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The morning commute problem with ridesharing and dynamic parking charges

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ABSTRACT

This paper studies the traffic flow patterns in a single bottleneck corridor with a dynamic ridesharing mode and dynamic parking charges. Schemes with different ridesharing payments and shared parking prices are investigated. Besides the scheme with constant parking charges and ridesharing payments, dynamic parking charges and ridesharing payments are derived to achieve congestion-free traffic in the corridor. With the dynamic ridesharing ratios, it is found that genuinely nonlinear departure rates and travel time functions can be generated in certain ridesharing cases, which was not observed in the traditional ADL model (Arnott et al., 1990) for the morning commute problems without ridesharing or with constant ridesharing ratios. Moreover, comparing different configurations of ridesharing arrangements and parking charges, the results show that constant parking charges with constant ridesharing payments may not significantly improve system performance over the traditional morning commute with solo-drivers, while dynamic parking charges with properly selected constant ridesharing payments can achieve better system performance in terms of vehicle-miles-traveled, vehicle-hours-traveled and total travel costs, by encouraging ridesharing and spreading vehicular demand over time to eliminate queuing delays.

1. Introduction

Traffic congestion often occurs in corridors in modern cities during the morning commute from residential areas to workplaces in the central business district (CBD). The increasing traffic congestion on commuting corridors usually leads to significant travel delays and other externalities, such as extra fuel consumption and air pollution. Among many instruments used to manage auto travel, ridesharing, also referred as carpooling, has been considered as an important demand management tool to reduce travel times, air pollution and other externalities (Kelly, 2007), and has been practiced for decades (Ferguson, 1997). In 1970, 20.4% of American workers commuted to work by carpool, according to the US Census. However, in the past few decades, ridesharing has declined to 10.7% in 2008 (Chan and Shaheen, 2012).

Recently, the ridesharing market starts to grow rapidly, thanks to the popularity of GPS-enabled smart devices and the innovative ridesharing services. Paid ridesharing services, extended from the taxi-like ridesourcing services such as Uber and Lyft, are experiencing a rapid growth. Such paid ridesharing services create opportunities to better utilize the empty seats in commuting vehicles, and commuters can easily choose to be a driver or a passenger and be paired to each other in

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real-time. Unlike the traditional carpool services, recent paid ridesharing services allow travelers to be paired in real-time instead of in a pre-arranged fashion.

Traditional ridesharing/carpooling studies are mainly limited to static analysis and ignore the effects of traffic dynamics and peak spreading in the morning commute. Brownstone and Golob (1992) studied the effectiveness of incentives for ridesharing services using probit discrete choice models to predict commuters' mode choices in a static fashion. Baldacci et al. (2004) studies a special case of the carpooling as a Dial-a-Ride problem by formulating integer programming formulations. An equilibrium model based on nested logit model was proposed in Viti and Corman (2013), where the ridesharing was modeled based on static link flow and travel times. Recently, Xu et al. (2015) extended the static ridesharing problem for general networks with multiple origin-destination pairs, and formulated the ridesharing problem with pick-up and drop-off choices, in the form of a nonlinear complementarity problem. Enabled by emerging technologies and ridesharing marketplaces, recent ridesharing studies have started to explore dynamic ridesharing problems. A comprehensive review on optimization problems of dynamic ridesharing can be found in Agatz et al. (2012). Qian and Zhang (2011) studies the morning commute problem with transit, driving alone and carpool modes on a homogeneous population. The ridesharing payments were internalized in the homogeneous carpoolers, and thus neglected in the formulation. Viti and Corman (2014) proposed a joint model considering both day-to-day and within-day models for dynamic ridesharing. In their within-day model, roles of travelers and departure-time choices were updated via an iterative solution process. Recently, Liu and Li (2017b) proposed a time-varying compensation scheme for ridesharing user equilibrium, while the ridesharing ratio does not vary and fixed as one.

