Optimizing Performance of at-grade Intersection with Bus Rapid Transit Corridor and Heterogeneous Traffic

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ABSTRACT
Bus Rapid Transit (BRT) has emerged as a preferred mode of public transport in various countries all over the world for its cost effectiveness in construction as well as in operation and maintenance. The rapid transit feature of BRT is seen as a solution to many traffic problems in these countries. However, in developing countries like India, the right –of-way for most of the roads is restricted and traffic is heterogeneous in nature. Provision of BRT in existing right –of-way reduces the capacity available for other motorized traffic. As the buses travel with a certain frequency on dedicated bus- ways, the dedicated corridor remains unused for most of the period when other traffic on motorized vehicle (MV) lanes suffers from congestion. The problem gets severe at intersections. However, if buses are operated in mixed traffic it is no more rapid transit. Hence, a solution is required to address this problem and optimize the performance of traffic as a whole. This paper presents the effect if dedicated bus-ways end at a reasonable distance before the stop line at a busy signalized at-grade intersection, and bus lanes (beyond that) are made available to all the motorized vehicular traffic (heterogeneous traffic) at intersection. The performance evaluation is done in terms of average queue length, maximum queue length, average delay time per vehicle, vehicle throughput, average speed in network and emission of Carbon monoxide CO, mono-nitrogen oxides NO_x and Volatile organic compounds (VOC). It is observed that availability of bus lanes to other motorized traffic for a reasonable distance before intersection considerably reduces the average queue length, maximum queue length, average

delay time per vehicle and emission per vehicle, while there is an increase in vehicle throughput and average speed of all the vehicles in the network. Thus it results in reduction of congestion and performance enhancement of at-grade intersections and network. Results of investigation are relevant in international context. VISSIM, a microscopic simulation tool, is used to model the heterogeneous traffic and public transit lines under constraints of roadway geometry, vehicle characteristics, driving behaviour and traffic controls. The effect is investigated with different random seeds to obtain reasonable results for analysis.

Keywords: Bus Rapid Transit (BRT), Performance Optimization, Microscopic Simulation.

1. INTRODUCTION

Bus Rapid Transit (BRT) is a high quality, consumer oriented transit that delivers fast, comfortable and cost effective urban mobility [1]. Since BRT provide transit at a cost much lesser than other options, it is emerging as a preferable mode of transit in developing countries like India. However, urban roads in these countries have restricted right-of-way. Provision of BRT within the existing right-of-way does affect mobility of other vehicles and congestion for traffic (other than bus) gets increased. As the buses travel with a certain frequency on dedicated bus ways, the dedicated corridor remains unused for most of the period when other traffic on motorized vehicle (MV) lanes suffers from congestion. However, if buses are operated in mixed traffic it is no more rapid transit. Hence, a solution is required to address this problem and optimize the performance of traffic as a whole. The effect of dedicated BRT lane on other traffic becomes more evident at intersections. Intersections are usually the bottlenecks of the network and are the greatest and immediate source of the traffic accidents. Thus, Level of Service (LOS) at intersection significantly affects the overall LOS of road [2]. The critical aspect of increasing the throughput of any road system lies in increasing the throughput of the intersection. Thus, optimization of traffic performance as a whole, at intersection is required so that BRT may not greatly reduce overall potential capacity of system at intersection; at the same time, merits of BRT as rapid transit may be maintained.

Traffic in most of the developing countries as well as in some developed countries, is highly heterogeneous, comprising of different types of vehicles with widely varying static and dynamic characteristics [3, 4]. Traffic simulation is a powerful and cost-efficient tool for traffic research, testing different alternatives and evaluating them. The simulation model allows to predict the outcomes of a proposed change to the traffic system before it is implemented, and to evaluate the proposed solution [4]. Thus, in order to study the behaviour and various interactions at intersection, simulation studies are carried out. In this paper microscopic simulation tool VISSIM (version 5.3, official license available) is used to model urban traffic. VISSIM is a microscopic, time step and behaviour based simulation tool. The program can simulate multi-modal traffic flows, including cars, goods vehicles, buses, heavy rail, trams, light rail, 2-wheelers (scooter, motorcycles), 3-wheelers (auto rickshaw, tuk-tuk), bicycles and pedestrians. VISSIM has been used to model the heterogeneous traffic and public transit lines under constraints of roadway geometry, vehicle characteristics, Indian driving behaviour and traffic controls [5].

