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# Optimal parking provision for ride-sourcing services

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ABSTRACT

Ride-sourcing services have become increasingly important in meeting travel needs in metropolitan areas. However, the cruising of vacant ride-sourcing vehicles generates additional traffic demand that may worsen traffic conditions. This paper investigates the allocation of a certain portion of road space to on-street parking for vacant ride-sourcing vehicles. A macroscopic conceptual framework is developed to capture the trade-off between capacity loss and the reduction of cruising. Considering a hypothetical matching mechanism adopted by the platform, we further materialize the framework and then apply it to study the interactions between the ride-sourcing system and parking provision under various market structures.



## 1. Introduction

The proliferation of smartphones in recent years has catalyzed rapid growth of ride-sourcing services (also known as transportation network companies or TNCs) such as Uber and Lyft (Rayle et al., 2016). By requesting rides via mobile applications, customers of these ride-sourcing services are matched efficiently to affiliated drivers who drive their own non-commercial vehicles to provide for-hire rides. Such on-demand e-hailing services significantly reduce the search frictions and bring together riders and drivers with very low transaction costs (Anderson, 2014; He and Shen, 2015; Wang et al., 2016). As an evidence for the rapid expansion of ride-sourcing services, the number of active drivers on Uber increased exponentially in the U.S. from almost zero in 2012 to over 160,000 in 2014 (Hall and Krueger, 2015), and globally passed over the one-millionth landmark in 2015 (Lazo, 2015). According to a recent travel survey (the San Francisco Municipal Transportation Agency, 2015), ride-sourcing services have been used by 23% of residents in the San Francisco Bay Area at least monthly. Among the travel mode share in San Francisco, ride-souring services account for 2%. In comparison, the traditional taxi's mode share has declined to be less than 0.5%.

The great success of ride-sourcing services continuously generates heated discussions and has aroused extensive research interest on their impacts, operations and regulation. Previous studies have focused on the demographics of ride-sourcing riders and drivers (Hall and Krueger, 2015; Rayle et al., 2016; Hughes and MacKenzie, 2016; Kooti et al., 2017), efficiency and equity issues of the service (Smart et al., 2015; Ge et al., 2016; Hahn and Metcalfe, 2017), pricing strategies of the platform (Chen and Sheldon, 2016; Banerjee et al., 2016; Bimpikis et al., 2016; Taylor, 2017; Cachon et al., 2017; Zha et al., 2017a,b; Castillo et al., 2017), impacts on the traditional taxi market (Wallsten, 2015; Cramer and Krueger, 2016; Rayle et al., 2016; Nie, 2017; Lam and Liu, 2017), as well as policies and regulations (Koopman et al., 2015; Ranchordas, 2015; Zha et al., 2016, 2017a,b).

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The primary focus of this paper, however, is on the congestion effect of ride-sourcing services. Although their aggregate congestion externality remains controversial (Anderson, 2014; City of New York, 2016; Li et al., 2016; Nie, 2017), cruising of vacant ride-sourcing vehicles (RVs) itself undoubtedly induces extra VMT. Since there are only a limited number of spaces in downtown areas for RVs to park, vacant RVs can only cruise on roads while waiting to be matched with the next customer. In a road network filled with RVs, e.g., the San Francisco downtown area served by many Uber or Lyft vehicles, such cruising contributes additional traffic demand and slows down other traffic, making already-congested streets even worse. Such a phenomenon is expected to become much more severe when emerging shared-use mobility services play a major role in meeting travel needs in metropolitan areas. One intuitive solution is to segment a certain portion of road space to provide on-street parking for RVs to reduce cruising; however, such a plan also reduces road capacity and possibly yields more congestion. The research question is therefore how to find appropriate balance to determine the optimal provision of parking spaces for a given road network. To answer such a "big picture" question (Daganzo et al., 2012) or make a "sketchy decision" at a highly aggregated level (Nie et al., 2016), this paper develops a macroscopic modeling framework that uses only a few parameters but attempts to capture the major underlying mechanisms of the ride-sourcing system under parking provision.

