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Development of model-based transit signal priority control for local arterials

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Abstract

This paper presents a transit signal priority (TSP) model designed to benefit both bus riders and passenger-car users. Most of conventional priority methods are applied at the isolated intersection. However, this kind of control strategies may failed to reduce the travel time since the prioritized buses have to stop at the downstream intersections. Therefore, along the line of headway-based research, this study intends to develop a new TSP control approach with the concerns of bus passenger delay on the entire arterial. Moreover, a basic method for queue length estimation is presented to evaluate the impacts of TSP control on passenger cars. The control objective is to minimize bus passenger waiting time at the downstream bus stop, simultaneously ensuring the total person delay of entire intersection is not increased. Using the microscopic simulation, the proposed strategy has shown its benefits in reducing bus passenger waiting time and total intersection delay.

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Keywords: bus signal priority control, headway-based bus operation, bus sequence, local arterial

1. Introduction

As one of the most effective strategy to relieve traffic congestion, public transit operation has received a lot of attentions during the past decades. To improve the regularity or punctuality of transit service so as to attract more passengers, transportation researchers and transit agencies have devoted great efforts to develop advanced transit systems, which aim to decrease the bus delay when passing intersections. Abkowitz et al. (1978) concluded many dynamic control strategies to improve bus service, such as transit signal priority, holding control, skipping stops, speed modifications, schedule adjustments, and express service. These strategies are typically appropriate for

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correcting disruptions that have already experienced, or for preventing propagation and further service degradation. Among those mentioned strategies, TSP control has been proved as the most economic and easily implemented strategy in real-world applications.

Wilbur Smith Associates and the Bureau of Traffic Research in the Los Angeles Department of Transportation first conducted bus preemption experiment and reduced bus travel time (Wilbur, et al., 1968). Subsequently, unconditional priority strategies (Yagar & Han, 1994; Skabardonis, 2000; François & Hesham, 2005; Zhou & Gan, 2009) have been designed to priority to all detected buses to reduce bus travel time. The control logic is quite simple and easily implemented without considering real-time bus operation. Meantime, other researchers have also developed conditional priority strategies (Hounsell, et al., 2000; Janos & Furth, 2002; Kenny & Amer, 2004; Satiennam et al., 2005; Ma & Yu, 2007; Hounsell et al., 2008; Altun & Furth, 2009; He, et al., 2011; Hounsell & Shrestha, 2012) based on priority rules considering bus readiness. These methods need to collect the real-time bus operation and location using Automatic Vehicle Location (AVL) system and real-time Bus Operation Management (BOM) system.

Recently, the priority strategies based on models have been proposed to minimize the total delay of all detected buses (Larry, et al., 2006; Ma, et al. 2010; Ma, et al., 2011), the total vehicle delay (Mirchandani et al. 2001; Eleni & Alexander, 2011; Li et al. 2011), and the total person delay of buses and passenger car (Chang, et al., 1996; He, et al., 2003; Vasudevan, 2005; Wu, et al., 2012) according to real-time bus operation and traffic condition. These are usual conditional methods, and consider bus readiness and the effects of passenger cars.

Despite the large amount of existing TSP methods, most of them are implemented for schedule-based bus services. However, a few methods to improve bus regularity for headway-based service are reported in the literature. Hounsell et al. (2000) introduced a ruled-based bus priority method which granted priority to late bus based on headway between current bus and the last preceding bus. Ling & Shalaby (2004) used reinforcement learning to determine the best duration of each signal phase based on bus headway deviation from schedule. Hounsell et al. (2008) summarized how bus priority at traffic signals works within iBUS in London, and then explored the effects of GPS locational errors on bus priority benefits. Grant bus priority based on headway deviation, which is calculated by comparing scheduled headway to actual headway. Altun & Furth (2009) presented a combination method including bus-hold at a stop and conditional signal priority for late buses to make buses uniform. Hounsell & Shrestha (2012) presented a new approach to grant bus priority based on headway-based service. Priority criteria is that forward headway is higher than backward headway; otherwise, non-priority. Later, Lin et al. (2013) presented a model-based TSP control with the variable priority time technique under isolated intersections to reduce the passenger waiting time at the next stop.

