International Journal of Transportation Science and Technology 6 (2017) 99–109

Contents lists available at ScienceDirect

International Journal of Transportation Science and Technology

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

Active signal priority control method for bus rapid transit based on Vehicle Infrastructure Integration ☆

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ARTICLE INFO

Article history:
Received 2 February 2017
Received in revised form 1 June 2017
Accepted 4 June 2017
Available online 16 June 2017

Keywords:
Intelligent transportation system
Active signal priority control
Bus rapid transit
Vehicle Infrastructure Integration
VISSIM

ABSTRACT

The implementation of signal priority control to reduce delays of BRT vehicles at signalized intersections is of practical and theoretical significance. In this paper, we propose an active signal priority control method for BRT vehicles that run on median-road exclusive BRT lanes at single intersections based on Vehicle Infrastructure Integration system. This method aims at maximizing average passenger benefit of BRT and other road users, and provides 8 signal priority control scenarios respectively for 8 BRT arrival modes that are based on estimating BRT vehicle travel time and locating arriving time window in a cycle. The delay, energy efficiency and passengers' comfort of BRT vehicles, and community vehicles' efficiency are also being considered. Finally, a model simulation was conducted by VISSIM modeling in a representative signalized intersection with BRT in Jinan City, China. The results indicate that the proposed method reduces average passenger delay by 13.43–25.27% and improves travel speed of BRT vehicles by 7.10–7.55% comparing to existing signal control scenarios. The proposed method is highly promising and can be applied to improve efficiency and safety of BRT at signalized intersections.

Introduction

Bus Rapid Transit (BRT) is a highly effective traffic mode that can relieve urban traffic pressure with its high quality, high efficiency, low energy consumption and low cost when comparing with other traffic modes. However, unlike the subway systems, the operation of BRT is subject to signal timing at the intersections that BRT vehicles travel though. The design of traffic signal phases, circle length and delay is directly affecting the operation quality of BRT.

In the situation of continuously increased car travel ratio and deteriorated urban congestion and exhaust pollution, it is of great practical significance to improve the service quality of BRT with advanced technologies. Vehicle Infrastructure Integration (VII) exactly brings new advances to improve the operational efficiency of BRT. VII is aiming at obtaining and integrating comprehensive transportation information and implementing the coordinated control of people, vehicles and roads in order to improve road capacity and relief traffic congestion, in the utilization of advanced technologies such as large-scale parallel computing and sensor networks. BRT vehicles can be given signal priority when passing through an intersection with VII's implementation of certain signal priority control algorithms such as green extension, red truncation, and special phase insertion, so that the operational efficiency of BRT system can be significantly improved.

Peer review under responsibility of Tongji University and Tongji University Press.

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http://dx.doi.org/10.1016/j.ijtst.2017.06.001
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Despite the great prospects of VII, the application of this technique still has immature parts especially the parts of signal priority control methods and algorithms. Some researches only found numerical methods for signal priority control and systematic results are still in a shortage. Therefore, this study proposes a real-time signal priority control algorithm for single intersections which can achieve the precise priority control of BRT vehicles that run on median-road exclusive BRT lanes, according to the information interaction between the vehicle and the signal controller. The proposed algorithm is based on VII to obtain vehicles information of location and speed precisely so that the travel time of BRT vehicles can be precisely predicted.

Literature review

The increasing proportion of bus rapid transit (BRT) delay at signalized intersections in total travel time has made the field of improving of BRT's level of service (LOS) a research hotspot with practical and theoretical significance. Chen et al. (2008) focused on the design and evaluation of BRT signal priority simulation under mixed traffic flow conditions. Zlatkovic et al. (2012) analyzed different transit signal priorities (TSPs) for a future BRT corridor in West Valley City, Utah to find the optimal TSP strategy from no-TSP, TSP, TSP with phase rotation, and custom TSP strategies. He finally found that Custom TSP would provide major benefits for BRT in travel times, delays, and stops. Alomari et al. (2016) evaluated the performance of various BRT with and without TSP along International Drive (I-Drive) in Orlando, Florida and simulation results showed that TSP and BRT scenarios were effective in reducing travel times (up to 26%) and delays (up to 64%), as well as increasing the speed (up to 47%), compared to the base scenario.

BRT Signal priority contains two critical parts – travel time prediction and active priority control. In the field of travel time prediction, Balke et al. (2000) proposed a prediction model to predict the travel time of a BRT vehicle to arrive at a bus stop and stop line at a signalized intersection, and whether to implement TSP can be determined based on travel time prediction. The results showed a significant decrease of travel time with TSP. Ma et al. (2007) studied the relationships between bus frequency, signal cycle and number of arrival-time-point, and obtained optimal number of arrival-time-point by analyzing their effects on the deviation of bus average delay and headway. Kim and Rilett (2005) developed an improved TSP algorithm that explicitly considers the prediction interval to reduce the negative impacts of nearside bus stops. They used weighted-least-squares regression models to estimate bus stop dwell time and the associated prediction interval, and tested the proposed TSP algorithm on a VISSIM model. It was found that the proposed TSP algorithm improved bus operations without statistically significant impacts on signal operations. Kumar et al. (2015) proposed a model-based algorithm motivated by the Kalman filter identifying the optimum inputs to predict bus travel time using GPS data. A case study was conducted on two selected bus routes in the city of Chennai, India and the results obtained from the algorithm are promising and showed the prediction accuracy to be within ±5 min for a prediction window of 30 min during 92% of the instances.

In the field of active priority control, Yang et al. (2001) proposed a bus signal priority control method within fixed cycle. The proposed method determines green time of each phase by minimizing total passenger delay. Ling and Shalaby (2004) proposed an adaptive traffic signal priority strategy based on Reinforcement Learning (RL). The RL conducts priority by allowing transit vehicles to recover to the scheduled headway. Janos and Furth (2002) developed a bus priority control strategy that responds quickly to and recovers quickly from priority interruptions, which is applicable to the case of high bus arrival frequency. Nichols and Bullock (2004) analyzed the upper bound of benefits brought by active bus priority. To reduce the impact of TSP on community vehicles, Balke et al. (2000) and Wu et al. (2013) used real-time GPS data of bus to predict arrival time to stop line at intersections and stops, and accordingly determine whether to switch priority phase for buses. Wang et al. (2014) established a cooperative bus priority system in connected vehicle environment. The system was deployed and validated at an intersection with two adjacent bus stops in the city of Taicang, China, and the results indicated that the proposed system could reduce travel time and decrease the number of stops. Zeng et al. (2014) proposed a stochastic mixed-integer nonlinear program (SMINP) model to implement real-time TSP control.

It can be seen from literature review that many researches focused on models or algorithms of bus priority that are developed using numerical or simulating methods, which have not yet form systematic results. For example, the lack of implementing technology or application scenarios prevents priority algorithms from being directly applied to real operation situation of BRT system. Besides, the researches are not adequate with regard to coordination between public transit and community vehicles. BRT priority can make a significantly negative impact on community vehicles in some cases, even result in crashes that are evitable without priority.

Active BRT signal priority control method

Basic considerations of active BRT signal priority control method

Real-time location and timetable deviation of BRT can be directly obtained from GPS system equipped on each BRT vehicle, so that priority control can be implemented according to schedule adherence of BRT. The proposed priority control method is based on the following considerations.