Transit Performance Evaluation at Signalized Intersections of Bus Rapid Transit Corridors

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Abstract: Bus Rapid Transit (BRT) is one of the mass transportation solutions consisting of infrastructures integrating dedicated bus lanes and smart operational service with different ITS technologies like Transit Signal Priority (TSP). Delay at an intersection is among the major factors for poor transit performance. This study examines the performance of buses at intersections of BRT corridors, which are privileged with Signal Priority on the dedicated lane. Simulation models were developed for the selected intersection together with the real-time calibration and validation. Statistical comparisons were conducted to test the alternative scenarios aimed at visualizing the deployment advantages. TSP options were evaluated by using PTV VISSIM with VisVAP add-on simulation tool. Alternative scenarios with and without TSP were tested to measure the performance of BRT buses along with impact assessment on the general traffic. TSP reduces travel time and control delay, improves travel speed and the results depicted a reduction in average passenger delay by 10–20%. The improvement on travel speed at an intersection of BRT vehicles were determined to be 6–8%. Prioritizing buses has diminutive impact on the general traffic, nonetheless, it is the easiest way of improving transit performance.

1 INTRODUCTION

Many of the cities around the world are experiencing alertly growing traffic congestion in urban areas and motorway networks. The impact of congestion could be calmed down by optimizing the performance of the traffic infrastructure through various traffic management and operational strategies. The effectiveness of the proposed mitigation measures are examined in carefully designed experiments for a real highway stretch with real demand scenarios. Furthermore, the behaviour of the proposed intervention schemes is examined and evaluated through microscopic simulation models along with refined validation (Ziaei and Goharpour, 2019; Papadopoulou et al., 2017; Gunawan et al., 2014). Bus Rapid Transit (BRT) is one of the efficient and sustainable solution enhancing mass transportation performance. It is a high quality bus-based transit system that provides dedicated lanes for buses and is therefore considered to be fast, safe, comfortable, and cost effective. It requires an improvement in the infrastructure like BRT dedicated lane, integration of the service and operation with different intelligent transport technologies like Transit Signal Priority (TSP), because of this, it is considered to be an effective and cheap way of improving transit service reliability and efficiency (Prayogi and Satwikasari, 2019; Raj et al., 2013; Deng et al., 2013).

TSP is an Intelligent Transportation System (ITS) component that modifies the normal signal operation process to better accommodate transit vehicles. It aims to reduce the delay and travel time of transit vehicles, thereby increasing the quality of a transit service, meanwhile, it should attempt to provide these benefits with minimal impact on other road users (Shaaban and Ghanim, 2018; Parr et al., 2014; Albright and Figliozzi, 2012). Various cities are implementing BRT for making public transport an attractive travel option; nevertheless, it is better to develop virtual models in order to visualize the impact of TSP performance, which should be done

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before implementation on signalized intersections of BRT corridors. It aids in envisaging the real-world characteristics of the traffic operational conditions. It also assists in visualizing traffic performance impacts under different situation and scenarios, which help decision makers to choose the best approach during deployment period (Prayogi and Satwikasari, 2019; Gunawan et al., 2014; Krajzewicz et al., 2012).

Various microsimulation software's are available on the market and used as tools for the evaluation of traffic management and control. Released in 1992, PTV VISSIM (Planung Transport Verkehr - Verkehr In Städten - SIMulations model) is a microscopic, time step and behaviour-based simulation model developed to model urban traffic and public transit operations. It can operate with the analyses of various traffic and transit operations under various conditions and aid the assessment of traffic impacts of physical and operational alternatives in transportation planning. VISSIM itself can be considered as a very technical software to work with, due to its complexity and versatility. Application of the simulation tool include functions of testing TSP timing alternatives (Papageorgiou et al., 2006; Smith et al., 2005; Ngan et al., 2004; Park and Schneeberger, 2003).

