



This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits use, distribution, and reproduction in any medium, provided the original publication is properly cited. No use, distribution or reproduction is permitted which does not comply with these terms.

A SIMULATION APPROACH FOR EVALUATING CONGESTION AND ITS MITIGATION MEASURES ON URBAN ARTERIALS OPERATING WITH MIXED TRAFFIC CONDITIONS

Chintaman Santosh Bari , Tanmayee V. Gunjal, Ashish Dhamaniya *

Department of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, India

*E-mail of corresponding author: adhamaniya@gmail.com

Resume

Present study evaluates the various congestion indexes in terms of speed performance index, volume to capacity ratio and congestion index based on travel time on the urban roadway network of 5.7 km in length, operating with mixed traffic conditions (traffic with varying static and dynamic characteristics of vehicles). The mitigations measures have been proposed to cater to the present traffic demand by converting the uncontrolled intersection to a partially controlled or signal-controlled intersection. In order to check the effectiveness of such mitigation measures, various scenarios have been generated in the developed and a well calibrated simulation model. It has also been observed that the speed performance index has improved by 8.88 percent while providing channelized intersection at one of the point elements and 11.52 % when the two-point elements have converted to channelizing intersection.

Article info

Received 25 October 2021

Accepted 7 February 2022

Online 4 May 2022

Keywords:

congestion
intersection
simulation
speed

Available online: <https://doi.org/10.26552/com.C.2022.3.D126-D140>

ISSN 1335-4205 (print version)

ISSN 2585-7878 (online version)

1 Introduction

Rapid urbanization in cities has intensified urban infrastructure requirements creating pressure on the sustainable and efficient development of transport facilities. There has been an increase in the world's urbanization by 13% in the last three decades and it is expected that it will reach up to 66% around 2050 [1]. Further, the growth rate of urbanization in developing countries is rapid compared to developed countries [2]. It is well described in the literature that road densities increase with an increase in population density and vice versa [3]. The higher road density leads to higher additional infrastructure per worker [4], causing the migration of the rural population towards the urban lands creating the new residential zones outside the city land. With an increase in population, a substantial increase in the vehicular growth rates is observed. The growth rate in vehicle population made the traffic problems more critical and complicated. The trip rates increased along with the population growth, as well, causing the rise in traffic on the road network and thus creating bottleneck situations with congestions and vehicular delays in metropolitan cities. Traffic congestion is now a severe urban problem and is one of

the significant concerns of traffic engineers, as well as travelers.

The congestion can occur due to the frequent change in macro and micro level parameters looking to the present traffic demand [5]. The micro-level parameters are related to the traffic plying on a particular facility, while the macro-level parameter is related to the overall demand of the facility [6]. The congestion mostly gets set off due to the micro-level parameters, while its effect on the macro level is operated by the parameters that provide the occurrence of congestion. While dealing with the micro-level parameters, the congestion may be caused by the exceedance of the traffic demand over the road capacity, causing the reduction in traffic stream speed. These speed reductions cause longer trip times and also vehicular queuing, mostly at intersections. Longer trip delays may occur due to frequent events such as road accidents, breakdown of vehicles in the traffic stream, traffic signal timings, the geometry of the intersections, etc. [7]. Some special events also cause traffic congestions, such as political rallies, bad weather conditions, social gatherings, etc., but are not frequent. Further, looking towards the macro-level demand, the demand is the function of the land use pattern, employment status, employment opportunities, income

level of the particular people causing the demand, car ownership and other regional, political, or historical background of the city.

This increase in congestion level leads to the extra delay to the road users and the personage tension and high amount of emissions [8-10]. Traffic in developing countries such as India, Taiwan and Vietnam is highly heterogeneous in nature, characterized by a broad mix of vehicles with diverse static and dynamic features in the absence of a lane discipline. This mixed traffic nature promotes extra challenges for dealing with the congestion, starting from finding the reasons behind it to the field applications of the mitigation measures. To deal with congestion, mitigation measures such as a change in intersection geometry, signal timings, etc. must be undertaken. These measures are costly and time-intensive to apply in the field. Hence, in the present study, the simulation tool is applied to study the congestion and emission level for different geometric improvements for an urban arterial network.

2 Literature review

Literature regarding the cause of congestion and the mitigation measures was being reviewed and is given below.