This paper presents the effect if bus-ways end in good time before the stop line at busy signalized at-grade intersection, and dedicated bus lanes are made available to all the motorized vehicular traffic (heterogeneous traffic) at intersection. The performance evaluation is done in terms of vehicle throughput, average queue length, maximum queue length, average delay time per vehicle, average speed and emission of Carbon monoxide CO, mono-nitrogen oxides NO_x and Volatile organic compounds (VOC). The effect is investigated with different random seeds to obtain reasonable results for analysis. It is observed that availability of bus lanes to other traffic for a reasonable distance before intersection considerably reduces the average queue length, maximum queue length, average delay time per vehicle and emission per vehicle, while there is an increase in vehicle throughput and average speed of all the vehicles(in network). Thus it results in reduction of congestion and performance enhancement of at-grade intersections and network. The reduction of emissions per vehicle may be translated in reduction in Carbon-dioxide which may lead to earning of carbon credits.

So far, various literatures present studies only to justify BRT as a solution to traffic problems. However, the countries which are opting for BRT realized that BRT is a solution at the cost of congestion of other motorized traffic. Thus it is in fact, a shifting of congestion from one mode to other. Hence, there is a need of optimization of traffic as a whole so that all the modes may get benefitted from the solution and there may be maximum ease of congestion. This paper presents one of such investigation.

2. SIMULATION MODEL

VISSIM uses the psycho-physical driver behaviour model developed by WIEDEMANN [5]. The basic concept of this model is that the driver of a faster moving vehicle starts to decelerate as he reaches his individual perception threshold to a slower moving vehicle. Since he cannot exactly determine the speed of that vehicle, his speed will fall below that vehicle's speed until he starts to slightly accelerate again after reaching another perception threshold. This results in an iterative process of acceleration and deceleration. Stochastic distributions of speed and spacing thresholds replicate individual driver behaviour characteristics. VISSIM's traffic simulator not only allows drivers on multiple lane roadways to react to preceding vehicles, but also neighbouring vehicles on the adjacent travel lanes, are taken into account. Moreover, approaching a traffic signal results in a higher alertness for drivers at a distance of 100 meters in front of the stop line. VISSIM simulates the traffic flow by moving "driver-vehicle-units" through a network. Every driver with his specific behaviour characteristics is assigned to a specific vehicle. As a consequence, the driving behaviour corresponds to the technical capabilities of his vehicle. Attributes characterizing each driver-vehicle-unit are (1) Technical specifications of the vehicle, e.g. length, maximum speed, potential acceleration, actual position in the network, actual speed and acceleration (2) behaviour of driver-vehicle-unit, e.g., psycho-physical sensitivity thresholds of the driver (ability to estimate, aggressiveness), memory of driver, acceleration based on current speed and driver's desired speed (3) interdependence of driver-vehicle-units, e.g. reference to leading and following vehicles on own and adjacent travel lanes, reference to current link and next intersection, reference to next traffic signal.

Vehicular parameters are modelled in VISSIM defining parameters required to describe the various vehicular characteristics and also the parameters which govern the movement of the vehicles during simulation. This includes functions where the various acceleration and deceleration values which can be taken by various vehicles are specified. Speed distributions for various mean speeds of vehicles, weight and power of the vehicle, colour of vehicles during simulation, vehicle model in 2-D and 3-D distribution and dwell time distributions are specified according to the traffic conditions. Thus the various types of vehicles viz., car, jeep, taxi, SUV, two wheeler (scooter and motorcycle), three wheeler (auto rickshaw), bus, HGV, slow moving vehicle are specified along with their dimensions, functions and distributions. Along with these the parking lot selection, parameters for public transport and assigning of Indian urban driver behaviour model, are performed [5, 6].

3. DATA COLLECTION

In order to have conclusion from the investigation which may be relevant in international context, study area is chosen as Delhi. Delhi, the capital city of India and eighth largest metropolises in the world, with a population of approx 16.75 million has population density of 11,297 persons per sq km. The total area of Delhi is 1483 sq km with an urban area of about 925 sq km. The female and male ratio is 0.866:1 and literacy ratio is 86.34%. As per latest officially published data, in 2007-08 total vehicles in Delhi were 5.62 million with 5.31 million private vehicles and 0.31 million commercial vehicles. The composition of vehicles based on ownership is approximately 30.74% four wheeler private vehicles, 63.58% two wheeler private vehicles, 1.33% three wheeler (auto-rickshaw), 0.55% taxi, 0.94% buses and 2.86% goods vehicles including tractors. The annual compound growth rate of private vehicles is 6.84% while that of commercial vehicles is 0.81%. The transportation network of Delhi is predominantly road based and around 46% of total personal trips in Delhi are completed by using public transport system (bus and metro). The road network in Delhi is approximately 31,000 km. Since 1971 the road network is increased 3.7 times while the number of vehicles increased 26.29 times. The imbalance between growth of vehicles and road network emerged in heavy traffic congestion and reduced vehicle speed. There are number of roads in Delhi where traffic congestion is a regular and daily phenomenon [7, 8]. Such situation exists in many cities all over the world.

