Transportation Research Part C 90 (2018) 411–432

Contents lists available at ScienceDirect

Transportation Research Part C

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

An analytical model to conduct a person-based evaluation of transit preferential treatments on signalized arterials☆

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ARTICLE INFO

Keywords:
Transit signal priority
Transit preferential treatments
Dedicated bus lanes
Queue jumper lanes
Person delay
Person discharge flow

ABSTRACT

The complexities of urban transportation networks where multiple modes with different characteristics and needs travel in combination with constraints on space and funding make the sustainable management of these systems a challenge. In order to improve transit service, space (e.g., dedicated bus lanes) and time (e.g., transit signal priority strategies) Transit Preferential Treatments (TPT) are deployed to improve transit operations. The objective of this paper is to develop an analytical model that allows for a person-based evaluation of alternative TPTs when considered individually and in combination. In particular, the analytical model is developed to assess person delay and person discharge flow at any intersection that is part of a signalized arterial, where auto arrivals are in platoons. The performance of TPTs is evaluated using both the analytical model and through microsimulation tests on two intersections of San Pablo Avenue in Berkeley, CA. Space TPTs such as dedicated bus lanes and queue jumper lanes are beneficial in reducing bus person delay when provided in addition to the existing lanes; however, the effectiveness of time TPTs such as green extension depends on the level of auto demand in combination with signal settings. Changes in person discharge flow are not significant for any of the treatments tested with the exception of the bus lane substitution with and without green extension, which led to a significant decrease in person discharge flow. Increased bus frequency increases the effectiveness of transit signal priority in reducing total and bus person delay. The analytical model results produce ranking outcomes that are comparable with the microsimulation ones and therefore, the model may be used for a quantitative evaluation of TPTs without the need for data intensive and time consuming calibration efforts required for microsimulation models. The developed model can be used to guide infrastructure and investment decisions on where such TPTs should be implemented and under what conditions space TPTs should be combined with time TPTs to improve person mobility.

1. Introduction

Managing operations in multimodal transportation systems has become a challenge in an era of connected vehicles and limited resources. The competition of modes with different characteristics introduces many challenges on how to more efficiently improve person mobility for all users by allocating space (i.e., lanes) and time (i.e., signal timing) to the various users.

At the same time the prevalent use of real-time communication systems on transit vehicles has introduced a plethora of

☆ This article belongs to the Virtual Special Issue on “Future Traffic Management”.

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https://doi.org/10.1016/j.trc.2017.12.010
Received 4 December 2016; Received in revised form 2 December 2017; Accepted 13 December 2017
Available online 31 March 2018

opportunities for real-time monitoring and control of multimodal transportation systems and specifically transit that tends to carry more passengers than private vehicles. Connected transit vehicles through Automatic Vehicle Location (AVL) and Automated Passenger Counter (APC) systems provide real-time data on location, speed, and transit vehicle passenger occupancy, facilitating implementation of strategies that can result in more efficient and reliable public transit systems. A widely used application of these technologies are Transit Signal Priority (TSP) strategies (i.e., time Transit Preferential Treatments (TPTs)) and in particular, active TSP strategies that utilize real-time information on transit vehicle location and in some cases, passenger occupancy to provide priority to transit vehicles at signalized intersections. TSP strategies are used in an effort to improve transit travel times and the reliability of the transit system. The most common active TSP strategies are phase extension (i.e., green extension) and phase advance (i.e., early green or red truncation). However, TSP can also be provided through phase rotation or phase insertion.

In addition to optimizing signal timings, recent efforts have also focused on optimal allocation of space. Space TPTs such as dedicated bus lanes (DBL) and queue jumper lanes (QJL) have been used and are often proposed as solutions to improving transit operations since they have the potential to substantially reduce transit delay. DBLs provide transit vehicles with a dedicated lane, while QJLs provide a pocket just upstream of the intersection's stop line that transit vehicles can use to bypass the queue and can be accompanied by an extra transit priority signal phase or not. Advanced technologies can also facilitate space allocation optimization in real-time.

