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A Simulation Study for Improving the Traffic Flow Efficiency of an Intersection Coupled with BRT

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Abstract

This study mainly focuses on improving traffic flow efficiency of Bhathena intersection coupled with BRT system located in the city of Surat, India. With the help of field data, the study intersection is modeled in microscopic simulation software VISSIM 8.0. Based on this, a simulation model is calibrated and validated by comparing travel time of the probe-vehicle and the observed queue lengths among other observed data and simulation results in such way that absolute percentage error is limited to15 percent. In order to improve the traffic flow behavior at the intersection in terms of reducing travel time, traffic signal design is carried out using Webster’s approach of signal design. The various scenarios include the design of 2-phase, 3-phase, 4-phase signal systems. In each of the scenarios, the signal design is carried out based on Webster method and same traffic signal system is simulated in VISSIM model and the travel time results across the arms were compared with the base case. It was observed that the 3-phase system is suitable to the intersection keeping in consideration BRTS operation.

Keywords:BRTS, simulation, traffic signal design, traffic flow behaviour, Webster’s method

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1. Background

Bus Rapid Transit (BRT) is a high-quality, bus-based transit system that delivers fast, comfortable, and cost-effective services at metro-level capacities. It does this through the provision of dedicated lanes, with busways and iconic stations typically aligned to the center of the road, off-board fare collection, and fast and frequent operations. With the right features, BRT is able to avoid the causes of delay that typically slow regular bus services, like being stuck in traffic and queuing to pay onboard.

A BRT corridor is a section of road or contiguous roads served by a bus route or multiple bus routes with a minimum length of 3 kilometers (1.9 miles)(ITDP, 2014) that

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has dedicated bus lanes. Five essential features that define BRT have dedicated Right-of-Way, busway alignment, off-board fare collection, intersection treatments, platform-level boarding. BRTS has to be designed in such a way that the generalized cost of travel by BRTS mode is reduced. Travel time reliability plays a key role in enhancing the efficiency to a particular mode of transportation. Delay is the most important parameter contributing to the travel time of trips in urban areas. Provision of BRTS corridor should not adversely affect the travel characteristics of the adjacent Non-BRTS corridor. BRTS occupies some proportion of the width of the road and hence, proper care has to be taken in designing the BRTS. The evaluation of existing BRTS in different Indian cities, where the delays are significant for both BRTS and Non-BRTS traffic has to be carried out periodically to improve the efficiency of the transportation system. The delays are caused basically at the intersections on urban roads. In the case of partially closed BRTS, the delays at the areas of interaction of BRTS corridor and Non-BRTS traffic on a segment are critical and these delays significantly contribute to the overall travel time of the entire corridor. The evaluation of such a segment of a particular corridor, which includes the critical intersections which are to be evaluated. This evaluation can be carried out effectively with the help of microscopic simulation. Further, the effectiveness of various traffic control or management measures can be studied through simulation technique before adopting in the field.

Further to understand the performance of the BRTs researchers attempted various studies which include BRTs planning (Wright & Hook, 2007), comparative assessment on network (Hensher & Golob, 2008), demand and supply analysis (Currie, 2015), passenger travel behavior (Tao et al., 2014), impacts on land use(Cervero & Kang, 2011), Accessibility of BRTs (Tribby & Zandbergen, 2012) commuting behavior (McDonnell & Zellner, 2011) etc. From the above-mentioned studies, it was inferred that most of the works heavily concentrated on understanding BRTs performance at a microscopic network level. On the other hand, at a microscopic level when BRTs is interacting with mixed traffic near intersections, both BRTs traffic and mixed traffic shares the common road space. It was observed that most of the literature available is focused on point scale rating of BRT, based on the infrastructural facility provided by the BRT system and traffic parameters along the corridor. At the same time, it is equally important to conduct a performance evaluation of BRT systems by considering whether BRTS can accommodate the present and future demand for a designed level of service. The present study is formulated based on the quantitative approach using the microscopic simulation. Further with a chance of dominance from mixed traffic on the common road space, the BRTs performance can be affected. On these lines very few research works(Li et al., 2009; Lindau et al., 2010; Arhin et al., 2016)covered this problem. In addressing Godavarthi et al., (2014)simulated BRTs network and suggested microscopic traffic simulation tools in finding optimized solutions. Considering this in the present work, it was planned to use microscopic traffic simulation tools in finding the optimized solution for intersection coupled with BRTs.

With the advent of new technologies in recent times, microsimulation tools tend to play a major role in assessing the performance of transportation components. Some of the research work (Hidas, 2005; Fellendorf & Vortisch, 2010; Treiber et al., 2011).On the other hand, in case of mixed traffic conditions in India, with variation in driving behavior. The simulation strategies haven’t taken any shape as a result very few studies have been reported in this context which includes(Rajuet al., 2019; Rajuet al., 2019; Raju et al., 2018) etc.Further, some of the researchers strategized Vehicle Actuated Programming (VAPs) in transportation studies which includes toll studies(Bains et al., 2017), intersections(Chepuri et al., 2018) etc. Based on the literature from mixed traffic conditions it was inferred that robustness of simulation models mainly dependent on driving behavior. On these lines, the present study focusses on the effective management of traffic at the most congested intersection of the BRT lane and minimize the delays demonstrated through microsimulation.

2. Methodology

Based on the literature review, along with couched opportunities, the present work is planned to carried to improve the traffic flow efficiency of the intersection. On these lines, the entire work is devised in three phases. In the first phase, data collection has been carried out, which includes traffic volume, desired speeds, turning movement counts, travel times, etc. In the second phase, the simulation model is calibrated, by means of coding Vehicle Actuated Programming (VAPs). Finally in the last phase, for the considered intersection, traffic signal design is carried out over different phase systems and tested in simulation models. On these lines, the entire flow of the work is presented in figure 1.

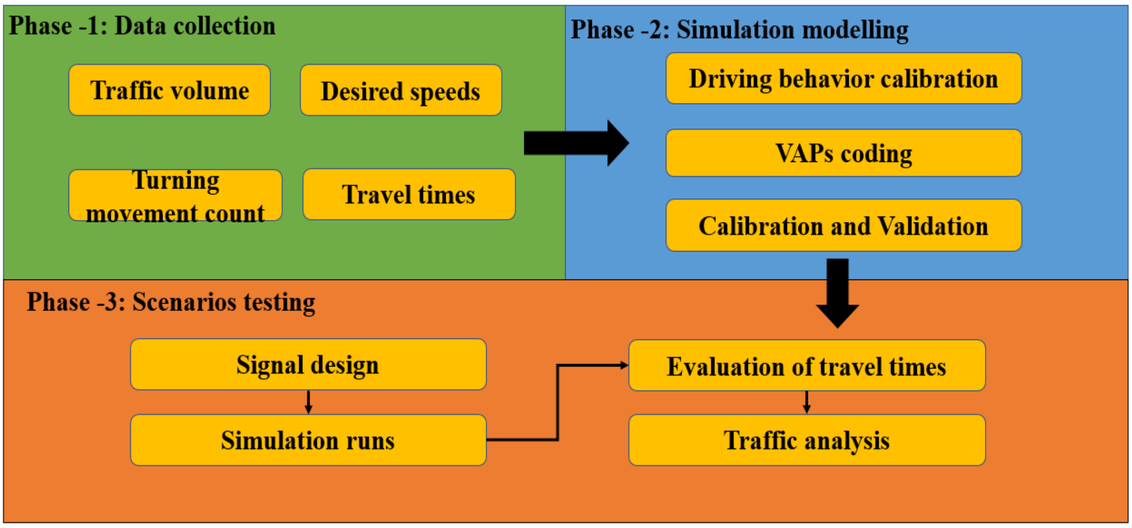

Figure1:Methodological frame work adopted in the present study

3. Study area

Surat BRTS aims at developing the Public Transportation system and focuses on the mode shift from private transport to public transport. BRTS consists of three corridors of which two corridors are operational till August 2015– from Udhna to Sachin GIDC (10km) and from Y-junction to Sarthana Nature Park (17 km). The present study focuses on the evaluation of Stage II corridor as shown in figure 2(a), which connects Y-junction to Sarthana. For the current study, Phase I stage II corridor of Surat BRTS has been chosen, which acts as an important link between the South-West zone (Y-junction) and the farther side of the East zone (Sarthana) through the Canal.

This stretch is approximately 19kilometers in length with an average travel time of 40minutes. As per the preliminary speed and delay surveys carried out in this particular corridor, it has been observed that delays are more for BRTS buses as well as Mixed Vehicle traffic at Bhathena junction in figure 2(b). This intersection becomes a critical section as delays were observed to be significant both for BRTS and Non-BRTS traffic. This is because of the chaotic traffic movements that are observed in the field. Proper control has to be enforced on the vehicular stream for reducing the chaos at the intersection and also delays at that intersection section. In this study, the arms of the intersection were given identity as Udhna arm (leg 1), City out arm (leg 2), Bride arm (3) and City-In(4) are as shown in figure 2(c).