Operational measures like TSP may have positive as well as negative impact on the general traffic. In general, TSP helps the public transport vehicles to easily pass the congested signalized intersection. However, due to lack of different operational and technical problems, the efficiency of this technology could be highly distorted and to cope with this, the responsible authority shall assess its effectiveness in regular basis. It is always better to see the impact or the possible problem, which may be affecting the operation of transportation systems (Shaaban and Ghanim, 2018; Deng et al., 2013; Ngan et al., 2004). Since such infrastructure could be costly and may cause impedance to the general traffic, investigations should be conducted to evaluate their possible impacts behind their expected benefits. In this regard, this study provides additional insights as it focuses on the evaluation of TSP performance at signalized intersection along the BRT corridor with the developed microsimulation models, together with the real-time calibration and validation.

2 LITERATURE REVIEW

TSP can be an effective method for improving transit service, efficiency, and reliability despite increasing congestion. However, unless the results of this method are measured and evaluated, the system will never actually contribute its maximum potential benefit. Ultimately, the goal of TSP is to improve transit performance; nevertheless, from local routes to BRT, understanding of how TSP affects the performance of a system is prerequisite to maximizing the benefit of such measures. The primary aspects of transit service that are exaggerated by TSP include travel time, speed, and reliability. Four primary performance measures that can be used to determine travel speed and reliability are average speed, statistical variability in travel time, percentage of buses arriving on time and frequency/variance of headway (Shaaban and Ghanim, 2018; Smith et al., 2005).

TSP technologies can be used to extend or advance green times or allow left turn swaps to allow buses that are behind schedule to get back on track, improving schedule adherence, reliability, and speed. The technology requires traffic signal controllers with imbedded software, TSP capable equipment on the transit vehicle and equipment at the intersection for identifying the transit vehicle and generating low priority request when appropriate (Albright and Figliozzi, 2012; Ngan et al., 2004; Baker et al., 2002). TSP strategy is used to extend the green interval by up to a preset maximum value if a transit vehicle is approaching. Detectors are located so that any transit vehicle that would just miss the green light (by no more than the specified maximum green extension time) receive extended green time and is able to clear the intersection rather than waiting through an entire red interval (Parr et al., 2014; Smith et al., 2005).

Green Extension provides a benefit to a relatively small percentage of buses (only the delayed buses that arrive during a short time window). However, the reduction in delay for those buses that do benefit is large (an entire red interval). This strategy is used to shorten the conflicting phases whenever a bus arrives at a red light in order to return to the bus's phase sooner. The conflicting phases are not ended immediately like they are for emergency vehicle preemption systems, but are shortened by a predetermined amount. Early green benefits a large portion of buses (any bus that arrives at a red light), but provides a relatively modest benefit to those buses. Early green can be combined with green extension at the same intersection to increase the average benefits for transit (Shaaban and Ghanim, 2018; Wolput et al., 2015; Parr et al., 2014; Albright and Figliozzi, 2012; Dion et al., 2004; Baker et al., 2002).

VisVAP (VISual Vehicle Actuated Programming) is an optional add-on module of PTV VISSIM for the simulation of programmable phase or stage-based traffic actuated signal program controls. The control logic is described in a text file using a simple programming language. During VISSIM simulation runs or in the text mode, VisVAP interprets the control logic commands and creates the signal control commands for the VISSIM network. At the same time, various detector variables reflecting the current traffic situation are retrieved from the simulation and processed in the logic. In signal priority logic, various studies disclosed that early green and extended green or red truncation of TSP strategies are the most used approaches (Smith et al., 2005; Dion et al., 2004; Ngan et al., 2004; Baker et al., 2002).

3 CASE STUDY AND METHODS

In this study, the project of the line B2 of the BRT network (Fig. 1) was considered, which is developing along an axis crossing Addis Ababa city from North to South, the entire B2 BRT line stretches nearly 20 km. The standard cross-section has two directions central lane bus ways having 3.5m lane width per direction with passing lanes of 3.5m width on the adjacent sides for the general traffic. Along the corridor, the cross-section converted was between 25-40 meters width for works related to both the BRT corridor and the mixed traffic.

