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Citation for the original published paper (version of record):
Ghanbarikarekani, M., Zeibots, M., Qu, X. et al (2020). Minimizing the stop time of private vehicles at intersections with LRT signal priority systems. Transportation Research Procedia, 48(2020): 939-945. http://dx.doi.org/10.1016/j.trpro.2020.08.112

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Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 48 (2020) 939–945

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research – WCTR 2019, Mumbai, 26-30 May 2019

Minimizing the stop time of private vehicles at intersections with LRT signal priority systems

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Abstract

There are some strategies suggested to improve the performance of intersections and increase the demand for public vehicles by prioritizing them. To this end, several methods have been used such as Transit Signal Priority (TSP) system for Light Rail transit (LRT). LRT signal priority is a timing strategy that gives priority to LRTs at signalized intersections through changing the sequence of phases, extending green time and reducing red time at LRT's phase. In this paper, we propose a model to improve LRT signal priority systems. The developed model minimizes the green extension and red reduction of LRT's phase by estimating an optimal speed for LRTs reaching the stop line. Consequently, the priority of LRTs would be maintained while the performance of private vehicles would be improved by decreasing their stop time.

Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

Developing the infrastructure of public transport systems plays a vital role in moderating traffic congestion in urban areas. One of these improvements is providing public vehicles priority through TSP. TSP is a procedure for traffic signal timing that prioritize public vehicles e.g. bus, tram, and LRT at level crossings. Although implementing TSP has remarkable benefits for public vehicles, it requires specific infrastructure. These requirements include detectors, essential hardware and software for the traffic signal, automated vehicle location (AVL), communication tools, and centers for managing traffic conditions. It should be mentioned that the necessity of each of these

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2352-1465
10.1016/j.trpro.2020.08.112

components is based on the TSP strategies implemented (Li, 2008). TSP is an effective strategy for improving LRTs' functionality. However, this method has some negative impacts on private vehicles in terms of delay, number of stops and travel time due to the extension of red time in their phases. To solve these weaknesses, several policies have been suggested including providing responsive phase sequence, predicting the arrival time of LRT and implementing priority, coordinating traffic signals and real-time policies, adaptive control to traffic condition and demand.

Among studies done for prioritizing the public transit vehicles, some of them are responsive to the traffic condition and demand (Dion & Hellinga, 2002; He et al. (2014), Cesme & Furth, 2014; Asim et al., 2012; Li, 2008). According to the research conducted by Dion and Hellinga (2002), a real-time optimization model depending on traffic conditions was proposed. This model considered two features; firstly, the conflicts in traffic flow caused by transit vehicles due to giving services to passengers; secondly, the number of improvements caused by prioritizing transit vehicles. Their suggested model applied to isolated intersections would reduce delay in both fixed-time and actuated signals. Additionally, their suggested model reduced the delay in fixed time intersections using the implementation of the responsive traffic control. In contrast, the decrease of delay at actuated intersections achieved through the model by prioritizing transit vehicles.

Yagar and Han (1994) provided responsive phase sequence for prioritizing the transit vehicles, which was based on rule decisions, and then the signal orders were investigated. Finally, they showed that this method reduced the total delay in comparison to the fixed-time signal.

These days, controlling through coordinating the actuated signals and implementing the signal priority systems are fundamentally used, even though they have a conflict with each other. One way to solve this problem is providing priority for transit vehicles by letting them send signal while approaching the intersections. On the other hand, this may cause a crash in the arriving vehicles at the intersection. In order to eliminate this crash, He et al. (2014) presented real-time policies and the signal coordination. Moreover, their proposed model could decrease the average delay of transit vehicles as well as passenger delay of cars. More specifically, this model would be more efficient in oversaturated conditions and occurrence of remarkable transit vehicles.

Cesme and Furth (2014) explored an innovative model for traffic signal control, which is based on real-time control. The model, which is named "self-organizing signals", has further procedures that make coordination tools. Asim et al. (2012) suggested an adaptive model for actuated signals, which preempts LRT at intersections based on traffic flow and LRT travel time for the sake of minimizing delay, the number of stops, and queue length with providing LRT pre-emption even in congested conditions. Bin (2012) investigated the influence of real-time parameters on the operation of the transit signal priority.