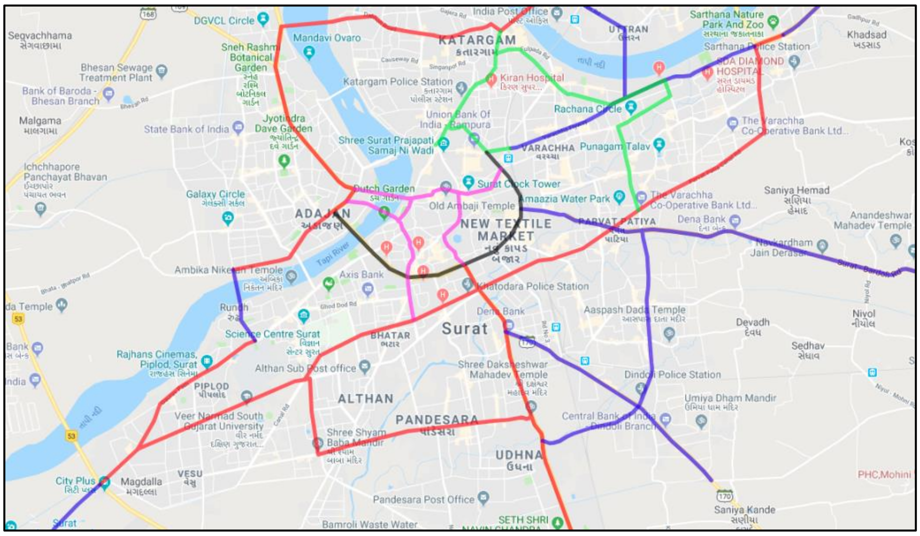

Figure 2(a): Surat BRTS network

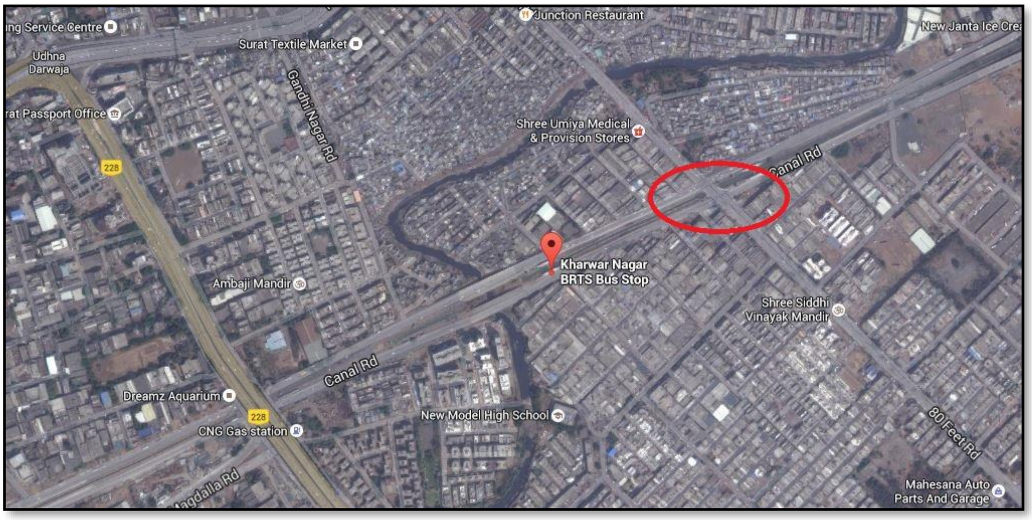

Figure 2(b):critical section: Bathena Intersection

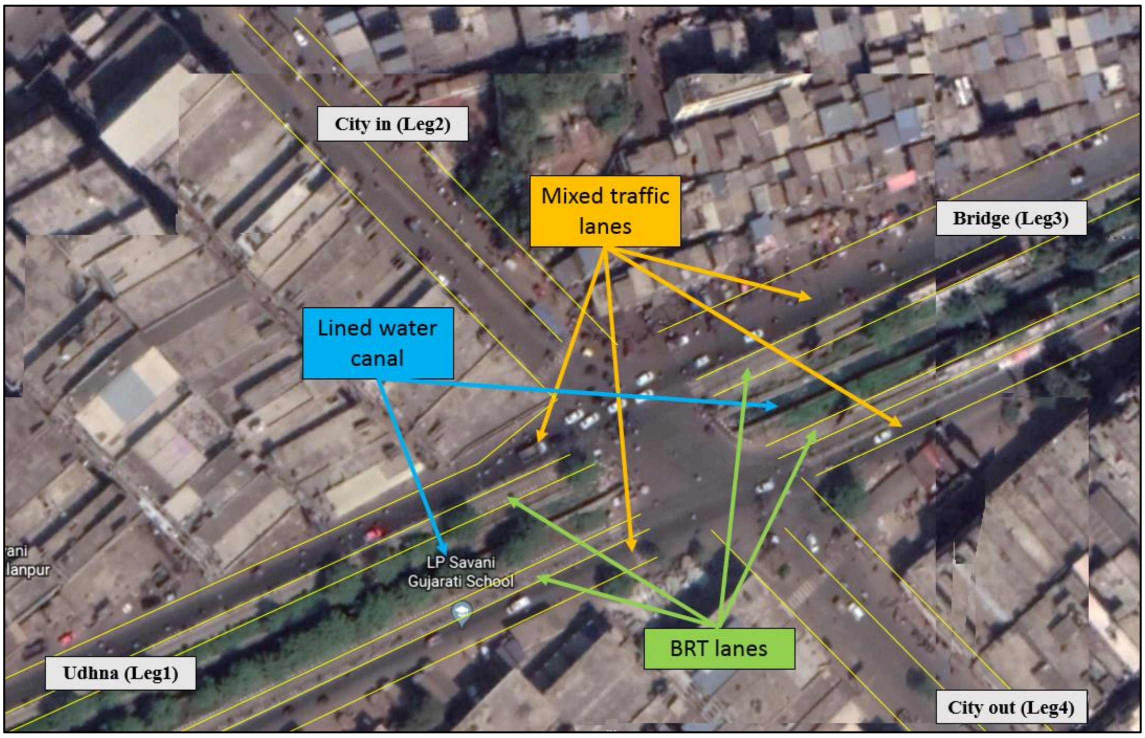

Figure 2(c): critical section: Bathena Intersection

The simulation model is developed using VISSIM for the stretch of 1.2kms including Kharwarnagar and Bhathena intersections. Thus, developed microscopic simulation model has been validated and used for further analysis to reduce the delays over the intersection. Hence, the overall travel time for traffic movement in all directions can be reduced over the study stretch, so as to avoid chaotic traffic interactions and thereby, enhancing the safety levels.

4. Data collection

The study of the Bathena intersection was initially initiated by conducting preliminary speed and delay surveys which were conducted over the BRTS stretch. These surveys were conducted for a period of seven days on one onward and return trip in the morning hours of 10 AM to 11 AM and in the evening hours of 5 PM to 6 PM. These surveys are carried out for three modes of transport namely bus, car and motorized three-wheeler (auto) along the same corridor. From the results, it was found that Bathena intersection is the critical section where delays for both BRT and Non-BRT traffic is predominant as shown in Figure 3. It indicates that there is a reduction in the speed of vehicles while passing the intersection from Udhna side to the bridge side.

Figure 3: Speed vs distance plots of vehicles over the intersection on a typical day (Udhna to Bridge approach)

In order to improve the traffic flow over the intersection using the simulation approach, the study has been carried forward by conducting various traffic surveys over the Bathena intersection. These surveys include road inventory surveys, volume count surveys, speed and delay survey, spot speed surveys. Road inventory survey will be helpful for the development of the simulation model according to the field geometry. Volume count surveys are useful for the volume inputs in the simulation model and also for the design of the signal. Spot speed survey data is useful for the development of the desired speed distributions in the model.

5. Simulation of intersection

5.1 Base network creation

One of the major objectives of the current study is to model the most critical intersection using the simulation tool, VISSIM. As mentioned earlier, Bhathena intersection has been identified as the most critical intersection along the study section as per the preliminary analysis. Bhathena intersection consists of four arms, namely City In, Bridge, City Out and Udhna. Based on the road inventory surveys, the road network is modeled with the help of links and connectors in VISSIM.BRTS road network is created using the width of the BRTS corridor collected from road inventory survey. At the intersection area, 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 the bus at bus stops are given as inputs, which were obtained from the BRTS survey. The base network model in VISSIM is created using road inventory survey data for the selected intersection as shown in Figure 4.

