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Evaluation of BRTS Corridor in India Using Microscopic Simulation: A Case Study in Surat City

Akhilesh CHEPURI[a], Rakesh KULAKARNI [b], Manraj Singh BAINS[c], Shriniwas ARKATKAR[d], Guarang JOSHI[e]

[a,b]*Post Graduate Student, S V National Institute of Technology, Surat*
[c]*Transport Consultant, Trans Axiom, Chandigarh*
[d]*Assistant Professor, Sardar Vallabhbhai National Institute of Technology, Surat*
[e] *Associate Professor, Sardar Vallabhbhai National Institute of Technology, Surat*
[a]*E-mail: akhileshchepuri@gmail.com*
[b]*E-mail: rakesh.kulakarni@gmail.com*
[c]*E-mail: manraj.bains@transaxiom.in*
[d]*E-mail: sarkatkar@gmail.com*
[e]*E-mail:gjsvnit92@gmail.com*

Abstract: The congestion at intersections in the case of open BRTS results in delay to both BRT buses and private traffic. The present study consists of the evaluation of traffic flow characteristics on a 1.8 Kilometers of BRTS corridor in Surat city, which includes four intersections. Very less literature is available on the evaluation of hybrid BRTS under Indian traffic conditions. The work aims to evaluate the delays caused to the traffic at these intersections using the microscopic simulation software, VISSIM 7.0. The work also comprises of system performance evaluation of BRTS, which includes investigation on causes of delay and overall its impact on the BRTS. The study is carried out for suggesting the feasible traffic management measures, which may result in reduction of delay and travel time to both BRTS buses and private traffic, which may eventually result in emissions reduction.

Keywords: BRTS, travel time and delay, simulation, traffic management and performance

1. INTRODUCTION

Bus Rapid Transit System (BRTS) is one of the most popular forms of semi-rapid public transit system with moderate capacities and more importantly minimal capital costs compared to other forms of public transportation system, which makes it favorable for developing nations such as India, China, Brazil, Indonesia, etc. (Hook (2005). In the past decade or so, Bus Rapid Transit (BRT) has become a popular mass transit option for a number of cities around the world. Curitiba, Brazil in 1974 has started such system for the first time for the city passengers. Two types of BRTS namely, Closed and Open BRTS are functional in some of the Indian cities with the most popular being the Ahmadabad BRTS, where in the closed BRTS network is in vogue, whereas the Delhi BRTS, being a pilot corridor only as of now, is an Open BRTS. The development of sustainable transportation system gained importance because of several adverse environmental impacts caused by vehicular traffic in India. With the rapid increase in the automobiles leading to traffic congestion, urban sprawl, air pollution and other such ill effects there is an immediate need for improving the transportation systems in the cities in the world.

BRTS has to be designed in such a way that the generalized cost of travel by BRTS is reduced. Travel time reliability plays a key role in adding the efficiency to a particular mode of transportation. Delay is the most important parameter contributing towards the travel time of trips in urban areas. Provision of BRTS corridor should not adversely affect the travel characteristics of adjacent mix-vehicle lane. BRTS occupies some proportion of the width of the road and hence, proper care has to be taken in designing the BRTS so that effective utilization of road space can be achieved. The evaluation of existing BRTS in different Indian cities, where the delays are significant for both BRTS and mix-vehicle traffic has to be carried out periodically to improve the efficiency and safety of the transportation system as a whole. The delays are caused basically at the intersections in urban roads. In the case of "Partially-closed" or "Hybrid" BRTS, the delays at the areas of interaction of BRTS corridor and non BRTS traffic in a segment are critical and these delays significantly contribute to the overall travel time of the entire corridor. The evaluation of such segment of a particular corridor which includes the critical intersections is to be evaluated. This evaluation can be carried out effectively with the help of microscopic simulation.

Surat (a city in Gujarat state) is known for its textile manufacturing, trade, diamond cutting and polishing industries, intricate zari works, chemical industries and the gas based industries at Hazira (town of Surat District) established by leading industry houses such as ONGC, Reliance, ESSAR, and Shell, given the sound economic base. The city is located on the Delhi-Mumbai Industrial corridor. Several SEZs are being set up outside the city limits. Rapid growth is continuing. The city is expected to grow to accommodate 8 to 9 million people by 2031 from the present population of 4.4 million with an average population growth rate of 6%. Growth management is a major issue. Despite the size and economic importance the city commands, the city still does not have an efficient public transport system. Incomplete network, missing hierarchy in road network system, poor quality of facilities for pedestrians and bicyclists, and inadequate traffic management are some of the critical issues the city is facing with at present. The inner ring road, which is yet to be completed as a full ring, is faced with number of problems. The sustenance of Surat's growth can only be possible with the development of an efficient transportation system. The Local Government and the State Government have initiated several measures to ameliorate the situation. The average length of work purpose trip in Surat is 5.95 km, while average educational trip length is 3.97 km at city level. The other purpose trip length is reported varying 2.8 Km to 5.9 km across different income groups. Longer trip lengths are reflecting on potential demand for mass public transportation in the study area. Nearly 80% of travel is for compulsory purposes like work and education, remaining 20% is for purposes like shopping, recreation etc. At present most of the commuters uses their private vehicles for travel. Study area lacks of proper public transit system one can say it is very poor in all aspects, and due to this population of para-transit in study area in considerably high and accounted more than 80000 till date (RTO Surat). Prior to 2007 Gujarat State Road Transport Corporation was operating the city bus service. It is ironical that the fleet size has gradually decreased against increase in city population and hence the travel demand, till it was closed down in 2007 completely. Since 2007 bus transport system are introduced by SMC in Surat city. The existing bus transit system is operated by public private partnership since 2007 for 44 routes in the city with deployment of 121 buses.

Surat BRTS aims at developing the Public Transportation system and focuses on the mode shift from private transport to public transport. BRTS in Surat city consists of three corridors. One corridor is operational till date which extends from Udhna Darwaja to Sachin GIDC for about 9.5 km. Present study focuses at the evaluation of 1.8 km stretch along the Udhna Darwaja – Sachin BRTS corridor in Surat city in one direction as shown by red border in figure 1. Selected direction is traffic leading from Udhna Darwaja towards Sachin. The stretch extends from Udhna Darwaja BRTS bus stop to Udhna Teen Rasta BRTS bus stop and includes four major intersections. All of these intersections are un-signalized in traffic control. Simulation model for the stretch is developed using VISSIM 7.0 and the model is validated using trial-and-error process. Model validation is carried out so that few important derived parameters from the simulation should reasonably be in agreement with the field observations. Iteration process in the validation is carried out till the error of 13% is achieved. Keeping in view the complexity of modeling of traffic flow characteristics under highly heterogeneous traffic conditions, the error of 13% may be considered reasonably well. Also for few traffic streams, it is even less than 5%. Analysis includes the delay calculations at the critical intersections and incorporating the traffic management measures in the VISSIM model so that delays are reduced and hence the overall travel time is reduced for the selected stretch to get maximum efficiency.