In summary, focusing on aggregate behaviors in an e-hailing ride-sourcing system, this paper aims to propose an effective macroscopic modeling framework to describe the operations of the system and capture the impacts of parking provisions. The next section first reviews relevant studies and differentiates this paper from other existing endeavors in modeling curbside parking for passenger cars. Section 3 establishes a conceptual framework, integrating components concerning each aspect of a ride-sourcing system. In Section 4, we employ a deductive approach to further materialize the framework based on a simplified matching mechanism between RVs and customers. Section 5 then applies the derived model to formulate the optimal parking provision strategies as mathematical programs. Numerical experiments are generated to compare the properties and performance of ride-sourcing systems and the corresponding parking provision strategies under two different market structures. Section 6 concludes the paper and discusses possible directions for future research.

## 2. Literature review

To the best of our knowledge, none of the previous studies has explicitly considered the idea of providing on-street parking spaces for RVs. Two relevant facilities that may come to mind are taxi stands and on-street parking for private cars. Therefore, the rest of this section briefly reviews the state-of-the-art regarding each facility and then emphasizes how the system therein differs from the concept discussed in this paper.

Taxi stands are prescribed places where taxis can form queues and serve customers in a first-come-first-serve fashion (Salanova et al., 2014). They are usually established in hotspot areas such as railway stations, airports and hotel or mall entrances, to reduce the uncertainty associated with the meeting between taxis and customers (Salanova et al., 2011). In the literature, taxi stands are traditionally modeled with the queueing theory, by using either single-ended queues where customers arrive randomly and are served sequentially by taxis (e.g. Manski and Wright, 1976) or double-ended queues that capture random arrivals of both sides (e.g., Kashyap, 1966). Based on a double-ended queue framework with a limited capacity for waiting taxis, Matsushima and Kobayashiv (2006, 2010) subsequently investigated the endogenous formation and equilibria of markets with single and multiple taxi stands. They found that the market efficiency can potentially be hampered if the capacity of waiting taxis at a taxi stand is not restricted. Apart from the aforementioned structural models, aggregate models were proposed to delineate taxi drivers' choices between waiting at taxi stands and serving relatively uncertain customer demands via either radio dispatch (Schroeter, 1983) or street search (Yang et al., 2010). Recently, another group of studies empirically assessed the relation between supply and passenger demand at taxi stands and provided policy implications on the number and locations of taxi stands in urban regions (e.g. Cooper et al., 2010; Wong et al., 2014). However, none of previous studies has considered the impact of taxi stands on traffic congestion. Little is known about how the cruising of taxis would be affected by a newly developed stand in a downtown area.

Different from taxi stands, parking spaces in this paper are provided for RVs to reduce cruising and the costs associated with it. Passengers do not come to those parking spaces to meet RVs. Instead, all matchings are made by the online platform. Staying parked or cruising, an RV experiences little difference in the probability of being matched with a nearby customer, as the matching is made with a sufficiently large radius. Consequently, a ride-sourcing driver would likely seek for parking after dropping off a passenger. In contrast, taxis may not take taxi stands even if they are available, because street hailing may possibly yield higher profits (Wong et al., 2014).

In the investigation of curbside parking for private cars, a crucial consideration is the cruising of private cars when searching for parking. Following the work of Arnott and Inci (2006), researchers have developed various theoretical frameworks (e.g., Arnott and Rowse, 2009; Geroliminis, 2015; Cao and Menendez, 2015; Liu and Geroliminis, 2016) to model the impact of cruising on traffic congestion and propose potential solutions to it. The most relevant to this paper are Arnott and Inci (2006, 2010) and Arnott et al. (2015). The former discussed the equilibrium and stability of a road traffic system in which surface space can be allocated between road and parking. The latter investigated the optimal pricing and capacity of downtown on-street parking, with or without garage parking as a supplementary choice. While this paper accounts for the same cruising effect, the parking system of interest exhibits different characteristics. First of all, different from parking provision for private cars where pricing can be introduced to regulate parking demand, curbside parking spaces in this paper are provided for free to RVs, as a tool to reduce congestion and encourage shared-use mobility. The congestion impact of these parking spaces are much more complicated, as the ride-sourcing system pertains to a two-sided market built on the