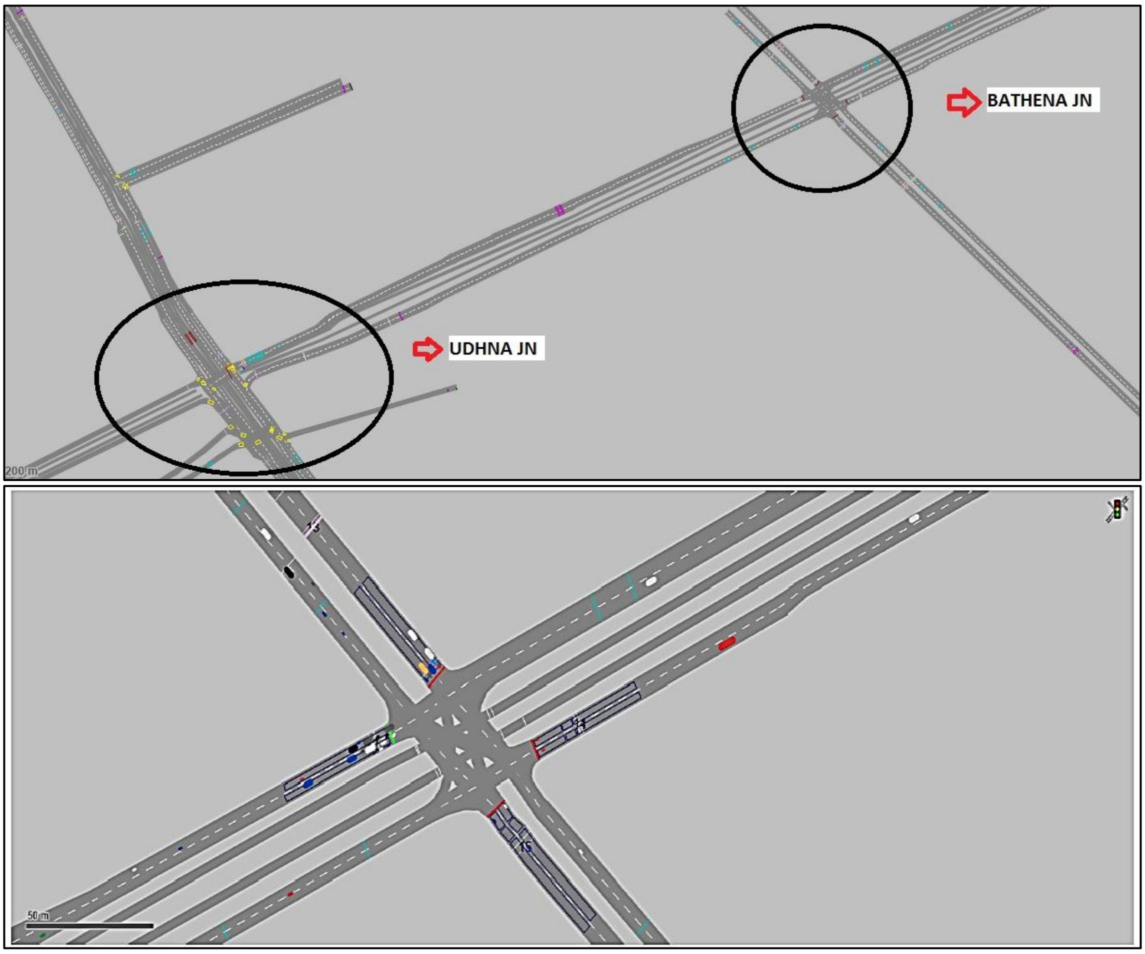

Figure 4: Road network modelled in VISSIM

5.2 Volume and other inputs

The simulation is run for a total duration of 4500 seconds, out of which first 900 seconds are considered as buffer time. This buffer time is important so as to account for the effect of the accumulated vehicles in the road network before the start of the actual simulation. Simulation results were considered for last 3600 seconds (out of 4500 seconds) after buffer time. The vehicular inputs for each link are given in VISSIM model using the data processing of CVC (Classified Vehicular Count) data. The total volume of different vehicular types for one peak hour survey period is given in the VISSIM model as shown in figure 5(a) along with the composition of vehicles in figure 5(b). Twenty-five percent 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 volume inputs of individual vehicular category considered in the present study are given as input. The time headway of BRTS buses is given as inputs for the designed public transport lines. The speed distribution of different vehicular categories as shown in figure 5(c). For each vehicular category obtained from the spot speed data were given as inputs to the simulation model.

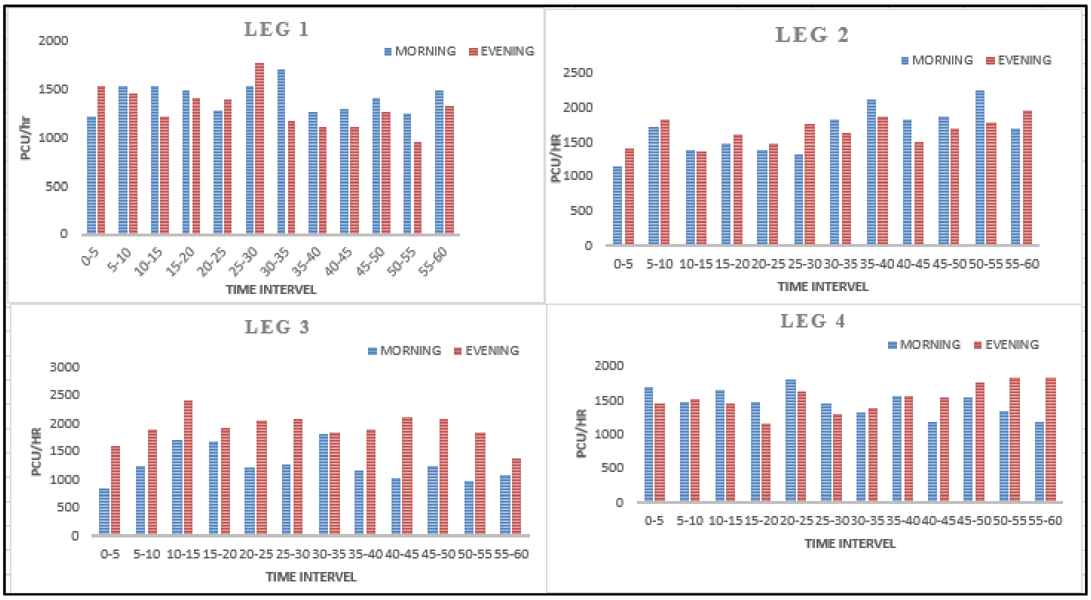

Figure 5(a): Travel volume over the legs of the intersection

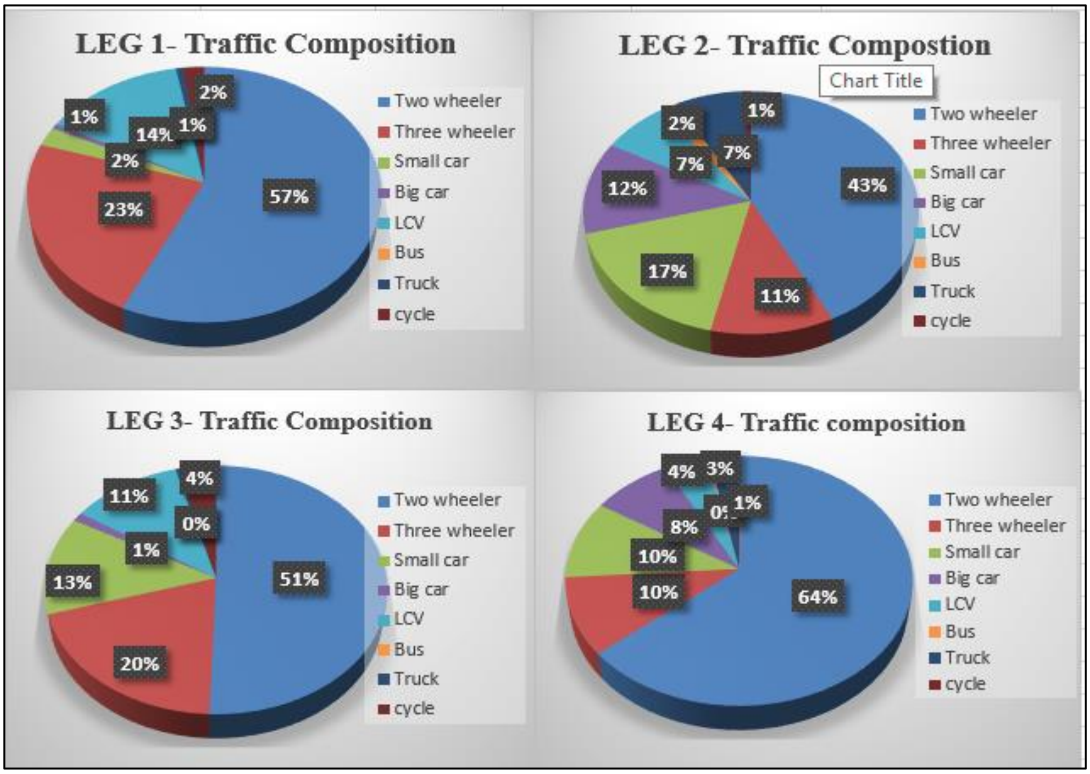

Figure 5(b) Traffic composition over the legs of the intersection

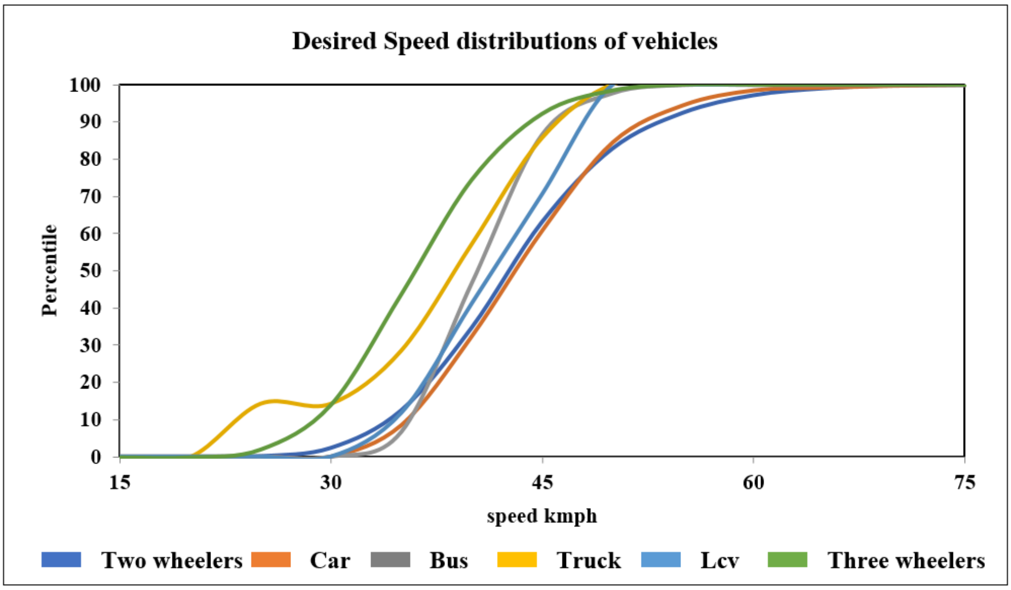

Figure 5(c): Desired speeds of the vehicles over the study section

5.3 Trajectory extraction

In the present study, for calibrating driving behavior a random 10 minutes' vehicular flow is selected, vehicular trajectories were developed for a trap length of 120m to judge the driving behaviour. In this study, Traffic Data Extractor powered by IIT Bombay was used for developing vehicular trajectories. With the help of that software, vehicle trajectory in terms of longitudinal and lateral positions was tracked for a given time frame at an interval of 0.5 sec along with vehicle type. In order to study the following behavior with the help of vehicular trajectory data. Time-space plots are developed for vehicles as shown in Figure 6 and the details of the trajectory data are reported in table 1.

