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Expirable parking reservations for managing morning commute with parking space constraints

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ABSTRACT

When total parking supply in an urban downtown area is insufficient, morning commuters would choose their departure times not only to trade off bottleneck congestion and schedule delays, but also to secure a parking space. Recent studies found that an appropriate combination of reserved and unreserved parking spaces can spread the departures of those morning commuters and hence reduce their total travel cost. To further mitigate both traffic congestion and social cost from competition for parking, this study considers a parking reservation scheme with expiration times, where commuters with a parking reservation have to arrive at parking spaces for the reservation before a predetermined expiration time. We first show that if all parking reservations have the same expiration time, it is socially preferable to set the reservations to be non-expirable, i.e., without expiration time. However, if differentiated expiration times are properly designed, the total travel cost can be further reduced as compared with the reservation scheme without expiration time, since the peak will be further smoothed out. We explore socially desirable equilibrium flow patterns under the parking reservation scheme with differentiated expiration times. Finally, efficiencies of the reservation schemes are examined.

1. Introduction

Parking is a growing problem in many downtown areas around the world. The time spent on searching for a parking space often constitutes a substantial portion of travel cost of individual drivers, and thus has considerable impacts on their travel choices. Bifulco (1993) introduced parking search times, types and fees in a static stochastic traffic assignment model for the evaluation of various parking policies. Arnott and Rowse (1999) examined the steady-state equilibria of cars cruising for parking on a circle when parking is unsaturated. Arnott and his collaborators have conducted a series of follow-up studies on the parking problem integrating traffic congestion and on-street or curbside parking (e.g., Arnott and Inci, 2006, 2010; Arnott and Rowse, 2009).

Besides parking search time, parking fee is another factor that may significantly affect commuters' travel behaviors. Many researchers have considered parking fee as an instrument to help manage traffic. In a static context, Glazer and Niskanen (1992) optimized parking fees and showed that if road usage is suboptimally priced, a lump-sum parking fee can increase social welfare. Arnott et al. (1991) concluded that parking fees alone can be efficient in increasing social welfare in morning commute and a combination of road tolls and parking fees can yield system optimum. Verhoef et al. (1995) conducted a diagrammatic analysis on how parking fees and physical restrictions on parking space supply affect individual travel cost

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and modal split. Anderson and de Palma (2004) treated parking as a common property resource and examine the benefits of pricing it. Zhang et al. (2008) derived the daily commuting pattern that combines both the morning and evening commutes, and investigated mechanisms and efficiencies of several road toll and parking fee regimes. To account for the temporal aspect of parking, Zhang and van Wee (2011) further introduced a duration-dependent parking fee scheme into their daily commuting model. More recently, Qian et al. (2012) investigated how parking fee and parking supply can be optimized to mitigate traffic congestion. Fosgerau and de Palma (2013) proposed the parking fee at the workplace as a substitute of congestion pricing and showed that at system optimum, the commute to work is divided into two distinctive intervals by an optimal parking fee. At one interval, the parking fee is zero and does not eliminate the queue at a bottleneck. At the other, it varies with time such that no queue is present while bottleneck capacity is fully utilized.

In addition to parking fees and search times, previous studies also considered how the availability of parking shapes commuters' travel patterns. It is reported in Qian et al. (2011) that parking availability will affect commuters' choices of departure time, travel mode and route. Zhang et al. (2011) explored the morning commuting equilibrium when the destination provides inadequate parking spaces to accommodate potential private cars. In the spirit of tradable mobility credits proposed by Yang and Wang (2011), Zhang et al. (2011) introduced a tradable parking permit scheme for managing the morning commute with limited downtown parking spaces. Recently, Yang et al. (2013) proved that, when the parking supply is insufficient, dedicating some spaces for reservations while keeping the rest open for competition can smooth out traffic arrivals to the bottleneck and thus reduce the total system cost. This is because commuters without a reserved parking space are compelled to leave home earlier to secure a public parking space.

In Yang et al. (2013), reservations of a parking space do not expire. They are valid no matter when commuters with a reservation choose to arrive. This study considers an expirable parking reservation scheme under which commuters with a parking reservation have to arrive at the parking spaces for the reservation before a predetermined expiration time. We first consider the simplest situation when all parking reservations have the same expiration time. As such, the parking reservation scheme considered in Yang et al. (2013) is indeed a special case of our scheme where the identical expiration time is sufficiently large. We then consider parking reservations with differentiated expiration times. In this case, total travel cost may be further reduced since departures of morning commuters will be more dispersed due to differentiated expiration times. In other words, their departures are staged by those different expiration times. Finally, we examine the efficiencies of parking reservation schemes with identical and differentiated expiration times.

Following Yang et al. (2013), we consider a traffic corridor with two travel modes: a highway and a parallel transit line with dedicated right-of-way. For the highway, a single bottleneck is considered in order to make our model more tractable. Vickrey (1969) was the first to introduce the bottleneck model of congestion dynamics. Existence and uniqueness of the time-dependent equilibrium distribution of arrivals at a single bottleneck have been established in Smith (1984) and Daganzo (1985) respectively. The bottleneck model can generate insights concerning the formation and mitigation of traffic congestion. It has been extended to study various issues, including congestion pricing (Arnott et al., 1990; Laih, 1994; Xiao et al., 2012), Pareto-improving strategies (Daganzo and Garcia, 2000; Xiao and Zhang, 2013), demand elasticity (Arnott et al., 1993a; Yang and Huang, 1997), heterogeneous commuters (Newell, 1987; Arnott et al., 1994; Lindsey, 2004; van den Berg and Verhoef, 2011; Liu and Nie, 2011; Doan et al., 2011), small networks including routes in parallel and routes in series (Kuwahara, 1990; Arnott et al., 1993b; Tabuchi, 1993; Zhang and Zhang, 2010), pricing on general queuing networks (Yang and Meng, 1998), stochastic capacity and demand (Arnott et al., 1999; Lindsey, 2009; Xiao et al., 2013b), integration of both morning and evening peak hour commute (Zhang et al., 2005; Gonzales and Daganzo, 2013; Daganzo, 2013), travel time reliability (Yin et al., 2004; Li et al., 2012), congestion derivatives (Yao et al., 2010; 2012), tradable mobility credits (Tian et al., 2013; Nie and Yin, 2013; Xiao et al., 2013a).

The remainder of the paper is organized as follows. Section 2 revisits the Wardropian bi-modal equilibrium under insufficient parking spaces and with parking reservations. In Sections 3 and 4, parking reservation schemes with identical and differentiated expiration times will be discussed, respectively. Section 5 evaluates the efficiencies of expirable parking reservation schemes. Finally, Section 6 concludes the paper and provides some discussions.

2. Basic setting and considerations

It is assumed that there are N commuters traveling from a residential area to the Central Business District (CBD) every morning with two travel modes to choose: a transit line with dedicated right-of-way and a parallel highway with a single bottleneck. Commuters are assumed to have a common preferred arrival time t^* at the destination, and early or late arrival will be penalized. It is also assumed that parking spaces are located at the destination, and the walking time between parking spaces and the workplace is ignored for simplicity. The numbers of auto and transit commuters are denoted by N^A and N^T respectively, and $N = N^A + N^T$.

2.1. Generalized travel cost

2.1.1. Auto commuters

The auto commuter' travel cost consists of his or her actual travel time cost and early or late arrival penalty. Departing at time t, the travel cost of the auto commuter is given by