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Assessment on the effect of transit priority strategies on travel time delay at signalized road network having mixed traffic

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Abstract

Transit Priority strategies have been implemented in many cities to improve levels of service for transit passengers and to encourage modal change. This research endeavours to make a quantitative comparison between Dedicated Bus Lane (DBL) and Transit Signal Priority (TSP) to identify the most viable scheme for road network, considering heterogeneous traffic movement and frequent lane changing phenomena. For each priority schemes, 16 different scenarios with varying traffic volume and bus composition, have been simulated with VISSIM for 691,200 simulation seconds in total, to evaluate the effectiveness of priority methods for prevailing traffic conditions in terms of average traffic delay. This paper perceives that TSP is more effective alternative than DBL when share of public transport (PT) in the road network is 12.5% or less, as TSP minimizes delay of overall traffic, at least 10% or in some cases up to 42% more than what DBL does.

Keywords: Transit signal strategies, Dedicated Bus Lane (DBL), Transit Signal Priority (TSP), heterogeneous traffic.

1. Introduction

Urban traffic congestion severely impairs the effectiveness and attractiveness of bus systems (Eichler and Daganzo, 2006). With the development of modern society, traffic congestion problems have attracted considerable attention from a range of scholars (Nagel and Schreckenberg, 1992; Chowdhury, Wolf, and Schreckenberg, 1997; Zhu, Lei, and Dai, 2009; Zhu, 2010). Despite the limited resources, transit agencies have to spend a considerable amount of time and effort to address traffic congestion and reduce traffic delay. Inexpensive solutions that do not involve new infrastructure are the most desirable ones (Eichler and Daganzo, 2006).

With the development of monitoring technology, many cities have introduced Dedicated Bus Lane (DBL) and Transit Signal Priority (TSP) schemes to provide priority to buses at traffic signals for improving the flow conditions of buses (Viegas and Lu, 2001; Nelson, Brookes, and Bell, 1993; Smith, Nelson, Bell, and Dickinson, 1994). TSP remains one of the principle strategies adopted in many towns and cities to improve the levels of service for bus passengers and to encourage modal change (Hounsell, McLeod, and Shrestha, 2004) as it plays an effective role in inducing service regularity especially when buses are late, thus reduces travel time. By a series of detectors or an Automatic Vehicle Monitoring (AVM) system, buses can be located, and the signals can be adjusted to favor bus movements (Viegas and Lu, 2001). In addition, usage of 'virtual' detectors can eliminate the need for an on-street hardware to detect buses and also can provide much more flexibility in the number of detectors and their locations (Hounsell, Shrestha, Bretherton, Bowen, and D'Souza, 2008).

Fig. 1. Eye view of the study area.

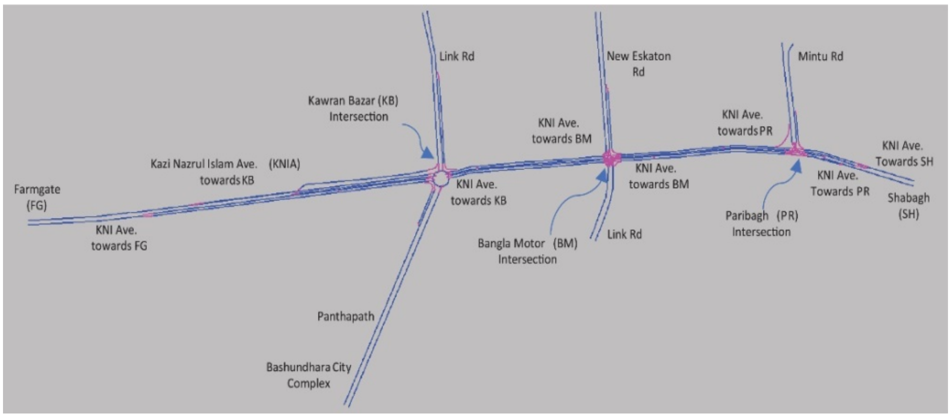

Fig. 2. VISSIM graphical user interface (GUI) of the road network.

Several studies have been conducted to explore bus priority methods in road networks having lane based homogeneous traffic system, which is not the case in Dhaka city, capital of Bangladesh.