Islam et al. (2016) and Asim et al. (2012) conducted research in the field of prioritizing LRTs at traffic signals. In the study conducted by Islam et al. (2016), three approaches were proposed: providing simple priority for LRT, predicting LRT arrival time and implementing priority, and prioritizing LRTs and buses with estimating the arrival time of LRT. They demonstrated that the second method led to the best results.

TSP strategies could be implemented in order to develop traffic condition at the network level (Bagherian et al., 2015; Ahmad & Hawas, 2015). TSP system has three main strategies:

- Green extension strategy prolongs the green time of the LRT phase once an LRT is detected by the LRT detector in order to let the LRT discharge the intersection.
- Red reduction, that decreases the red time of the phase, which is before the LRT phase; hence, the detected LRT would receive timely green time.
- Changing the sequence of phases when the LRT is detected (Zhou and Gan, 2009).

While this method could improve the performance of the LRT systems through decreasing their delay, travel time, and the number of stops, it would penalize cars in other phases by increasing their stop time. This paper aims to develop an algorithm responsive to the traffic signal at intersection to compute the LRT's speed arriving at the intersection for the sake of minimizing the green extension and red reduction.

Nomenclature

A	Transit Signal Priority (TSP)
B	Light Rail Transit (LRT)
C	green extension
D	red reduction

2. Methodology

This paper aims to prioritize LRTs as well as to minimize the stop time of vehicles in the cross streets. To this end, the speed of the arriving LRT is determined based on the traffic signal timing once the LRT is passed through the detector located at a specific distance from the stop-line. In this case, LRTs would reach the stop-line when the minimum green extension or red reduction is needed. Consequently, stops and delay of other vehicles in other approaches would be minimized.

Several parameters need to be determined in order to formulate the model. The first Parameter is the location of installing the detector ($L_{detector}$), which is calculated by Eq 1. It is needed to install the detector on the LRT route near the stop line to detect the existence of the LRT immediately. The mentioned detector must be located upstream of the stop-line in a required distance that could be applied to adjust and implement the appropriate speed of arriving LRT (As shown in Fig. 1).

$$L_{detector} = Max\,[\frac{V_{Max,LRT}^2 - V_{current,LRT}^2}{2a_{LRT} \times 3.6^2}, \frac{V_{\min,LRT}^2 - V_{current,LRT}^2}{2a_{LRT} \times 3.6^2}] \quad (1)$$

$L_{detector}$ is the required distance (m) from the stop-line for installing the LRT detector for the sake of determining the arriving LRT, a_{LRT} is the usual acceleration and deceleration of LRT systems (m/s2), which is assumed 1.32 m/s2 (RTSA presentation, 2014). $V_{Max,LRT}$, $V_{\min,LRT}$, and $V_{current,LRT}$ are respectively the maximum, minimum, and current speed of LRTs (km/h).

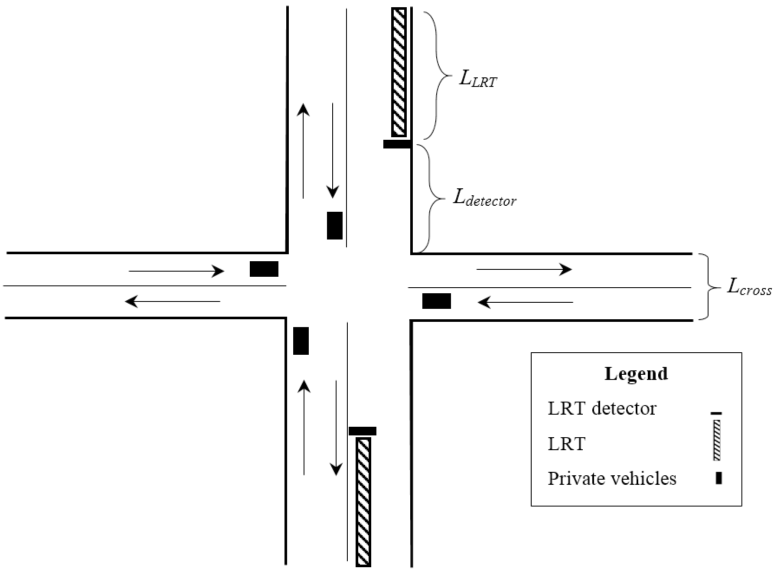

Fig. 1. The positioning of the LRT's detectors upstream of the stop-line on LRT route

Second parameter needs to be determined is the traffic signal of LRT approach when the LRT is being detected, whether it is green (G_{LRT}) or red (R_{LRT}).