This study will follow the line of TSP under headway-based service and extend the research to account the additional operation manner on local arterials. Compared with the isolated intersection control, the operated buses can encounter much more complicate situation along arterials. For example, the bush with granted priority at upstream intersection can lost its efficiency due to the existing of bus stops between two intersections. And the unpredictable of bus dwelling time can result to the delay at downstream intersection. To response to such need and effectively and practically grant TSP to buses on the arterial, the paper will address those listed issues:

[1]. Design a model-based TSP method to handle multiple priority requests with different bus sequence based on headway bus service;

[2]. Estimate the benefit for bus passenger at the next bus stop, in-bus passengers and passenger-car users on the arterial before and after TSP control to determine the optimal priority time; and

[3]. Design the system framework and present a simplified solution to implement the proposed model.

This paper is organized as follows, in the following section, the problem nature along with our research background in introduced in detail; the third section presents the model development process and describes the computation of each important factor; given a real-world case, the numerical example section implements the proposed control model for evaluation; some conclusions are provided in the last section.

Nomenclature

$h_f(r,k,i)$	Actual forward headway of bus *k* on route *r* at stop *i* before TSP control
$h_b(r,k,i)$	Actual backward headway of bus *k* at stop *i* before TSP control
$d_w^B(r,k,i)$	Average bus passenger waiting time for bus *k* arriving at the next stop *i* before priority
$\Delta d_w^B(r,k,i)$	Average bus passenger waiting time for bus *k* arriving at the next stop *i* after priority
$n_w^B(r,k,i)$	Number of bus passengers at the next stop *i*
α_r	Accuracy of bus headway estimation ($\alpha_r < 1$)
T	Duration of common cycle length at the arterial
$t_{m,p,q}^g$	Green duration for movement *p* during period *q* at intersection m
$\Delta t_{r,k}$	Extra green time to discharge bus *k* through the current intersection m
$a(r,k,i)$	Estimated arrival time of bus *k* at stop *i*
$f(m;t)$	Signal status of intersection *m* at time *t* (1-green signal, 0-red signal)
$L(r,k,m+1)$	Standing time duration of current signal when bus *k* arrives at intersection m+1
$s_r(m,m+1)$	Status indicates whether there is bus stop between intersection m and m+1(1-Yes, 0-No)
$n_t^B(r,k)$	Number of in-vehicle passengers
$d_t^B(r,k)$	Delay reduction in travel time for bus k after TSP control
$I(i;t)$	Set of buses dwelling at stop *i* at time *t*
$N_{I(i;t)}$	Size of set *I*(*i*;*t*)
$C(i)$	Capacity of bus stop
$l(r,k,i)$	Remaining time of bus *k* leaving from stop *i*
$\theta(m,m+1)$	Offset between intersection *m* and *m*+1
$t(m,m+1)$	Average travel time from intersection *m* to *m*+1
v_p	Arrival rate of passenger cars at the prioritized movement (veh/s)
Δt	Duration of extra green time which need to be optimized
Δt	Maximal allowable priority time for the arterial
n^P	Average number of in-vehicle bus passengers
N_{np}^P	Estimated initial queue of passenger cars at the non-prioritized movements (veh)
t_{np}^C	Duration of green time to clear the initial queue (s)
v_{np}	Arrival rate of passenger cars at the non-prioritized movements (veh/s)
TV^B	Unit time value of bus passengers
TV^P	Unit time value of passenger-car users

2. Problem nature

TSP control aims to improve bus operations on the arterial without increasing the total person delay on the arterial. Most of conventional priority methods are applied at the isolated intersection. However, this kind of control approaches cannot improve the regularity of headway-based bus service on the arterial because the prioritized buses have to stop at the downstream intersections. Therefore, along the same line of headway-based research, this study intends to develop a new TSP control approach with the concerns of bus passenger delay on the entire arterial. Specifically, the objectives of this paper are to:

[1]. Handle with multiple priority requests from different routes on the arterial and consider the impacts of bus sequence on the efficiency of TSP control because some buses are ahead and some are behind their schedules as shown in Fig. 1.

