IMPACTS OF BUS ONLY LANES ON SIGNALIZED INTERSECTION UNDER HETEROGENEOUS TRAFFIC CONDITIONS

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Abstract

The unsolicited delays and unpredictable travel times are common in urban areas of Pakistan hence making it difficult to maintain the image of public transport. Bus priorities provided in terms of dedicated bus lanes at intersections are considered as a solution to improve the conditions for public transport. Conversely, dedicated lanes may negatively affect the performance of other vehicular classes. This study quantifies the impact of Bus Only Lanes (BOLs) on the intersection's performance as well as on the performance of individual vehicular class. The VISSIM microsimulation tool was employed to a signalized intersection located in urban area under heterogeneous traffic conditions. Sensitivity analysis followed by trial and error method was conducted to calibrate the microsimulation model. The calibrated VISSIM model was utilized to run three scenarios; scenario-1: existing conditions, scenario-2: converting existing lanes to BOLs and scenario-3: providing additional lanes as BOLs. The results indicated that for scenario-2, buses experience 14-16% lesser travel time and 10.5% reduction in delays as compared to scenario-1 due to dedicated right-of-way, while all other vehicular classes experience deteriorated conditions. Scenario-2 affected the intersection's performance and caused an increase of 5.6% in average delay, 9.0% in average maximum queue length and reduction in average speed by 9.8%. However, in scenario-3, BOLs as additional lanes improved the conditions for buses and also reduced the travel time and delays for other vehicular classes. It is established that the present findings may assist the planners and decision makers to revisit the policies for public transport services.

Keywords: **Bus only lanes, heterogeneous traffic, signalized intersection, calibration**

Introduction

Presently, a major rise in the use of private cars over public transit is one of the leading visible problems and causing negative consequences both environmental and non-environmental (Sharma and Kumar, 2012). Expansion of population and urban geographies has become a severe problem because of the development of society and the economy (Chen, 2015). Most of the cities in Pakistan are

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experiencing rapid growth in the use of private vehicles and slow pace in infrastructure development. Transportation infrastructure is one of the vital elements of urban development. Rapid urbanization and motorization have induced traffic congestion, greenhouse gas emissions, and other environmental consequences (Bharadwaj *et al*., 2017; Condurat *et al*., 2017; Guo *et al*., 2018). To alleviate such deteriorated urban transport conditions, there is a need to enhance the public transport services by improving travel time of buses. Buses face longer travel times as compared to private vehicles due to significant delays at bus stops and time consumed during boarding and alighting. Also, buses have to follow indirect routes to serve the maximum areas of the city. Since, the aforementioned factors cannot be controlled to improve the travel time for public transport buses, but these buses can be given a favor in terms of design or signal priority at signalized intersection. This priority can minimize the delays for buses occurred at signalized intersection. The concept of using bus priority at signalized intersections is not new. Sunkari *et al.* (1995) developed a model to evaluate bus priority at signalized intersection. Public transport priority has been considered as a potential solution for the foregoing problems and can also improve the efficiency of traffic flow (Chen *et al*., 2016). Bus priority lanes have been implemented in many countries to improve the reliability of public transport system (Ahmed, 2014). Such priorities can improve the conditions for buses but conversely, these can affect the overall performance of intersection. This can also negatively affect the performance of other vehicular classes. This study has been carried out to evaluate the impacts of bus priority in terms of exclusive lane on the performance of other vehicular classes and the performance of signalized intersection under heterogeneous traffic conditions.

Related Work

In the last decades, various strategies have been developed to offer priority to the buses at signalized intersections. Two different measures are considered for bus priorities at intersections; design-based and control-based. Shalaby *et al*. (2003) conducted a study on evaluating the various transit priority options by using microsimulation model in King Street Toronto. The study used simulations to evaluate four scenarios and recommended the prohibiting of all left turns and prohibiting traffic from King Street for improvement of transit service. Papageorgiou *et al*. (2009) studied the various scenarios of dedicated bus lanes. The study concluded that travel time, average speed and time delay show significant improvement for the public transport buses.