The BRT is introduced in Delhi to solve its traffic problems and first BRT corridor of Delhi is from Ambedkar Nagar to Delhi Gate a distance of nearly 14.5 km. Phase 1 of this corridor from Ambedkar Nagar to Moolchand Junction is operational, which is 5.8 km long. The location of the first corridor is shown on Figure 1 [7, 8].

Chirag Delhi intersection (Figure 2) which is fourth junction on the BRT corridor at CH 2980 and is a signal controlled 4 legged junctions is chosen to study the effect of BRT on other traffic at an at-grade intersection and to optimize the performance of intersection by making BRT corridor available for all vehicles for some reasonable distance before intersection. This intersection handles a large number of vehicles and pedestrians and witnesses daily traffic congestion. The entire geometry of the intersection was measured to replicate the intersection in simulation. Video-grapy

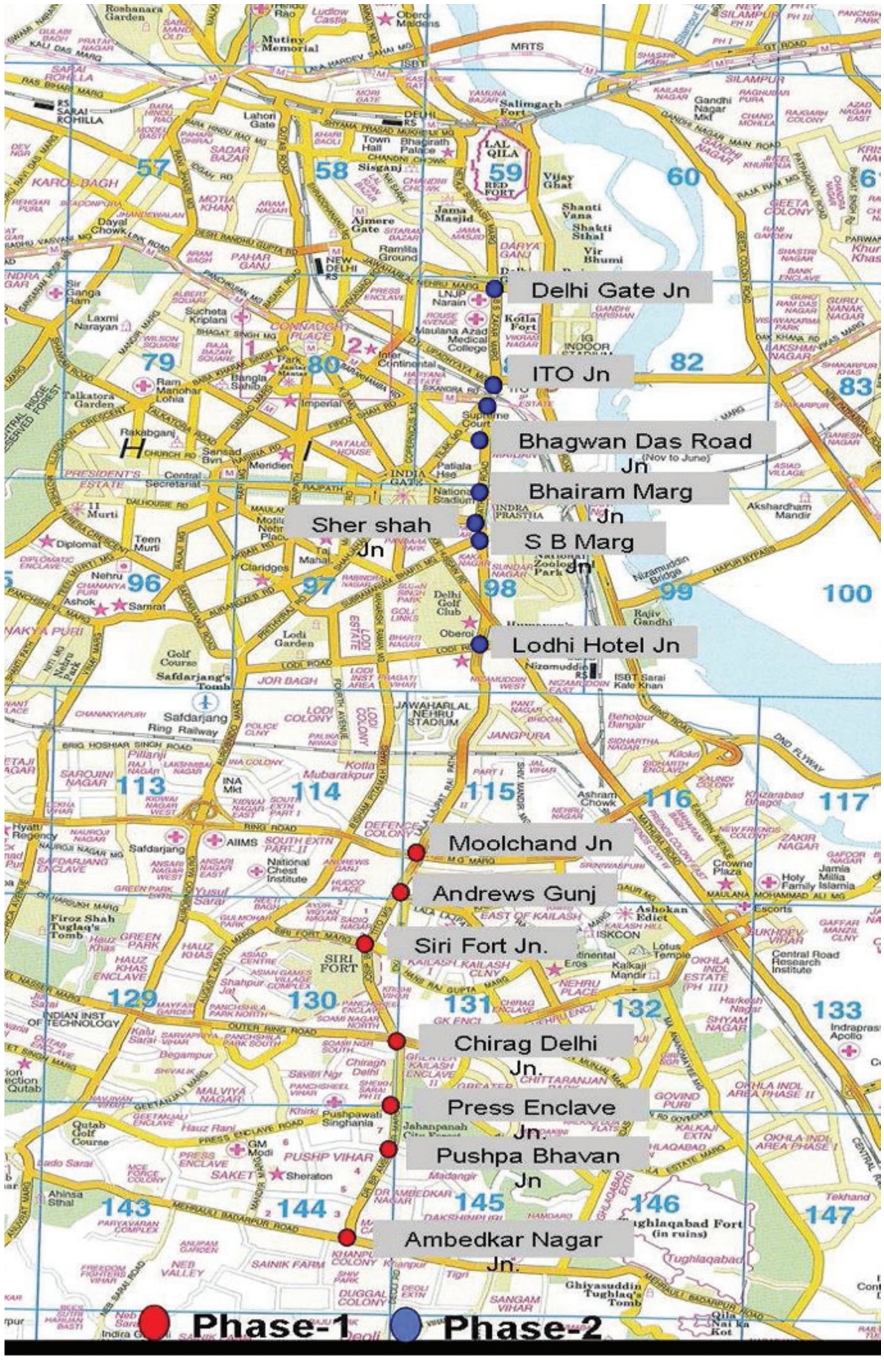
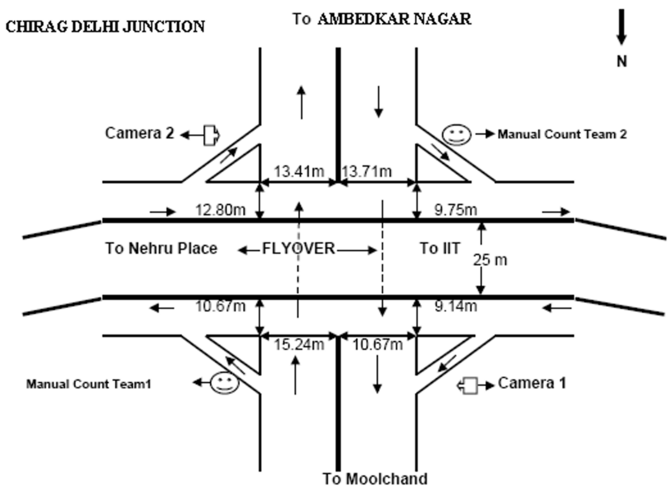