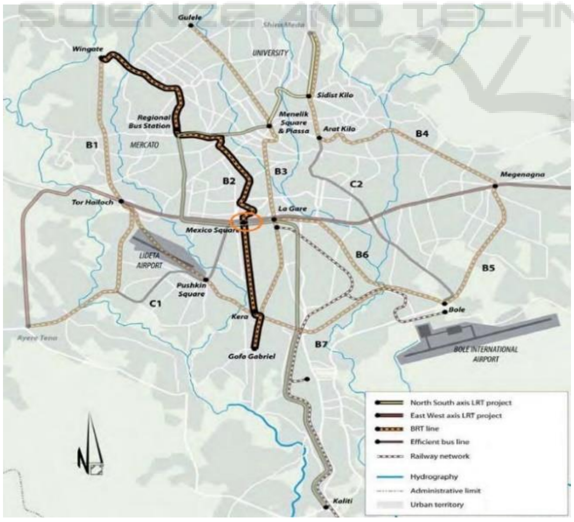


Figure 1: The proposed BRT corridor (B2 line) in Addis Ababa city (Source: (LTPA, 2010)).

This study describes the relationship and impact on traffic performance of the BRT-B2 operation at selected intersection (Mexico square signalized intersection), which is considered for TSP study (Fig. 2). Actual field data on classified intersection volume at each leg by vehicle type, traffic signal cycle lengths, traffic composition, road geometry, categorized average vehicle sizes, mid-block traffic volume, spot speeds and observation data on traffic operation were accumulated for developing the simulation models in VISSIM.

Moreover, additional data were collected from field for samples of vehicles based on standard literature. Such data include actual vehicle categorized travel time (Garber and Hoel, 2008), time headways (Shawn et al., 1998), categorized total traffic delays (Garber and Hoel, 2008; Bhavsar et al., 2007), queue lengths (Shawn et al., 1998) and speed data (Garber and Hoel, 2008; Currin, 2001) to verify the validity of the simulation results with the actual traffic conditions. Accordingly, the summarized data collected based on the above sampling strategies were utilized in the development of the simulation models.

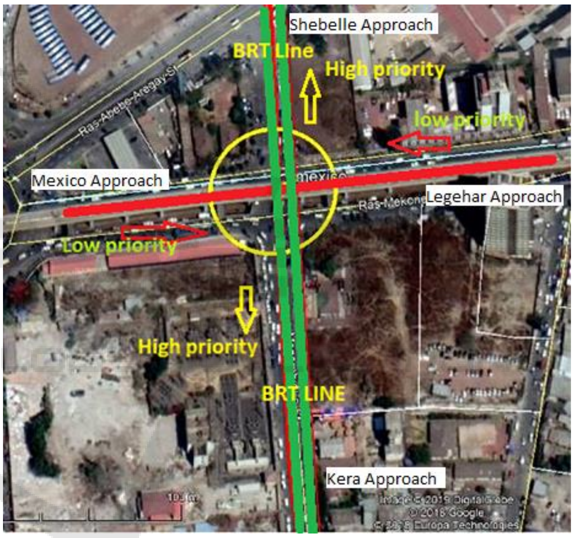


Figure 2: BRT direction at Mexico square signalized intersection near Ras Mekonen avenue.

The Mexico square signalized intersection is the junction where the BRT is given priority and expected to pass the intersection with insignificant impact on the general traffic. The BRT direction is North to South, which will be receiving signal priority over the East to West general traffic (Fig. 2).

Basic measurements are taken at the intersection, which are preliminary geometric data input for the VISSIM model.

Intersection volume and spot speed study were conducted on each approach of the intersection to determine the distribution along the intersection (Fig. 3). Furthermore, the speed data are also used for calibrating the PTV VISSM model to ensure the correct representation of the field conditions.