In 1975, Glover and Simon [4] concluded that the higher population density leads to massive road construction and thus a substantial increase in the road density was observed. Similar observations were given by Ji et al. [11] for Beijing province in China. They also concluded that the built-up area is more intense near the highways (expressway considered in the study). Tripathi [12] suggested that there may not be a significant effect on the population agglomeration due to the improvement of the infrastructure facilities with the help of the estimated regression equation for India. Dingil et al. [13] concluded that less congestion is observed for cities with higher Gross Domestic Product (GDP). In addition, cities with a high-density population may face lower congestion if there is high rail infrastructure per person. Cleveland et al. [3] concluded a nonlinear relationship between the population density and road length per resident. Das and Saw [14] developed a mixed traffic congestion model using the speed drop factor and the Mixed Traffic Impedance (MTI) applying the speed profile. The developed method can also consider roadside disruptions, such as parking, pedestrian encroachment, land-use impacts and vendor areas. Asaithambi et al. [15] investigated the impact of lane discipline, intraclass variability and composition on traffic flow characteristics under heterogeneous traffic conditions in India using the microscopic simulation model. They found that the stream speed was affected by composition, intraclass variability and lane discipline in a statistically significant way. He et al. [16] used the speed performance index, road segment and network

congestion indexes to measure congestion levels on the urban road network. The traffic congestion modeling is done in the study using a congestion index based on journey time and the volume to capacity (v/c) ratio to analyze congestion. Gautam and Jain [17] divided the route into independent segments to apply the aggregate traffic behavior to estimate congestion on urban arterial and sub-arterial roads in a metropolis with heterogeneous traffic conditions. Wang et al. [18] considered the travel time for representing traffic congestion along with saturation degree, average speed, travel efficiency, low-speed proportion, total delay and average halting number. They found that the traffic congestion increases as the number of vehicles on the road increases due to reduced vehicle speed. Made and Wedagama [19] concluded that the impact of different types of vehicles on the road congestion is necessary to study for defining the traffic management goal in mixed traffic situations.

Afrin and Yodo [20] analyzed existing road traffic congestion measures and offered helpful suggestions for establishing a long-term, robust traffic management system. Comparison of seven congestion measures: speed, travel time, Level of Service (LOS), delay, relative congestion index, road segment congestion index, congested hour, travel time index and planning time index was done. Results showed that the speed can be easily comprehensible but did not consider nonrecurring conditions. Further, travel time can account for both time and space but does not include capacity. Fellendorf and Vortisch [21] illustrated the detailed methodology for calibration and validation of simulation models both at microscopic and macroscopic level in VISSIM. They concluded that the distribution of intended speeds was one of the essential input parameters for the lane usage. The paper's findings revealed that simulation tools based on the psychophysical car-following model could accurately simulate traffic flow under a variety of real-world scenarios. Jie et al. [22] revealed that the preferred speeds, top-end mean values of the acceleration and deceleration patterns observed in the field were significantly lower than VISSIM's default parameter. The results showed that drivers are less aggressive in real compared to simulation default parameters in VISSIM. Rao and Rao [6] developed the measure for identifying the congestion on the urban arterials operating with mixed traffic conditions in India. They observed the congestion stream speed ranging between 18 km/h to 22 km/h. Sun et al. [23] evaluated the traffic congestion occurring on urban arterial using the travel time and traffic volume in China. They concluded that the travel time-based measure gives noticeable results about congestion. Samal et al. [9] studied the traffic congestion on the urban arterial in India using the travel time reliability measures. They found that the users were wasting 50% of the time in the congestion.

From the literature review, it can be summarized that Congestion Index (CI), such as speed performance

index, index based on travel time, volume to capacity (V/C) ratio etc. are the measures for evaluating the traffic congestion. Further, it is better to know prior the congestion level occurring after improvement in terms of geometric characteristics for network-level analysis. The present study is taken to select the best suitable measures for congestion mitigation occurring on the urban arterial road by changing the geometry of the intersections. The microsimulation approach is used to study the congestion and emission level for different geometric improvements for an urban arterial network as it is a cost-effective approach [24]. From literature, it can be seen that the VISSIM can represent the mixed traffic and non-lane based traffic nature and therefore, it is used in the present analysis.

3 Description of the study stretch

In the present study, an urban arterial network in the city of Surat has been considered as a case study. Surat is considered in the present study because it is the fastest-growing city with rank fourth in 2016 among all the cities in the world. It had an annualized Gross Domestic Product (GDP) growth rate of 11.5% over the seven fiscal years between 2001 and 2008. Surat had a population of 4.46 million, according to the 2011 India census. Vehicle registered in Surat raised to 3 600 000 in 2011-12. Further, it is one of the smart cities under the Smart City Mission of India.