According to a study jointly conducted by the Metropolitan Chamber of Commerce and Industry (MCCI) and Chartered Institute of Logistics and Transport Bangladesh in 2010, it was revealed that the annual cost of traffic congestion in capital Dhaka was around Tk 1 billion a day. The study found that about 3.2 million business hours were lost every day due to the traffic jams. A more recent assessment concluded that the estimated loss is now 50% more than what it was in 2010, adding up to a staggering amount of about Tk 550 billion annually (Hossain, 2015). Moreover, heterogeneous traffic flow provides incentive to traffic congestion as the presence of non-motorized vehicles impedes the movement of motorized vehicles due to its lower speed. As bus plays the role of PT in Bangladesh, it is high time to evaluate the effectiveness of priority schemes in the context of prevailing traffic condition of Bangladesh for improving the road network performances.

Phase 1 Phase 2 Phase 3

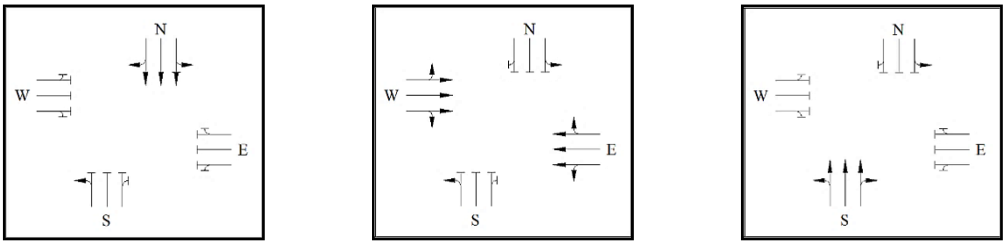

Fig. 3(a). Stage diagram for the signal controls at Kawran Bazar intersection.

Phase 1 Phase 2 Phase 3

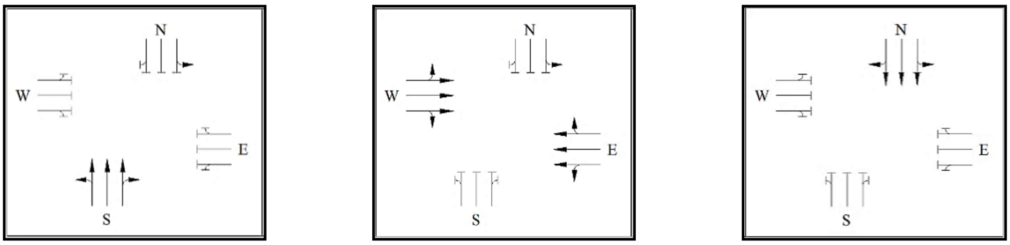

Fig. 3(b). Stage diagram for the signal controls at Bangla Motor intersection.

Phase 1 Phase 2 Phase 3

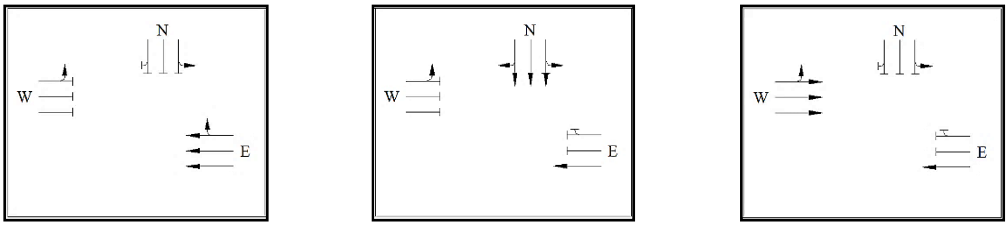

Fig. 3(c). Stage diagram for the signal controls at Paribagh intersection.

Fig. 3. Stage diagram for the signal controls at the intersections.

The study is concerned with the effectiveness of DBL and TSP for local traffic conditions. Evaluation of the performances of DBL and TSP under non-lane based mixed traffic conditions will be assessed on the basis of not only the travel time delay of bus transit but also its effects on overall traffic in the signalized corridor using micro-simulation tool VISSIM, as the evaluation environment.