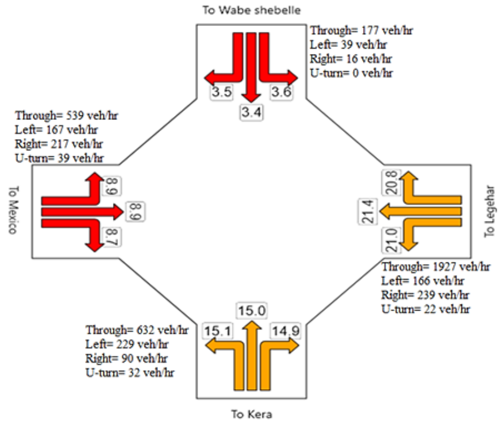


Figure 3: Total hourly volume on each approach and average travel speed including all delay effects (km/h).

The signal data for the four phases were recorded for creating the signal program in VISSIM (Table 1), which facilitates the creation of a realistic base model.

Table 1: Fixed time signal cycle lengths at Mexico square signalized intersection.

Signal Phase	Shebelle Approach	Legehar Approach	Kera Approach	Mexico Approach
Green (sec)	11	82	40	40
Amber (sec)	3	3	3	3
Red (sec)	171	100	142	142
Total Cycle time of the intersection (sec)	185			

3.1 Developing the Base Micro Simulation Model

According to LTPA (2010), the proposed BRT B2 works with a virtual loop detector installed on the bus lane. When a bus arrives in the virtual loop, it detects the bus arrival and sends a signal to the traffic signal controller at the junction. The controller will initiate the bus priority signal cycle, which will reduce the green signal time for other arms of the junction or extend the green signal for the bus lane to prioritize the transit operation. Green Extension of a buffer time less than or equal to 10-25 s, whereas Red Truncation /Early Green/ of termination less than or equal to 10-25 s are considered in the BRT B2 corridor. In this study, fixed Green extension and Early green time are taken as 15s.

In developing the model with PTV VISSIM, scaled background map of the intersection along the BRT dedicated lane ensures accurate geometric representation. The selected Mexico square signalized intersection was modelled on VISSIM using the data obtained from field (geometric data like lane width, approach length, segregated lane, and section of the BRT-B2 corridor) and secondary data sources (Fig. 4). Validation of the PTV VISSIM model were conducted using speed data from the field and data from the software output with justified confidence interval. Afterwards, evaluation of the TSP setups was performed at the intersection.

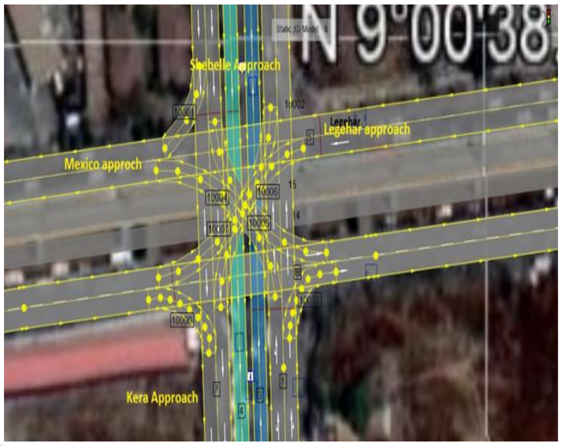


Figure 4: Snapshot of simulation model with the links, splined connectors, and reduced speed areas at Mexico square signalized intersection.

Overall, in the model development, PTV VISSIM annex software (VisVAP) were used to program the actuated signal controller. Scenario 1 will be with No Green Extension /No Early Green, where the Existing fixed cycle time is adopted as it is. In Scenario 2, the program consists of green extension of 15 s, early green time of 15 s and the interruption of cycle time based on the call from the BRT buses reaching the detectors.