The selected arterial is the busiest route in the southwest zone of Surat. It connects the busiest Athwa Gate intersection on one end and Dumas (a tourist attraction) on the other end. It is the main corridor for reaching the Surat Airport and the Kandla Port (one of the major ports of India). In addition, shopping malls and other recreational activities are mostly present along

this corridor. For all these reasons, the demand exceeds the capacity of the arterial and frequent congestion was observed in the peak hours. The study was conducted along with a 5.7-kilometer long road network of six-lane urban arterial road that consists of six different links. The network begins at the Athwa Gate Circle and concludes at the Rahul Raj Mall. The whole stretch has been divided into six segments (Figure 1), as Athwa Gate to Police Parade Ground (Section-1), Police Parade Ground to Parle Point (Section-2), Parle Point to Sargam (Section-3), Sargam to Sardar Vallabhbhai National Institute of Technology (SVNIT) (Section-4), SVNIT to Kargil Chowk (Section-5) and Kargil Chowk to Rahul Raj Mall (Section-6).

In this road network, one signalized intersection is present between Section-1, recognized by the name Chopati. Two major rotaries are at Kewal Chowk and Kargil Chowk, while one minor rotary is at Parle Point, also an intersection near Police Parade ground named as Synergy Group point. For convenience, in further discussions, they are referred to as intersections 1, 2, 3, 4 and 5 for Chopati, Synergy intersection, Parle Point, Kewal Chowk and Kargil Chowk intersection, respectively.

4 Data collection and extraction

Data collection serves as a foundation to carry out further research work. It was important to measure the traffic load on the field in order to construct an accurate picture of the current scenario in the VISSIM simulation. In this study, data collection basically consisted of three parts. As the first was speed data collection using the radar gun; the second was the volume data collection by the process of video recording



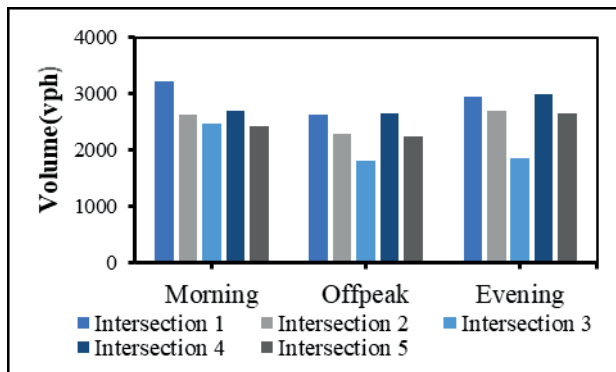
Figure 1 Study Stretch from Athwa Gate to Rahul Raj Mall