Vu *et al*. (2013) considered the design-based strategy and compared the performance of three types of bus lanes; bus priority lane, roadside bus only lane and the ordinary lanes. With the help of PARAMICS, the study concluded that the bus priority lane type can help to reduce the passenger travel time. A study conducted by Ahmed (2014) conducted research on exploring new bus priority methods at isolated vehicle actuated junctions in the United Kingdom. Two bus priority options were elaborated such as passive and active. This study concluded that for “always green for bus method”, bus travel time savings were much higher when compared with other considered methods. Some studies compared the performance of both strategies i.e. design-based and control-based. Malandraki *et al*. (2015) applied both design-based and control-based strategies to minimize the average delay time for the buses without creating major disturbances to the rest of the network. The study employed microscopic simulator AIMSUN and concluded that average delay time for the buses significantly reduced. Chen *et al.* (2016) presented the PARAMICS microscopic simulation model for evaluation of the performance of bus lanes on urban expressway based on survey data. This research determined that bus priority lane reduced traffic congestion and helped to attract more travellers to use public transportation.

In addition to design-based strategies, control-based strategies are also considered effective in enhancing performance of public transport vehicles. A control-based strategy was presented by Wahlstedt (2011). This study determined the impacts of bus priority by coordinated traffic signals. Base on the VISSIM simulations, the study found 6% reduction in the travel time. Another study by Guler *et al*. (2015) explored the signal priority for buses at single lane approach signalized intersections. This research theoretically determined that buses can attain delay savings buses but cars experience negative impacts. Abdelfatah and Abdulwahid (2017) conducted a study to investigate the impact of bus only lanes on traffic performance under diverse traffic conditions in urban areas of the UAE by employing VISSIM software. The study found that turning percentage at the intersections has a momentous impact on the performance of bus only lanes. Bie *et al*. (2020) integrated bus signal priority with midblock pre-signals and found that the proposed method decreased delays for buses by 70.7% and also improved the conditions for general vehicles. In a recent study, Hassan *et al*. (2021) integrated both exclusive lane and bus priority signal control strategies in mixed traffic stream. The study conducted three modal-split based scenarios by using VISSIM simulations. The study endorsed the effectiveness of Bus Rapid Transit (BRT) in alleviating traffic problems.

The above-mentioned studies were conducted by various researchers to reduce travel time, traffic congestion and to improve the overall efficiency of the intersection by providing the priority in terms of either signal phase or exclusive lanes. Various tools were used in these studies including VISSIM, PARAMICS and AIMSUN. Importance to calibration part for adjustment of microsimulation model parameters was not given to the extent required. Since, the driving behaviour for heterogeneous conditions is quite unpredictable, so, it needs detailed calibration and a slight difference of driving behaviour in such heterogeneity can lead to entirely different output. Among the above-mentioned studies, few researchers have considered some existing vehicular classes and the impact on individual vehicular class was not fully explored in the previous studies. Therefore, this study focused on the performance of individual vehicular class by introducing BOLs. Out of above-mentioned, mostly studies considered priority to public transport buses by providing priority signal phase. Only one study considered impact of proposed signal priority on the vehicular performance but the site conditions studied were an intersection with single lane approaches (Guler *et al.*, 2015). It also studied the impact of signal priority only on cars and buses and none of other vehicular classes were studied. Since, some para-transit services based on wagons or pickups are operating parallel to buses in many cities of developing countries. So, impact of new proposed strategy either design-based or control-based must be evaluated on the all prevailing vehicular classes in addition to impact to intersection's performance. Quantification of delays to cars and wagons will help the planners and decision makers to revisit the policy on carpooling and vanpooling. The objective of this study is to evaluate the impacts of BOLs on performance of individual vehicular class as well as on the overall intersection's performance.

To fulfill the stated objective, three scenarios have been considered and analyzed in microsimulation environment by using VISSIM. A dedicated lane of 200 m (100 m upstream and 100 m downstream) on both approaches of major road was allocated for only public transport buses at case study intersection. The current vehicular composition at the case study intersection represents seven vehicular classes ranging from passenger cars to heavy vehicles. This study will provide a framework to evaluate the impacts of any proposed physical priority treatments for buses at the signalized intersection. Since, this study evaluates the impact of proposed modifications on each individual vehicular class, so, the applicability of the proposed framework can also be extended to assess the impact of bus priorities on any car-pooling, van pooling or taxi services in the city. This study will be able to guide the decision-makers; transport planners and other align departments to enforce any physical strategy at signalized intersections to improve the image of public transport.

