Examining Performance of an Urban Corridor Using Microscopic Traffic Simulation Model under Mixed Traffic Environment in India

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Abstract
The congestion at intersections in the case of dedicated mass transit system like Bus Rapid Transit Systems (BRTS), in conjunction with arterial roads results in delay to both BRT buses as well as private motorized traffic. The present study is focused on the evaluation of traffic flow characteristics on a busy road section of an urban arterial corridor with BRT system in Surat city, which includes five intersections. The work aims to evaluate the delays caused to both BRT buses and motorized vehicular traffic at the intersections using the microscopic simulation model, VISSIM 7.0. The present work attempts to deploy the simulation technique as a tool for improving the performance of the urban arterial corridor. The work focuses on the development of the microscopic simulation model of the study stretch including the model calibration and validation. Thus, developed simulation model was used for evaluating the feasible alternative traffic management measures, which may result in reduction of delay and travel time to both BRT buses as well as private vehicles in motorized lane, which may eventually result in emissions reduction also. Furthermore, it is emphasized that the performance of the overall transport system in the urban corridor can be improved by implementing well tested traffic management strategies using simulation beforehand.

Keywords: Urban arterial, BRTS, delays, travel time, simulation, traffic management.

1. Introduction

Performance of urban arterial can be measured in terms of various performance indicators, which can be termed as measures of effectiveness. The traditional and conventional performance indicator that is being used for evaluating the level-of-service of any road facility, in general, is Volume to Capacity (V/C) ratio at given level of operating speed. In case of urban roads, this measure alone may not be appropriate enough to evaluate the overall operational performance. Also the measurement of capacity and its direct implication under varying traffic compositions may be difficult to comprehend, especially in the case of heterogeneous traffic conditions. Also simple measures like delay and travel times are easily perceivable and can be communicated to travelers as well. So, it is quite imperative that the delays and travel times under varying flow conditions are to be studied so as to assess the performance of a particular urban road. Further, dedicated mass transit systems like Bus Rapid Transit Systems (BRTS), Light Rail Transit System (LRTS) etc. have to be given due considerations in evaluating the performance of the corridor, which are integrated with them. Also, the movement of pedestrians (if dominant) has to be considered for assessing the performance of overall roadway facility. The variations in travel time and delays for the mass transit systems, corresponding to traffic management strategy of Mixed Vehicle (MV) traffic lanes are to be duly examined. Performance measures like travel time variability and reliability along with delays will produce better understanding of the traffic flow characteristics under prevailing traffic conditions. The aspect of travel time reliability (TTR) for calculating the different indicators can also be used to measure the effectiveness of rerouting of traffic (please see Torrisi et al., 2017 and Torrisi et al., 2016).

The delays on urban road in general, are majorly derived from incidents, traffic interruptions (intersections) and insufficient road width or capacity for traffic flow movement. Apart from roadway capacity, the overall performance of urban corridor under given roadway and traffic conditions depends mainly on delays at intersections and at merging or diverging sections. The intersection delays can be minimized with ease unlike delays at merging and diverging sections. Also, the delays at intersections majorly contribute to the overall travel time of the interrupted road corridors. Delays at all intersections over a road section or corridor may not equally contribute to the overall corridor performance. The delays at some critical intersections may adversely affect the traffic movement in all directions of flow. In general, the intersections which have comparatively higher delays in a segment of the corridor may be termed as critical intersections. These are the intersections, where two major urban roads of significant traffic flows cross each other at the same level (at grade). In the absence of proper traffic control and management, these intersections deteriorate the performance of roads traversing through it. Hence, such critical intersections are to be critically assessed based on the existing traffic conditions and suitable traffic management or control measures needs to be adopted.

The intersection delays can be possibly minimized with the enforcement of traffic signal with appropriate signal timings for the smoother maneuvering of vehicles at the conflict areas of the intersections. The existing traffic signal timings (in case of signalized intersections) can be optimized so as to reduce the overall delays in the system. Intersections with manual control may also serve the purpose of safe maneuvers and thereby, avoiding any chaotic movement. This will reduce the risk of probable crash occurrence and also the delays to the traffic stream. In some cases, where there is no feasibility of providing traffic signals or manual control, the effective traffic control or management measures (like traffic diversions or adoption of traffic calming devices) can be implemented for improving the road performance. The available traffic management measurements, which can be feasibly implemented, are to be evaluated so that the best feasible measure can be adopted. These measures can be adopted as traffic management measures on short-run basis or for emergency purposes. Further, in a long-run, feasible permanent traffic management strategy can be implemented based on the future traffic forecasts. The alternative traffic management strategies can be better evaluated or prioritized with the help of microscopic simulation technique before actual field implementation.

Present study focuses on the evaluation of 1.8 kilometers stretch along the Udhna Darwaja – Sachin BRTS corridor in Surat city in one direction. The selected stretch extends from Udhna Darwaja BRTS bus stop to Udhna Teen Rasta BRTS bus stop and includes four major intersections. It was observed from the preliminary surveys that all of these intersections are un-controlled. The roads connected through these intersections carry huge traffic during the peak periods of the day. As the intersections present along these roads are uncontrolled, chaotic and unsafe traffic movements are observed during peak hours and thereby, delays are increased significantly because of vehicular queues. Also, BRT bus line is passing through this intersection and faces significant delays at this intersection because of improper traffic control. In the present study, the simulation technique was adopted to evaluate the effect of two feasible traffic diversion scenarios, which can be adopted at the intersection so as to reduce the overall vehicular delays in the corridor. The simulation model for the stretch is developed using VISSIM 7.0 and the model is validated using the trial-and-error process. Model validation is carried out so that few important derived parameters from the simulation are in with the field observations. Iterative process in the validation stage is carried out till the minimum error of 15% is achieved. Analysis includes the comparison of delays calculated at the critical intersections for before (base case) and after implementation of the traffic management measures in the VISSIM model. Best feasible alternative measure is proposed which results in minimum delay to both BRT buses and motorized vehicular traffic.

2. Literature Review

From review of literature (past studies), it is noted that as there are very less research contributions in the area of evaluation of urban corridor under Indian traffic conditions, also considering the public transport system (present if any) inclusively. The literature related to microscopic simulation techniques are also studied in order to understand the various simulation parameters to be adopted in VISSIM 7.0 according to the study area's traffic characteristics. Siddique & Khan (2006) wanted to evaluate the capacity of BRTS 20-years later and three scenarios were built showing different numbers of buses and operating conditions. This study corresponds to a BRT system operation in the city of Ottawa, Canada. This research shows as main result, differences up to 35% between the estimated capacities using the Highway Capacity Manual-2000, when compared with simulation results. This outcome confirms how the use of formulas and deterministic conditions can yield significantly different results from the capacity of a system compared to a micro-simulation model and thereby, confirms need of using stochastic elements in the process. Arasan and Vedagiri (2010) developed a new simulation model "HETEROSIM". This is developed considering the mixed traffic conditions in India. Rangarajan (2010) developed a micro-simulation model to analyze a traffic situation before and after the implementation of a BRTS for the city of Pune in India being the first city to introduce BRTS. The comparison of BRTS with the regular bus transit system (without dedicated or segregated bus lanes) is carried by modeling and simulating both systems under various scenarios. Results indicated that BRTS not only carry savings in travel time, but also represents a more efficient system compared to a system without segregated bus lanes.