3.2 Routing Decision and Vehicle Attributes

Combining inputs of vehicle attributes, vehicle route per direction, speed distribution and inputs of public transport characteristics for the BRT, general routing of BRT buses was made following the traffic behavior in the dedicated lane. Defining vehicle routes (static vehicle route decision) were configured based on the actual field conditions by considering the direction of the link flows (Fig. 5). Then, link relative flows were entered in each direction for separate movement types of the intersection. Each routing decisions show the branches of possible movements with their corresponding relative flows/traffic volumes. Directional traffic flow at the intersection was assigned in VISSIM with relative flow of vehicles along with the vehicle types, each volume input was calibrated later for better level of accuracy in the model. Before inserting the relative vehicle volumes at each leg, new vehicle compositions were defined for those vehicle types that does not exist by default in VISSIM to represent the actual vehicle types in the corridor.

Figure 5: Snapshot of simulation model with the vehicle routes at Mexico square signalized intersection.

3.3 Signal Controller

A detector was placed on the BRT dedicated lane near the signalized intersection (Fig. 6). Signal control on the intersection were based on the existing signal scheme and priority given via the sensor, which is initiated by a call by the BRT buses approaching at an intersection. By interrupting the fixed signal cycle, an optimum green extension and red truncation was incorporated in to the system.

Modelling traffic signal control to emulate the 'before' case and to deploy a 'green extension/early green' priority logic to scrutinize the 'after' case is the main element of this study. Therefore, it was very important to outdo the signal control data and to program the model for deploying the priority strategy. In this research, VisVAP based approach was chosen to model selected intersections signal program in VISSIM, which includes different signal head groups attributed to different lane geometric configurations.

One of the primary importance in this research was guaranteeing minimum disruption of traffic signal operations. This feature was especially important to the selected study junction, where the main corridor is a major urban road carrying high traffic volumes in peak hours; moreover, the deployment is planned for green extension. Therefore, the study incorporated a 15 s green extension and 15 s red truncation to evaluate the possible outcomes of the strategies.

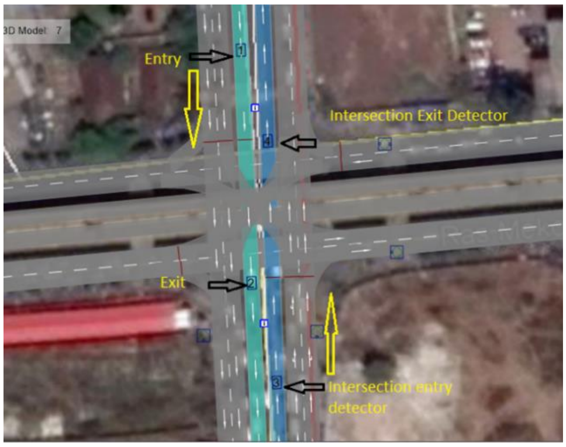


Figure 6: Signal and detector coordination in VISSIM.

3.4 Validation of the Model

The validation and calibration of the model is an important process in the simulation process, since it delivers credibility to the results by closely representing the actual conditions. Calibration involves adjusting the default values of PTV VISSIM software, which may not be the representative of the driving and geometric characteristics of the study segment. The validation process involves comparing and justifying the result (field and VISSIM output) with level of accuracy given by confidence interval (Raj et al., 2013; Vedagiri & Jain, 2012; Park and Schneeberger, 2003). Typical calibration measures include the consideration of traffic parameters like volume, delay, and travel speeds. In this study, average operating speed (spot speed) was used as a measure of effectiveness parameter for the transit network.

Average spot speed of vehicles within the speed distribution ranges from 5 to 55 km/h. VISSIM allows the operating speed of a class of vehicles to be controlled during the simulation process. The average operating speed was in the range of 5 to 60 km/h, which closely relate with the field data. Furthermore, the signal time distributions for 'No TSP' case observed from the VISSIM output are similar to the inputs from field conditions, which provides further support for the signal control. The speed distribution in VISSIM and in the field favourably compare with one another with 95% confidence (Fig. 7). Therefore, the model is closely related to the real traffic behaviour in the field.