[2]. Analyse the effect of downstream bus stop on TSP control. If there is a bus stop at the downstream, prioritized buses discharged into the next stop should not exceed the capacity of bus stop against spillback to the upstream intersection. Otherwise, the goal of TSP on the arterial is to discharge buses through the current and downstream intersections without any stop, which is significantly different from one under isolated intersections.

[3]. Estimate accurate delay reduction in travel time for passenger-car drivers on the arterial by considering whether prioritized passenger cars can continuously traverse the downstream intersection without any stop or not.

This paper will extend traditional TSP approaches at isolated intersections to the local arterial. The TSP strategy with green extension only is employed to implement the priority. The proposed control procedure is demonstrated in Fig. 1 and the detailed description is given as follows:

Step 1. Calculate the maximal allowable duration for green extension in terms of detected traffic demand (Lin et al. 2013);

Step 2. Estimate delay reduction for on-boarding bus passengers in the target arterial segment and ones at bus stops before and after TSP control；

Step 3. Compute the delay variation for passenger-car drivers in the target arterial segment; and

Step 4. Optimize the duration of green extension depending on the given objective function.

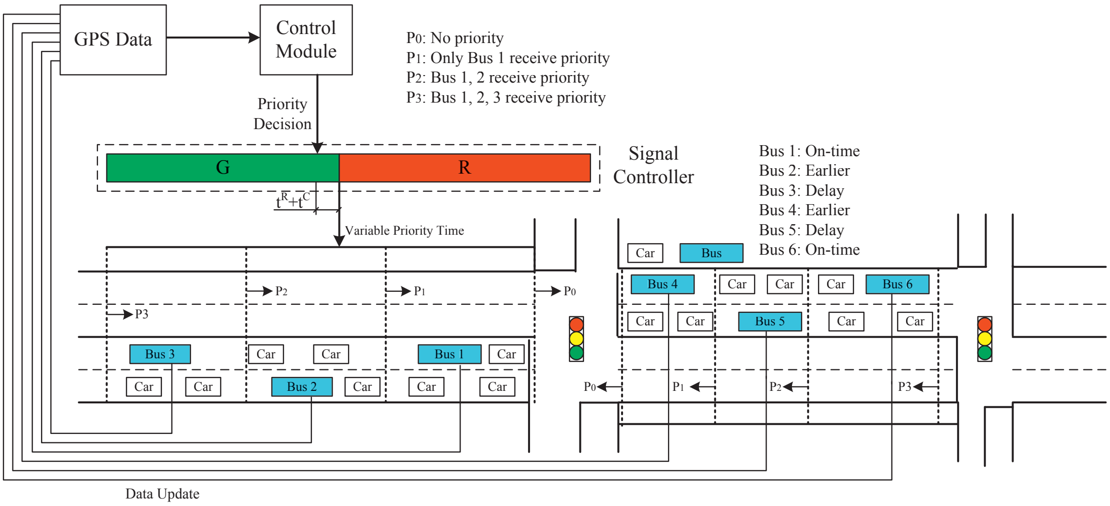


Fig. 1. Control logic of the proposed TSP on the arterial

3. Model development

During the TSP execution period, the affected vehicles can be categorized into three categories: (1) prioritized buses; (2) discharged passenger cars on the priority movements; (3) blocked passenger cars on the non-priority movements. Firstly, one should estimate the delay variation of three kinds of vehicles with TSP control. And then, optimize the duration of green extension to minimize bus passenger waiting time at the next stop without increasing total person delay on the entire network. To estimate delay of affected vehicles, four assumptions are given as follows:

- Only grant the priority to traffic movements on the arterial;
- Extra green time of prioritized movements is equal to truncated green time of straight-through movements on the cross street such as to the common cycle length is unchangeable;
- Green time can clear the initial queue for each movement;
- Passenger cars do not affect buses in the entry into the bus stop or exit from one.

3.1. Bus passenger delay estimation

Bus passenger delay is consisted of on-boarding passengers delay and passenger waiting time at the bus stop. Moreover, if there is bus stop between the target intersection and the downstream, one should consider the capacity of bus stop when giving the priority, particularly ones where there are a lot of multi-overlapped routes.