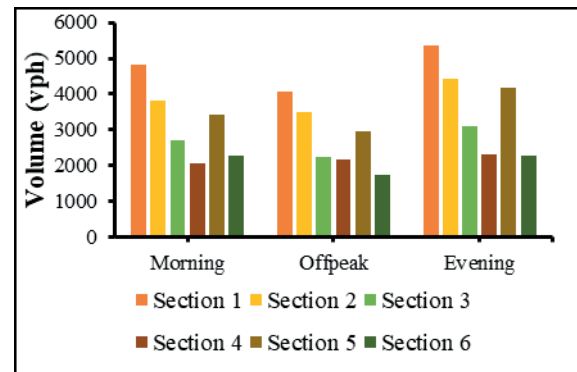
2 (a) Videographic survey



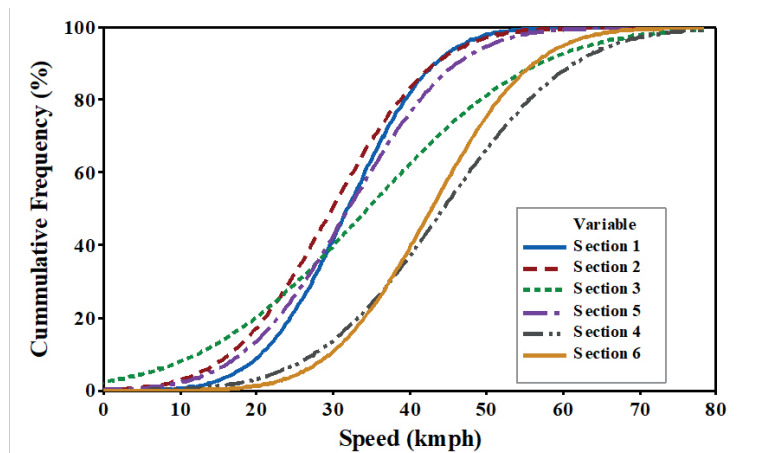
2 (b) Spot speed survey



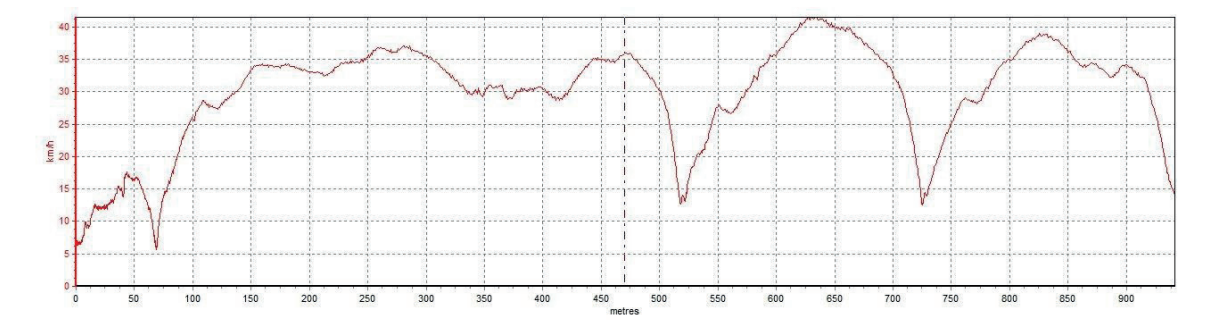
2 (c) Variation of volume for each intersection



2 (d) Variation of volume for each midblock



2 (e) Speed CDF at different midblock sections for 2W



2 (f) Sample Speed-Distance plot from P-box survey

Figure 2 Field Data Collection

using a video camera in the field and lastly, the travel time data collection with the help of a performance box (P-box) instrument. Collected data was extracted to give input to the developed simulation model. MS Excel, Minitab and Performance box software were used to analyze the data.

Indian traffic includes various vehicle classes with varying static and dynamic features. Hence, for the study purpose, all the vehicles were classified into five different vehicle classes such as motorized two-wheelers (2W), motorized three-wheelers (3W), small cars (SCs), big cars (BCs) and buses. The vehicle classification is carried out as per the Indian Highway Capacity Manual (Indo-HCM) [25]. The SCs include all the hatchback and sedan cars, while the BCs include all the crossover utility vehicles (XUVs) and sport utility vehicles (SUVs).

4.1 Video graphic survey

A video graphic survey was carried out using a high-resolution video camera in the field for all five intersections and six midblock sections (Figure 2 (a)). The camera is mounted at a high vantage point such that all the turning movements and good view of all the crossroads of the intersection were observable from the position. Data were collected for the morning peak, evening peak and for off-peak separately. Traffic composition and turning movement counts were retrieved from the recorded video footage by playing recorded video on a large screen in the laboratory and data was gathered in 5-minute intervals. The analysis is done independently to look at traffic mix in the morning, off-peak and evening hours.

Figures 2 (c) and (d) show that volume for off-peak is less both for midblock sections and intersections. In addition, it can be observed that the volume observed at Section-1 is higher and for Intersection-1, volume is bigger as compared to the others. Further, from the field observed traffic composition, it is found that 2Ws account for the majority of traffic (averagely 46 %), followed by small cars (averagely 38 %), 3W (averagely 11 %), big cars (averagely 5%) and finally buses. The analyzed volume and composition are provided as input to the prepared model.

4.2 Radar gun survey

Figure 2 (b) shows the field speed data collection by using a radar gun. For Section-5 and Section-6, a dedicated BRTS corridor is available, so there is a negligible variation in the speed of buses both spatially and temporally. Keeping this fact in mind, a sample of buses was skipped for this section. The cumulative density function (CDF) for all the vehicle categories, considering peak and off-peak time, was studied. The graph shows an "S" shaped curve, i.e. the speed follows the normal distribution (Figure 2 (e)).

4.3 Travel time data collection by P-Box Survey

Travel time data was collected with help of the Performance Box (P-Box) instrument. The P-Box is a self-contained Global Positioning System (GPS) data logger and a performance meter. A 10 Hz fully calibrated GPS engine provides accuracy and precision and the data can be stored on a removable SD flashcard. It gives the real-time data of speed, acceleration, latitude, longitude etc. [26]. For recording the real-time data of each vehicle, the antenna is connected to the vehicle's body part. The data obtained from the P-box instrument was then analyzed using Racelogical P-Box software [27]. Figure 2 (f) shows the sample speed distance plot obtained from the P-box.