2. Research background

Extensive studies have been carried out in the context of DBL and TSP for network modeling which have been illustrated below.

2.1 Dedicated Bus Lane (DBL)

Feather, Cracknell, and Forster (1973) demonstrated the bus priority schemes using part-time, with-flow bus lanes. Furthermore, for the implementation of a contra-flow freeway bus lane in urban areas, Levinson and Sanders (1974) developed a person-delay model which quantified the number of buses required for contra-flow bus lane. However, extensive investigation for the performance evaluation of DBL had been conducted based on travel time (Cox, 1975; Tanaboriboon & Toonim, 1983), travel speed (Rouphail, 1984), reliability of Bus (Shalaby &

Soberman, 1994), and modal shift (Choi & Choi, 1995) while Shalaby (1999) examined changes in performance parameters of through buses and adjacent traffic following the introduction of reserved lanes in an urban arterial using TRANSYT-7F simulator. Moreover, Currie, Sarvi, and Young (2007) developed a methodology employing traffic micro-simulation modeling to assess road-space re-allocation impacts, travel behaviour modeling to assess changes in travel patterns and a social cost-benefit framework to evaluate impacts. The study suggested that road-space reallocation would be difficult to be economically justified in road networks where public transport usage is low and car usage is high. Arasan and Vedagiri (2010) studied the impact of the provision of reserved bus lanes on urban roads by developing a microsimulation model of heterogeneous traffic flow. According to the study, if an exclusive bus lane had been provided under the assumed roadway and traffic conditions, then, the mean running speed of buses could be up to 65 km/h (depending on the bus stop spacing and the dwelling times, the corresponding mean journey speed may work out to be about 39.5 km/h) and the mean running speed of the stream of traffic comprising all the other motor vehicles (other than buses) enjoying level of service of C would be 43 km/h. Amongst the recent studies, Ben-Dor, Ben-Elia, and Benenson (2018) carried out MATSim simulations to identify the effects of introducing extra DBL and transforming existing lane into DBL taking into consideration road network and traffic characteristics of the city of Sioux Falls. Results showed that at a reasonable level of congestion, use of public transport (PT) had increased by almost 20%. According to their study, the performance of DBL depended not only on the level of congestion but also on the population size of the city.

Table 1
Detector distance and priority extension time

Intersection	Approach	Average Queue Length (m)	Detector Distance (m)	Estimated Travel Time (sec)	30% Extra to Cover Journey Time Variations (TRG, 2007) (sec)	Priority Extension Time (sec)
Kawran Bazar	N-S	170	150	25	8	33
Intersection	S-N	168	150	25	8	33
Bangla Motor	N-S	153	150	25	8	33
Intersection	S-N	156	150	25	8	33
Paribagh	N-S	130	150	17	7	33
Intersection	S-N	101	100	17	7	24

2.2 *Transit Signal Priority (TSP)*

TSP control developed since the late 1960’s (Smith,1968) has been recognized as one of the most promising ways in reducing bus travel time at local arterial to improve the efficiency and reliability of bus operations. However, Department of the Environment, Transport and the Regions in London (DETR, 1997) provided a number of measures for the priority of buses. Recently, Wahlstedt (2011) focused on impacts of Bus Priority in coordinated traffic signals and he insisted that PT priority would result in shorter travel times for buses and longer travel times for crossing traffic and traffic following the prioritized buses in one direction. Apart from that, a new approach of Cooperative Bus Priority at Traffic Signals was suggested by Hounsell and Shrestha (2012) which suggested that greater regularity benefits could be achieved through a strategy where priority for a bus would rely not only on its own headway but also on the headway of the bus behind (the following bus). According to Chiabaut, Xie, and Leclercq (2012), since the green phases of traffic signals would require accommodating buses as well as the remaining traffic, it would reduce the effectiveness of TSP. Furthermore, Ahmed (2014) evaluated the performance of bus priority at isolated vehicle actuated junctions using green extension, recall and always green for bus and estimated bus travel time savings for placements of detector at different distances before the stop line.