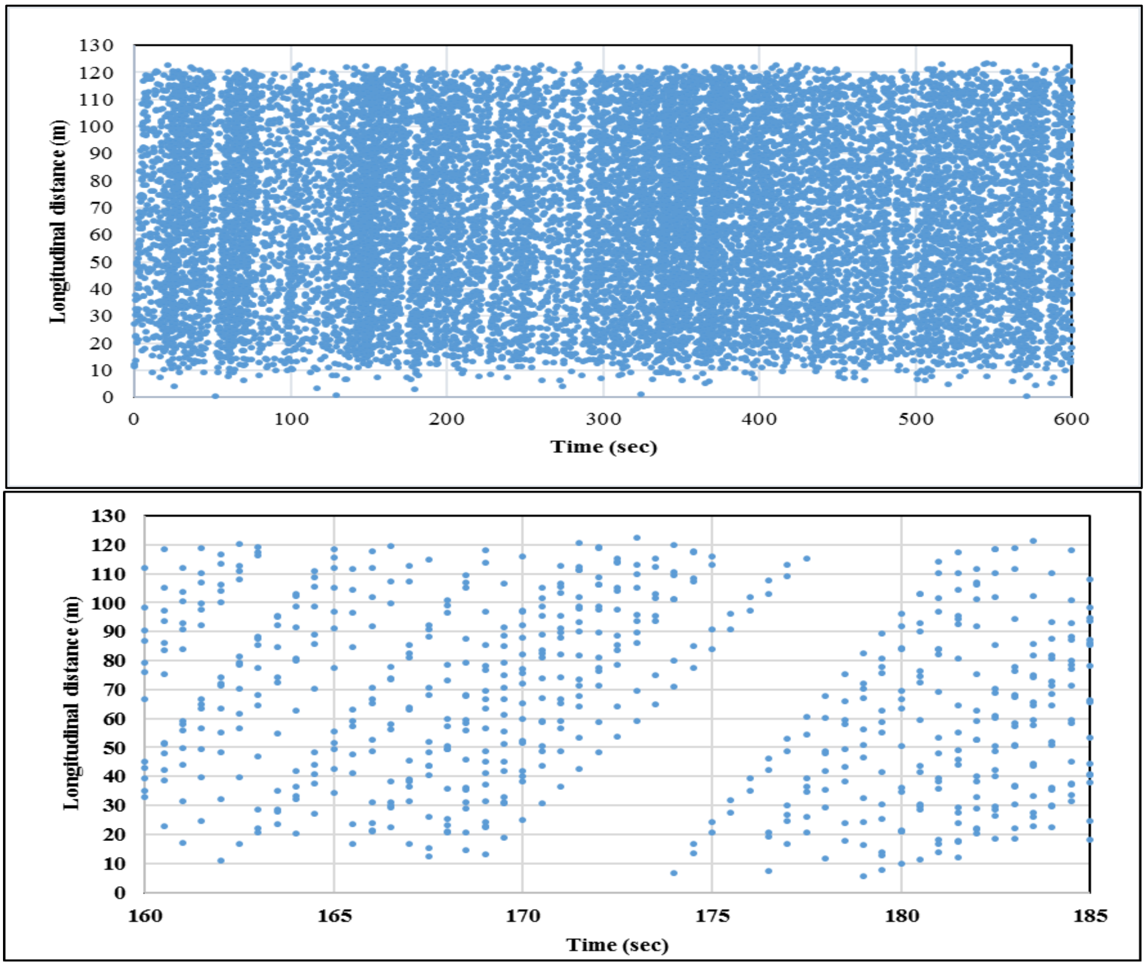

Figure 6: time space plots of vehicles.

Table 1: Details of trajectory data

Characteristics	Properties of study locations
Roadway type	Urban arterial road
Trap length	130m
width	7.5 m
Speed limit	60 KMPH
Duration of trajectory data analysis	15 minutes (0.5 sec interval)
Duration of macro-level analysis	-
No of vehicles tracked	954 vehicles

Based on visual inspection, the vehicular trajectories which are in the following condition are identified. From the identified following pairs hysteresis plots in terms of (relative distance vs relative speed) plots were plotted for the subsequent vehicles having lateral overlap and taken asleader-follower as explained in figure 7. These hysteresis plots were aggregated based on certain following vehicle category.

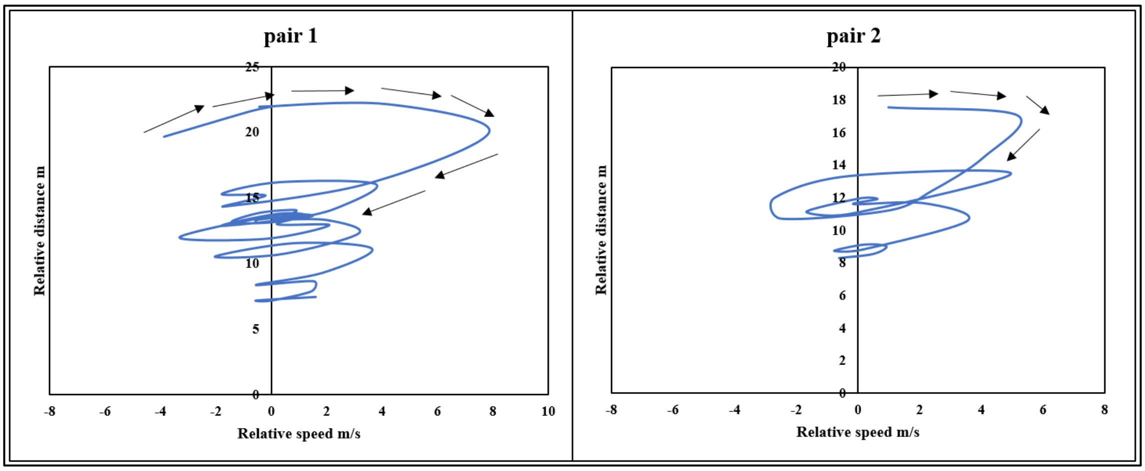

Figure 7:Hysteresis plots among following behavior

5.3 Wiedemann's Model

In this study, vehicle following behavior is calibrated using wiedemann74(Wiedemann, 1974), as these models are chosen because of its applicability in a microscopic traffic simulation tool, VISSIM. Wiedemann's model is a psycho-physical model, which determines the follower vehicle's behavior based on the thresholds of relative distance and relative speed on the subject to the leader vehicle(Higgs et al., 2011; Durrani et al., 2016). The basic idea involved in modeling the thresholds is that Wiedemann's models assume that a driver can be in one of the four modes. They are free driving, approaching, following and braking. Considering all these driving modes, different thresholds are defined as shown in figure 8.

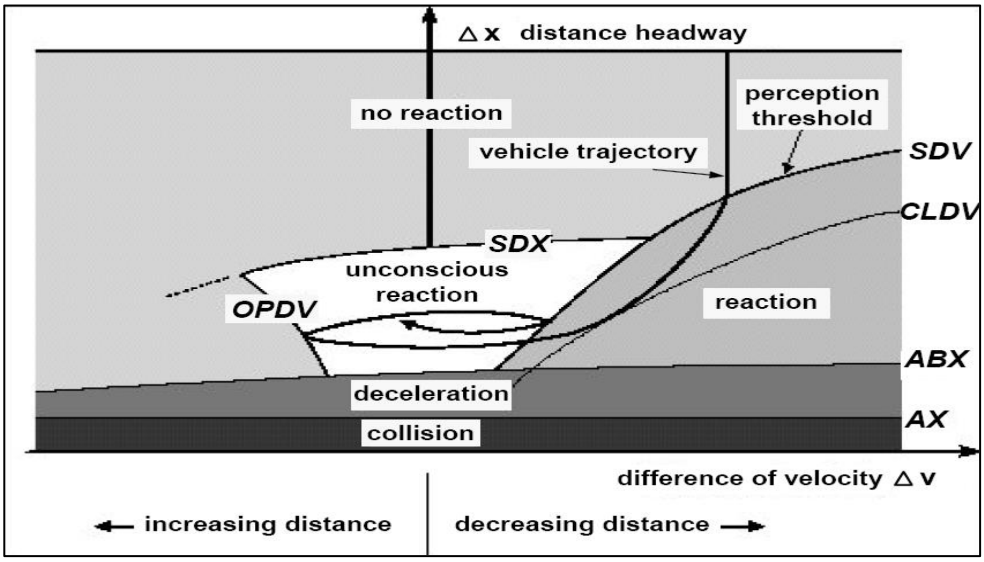

Figure 8:Wiedemann theoretical plot for calibrating following behavior(Rajuet al., 2017)