Methodology

The methodology involved in this study is divided into two phases; 1) calibration and validation of the model for local conditions and 2) introduction of BOLs in the calibrated model.

Phase-I: Model Development and Calibration

The first phase focuses on calibration and validation and it is further divided into several distinct steps as under;

Selection of Study Site

Following key factors were considered while selecting site for this study;

- The site must represent sufficient traffic volume
- It must be a pre-timed signalized intersection
- It must incorporate various public transport routes
- It must represent most of the present vehicular classes available in the city

Garhi Shahu intersection as shown in Figure 1(a) fulfilled the requirements and was selected as case study site. This 4-leg signalized intersection is located in Lahore, the provincial capital of Punjab and second largest city of Pakistan. The population of the city was recorded as 11.12 million inhabitants in 2017 and covers total area of 1772 km^2 (Bureau of Statistics Punjab, 2020) Lahore has a good representation of all road classes to cater a huge number of daily trips. Privately owned cars, two-wheelers, and three-wheelers contribute more than 95% of total registered vehicles in Lahore (Bureau of Statistics Punjab, 2020). The selected intersection is located near to public transport terminals and experiences the movement of various public transport vehicles during the entire day. The delays incurred at this intersection contribute a lot to overall performance of the public transport system.

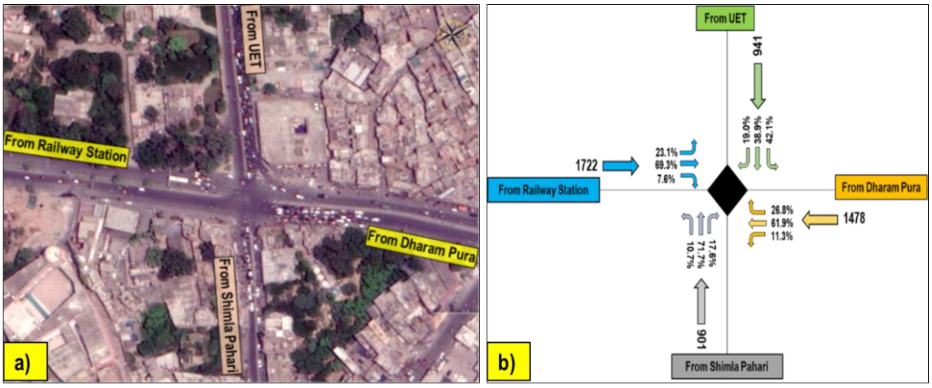


Figure 1. **a) Satellite image of the selected intersection b) Peak hour traffic volume and turning proportion from each approach**

Table 1. Vehicle composition along each approach

Approach	Car/Jeeps	Rickshaw/ Qingqi	Motorcycle	Passenger Bus	Wagon/ Pickup	Heavy Vehicles
From Dharam Pura	27.5%	12.3%	54.5%	0.9%	3.1%	1.7%
From UET	26.8%	19.5%	51.0%	0.8%	1.4%	0.5%
From Shimla Pahari	13.5%	14.4%	63.4%	0.0%	7.8%	0.9%
From Railway Station	11.1%	24.1%	58.8%	0.9%	4.2%	0.9%

Selection of Measure Of Effectiveness (MOE)

This step involves the selection of any specific MOE for the study to compare the field and simulation output. A model is considered calibrated when difference between MOE values from simulations and from actual field data is within acceptable range. The MOE is selected by keeping in mind that it can be collected from field with required accuracy and it is an output of the simulation tool under consideration. For this study, average queue length is selected as MOE (Sharma and Swami, 2012; Azam *et al.*, 2019) and data on this measure is collected from selected site.

Data Collection

For a calibration study, the quality of the data must be thoroughly checked before starting the calibration process (VDOT, 2020). Data collected in this study is broadly categorized into two aspects; site inventory data and operational data. Site inventory data includes the physical elements of the study site and represents the number and width of lanes, lane configuration, location and length of storage lanes and channelization for free left turns. The satellite image showing site geometry is presented in Figure 1(a) and traffic volumes from each approach along with turning proportions are shown in Figure 1(b). Since, the selected intersection is in urban area and terrain is level, so, grades for all approaches are assumed as zero. In addition, the on-street parking and pedestrian movement are not incorporated in the model due to insufficient data on these aspects.