Figure 1. BRT Corridor -Delhi

method using synchronized high definition (HD) video cameras is used to extract traffic data for traffic composition, traffic moving through, right and left, queue length as well as time spent by vehicle in queue. The data was supplemented with manually collected data on road geometry and classified traffic survey to cover any omission during video recording. Travel times of vehicles going straight and turning right are collected. The traffic surveys were carried out during the morning peak period of 9am to 10am and evening peak period of 6 pm to 7 pm. The traffic data is shown in Figure 3 and table 1.



(a)

(b)

Figure 2. Chirag Delhi Intersection (a) before BRTS (b) after BRTS

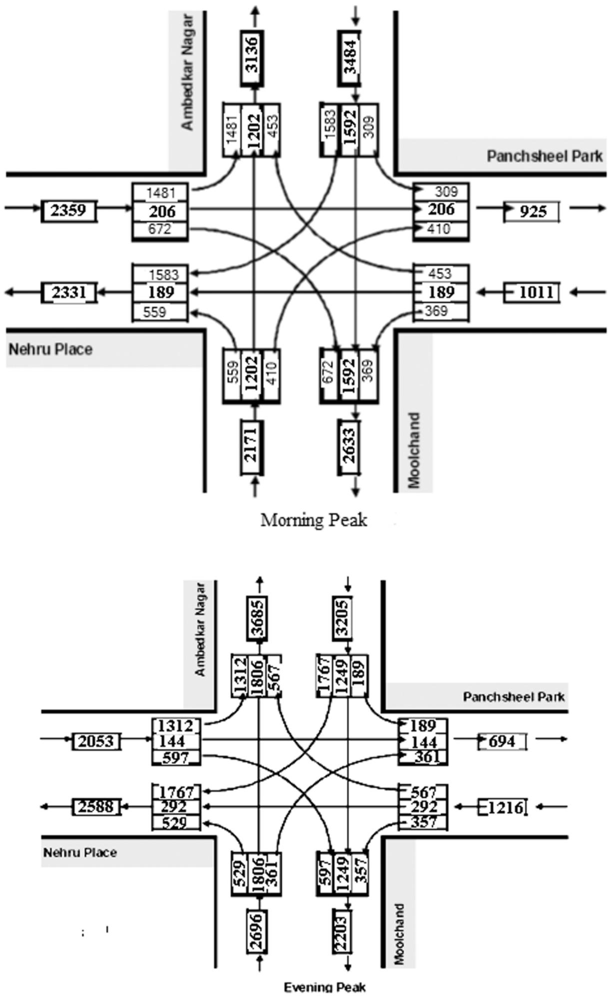


Figure 3. Traffic flow in PC with turning movements

Table 1. Traffic composition

Percentage of traffic composition for (08:00-20:00)

Car/Jeep/Taxi	Two wheeler	Three wheeler Auto Rickshaw	Bus	HGV	Slow moving vehicle
39	41	11	2	1	6

3.1 Calculation of Passenger Car (PC)

The PC value of a vehicle type is considered as dynamic instead of considering it as a constant. As it has been established by researches that in case of vehicles that are larger than passenger cars, at low volume levels , the PC value decreases with increase in traffic volume and at high traffic volume levels, the PC value increases with increase in traffic volume and whereas, in case of vehicles that are smaller than passenger cars, at low volume levels, the PC value increases with increase in traffic volume and at high volume levels, the PC value decreases with increase in traffic volume. Accordingly PC graphs developed by [4] for heterogeneous traffic are used to calculate PC of traffic up to V/C ratio equal to 1 and by extending these to account for V/C ratio more than 1 (Table 2).

