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A dynamic pricing strategy for high occupancy toll lanes

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ABSTRACT

High Occupancy Toll (HOT) lanes are emerging as a solution to the underutilization of High Occupancy Vehicle (HOV) lanes and also a means to generate revenue for the State Departments of Transportation. This paper proposes a method to determine the toll price dynamically in response to the changes in traffic condition, and describes the procedures for estimating the essential parameters. Such parameters include expected delays, available capacity for toll-paying vehicles and distribution of travelers' value of time (VOT). The objective function of the proposed pricing strategy can be flexibly modified to minimize delay, maximize revenue or combinations of specified levels of delay and revenue. Real-world data from a 14-mile of freeway segment in the San Francisco Bay Area are used to demonstrate the applicability and feasibility of the proposed method, and findings and implications from this case study are discussed.

1. Introduction

High Occupancy Vehicle (HOV) lanes are special-use lanes that enable vehicles with a predetermined number of passengers to bypass congested traffic in general purpose (GP) lanes, and have been widely installed along the crowded urban freeways to improve the overall mobility within metropolitan freeway systems. However, the benefits of HOV lanes can be nullified when HOV lanes are severely underutilized (Chen et al., 2005; Kwon and Varaiya, 2008). To mitigate the inefficiency that arises from the underutilization and to generate revenue, many transportation agencies are considering the installation of High Occupancy Toll (HOT) lanes, as a solution. The HOT lanes are one type of HOV lanes that can be accessed by Low Occupancy Vehicles (LOV) at a fee.

Several pricing strategies are currently employed by federal and regional transportation agencies. Some agencies use a deterministic pricing strategy by which the toll varies with respect to time of day without considering the level of congestion (Shin and Hickman, 1999; Sullivan et al., 2000; Sock-Yong and Toh, 2004). Other agencies use a dynamic pricing strategy in which toll amount varies based on downstream traffic density (i.e., number of vehicles per mile) rather than expected traffic delays in GP lanes or travel-time savings by using HOT lane (Supernak et al., 2002a,b; Halvorson and Buckeye, 2006; Brady,

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2007). However, the existing pricing strategies (Liu and McDonald, 1999; Verhoef et al., 1996) rarely consider the differences in travelers' value of time (VOT). This resulted in a deterministic (and often unrealistic) mode choice behavior: it fails to allow freeway users to choose different services according to their own preferences based on their analysis of pricing. In previous studies, the heterogeneity in VOT has been recognized and identified (Calfee and Winston, 1998; Calfee et al., 2001; Small and Yan, 2001), and the importance of incorporating the heterogeneity in determining the benefit of value pricing has been documented in previous studies (Small et al., 2005; Verhoef and Small, 2004).

This study proposes a dynamic pricing strategy that takes the differences in individual's VOT into consideration and seeks to include the expected traffic delays in GP lanes estimated in real-time when determining the toll price. It is described in Section 2 that the assumptions, the processes of estimating GP lane delay and the method of evaluating HOV lane capacity that can be allocated to serve the HOT demand. The discussion of how the VOT distribution had been determined using the mixed logit model in this study is also presented in Section 2. Section 3 explains the proposed dynamic pricing strategy. The proposed strategy has been applied to the data obtained from 14-mile corridor along the Interstate 680 in the San Francisco Bay Area. The findings from applying the pricing strategy are reported in Section 4. This paper ends with a summary of the findings and discussions of their implications in Section 5.

2. GP Lane delay, HOV lane utilization, and value of time distribution

2.1. GP lane delay estimation

Suppose that there exists a freeway and it has only a pair of ingress and egress points and HOV lane is separated from GP lanes as shown in Fig. 1(a). Although the case in the figure has been simplified for illustration purpose, the method can be extended for the cases with multiple access points or multiple bottlenecks by applying serial queuing analysis, in which the departure from the upstream bottleneck or access points would be the arrival to the downstream bottleneck or access point (Newell, 1982; Daganzo, 1997). The ingress and egress of the HOV lane in the Fig. 1(a) span an active bottleneck, which is marked by gray triangle. $A(t)$ and $E(t)$ in Fig. 1(b) show the cumulative numbers of vehicles arriving at upstream and downstream of the bottleneck by time t, respectively. $a(t)$ is the arrival rate at upstream (vehicles per unit time) and C is

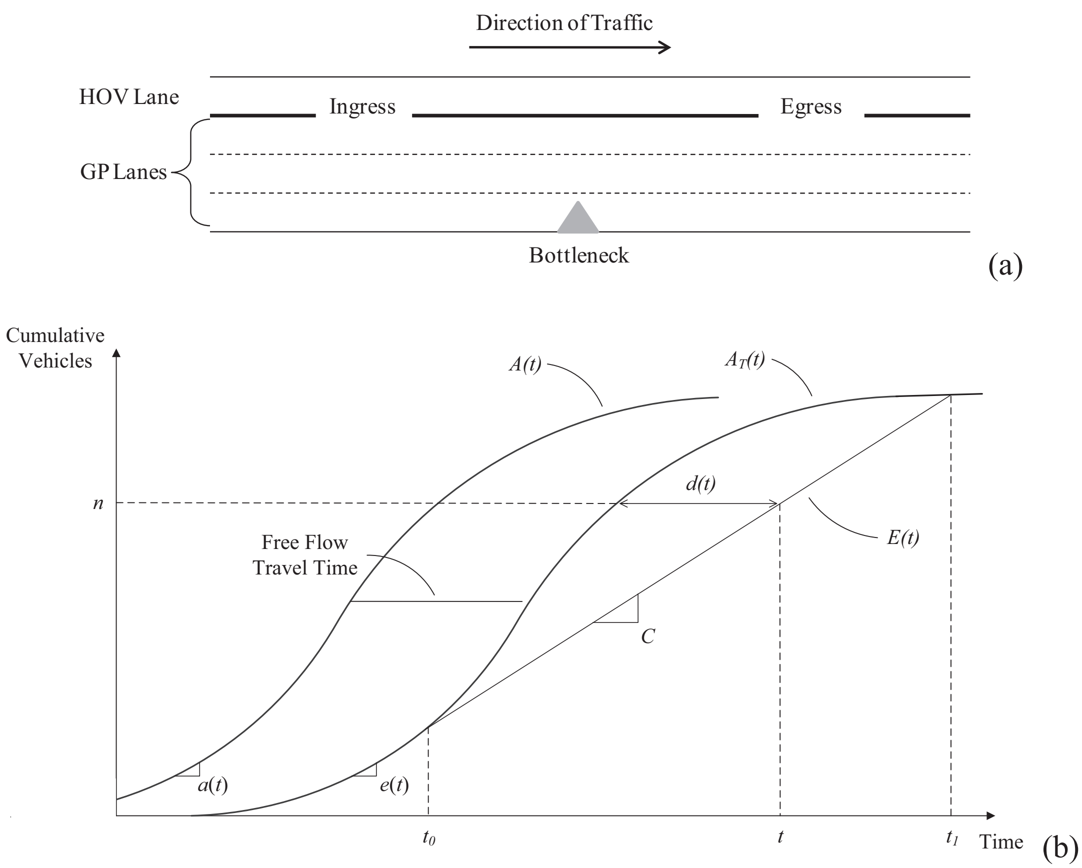

Fig. 1. (a) Freeway segment with limited HOV access and (b) hypothetical queuing diagram for GP lanes.