5 Development of a simulation model

After acquiring these large datasets of five intersections and six midblock sections with their traffic volume, speed and travel time, the next step is to build the simulation network model in VISSIM. The base network model is developed with the help of links and connectors, as shown in Figure 3. For the link, the length and the number of lanes are provided as an input to the model (Figure 1). The traffic is highly heterogeneous in India. There is a wide variation in composition and volume per 5-minute count and therefore the 5-min count, is found reasonable, to depict the flow rate [25]. Therefore, in the present study also, the 5-min flow rate and traffic composition for that volume (12 x time interval) for an hour, were given as input for simulation. (Figures 2 (c) and (d)).

Figure 3 shows different intersections along the road network developed in the VISSIM. As observed in the field, Intersection-5 was the signalized intersections. The timings of the signals were observed from the field and were given as input. For other intersections, conflict areas were provided at merging and diverging sections.

Speed distribution is provided from collected data for each category of the vehicle separately for morning peak, evening peak and off-peak. Figure 4 (a) represents the default speed distribution given in the VISSIM. Figures 4 (b) and 4 (c) show the sample field observed speed distribution applied for 2W and SC, respectively.

6 Calibration of the model

As the driving behavior in India is significantly different from developed countries, any model built-in VISSIM must be calibrated to represent the field conditions accurately. Wiedemann 74 and Wiedemann 99 are the two psychophysical perception car-following models included in VISSIM. Wiedemann 74 is more typically used to represent urban traffic and hence is