Table 2. Volume Capacity Ratios

From	To	AM Peak Flow	Design Capacity at LoS C	Volume/Capacity Ratio
North bound				
Press Enclave	Chirag Delhi	3484	2400*	1.45
Chirag Delhi	Siri Fort	2633	2400*	1.09
Southbound				
Siri Fort	Chirag Delhi	2696	2400*	1.23
Chirag Delhi	Press Enclave	3685	2400*	1.53

* 2 lane carriageway in 1 direction' "Guidelines for Capacity of Urban Roads in Plain Areas", 1990

4. MODEL CALIBRATION AND VALIDATION

The model construction procedure consists of (i) identification of important geometric features (ii) collection and processing of traffic data (iii) analysis of mainline data to identify recurring bottlenecks (iv) VISSIM coding (v) calibration based on observations from (iii). Calibration is the process by which individual components of simulation model are refined and adjusted so that simulation model accurately represents field measured or observed traffic conditions. With regard to calibration, traffic simulation model contain numerous variables to define and replicate traffic control operations, traffic flow characteristics and driver behaviour. VISSIM simulation model contains default values for each variable, but also allows a range of user applied values for each variable. These variables are changed as per field measurements and observed conditions [5].

The geometry of existing network from Puspa Bhawan to Sri Fort with detailing of Chirag Delhi intersection was created using links and connectors which are the building blocks of VISSIM network. The number of lanes per road and width of each lane, left turning lanes on each approach road, central median, traffic islands and other road features were specified as per existing. After creation of network, the vehicle input for various links was given. This is followed by specifying the various routes in which vehicles travelled and the volume of these vehicles in each route is specified. The other features viz. positioning of speed limits, conflict zones, stop signs, signal heads are specified as per existing. The Transit stops are created and Transit lines are defined as per existing. The data collection points, travel time sections, queue counters and nodes are placed. The Indian driving behaviour is calibrated for the following parameters:

standstill longitudinal distance between the stopped vehicles, headway time in seconds, following variation which restricts the longitudinal oscillation and indicates how much more distance than desired distance a driver allows before he intentionally moves closer to vehicle in front, threshold for entering 'following' controlling the start of deceleration process, following threshold which controls the speed differences during the 'following' state, speed dependency of oscillation, oscillation acceleration, standstill acceleration, minimum headway, maximum deceleration of vehicle and trailing vehicle for lane change, overtaking characteristics, minimum lateral distance at different speeds, waiting time for diffusion. The vehicles are calibrated for desired speed distribution, weight distribution, power distribution and model distribution. The links are assigned behaviour according to driving behaviour. On Indian roads, because of heterogeneity of traffic, it is difficult to enforce lane discipline. Hence, vehicle occupies lateral positions on any part of road based on space availability; overtake within lane from both the sides. The validation of the model was carried out by comparing maximum queue length simulated by model for existing intersection on each approach road with field observed values. The simulation model was given multirun with 20 random seed numbers and average of 20 simulation runs was taken as final output of the model. The value of t-statistic, calculated based on observed data (t_o) for all the four approach road is below 2.00. The critical value of t-statics for level of significance of 0.05, at 19 degrees of freedom is 2.093. Thus, value of t-statistic, calculated on the basis of observed data, is less than the corresponding table value. This shows that there is no significant difference between the simulated and observed average queue lengths.

5. INTERSECTION MODIFIED FOR BRT BUS WAYS ALLOWED FOR OTHER TRAFFIC FOR CERTAIN DISTANCE

The model validated as above is used to study the effect if dedicated bus ways are allowed to other traffic for some distance (60m) before intersection. This distance is reasonable distance to make study while not disturbing existing BRT in major way. Chirag Delhi intersection is a 4 lane dual carriageway road, at the junction, with a segregated two lane BRT corridor along the centre of the road, segregated cycle tracks and footways on both side of road. The bus lanes width is 3.3 m thus total 6.6m while 6.75m on each side is for motorized vehicles. The Outer Ring Road passes on a flyover at this junction in the east to west direction.

The entry movements along the BRT corridor of this junction are critical and queues take a number of signal cycles to clear. Critical flows include:

(1) The straight through movements from north – south and the reverse;
(2) The right turning movement from the south to Nehru Place to the east;
(3) In addition there are heavy right turning flows from the Outer Ring Road, from east to north and west to south; and
(4) The left turn from the north to Nehru Place, to the east, also carries a high volume of traffic.

Figure 4. shows the Chirag Delhi Junction for VISSIM simulation.