3.1.1 Passenger waiting time

Under headway-based bus operations, the higher the passenger arrival rate at bus stops is, the higher the departure frequency is. The aim of bus service is to make buses uniform to each stop and avoid bus bunching as much as possible. The estimated headway after TSP control can be calculated by the use of method in the separate paper (Lin et al., 2013). Furthermore, assuming a small headway and randomly arriving passengers along a bus route, the average passenger waiting time at one stop can be estimated with the following equation (Kulash, 1971):

$$d_w^B(r,k,i) = \frac{(h_f(r,k,i))^2 + (h_b(r,k,i))^2}{2(h_f(r,k,i) + h_b(r,k,i))} \tag{1}$$

If bus bunching happens along a bus route, the average waiting time should be estimated according to another equations proposed by authors (Lin et al., 2013). Thus, after TSP control, the total passenger waiting time reduction can be estimated by:

$$d_w^B(\Delta t) = \sum_{r\in R} \alpha_r \sum_{k\in K_r} n_w^B(r,k,i)(d_w^B(r,k,i) - \Delta d_w^B(r,k,i)) \tag{2}$$

where, α_r denotes the accuracy of bus headway estimation with priority. When there is the bus stop at the downstream, $\alpha_r = 1$; otherwise, $\alpha_r < 1$ because it is extremely difficult to estimate the bus arrival time in a long-distance having one or more signalized intersections. Generally, this parameter can be calibrated by the historical data.

3.1.2 In-bus passenger delay

When buses traverse a coordinated arterial, the travel time depends on bus arrival time, bus speed and signal timing on the arterial. Therefore, the TSP control at isolated intersections cannot always reduce the in-vehicle passenger delay. This study presented a method to accurately estimate travel time reduction for on-boarding passengers through continuous two intersections before and after TSP control such as to compute the benefit of TSP control on reducing passenger travel time.

Assuming the coordination of two adjacent intersections is pretty good, one can estimate the in-bus passenger delay reduction by the following equation:

$$d_t^B(r,k) = \begin{cases} T - t_{m,p,q}^g - \Delta t_{r,k} & s_r(m,m+1) = 1 \\ T - t_{m,p,q}^g - \Delta t_{r,k} & s_r(m,m+1) = 0, f(m+1; a(r,k,m+1)) = 1 \\ t_{m+1,p,q}^g - t_{m,p,q}^g - \Delta t_{r,k} + L(r,k,m+1) & s_r(m,m+1) = 0, f(m+1; a(r,k,m+1)) = 0 \end{cases} \tag{3}$$

According to equation (3), total passenger delay reduction can be computed by

$$d_t^B(\Delta t) = \sum_{r \in R} \sum_{k \in R_r} n_t^B(r,k) d_t^B(r,k) \tag{4}$$

3.1.3 *Effect on bus stops*

In the cities having transit oriented development, the overlap of bus routes on the arterial is extremely high. Taking the city of Jinan, China for example, there are more than 15 routes at the stop (36.648434, 117.027074) named “Shungeng Road” on the east-west arterial called Jingshi Road. During peak hours, the number of buses frequently exceeds the capacity of bus stop, especially spillback to upstream intersection. Therefore, one must consider the constraint of the bus stop on capacity against spillback to upstream junction when giving the priority. The set of bus vehicles dwelling at the stop i at time t can be computed by

$$I(i;t) = \{(k,i;t) \mid l(r,k,i) > 0 \text{ and } a(r,k,i) > t\} \tag{5}$$

In order to maintain the benefit for priority buses, the following constraint should be satisfied when giving the priority

$$N_{I(i;t)}(\Delta t) \le C(i) \tag{6}$$

3.2. *Passenger-car users’ delay reduction on the arterial*

At the target intersection, some passenger-cars on the arterial discharged into the downstream during the priority period. Difference from the isolated intersection, time saving of these vehicles with priority depends on whether these can continuously traverse the current intersection and the downstream one or not. Assuming that the arrival rate of passenger cars on the arterial follows a uniform distribution during the green extension period, one can estimate the average person delay reduction on the arterial when receiving priority with transit vehicles can be shown as follows:

$$d_p^P = \begin{cases} T - t_{m,p,q}^g - 0.5\Delta t & \text{if } \Delta t \le t^* \\ \dfrac{t^*}{\Delta t}(T - t_{m,p,q}^g - 0.5t^*) + t^* & \text{otherwise} \end{cases} \tag{7}$$

where, $t^* = t_{m+1,p,q}^g - t_{m,p,q}^g + \theta(m,m+1) - t(m,m+1)$. And then, total person delay reduction on the arterial can be computed by the following equation

$$d_p^P(\Delta t) = n^P d_p^P v_p \Delta t \tag{8}$$

3.3. *Passenger-car users’ delay increase on the cross street*

Extra green time of the arterial is equal to truncated green time of the cross street. Thus, note that the vehicles on the cross street will inevitably experience extra delay with comparisons to no priority. The calculation of the additional delay is based on three kinds of vehicles: ones are from initial queuing vehicles, the second ones are approaching vehicles during the TSP execution period, and the third ones are composed of blocked vehicles which cannot pass the intersection due to truncated green time. The average delay per initial queuing vehicle can be expressed by:

$$d_{np}^{P}(1) = \Delta t \tag{9a}$$

Assuming that the arriving rate of passenger cars to the TSP intersection is uniformly distributed during TSP execution period, the extra average person delay for approaching vehicles can be approximated as follows:

$$d_{np}^{P}(2) = 0.5\Delta t \tag{9b}$$

A partial of vehicles cannot pass the intersection due to the truncated green time will experience additional delay, which can be computed by the following equation

$$d_{np}^{P}(3) = T - t_{m,p,q}^{g}(m) + 0.5\Delta t \tag{9c}$$

In a sum，total person delay increase on the cross street during TSP execution period can be estimated by

$$d_{np}^{P}(\Delta t) = n^{P}[N_{np}^{P} d_{np}^{P}(1) + v_{np}(t_{np}^{C} d_{np}^{P}(2) + \Delta t d_{np}^{P}(3))] \tag{10}$$

In response to the aforementioned concerns, one can calculate the total person delay reduction for those on-board bus riders, those waiting at the downstream bus stops, and those passenger vehicles users at the target intersection during the TSP execution period. The objective function of the proposed model for TSP control can be expressed by

$$\max.\ D = d_{w}^{B}(\Delta t) \tag{11}$$

Constraints:

$$N_{I(i;t)}(\Delta t) \le C(i) \tag{6}$$

$$TV^{B}(d_{w}^{B}(\Delta t) + d_{t}^{B}(\Delta t)) + TV^{P}(d_{p}^{P}(\Delta t) - d_{np}^{P}(\Delta t)) \ge 0 \tag{12}$$

$$\Delta t \le \Delta t_{\max} \tag{13}$$

The proposed TSP control approach will grant a bus priority to the arterial with the extended green seconds to minimize the total bus passenger waiting time with limiting traffic disruptions on the cross street.

4. Numerical example

4.1. Experimental Design

To illustrate the applicability and efficiency of the proposed approach, this paper has employed VISSIM simulation model as an unbiased tool for performance evaluation. Using the VISSIM-COM interface, this study developed a program to simulate bus operations and signal control logic with VB.NET and MYSQL database. During the simulation, the program detects and records the real-time bus locations, automatically computes the time-varying headway of each bus for each route, and adjusts the signal timings according to the bus arriving sequence.

To evaluate the effectiveness of the proposed decision process for buses on the arterial, one selected an arterial with two-way 6 lanes as a test case, and its key traffic and geometry are listed below:

- There are six signalized intersections along the arterial, and only 2 have the function to offer the bus priority function;
- There is no bus stop at the downstream of one intersection having priority function; and the downstream of the other has a bus stop;
- The length of the arterial is about 6km;
- The volume and capacity ratio (v/c) is about 0.7;
- The mean headway is about 6 min;

- There are 10 bus routes in two directions;
- No bus exclusive lane is available on the arterial;
- The duration of simulation time is about 2700 seconds;
- The equivalent passenger number for bus and passenger-car is 30 and 1 per vehicle, respectively;
- The time value of bus passengers and passenger car users is 0.7 and 1.0, respectively.