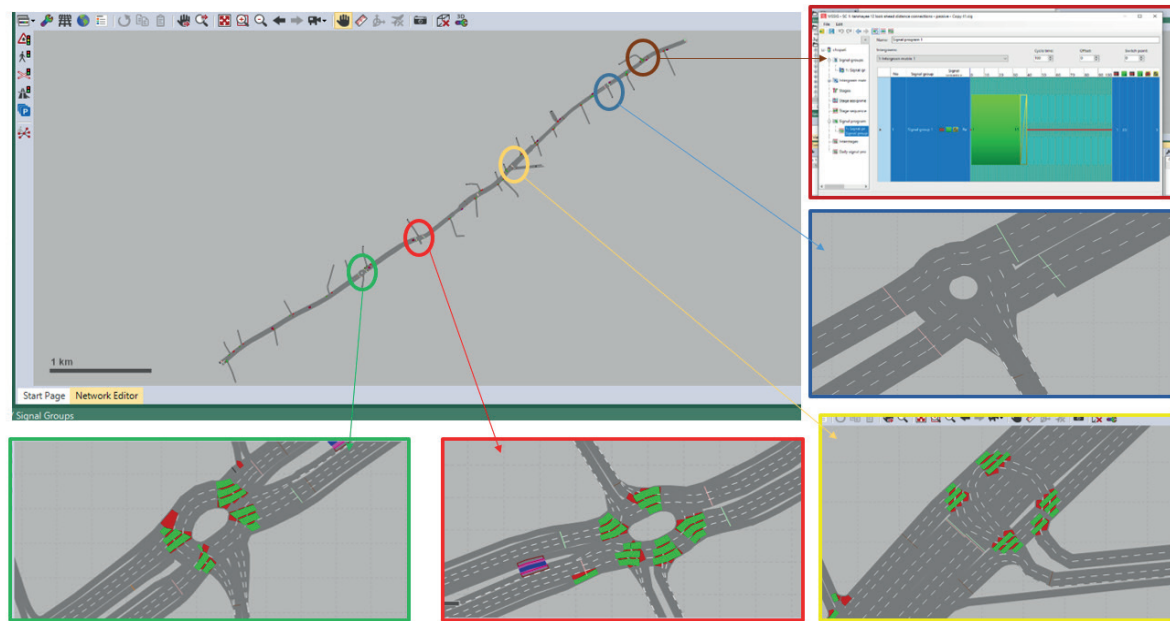


Figure 3 Established road network in VISSIM

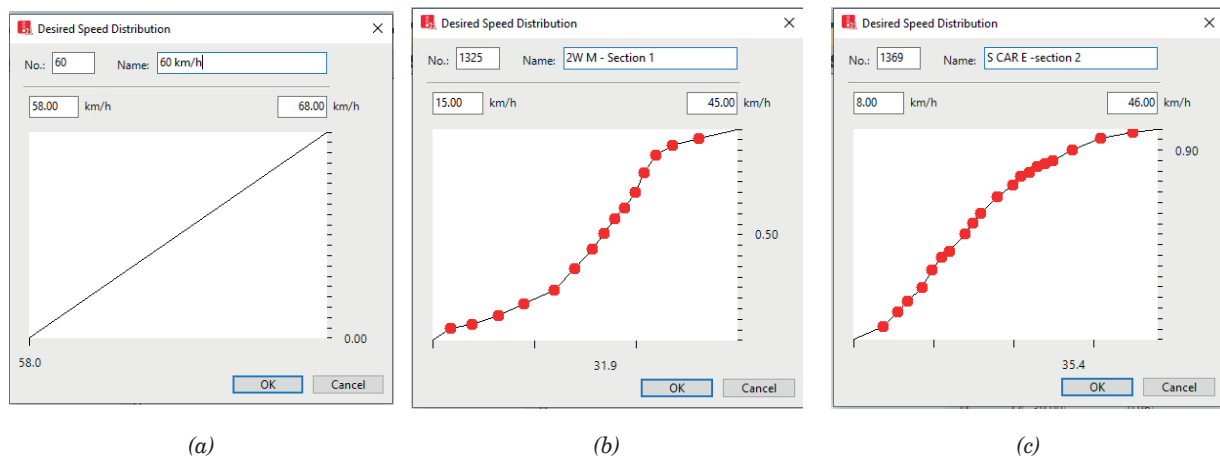


Figure 4 Sample Speed distribution provided as input (a) Default in VISSIM (b) for 2W (c) for SC

adopted here [28]. The methodology for calibration is shown in Figure 5. Calibration is the process of fine-tuning the model's input parameters to accurately replicate observed traffic circumstances. The manual trial and error method is used for calibration in this study. The simulation run should be performed until no significant difference is found between the observed and the simulated values. In this research, calibration is done using the speed and volume data, whereas validated by the collected field travel time data for the entire network. Firstly, the VISSIM results were generated for the default parameters for three random seeds. It was observed that the VISSIM output did not match the field data and was having a significant error. After that, the default parameter values are updated during the calibration until the difference between the actual and simulated measures, such as flow and speed, was less than the required threshold value. For each vehicle category, the values of driving behavior

parameters, obtained after the calibration, are shown in Table 1.

6.1 Calibration by speed

The speed distribution curve obtained from the simulation run was compared to the field data to check the effectiveness of the model. For each intersection, the speed frequency curves are plotted for simulated and field data. From Figure 6 (a), it can be concluded that there is a negligible discrepancy between simulated and field speeds because the two curves are almost similar. Further, the F-test was conducted to determine whether the statistically significant difference exists between the simulated and field data. Here, the F-value is less than $F_{critical}$ for all time periods and for all intersections and hence, it can be concluded that the simulated speeds can represent the field speeds well.

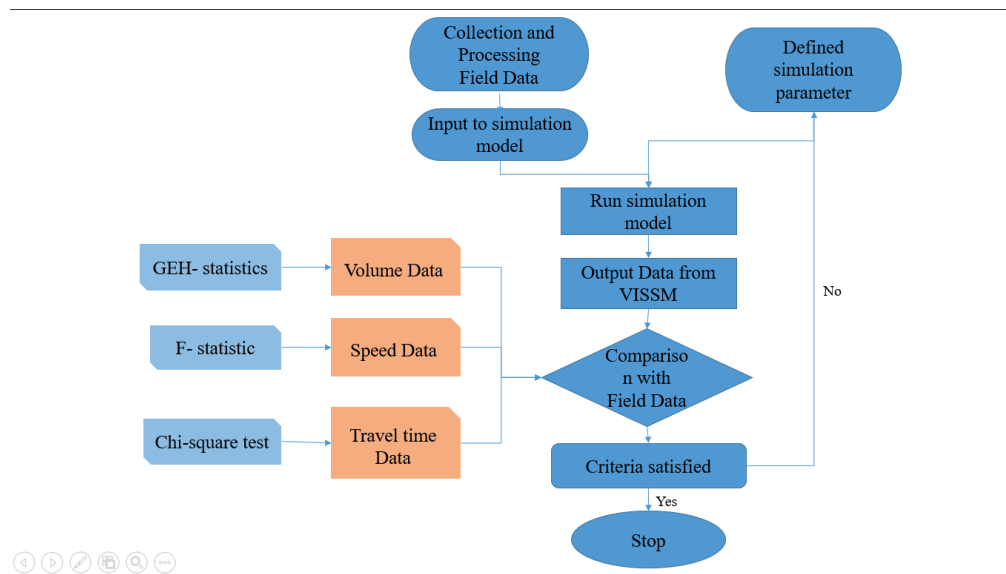
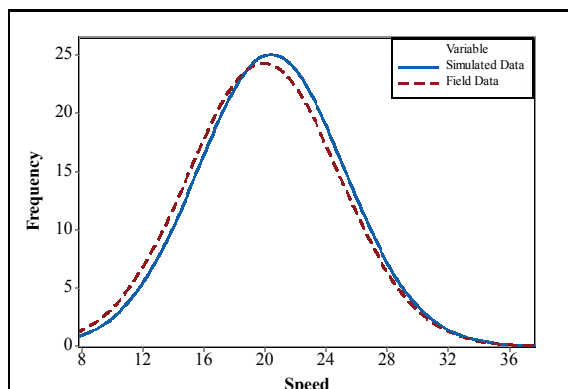