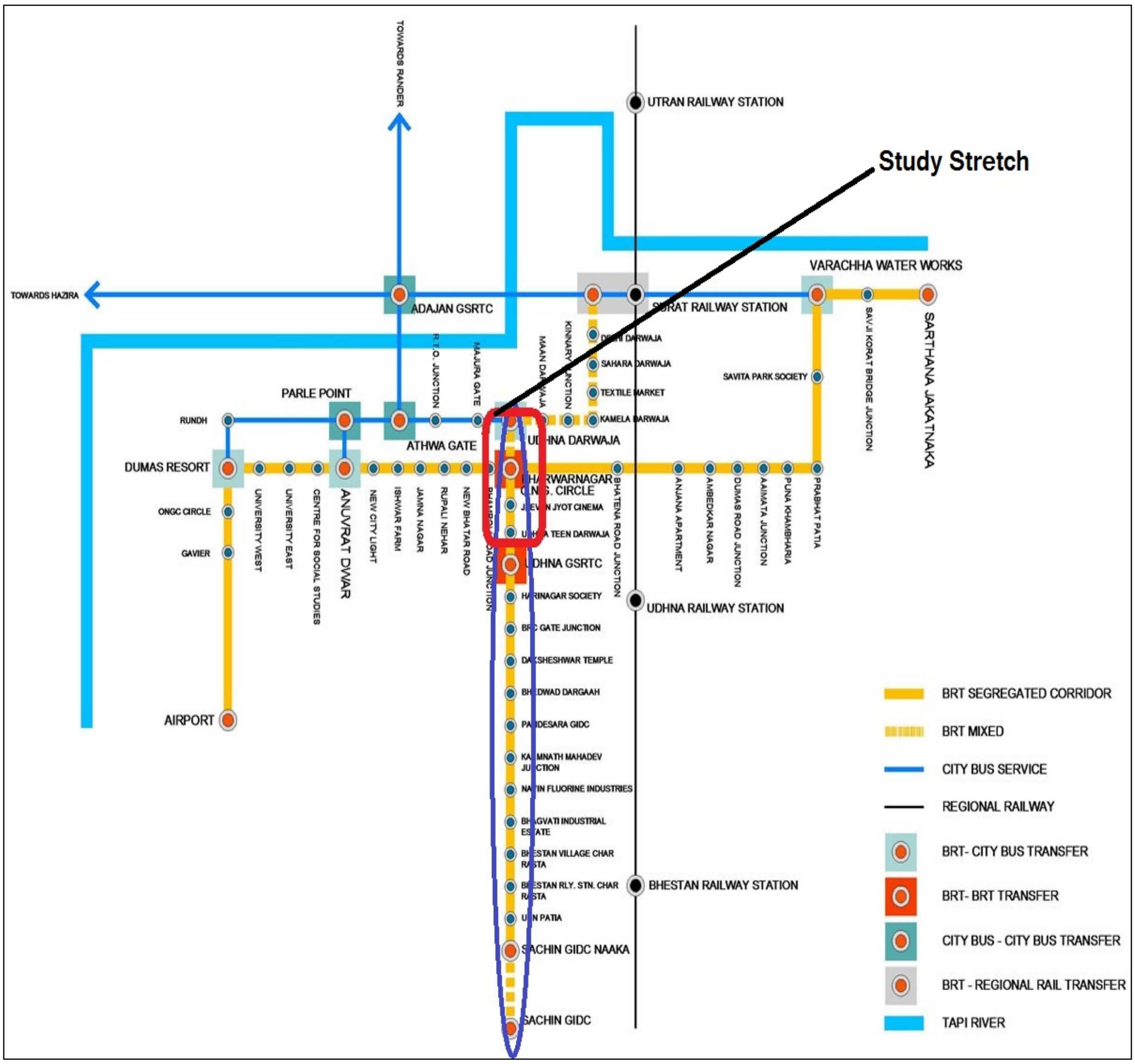


Figure 1. Surat BRTS Network and Study Stretch marking

2. LITERATURE REVIEW

For review of literature, the present work is vital as there are very less research contributions in the area of BRTS evaluation under Indian traffic conditions. Siddique & Khan, (2006) wanted to evaluate the capacity of BRTS 20 years later. 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 very different results from the capacity of a system compared to a micro simulation model and confirms the 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. The literature related to microscopic simulation techniques are also studied in order to understand the various simulation parameters to be modified in VISSIM 7.0 according to the study area characteristics. 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 author also compared the BRTS with the regular one by modelling and simulating both systems under various scenarios. This research shows how 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, BRTS evaluation in India 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 (ITDP Report, 2012).Many of the available research works suggested the use of microscopic simulation for the evaluation of BRTS in India (Velmurugan et.al, 2013). As the 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 non BRTS traffic mutually. The BRTS evaluation has been carried out in many research works in Indian metropolitan cities like Delhi using the quantitative, qualitative and economic perspectives (CSIR-CRRI Report 2012). The present study is formulated based on the quantitative approach using the microscopic simulation. But, this rating based on some parameters may not solely act as the effective performance indicator of the BRTS. This rating system can be combined or integrated to some microscopic simulation models to arrive at more accurate evaluation. Less literature review is available based on the segment analysis in BRTS corridor. The present study also aims at providing the effective traffic management measures for reducing the delays at the critical intersections along the selected segment using the microscopic simulation using VISSIM software. 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 Mixed Vehicle (MV) lane and Bus lane of Delhi BRT corridor were optimized using the Golden Section method (Sheffi, 1985). 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. However, study has not studied delays to different traffic streams at a given intersection in simulation study, which has been focused in the present study. Research studies have also been carried out analyzing the performance evaluation of mass public transit system based on some standard guidelines prescribed in Transit Capacity and Quality of Service Manual (TCQSM- 2003 and Vuchic, 2009). This manual was developed from some case studies in United States.