4.2. Experimental Results

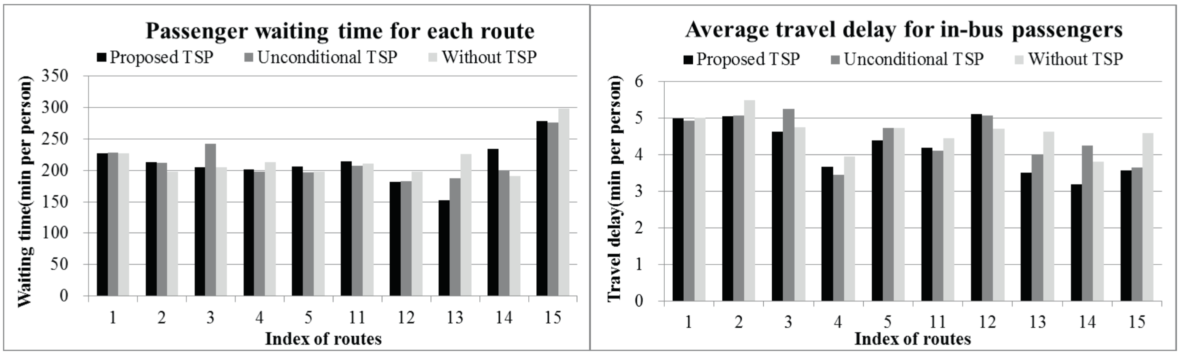
For control efficiency and convenience of case illustration, this study evaluates the developed TSP control method with the following three scenarios:

- Scenario 1: without TSP control;
- Scenario 2: Unconditional priority with 15s green extension); and
- Scenario 3: Proposed TSP control.

Some performance indexes are employed to validate the proposed approach: passenger waiting time, in-bus passenger travel delay on the arterial, passenger-car users' delay, and total person delay of the entire network as shown in Fig. 2. Some key findings are summarized below:

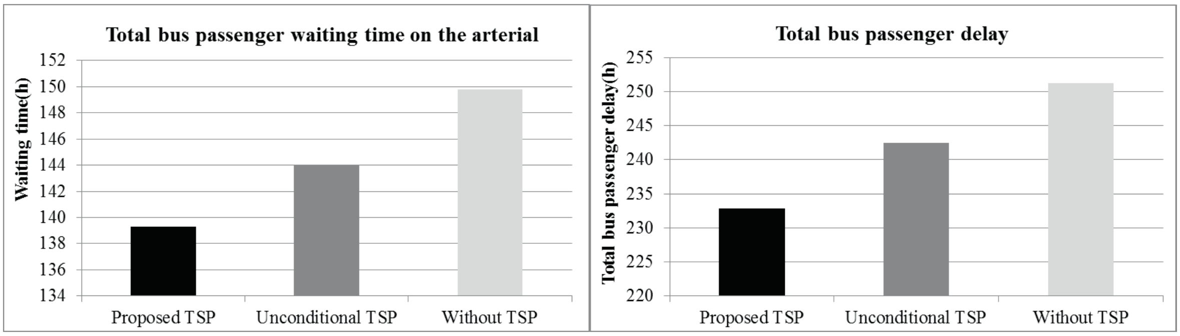
1. The proposed TSP control can outperform unconditional control according to delay reduction in passenger waiting time (3.3%), in-bus passenger travel delay (5.1%), passenger-car users' delay (about 4.4%), and total person delay on the network (about 4.2%). Despite the indifference in average headways among these three controls, bus passenger travel time reduction with the proposed strategy is far less than that under the other two methods, in particularly for routes 13, 14 and 15; and

2. The proposed control method concurrently considers the impacts of TSP priority on buses and passenger cars on the arterial. Therefore, it can also achieve a better performance with response to reduction on bus passenger delay and total person delay to traverse the arterial. Compared to the approach of "unconditional priority", the proposed model can reduce the average waiting time and in-bus passenger travel time. The reason is that some on-time or ahead of time buses are enforced to obtain priority under the "priority to all buses" scenario, and the prioritized buses can arrive at bus stop on time or traverse the downstream intersection as soon as possible. Moreover, the total person delay for the entire network can be reduced during the TSP execuation period since the TSP with the strategy of "unconditional priority" may bring significant impacts on cross-street traffic flows by comparing to the developed method in this paper.



