Transportation Research Part C 40 (2014) 49–62

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Integrated optimization of transit priority operation at isolated intersections: A person-capacity-based approach

Wanjing Ma [a,*], K. Larry Head [b], Yiheng Feng [b]

[a] Key Laboratory of Road and Traffic Engineering of the Ministry of Education, Tongji University, 4800 Cao'an Road, Shanghai, PR China

[b] Department of Systems and Industrial Engineering, The University of Arizona, 1127 E. James E. Rogers Way, P.O. Box 210020, Tucson, AZ 85721-0012, United States

ARTICLE INFO

Article history:
Received 11 April 2013
Received in revised form 11 December 2013
Accepted 30 December 2013

Keywords:
Exclusive bus lanes
Lane markings
Bus signal priority
Person capacity

ABSTRACT

In this paper, a person-capacity-based optimization method for the integrated design of lane markings, exclusive bus lanes, and passive bus priority signal settings for isolated intersections is developed. Two traffic modes, passenger cars and buses, have been considered in a unified framework. Person capacity maximization has been used as an objective for the integrated optimization method. This problem has been formulated as a Binary Mixed Integer Linear Program (BMILP) that can be solved by a standard branch-and-bound routine. Variables including, allocation of lanes for different passenger car movements (e.g., left turn lanes or right turn lanes), exclusive bus lanes, and passive bus priority signal timings can be optimized simultaneously by the proposed model. A set of constraints have been set up to ensure feasibility and safety of the resulting optimal lane markings and signal settings. Numerical examples and simulation results have been provided to demonstrate the effectiveness of the proposed person-capacity-based optimization method. The results of extensive sensitivity analyses of the bus ratio, bus occupancy, and maximum degree of saturation of exclusive bus lanes have been presented to show the performance and applicable domain of the proposed model under different composition of inputs.

1. Introduction

Traffic congestion has long been one of the pressing issues in many cities. It is highly recommended by many researches and authorities that providing high level of service of public transit system would encourage more travelers to choose transit mode for their travels hence mitigate traffic congestion. Granting signal priority and designing exclusive bus lanes are two typical strategies which can be used to improve speed and reliability of public transit system. Exclusive bus lanes can be implemented with relatively low cost and short implementation time, and they are considered a cost-effective approach for providing a high-quality transit service (Deng and Nelson, 2011); in addition, they can effectively improve the reliability and increase the speed of buses by avoiding the need for them to share road space with congested urban traffic. Since the 1930s, when the idea of exclusive bus lanes was first introduced, several studies have specifically examined bus prioritization measures (Currie, 2006; Eichler and Daganzo, 2006; Fuhs and Obenberger, 2002; Hounsell and McDonald, 1988; Levinson et al., 2003; Mesbah et al., 2008; Song, 2000; Viegas and Lu, 2004). Although exclusive bus lanes effectively improve bus prioritization, a major potential limitation in their implementation is the reduction in road capacity for other types of vehicles, which results in increased levels of congestion at signalized intersections.

The prioritization problem can also be addressed by transit signal priority (TSP) strategies. TSP strategies are of three main types: passive priority strategy, active priority strategy, and real-time priority strategy (Balke et al., 2000). Passive

* Corresponding author. Tel.: +86 21 69584674; fax: +86 21 69589475.
E-mail addresses: mawanjing@tongji.edu.cn (W. Ma), klhead@email.arizona.edu (K.L. Head), yihengfeng@email.arizona.edu (Y. Feng).

0968-090X/$ - see front matter
http://dx.doi.org/10.1016/j.trc.2013.12.011

priority strategies operate continuously regardless of whether transit vehicles are present, and they do not require a transit detection/priority request generation system (Skabardonis, 2000). Active priority strategies prioritize a specific transit vehicle following detection or upon receiving a priority request from the vehicle/system (Furth and Muller, 2000; Yagar and Han, 1994). Adaptive/real-time TSP strategies provide priority while simultaneously trying to optimize signal timings under given performance criteria such as person delay, transit delay, vehicle delay, and/or a combination of these criteria (Baker et al., 2002; Chang et al., 1995; Christofa and Skabardonis, 2011; Furth et al., 2010; Ma et al., 2010; Mesbah et al., 2011; Mirchandani et al., 2001; Stevanovic et al., 2008).