3. STUDY AREA

Surat city is located on the bank of the river Tapti in the state of Gujarat and has about 6 km long coastal belt along the Arabian Sea. Surat is at latitude 21.10‟ N & Longitude 72 54‟ E, where, its course swerves suddenly from the north-east to south-west. It covers an approximate area of 326 Square Kilometer. Surat is India's ninth and Gujarat’s second most populous city (2011). It became a metropolis in 1991. The city has been experiencing rapid growth in population since last two decades. The growth rates have been one of the highest in the country. High rate of growth experienced by the city over five successive decades has been a major feature in the city’s growth, necessitating prompt responses in supply of infrastructure. Surat is known for its textile manufacturing, trade, diamond cutting and polishing industries, intricate zari works, chemical industries and the gas based industries at Hazira established by leading industry houses such as ONGC, Reliance, ESSAR, and Shell. The city economy is characterized by large number of small and medium size unorganized industries. The industrial base is labour intensive. Out of the total 3,12,782 small scale units registered (up to Sept 2006) in the state, Ahmadabad and Surat districts leads the list with high number of small scale industrial units at 65,763 and 47,404 units, respectively constituting 21% and 15.2% of total SSI units in the State. The share of Surat has increased from 12.6% in 1980 to 15.2% in 2006. In terms of factory sector also the share of Surat is significant. In Gujarat there were 3911 registered factories in 1960 employing 0.35 million workers, which increased to total of 27089 registered working factories employing 0.8 million of workers (2001) in Gujarat, Surat accounted for 1900 units providing for about 0.14 million jobs. Much of the industrial development is located within the limits of Surat city. In fact, Surat is truly an industrial city with over 50% of workforce engaged in manufacturing activity. While the problem of unemployment is almost non-existent, the wages are also lower and the workers are generally deprived of social and other benefits. The vehicles registered in Surat RTO area has raised from fifty thousand in 2001 to 1.2 million in 2012. The vehicular distribution can be given as: Two wheelers comprise nearly 77% of the total number of vehicles while cars constitute about 14%, three wheeler 4% and 5% other vehicle in Surat city. 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%.It is extremely important to encourage usage of public transportation to attract more users, for which it is very vital that the planning, design, operation and management of the public transportation system must be done with proven practices. Hence, as attempt has been done in the present study to evaluate the present status of the BRTS in Surat on one of the corridors, Udhna Darwaja to Sachin GIDC in Surat city.

The study corridor consists of a segment of BRTS extending from Udhna Darwaja to Sachin GIDC in Surat city. Three-lane dual carriageway arterial road is designed and constructed by the Surat Municipal Corporation as a part of a plan to connect Surat City with Gujarat Industrial Development and Corporation industrial area near Sachin. The total length of the BRTS corridor is approximately 9.5 km. It was decided to conduct a reconnaissance survey in order to identify the critical locations of delay and traffic congestion. For this purpose, the travel time was measured using performance-box, GPS equipment, which gives real time speed every 0.1 seconds. Five trail runs were made to arrive at the critical locations of delay and hence, the segment of about 1.8 km out of the total 9.5 km BRTS corridor was selected for further study.

The study segment comprises of five intersections, which are selected after reconnaissance survey. The critical intersections are selected based on the delay to BRTS buses and also intensity of 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. This has enabled the team to get an idea about delays at various locations in BRTS corridor. All the major side roads intersecting the main corridor were identified in order to understand the overall traffic situation and deployment of man-power for collecting traffic data collection. The selected segment of 1.8 km also consists of a flyover extending from the distance of about 100 meters away from Udhna Darwaja towards Sachin. Length of flyover was measured as 550 meters. The study stretch considered comprises of five BRTS bus stops and are indicated in figure 2 given below.

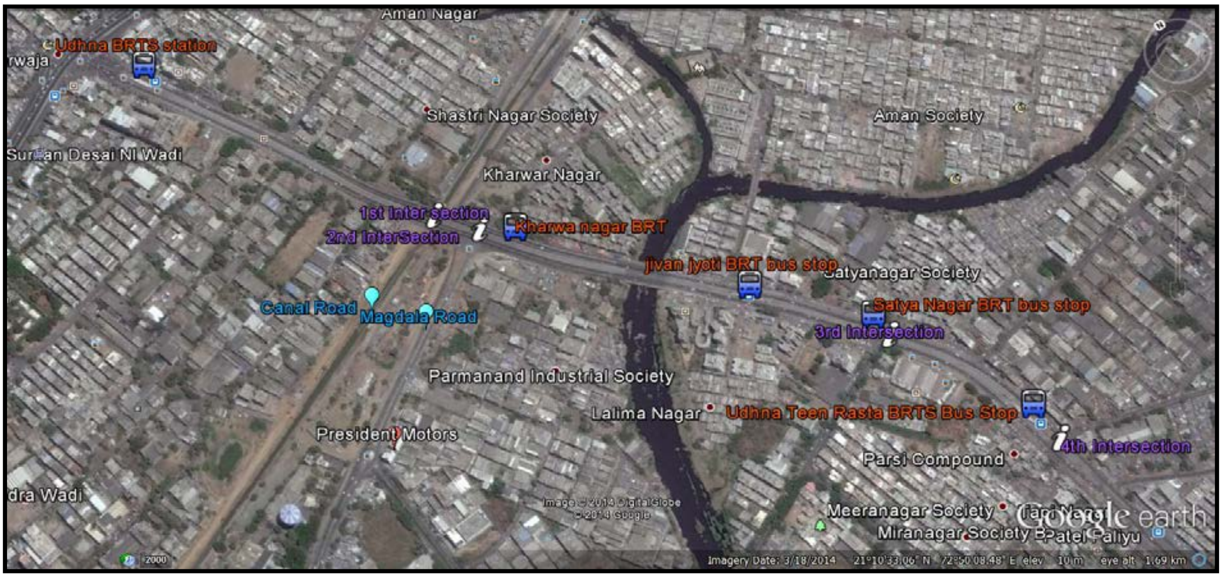


Figure 2. Google Image of study segment (1.8km) with road names and BRTS bus stops

4. DATA COLLECTION

The traffic surveys were conducted in order to collect data on road inventory, classified volume count, speed and delay and spot speeds. The road inventory data is very important for creating geometry and development of network in VISSIM for modeling the traffic operation 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 the field observed conditions. These data sets along with microscopic characteristics such as acceleration, deceleration characteristics, lateral gaps, etc. are used for validating the simulation model, VISSIM. For validating the model, the speed and delay data, which are derived parameters of the BRTS, can be useful to check the credibility of the model for evaluating the traffic operation and management of the BRT corridor as a whole.

4.1 Road Inventory Survey

The Road Inventory Survey is carried out to measure the road geometry and characteristics like width of the carriage way of different arms, width of BRTS corridor, and entry and exit widths at intersections as shown in figure 3. This Survey is carried out manually using measuring tape during the early morning hours of free flow 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 to design the intersection zone appropriately in the VISSIM model. This survey is carried out primarily for the selected 1.8 Km segment in two directions along with the intersecting side roads. Though the direction of Udhna Darwaja to Sachin is considered for the study purpose, the road widths of the Sachin - Udhna Darwaja road is also measured in order to create the traffic modelling in VISSIM at the intersections also. The vertical levels of flyover are considered at various points along with the chainage readings and the average gradient of the flyover is found out to design the flyover in VISSIM. The width of BRTS corridor is also measured across the various sections along the study segment.