In some studies, evaluation of BRTS in some of the Indian cities is also carried out based on some scores and ratings considering some parameters like service planning, infrastructure, station design and station bus interface, quality of service and passenger information systems and integration and success. Many of the available research works suggested the use of microscopic simulation for the evaluation of BRTS in India (Gautam *et al*. (2013)). As BRTS is located in some metropolitan Indian cities with space restrictions for road constructions and widening, the evaluation needs to be carried out periodically, so that the delays are reduced significantly both for the BRTS and mixed traffic, mutually. The BRTS evaluation has been carried out in many research works using the quantitative, qualitative and economic perspectives. From the literature review, it can be seen that, there are many studies focused on evaluating the performance of public transportation system, but with less emphasis on private transport system. Besides, encouraging the public transport, private transport has to be equally considered for improving the efficiency of the overall transport system as a whole. Raj *et al*. (2013) studied a quantitative performance approach using micro-simulation technique, which has been formulated and aimed to evaluate the open system BRTS corridor functioning in Delhi. The study was basically focused on engineering parameters for evaluating the performance of BRTS. The link performance functions developed for the MV lane and Bus-lane of Delhi BRT corridor were optimized using the Golden Section method India (Gautam *et al*. (2013)). It was observed that 0.677 is the optimal point i.e. V/C for the MV Lane and 0.640 for the Bus Lane of Delhi BRT corridor and the corresponding traffic volume is 2438 PCU/h and 1120 PCU/h on the corresponding MV lane and BRT Lane, respectively.

As reported, very less literature is available based on the segment analysis on BRTS corridor. Also past research works did not emphasize on the assessment of comparison of feasibility of different traffic management alternatives for improving the efficiency of an urban road. Alos studied did not focus upon the detailed methodology for developing the microscopic simulation model under heterogeneous traffic conditions. The present study aims at identifying the critical segment in an urban corridor with BRTS, which majorly affects the corridor performance in general. This study also elaborates the detailed methodology of identifying the effective traffic management measures for reducing the delays over road section using the microscopic simulation model.

3. Study Section

Surat city is located on the bank of the river Tapti in the state of Gujarat and has an approximate area of 326 Square Kilometer. The modal share, currently in Surat city is: Private vehicles (cars and motorized two-wheelers: 60% to 70%; Intermediate Public Transport (Auto rickshaw): 20% to 25% and the modal share of public transport is less than even 1% (Service level benchmark- Urban transport report). It is extremely important to encourage the usage of public transportation to attract more users so as to enhance the mode share by public transport means. This is only possible with the effective planning, design, operation and management of the public transportation system with proven practices. In conjunction with this, private transport cannot be completely ignored and aim should be focused at improving the performance of the overall transport systems.

A reconnaissance survey was conducted in order to identify the critical segment over the selected BRTS corridor in terms of delay and traffic congestion. For this purpose, the travel time was measured using performance-box, a GPS equipment, which gives real time speed every 0.1 seconds. Five trial runs were made and then, the segment of about 1.8 km out of the total 9.5 km BRTS corridor was selected for detailed investigation. The selected study segment comprises of five un-controlled intersections. Further, critical intersections along the selected study segment (1.8 Kms) are identifed based on the delay to both BRTS buses and also mixed traffic comprising of motorized two-wheelers, three-wheelers, cars, Light Commercial Vehicles (LCV), Bus and Trucks.

The travel time for MV lane was also measured using cars as well as two-wheelers probed with GPS equipment as test vehicles under peak hour and off-peak hour traffic. All the major side roads intersecting the main corridor were identified in order to understand the overall traffic situation and also for planning of requirement of man-power for collecting traffic data collection. The selected segment of 1.8 km also consists of a flyover of 550 meters length, extending from the distance of about 100 meters away from Udhna Darwaja towards Sachin. The considered study section comprises of five BRTS bus stops, and is shown in Figure 1.

Figure 1: Google Image of study segment (1.8km) with road names and BRTS bus stops

4. Data collection

The traffic surveys were conducted in order to collect required primary data of road inventory, classified volume count, speed and spot speeds. The road inventory data is very important for creating the road geometry as per real field conditions and development of network in VISSIM for modeling the traffic operation both in BRT and MV-lanes. Classified volume count and spot speed data is mandatory for characterizing the different arms of intersections along with the mid-block sections in BRT and MV lanes, as per field observed conditions. These data sets along with microscopic characteristics such as acceleration, deceleration characteristics, lateral gaps, etc. are used for the development of the simulation model, VISSIM. For validating the model, the speed and delay data (which are derived parameters of the BRTS& MV lane traffic under prevailing roadway and traffic conditions) are considered for checking the credibility of the model for evaluating the traffic operation and management of the selected urban-corridor section as a whole.

The Road Inventory Survey was carried out to measure the road geometry and characteristics like width of the carriage way of different arms, width of BRTS corridors shown in Figure 2. This Survey is carried out manually during the early morning hours of free-flow or no-traffic conditions to ensure the safety of the surveyors and enhance the ease of measurement. The effective width of the carriage way at the intersections was found out for designing the intersection zone appropriately in the simulation model. The vertical levels of flyover are considered at various points along with the chainage readings and the average gradient of the flyover was also measured to design the flyover in VISSIM.

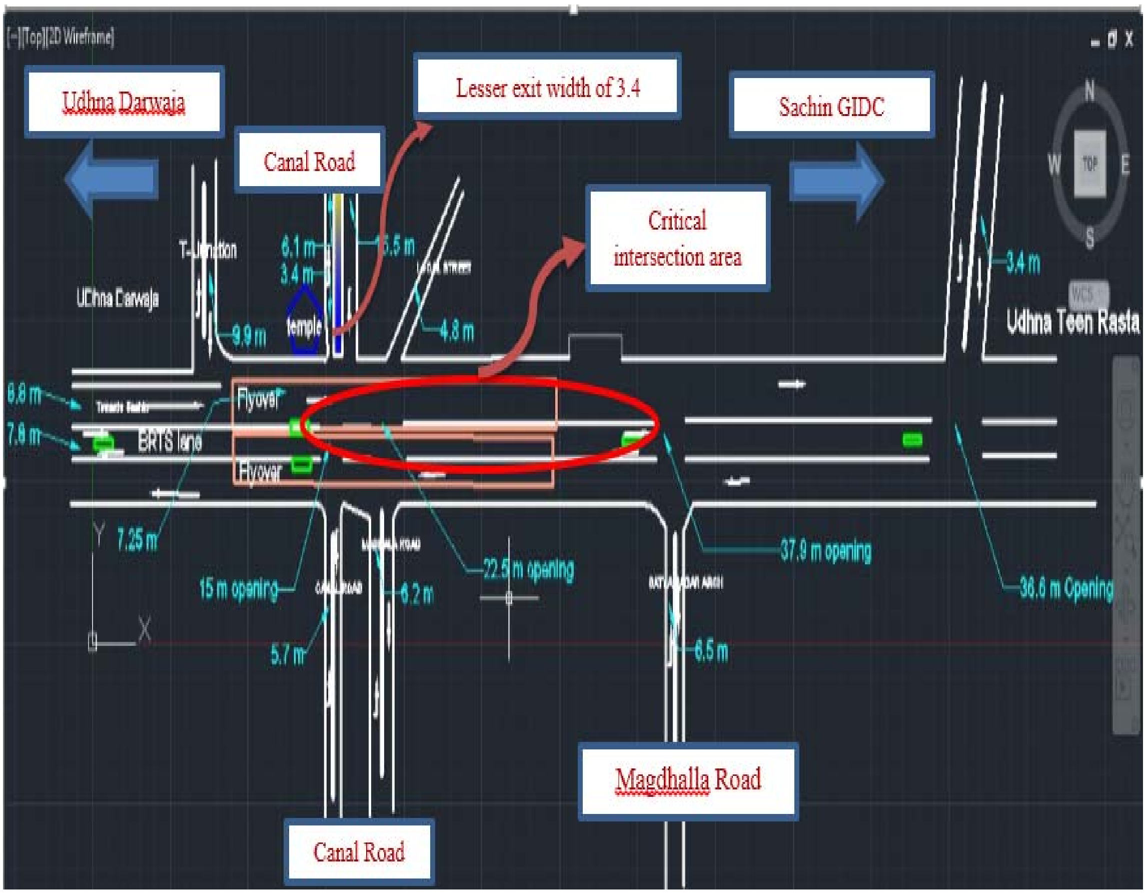

Figure 2: CADD drawing illustrating Road Inventory Survey outputs

The classified volume count surveys were conducted for the morning peak hour (11:30 AM to 12:30 PM) and evening peak hour (5 PM to 6:30 PM).Turning movement count survey was also conducted on all the five intersections using manual method in some directions and Video graphic method is employed in other directions based on the availability of vantage points for mounting video camera. Video graphic method is also employed for capturing the traffic flow in some directions, because of limited resources. In video graphic method, three cameras are installed at three different locations at one of the major critical intersections as shown in Figure 3. The cameras are fixed over tripod stands and are mounted with synchronization in such a way that they can capture intended directions of traffic flow with maximum possible visibility and accuracy.

