaction payment rule, we first relax the *single output restriction* (suppliers can only submit bids on a single unit of one commodity) and propose a "demander competition padding method (DC-PM)" auction mechanism, which is used to solve potential budget deficit. To avoid the likely distorted social welfare resulted by the DC-PM auction mechanism and to add budget surplus, we further modify the parking slot allocation rule and the transaction payment rule in the DC-PM auction mechanism, and propose a "modified demander competition padding method (MDC-PM)" auction mechanism. Three economical properties of both auction mechanisms, i.e. incentive compatibility, individual rationality and budget balance, are proved. Numerical experiments show that the proposed two auction mechanisms can realize asymptotic efficiency as both demanders and suppliers approach infinity. Moreover, the DC-PM auction mechanism is superior to the MDC-PM auction mechanism with respect to participants' utilities and can maintain the strict lexicographic allocation order, and the MDC-PM auction mechanism outperforms the DC-PM auction mechanism in terms of welfare efficiency and platform's payoff. Issues of managerial implications for shared parking problem are further discussed in this paper.

1. Introduction

Parking problem is an essential component of urban transport system and its convenience affects the accessibility much (van Ommeren et al., 2011). With higher percentage of car ownership and less land resource available in big cities, parking is becoming a major challenge for both commuters and transport authority. Cruising for parking slots causes traffic congestions and emissions (Shoup, 2006) which often happens when the supply of parking slot cannot satisfy the parking demand. However, simply increasing capacity by building new parking slots or expanding existing ones has proved to be self-defeating since new parking demand will offset the effect in the near future.

* Corresponding author.
E-mail address: mengxu@bjtu.edu.cn (M. Xu).

https://doi.org/10.1016/j.trb.2018.01.008
0191-2615/

Various aspects of parking management, including emerging technologies and new schemes to efficient usage of parking resources, are extensively studied, e.g., pricing strategy, real-time parking slot reservation and allocation (Zou et al., 2015; Guo et al., 2016). *Different existing parking management studies are generally target for public parking resources, this study has focused on private parking slots.* Private parking slots could be actually utilized to mitigate parking challenge under proper circumstance. In general, a typical feature of commuting in an urban residential area is the daily *'go out early and come back at dusk' pattern*, i.e., private parking slot owners drive their cars out to work in the morning and will be back in the evening, which makes their private parking slots idle during their out time. These idle slots can be efficiently utilized to satisfy the parking demand of other drivers with *flexible parking schedules* for non-work activities (e.g., shopping, watch movies with optional times etc.). Here, the non-work activity is different from the work activities with tight time scheduling, and it allows adjustable schedule with time flexibility. There are some statistics on the idle parking slots in different cities, e.g., the private parking slots account for 58.1% of total parking slots in Beijing, and nearly 800,000 private ones leave unused during working period (Beijing Transport Institute, 2016). Similar cases can be also found in Hong Kong and other high-density cities (http://www.td.gov.hk/en/transport_in_hong_kong/parking/carparks/).

There are currently rising applications of shared parking in high congestion cities, e.g. Beijing, Shanghai, Hangzhou. Specifically, some instructions for encouraging the development of shared parking are also issued, e.g., the Beijing People's Congress Standing Committee (2017) just issued the *Parking Management Regulations for Automotive Vehicles in Beijing (the second draft)* to the public, in which the parking slots owned by government agencies, groups, enterprises, institutions and private users are encouraged to open to the public with the shared pattern. In this way, some trial works are stretched in Xicheng District of Beijing (http://net.yesky.com/internet/174/222356174.shtml), where dozens of groups and enterprises are included in the shared parking practice with the support of Apps (e.g., Airparking), and the parking problems are effectively solved in a small scale. Therefore, shared parking provides a new approach to dealing with urban parking problem.

As an innovative measure of parking management, shared parking can be regarded as a supplement to public parking management. It is proposed to accommodate the gap between excessive parking demand and insufficient supply, or at least scattering the over-concentration parking demand in some hot parking area (e.g., CBD). For the shared parking management problem, there are two keys, i.e., an appropriate slot allocation rule considering parking time assignment and a reasonable parking price suitable for private reservation value. *We realize that the most prominent difference between shared parking and public parking is the rule-making right*. The rule-making right for public parking slot is owned by slot suppliers (e.g., local government), which could cause imbalance trade, e.g., the parking tolls are directly set by government with uniform price or tiered price, ignoring the participants' private reservation values. For shared parking, however, the rule-making right is owned by the third-party organization, i.e., parking platform. The slot owners are no longer in charge of transaction, they just need to raise their available parking slots to the parking platform, and the parking platform will manage these private parking slots and assign them, which forms a double or bilateral trade environment. Currently, few studies have ever focused on reasonable parking slot allocation rule and personalized pricing rule in a double environment with the approach to shared parking problem.

For the proposed shared parking problem, we consider that the parking slot's using right is sharable, and it can be approached by truthful double auction mechanism derived from auction theory (Krishna, 2010) and mechanism design theory (Mookherjee, 2008). Rationales for the consideration to use auction mechanism include but not limited to: 1) In auction mechanism, the commodity can be allocated to the best demander who bid the highest price, and in shared parking problem, the commodity can be specified as parking slot's using right, and we also expect the slot can be allocated to the user who values the slot most; 2) The role of parking platform in shared parking corresponds to the role of auctioneer in auction mechanism; 3) The auction mechanism aims at maximizing social welfare, which guides the resources allocation rule, and this target is also suitable for shared parking slot allocation; 4) In practical parking trading case, the higher price a slot user bids, the more likely he can acquire the slot's using right, which is in accordance with the strict order of bid prices in auction mechanism. Generally, auction mechanism provides an efficient way to allocate resources and set prices, which is appropriate to modelling the shared parking problem. Actually, auction mechanism is widely used in the field of transportation, such as railway slot allocation in Germany (Borndorfer et al., 2005) and license plate auction in Shanghai (Chen and Zhao, 2013). These works also inspire this study. Further, we emphasize that truthful bidding should be the dominate strategy for each participant, considering that it can avoid the potential cases that demanders/suppliers overbid or underbid intentionally to win an auction (an unqualified demander/supplier win an auction to use/let a slot by untruthful bidding while a truthful demander/supplier with higher/lower bid price lose in the auction). Moreover, in the proposed shared parking problem, we allow both slot users and slot owners have private expected values to the slots, and double auction provides a better approach than one-sided auction. Therefore, we focus on the approach to use truthful double auction mechanism for the shared parking problem, and these issues will be integrated into parking slot allocation rule and transaction payment rule.

We consider the scenario as follows: The auction for shared parking problem is dependent on a "parking platform", which not only collect biding information but also in charge of transaction. Two types of "participants" i.e., private slot owners and slot users are involved, when using the auction terminology to description, we name the slot owner as "supplier", whilst the slot user as "demander". The slot supplier has the typical commuting feature in an urban residential area with the *daily 'go out early and come back at dusk' pattern*, and the slot demander has *flexible time schedule for parking demand*. For the convenience of distinction in the rest of this paper, we will refer to a supplier as "she" and a demander as "he" in following statement. We also refer to parking slot's using right as "commodity". To focus on the auction mechanism design