After identifying leader-follower pairs it was attempted to calibrate the wiedemann74 model. From the literature (Menneni et al., 2008; Chatterjee et al., 2009; Rajuet al., 2017)it was clear that wiedemann74 model is represented in a linear equation, given as

$$ABX = AX + (bx\_add + bx\_mult * N\ [0.5, 0.15]) * \sqrt{Vslower} \quad (1)$$

The parameters need to be calibrated in the wiedemann74 model are AX, bx_add, and bx_mult. From the aggregated hysteresis plots of vehicles, ABX is defined as the minimum relative distance in the aggregated hysteresis for each following category. Similarly, Vslower is the speed of a slow-moving vehicle, which can be either the leader or the follower, which had been calculated based on the hysteresis data. N is the weighting factor of the bx_mult parameter, in this study, it is assumed as 0.5. Based on equation (1), the optimized values of AX, bx_add (additive coefficient) and bx_mult (multiplicative coefficient) are evaluated. On this basis, optimization is repeated for numerous runs until the variation among the calibrated parameters from the runs found to be less and the calibrated parameters. While optimizing an objective function, a few parameters are interdepended among them, there is a chance of obtaining different values along with satisfying the objective function. To avoid this optimization runs were carried repetitively with a change in population size and number of stall generations.

5.4 Lateral behavior

Along with the following behavior, lateral behavior plays a major role in driving behavior. On these lines numerous researchers (Wan et al., 2014; Mathew et al., 2013; Pérez et al., 2011)attempted in modeling lateral behavior. To calibrate the lateral behavior in the present study, with the help of vehicle trajectory data, from the time-space plots the vehicles which are overtaking or passing vehicle pairs were identified. Based on the overtaking/passing vehicle speed the lateral gaps were clustered for every 5kmph speed interval, for this cluster minimum and the average value of lateral clearance was calculated. In VISSIM microsimulation tool, lateral clearances at standstill conditions and at 50kmph were given as inputs for lateral behavior, for that a linear regression equation is fitted to the data as shown in figure 9 and the lateral clearance share is calculated with the help of that equation for standstill conditions and at 50kmph for each vehicle category.

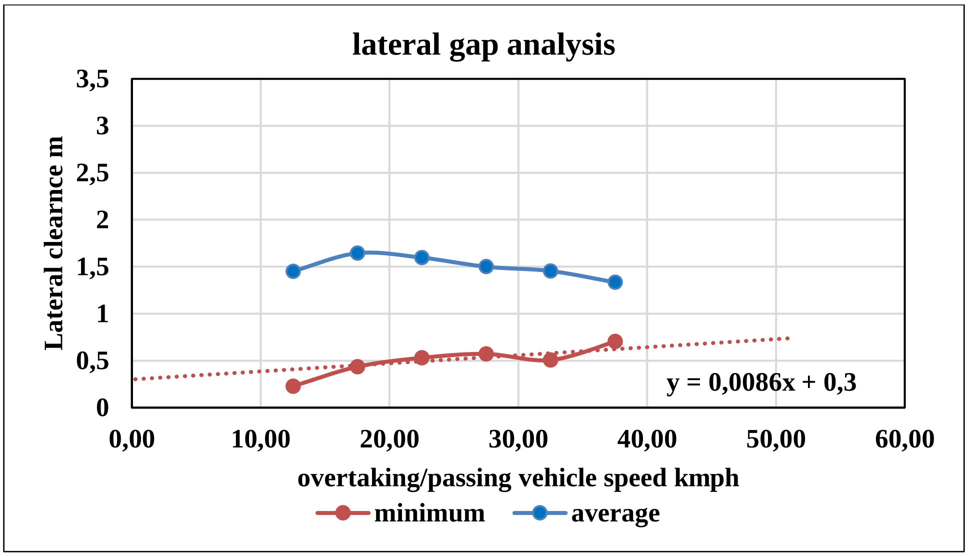

Figure9Variation of lateral clearance with speed.

5.4 Modelling VAPs

During the time of traffic surveys, high traffic volumes are prevailing and with the help of traffic police people, traffic control is enforced at the intersection. The logic behind the traffic management of intersection is that traffic movement can be controlled based on queue length on each arm. In order to replicate this kind of behavior, Vehicle Actuated Programming (VAPs) was designed over the arms of intersection in the simulation model. On these lines, in case of heterogeneous traffic, various studies (Goodall et al., 2013; Zheng et al., 2010; Viti & van Zuylen, 2010)had come up in optimizing the traffic signals. The VAPs will work similarly to the traffic control performed by the police, which allows traffic flow based on queue length generated in each arm as given in figure 10. Again, sensitivity analysis is carried out on a maximum green time of each VAPs so that the travel times and queue lengths represent field conditions in a better way without having a significant variation in terms of percentage error.

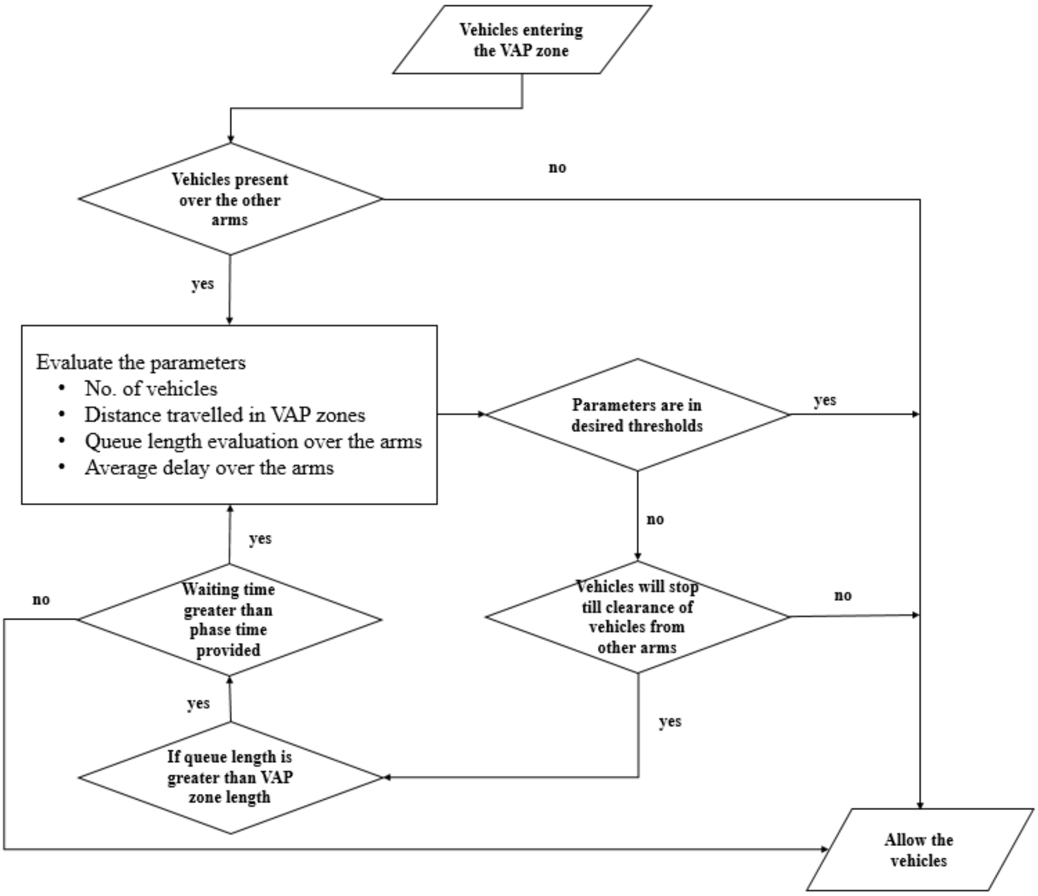

Figure 10: Methodology adopted in coding the VAPs to induce manual traffic control

6. Validation of simulation model

In order to validate the simulation model to test its robustness in representing the field conditions, vehicular travel times and queue lengths were considered. Based on this, simulation is carried out by the trial-error method by a sensitivity analysis on VAPs in such a way that the percentage error between the travel time data of probe vehicle category from the observed and simulation is limited to 10 percent as shown in Table 2 and Figure 11. On a similar basis, the percentage error among queue lengths was calculated over the arms of the intersection, it was found that error is limited to 15 percent which is shown in Figure 12 and explained in Table 3. In the present study, travel times and queue lengths are used as derived validation parameters. Simulated travel time data in different directions are compared with the field-collected data. Similarly based on the observed queues over the arms queue length were calculated and compared with that of simulation output.