As explained in the pioneer work of Vickrey (1969) and further studies extending Vickrey's work in the last several decades, traffic congestion in morning commute can be modeled as a deterministic queuing process. Given the early and late arrival penalties, individual drivers compete with each other to reach a user equilibrium with respect to their commuting costs. At the equilibrium, drivers arriving earlier than the preferred time may benefit from less travel times in the queued corridor, but encounter higher early arrival penalties; drivers arriving later than the preferred time may also benefit from reduced travel times, but suffer from higher late arrival penalties. Under such an equilibrium, the overall system cost is increased from its optimum due to the deadweight loss in terms of drivers' queuing delays. However, without the consideration of such traffic dynamics and departure-time choice (which leads to peak spreading), static models fail to properly capture the congestion phenomena in the morning commute, or develop time-varying pricing policies to relieve traffic congestion. In Vickrey (1969), a dynamic toll was proposed to eliminate the queuing congestion at the bottleneck. A large number of studies (e.g., Arnott et al., 1990; Arnott and Kraus, 1998) have been made to extend Vickrey's work, but none of these studies, to the best of our knowledge, has included ridesharing in its analysis.

Parking is a critical component of daily commuting trips. As pointed out in the literature (e.g. Button, 1995; Johansson and Mattsson, 1995), parking charges have been suggested as an efficient alternative instrument for managing travel demand. Most of the parking pricing studies are limited to static cases (e.g., Spiess, 1996; Vianna et al., 2004). Although in Vickrey's bottleneck model, it was suggested that congestion toll could be served to eliminate the queuing delays, while in reality, congestion toll has often met with strong public resistance. As a result, only a few cities in the world have successfully adopted congestion charging. On the other hand, people are used to pay low or no parking fees in suburban shopping malls but higher fees in downtown areas. From the perspective of congestion pricing theory, properly designed parking charges have almost identical effectiveness in influencing commuters' travel choices, while at the same time, they are easier to implement than congestion tolls. The availability of cutting-edge sensing and information technologies enables the dynamic parking pricing and the transmission of price signals to commuters in real-time. For instance, the SFPark program establishes varying parking prices in different time-of-day in the San Francisco downtown area, and the online system is able to broadcast the prices to the travelers via smartphone apps and web pages. Recent studies have integrated parking and morning commute to leverage parking to influence morning commute travel demand. Zhang et al. (2008) integrated both morning and evening commute with road tolls and parking fees in a linear city. Qian et al. (2012) derived the optimal parking fees, capacities and access times in the morning commute scenario to minimize total social costs. Yang et al. (2013) studied the morning commute problem with parking space constraints. Fosgerau and De Palma (2013) developed a dynamic parking charge scheme to a single bottleneck. Qian and Rajagopal (2015) analyzed optimal dynamic pricing for morning commute by considering parking cruise, parking occupancy in the generalized costs.

Most studies and practices on parking pricing have not considered the dynamic ridesharing demand in the morning commute, with a handful exceptions in recent studies (Liu and Li, 2017a; Xiao et al., 2016). There are still open questions to explore. For instance, does the combination of dynamic ridesharing and parking charges have an influence on the traffic flow patterns in the morning commute? If so, how to effectively use such combination to manage traffic congestion and reduce the environmental costs? In the traditional morning commute problem, the optimal pricing is uniquely determined once the bottleneck characteristics and the piecewise linear arrival penalty function are given. However, in the ridesharing schemes, parking charges and ridesharing payments may lead to multiple combinations of pricing strategies, if they are simultaneously considered. Due to the lack of studies for pricing strategies with parking charges and ridesharing payments coherently in the ridesharing scheme, it is not clear that whether the traditional pricing schemes for solo drivers can be transferred to the ridesharing schemes.

In order to answer the above questions, this paper formulates an analytical continuous-time dynamic ridesharing problem for a single bottleneck in the morning commute, in the context of dynamic user equilibrium of departure-time and ridesharing mode choices. It also designs policies with proper parking charges and ridesharing payments by analyzing and

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