The other parameters are the duration of green time (G_{LRT}) or red signal (R_{LRT}) at the time that the LRT is being detected, which is determined as the percentage of the total duration of green or red. (α is the percentage of green duration in LRT phase, and β is the percentage of red duration in LRT phase).

Other parameters are t_1 and t_2 , which are respectively the required time (sec) for the LRT to increase/decrease its speed in order to pass the intersection within the remaining green / red time and its extension/reduction, and the required time (sec) for the LRT to pass the intersection with its increased/decreased speed within the remaining green / red time and its extension/reduction. To formulate the algorithm, it is also essential to have L_{LRT} (the length of LRT (m)), and L_{cross} (the width of the cross street (m)).

In order to compute the appropriate speed of LRTs in prior to the intersections with an actuated signal to minimize the green extension or red reduction at LRT's phase. First part (Eq. 2 to 7) elaborates the procedure required for calculating LRTs' speed when the LRT is detected by the detector and its signal is green.

Objective function:

$$F(x) = \min\,[G_{extension}] \tag{2}$$

Subject to:

$$10km/h \le V_{suggested} \le 30km/h \tag{3}$$

$$0\sec \le G_{extension} \le 20\sec \tag{4}$$

$$0.1 \le \alpha \le 1 \tag{5}$$

To determine the LRT's speed through minimizing the duration of green extension, the LRT's travel time needed for going through the intersection from the detector should be calculated (Eq. 6). This time is the time for increasing the LRT's speed at the detector, and the time for continuing its way with the suggested speed to pass through the intersection (Eq. 7).

$$\frac{1}{2}at_1^2 + V_0 t_1 + V_{suggested} t_2 = L_{\det ector} + L_{cross} + L_{LRV} \tag{6}$$

$$t_1 + t_2 = \alpha\, G_{LRV} + G_{extension} \tag{7}$$

Second part (Eq. 8 to 13) formulates the model for estimating LRTs' speed when the LRT is detected by the detector and its signal is red. Same as estimating the minimum green extension, reducing the red signal of LRT's phase is done using optimizing the speed of LRT. This method is used when an LRT is detected in the red signal.

Objective function:

$$F(x) = \min\,[R_{reduction}] \tag{8}$$

Subject to:

$$10km/h \le V_{suggested} \le 30km/h \tag{9}$$

$$0\sec \le R_{reduction} \le 20\sec \tag{10}$$

$$0.1 \le \beta \le 1 \tag{11}$$

For the sake of determining the speed through minimizing the duration of red reduction, the travel time of the LRT for reaching the stop line from the detector has to be calculated. Therefore, the time needed decreasing the speed of the LRT at the detector, and the time required for continuing its way to reach the stop line would be estimated.

$$-\frac{1}{2}at_1^2 + V_0 t_1 + V_{suggested} t_2 = L_{detector} \tag{12}$$

$$t_1 + t_2 = \beta\, R_{LRV} - R_{reduction} \tag{13}$$

3. Results and discussion

The proposed model needs to be analyzed numerically using an example of intersection with transit signal priority for LRTs. In this case, the condition of applying the model would be demonstrated by comparing the results. For the sake of analyzing this model, some assumptions have been assumed which are presented in Table 1. More specifically, these assumptions include the duration of green and red time, the maximum, minimum and average speed of LRTs, the acceleration and braking rates of LRTs, the length of LRT and the width of the cross street. $L_{detector}$, t_1 and t_2 could be calculated using the mentioned parameters (assumed in Table 1) and the equations (proposed in the previous section).

Table 1- Assumptions for parameters used in the model

Parameters	Values
Green duration of the LRT phase (G_{LRT})	30 s
Red duration of the LRT phase (R_{LRT})	90 s
Current speed of LRT (V_0)	30 km/h
$L_{detector}$	160 m / 30 m
L_{cross}	14 m
L_{LRT}	30 m
α	0.5
$G_{extension}$	0 s
β	0.5
$R_{reduction}$	0 s

According to the parameters shown in Table 1, this model paves the way for determining the LRT's speed required for reaching the intersection. More specifically, the speed calculated through the model would be the optimum speed for the LRT to pass through the intersection with the minimum green extension or red reduction. Hence, the number of stops, delay and travel time of private vehicles in other phases would be minimized. It has to be noted that the speed would be optimized through determining the minimum green extension or red reduction needed, and the percentage of the remained green or red time once the LRT is detected. Moreover, the acceptable limitations for applying the proposed model could be achieved using the assumptions and the calculations output presented in Table 1. In order to illustrate the procedure and result of implementing the modifying model, Figures 3 and 4 are presented. The figures depict the estimated speed for LRT, respectively, with the minimum green extension when $\alpha = 0.5$ and the minimum red reduction when $\beta = 0.5$.