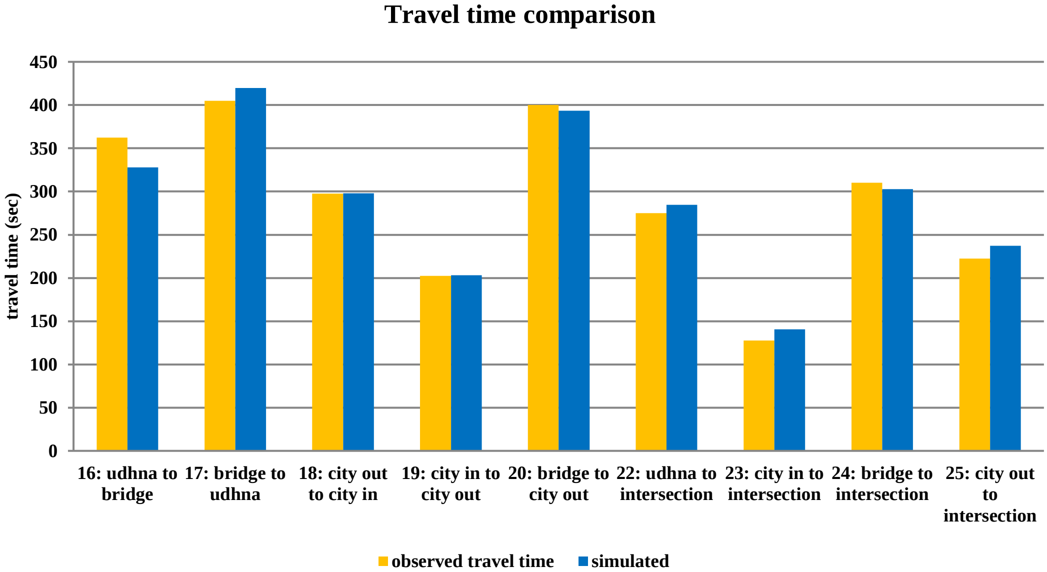

Figure 11: Travel time comparison of Two wheelers among field data and simulation

Table 2: Comparison of travel times among field data and simulation of two wheelers

Traffic Direction	**Observed travel time (seconds)**	**Simulated travel time (seconds)**	**Percentage Error**
Udhna to Bridge	362.5	327.9	9.5
Bridge to Udhna	405	419.7	-3.6
City out to City in	297.5	297.9	-0.1
City in to City out	202.5	203.0	-0.2
Bridge to City out	400	393.5	1.6
Udhna to Intersection	275	284.8	-3.6
City in to intersection	127.5	140.6	-10.3
Bridge to intersection	310	302.7	2.4
City out to intersection	222.5	237.1	-6.6

Table 3: comparison of queue length over the arms of intersection

Arm of the intersection	Observed (in meters)	Simulated (in meters)	Percentage Error
Udhna	240	204.8	14.7
City in	230	200.1	13.0
Bridge	320	351.5	-9.8
City out	300	287.3	4.2

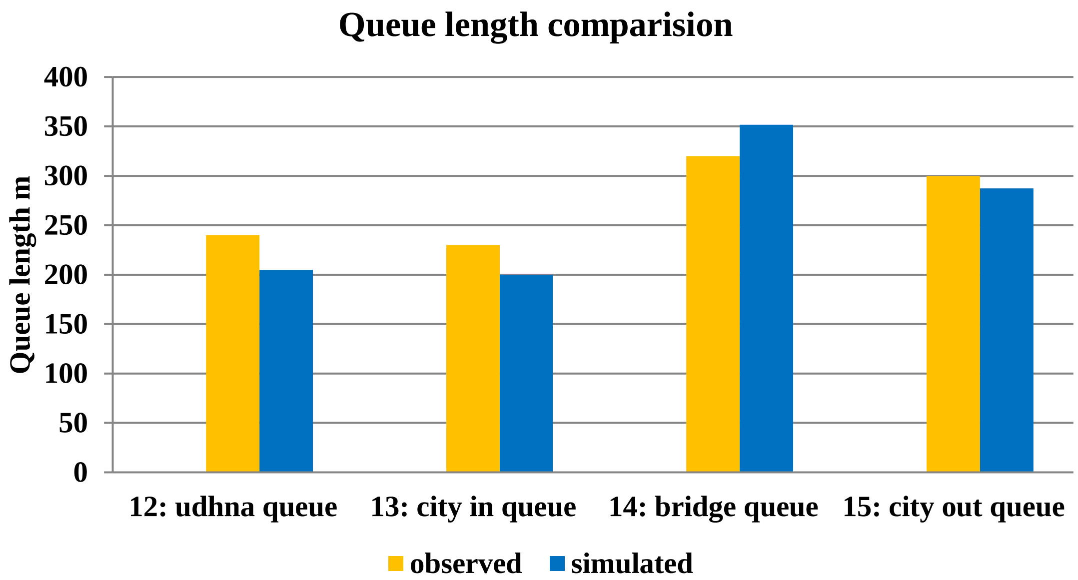

Figure 12: Comparison of queue length at different approaches of intersection

After the simulation of Bathena intersection, the study has been carried forward for reducing travel times and queue lengths over the arms of the intersection, which form the major objective of this study. For this purpose, the traffic signal system has been designed in the simulation model for enhancing the overall traffic flow efficiency at the intersection. Moreover, traffic flow along all the approaches have already crossed the signal warrants as per standard practices. Considering signal design as an effective traffic management strategy, different scenarios accounting to the different number of phases are simulated using the validated model.

7. Traffic signal design

Three different systems of a traffic signal are design is carried out using Webster approach. Based on this percentage reduction in travel time and queue length is reported for different phases. The signal design in this study has been carried out as per recommendations of Indian Road Congress (IRC), (1985). Based on the signal warrants of these guidelines, the intersection has surpassed all the types of signal warrants. This further highlights the importance of the design of a traffic signal for the effective management of traffic. On the other side, in conflicting to the above standard practice, various studies(Murthy & Mohle, 2013; Hossain, 2001; Radhakrishnan & Mathew, 2011; Minh & Sano, 2003) reported inaccuracy of saturation flow estimation. To address this issue for heterogeneous traffic context, different models are developed to calculate saturation flow using approach width of the intersection and the percentage composition of a vehicle entering the intersection (Raval & Gundaliya, 2012)which has been used in this study for signal design. Webster method of signal design used for calculating the cycle time for different phases. Based on this cycle time is worked out as recommended by Webster's formula, given in equation (2). In general, equation (2) is about identifying the cycle time, with reference to lost time and volume to saturation flow ratio. With a change in the number of phases of signal design, the lost time and volume to saturation flow ratio varies and resulting reformed cycle time.

$$C_0 = \frac{1.5L+5}{1-\sum_{i}^{n} Y} \qquad (2)$$

Co = Optimum cycle length in seconds
L = Total lost time per cycle
Y = Volume/Saturation flow for critical approach in each phase.
From the literature, it was found that several models are developed over the years for calculating the saturation flows.
Some of them are shown below:
(i) *Webster* Model
S = 525 x W (3)
S = Saturation flow (PCU/ hr); *W* = Width of Approach road in meter
(ii) Saturation Flow Model Width Approach
S = 626W + 268 (4)
(iii) Saturation Flow Model Traffic Composition Approach
S = 647*W*+ 709*tw*+ 270*b*+ 702*au*- 1568*car*- 1552*bic* (5)
Where,
W = Width of road in m; tw = Proportion of two-wheeler in percentage; b = Proportion of buses in percentage; au = Proportion of auto rickshaw in percentage; car =Proportion of car in percentage; bic = Proportion of bicycle

Based on the above equations, the saturation flow for each approach of the intersection is calculated. Out of these saturation flow models, models based on width approach and composition are found to give better results for designing the signals. In this study saturation flow model based on the road width as shown in equation (4) is used for calculating saturation flow over the arms.

7.1 Four phase signal design

The four-phase signal design of the intersection is carried out by estimating the saturation flows of each approach and followed by calculating the green time of each approach. From Webster's equation, the optimum cycle time is around 220seconds, which includes 2seconds of red amber time and 2seconds of amber time each signal phase. Based on this, green times were calculated for each phase as reported in Table 4. In order to facilitate the efficient movement of traffic, arm-wise phase approach is considered initially. The first phase is given to through moving traffic of Udhna and bridge, and then by right-turning traffic movement of these arms followed by through and right turning movements of the city out and city in arms. The traffic flow considered during each phase of the signal is shown in Figure 13. The time phase diagram for the four-phase signal design is shown in Figure 14.

Table 4: Four phase system

Cycle Length = 220 seconds			
Phase	**Section**	**Direction**	**Green Time (seconds)**
1	Udhna-bridge	straight	85
2	Udhna-bridge	right	20
3	Cityout- Cityin	straight	70
4	Cityout- Cityin	right	30