The other category of the collected data is related to operational characteristics of the site and involves the traffic volumes, control type, signal timing, signal phasing and posted speed information. Traffic volume data was collected for a total of 6 h by considering two h' period in morning, afternoon and evening on 18/12/2019 and peak hour was determined. Data collection was done on all approaches by considering all the vehicular classes.

Table 1 above shows the distribution of vehicle classes for all approaches. The cars in the field are a mix of small and larger length cars, so, this category is further divided to two categories in vehicle modeling i.e. passenger car 1 and passenger car 2. It can be seen that for every approach, the highest proportion is for motorcycle. At each approach proportion for motorcycle is more than 50% which is associated with the unpredictable driving behaviour and lane changes at signalized intersections. The selected site is a fixed time signalized 4-leg intersection with 4-split phases and operating with a cycle length of 150 sec. Amber time for each approach is 3 sec and the operation considers 1 sec as all-red time.

Data on selected MOE, queue length was collected by counting the number of completely stopped vehicles in a lane on two approaches (one major and one minor) and then these number of stopped vehicles were multiplied by 6.1 m (20 ft) to get the maximum queue length as specified by Shaaban and Radwan (2005).

Model Setup and Initial Modeling

This step involved the development of model for the selected intersection and input of all collected data. First of all, Google image of the study site was imported and scaled into VISSIM. Then links were drawn and numbers of lanes for each approach were the same as in actual site conditions. Connectors were used to join those links to reflect the left and right turning maneuvers from each approach. Priority rules were defined for the free left turns by giving priority to the through movement from the other approach. Static routes were defined from each approach to guide the vehicles on their respective path along an approach. Seven vehicular classes were considered and accordingly 3D models were selected for visual purposes. Composition of vehicle classes along each approach was considered according to the traffic volumes. Traffic signal control was configured according to the observed signal timings and sequence. After setting traffic volumes, routing decisions, priorities and signal control, the model was run with default parameters.

The simulations with default parameters were done to check the distribution of the desired input as compared to the actual field data. The results from the simulation output showed that the average maximum queue length is overestimated with the default calibration parameters. The results endorse the adjustment of the calibration parameters according to the local traffic conditions.

Model Calibration

This step is of prime importance in reflecting the actual field conditions in simulation tool. Although, the simulations are emerging as solution to various design and alternative evaluation, however, a poorly calibrated model can lead to the selection of incompetent alternative which is showing good performance in simulations but performs differently in the real scenario (Li *et al*., 2011). So, this step must be performed carefully. To calibrate a VISSIM model, the parameters regarding lane changing, speed distribution and driving behaviour are adjusted (VDOT, 2020). For this study this step was done by selecting the parameters based on previous literature (Park and Qi, 2005; Muniruzzaman *et al*., 2016; Suresh and Rajbongshi, 2016; Jayasooriya and Bandara, 2018), engineering judgment and some modifications based on the collected data. Sensitivity analysis was done to select the most sensitive parameters. From the sensitivity analysis, three car-following parameters; average standstill distance, additive part of the safety distance and multiplicative part of the safety distance were selected and their values were selected by trial and error method by increasing and decreasing the values by 10% and obtaining the respective output for selected MOE (Maheshwary *et al*., 2019). The combinations of the values which gave minimum difference between simulation and field value were selected as final calibration parameter set. Some other factors were modified based on the filed observations and engineering judgment. Since the traffic conditions are highly heterogeneous and driver do not follow any lane discipline, so various other factors related to positioning in a lane, lateral distances and overtaking decision from left or right were modified according to the field observed conditions. Final calibration was done on the basis of the parameters shown in Table 2.

