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Traffic managements for household travels in congested morning commute

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ABSTRACT

Due to the high car ownership cost or car ownership restrictions in many major cities, household travels, which include multiple trips for all the household members, become very common. One typical household travel can be observed as the consecutive school trip and work trip, which sends the traveler's children to school first and then drive to their workplaces. In this paper, we analyse the departure time choice of the household travels and the equilibrium trip scheduling, i.e., extending the standard Vickrey's bottleneck model from work commute with one single preferred arrival time (work start time) to household commute with two consecutive preferred arrival times (school start time and work start time). Then, we investigate one step toll in peak hour window to best manage the morning commute of household travels and analyse the impact of the school-work start time difference on individual cost, social cost and traffic managements, so that we can optimally set the school-work start time difference to minimize the total travel cost. In addition, an alternative tradable credit scheme is designed to manage the morning commute as a replacement of the road toll scheme.

1. Introduction

Traffic congestion in the morning peak hours has been one of the most challenging urban problems faced by many major cities in the world. It is imperative for the urban traffic management agencies to understand the travelers' choice behavior and equilibrium travel patterns so that efficient management measures (e.g., pricing, tradable credit) can be devised to reduce the congestion in morning commute traffic. The analysis of morning commute can be originated from the seminal work of Vickrey (1969). After that, a large body of literature has emerged working on this problem (Hendrickson and Kocur, 1981; Smith, 1984; Daganzo, 1985; Arnott et al., 1990b; Nie and Yin, 2013; Liu and Nie, 2011; Liu et al., 2015, 2012; Xiao et al., 2010; Qian and Zhang, 2011; Qian et al., 2011; Qian and Rajagopal, 2013, 2014). Most of these studies are based on the assumption that travelers choose the departure time to minimize individual travel cost, which includes both travel time and scheduling delay. Analytical approaches are employed to obtain the travelers' equilibrium trip scheduling in the morning peak hours.

Most of the previous studies in the literature analyzed the morning commute for individual travelers. However, in many Asian cities, a large amount of morning commute trips are indeed household travels, i.e., multiple trips made for the household members, rather than only one person. For example, in Singapore, due to the high car ownership cost (certificate of

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entitlement), most of households have only one private car, which is used to make household travels in the morning. Indeed, many Singaporean families decide to buy a car mainly because they want to use the car to send their children or pick up their children to and from the school. It is very common in Singapore that the drivers firstly make school trips to send the children to the school and then they drive to their own workplaces. The fact that one can often observe congested traffic in the bottleneck transport facilities before schools in Singapore even if most of Singaporean public schools set very early school time (7:30 am) necessitates the study on how traffic management measures should be proposed to contain traffic congestion for these household travels. The departure time choice for household travels is certainly different from that for only individual trip, as multiple household members are involved in the joint decision, i.e., the members' preference of arrival times and intra-household interaction have to be considered in a group decision-making manner. In this study, it is assumed that morning household travel is comprised of multiple household member trips, and the departure time choice is made to ensure the total household travel cost, i.e., the travel time cost and scheduling delay cost for all the household members, is minimized. It is necessary for the traffic managers to understand the travelers' choice behavior for household travels and thus the equilibrium trip scheduling of the morning commute traffic with household travels, so that efficient traffic management measures can be designed to reduce the traffic congestion for morning commute traffic.

Despite that there is a large body of literature studying the morning commute traffic equilibrium for individual traveling, the research works on household are much less. Zhang et al. (2009) developed a household-based discrete choice model by integrating different types of household choice models based on latent class modeling approach and the approach of random utility maximization was applied. Li et al. (2014) proposed day-long activity-travel scheduling model to simultaneously determine the departure times for both morning and evening commutes, along with allocations of time spent on travel and activities at home or at the workplace. One can find that the obvious different departure time choice behavior for the household travels, in which the travel costs of all the household members must be considered and balanced, will affect the equilibrium scheduling of the morning commute significantly. In this study, we will firstly analyze the equilibrium trip scheduling of household travels in the morning commute and determine the equilibrium travel pattern by applying the bottleneck model approach. Then, based on the equilibrium travel pattern, we seek to propose optimal management measures to contain the traffic congestion.

To alleviate the congestion in morning commute, many management measures have been proposed. Vickrey's analysis shows how individuals' choice of departure time might shape traffic congestion and reveals the promise of policy interventions in managing this type of traffic congestion. Among these policies, the Vickrey's time-varying toll is the one that is most studied, which could completely eliminate the travel congestion delay induced by the bottleneck. However, in principle, the Vickrey's toll is the Pigouvian toll and thus shares its limitations. Moreover, the time-varying feature of the Vickrey's toll is indeed impractical, as a continuously changing toll may emit more pricing signals than what commuters could effectively recognized and respond to Bonsall et al. (2007). Many studies in the literature then proposed some alternatives to the Vickres toll. One typical example is the so-called step toll, which keeps toll rates constant in one or more predefined discrete time windows (Arnott et al., 1990b, 1993; Laih, 1994, 2004; Lindsey et al., 2010). Nie (2013) proposes a new tradable credit scheme (TCS), which is a simple alternative to the toll scheme. Under this scheme, the managers set a peak time window, the individuals who pass the bottleneck during this window will be charged some credits; individuals who pass the bottleneck out of this window will be rewarded with some credits. And there is a market for users to buy or sell the credits. The advantage of this scheme are as follows: firstly, managers do not need to allocate the credits to the individuals initially (compared to Nie, 2012; Xiao et al., 2013; Yang and Wang, 2011); secondly, the scheme does not rely on the trading market to alleviate the congestion; lastly, the scheme is easy to be implemented and more likely to be accepted by the public.

In this study, we consider a typical household travel consisting of two trips, i.e., firstly send the children to school and then go to workplaces through a single road. It is assumed that there exists a single bottleneck located before the school destination. We analyse the departure time choice of the household travels and the resultant equilibrium trip scheduling of household travelers. We investigate how to design traffic management measures to best manage the morning commute traffic with household travels. In this paper, we only use one step toll scheme to manage the congestion, wherein traffic management designs a peak time window to charge individual household travelers who enter the bottleneck in this peak time window. We further analyse the impact of the school-work start time difference on individual cost, social cost and traffic management tolls, so that we can optimally set the school-work start time difference to minimize the total travel cost. Besides, we also analyze how to design an alternative tradable credit scheme to replace the toll scheme to manage the household travel morning commute traffic.

In summary, this study contributes to the literature of morning commute management in the following aspects: Firstly, this study extends the standard Vickrey's bottleneck model from work commute with one single preferred arrival time (work start time) to household commute with two consecutive preferred arrival times (school start time and work start time). Secondly, this study explicitly investigates the impact of the school-work start time difference on individual cost, social cost and traffic management tools, so that the optimal school-work start time difference can be designed. Thirdly, under the optimal setting of school-work start time difference, the optimal traffic managements, including the one step toll scheme and an alternative tradable credit scheme, are determined.

The remainder of this paper is organized as follows. Section 2 presents the departure time choice behavior of the household travels to obtain the resultant equilibrium travel pattern for a typical household travel with school and work trips. Based on the setting of school-work start time difference, two different situations are discussed. In Section 3, we first present a single step toll model for one situation. Under the toll model, we deduce the optimal toll rate for different time intervals