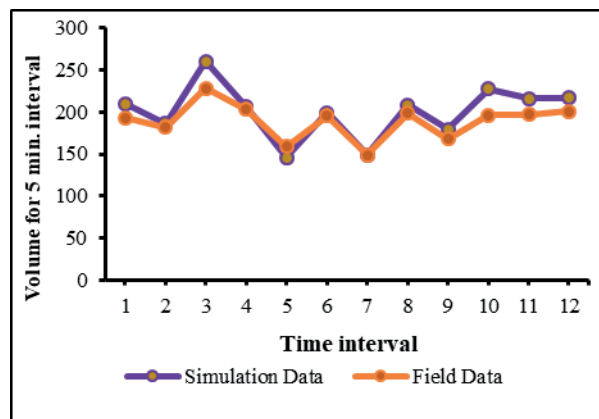
Figure 5 Flowchart of calibration

Table 1 Calibrated values of the traffic parameters

Parameter		Default	Calibrated parameter				
			2W	SC	3W	BC	Bus
Minimum look ahead distance		0	30	30	30	30	30
Minimum look back distance		0	20	10	10	10	10
Model parameter	Average standstill distance	2	0.2	0.2	0.4	0.4	0.4
	Additive part of safety distance	2	0.1	0.1	0.1	0.1	0.4
	Multiplicative part of safety distance	3	0.5	0.5	0.5	0.7	0.75
Lane change behavior	Minimum clearance	0.5	0.4	0.4	0.5	0.5	0.4
	Safety distance reduction factor	0.6	0.5	0.5	0.5	0.5	0.5
Minimum lateral distance	Distance standing (at 0 kmph)	0.2	0.2	0.2	0.2	0.2	0.2
	Distance driving (at 50 kmph)	1	0.5	0.5	0.5	0.5	0.5