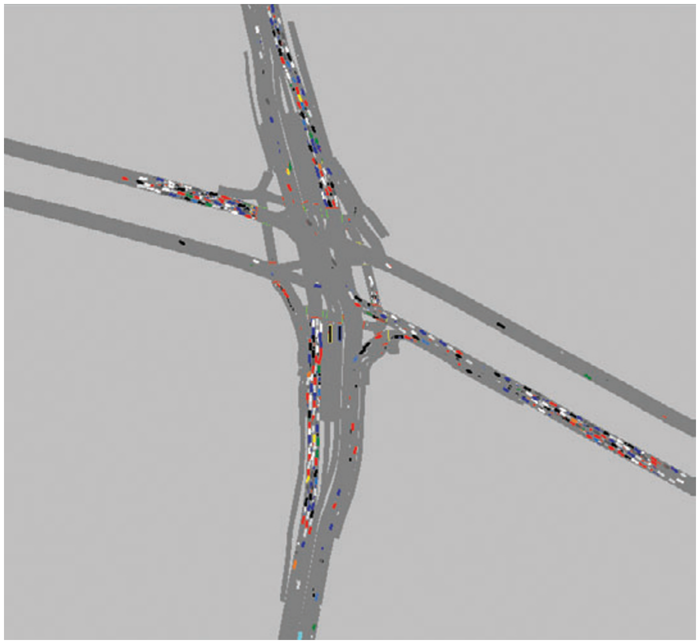


Figure 4. Chirag Delhi Junction VISSIM simulation snap shot

6. PERFORMANCE EVALUATION OF INTERSECTION EXISTING V/S MODIFIED (MODIFIED BRT WITH BUS LANES OPEN TO ALL MOTORIZED VEHICLES AT INTERSECTION)

Evaluation of performance of intersection is carried out for measurements of effectiveness (MOEs) such as average queue length, average delay per vehicle, emissions (CO , NO_x ,VOC), fuel consumption , maximum queue length , number of vehicles etc. The MOEs are plotted for both the cases to appreciate the changes when bus lanes are made available to all the motorized vehicles for length of 60m before intersection. Figure (5) to Figure (10) are arranged all together for reader's convenience and the results are interpreted after the figures.

Figure 5 to Figure 10 shows net effect if bus-way ends in good time (60m) before the stop line at busy signalized intersection, and dedicated bus lanes are made available to all the traffic (heterogeneous traffic) at intersection. Figure 5 shows that average queue length decreases significantly by approx. 44%. Figure 6 shows that maximum queue length is reduced by 40%. Figure 7 shows that average delay time per vehicle gets reduced by approx 32%. Figure 8 shows that throughput is increased by 6%. Figure 9 depicts the effect on emissions. Emissions are reduced as the average delay time is reduced; however, it gets increased when the number of vehicle passing through intersection increases. The net effect is the reduction in emission by 19%. Figure 10 shows that average speed of vehicles in the network gets increased by approx. 23%. It increases from 12.45 km/hr to 15.40 km/hr.