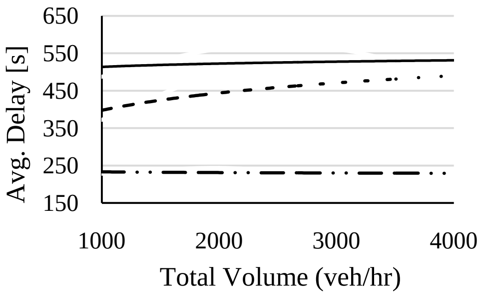

Fig. 4(a). Average Delay per Bus [s]
(Bus Demand – 10% of Total Volume).

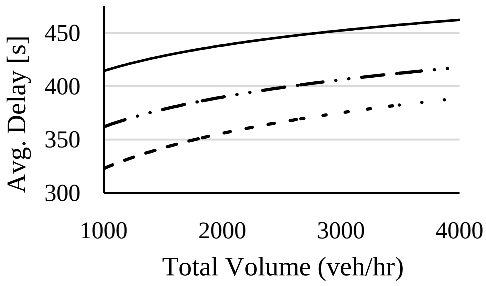

Fig. 4(b). Average Delay per Vehicle [s]
(Bus Demand – 10% of Total Volume).

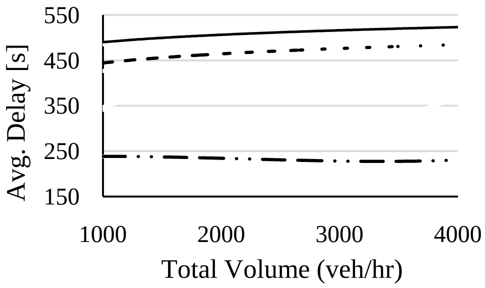

Fig. 4(c). Average Delay per Bus [s]
(Bus Demand – 12.5% of Total Volume).

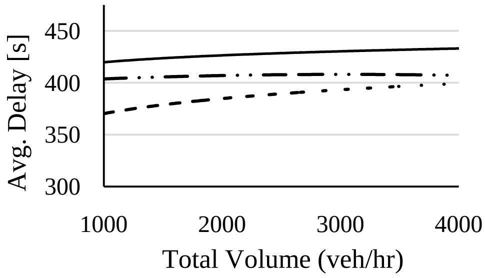

Fig. 4(d). Average Delay per Vehicle [s]
(Bus Demand – 12.5% of Total Volume).

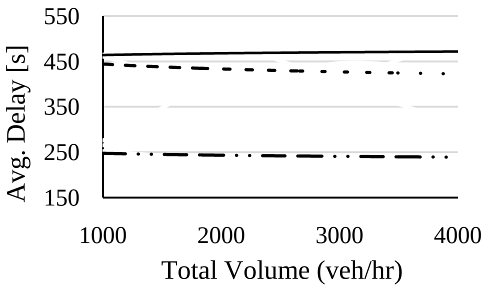

Fig. 4(e). Average Delay per Bus [s]
(Bus Demand – 15% of Total Volume).

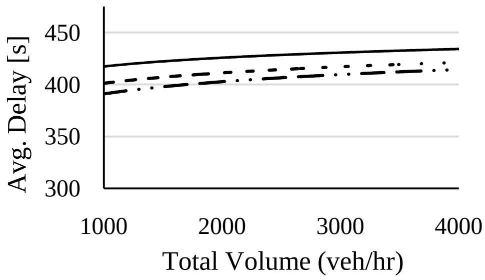

Fig. 4(f). Average Delay per Vehicle [s]
(Bus Demand – 15% of Total Volume).

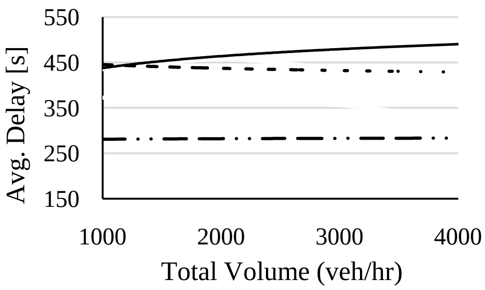

Fig. 4(g). Average Delay per Bus [s]
(Bus Demand – 17.5% of Total Volume).