In order to improve traffic and transit operations in urban multimodal transportation systems, while utilizing advanced technologies, it is imperative that TPTs are evaluated both when implemented individually and in combination accounting for the number of passengers that different types of vehicles carry. Models that allow for this type of evaluation are the necessary foundation based on which traffic management strategies and space allocation decisions can be made to improve person mobility. Analytical models based on minimal input requirements that can be easily transferable are therefore necessary to provide insights related to person-based outcomes when certain TPTs are present. This is because, in contrast with microsimulation models, such analytical models provide closed form equations that can be incorporated in mathematical programs to provide optimal signal timings or space allocation decisions. For example, a real-time signal control system that determines optimal splits by minimizing total person delay requires delay predictions for the next cyclefor vehicles detected at some distance upstream of an intersection. Analytical models can be used to provide those delay predictions.

The objective of this research is to develop an analytical model to estimate delay and discharge flow, and therefore, person delay and discharge flow, at intersections that are part of signalized arterials (i.e., platooned car arrivals). This is done while accounting for the presence of TPTs when implemented individually and in combination for both undersaturated and oversaturated conditions. The contributions of this paper are that it develops an analytical model able to estimate person delay and person discharge flow under the presence of both space and time TPTs with minimum input requirements and without the need for extensive calibration efforts and time consuming microsimulation tests. As a result, it allows for computationally efficient comparisons of various transit preferential treatments and their person-based performance, and is easily transferable to any arterial of interest. The proposed model accounts for both undersaturated and oversaturated conditions and is able to handle person delay and person discharge flow estimation under the presence of queue spillbacks. In addition, it can provide a ranking of various TPTs and their combinations when person delay or person discharge flow is the measure of interest. As shown in this paper, these rankings are consistent with rankings that are obtained from microsimulation models. In addition, the comparative and sensitivity analyses that is performed in this study can provide insights on factors affecting the performance of those treatments. Existing studies are either based on microsimulation models that require extensive calibration efforts or have not considered the combined effects of space TPTs and TSP strategies on person-based measures of effectiveness.

2. Background

A comprehensive search of the literature reveals that so far, TPTs have been mostly evaluated with the use of vehicle-based measures of effectiveness (MOEs) such as vehicle delay, vehicle travel time, number of stops, transit delay, schedule adherence, and cross-street delay. Vehicle-based measures focus on the vehicle rather than the person level, while person-based ones such as person delay and person discharge flow allow for a more comprehensive evaluation of treatments used to improve the performance of transit vehicles and the impact of those treatments on all travelers, regardless of their travel mode.

The majority of current studies have investigated the impact of space preferential treatments and TSP strategies on traffic and transit performance, through field and simulation studies. Field studies have primarily focused only on studying TSP strategies (Kloos et al., 1994; Mirabdal and Thesen, 2002; Kittelson et al., 2003; Zheng et al., 2009; Pessaro and Nostrand, 2011), and fewer on intermittent bus lanes (IBLs) (Viegas et al., 2007; Currie and Lai, 2008) or DBLs (Danaher et al., 2007; Surprenant-Legault and El-Geneidy, 2011). Simulation studies have also mostly assessed various types of TSP strategies (Skabardonis, 2000; Chang et al., 2003; Dion et al., 2004; Kamdar, 2004; Rakha and Ahn, 2006; Liao and Davis, 2007; Ekeila et al., 2009; Oliveira-Neto et al., 2009) and fewer of them bus lanes with intermittent priority (Carey et al., 2009), or dedicated bus lanes (Arasan and Vedagiri, 2010; Iswalt et al., 2011; Gonzalez et al., 2013; Truong et al., 2015).

Very few simulation or field studies have investigated the performance of combined space and time TPTs. Sakamoto et al. (2007) investigated the impact of bus rapid transit (BRT) strategies, more specifically a combination of DBLs and TSP through a pilot project on a 3-km corridor in Japan. Lahon (2011) researched the impacts of the combination of QJLs and TSP strategies at six signalized intersections in California through microsimulation, and Zyryanov and Mironchuk (2012) the combination of IBLs and TSP strategies through microsimulation on a two-intersection arterial segment in Russia. Finally, Zlatkovic et al. (2013) investigated the effects of QJLs and TSP strategies when implemented individually and in combination along a signalized arterial corridor in Utah through