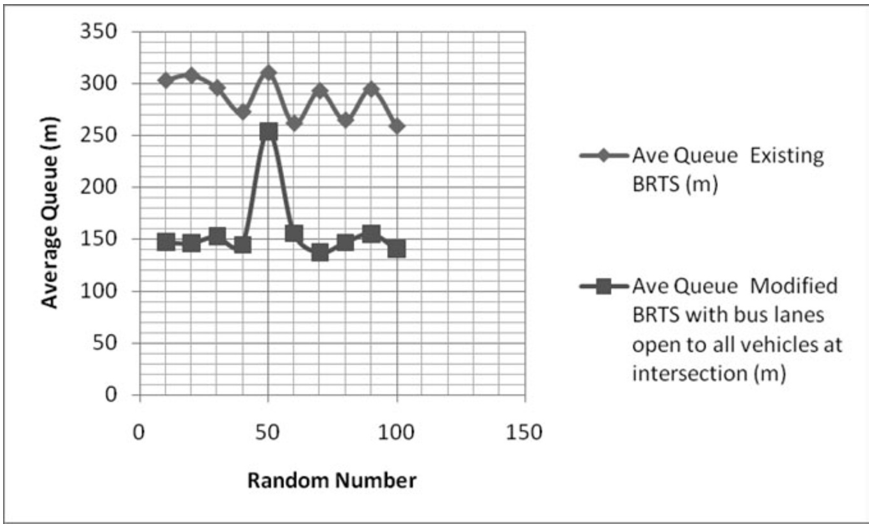


Figure 5. Comparison-Average Queue Length

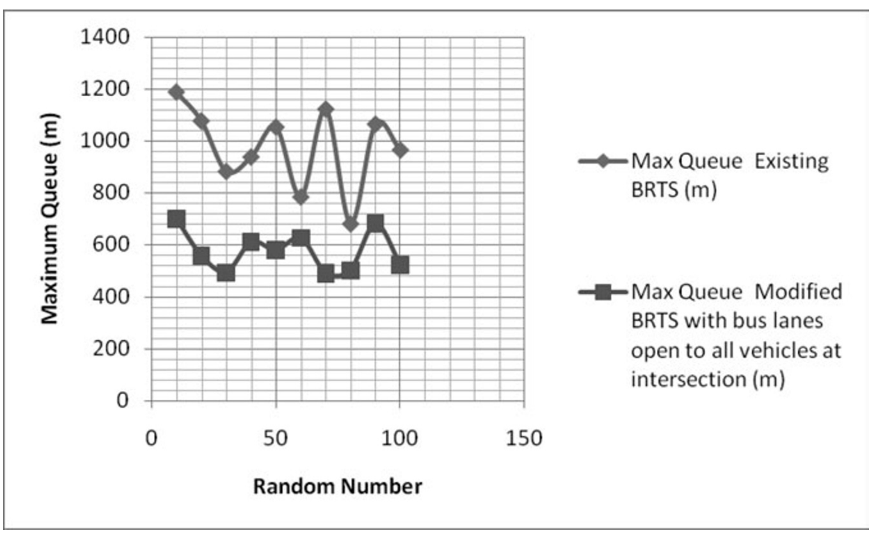


Figure 6. Comparison-Maximum Queue Length

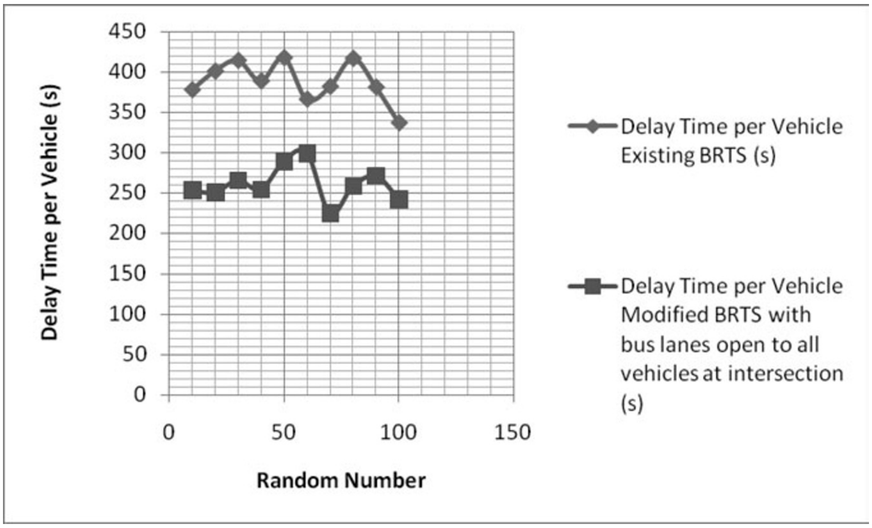


Figure 7. Comparison-Delay time per vehicle

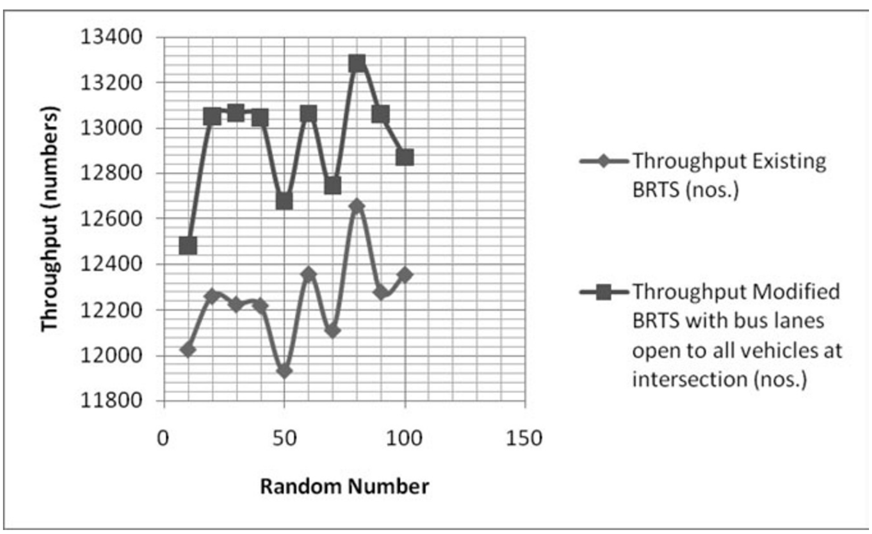


Figure 8. Comparison-Throughput

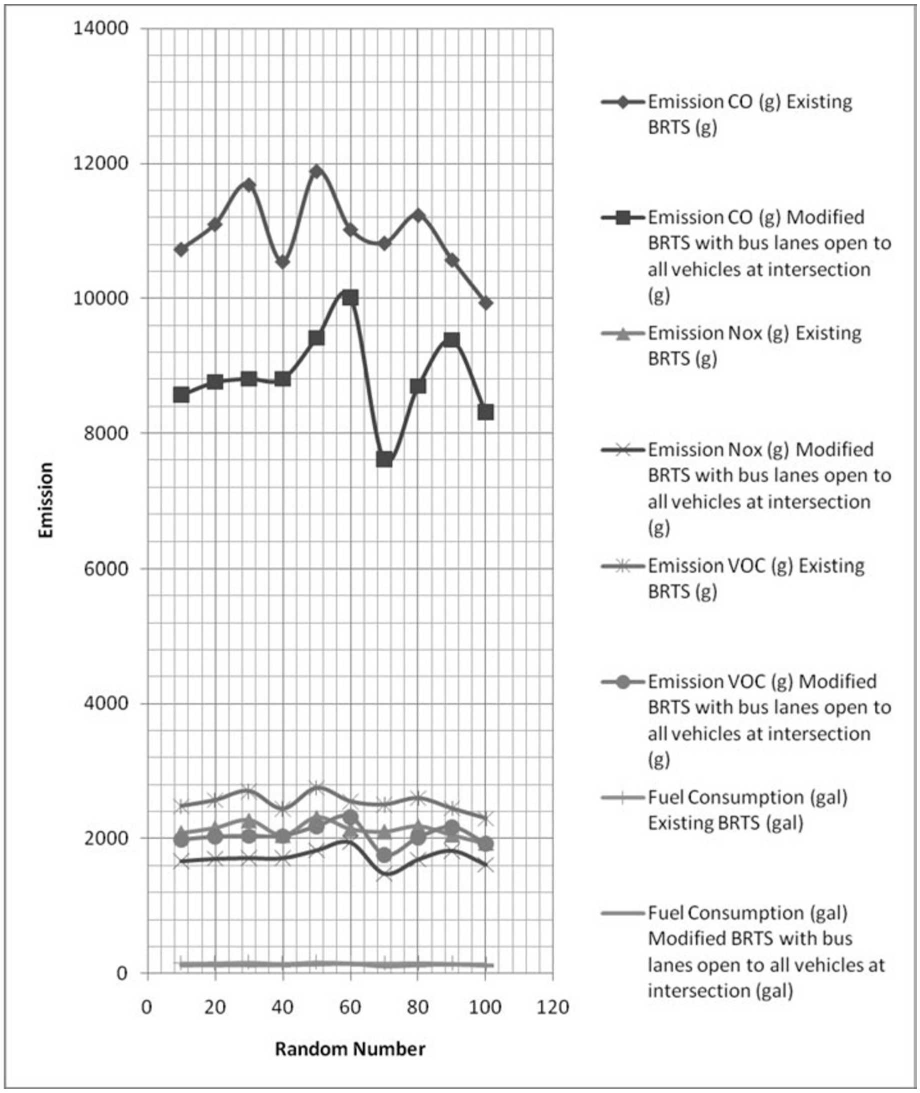


Figure 9. Comparison-Emission CO, NOx, VOC, Fuel Consumption

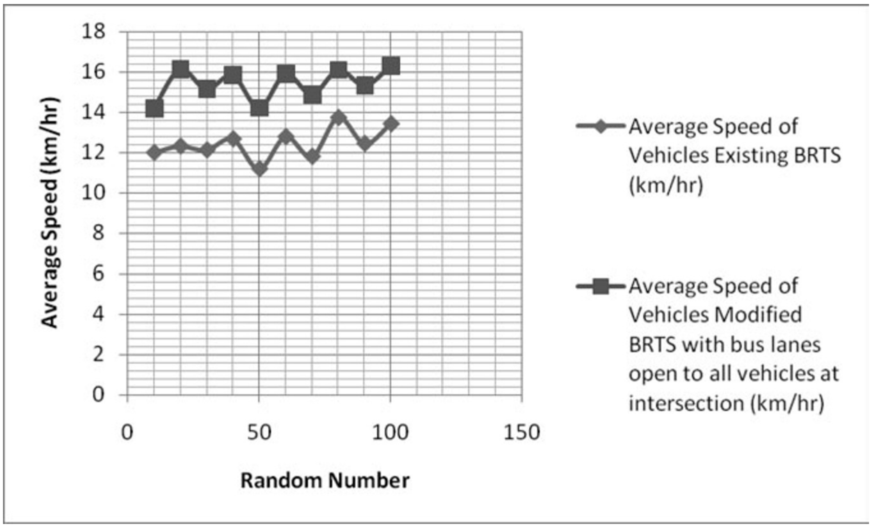


Figure 10. Comparison-Average Speed

7. CONCLUSION

In case of busy signalized at-grade intersections with BRTS corridor, if bus-way ends in good time before the stop line and dedicated bus lanes are made available to all the motorized vehicles (heterogeneous traffic) at intersection, the effect is significant decrease in average queue, maximum queue length and average delay time per vehicle. The throughput gets increased and there is a significant reduction in emissions and fuel consumption. The average speed of vehicles in the network gets increased by approximately 23%. This solution can bring about significant improvement in performance of intersection. The heterogeneous traffic under any driving behaviour can be modelled under constraints of roadway geometry, public transit lines, vehicle characteristics and traffic controls in microscopic simulation tool VISSIM and the simulations studies can be used to study the effect of various traffic improvement measures.

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