Speed variation of selected vehicular categories (Car, Motorized two wheeler) and BRTS bus was collected using the performance box (velocity or V-box) during the time period of data collection. From the speed profile data, delays at each intersection are evaluated. Critical intersections are identified based on the maximum amount of delays observed along the road section. The travel time data collected using the performance box and manual methods in different directions is used for the validation of VISSIM simulation model. Number of runs of travel time data for each possible direction at the intersection for two wheelers (since Two-Wheelers are found to be in maximum proportion an all approaches of intersection) is collected for the purpose of the validation process of the base network model.

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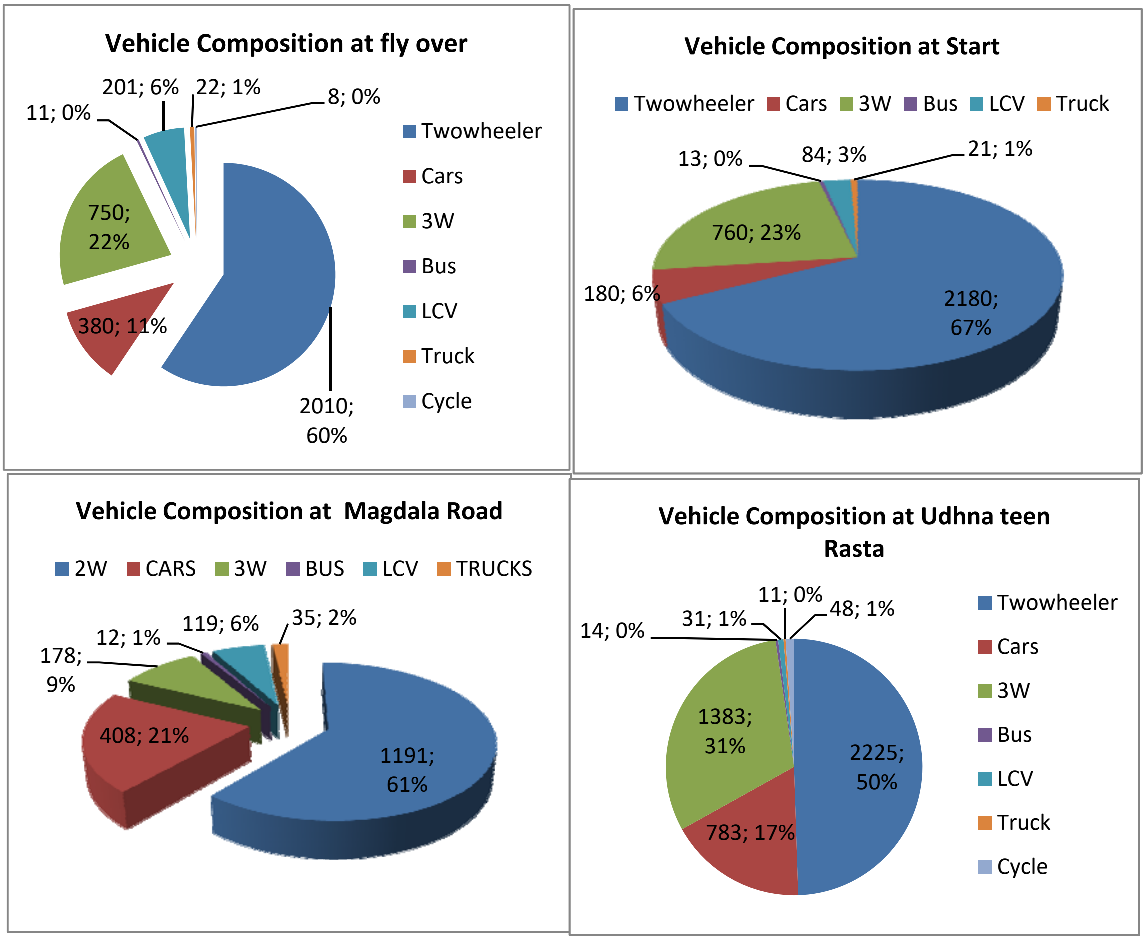
Figure 3: Camera Positions for Video graphic Survey

Spot Speed Survey was carried out using Radar guns at different approaches of each arm just before every intersection zone. This survey helps in determining the free-flow speeds of different vehicular categories in each arm before entering the intersection zone. This data was used for modeling speed distributions (Normal) in VISSIM model. The spot speeds of different vehicular categories are collected for every 5-minute interval in the morning peak hour for total of thirty minutes. The sample size was adopted depending on the traffic composition in various arms and was fully independent. The error in spot speed reading is avoided by keeping the angle of deviation of line of sight of gun with center line of vehicle as minimum as possible.

The travel time data for the BRTS buses was collected using ANPRS (Automatic Number Plate Registration System) which collectes travel time data based on vehicle detection along with its number plate at entry and exit points. The travel time data was collected for about five hours in a day during 11 AM to 4 PM. Two cameras were installed at points and focused in such a way that registration license plate of BRTS buses is visible and captured by the cameras. One camera is installed at a ramp at the exit point of Udhna Darwaja BRTS bus stop, which is originating point of BRTS corridor. Another camera is installed at the exit point at Sachin GIDC BRTS bus stop, which is at a distance of around 8.5 Km from Udhna Darwaja. Number of boarding and alighting passengers in each BRTS bus stop is noted and the dwell time at each bus stop is also measured for and the average is given as input to VISSIM model.

5. Data extraction and processing

The data extraction process consists of enumerating the number of vehicles in each direction of traffic flow at intersections from the videos as well as manual traffic count survey sheets. The volume count is carried out for the morning peak hour considering five-minute time interval. The total number of vehicles generated from every arm is calculated for every ten-minute for the duration of one hour each in morning peak hour. This is calculated by adding the number of vehicles counted in every possible direction from the arm. The relative flows for each direction in an arm are calculated by dividing the number of vehicles in a direction of the arm with the total number of vehicles generated from that arm. This is required to give vehicular volume inputs for every link at the starting positions in VISSIM model. In this case, the sum of relative flows for all



the directions in an arm will be equal to one (i.e.100%). The traffic composition at different roads in the study stretch is obtained from the Classified Vehicular count data and results are shown in Figure 4.

Figure 4: Traffic composition data at different locations on BRT corridor

The data from two cameras of ANPRS is collected and the time stamps for each registration number of a bus are matched at both the stations and time stamps for that

BRTS bus at the origin and destination are noted. Travel time for each BRTS bus is calculated based on the difference between time stamps of that number plate of a bus at the two stations and travel time analysis is carried out as shown in Table 1. Average waiting time of BRTS bus at various bus stops is calculated approximately from the reconnaissance survey. The mean travel time for bus in one direction of BRT corridor, considered under this study was found to be 26.352 minutes with a standard deviation of 0.61 minutes. Journey speed of BRT buses was observed to be about 22 Kilometer per hour (Kmph) over a length of 9.5 km.