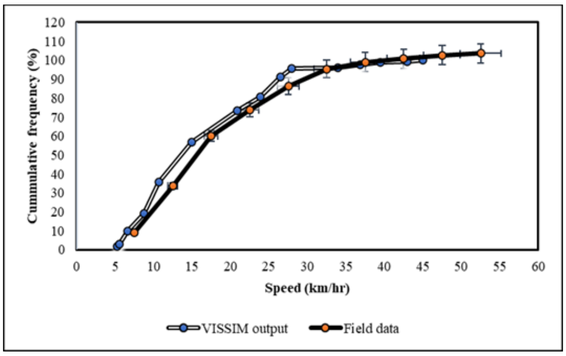


Figure 7: Comparison of speed distribution from PTV VISSIM with field measurement.

3.5 Simulated Signal Scenarios and Scenario Management

Two scenario groupings were implemented in simulation runs that can be distinguished by certain characteristics being simulated. The two scenarios analyzed were the No Transit Signal Priority (scenario I) and with Transit Signal Priority (scenario II). The change in signal phases coordination (either Green extension or early Green) within the two scenarios brought considerable alteration in the performance of transit operation (Fig. 8).

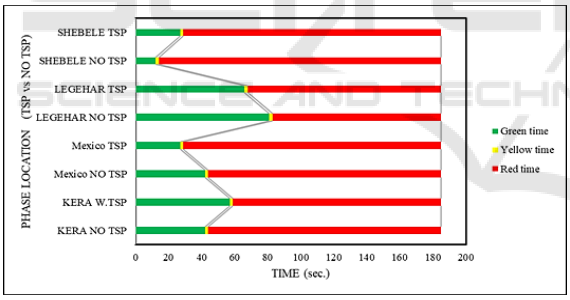
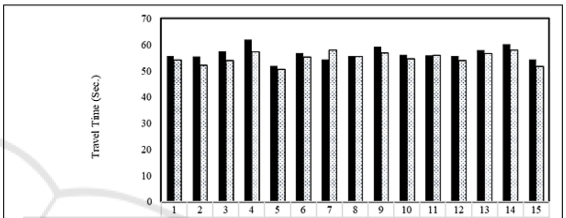


Figure 8: Green Extension and/or early Green on intersection phase in the two scenarios.

To investigate the impact of signal priority on the performance of BRT B2 buses and general traffic, scenario management were considered during the simulation to facilitate the assessment of traffic parameters. The basic conditions of TSP plan and way of detecting the bus arrival at an intersection, green extension of 15 s (GE-15), and red truncation /early green 15 s (EG-15) are critical dimensions in the scenarios. In general, 15-20 s of GE and EG extension was fused in the simulation network. The above signal modification of green extension and/or early green was made on the existing signal to experiment on the variations that occur. The changes in the signal coordination was made with the help of VisVAP logic, which was used for programming the detector call.

4 RESULTS AND DISCUSSIONS

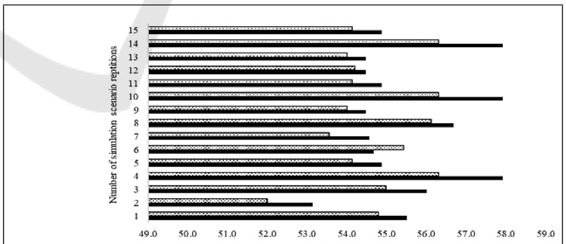
The extracted output data from PTV VISSIM result directory include travel time, delay, and queue length of BRT buses, and the general traffic. For the assigned approach crossing segment at the intersection (North to South), the vehicles travel time were extracted from VISSM output directory for both scenarios (Fig. 9). There is a significant improvement in the travel time of BRT the North to South line by an average of 2.83% decrease in the overall travel time.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Travel time with out priority	55.72	55.4	57.54	61.85	51.9	56.73	54.3	55.67	59.19	56.08	55.88	55.75	57.92	60.08	54.28
Travel time with priority	54.22	52.11	53.87	57.34	50.48	55.2	57.82	55.39	56.73	54.53	55.84	53.96	56.53	57.93	51.77

Figure 9: Travel time of BRT vehicles from North bound Shebelle approach to South bound Kera approach.