4.2 Classified Volume Count Survey

The traffic volume data is collected for the morning peak hour (11.30 AM to 12.30 PM). Turning movement count survey is conducted at all the five intersections using manual method in some directions and Video graphic method is employed in the other directions based on the vantage point for mounting video camera. Manual method use field personnel to count and classify traffic flowing past a fixed point. Traffic enumerators need to be posted on each arm of the intersection. At a four arm intersection, the count at each arm of the traffic entering the intersection are broken down three categories left turning, right turning and straight ahead traffic. Traffic surveys are conducted during morning peak hours and evening peak hours. But in the present study for developing the simulation model, morning peak hour data is used. The Traffic Volume count is carried out considering six vehicular categories namely Motorised Two-wheelers, Motorised Three-wheelers, Cars, LCV, Bus and Trucks. Volume count in each approach of arm and relative flows in each direction are to be given as inputs in VISSIM model. In video graphic method, three cameras are installed at three different locations at one of the major critical intersections as shown in figure 4, as example. The cameras are installed over tripod stands and are aligned in such a way that they can cover intended directions of traffic flow with maximum possible visibility.

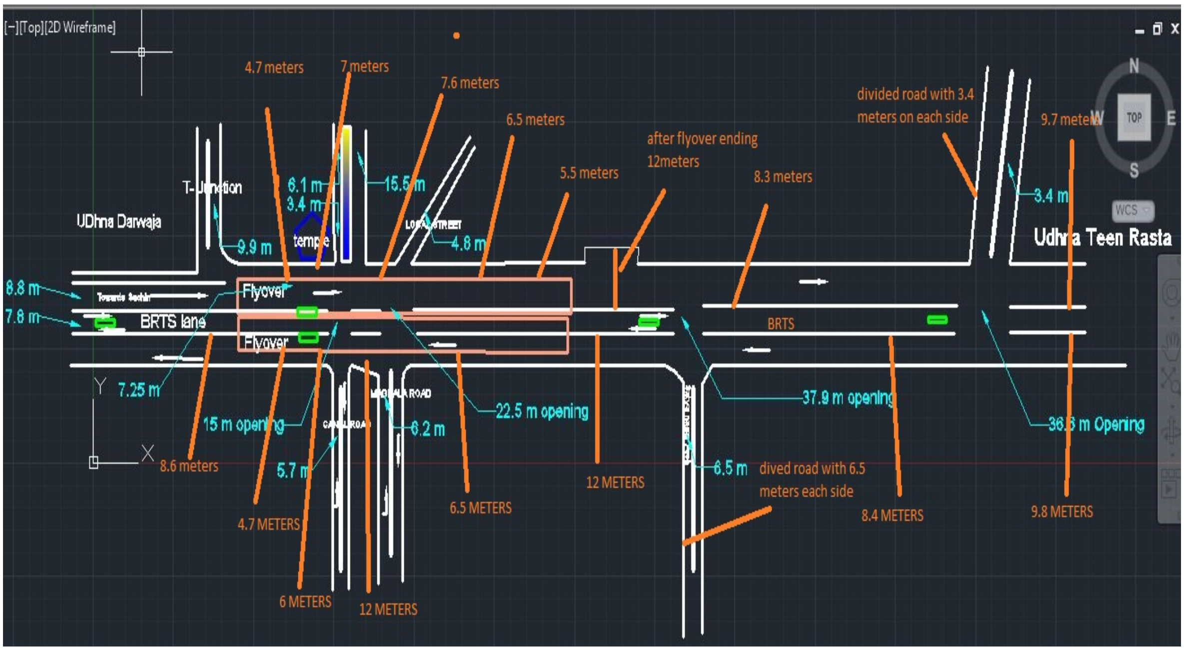


Figure 3. CADD drawing illustrating Road Inventory Survey outputs

Figure 4. Camera Positions for Video graphic Survey

4.3 Speed and Delay Survey

Speed variation of Car, Motorized two wheeler and BRTS bus is collected using V-box, a GPS equipment to evaluate the travel time and delays during the time period of data collection. From the V-box data, delays at each intersection in the stretch are evaluated and the critical intersections are identified. The travel time data collected using V-box and manual methods in different directions is used for the validation of VISSIM model. Number of trials 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.

4.4 Spot Speed Survey

Spot Speed Survey is carried out using Radar guns at different approaches of each arm just before every intersection zone. Two radar guns are employed to collect the spot speed data of the vehicles during the free flow conditions. 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 as speed distribution input in VISSIM modeling. The spot speed of different vehicular categories is collected for every 5-minute interval in the morning peak hour for total about fifteen minutes. The sample size is random and was adopted depending on the traffic composition in various arms. The error in spot speed reading is avoided by keeping the angle of deviation less than 15 degrees.

4.5 BRTS Performance Survey

The travel time data for the BRTS buses is collected using ANPRS (Automatic Number Plate Registration System) which is a recent technology. The travel time data was collected for about five hours in a day during 10 am to 4 pm. ANPRS setup consists of two cameras and two laptops with cables. The laptops with LINUX operating system are equipped with the necessary software to collect and store the data in the system. The stored data consists of image of the number plate of BRTS buses, registration number and time stamps. After capturing the registration number image of vehicle, it decodes the image and directly generates the registration number in the report. Video of the entire time duration of capturing has been recorded and stored in order to cross check the number plate data decoded by the system. To avoid the error in decoding, the image of the number plate can be used to check the decoded number plate with the actual one.

Two cameras were installed at points and focused in such a way that number 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.

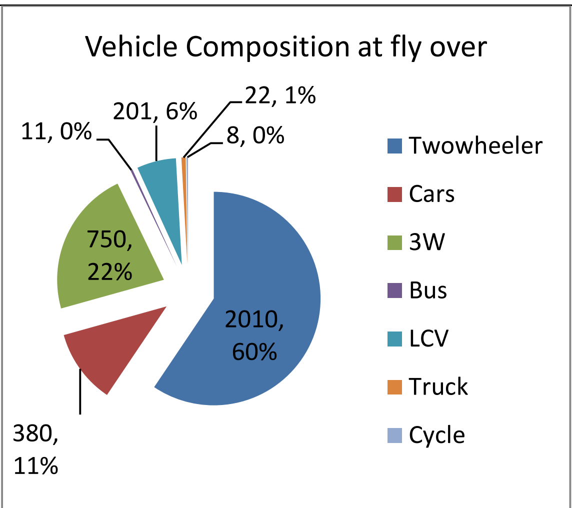
Another camera is installed at the exit point at Sachin GIDC BRTS bus stop which is at a distance of around 8.5 Km from Udhna Darwaja. Using the time stamps of each number plate at both the stations, the travel time is calculated for every bus. There are eight BRTS buses operational in the selected corridor round the day. So, the registration numbers of the vehicles are repeated with a time lapse which indicates the time taken by a bus for round trip Udhna Darwaja - Sachin GIDC –Udhna Darwaja. This time lapse may also include the halt time of a BRTS bus. The time headway can also be evaluated for BRTS buses based on the consecutive vehicles time stamps. 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.