The results based on the selected calibration parameters (Table 2) are shown in the Table 3 below. It can be seen that Mean Absolute Percentage Error (MAPE) value between the simulation output and actual field value are below 10% (Spiegelman *et al*., 2016). The model is accepted as calibrated and considered ready for evaluation of any design or operational modification. The next phase of this study describes the introduction of BOLs along

Table 2. Adjusted calibration parameters and their values

Aspect	Parameter	Default	Calibrated
Car Following	Average Standstill Distance (m)	2	1
	Additive part of the safety distance (m)	2	0.75
	Multiplicative part of the safety distance (m)	3	1.25
Lane Changing	Overtake reduce speed areas	Not Allowed	Allowed
	Overtake on same lane – Left	Not Allowed	Allowed
	Overtake on same lane – Right	Not Allowed	Allowed
Lateral Aspects	Desired position at free flow	Middle of lane	Any
	Observe adjacent lanes	Not Allowed	Allowed
	Consider next turn	Not Allowed	Allowed
	Minimum lateral distance at 0 km/h (m)	0.2	0.3
	Minimum lateral distance at 50 km/h (m)	1	0.8

Table 3. Queue length (m) results for model calibration

Approach	Simulation Output	Field Data	MAPE Value
From UET (Minor)	71.4	68.3	4.5%
From Dharam Pura (Major)	122.6	115.5	6.2%
Remarks	MAPE value is <10% (acceptable)		

Table 4. Average travel time (sec) results for model validation

Approach	Simulation Output	Field Data	MAPE Value
From UET (Minor)	30.91	29.00	6.66%
Remarks	MAPE value is <10% (acceptable)		

the major road and their impact will be evaluated on the general traffic and on the performance of public transport buses by using the calibrated model.

Validation and Visualization

Another data set from same site but for different time period is considered for validation purpose. The data used for validation possess the same site geometry, control conditions with different traffic volume and proportion of vehicular classes. Average travel time for all vehicles is used for comparison of results. A 90 m section along minor approach (from UET) was considered. The results obtained from calibrated model and data from field are shown in Table 4 below. Also, visual observations showed that the model produced traffic conditions identical to field traffic conditions.

Phase-II: Introduction of (BOLs)

This phase refers to the assessment of intersection performance before and after the introduction of BOLs. To compare the performance, three scenarios reflecting different geometric configuration for BOLs have been considered. Impact of BOLs on general traffic is evaluated based on travel time and delay time experienced at intersection. To employ the required scenario, a Bus Only Lane of 3.5 m on each side of median is provided. The idea to provide BOLs near a signalized intersection is to give priority to the buses in terms of dedicated space and signal time. A length of 200 m from stop bar (100 m for downstream and 100 m for upstream) along major approaches on both sides of median has been specified to buses. The bus will move in mixed traffic until it reaches at start of BOL. After reaching at start of BOL, the bus will isolate itself from mixed traffic and follow the dedicated path to the stop bar. Also, a customized signal plan has been proposed to improve the conditions for buses. The buses get green time earlier than other general traffic so that these buses cross the intersection quickly and can reach to the downstream end of BOL earlier than other general traffic. The available road capacity ahead of general traffic will help buses in reducing delays caused due to reduction in speed while leaving BOLs and adjusting their speeds in mixed traffic. The BOLs have been proposed along major approaches only. The right turning traffic from major to minor road is shifted to the nearest U-turns available. However, traffic from minor road can take right turn to the major road during their phase time. The explanation of the considered scenarios has been given below;

Scenario-1: Existing conditions

This scenario reflects the current site conditions as shown in Figure 2(a). It is considered as base scenario to compare the performance of the other two scenarios. The model developed for this scenario follows the existing road geometry, flow, control and vehicle characteristics. The vehicle composition and turning configurations are as per current site conditions.

Scenario-2: Converting existing lanes into BOLs

This scenario involves utilization of existing lane as BOL as given in Figure 2(b). The specific length of existing lane will be considered as BOL and will only be used by buses. None of the other vehicle classes use this 200 m section in any case. This conversion of existing lane reduced the road capacity for other vehicular classes along the major approaches. Also, availability of dedicated lane on both sides of median will limit the right turning traffic from major approaches towards minor approaches. This right turning traffic can be shifted to nearby U-turns and performance of those U-turns can be assessed in future studies. Except this lane conversion, all components including lane configurations, geometric and control conditions will remain similar to scenario-1.

Although, the scenario-2 affects the operational performance of all vehicular classes except buses, but the proposed geometric setting can be achieved without any widening or land acquisition. The need of the hour is to quantify that to what extent, the performance of general vehicular classes will be compromised?