Table 1: Travel Time Analysis for BRTS Bus (minutes)

Reg.no.	Entry time (h:m:s)	Exit time (h:m:s)	Travel time (h:m:s)
GJ05BT9851	10.49.03	11.13.49	0.24.46
GJ05BU3398	10.58.09	11.24.28	0.26.19
GJ05BT9909	11.05.55	11.33.28	0.27.33
GJ05BU3824	11.13.00	11.40.47	0.27.47
GJ05BT9827	11.20.44	11.44.37	0.23.53
GJ05BT9845	11.30.02	11.52.41	0.22.39
GJ05BU3387	11.38.26	12.02.28	0.24.02
GJ05BU3663	11.46.37	12.13.04	0.26.27
GJ05BT9860	11.53.18	12.17.38	0.24.20

(**Note**: h: m: s is hour: minute: seconds)

Spot speed data collected using radar guns in the free-flow conditions during the early morning hours is recorded. The parameters like minimum, maximum, 15th, 50th, 85th percentile speeds for each vehicular category are calculated and are used for calibrating the simulation model. This data was used for assigning the desired speed distribution to the various vehicular categories considered as inputs in the simulation model. This is the very important input, as it characterizes the road surface, drivers and type of road for a given vehicle category. Data collected from V-box using the external memory card is transferred in to the computer system using Performance-box software provided by the V-box manufacturer. Various plots like Speed V/s Time, Speed V/s Distance for various modes like BRTS bus, car and motorized two-wheeler are extracted. This data was collected at different locations of corridor, which was further used for validating the simulation model.

6. Microscopic simulation of study segment

Microscopic simulation can be effectively used for assessing the effectiveness of traffic control measures or performance of road segments including intersections (Rao et al. (2015), Shekhar babu et al. (2017)). Apart from this, simulation is an effective tool for evaluating the impact of transit signal priorities on travel time and delays along the arterial roads (Stevanovica et al. (2008)). The methodology to be followed for the microscopic simulation of traffic flow on the selected urban arterial using a simulation model, named, VISSIM is shown in the form of a flow chart in Figure 5. In microscopic simulation, a model which accurately represents the existing situation according to field conditions is known as the 'Base Model'. The base model development in traffic simulation can be summarized in the following steps: (1) Developing base network, (2) Defining model parameters (stochastic and deterministic), (3) Calibrating the model, and (4) Validating the model.

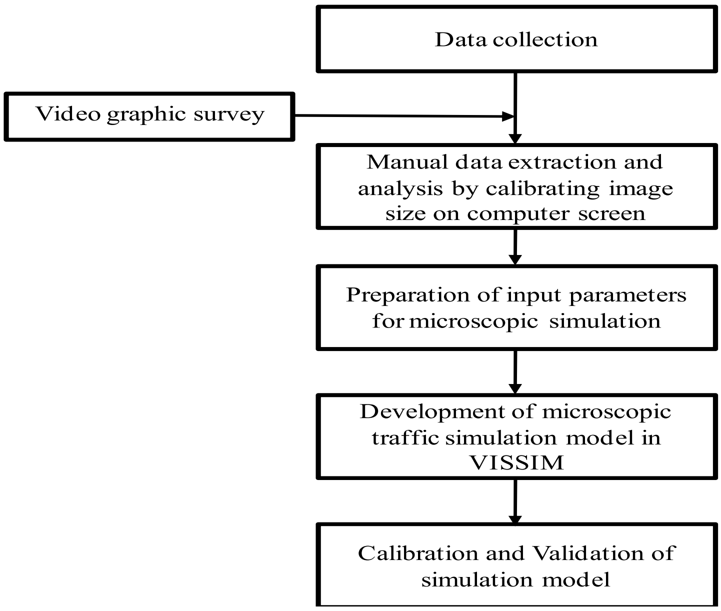


Figure 5: Details of model development in VISSIM

6.1 Base network creation

The base network model in VISSIM is created using Road Inventory Survey data for the selected segment. The model comprises of five intersections namely A, B, C, D and E as shown in the snapshot of simulation screen, as Figure 6. Out of these five intersections, B and C intersections are observed to be critical, as there are huge amount of delays recorded because of higher traffic volumes and insufficient road width on some sections of the arms of these intersections. In simulation model, the segment of 1.8 Km is constructed using various links with varying road widths taken along the segment. The side roads intersecting with the main road stretch are modeled up to a length of about 50 meters away from the main stretch on both sides of the stretch. The gradient of flyover is plotted in the simulation model as observed in the field (from elevations), as measured in the road inventory survey. Different links in a direction are created to account for the varying road widths at different sections of the segment. The connectors are used to connect the intersecting roads with main stretch. Number of lanes is assumed approximately based on the field measurement, as there are no proper road markings in the field. Total width of a road is divided by the number of lanes assumed to arrive at each lane width. BRTS road network is created using the width of BRTS corridor collected from Road Inventory Survey. BRTS road network link in VISSIM is designed using the PT lines (Public Transportation lines) option. The inputs for PT lines like headway of the buses, waiting time of bus at bus stops are given according to data collected from BRTS performance survey. Present study segment comprises of two BRTS bus stops excluding the originating and destination bus stop. The dwell times (stop-time of BRT bus at each bus stop) distribution for each BRTS bus stop is designed according to observations during the BRTS Bus occupancy survey.