On the one hand, in all transit signal priority strategies, it is assumed that the lane function (e.g., straight-ahead or left-turn) of both exclusive bus lanes and passenger car lanes are provided as exogenous inputs. On the other hand, these exclusive lane design methods did not address the interactions between lane assignments and signal timings. Moreover, the design of lane markings for the passenger lanes is also usually considered a prerequisite for calculating signal timings. The conventional approach is to design lane markings on a trial-and-error basis in which an initial set of lane markings is first assumed, and then, the signal settings are determined based on this lane configuration. After assessing the performance of different approaches at the signal-controlled intersection with optimal settings, the lane markings are revised (if necessary) based on the engineer's experience. The procedure is repeated until the performance of the intersection meets the requirement (Wong and Wong, 2003).

However, for complicated intersections, it is very difficult to determine an optimal set of lane markings for transit and traffic movements with corresponding transit priority. For example, consider one approach of a signal-controlled intersection with four traffic lanes, as shown in Fig. 1. If one lane is marked with an exclusive bus lane, the lanes available for passenger cars decrease, as a result of which the saturation flow of passenger car lanes decreases substantially and a longer cycle length is required to discharge the same level of traffic volume, which might induce longer delay of buses. Even if the exclusive bus lane is fixed (e.g., in a Bus Rapid Transit corridor), the lane markings are still very difficult to optimize. Therefore, the conventional isolated signal timing optimization and lane assignment methods may not always produce a truly optimal set of lane markings and signal timings for the intersection, especially if transit priority operation is considered.

Several previous attempts to combine the design of lane markings and the calculation of signal timing (Lam et al., 1997; Wong and Heydecker, 2011; Wong and Wong, 2003) optimized lane markings and signal timings simultaneously. However, they did not simultaneously address transit priority issues. If transit demands and exclusive bus lanes are also considered, the single mode traffic control problem transforms into a multi-mode traffic control problem that requires specific consideration of the features, level of priority, and performance of each mode. In one of our previous attempts to combine the design of lane markings and signal timings for transit priority operations (Ma and Yang, 2007), it was shown that the average delay of transit vehicles can be reduced with limited negative impact on general traffic at an intersection with an exclusive bus lane. However, only one approach was considered in this study. The problem will become more complex if the existence of an exclusive bus lane and all approaches at the entire intersection are taken into account. Moreover, it combines the objectives of transit priority and traffic operations into a single objective function by setting different weights, and the optimal solution obtained depends on the relative values of the weights specified.

Thus, this paper aims to formulate the intersection design problem with the consideration of transit priority operation into a mathematical program and includes the intersection's geometric layout, individual lane usages, exclusive bus lanes, and signal timings as design variables that can be optimized simultaneously to achieve higher intersection reserve person capacity. The reserve capacity maximization idea is a well-known concept. Based on the assumption that the traffic flows for the traffic movements in the intersection will increase in proportion to the demand matrix, the maximum reserve vehicle capacity is obtained by determining the largest common multiplier (Allsop, 1972; Gallivan and Heydecker, 1988; Wong and Heydecker, 2011; Wong and Wong, 2003; Wong and Yang, 1997). However, in previous studies, only one mode, namely, passenger car, was considered, and neither the design of exclusive bus lanes nor bus signal priority was addressed. The proposed person capacity maximization method considers all of these factors. Because the final objective for the design of intersections is to accommodate more passengers rather than vehicles, person capacity maximization is employed as the objective of this integrated optimization model. The person capacity is defined as the total number of people that can be accommodated by the intersection. It can be calculated based on the capacity of passenger cars and buses multiplied by their

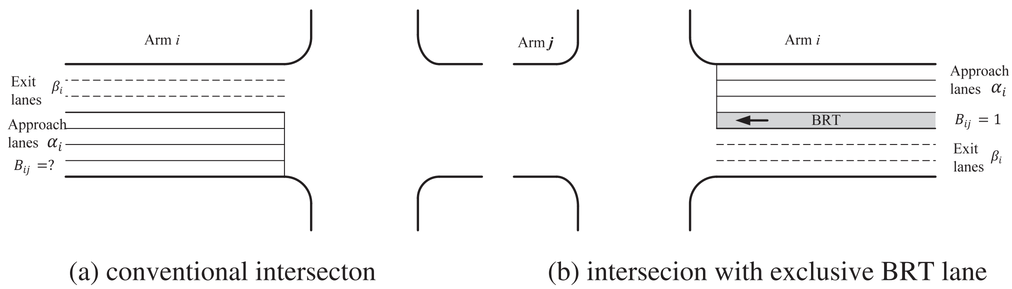

Fig. 1. Numbering convention for destination arms in an example junction.