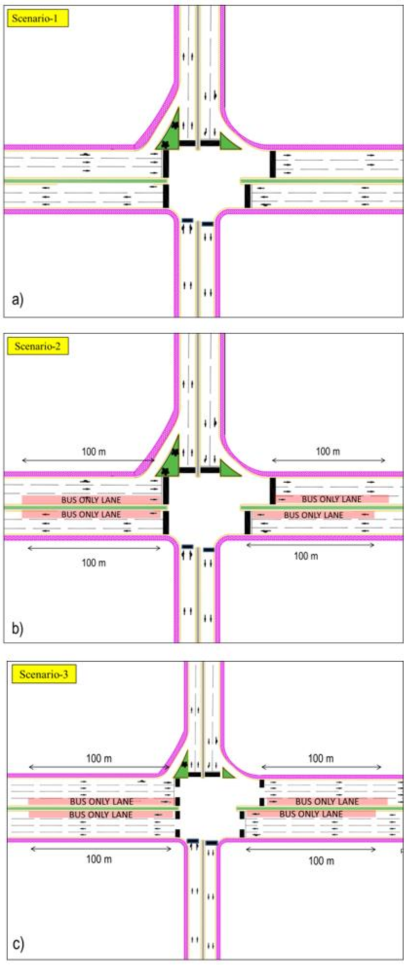


Figure 2. **Geometric conditions considered in all scenarios a) scenario-1 b) scenario-2 c) scenario-3**

Scenario-3: Providing Additional Lane as BOLs

The scenario-3 considers additional lanes on both sides of median and these additional lanes are considered as BOLs as shown in Figure 2(c). The length of additional lanes on both sides of median will be exclusively used by buses, while mixed traffic will move on the rest of lane length. Although, this scenario provides a balance of performance between buses and all other vehicular classes, but involves widening of road to incorporate space for additional lanes. If this scenario is to be adopted in an urban setting, it might involve huge costs for land acquisition.

Analysis and Results

This section describes the output obtained based on the impact of BOLs on performance of vehicular

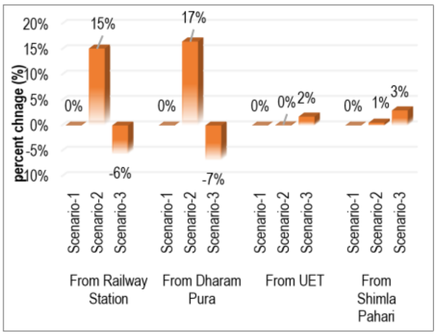
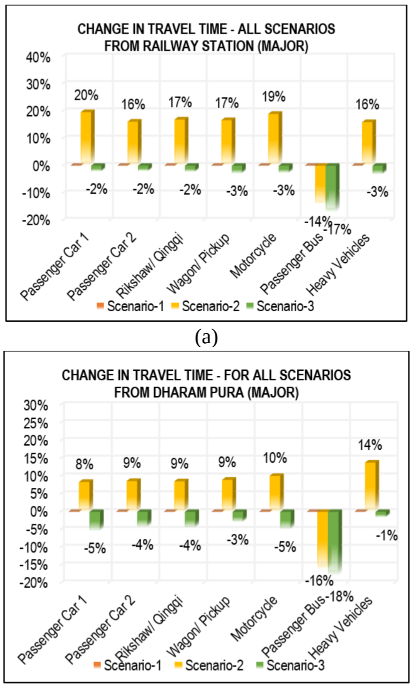


Figure 3. **Percentage changes in queue length for all considered scenarios**

classes as well as on intersection's performance. Assessment made before the introduction of BOLs is compared with the output obtained after the inclusion of BOLs. Impact of BOLs is determined based on three considered scenarios. All three scenarios are employed based on already calibrated model.