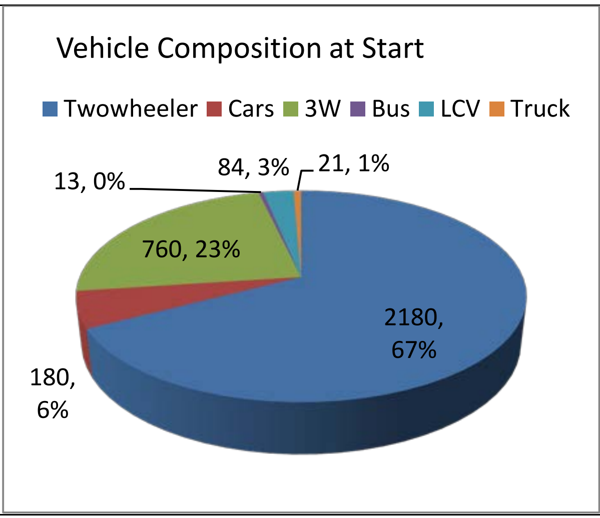
5. DATA EXTRACTION AND PROCESSING

5.1 Classified Vehicular Count

The data extraction process consists of enumerating the number of vehicles in each direction of intersections from the videos recorded using cameras. The volume count is carried out for the morning peak and evening peak hour considering five-minute time interval. These counts are entered in MS Excel sheets direction wise at all the intersections. The directional classified vehicular counts done manually for some directions are also entered in MS excel.

The total number of vehicles generated from every arm is calculated for every ten minutes for the duration of one hour each in morning and also the evening. This is done 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 observed in 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.The traffic composition at different roads in the study stretch is obtained from the Classified Vehicular count data and results are shown in figure 5.





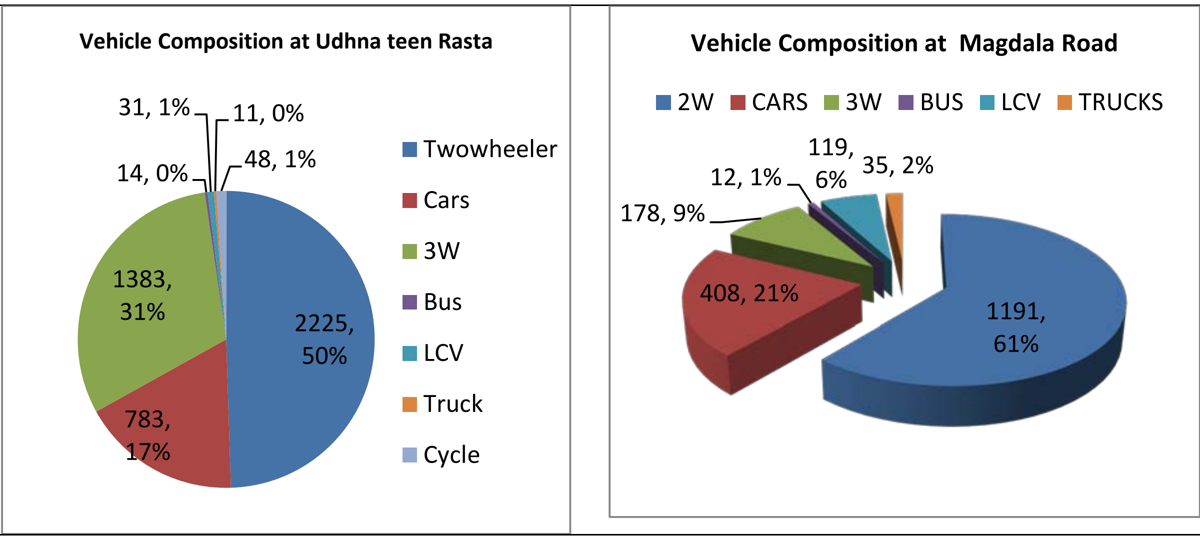


Figure 3. Traffic composition data at different locations on BRT corridor

5.2 BRTS Performance Survey

The data from ANPRS from two cameras is collected and stored in the two laptops. The stored time stamps and registration number data is retrieved using “Generate Reports” option in the interface of the software in the laptop. The reports are generated in the PDF format and are manually entered in to Excel sheet to calculate the travel time. 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 analysis also done for that Travel time as shown in table 1. Average waiting time of BRTS bus at various bus stops is calculated approximately from the reconnaissance survey and also from the V-box data. 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, maintain a journey speed of about of 22 km/h over a length of 9.5 km.

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

Sl.no.	Registration no.	Entry time (h:m:s)	Exit time (h:m:s)	Travel time (h:m:s)
1	GJ05BT9851	10.49.03	11.13.49	0.24.46
2	GJ05BU3398	10.58.09	11.24.28	0.26.19
3	GJ05BT9909	11.05.55	11.33.28	0.27.33
4	GJ05BU3824	11.13.00	11.40.47	0.27.47
5	GJ05BT9827	11.20.44	11.44.37	0.23.53
6	GJ05BT9845	11.30.02	11.52.41	0.22.39
7	GJ05BU3387	11.38.26	12.02.28	0.24.02
8	GJ05BU3663	11.46.37	12.13.04	0.26.27
9	GJ05BT9860	11.53.18	12.17.38	0.24.20
10	GJ05BT9974	12.01.35	12.28.10	0.26.35
11	GJ05BT9826	12.09.39	12.35.31	0.25.52
12	GJ05BU3648	12.18.48	12.52.44	0.33.56

Mean	26.352
Standard Error	0.609163
Median	26.45
Mode	26.66667
Standard Deviation	3.045816
Sample Variance	9.276998
Kurtosis	2.071283
Skewness	1.125247
Range	12.85
Minimum	21.6
Maximum	34.45
Sum	658.8
Count	25

13	GJ05BT9851	12.26.47	12.53.27	0.26.40	Largest(1)	34.45
14	GJ05BU3398	12.34.28	13.02.54	0.28.26	Smallest(1)	21.6
15	GJ05BT9909	12.41.11	13.09.38	0.28.27		
16	GJ05BU3824	12.49.42	13.16.48	0.27.06		
17	GJ05BT9827	12.56.59	13.20.55	0.23.56		
18	GJ05BT9845	13.06.33	13.28.09	0.21.36		
19	GJ05BU3387	13.14.10	13.48.37	0.34.27		
20	GJ05BU3663	13.23.00	13.51.19	0.28.19		
21	GJ05BT9860	13.29.08	13.55.52	0.26.44		
22	GJ05BT9974	13.37.43	14.03.31	0.25.48		
23	GJ05BT9826	13.46.08	14.10.31	0.24.23		
24	GJ05BT9874	13.53.41	14.15.48	0.22.07		
25	GJ05BT9851	14.01.00	14.27.40	0.26.40		

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

5.3 Spot Speed Data

Spot speed data collected using radar guns in the free flow conditions during the early morning hours and is entered into Excel sheet. The parameters like minimum, maximum, 15th, 50th, 85th percentile speeds for each vehicular category are calculated using SPSS tool. This data was collected at different locations of corridor, which further can be useful for calibrating the simulation model. This data was used for giving the Speed distribution as input to the simulation model.