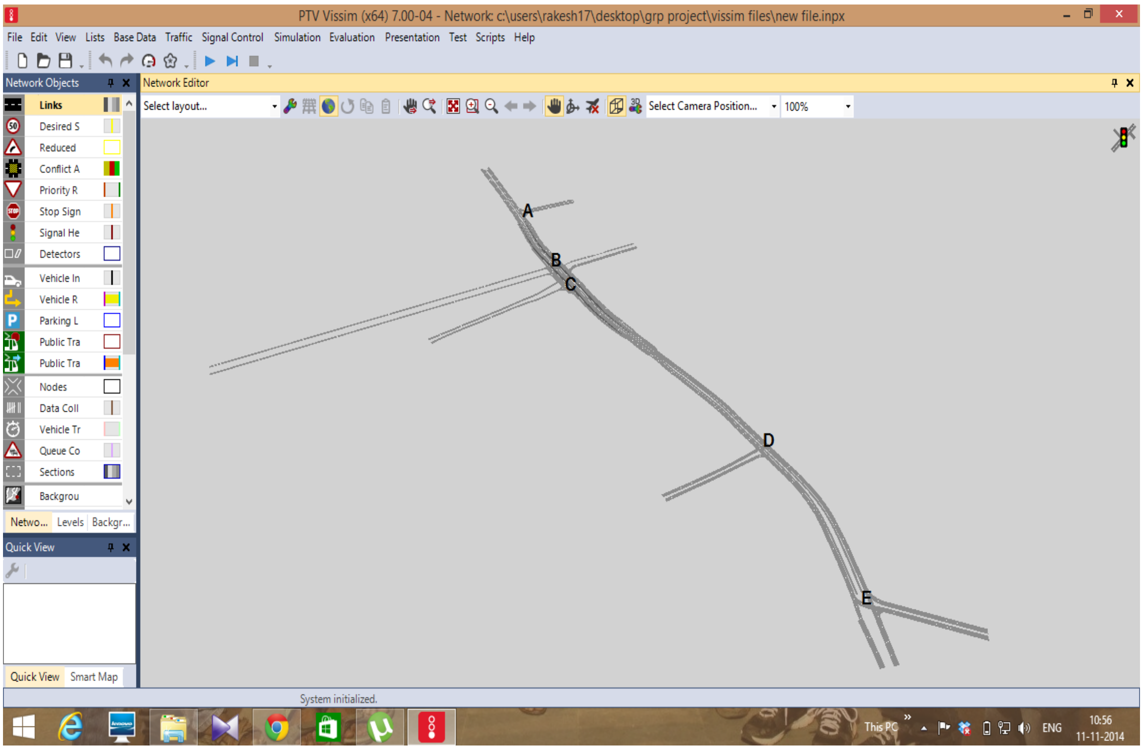


Figure 6: Overview of modelled network in VISSIM 7.0

6.2 Volume and other inputs

The vehicular inputs for each link are given in VISSIM model using the processed data of CVC (Classified Vehicular Count) surveys. Percentage volume of total volume generated from an arm for different vehicular types for one peak hour survey period is given as relative flows in different directions in VISSIM model as shown in Table 2. Twenty five percentage of the peak hour traffic is given as inputs in the buffer time of 900 seconds. The connectors are designed to connect the links at the intersections as per the field observations. The considered vehicular categories are motorized two-wheelers (2W), three-wheelers (3W), cars, LCVs, buses and trucks. Volume inputs (veh/h) of each vehicular category in VISSIM are given for one hour as input. The time headway of BRTS buses and waiting time of BRTS buses at the bus stops is given as inputs for the designed PT lines in the model. The desired speed distribution of different vehicular categories is given according to the minimum, maximum, free flow speed and various percentile (15th, 50th, 85th, 95th etc.) speeds of each vehicular category obtained from the Spot Speed surveys as shown in Figure 7. The speed distributions (which is a normal distribution) which are used by various studies (Katti and Raghavachari (1986), Bains et al. (2012)) under similar traffic conditions, are also observed to be closely matching with that of data collected in the present study.

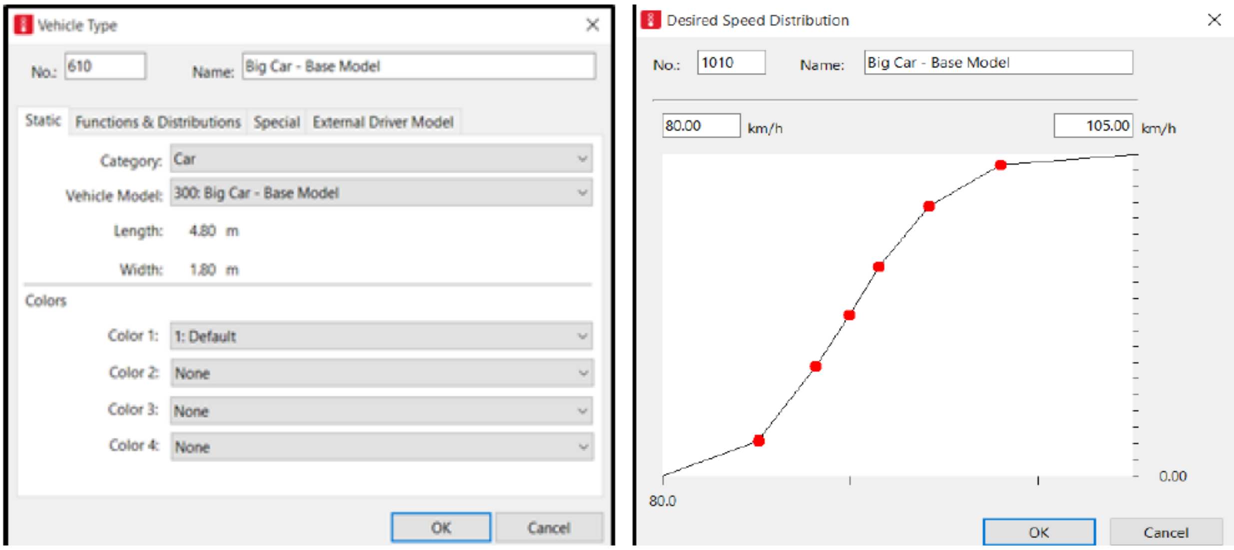


Figure 7: Desired speed distribution of different vehicular categories in VISSIM 7.0

Table 2: Vehicular Volume Inputs in VISSIM (Veh/h)

Direction		**Type of vehicle**					
Origin	**Destination**	**2W**	**Cars**	**3W**	**Bus**	**LCV**	**Truck**
Udhna Darwaja	Sachin	2374	233	840	15	84	25
Side road	Flyover	468	33	73	4	76	6
Side road	Sachin	171	16	62	0	46	0
Canal road	Magdalla road	1684	412	105	9	205	10
Canal road	Sachin	301	90	54	0	50	1
Canal road	Opposite side of canal	269	137	26	0	30	6
Magdhalla road	Sachin	774	343	114	4	74	11
Magdhalla road	canal road	417	65	64	8	45	24
Local street	Magdalla road	234	21	31	0	14	0
Local street	Sachin	156	5	21	0	4	1
Satya Nagar Arch	Sachin	498	279	108	1	61	12
Satya Nagar Arch	Udhna Darwaja	496	56	130	0	18	0
Side Road at End	Sachin	503	66	208	2	48	4
Side Road at End	Udhna Darwaja	598	123	244	5	53	7
Flyover	Udhna Darwaja	2795	321	699	10	295	0
Unn Teen rasta	Udhna Darwaja	1082	167	381	6	108	13
Sachin	Udhna Darwaja	2332	413	1133	14	414	6

6.3 Calibration of the model

This step involves calibration of the model, which majorly includes:

- the incorporation of static and dynamic characteristics of different vehicular categories under Indian traffic conditions,
- the modification of default vehicular geometrical and mechanical parameters. These may include the length, width, wheel base, axle spacing, power and weight of the different vehicular categories considered (Arasan and Arkatkar (2011).

- modification of the default parameters of a particular car following model in VISSIM

Default values of driving behavior and vehicular models and characteristics in VISSIM are in agreement to developed countries, which possess the characteristics of lane-discipline and right hand side driving rule. The 2D/3D models of different vehicular categories and driving behavior model parameters for Indian traffic conditions are collected from various sources for the base model development. The field observed macroscopic and microscopic characteristics of traffic flow are used for calibrating the model. Then, a check was made (as validation) for testing the ability of the model to replicate the field conditions. By giving the parameters listed in Figure 8 as an input to simulation model, simulation runs were carried out in order to estimate the output. In the proposed study, the calibration and validation processes were carried out by trial and error method. The model calibration and validation process to be followed in general for varying roadway and traffic conditions is also explained in the form of a flow chart as shown in Figure 8.