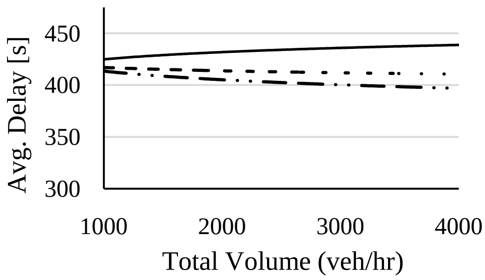

Fig. 4(h). Average Delay per Vehicle [s]
(Bus Demand – 17.5% of Total Volume).

Do Nothing — Transit Signal Priority — Dedicated Bus Lane

Fig. 4. Average delay for different traffic volume and bus demand.

However, between the two above mentioned priority strategies, it is clear that TSP is considered as signalized priority whereas DBL is considered as road space priority in the case of prioritizing transit vehicles. An insignificant number of studies have been done on the suitability and application of such priority schemes in context of developing countries having mixed traffic conditions along with weak lane discipline. Our research shed lights on these facts to make a qualitative comparison between these schemes to find the most viable solution for the developing countries.

To reflect the dynamic nature of the transportation system in a stochastic fashion, microscopic traffic simulation tools are extensively used in research now-a-days (Ahmed, 2014). VISSIM provides various car-following and lane changing model and its simulation results are closer to real world (Ghariani et al., 2014). VISSIM is also considered as a multimodal simulator. In VISSIM, vehicle of various types such as passenger cars, buses, trucks, and heavy and light rail vehicles as well as pedestrians and cyclists can be integrated with the model (Saidallah et al., 2016). It also facilitates to incorporate nonconventional vehicle (rickshaw) which constitutes major proportion of traffic composition of the study area. Moreover, it performs better over other simulating software in the context of modeling complex road network with traffic control and transit elements (Ratrout and Rahman, 2009). The simulation tool utilizes psycho-physical driver model and calculates total delay with respect to each link whereas CORSIM enumerates average delay for each approach (Jones et al., 2004). Besides, time headway can be used in VISSIM which provides more control on bus generation whereas in PARAMICS, generation of bus relies on the distribution. Also, multiple calibration parameters are available in VISSIM to allow the simulated network to replicate the real situation (Ahmed, 2014). In addition, VISSIM is not only user friendly according to Bloomberg and Dale (2000), Thorrignac (2008), Boxill and Yu (2000), Ratrout and Rahman (2009), Kotusevski and Hawick (2009) but also has better visual display capabilities (Barrios, Ridgway, and Choa, 2001; Choa, Milam, and Stanek, 2004; Thorrignac, 2008; Ratrout and Rahman, 2009). So, for modeling a road network having signalized intersections where traffic flow is characterized by heterogeneous traffic and frequent lane changing phenomena, VISSIM model will be most suitable according to illustrations narrated above and previous research.

3. Study area and data collection

To assess the impact of DBL and TSP, Kazi Nazrul Islam Avenue has been considered as the study area. Considerable number of traffic with high percentage of bus generating from the surrounding commercial and industrial zone made this approximately 2.5 km long, a 6-lane major arterial with two four-legged intersection and one 3-legged intersection suitable for research purpose. In Figure 1 and Figure 2, outline of the study area and the coded model of the network have been illustrated respectively. Traffic volume data were collected at two peak hours, morning peak- 8:00 am to 11:00 am and afternoon peak hour- 1:00 pm to 5:00 pm for consecutive 3 days; 2 weekdays and 1 weekend.

4. Signal phasing and control system

All the junctions in the network have Fixed Time Traffic Control and their phases are demonstrated in Figure 3. But in the model, vehicle actuated signal controller has been developed for the application of TSP.

5. Development of model

A microscopic model of the test site has been coded using Verkehr in Staedten simulation (VISSIM 5.30), a psychophysical car-following model-based microsimulation software to represent the traffic and driving behaviours at the intersection and evaluate the performance of the proposed scheme. As there was mixed traffic condition in the site, calibration parameters have been changed accordingly inside the VISSIM. Lane changing behaviour, lateral distances, longitudinal distances have been considered as per the site conditions. The signal phasing sequence along with the red, green time and cycle time was recorded from the site and has been added into the software with the help of VISSIG. Traffic volume, turning movement counts and vehicle composition for each approach have been taken as per the field data. The desired speeds have also been taken from the field observation.