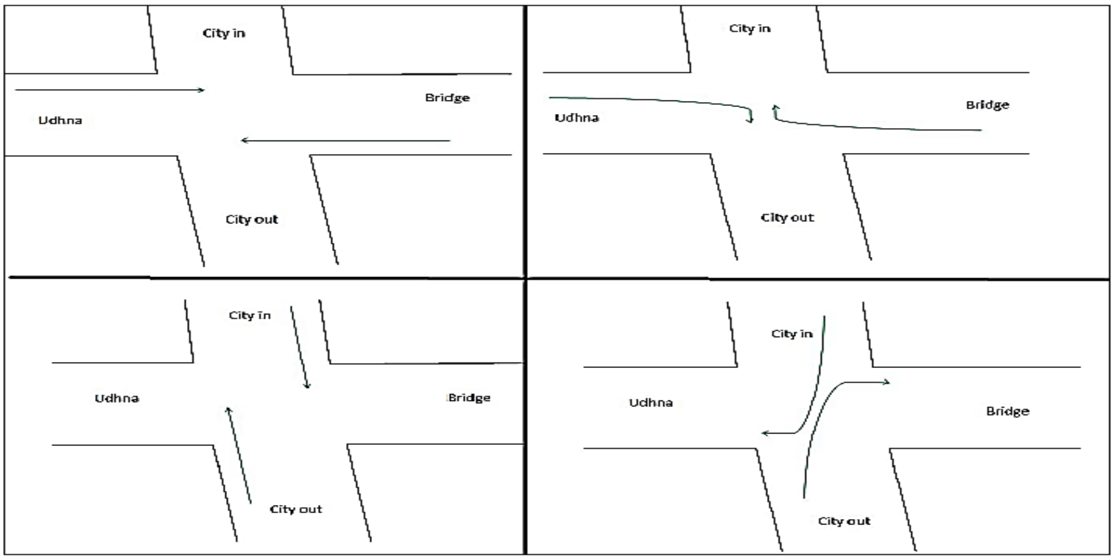

Figure 13: Four phase system traffic flow pattern

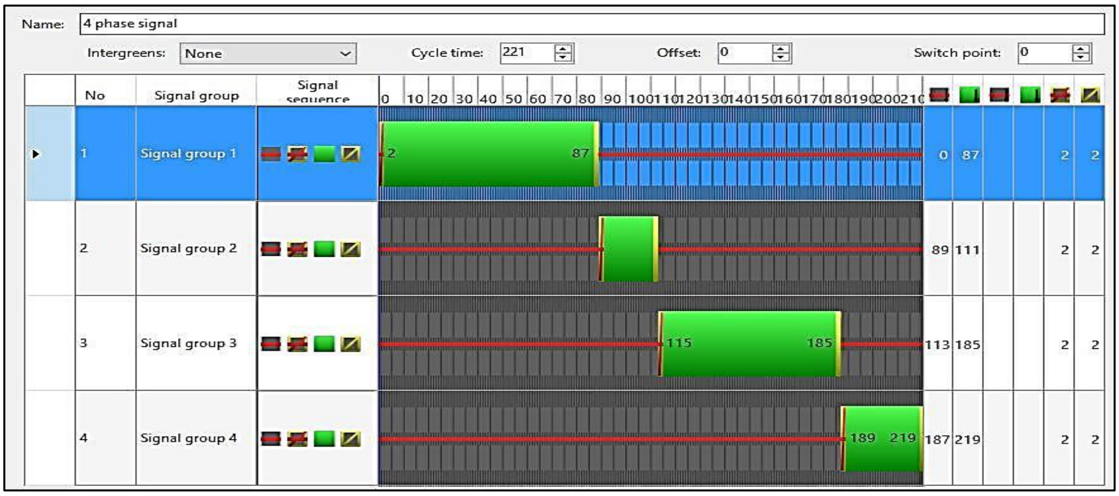

Figure 14: Four phase system phase diagram in VISSIM

7.2 Three phase signal design

The three-phase signal design of the intersection is carried out in a similar manner to four-phase signal design. The optimum cycle time is found to be 190 seconds, which includes 2secondsof red amber time and 2seconds of amber time for each phase. In this case, the first phase is designated for through moving vehicles of the city out and city in and then right-turning traffic of these arms followed by through, right-turning traffic of Udhna approach and bridge approach. The green phase time obtained as per the design of three-phase signal design is depicted in Table 5. Similarly, flow pattern diagram and phase diagram are explained in Figure 15.

Table 5: Three phase system

Cycle Length = 190 seconds			
Phase	**Section**	**Direction**	**Green Time (seconds)**
1	City out- Cityin	straight	60
2	City out- Cityin	right	32
3	Udhna-Bridge	straight,right	87

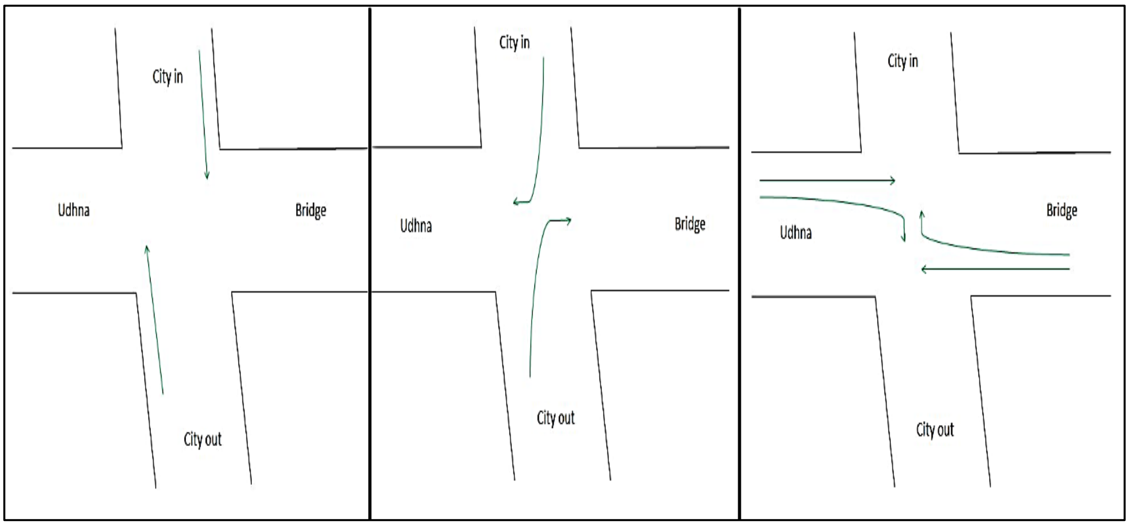

Figure 15: Three phase system traffic flow pattern

7.3 Two phase signal design

Optimum cycle time for two-phase is found to be 130seconds, which includes 2seconds of red amber time and 2seconds of amber time for each phase and then, green time for each phase is calculated. In this case, the first phase is given to through moving traffic of Udhana and Bridge, then followed by the city out and city in. The green time phase diagram for the two-phase signal design has been calculated similarly to three phases and four-phase signal design. The values are shown in Table 6. Traffic flow pattern and phase diagram are explained in Figure 16.

Table 6: Two phase system

Cycle Length = 130 seconds			
Phase	**Section**	**Direction**	**Green Time (seconds)**
1	udhna-bridge	straight,right	68
2	cityout-cityin	straight,right	54

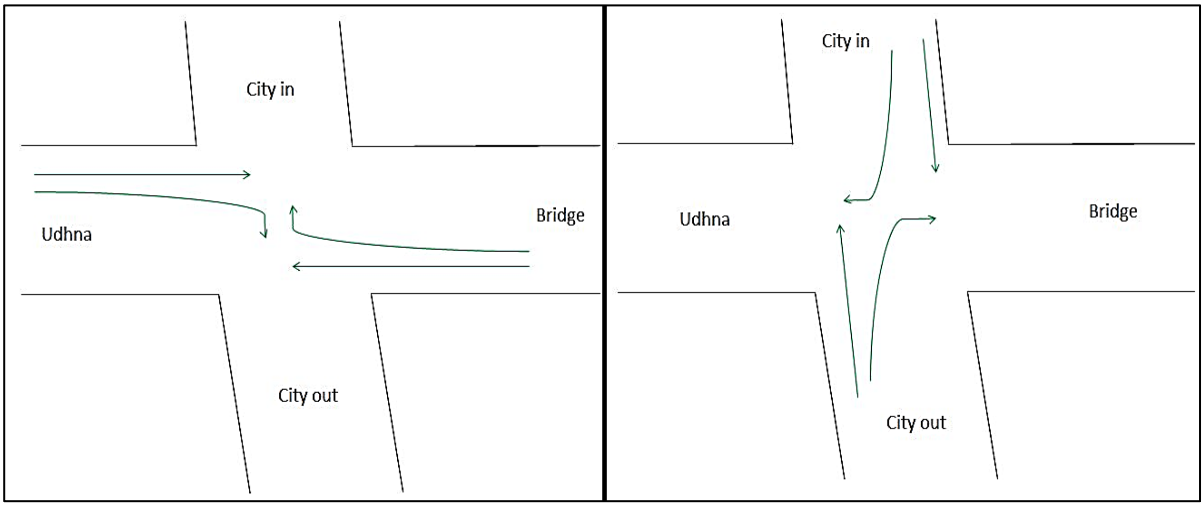

Figure 16: Two phase system flow pattern

Effect of signal design on intersection-control parameters

Based on traffic signal design, different phases of the signal system were implemented in the simulation model and analysis was carried for analyzing the travel time vehicle in simulation and queue length for each of these cases as reported in Table 7. It was identified that travel time over the segments was reduced from 4-phase system to the 2-phase system as reported in Table 8. A positive sign (+) indicates the reduction in travel time and negative (-) sign indicates an increase in travel time and the change in magnitude was reported along with a sign in the following Tables. Similarly, a variation of travel time over different phases was explained in Figure 17. From Table 8 it can be observed that travel time is reduced by a certain amount for all the nine traffic directions. Whereas in the case of 4-phase (col-3 of Table 8) and 3-phase (col-4 of Table 8), travel times are observed to be increasing in some of the traffic directions. In the case of the 3-phase system, travel time in the major arms (Udhna to Bridge and Bridge to Udhna) is observed to be reduced by a significant amount when compared to 4- phase scenario. Also, higher cycle times in the case of 4-phase scenario (col-6 of Table 7) resulted in higher travel times when compared to other scenarios.