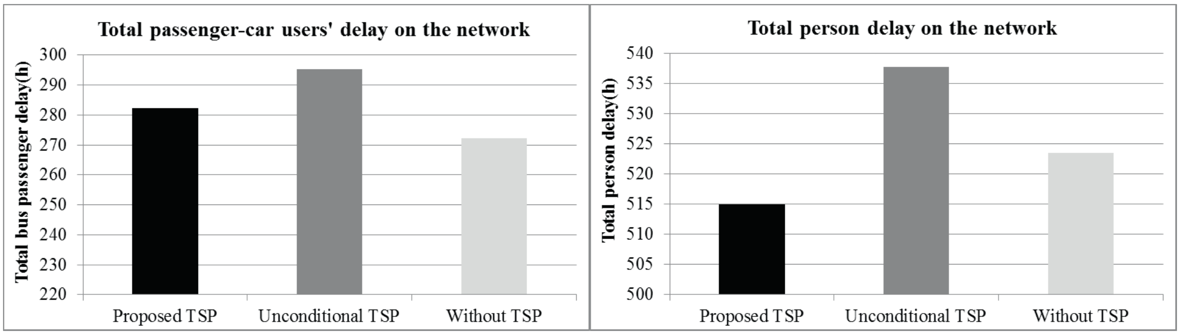
(A) Bus passenger waiting time for each route

(B) In-bus passenger travel delay on the arterial



(C) Total bus passenger waiting time

(D) Total bus passenger delay



(E) Total passenger-car users’ delay on the network

(F) Total person delay on the network

Fig. 2. Comparisons under three TSP control methods

5. Conclusions

This paper presents a headway-based TSP control system for multiple bus requests from different routes on the same movements. The objective of proposed model is to minimize the passenger waiting time at the next bus stop without significantly causing disruptions to the crossing street. The proposed model utilizes the variable priority time technique to determine the duration of green extension for each intersection having priority function depending on the total person delay estimation by considering the impacts of the downstream signal controller. Simulation-based evaluation clearly shows that the proposed TSP control for the arterial can significantly provide some benefits to transit vehicles by the cost of few cross-street passenger delay increase.

Future study along this line will address the following two issues: 1) conduct more extensive experiments or field tests to validate the reliability and effectiveness of the TSP control under various geometry configurations and traffic demand patterns; and 2) use the bus dwelling time at stops and GPS bus location data to design a bus progression control system on urban arterials.

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References

Kulash, D. (1971). "Routing and scheduling in public transit systems," dissertation presented to Massachusetts Institute of Technology, at Cambridge, Mass., in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abkowitz M., et al. (1978). Transit service reliability. Report No. UMTA-MA-06-0049-78-1, U.S. Dept. of Transp., Washington, D.C., Dec.

Wilbur Smith and Associates, Westinghouse Airbrake Co., and Institute of Public Administration. (1968). Study of Evolutionary Urban Transportation, Volumes I, II and III. U.S. Department of Housing and Urban Development.

Hounsell N., and B. Shrestha. (2012). A New Approach for Co-operative Bus Priority at Traffic Signals. *IEEE Transactions on Intelligent Transportation Systems*, pp. 6-14, Vol. 13, No. 1.

Zhou G., and A. Gan. (2009). Design of Transit Signal Priority at Signalized Intersections with Queue Jumper Lanes. *Journal of Public Transportation*, Vol. 12, No. 4.

François D. and R. Hesham. (2005). Integration Transit Signal Priority with Adaptive Traffic Signal Control Systems, presented at 84th Annual Meeting of the Transportation Research Board, Washington, D.C.

Skabardonis A. Control strategies for transit priority. (2000). Transportation Research Record: *Journal of the Transportation Research Board*, No. 1727.

Yagar S. and B. Han. (1994). A procedure for real-time signal control that considers transit interference and priority. *Transportation Research B* 28(4), pp.315-331.

He Q., K.L. Head, and J. Ding. (2011). Heuristic Algorithm for Priority Traffic Signal Control. Transportation Research Record: *Journal of the Transportation Research Board*, No. 2259, pp.1-7.