6. Calibration and validation

The geometry of the existing network and other road features have been replicated in VISSIM model to calibrate the model. Two customized link behaviour types have been defined in this regard: (1) roadway capacity reduction adjacent to gas station; and (2) random pedestrian movement at intersection. Moreover, queue formation as per existing condition has also been set in the model. Although there is a foot over bridge at Bangla Motor intersection, some pedestrian still crosses the road abruptly which induces additional delay at this intersection. From the survey, it was found that around fifty (50) pedestrians in an hour use the at-grade road for crossing. Owing to the mixed traffic condition (motorized and non-motorized), it is difficult to enforce lane discipline. Hence, vehicle occupies lateral positions on any part of road based on space availability; fast moving vehicle pass slow vehicles from both sides. So, non-lane-based driving behaviour is modelled to replicate the ground reality. However, traffic simulation model contains numerous parameters to define and replicate the traffic flow in the network, traffic flow characteristics and driver behaviour which have been changed to replicate field measurements and observed conditions.

The calibrated VISSIM model has been further validated against field data independent of the calibration dataset. Three parameters, namely GEH (Geoffrey E. Havers) value, traffic flow and queue length, have been used to validate the base model. GEH value indicates good fit when it is less than 5 (Holm et al. 2007). The values of eleven approach roads of three intersections obtained from five simulations run vary between 0.37-3.92, which can be considered as acceptable. Furthermore, while comparing the observed and simulated traffic, observed traffic were 620 during field survey at New Eskaton Road and for the same road, the simulated model yielded 569 traffic. Moreover, maximum queue length of 170 m was found during the survey and during the simulation run, maximum 202 m queue length has been found to form.

7. Bus priority techniques adopted

To evaluate the applicability of transit priority schemes in the context of traffic conditions in the field, the model has been coded with different volumes ranging from 1000 to 4000 vehicles/hour in the priority approaches as peak hour flows observed in the field had varied in this range. Moreover, it was also observed that bus to total vehicle ratio had varied from 9% to 17% in the study area. As the mobility of urban city dwellers during peak hours increases, so does the demand for the buses. As a result, the number of operational bus increased. This study considers ratio of operational buses to total volume of vehicles as an indicator of bus demand. So, the model has been simulated for different volumes having bus to total vehicle ratio varying from 10% to 17.5% with a sensitivity of 2.5%; a total of 16 scenarios have been assessed to evaluate the performances of the priority strategy regarding delay of bus and all vehicles.

7.1 Do nothing

This scheme is the resemblance of the existing condition. Right of way in each direction has three lanes with no road space priority or signalized priority. All the intersections in the study area practice fixed time traffic control system. Model has been simulated with the traffic data obtained from the site.

7.2 Dedicated bus lane

Our study has integrated DBL strategy in mixed traffic condition, in which the right lane is reserved for buses as it was mostly followed in the earlier research (Patankar, Kumar, and Tiwari, 2007). In comparison with traditional bus services, fewer bus stops may be constructed to speed up bus operations (Li et al., 2009). The spacing of stations along bus lane ranges from 600 to 6000 meter, enabling buses to operate at high speeds. (Jepson, and Ferreira, 2000). As in our test site, the distance between consecutive bus stops was found to be 2000 m, which is greater than the length of the prioritize lane of 2 km, so there is no necessity for modeling any bus stops. In addition to that, our research is much focused on the mobility of the transit vehicles rather than the reliability of the bus at the stops.

7.3 Transit signal priority

For incorporating vehicle actuated signal controller and various bus priority strategies, VAP and VisVAP interfaces have been used. Research conducted by Ahmed (2014) has suggested that if green extension is adopted as TSP only, with the increase of detection distance of buses from stop line, travel time savings escalate. The study also proposed that even though benefits from recall would be much higher compared to green extension with usual detection, it would have negative impact on general traffic. However, TSP, having both green extension and recall being implemented together, would incur traffic flows on non-prioritize approaches if the flow is very high in those approaches. Our study has adopted only green extension as transit priority scheme due to the fact that there were considerable numbers of other vehicles on the non-prioritized approach as observed in the collected traffic data. Considering average queue length that had been found at the prioritize approaches from the field, detection distance has been calculated for our model. Detection distance and green time extension for individual approaches of all three intersections have been illustrated in Table 1.