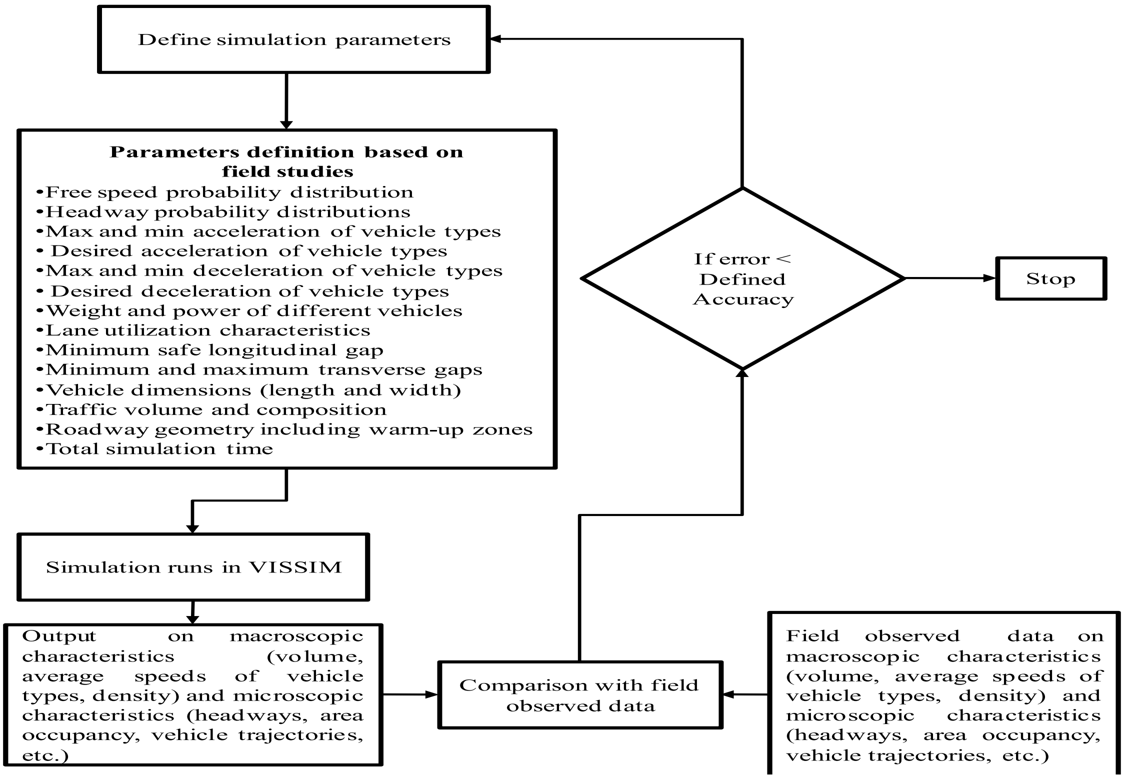


Figure 8: Calibration and validation procedure for the development of simulation model

Also, left hand driving rule was adopted in the present study, as the study pertains to Indian traffic conditions. Weidman-74 driving behavior model is adopted in accordance to Indian traffic conditions and the parameters (average standstill distance, additive part of safety distance, multiplicative part of safety distance) are set based on the previous research studies (Matthew and Radhakrishnan (2010)). These values are adopted based upon the trial and error process and the traffic characteristics in the selected study area. These can also be adopted based on the values considered for the similar research works carried out in the past (Khan and Maini (1999), Matthew and Radhakrishnan (2010), PTV User Manual (2012), Arkatkar *et al.* (2016)).Table 3 provides the calibrated values used for cars, motorized two wheelers and three wheelers as example. The driving behavior for different vehicular classes is designed in accordance to the various past studies (Bains *et al.* (2013) and observation of filed conditions from video recording and trial and error method. Also, parameters of lane changing under driving behaviuor are also calibrated and modelled accordingly to replicate the field conditions based on visual perception for every simulation run.

Table 3: Calibrated Widemann-74 parameters for different vehicular categories

Parameter	Calibrated values (For Cars)	Calibrated values (For Auto Rickshaws)	Calibrated values (For Motorised Two wheeler)	*Default values
Average standstill distance (meters)	0.9	0.7	0.9	2.0
Additive part of safety distance	0.7	0.6	0.5	2.0
Multiplicative part of safety distance	0.5	0.4	0.4	3.0

Under the lateral behavior, parameters of time between direction changes and minimum lateral distance during stand still conditions and vehicular movement at particular speed were calibrated based on observations from the video recording and hit-and-trial method. Any particular vehicle moving in a traffic stream has a tendency to maintain sufficient lateral clearance on the left and right sides with respect to other vehicles/curb/median to avoid side friction. These lateral clearances depend upon the speed of the vehicle being considered, adjacent vehicular speeds, and also their respective vehicle categories, in general. Very low values of lateral distance at 50km/h and in stand still conditions (when speed is 0 Kmph) lead to unrealistic overtaking behavior. In general sense, the low values of these parameters reflect aggressive driving behavior and hence this parameter is to be carefully observed and calibrated.

The conflict areas are to be defined at the intersection areas, where the links and connectors are overlapping. The status of conflict areas is set according to the field observations as shown in Figure 9. There are four types of conflict areas in VISSIM model as shown in Figure 10 namely 1 waits for 2, 2 waits for 1, undetermined and passive. First two states implies that priority is assigned either for the vehicles on major and minor roads to enter in to a conflict zone. These are to be used when the major street crosses the minor street. When two major roads intersect, either undetermined or passive are to be used. Undetermined state implies that vehicles in both the intersecting roads act as if they were in the same link. This state of conflict areas was considered for modeling the traffic movement at merging and diverging sections. Passive state implies that the priority is not assigned at all and this will result in the collision of the vehicles during the simulation run. This is the default status that simulation model assigns itself as soon as it detects the conflict areas where traffic from intersecting roads meet each other. This status also needs to be set based on the filed observations and may vary from one road facility to the other.

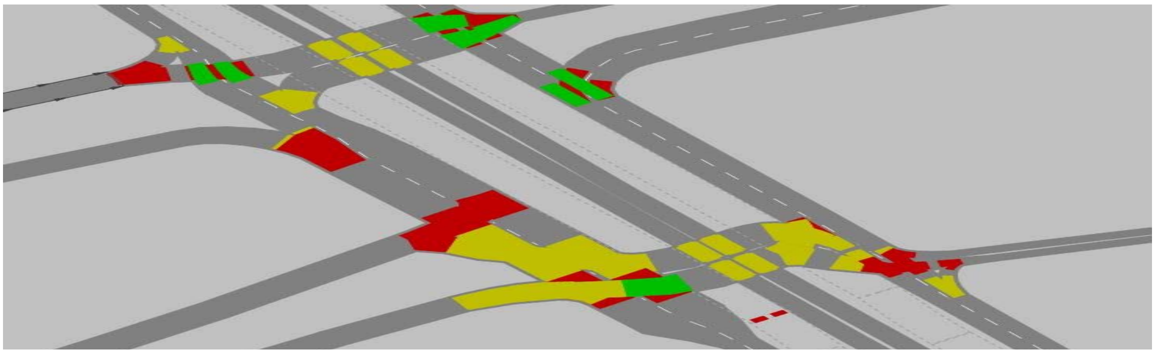


Figure 9: Modeling of Conflict areas in simulation model

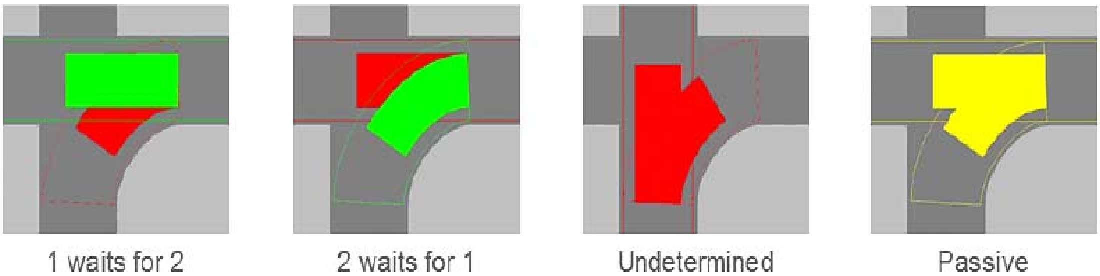


Figure 10: States of Conflict areas in simulation model

In the case of some un-signalised intersections, conflict areas alone may not be sufficient to simulate the exact behavior of traffic stream in accordance to field conditions. In these cases, priority rules are to be used along with the conflict areas to replicate the field conditions. Conflict areas alone may result in unnecessary queues in any one of the arms of the intersection. So, the priority rules are used to avoid the tailback in the links at the intersections. The priority rules are given generally at the merging areas and diverging areas as shown in Figure 11(b). The model calibration also includes the modifications of the priority rules parameters at the merging areas in the model as shown in Figure 11(a).