5.4 Speed and Delay Survey

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 bike are extracted. This data was collected at different locations of corridor, which further can be useful for validating the simulation model.

6. MICROSCOPIC SIMULATION OF BRTS CORRIDOR

The methodology to be followed for the microscopic simulation of traffic flow on expressways using a simulation model, named, VISSIM is shown in the form of a flow chart as shown in figure 6. In microscopic simulation using VISSIM, a model which accurately represents the existing situation is known as the 'Base Model'. The base model development 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.

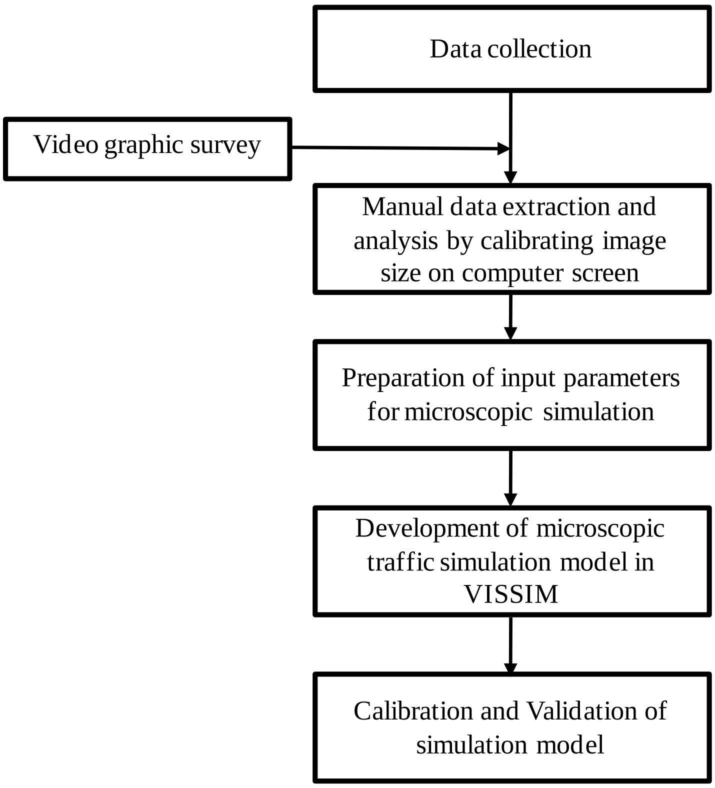


Figure. 6 Details of model development in VISSIM

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 figure 7.

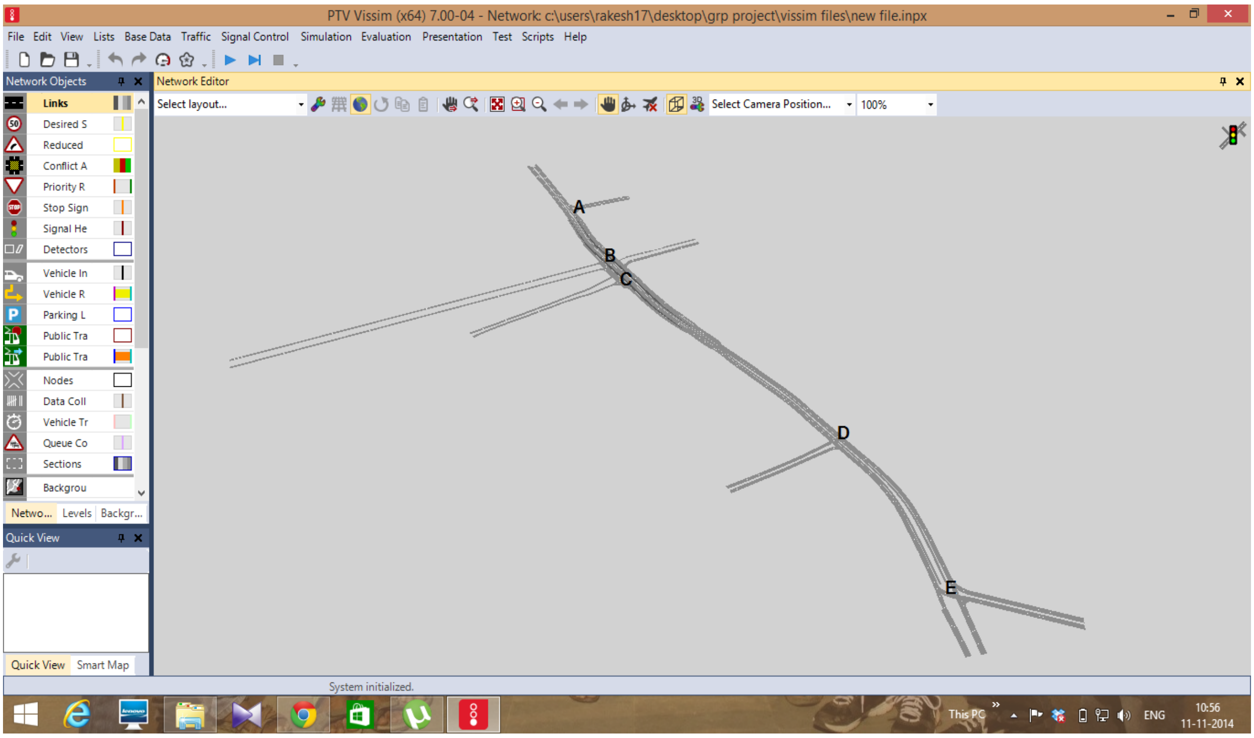


Figure 7.Overview of modelled Network in VISSIM 7.0

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 modelled up to a length of around 50 meters away from the main stretch on both sides of the stretch. The gradient of flyover is designed 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. At the intersections, the width available for BRTS buses is measured separately in order to design it appropriately in the VISSIM model. BRTS road network 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 as inputs, which were obtained from BRTS survey. Present study comprises of two BRTS bus stops excluding the originating and destination bus stop of 1.8 Km stretch. The dwell time distribution for each BRTS bus stop is designed according to observations during the BRTS Bus occupancy survey.