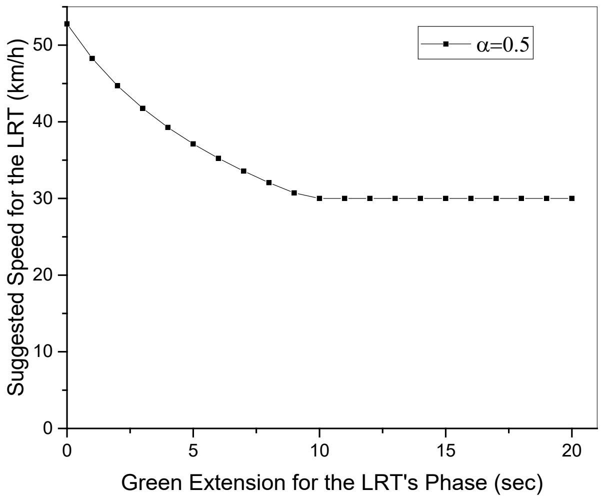

Fig. 2. Sample of calculating the optimum speed for the LRT by minimizing the green extension of the LRT's phase when $\alpha = 0.5$

According to Fig. 2, the optimum speed of the LRT is 53 km/h without extending green time. In other words, if the LRT moves in lower speed, more green extension should be implemented. As the maximum acceptable speed of LRTs is 30 km/h, the minimum green extension would be 10 s.

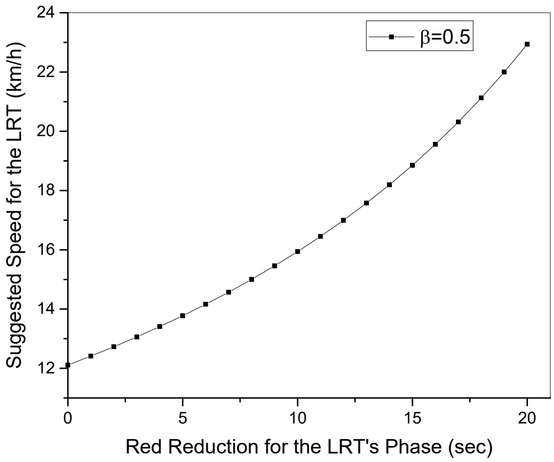

Fig. 3. Sample of calculating the optimum speed for the LRT by minimizing the red reduction of the LRT's phase when $\beta = 0.5$

As it is shown in Fig. 3, the appropriate speed of the LRT that needs no red reduction is 12 km/h. In other words, the amount of red reduction should be increased if the LRT moves in higher speed, which could cause much more delay in other phases. Consequently, applying the proposed model would prioritize LRT systems while the drawbacks of TSP on other phases are minimized.

4. Conclusion

Public transportation systems have been taken into consideration as a fundamental solution for solving traffic congestion in urban areas. More specifically, several strategies proposed for the sake of improving the functionality of public transport. Among transit systems, LRTs have a considerable role in transferring travelers in big cities due to their high occupancy.

LRT signal priority is a policy for signal timing at level crossings, which aims to prioritize LRTs. The LRT signal priority leads to the reduction of the total passenger delay; furthermore, people would be encouraged to use public transit instead of their own private vehicles because of its reliability. Hence, many problems of big cities such as traffic congestion and air pollution would be solved. However, it has to be mentioned that this strategy has some disadvantages for cars. In other words, giving priority to LRTs by changing the sequence of signals and prolonging the red duration of other phases worsen the performance of cars in terms of stop time, delay, and travel time.

This model is proposed in order to alleviate the drawbacks of LRT signal priority systems. As mentioned in the previous section, this model aims to suggest an appropriate speed for LRTs upstream of the stop line. Its objective is based on minimizing the needed green extension or red reduction. Consequently, the priority of LRTs and the optimization of private vehicles' performance would achieve at the same time.

Acknowledgements

The study is supported by the iMOVE Australia and Transport for New South Wales, under grant 5-001/2018.

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