Ma W., X. Yang, and Y. Liu. (2010). Development and Evaluation of a Coordinated and Conditional Bus Priority Approach. Transportation Research Record: *Journal of the Transportation Research Board*, No. 2145, pp. 49-58.

Head L., D. Gettman, and Z. Wei. (2006). Decision Model for Priority Control of Traffic Signals. Journal Transportation Research Record: *Journal of the Transportation Research Board*, No. 1978, pp. 169-177.

Ma W., Y. Liu, H. Xie, and X. Yang. (2012). A Dynamic Programming Approach for Optimal Signal Priority Control with Multiple High-frequency Bus Requests, *Journal of Intelligent Transportation Systems*. (accepted).

Eleni C., A. Skabardonis. (2011). Traffic Signal Optimization with Application of Transit Signal Priority to an Isolated Intersection. Transportation Research Record: *Journal of the Transportation Research Board*, No. 2259, pp. 192-201.

Li M., Y. Yang, W.B. Zhang, and K. Zhou. (2011). Modeling and Implementation of Adaptive Transit Signal Priority on Actuated Control Systems. *Computer-Aided Civil and Infrastructure Engineering*, 26, pp. 270-284.

Mirchandani P.B., A. Knyazyan, K.L. Head, W. Wu, (2001). "An Approach towards the Integration of Bus Priority, Traffic Adaptive Signal Control, and Bus Information/Scheduling Systems." *Journal of Scheduling*, Vol. 505, pp. 319-334.

Wu G., L. Zhang, W.B. Zhang, and M. Tomizuka. (2012). Signal Optimization at Urban Highway Rail Grade Crossings Using an Online Adaptive Priority Strategy. *Journal of Transportation Engineering*, Vol. 138, No. 4.

Vasudevan M. (2006). Robust optimization model for bus priority control under arterial progression. Ph. D. dissertation, University of Maryland, College Park, MD.

He S., Z. Li, and D. Xiao. A research on strategy of bus priority. (2003). Proceedings of Intelligent Transportation Systems, Vol. 2, pp. 1324-1328.

Altun S.Z., and Furth P.G. (2009). Scheduling Buses to Take Advantage of Transit Signal Priority. Transportation Research Record: *Journal of the Transportation Research Board*, No. 2111, pp. 50-59.

Hounsell N.B., B.P. Shrestha, J.R. Head, S. Palmer, T. Bowen. (2008). The way ahead for London's bus priority at traffic signals. *IET Intelligent Transport Systems*, Vol. 2, No. 3, pp. 193-200.

Ma W., and B. Yu. (2007). Serve Sequence Optimization Approach for Multiple Bus Priority Requests Based on Decision Tree. Proceedings of the Seventh International Conference of Chinese Transportation Professionals Congress.

Satiennam T., T. Muroi, A. Fukuda, and S. Jansuwan. (2005). An Enhanced Public Transportation Priority System for Two-lane Arterials with Nearside Bus Stops. Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 5, pp. 1309-1321.

Ling K. and A. Shalaby. (2004). Automated Transit Headway Control via Adaptive Signal Priority. *Journal of Advanced Transportation*, Vol. 38, No. 1, pp 45-67.

Janos, M. and P. G. Furth. (2002). Bus priority with highly interruptible traffic signals: simulation of San Juan's Avenida Ponce de Leon, Transportation Research Record: *Journal of the Transportation Research Board,* No. 1811, pp. 157-65.

Hounsell, N.B., F.N. McLeod, K. Gardner, J.R. Head, and D. Cook. (2000). Headway-based bus priority in London using AVL: first results. Tenth International Conference of Road Transport Information and Control, pp. 218-222.

Kimpel T.J., J. Strathman, R.L. Bertini, and S. Callas. (2005). Analysis of Transit Signal Priority Using Archived TriMet Bus Dispatch System Data. Transportation Research Record: *Journal of the Transportation Research Board*, No. 1925, pp. 156-166.

Lin Y.J., X.F. Yang, G. L. Chang, and N. Zou. (2013). Transit Priority Strategies for Multiple Routes under Headway-based Operations, presented at 92th Annual Meeting of the Transportation Research Board, Washington, D.C..