6.2 Model Inputs

The simulation is run for a total duration of 4500 seconds, out of which first 900 seconds are considered as buffer time. The vehicular inputs for each link are given in VISSIM model using the data processing of CVC (Classified Vehicular Count) data. Total volume of 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, three wheelers, Cars, LCVs, Bus and Trucks. Volume inputs 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 software. The speed distribution of different vehicular categories is given according to the minimum, maximum, free flow speed and 85th percentile speed of each vehicular category obtained from the Spot Speed data. The priorities for the various conflict points are given based on the field observations. The speed distributions (normal distributions) which are used by various researchers for example (Kadiyali, 1987; Katti and Raghavachari 1986 and Bains *et al.* 2012) under Indian heterogeneous traffic conditions are used in the model.

Priority rules are used to model the Un-signalized intersections in the study segment. The conflict areas are generally used to model the Un-signalized intersections in some cases. In the present study, the Priority rules are to be designed at the intersection areas because of the complex nature of traffic movements at the conflicting areas. The status of the conflict areas are varied based on the trial and error process in order to arrive at the field conditions. The visual validation was carried out for achieving and simulating the field conditions appropriately. Also the priority rules parameters are also varied and checked for the visual validation. Location of the priority rules also plays a key role in the vehicular movement at intersections.

Table 2. Vehicular Volume (Veh/Hr) Inputs in VISSIM

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
Madgalla road	Sachin	774	343	114	4	74	11
Madgalla 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 Driving Behavior

The Indian driving behavior is added in VISSIM manually apart from the default driving behavior types. This modification is necessary in the case of heterogeneous Indian traffic conditions. The driving behavior for different vehicular classes is designed in accordance to the various literatures available (Bains et.al, 2013). The parameters are adjusted based on the research experience by many authors for Indian Urban traffic conditions (Khan and Maini, 1999). Parameters of the car following model and driving behavior are modified based on the experiences of the authors (Bains et.al, 2013) under Indian traffic conditions.

6.4 Calibration of the Model

This step involves calibration and validation using the commercially available simulation model of traffic flow, named, VISSIM for its application (evaluating traffic management strategies of reducing delays) as one of the most important outputs of the present study. The field observed traffic flow macroscopic and microscopic characteristics can be used for calibrating the model. Then, a check will be made (as validation) for the ability of the model to replicate the field conditions. By giving the parameters listed in Fig. 8 as an input to simulation model, simulation runs can be carried out in order to estimate the output. 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. In the proposed study, the calibration and validation process would be carried out by trial and error method. The model calibration and validation process to be followed for varying roadway and traffic conditions is explained in the form of a flow chart as shown in Fig. 8. The calibration process includes 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). Default values are in accordance to the vehicular characteristics in European countries. The 2D/3D models of the vehicular categories are collected from various sources and these models are used in the network. The calibration process also includes modification of the default parameters of a particular car following model in VISSIM. The calibration process is basically a trial and error process and is carried out till the field conditions are observed to be simulated in the field.

There are two types of car following models in VISSIM software. In the present study case, Weidman 74 model is considered for the design of the base network model. New driving behavior is adopted in accordance to Indian traffic conditions. The parameters of the new driving behavior are set based on the previous research studies (Mathew and Radhakrishnan, (2010).). It consists of parameters like average standstill distance, additive part of safety distance, multiplicative part of safety distance. These values are to be 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 (Mathew and Radhakrishnan (2010).); PTV. (2012); Bains *et al* (2012); Bains *et al* (2013); and Arkatkar *et al* (2014).

The conflict areas are to be defined at the intersection areas, where the links and connectors are overlapping. 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, which are mostly left turning movements. The status of conflict areas is set according to the field observations. The calibration also includes the modification of status of conflict areas at the conflict points. It also includes the modifications of the priority rules parameters at the merging areas in the model.