Impact of BOLs on Individual Vehicular Class

Results obtained based on considered scenarios are extracted from the calibrated model. Three factors have been considered to compare the scenarios; queue length, travel time and delay time. A trend in queue length in the form of percent change for all scenarios by considering the scenario-1 as base case is presented in Figure 3 below. The percent change shown in graph below is only associated with average queue length for each scenario. The values were obtained from VISSIM by inserting queue counters at stop bars along each approach. The graph shows a clear trend of increased average queue length for the case of using existing lanes along major road as BOLs on both sides of median (scenario-2). As shown in graph, the major road approaches i.e. from Railway Station and from Dharam Pura show an increase of 15% and 17% respectively in average queue length for scenario-2 as compared to current conditions (scenario-1). The effect of conversion of existing lanes into BOLs is almost negligible for minor approaches since the configuration only changed along major approaches. While comparing scenario-2 and scenario-3, it can be seen that the average queue length is decreased by a maximum of 7% upon introducing an additional lane on both sides of median. A slight increase in average queue length has been observed along minor approaches. The vehicles from minor approaches might experience a slight change in performance due to increased traveling distance owing to introduction of additional lanes along major approaches.



(a)

(b)

Figure 4. **Travel time trend along major road for all considered scenarios; a) from Railway Station, b) from Dharam Pura**

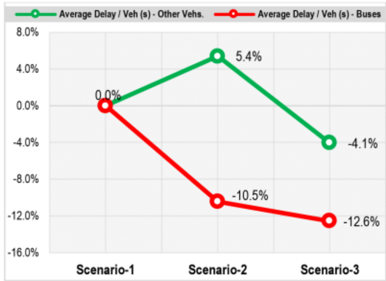


Figure 5. **Comparison of percent change in delays for scenarios 1, 2 and 3**

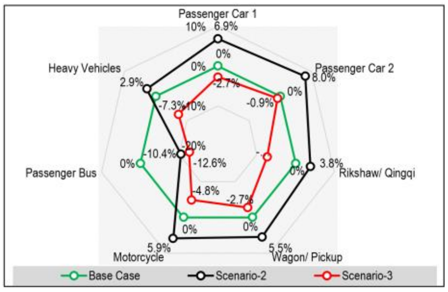


Figure 6. **Percent change in delay based on vehicular classes**

Changes in travel time based on each vehicular class along both approchaes of major road are illustrtaed in Figures 4(a) and 4(b). To understand the trend in travel time for all scenarios, only approches along major road are considered. Since, the introduction of BOLs is along major road, so, the impact of these BOLs in terms of travel time and queue lengths will be experienced more by the vehicles on major road. The percentage shown in graphs are obtained by considering the current conditions as base i.e. 0% for base case.

It can be observed from Figures 4(a) and 4(b) that in scenario-2, the travel time increased for all vehicular classes except buses. It means that BOLs served the purpose by improving travel time for public transport buses along major road approaches. But at the same time, other vehicles experience increased travel time due to reduced road capacity. Scenario-3 shows significant reduction in travel time due to enhanced roadway capacity along major road in the form of BOLs. Further improvement in travel time for buses in scenario-3 is due to reduced queue delays at start of BOLs. Overall improvement in average travel time for buses is observed from 17% to 18% for scenario-3 as compared to current conditions (scenario-1).

The other factor considered to compare the performance of all scenarios is delay experienced by each class of vehicle during scenarios-1, 2, and 3. Figure 5 illustrates the percent change in average delay for all vehicles and average delay for buses for considered scenarios. Scenario-2 refers to the reduction in capacity along major road and a consequent decline in intersection performance in terms of delays. An improvement of 10.5% in delay is observed for buses, whereas, negative impact of 5.4% increase in delay on all other vehicular classes is perceived for scenario-2. This increase in delay is due to reduction of capacity to cater the same vehicular demand. Scenario-3 improves the intersection's performance in comparison to scenario-2 and buses and all other vehicles experience 12.6% and 4.1% reduction in average delays respectively.

To have better visualization of the delay results for each vehicular class, a graph is shown in Figure 6. This graph represents the overall intersection performance in terms of delay per vehicle for all considered scenarios. Scenario-1 is taken as base case to see the effects of proposed actions on the delays to all vehicular classes.