8. Result and discussion

The model has been simulated, varying both traffic volume and bus to vehicle ratio simultaneously throughout 230,400 simulation seconds for ‘Do Nothing’ scenario and for each incorporated bus priority strategies. Later, the most suitable priority alternative can be decided for the prevailing traffic conditions in the test site based on average travel time delay for the traffic volume and bus to vehicle ratio, illustrated in Figure 4. These results have been extracted from the simulation by nodal evaluation of the road network. Considering the average delay of bus, it is clearly evident from the trend lines of Figure 4(a), 4(c), 4(e) and 4(g) that, DBL offers the best performances for prioritizing bus amongst the most practiced bus priority schemes around the world. The simulation study has shown that incorporating DBL strategy will decrease traffic delay of buses almost by 170 s (38%) at minimum from “Do Nothing” scenario, in all the experimental traffic volumes and proportion of bus under consideration. This number even increases up to 290 s (55%) in case of 4000 veh/hr traffic volume with only 10% or lower bus demand in the network, shown in Figure 4(a). This is due to dedication of a lane exclusively to bus in urban road network where they would face less interaction with other traffics, experiencing only signal stop delay. On the contrary, adopting TSP minimizes the average delay of bus by 110 s (22%) at most from “Do Nothing” scenario, according to this study. This phenomenon occurs when the experimental traffic volume in the network is lowest, 1000 veh/hr with only 10% of bus demand. Moreover, in the same traffic volume with 17.5% or more bus demand, TSP is found to be ineffective, as suggested by Figure 4(g). In terms of average delay of traffic, TSP has been found to be more effective than DBL up to 12.5% bus demand, irrespective of traffic volume in an urban road network having mixed traffic conditions. A close observation of Figure 4(b) and 4(d) implies that in case of lower volume of traffic, TSP minimizes average delay by 35-40 s more than what DBL does. This range slightly shifts to 10-20 s when traffic volume in the network rises to 4000 veh/hr.

As signal priority is triggered upon the detection of bus prior to the signal in case of TSP, other vehicles get more advantage of green extension than bus. It is due to weak lane discipline in the network that increased the degree of uncertainty of the bus reaching the stop line before red phase starts. Moreover, with the extended green period, other traffic experiences minimal signal stop delay. Besides, dedicating a lane (33% of total road space) exclusively to PT, which comprises of only 12.5% or lower percentage of traffic, shrinks the available lane for other traffic resulting in excessive delay. However, for the same demand of bus in the traffic stream, the scenario is completely opposite if only the average delay of bus is considered for network performance evaluation. As illustrated in Figure 4(a) and 4(c), adopting DBL reduces average delay of bus at least 160 s more than what TSP does in the road network.

Overall, for bus demand up to 12.5%, it is apparent that TSP is better option as DBL induces more delay to whole road network. However, with further increase of bus demand, Figures 4(f) and 4(h) suggest that DBL is preferable priority scheme than TSP for the signalized corridor having chaotic traffic conditions with weak lane discipline, based on both the average traffic delay of bus and vehicles.

9. Conclusion and suggestions

Transit priority schemes are now a common practice for prioritizing transit passengers in most cities around the world. A good number of studies have shown that priority objectives, methods and its benefits vary from place to place. It is obvious that DBL is the best option for transit vehicles as a lane is exclusively dedicated to those vehicles only. However, dedicating a larger portion of the road to transit vehicle, that comprises a lower percentage of the traffic volume, will induce more delays to the rest of the traffic. On the other hand, when demand of transit vehicle in mix traffic is insignificant (12.5% or less), chaotic haphazard movement of the traffic plays more advantageous role for other traffic rather than bus in developing countries. In this case, this research has remarked that TSP will render better performance than DBL. Nonetheless, with increment of bus demand from 12.5%, DBL becomes more suitable priority scheme. This study suggests a methodology that will help policy makers to investigate the suitability of a particular method to prioritize transit vehicles for the prevailing traffic condition in the road network.

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