Data extracted for the South to North flow indicated that there is a significance improvement in the travel time of BRT with an average 4.78% decrease in the overall travel time (Fig. 10).



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Travel time with priority	54.8	52.0	55.0	56.3	54.1	55.4	53.6	56.1	54.0	56.3	54.1	54.2	54.0	56.3	54.1
Travel time with out priority	55.5	53.1	56.0	57.9	54.9	54.7	54.6	56.7	54.5	57.9	54.9	54.5	54.5	57.9	54.9

Figure 10: Travel time of BRT vehicles from South bound Kera approach to North bound Shebelle approach.

The simulation result of average queue length from VISSIM results directory were summarized for average values based on vehicle composition and category of the general traffic (Table 2). The priority direction in Kera and Shebelle approaches has improvement in queue length, which was reduced by 1.5%-1.7%, whereas the non-priority side of the intersection the queue length increased by 1.1%-2.5%.

Table 2: Summary of average queue length at the different approaches of the intersection.

Queue Length	Shebelle Approach	Legehar Approach	Kera Approach	Mexico Approach
Queue length before TSP (meter)	11.8	52.2	32.8	28.3
Queue length after TSP (meter)	11.1	53.5	32.3	28.6
Difference (meter)	-0.7	1.3	-0.5	0.3
Percentage change (%)	-5.9	2.5	-1.5	1.1

The simulation results from PTV VISSIM indicated that for the selected BRT corridor, the travel speed increased by an average of 7.25%. The Speed variability for BRT vehicles with and without transit signal priority was significant.

From the overall results of the simulation scenarios, the average passenger delay for the multiple simulation cases signposted a positive result, which is an average of 10%-20% in delay reduction in comparison to the no priority case (Fig. 11).

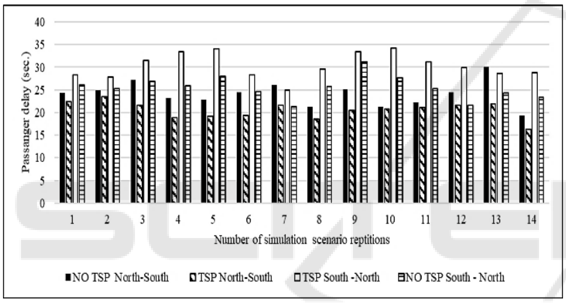


Figure 11: Average Delay of BRT vehicle passengers in the No TSP and With TSP scenarios.

5 CONCLUSIONS

This study presented crucial insights in developing a simulation model with relative comparison of various scenarios for experimenting transit signal priority approaches at intersections of BRT corridors. The study particularly addressed the performance of buses running on a segregated lane and receiving signal priority at junctions over the general traffic. Moreover, the influence on the general traffic performance was examined to evaluate the pre- and post-deployment conditions of the Transit Signal Priority on BRT corridors. Based on the experimental investigations, the following conclusions are made:

- the PTV VISSIM simulation output and statistical comparisons indicated that there is a significant improvement in the performance of BRT buses at an intersection level crossing because of the TSP;
- the introduction of TSP resulted in an average travel time reduction by a minimum of nearly 4% for BRT buses;
- the average delay reduction for passengers of the BRT line was found to be 10-20% and the travel speed of BRT vehicles was increased by 7-8%;
- TSP may reduce the queue length in the priority direction (parallel to the BRT lane) by nearly 2%, while in the non-priority direction, the queue may increase by a maximum of 3%.

Overall, implementation TSP have little impact on the traffic performance of the general traffic, while it can bring significant operational improvement on the vehicles of the BRT lane.

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CONFLICT OF INTEREST

The authors declare that they have no competing interest.

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