It can be seen from the graph (Figure 6) that in scenario-2, the delays for each vehicular class except buses increased from a minimum value of 2.9% for heavy vehicles to a maximum value of 8.0% for passenger car 2 as compared to base case. This increase in delays for scenario-2 is due to reduction in capacity while serving the same vehicular volume along major road. The significant reduction of 10.4% in delays is observed for buses due to dedicated right-of-way for buses along major road. The comparison of scenario-2 to scenario-3 shows a considerable reduction in delays for all vehicles including buses due to increased capacity and right-of-way. The reduction is consistent for all vehicular classes and ranges between a minimum values of 0.9% for passenger car to a maximum reduction of 12.6% for buses. The conditions for all vehicles are improved as compared to scenarios-1 and 2.

The reduction in delays for vehicles other than buses is due to absence of buses in traffic stream since buses travel on dedicated path. Although, the conditions for buses are same in scenarios-2 and 3, but the slight improvement in delay for buses is due to the reduction of queue delays at the start of the BOL in scenario-2, which decreases during scenario-3.

Impact of BOLs on Intersection's Performance

The geometric modifications considered to incorporate the dedicated space for buses have affected the performance of individual vehicular class as well the performance of intersection. The impact on intersection's performance has been extracted from calibrated model for considered scenarios in terms of average delay, average maximum queue length and average speed. The graph shown in Figure 7 shows the overall impact on intersection's performance for three scenarios. Scenario-1 has been considered as base case to study the impact of proposed action effectively.

It can be observed in Figure 7 that converting existing lanes into BOLs reduced the overall capacity and resulted in an increase in average delay, average maximum queue length and reduction in average speed. Scenario-2 caused the system an increase of 5.6% in average delay, 9.0% in average maximum queue length and reduction in average speed by 9.8%. Providing additional lanes as BOLs improved the conditions and provided balance conditions for all vehicular classes. An overall improvement in intersection's performance was observed for scenario-3. In comparison to scenario-1, significant improvement of 4.5% in average delay, 3.2% in average speed and 3.3% in average maximum queue length was observed.

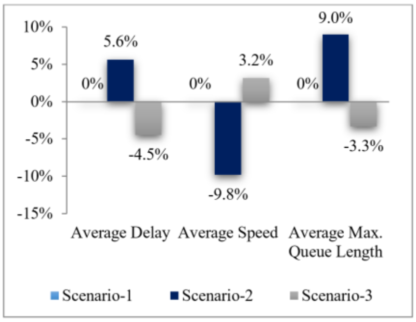


Figure 7. Percent change in performance measures for all scenarios

Conclusions

The study employed microsimulation tool, VISSIM to evaluate the impact of BOLs placed in the existing setting and as additional lanes to the current geometry. A signalized intersection located under heterogeneous traffic conditions is considered as case study and impact of BOLs on intersection as well as on individual vehicular class is evaluated in terms of queue length, travel time and delays. VISSIM model was initially calibrated by adjusting driver behaviour parameters and model was considered calibrated when MAPE value was below 10% for simulation and field data. Three scenarios were developed out of which scenario-1 represents current conditions, scenario-2 considers BOLs in current conditions and scenario-3 involves BOLs as additional lanes. Based on the output from simulation models, following conclusions have been drawn;

- The results showed that scenario-2 reduced the capacity along major road and subsequently resulted in an increase of queue length, travel time and delay for all vehicular classes except buses and the effect was negligible for minor road since the modifications were only carried out along major road.
- Scenario-3 improved the conditions by reducing queue length, decreasing travel time and overall delays to all vehicular classes.
- An identical impact on intersection's performance was also observed. Scenario-2 caused an increase in average delay, and queue length and reduction in average speed.
- Scenario-2 improved the conditions for buses at the cost of degraded performance of intersection and other vehicular classes. Scenario-3 provided a balance solution for intersection and all vehicular classes but it will involve acquisition of additional space for provision of BOLs as additional lanes.

The findings of this study can help decision makers to identify the potential locations to improve the travel times for public transport vehicles throughout their route by implementing the proposed strategy. This can help to improve the image of public transport and will make it competent to private modes in terms of travel time and induced delays at intersections. The focus of this study was to introduce the BOLs in current control conditions and no input was considered from signal optimization point of view. Future studies can investigate signal priority for buses in conjunction with BOLs to study the impacts which can results in improved performance for public transport vehicles and will provide a better sense of priority to the daily commuters. Also the planners and decision makers seeking to introduce any para-transit service can identify the impacts on wagons, rickshaws and other relevant vehicular classes to revisit the policies.

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