The parameters of the priority rules considered are minimum time gap, headway and maximum speed. The minimum headway signifies the distance from the conflicting zone against the movement direction up to the first vehicle which is moving towards the conflicting zone. If a vehicle is still within the conflicting marker, the headway can be considered as 0. The available time gap is the time that the first upstream vehicle will require in order to reach the conflict zone with its present speed. A vehicle which is already on the conflict zone is not taken into account. In a priority rule, the limiting time gap is specified: The vehicle must wait if the current time gap is less than the value which has been assigned. The positioning of these priority rules also play a key role in simulating the vehicular behaviours at the possible conflict areas, especially in merging and diverging sections. It is also carried out in a trial and error way so as to establish the vehicular priority behavior as that of observations from the field. For avoiding the tail backs at the intersections, the values of minimum time gap, minimum headway and maximum speed considered in the present study are 0 seconds, 12 meters and 180 Kmph respectively. Time gap is considered as zero so that vehicles will initially enter the partial conflict zone and then take a decision to wait or to proceed further. This is necessary for modeling the urban un-controlled intersections under mixed and non-lane disciplined conditions.

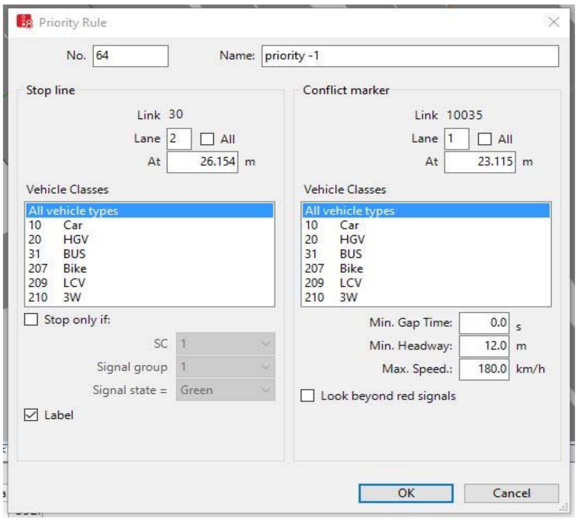


Figure 11(a): Overview of priority rule parameters in simulation model

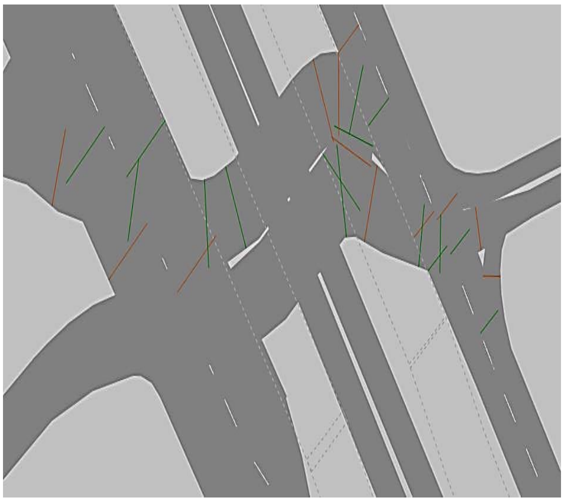


Figure 11(b): Overview of priority rule modeling in simulation model

6.4 Validation of the model

Validation is the process of checking the developed simulation model in terms of predicted traffic performance for road system against field measurements of traffic performance at macroscopic and microscopic levels. This can be done using macroscopic variables such as traffic volumes, travel times, average speeds of each of the vehicle categories, and speed distributions of each of the vehicle categories and also using microscopic variables such as headways, time gaps, vehicle trajectories and area occupancy over a wider range of roadway and traffic conditions. The selection of the validation parameter depends on the characteristics of network and purpose of simulation. In the present study, the travel time of two wheelers and BRTS bus was used as the validation parameter.

The travel time data was collected for two-wheeler during the morning peak periods in some directions. Travel time for BRTS bus was also considered in both the directions and used for the validation of the model. Similar travel time data are also obtained from the calibrated VISSIM model using travel time counters option. Field and VISSIM simulated travel times for each direction were compared to achieve at the minimum possible error. The priority rule parameters, buffer time volumes, driving behavior parameters are modified in the trial and error process in order to arrive at the minimum error indicating reasonable accuracy. The simulation is run for ten different seed numbers (based on least standard deviation) and the average values of the selected three seed numbers are considered as output, for validation purpose. The variation in random seed number results in stochastic variations of vehicular arrivals in network and thereby traffic flow variations take place. Accounting for these random variations, the arithmetic average of results of various seed numbers are considered to produce a meaningful result. The trial-and-error method is carried till the errors of field measured and simulated travel time is observed to be less than 15% as shown in Table 4.The simulation is run for a total duration of 4500 seconds, out of which first 900 seconds is considered as buffer time. The buffer time is necessary in order to create the cumulative traffic effect in the network before the start of the simulation. Simulation results are considered for the last 3600 seconds of the run only, representing the morning peak hour for which data collection was performed.

Table 4: Travel Time errors of Validated Model

Direction	Distance (meters)	Field observed travel time (seconds)	Average Simulated travel times (seconds)	Percentage error (%)
BRTS Udhna to Teen Raasta	1620.00	425.00	414.84	-2.39%
BRTS 3 Raasta to Udhna	1620.00	400.00	399.43	-0.14%
Canal road to temple	670.00	81.19	91.58	12.81%
Magdalla to Temple	616.00	300.00	272.57	-9.14%
Temple to 3 raasta(Free left)	450.00	58.00	59.78	3.07%
Flyover (3 raasta to Udhna)	550.00	47.00	52.41	11.51%
Flyover (Udhna to 3 raasta)	550.00	48.00	54.00	12.52%
Below Flyover (3 Raasta to Udhna)	550.00	120.00	122.93	2.44%

7. Traffic Diversion Analysis

Analysis basically includes the delay calculations for the different vehicular categories at the critical intersections from the simulation. The analysis primarily aims at the proposal of the effective traffic management measure to reduce the congestion at critical intersections (B) and thereby reduce the delays as minimum as achievable. The exit width at the Canal road of the intersection besides the temple is observed to be just around 3.6 meters as shown in Figure 3 and hence the speed of the vehicles is reduced considerably even at the exit of the intersection. This caused congestion and vehicular queues on Magdhalla Road also disturbing the BRT bus movement. The feasible traffic management measures are identified and are separately incorporated in the VISSIM model. The traffic management may also include the conversion of un-signalized intersections to signalised based upon the traffic volume, traffic diversions etc. A number of traffic diversion strategies are incorporated in the model successively and the delays for each case are evaluated in VISSIM. The quantitative comparative analysis for delays of BRTS buses and mixed traffic lanes both for the base model and also modified model, in each case, was performed and thus the best traffic management measure was selected finally.

The delays and travel time in various links in the base case are considered. The delays in Magdhalla road are observed to be high and queuing was observed during the simulation, which was also observed in the field. The delays are observed to be more at B-Intersection for Udhna to Sachin traffic and also for the traffic from Magdhalla road to canal road opposite temple. The most feasible rerouting of the traffic from Magdhalla road to canal road, opposite temple site (based on the space available) is analyzed as a traffic management measure and incorporated using an inter-connecting link between Magdhalla road and canal road, opposite temple site as shown in Figure 2. The interconnecting link is observed as a street in the field having width of 3.5 meters as shown in Figure 12. Out of the total traffic generated from Magdhalla road, some proportion is rerouted to canal road (XC as shown in Figure 12) and remaining is allowed to move normally along the existing route (XM as shown in Figure 12). Also, at the B-intersection the additional lane is added for the traffic flowing towards canal road besides temple. An additional lane of the opposite direction is modeled for this traffic as the width is predominantly high (about 10 meters) in the opposite direction. This is required as the road width available on that road is just 3.5 meters only in the base case. This traffic diversion is also practically feasible, because V/C ratio for canal road is less than 0.3 and that of Magdhalla road is around 0.8. The different possible traffic movements and BRT system at B and C intersections are depicted in Figure 12 for clear understanding of the study segment.