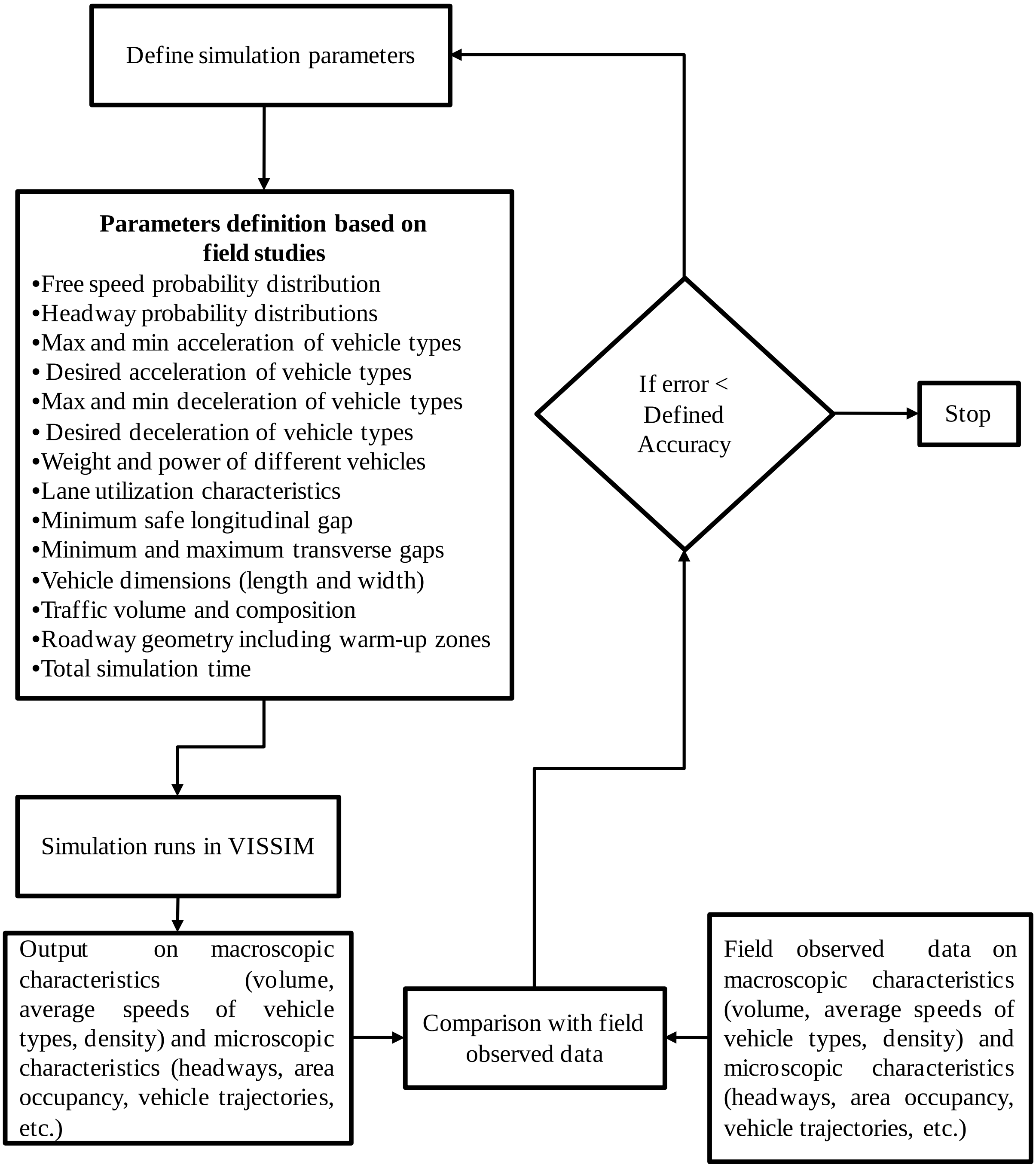


Figure. 8 Calibration and validation procedure for the development of simulation model

6.5 Model Validation

The simulation is run for a total duration of 4500 seconds, out of which first 900 seconds are 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. The travel time data collected for the different directions is proposed to be used as the validation parameter.

The data was collected for two-wheeler during the morning peak and evening peak hours in some directions. Travel time for BRTS bus is also considered in both the directions and used for the validation of the model. Similar travel time data are also to be obtained from the calibrated VISSIM model using travel time counters. Field and VISSIM simulated travel times for each direction are to be 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 travel time data of two- wheeler in different directions is collected from field and the VISSIM travel times are compared to arrive at the minimum error. Trial and error method is adopted to match both the data sets. The simulation is run for different seed numbers and the best ten seed number is selected based on the minimum achievable error.

The priority rules are designed at some merging areas where the conflict areas are observed to be solely inadequate. The priority rules location and parameters are modified in order to simulate the field conditions. The priority rule parameters considered are minimum space headway at various locations of un-signalized intersection. The status of conflict areas at different sections is also modified to achieve the validation of the VISSIM base network. 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 3.

Table 3. Travel Time errors of Validated Model

Direction	Distance (meters)	Average Travel Time Observed Values (seconds)	Average Travel Time Simulated Values (seconds)	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. DATA ANALYSIS

Analysis basically may include 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 and thereby reduce the delays as much 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 width can be extended and thus the base network model is modified and simulation is to be carried out to evaluate the results. The feasible traffic management measures are to be identified and are separately incorporated in the VISSIM model. The traffic management may also include the conversion of un-signalized intersections to signal based upon the traffic volume. The design of signals at the critical intersection carried out optimally in such a way that it accommodates the priority to BRTS bus and simultaneously also focuses on the reduction of delays for non BRTS traffic. A number of traffic management measures can be incorporated in the model successively and the delays for each case are calculated in VISSIM. The quantitative comparative analysis for delays of BRTS buses and non BRTS traffic for both the base model and modified model in each case is to be performed and thus the best traffic management measure is selected. Strong Enforcement as well as possible widening of canal road is required to reduce the delays.

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 templesite (as shown in figure 3). The interconnecting link is observed as a local street in the field having width of 4 meters. Out of the total traffic generated from Magdhalla road, some proportion is rerouted to canal road and remaining is allowed to move normally. 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 modelled for this traffic. This is required as the road width available in that road was 3.5 meters only.

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 such as: (i) Magdhalla road, (ii) Canal road opposite temple, (iii) Udhna Darwaja to Sachin is observed to be Minimum. Table 4 denotes 50C-50M that means that 50% of traffic is diverted through canal road and other 50% of traffic through Magdhalla road. Similarly 60(C)-40(M) denotes that 60% of traffic is diverted through canal road and other 40% of traffic through Magdhalla road.

Table 4. Travel time For Alternative strategies

Sl. No.	Travel Time counters	Travel Time (sec) derived in VISSIM Base case	After Diversion 50C-50M	After Diversion 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

As shown in the table 4, 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. Traffic generating from Magdhalla road is significant as the approach delays in that road was observed to be around 83 seconds in the validated base case model as shown in table 5. This delay was very high when compared to the delay of around 3 seconds in canal road.

Table 5. 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

7.1 Level of Service for Mixed Vehicle lane Traffic (Private Vehicles):

In the study stretch, in one direction of flow, the carriageway width for MV traffic is about 8.3 m at the start of study stretch and it reduces to single lane besides fly over and again it becomes two-lane road, having a carriageway width of 8.5 m after the end point of fly over. From the CVC counts the current Level of service of MV lane section in terms of volume-to-capacity (V/C) ratios has been calculated using the results reported by Arasan and Vedagiri (2010) for Heterogeneous traffic prevailing in India. From the table 6, it may be observed that the BRTS is found to be running at near to capacity level. Hence there is a strong need to attract private vehicle users to use BRTS.

Table 6. V/C ratio for Mixed Vehicle lanes of BRT corridor

Location	Width(m)	Volume(PCU)	V/C ratio
At the Start of Study Stretch	8.3	2380	0.73
AT the end of Study Stretch	8.5 m	3417	0.95

8. CONCLUSIONS AND RECOMMENDATIONS

The following are the important inferences and recommendations after evaluating the traffic management measures of Surat BRTS using microscopic simulation model in VISSIM:

i. Traffic rerouting and distribution of high amount of traffic from Magdhalla road to canal road can be an effective alternative strategy as shown in the analysis section using validated simulation model.
ii. Canal road has Volume to Capacity (V/C) ratio of around 0.2 and Magdalla road running besides it has higher Volume to Capacity 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.
iii. 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.

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. The delay in Magdhalla road has been reduced from 82.99 seconds in the base case to 23.81 in 50C-50M case and 11.26 seconds in 60C-40M case.
vi. At some stations, feeder service can be recommended to attract more commuters. For example feeder service at Kharwar Nagar station can be introduced to attract commuters from SURAT railway station.
vii. At some sections of BRTS, it is observed that private vehicles are violating traffic rules and illegally entering BRTS section, which is a major drawback towards safety as well as performance of BRTS. So strict enforcement is recommended.
viii. Proper enforcement for non-entry of private vehicles on BRTS corridor is essential to avoid the speed reduction of BRTS bus
ix. 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.
x. Conversion of un-signalised intersection to signalized with VAP (Vehicle Actuated Programme) signal for BRTS buses at B-intersection is recommended to reduce delays and travel time for traffic through this intersection.

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