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# Bi-level Programming Model for Exclusive Bus Lanes Configuration in Multimodal Traffic Network

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**Abstract**

Setting exclusive bus lanes (EBLs) on existing roads is a major measure to practise bus priority. However, the capacities for different vehicles will be changed with such strategies and then the travel times of different modes will be also changed. Accordingly, the presence of EBLs may be associated with significant impacts on the travellers' mode choices and the performance of the whole traffic network, especially in a congested condition. This paper attempts to propose a EBLs design model for multimodal traffic network, in which the total travel cost of all travellers in network is regarded as the optimization objective. Firstly, this paper analyses the effects of EBLs on the capacities for transit vehicles and private cars and formulates the corresponding impedance functions based on the travel demand. The complex travellers' choice behaviours (including mode choice and route choice) are analysed and a variational inequality model is then proposed to describe user equilibrium assignment problem in multimodal network. Further, a bi-level programming model is proposed to describe the EBLs design problem. The branch and bound algorithm is then given for solving the proposed bi-level problem. Finally, a numerical example is provided to illustrate the effectiveness and feasibility of such model and algorithm.


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*Keywords:* multimodal; exclusive bus lanes; travel choice; bi-level programming; branch-and-bound method

## 1. Introduction

In most of the big cities, bus priority strategy has widely been recognized as a potential solution for reducing automotive-related externalities like congestion and air pollution. As a major bus-priority measure, Exclusive Bus

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Lanes (EBLs) have a significant effect on improving bus operation efficiency and service quality and strengthening the attractiveness of the bus travel. However, the dedicated lane for bus vehicle may lead to a reduced number of lanes used for private cars, resulting in an increased travel time of travellers by car. Accordingly, the improper configuration of EBLs may deteriorate the efficiency of the whole transportation system. Therefore, it is important to optimize the configuration of EBLs to enhance the efficiency of the whole traffic network.

Most researches about EBLs have focused on its effect from the perspective of microscopic operations (Viegas and Lu, 2004; Arasan and Vedagiri, 2010; Chen et al., 2010). These studies have been done just for single road rather than the entire traffic network by using the simulation-based methods. Some scholars studied the modal split between bus and car in the presence of EBLs. For example, Vedagiri and Arasan (2009) estimated the travel shift caused by EBLs while considering congestion interactions between car and bus. Basso et al. (2011) analyzed optimal problem for a single link corridor with EBLs, in which bus frequency, vehicle size, distance between stops, and percentage of the capacity used by bus vehicles were regarded as variables to maximize social welfare. McDonnell and Zellner (2011) developed a prototype agent-based model to investigate the effect of Bus Rapid Transit (BRT) for system-wide patterns of modal share and travel times. However, these studies only considered the mode-split problem between different modes under the condition of EBLs, while the effects of EBLs on the congestions through the whole traffic network are not considered.

Several scholars also proposed equilibrium model for traffic assignment problem considering the impact of EBLs at the level of road network. For example, Abdelghany et al. (2007) proposed a dynamic traffic assignment and simulation model to assess different operational characteristics of BRT in terms of the potential impacts on transit ridership and the interacting auto traffic. Li and Ju (2009) considered the queuing delay with intersection capacity constraints and proposed a multi-modal dynamic stochastic user equilibrium assignment model to analyze the effect of EBLs. However, in these previous researches, only two extreme cases were considered: setting or not setting EBLs on all roads overall traffic network. Moreover, such models used a fixed link travel time, and EBLs design problem in traffic network was not taken into account. More recently, some researchers began to pay their attention to EBLs design problem. For example, Mesbah et al. (2011) proposed a bi-level programming model to optimize EBLs configuration based on user equilibrium in multimodal traffic network. Yao et al. (2012) also proposed a bi-level programming model to comprehensively analyze the combinational optimization problem of EBLs and bus frequencies in multimodal traffic network. Ma et al. (2014) proposed a person-capacity-based optimization method for the integrated design of lane markings, EBLs and passive bus priority signal settings for isolated intersections. Although these studies proposed equilibrium models for comprehensive considerations of modal split, traffic assignment and transit assignment under the condition of variable EBLs configurations, they have at least one of the following short-comings: (1) not perfectly considering the impact of EBLs on the capacities of transit vehicles and cars on the road, (2) not considering the characteristics of different modes in the impedance functions, for example, bus vehicles can carry more travellers than private cars, (3) neglected the unsymmetrical interferences between different modes in modeling user equilibrium model (4) using genetic algorithms for solving the optimization model, which cannot guarantee its convergence effect.

This paper attempts to put forward new idea for EBLs design problem through multimodal network. A bi-level programming model is proposed to describe such problem, in which the upper model is regarded as a system optimization problem with the objective of minimum travel time of all travellers overall the whole traffic network and the lower model is formulated as a variational inequality to describe the travellers' choice behaviors under the condition of EBLs configurations. Compared with previous studies, the contributions of this paper are the following: (1) the impacts of EBLs on the capacities of transit vehicles and cars are analyzed from the perspective of traffic engineering and the impedance functions for bus and car are constructed based on the travel demands rather than traffic flows, which considering the characteristics of different modes; (2) considering the unsymmetrical interferences between bus and car, a variational inequality model is proposed to describe user equilibrium problem with comprehensive considerations of modal split, traffic assignment and transit assignment; (3) a branch-and-bound based algorithm is used to solve the proposed 0-1 bi-level programming problem and the effective of algorithm is analyzed through a simple example.