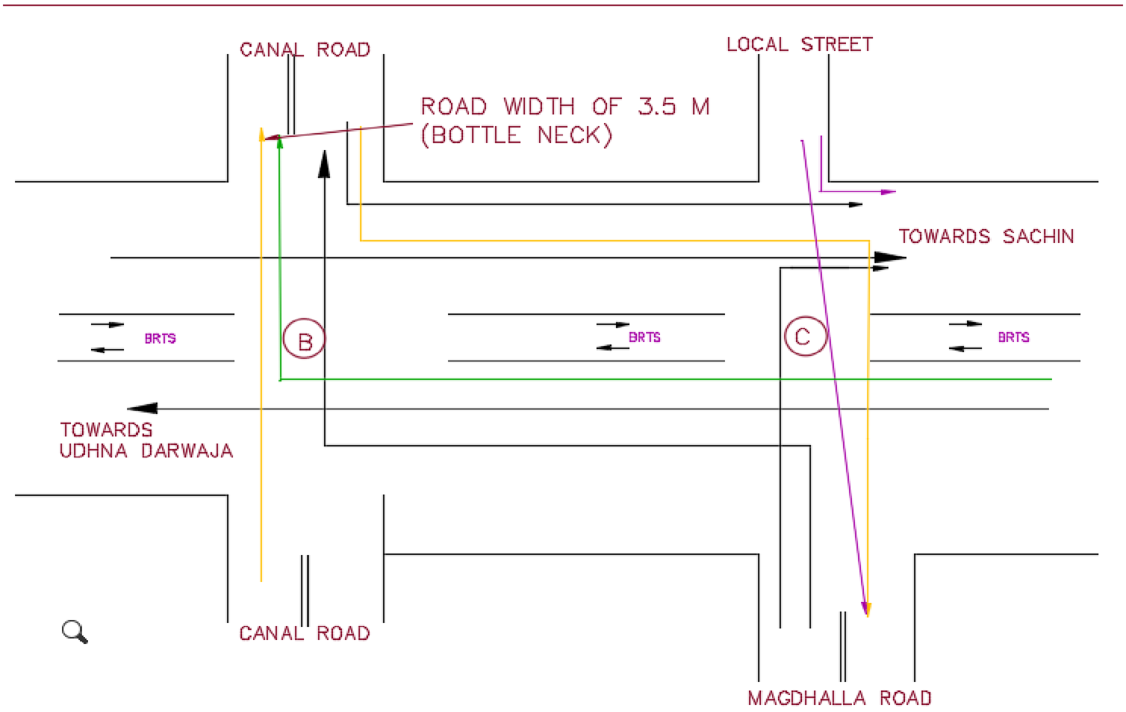


Figure 12: Strategies of Traffic movements in different directions at B and C intersections.

The proportional combinations are used like 50-50 and 60-40 (based on the available V/C ratios and available space for traffic movement) and the best combination is considered where the overall delay for roads like Magdhalla road, Canal road opposite temple, Udhna Darwaja to Sachin is observed to be minimum. In Table 4, 50C-50M denotes that 50% of traffic is diverted through canal road and other 50% of traffic through Magdhalla road. Similarly, 60C-40M denotes that 60% of traffic from Magdhalla road is diverted through canal road and other 40% of traffic through Magdhalla road itself. As shown in the Table 5, the travel time for Magdhalla to temple direction was reduced from 266 seconds in the base case to about 140 seconds in the strategy cases. This direction was observed to be critical from the field observations as it has large volume with significant delays. Though the delays in few other directions are increased, the delay reduction in Magdhalla to temple direction is of more significant. This is because of the higher values of V/C for traffic on Magdhalla road moving towards Canal road. Also, the approach delays in that road was observed to be around 83 seconds in the validated base case model as shown in Table 6. This delay was very high when compared to the delay of around 3 seconds in canal road.

Table 5: Travel time For Alternative strategies

		Travel Time (sec) derived in VISSIM		
Sl. No.	**Travel Time counters**	**Base case**	**After Diversion**	
			50C-50M	**60C-40M**
1	BRTS Udhnato 3 Raasta	456.59	456.92	457.35
2	BRTS Teen Raastato Udhna	484.04	481.93	482.33
3	Canal road to temple	91.56	87.13	96.02
4	Temple to Magdhalla road	95.25	174.09	184.62
5	Magdhalla to Temple	265.55	139.77	94.55
6	Temple to 3 raasta(Free left)	57.7	63.81	65.88
7	Flyover (3 raasta to Udhna)	51.505	51.62	51.36
8	Flyover (Udhna to 3 raasta)	53.4	53.53	55.99
9	Flyover end to 3 raasta	161.65	160.41	143.62
10	Below Flyover (3 raasta to Udhna)	112.09	118.3	70.82
11	Flyover to Udhna	25.24	24.18	24.01

Table 6: Delay variations in Alternative Strategies

Link Name	**Base case (sec)**	**After Diversion (sec)**	
		50C-50M	60C-40M
Main Stream	89.72	88.01	87.39
Canal road	2.95	13.17	24.06
Magdalla road	82.99	23.81	11.26

8. Conclusions and recommendations

The following are the important inferences and recommendations that are derived after evaluating the traffic management measures of segment of an urban corridor using microscopic simulation model in VISSIM:

i. Canal road has Volume to Capacity (V/C) ratio of around 0.2 and Magdalla road running besides it has higher V/C ratio. So, some proportion of rerouting of traffic from Magdhalla road to Canal road is recommended to avoid long queuing at B-intersection using validated simulation model. This traffic diversion can be effectively implemented in the field for reducing the longer queues on Magdhalla road.

ii. The travel time for Magdhalla to temple direction was reduced from 266 seconds in the base case to about 140 seconds in the strategy cases. This direction was observed to be critical from the field observations as it has large traffic volume with significant delays. Though the delays in few other directions are increased, the delay reduction in Magdhalla to temple direction is of quantitatively more significant.

iii. The delay on Magdhalla road has been reduced from 82.99 seconds in the base case to 23.81 for 50C-50M scenario and 11.26 seconds for 60C-40M scenario.

iv. 60C-40M case was observed to be better than 50C-50M case as the travel time in all the directions for the former case are observed to be reduced after incorporation of the traffic re-routing in the microscopic simulation model.

v. Road width just besides the temple is around 3.5 meters only and providing the extra lane for traffic flow from B-intersection to canal road is recommended to reduce the delays using validated simulation model.

Delays and travel times for private motorized vehicles are considerably reduced after the implementation of traffic management strategies. However, delays of BRT buses are neither significantly reduced nor reduced, which is appreciable. Further for reducing the BRT bus delays, vehicular actuated signal or transit priority signals are to be placed. Nevertheless, there are chances of increasing delays to private vehicles with transit priority signals in place. Some optimal solution has to be adopted which comprehensively reduces the delays of the overall network of all interacting transport systems. The aim of traffic engineer should be focused on minimizing the delays for the overall transport system rather than bias on private or public transport system. Different strategies are to be adopted and tested on trial and error basis and the effectiveness of these strategies can be potentially tested using simulation technique before actual field implementation. The methodology presented in this work can be useful for the enhancement of efficiencies of BRT systems and private transport system along urban roads in different Indian metropolitan cities. Once the validated simulation model is available, the performance evaluation of road sections with respect to future traffic forecast or future development or improvement plans can also be effectively carried out.

The simulation technique is most widely used in many fields of engineering including traffic and transportation planning. But the development of the simulation model for un-controlled intersections under mixed traffic and non-lane disciplined conditions is very complex and requires huge efforts and time. It is because of the involvement of design of large number of parameters and entities like conflict areas, priority rules. The present study focusses on the detailed methodology for the development of microscopic simulation model under heterogeneous traffic conditions like in India, which is predominant Asian Pacific region. The present study thus highlights the modelling of driving behaviour, conflict areas, priority rules that majorly affect the behaviour of urban traffic stream. The present study thus elaborates the applicability of widely used simulation model VISSIM in simulating the real-world traffic with the help of case study of a selected road section.

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