Table 7: Comparison of travel time over different phases over the intersection

Sr.no (1)	Section (2)	Simulated sec (3)	Travel Time sec 4-Phase (4)	3-Phase (5)	2-Phase (6)
1.	Udhna to bridge	310.4	186.4	119.2	103.1
2.	Bridge to udhna	415.1	521.6	163.5	129
3.	City out to City in	280.9	362.9	319.9	218.2
4.	City in to City out	199.6	254.4	232.2	65.1
5.	Bridge to City out	390.8	496.7	102.5	69
6.	Udhna to intersection	283.1	139.3	74.1	61.3
7.	City in to intersection	150.1	168.4	150.2	30.3
8.	Bridge to intersection	298.6	402	61.3	33.3
9.	City out to intersection	237	309.5	273.4	206

Table 8: Comparison of travel time change in percentage with base case over the signal phases

Sl.No (1)	Section (2)	% Reduction in Travel Time 4-Phase (3)	3-Phase (4)	2-Phase (5)
1	Udhna to Bridge	39.9	61.6	66.8
2	Bridge to Udhna	-25.7	60.6	68.9
3	City out to city in	-29.2	-13.9	22.3
4	City in to city out	-27.5	-16.3	67.4
5	Bridge to city out	-27.1	73.8	82.3
6	Udhna to intersection	50.8	73.8	78.3
7	City in to intersection	-12.2	-0.1	79.8
8	Bridge to intersection	-34.6	79.5	88.8
9	City out to intersection	-30.6	-15.4	13.1

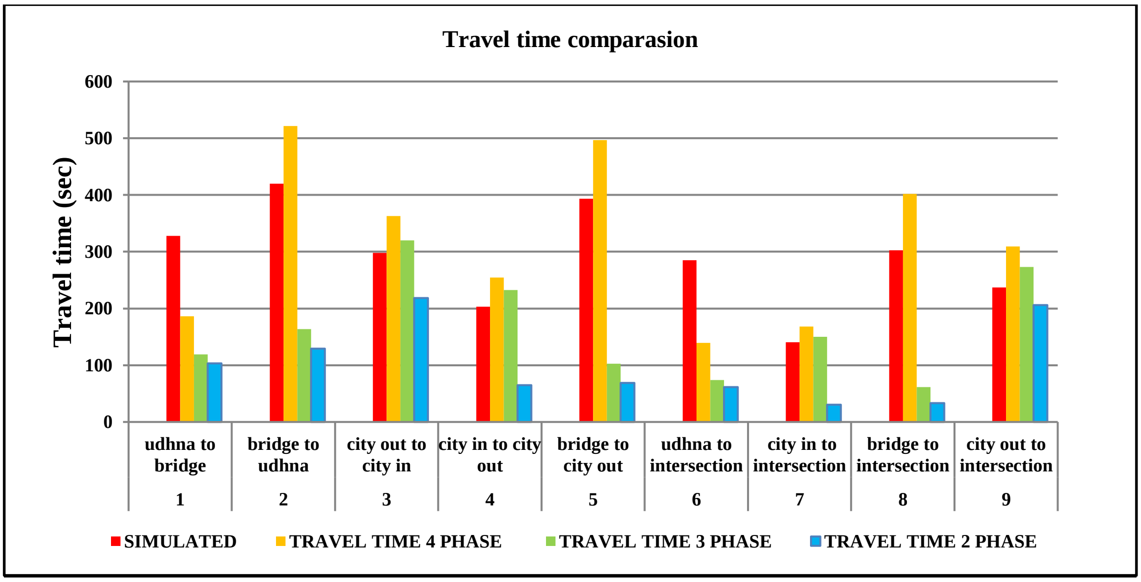

Figure 17: Travel time comparison over different phases of traffic signal system

On similar lines, queue length was also considered as a performance evaluation factor for the present study. From the simulation results, it was found that the queue length also decreased gradually from the base case as the number of phases in the signal design was reduced. Observed queue lengths for different scenarios simulated are presented in Table 9. From Table 9, it can be noticed that higher queue lengths are observed in case of 4-phase followed by 3-phase and 2-phase. Though 2-phase (col-5 of Table 8) signal design is observed to be effective in terms of travel time and queue length reduction, a higher number of conflicts may pose a serious threat resulting in unsafe movement of vehicles at the intersection.

Table 9: Queue length variation over different phases of traffic signal systems

Sl.No	Section	Observed	Simulated	Queue Length (m)		
				4-Phase	3-Phase	2-Phase
1	udhna queue	240	204.8	138.5	65.4	33.9
2	city in queue	230	200.1	214.8	209.8	188.0
3	bridge queue	320	351.5	358.0	43.2	12.1
4	city out queue	300	287.3	323.9	315.1	285.3

8. Effect of signal design on BRTS

The signal phase of Udhna – bridge (straight movement) is assigned for BRTS buses in all signal systems for simulation purpose of different phases of a traffic signal. There is a significant effect on BRTS in the system in terms of travel time for crossing the intersection. As we go from four phases to the two-phase system there is an increase in travel time of the BRTS buses because of the influence of Non-BRTS lane. This may be because of the fact that the vehicles moving in the non-BRT lane is having more accessibility in the intersection area. It was found that there is no significant change in travel time when comparing the overall travel time of the BRTS buses. The values from the simulated model for different phases have been depicted in Table 10. A study stretch of 440meters of BRTS lanes has is considered in the model covering the intersection for calculating the travel time and these are compared with that of observed field data in do-nothing scenario. The results of the comparison are depicted in Figure 18.

Table 10 Travel time comparison of BRTS buses over different signal system.

SNO (1)	SECTION (2)	SIMULATED SEC (3)	OBSERVED SEC (4)	4 PHASE SEC (5)	3 PHASE SEC (6)	2 PHASE SEC (7)
1	BRTS from udhna side	105	107	94	105	132
2	BRTS from bridge side	85	97	70	88	101

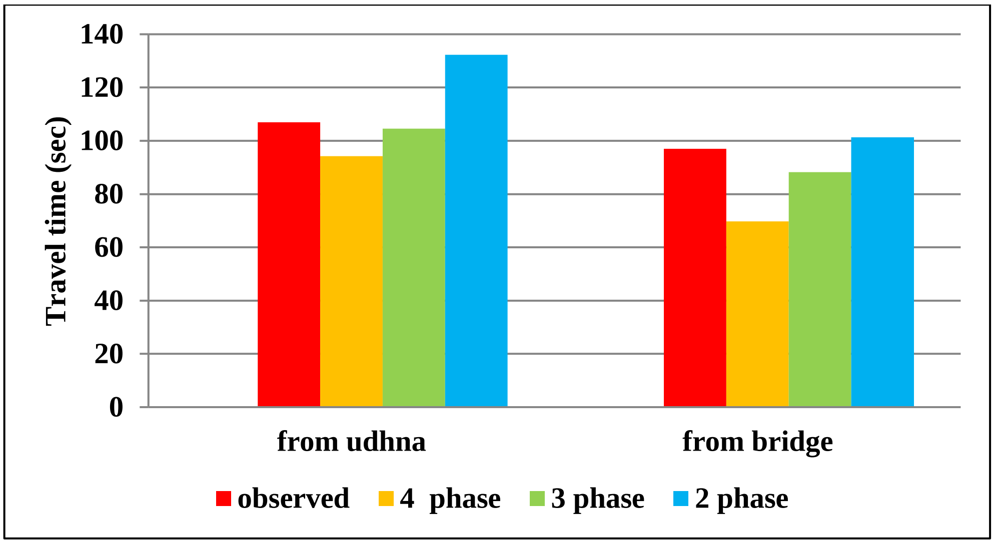

Figure 18: travel time comparison of BRTS buses

9. Findings

Based on the simulation studies on signal design, it is identified that in order to reduce the delay at the intersection different phase system of signals were designed. From this, we can conclude that because of high cycle time in the four-phase system it had increased travel time of vehicles in each arm around 25 to 30 percentage (col-3 of Table 8) in all major cases, even though BRTS system is benefited in terms of less travel time. Whereas in case of the three-phase system there is a significant reduction in travel time for the vehicles, which are moving in the Udhna and bridge arms around 60 to70 percent (col-4 of Table 8), which are the major arms of importance. on the other side, there is no significant change in travel time for the vehicle in minor streams city out and city in as well in BRTS section. In a similar way, results from the 2-phase system are analyzed. From that after implementing two phases in the simulation model, it is observed that there is a significant reduction in travel time from all four arms around 60 to 80 (col-5 of Table 8) in all major stretches. But adopting a 2-phase system in the field is quite risky because of conflicts generated from the right turners and straight moving vehicles from the opposite direction. Similarly, in case of BRTS, It was observed that in case of a 2-phase system, because of more accessibility of Non-BRTS traffic over the intersection has resulted in the increase of travel time for BRTS buses (col-7 of Table 10). By considering all the aspects, 3-phase signal system is more suitable. Hence, the 3-phase system is recommended for the Bathena intersection.

The present study can be extended by designing the vehicular actuated signal system for BRT and assessing its impact on overall delays of the system. This is very important as it enhances the efficiency of the BRT system and thereby boosts up the ridership of the system. Also, the effect of pedestrian flow is not explicitly considered for the signal design in the present scope of the study. In the future scope of the study, the pedestrian phase can be considered in the signal design so as to accommodate the safe movements and crossings of the vulnerable road users across the intersection.

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 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 the design of a large number of parameters and entities like conflict areas, priority rules. Further, the simulation is a trial and error process as the values of different parameters are modified for various combinations in a successive manner so as to arrive at field conditions. Also, the visual observation of the traffic stream plays an important role in the validation of the model. The present study highlights the significance of the simulation for designing the traffic signals at the intersections and checking their effectiveness before implementing in the field. This approach can be very useful to evaluate all possible traffic management strategies and opting for the best one before implementing actual improvement.

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