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Parking permits management and optimal parking supply considering traffic emission cost

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ABSTRACT

Given a many-to-one bi-modal transportation network where each origin is connected to the destination by a bottleneck-constrained highway and a parallel transit line, we investigate the parking permit management methods to minimize traffic time cost and traffic emission cost simultaneously. More importantly, the optimal supply of parking spots is also discussed in the policies of parking permit. First, we derive the total travel costs and emission costs for the two cases of sufficient and insufficient parking spot provisions at the destination. Second, we propose a bi-objective model and solve the Pareto optimal parking permit distribution, given a certain level of parking supply. Third, we investigate the optimal parking supply in the policy of parking permit distribution, with the objectives of minimizing both total travel cost and traffic emission. Fourth, we provide a model of optimizing parking supply, in the policy of free trading of parking permits. Finally, the numerical examples are presented to illustrate the effectiveness of these schemes, and the numerical results show that restricting parking supply at the city center could be efficient to reduce traffic emission.

Introduction

People in big cities are more and more concerned with the control of traffic emissions due to their negative effects on human health and the environment. In the past decades, the transportation and other related authorities devoted a great deal of efforts to reduce traffic emissions, and scholars have also become more and more interested in the science and engineering of traffic emission control. For example, quite a few researchers developed models to simulate and evaluate the network wide traffic emissions, in accordance with the variation of traffic conditions (Zhou et al., 2015; Tang et al., 2015; Smit et al., 2007; Smit and McBroom, 2009; Callan and Thomas, 2000). In addition, some researchers developed economical and mathematical models to reduce traffic emission in transportation networks. For example, Zhang et al. (2013) developed robust signal timing models to minimize traffic delay and the risk associated with human exposure to traffic emissions, based on a cell-transmission representation of traffic dynamics. Chen and Yang (2012) sought nonnegative link toll and corresponding rebate schemes for Pareto-efficient control of both vehicular congestion and emissions with a bi-objective optimization approach. Johansson (1997) applied marginal social cost pricing to maximize net social benefit with respect to congestion, emissions, and fuel consumption. Yin and Lawphongpanich (2006) showed that a traffic flow distribution on a

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network with minimum emissions can always be induced by a non-negative charging scheme. Emission control by other effective traffic management measures, such as speed limit (Cariou and Cheaitou, 2012; Madireddy et al., 2011; Franceschetti et al., 2013), and bus fleet management (Li et al., 2015), has also been studied.

Recently, the policies of parking permit distribution and trading have been proposed to manage urban transportation. Zhang et al. (2011) developed a bi-modal equilibrium model to derive the traffic commuting pattern, when the parking space at the destination is inadequate. They further showed that parking permit distribution and trading can eliminate the deadweight loss of competition for parking spots, and hence obtain a solution close to system optimum by the power of the market. Yang et al. (2013) and Liu et al. (2014a,b) investigated the parking permit management policies, when some parking spots have been reserved by certain commuters.

So far, parking permits are only used for reducing travel time cost (including unpunctuality cost), and has not been used for reducing traffic emissions yet, and one may wonder whether it is appropriate for traffic emissions control. With this objective in mind, in this paper we attempt to explore the possibilities of mitigating traffic congestion and traffic emissions simultaneously by parking permit distribution and trading. Moreover, the optimal supply of parking space in such policies is discussed.

First, in a many to one transportation network, we consider how to reduce the travel cost and emission cost simultaneously by parking permit distribution, given fixed parking supply. We establish a bi-objective programming model of minimizing both travel cost and emission cost. Then a constraint method is used to solve for the Pareto optimal solutions of the model, by minimizing the total travel cost subject to the constraint of emission cost.

Second, we investigate the optimal parking supply under the parking permit distribution developed in the first part, with the objectives of minimizing both travel time and traffic emission. In Zhang et al. (2011) only travel cost is considered as the objective function, and travel cost generally decreases with the increase of parking supply. But if traffic emissions are also considered as part of the objective function, the situation might be different. Therefore, combining the objective functions of minimizing travel cost and traffic emissions, there would be a new optimal level of parking supply, which needs to be obtained for the destination through a new family of models.

Third, we provide a model of optimizing parking supply when parking permits can be traded freely. As in Zhang et al. (2011), we investigate the optimization of parking supply by formulating a bi-level programming model. At the upper level, a weighted sum of travel cost and emission cost is minimized by determining optimal parking supply at the destination. The lower level problem describes a user equilibrium under the policy of parking permits trading with the given parking permits supply.

The remainder of the paper is organized as follows Section ‘The system cost analysis under bi-modal equilibrium’ derives the individual travel costs of car drivers and bus passengers, and gives the emission cost function, in the bi-modal network with a parking supply constraint. Section ‘Pareto optimal parking permit distribution’ presents the model and solves the Pareto optimal parking permits distribution, given a certain number of parking spots. Section ‘Optimal parking supply with parking permit distribution’ examines the optimal parking supply under the Pareto optimal parking permit distribution. Next, we discuss the optimal supply under free trading of parking permits. Section ‘Numerical examples’ presents numerical examples that demonstrate the effects of the above parking distribution and supply schemes. Finally, the conclusions are provided at the last section.

The system cost analysis under bi-modal equilibrium

We now analyze a many-to-one network shown in Fig. 1. In the network, each origin is connected to the destination by a bottleneck-constrained road and a parallel transit line, as in Tabuchi (1993). The parking supply in the destination is n. Let W

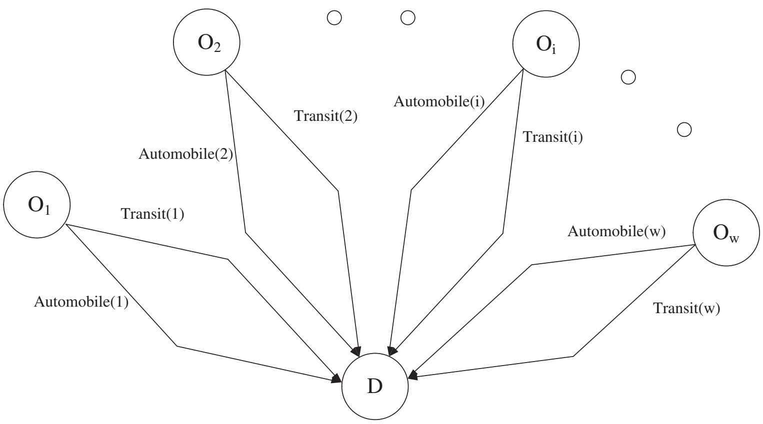

Fig. 1. A many-to-one transportation network.

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