6 (a) Comparison of Speed frequency curve for simulated data and field data

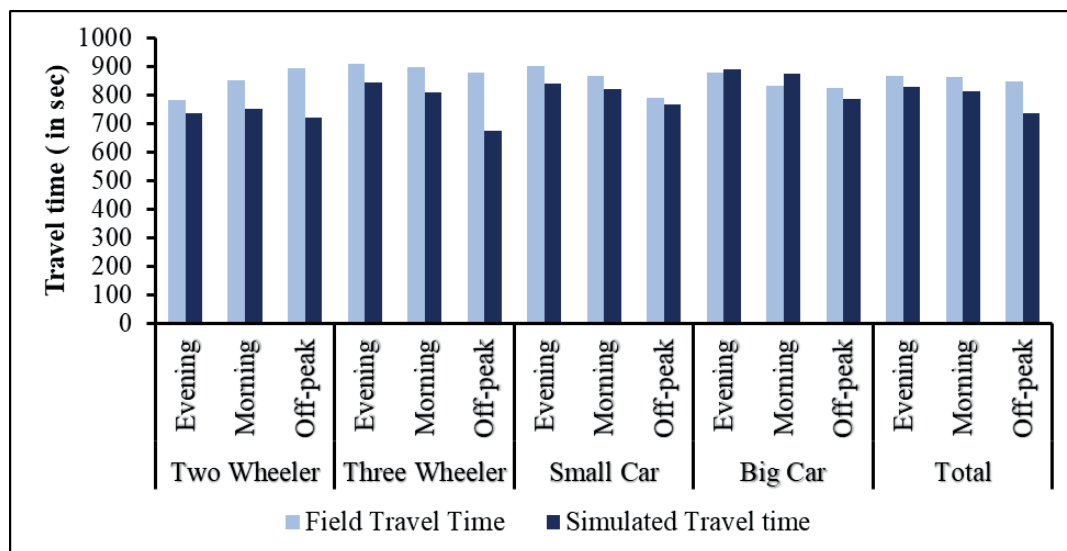


6 (b) Volume count of midblock for evening

Figure 6 Calibration results

Table 2 The GEH values for midblock for section 6

Time interval (s)	Morning			Off-peak			Evening		
	Field data	Simulated data	GEH value	Field data	Simulated data	GEH value	Field data	Simulated data	GEH value
0-300	193	-		117	115	0.19	235	232	0.20
300-600	182	161	1.60	137	140	0.25	310	310	0.00
600-900	228	215	0.87	141	135	0.51	334	338	0.22
900-1200	203	192	0.78	156	157	0.08	272	273	0.06
1200-1500	159	144	1.22	155	156	0.08	239	218	1.39
1500-1800	195	197	0.14	174	180	0.45	286	284	0.12
1800-2100	149	149	0.00	165	161	0.31	239	223	1.05
2100-2400	198	198	0.00	147	147	0.00	254	256	0.13
2400-2700	168	165	0.23	146	142	0.33	278	281	0.18
2700-3000	196	190	0.43	126	128	0.18	230	230	0.00
3000-3300	197	197	0.00	157	157	0.00	216	218	0.14
3300-3600	201	198	0.21	139	137	0.17	174	175	0.08

**Figure 7** Validation by the vehicle class-wise travel time

6.2 Calibration by volume

Volume calibration is carried out for each midblock section of six segments. The analysis for calibration of volume is carried out from the GEH statistics. The formula for the GEH Statistic is given by:

$$GEH = \sqrt{\frac{2(M - C)^2}{M + C}} \quad (1)$$

where: M is the hourly traffic volume from the traffic model and C is the real-world hourly traffic count.

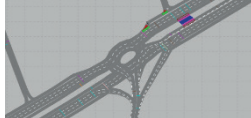
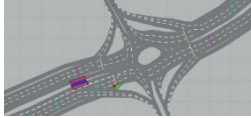
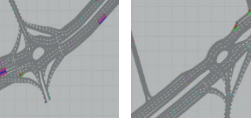
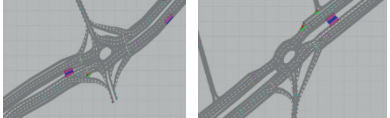
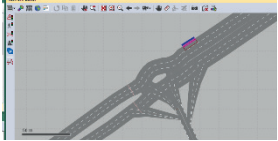
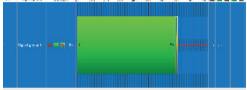
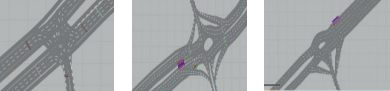
The GEH value less than five is considered as a good match between field and simulated data. At least 85% of volume in the model should have GEH less than 5 [29-30].

From Table 2 is observed that the maximum GEH value is 1.64 and the minimum GEH value is 0.00. The values are within the permissible limits, so it can be concluded that the model is well calibrated for volume at the given midblock. For other midblock sections, the GEH value for all 5-minute time intervals for the morning, off-peak and evening peak were less than 5 and hence it can be said that the model is well-calibrated.

6.3 Validation by the travel time

After calibrating the point and link elements, the entire network is validated using the travel time on the entire network. The chi-square test has been conducted

Table 3 Development adopted in scenarios

Scenario no.	Development adopted	VISSIM Modification
Scenario 1	Existing condition	
Scenario 2	Signalized intersection at intersection 5.	
Scenario 3	The channelized intersection at intersection 5.	
Scenario 4	Signalized intersection at intersection 4	
Scenario 5	The channelized intersection at intersection 4	
Scenario 6	The channelized intersection at intersections 4 and 5.	
Scenario 7	The signal at intersections 4 and 5.	
Scenario 8	The channelized intersection at intersection 2.	
Scenario 9	Re-designing signal timing for intersection 1.	
Scenario 10	A signal at intersection 5 and channelized intersection at intersections 4 and 2.	

to ensure that there is no significant difference in observed and simulated travel time. The observed data is considered field travel time and expected data is considered simulated travel time. The p-value from the chi-square test is 0.000, which is less than 0.05 for all the vehicle classes and for the morning, evening and off-peak. Thus, it can be said that the model is validated. Figure 7 shows the simulated and field observed travel times for different periods and vehicle classes.

7 Mitigation measures

The present study stretch is composed of various links and nodes with a number of access points. The nodes consist of uncontrolled, partially controlled and uncontrolled intersections and the whole study

stretch mostly has commercial and residential land use. Looking to the present traffic demand, the traffic on the entire facility has increased and reached the level of congestion at a certain time of the day and it is very frequent. In order to provide the mitigation measures, the present nodes have been upgraded to a higher category (partially controlled to signal control) based on current traffic demand and various scenarios have been generated in simulation to check their effectiveness to reduce the congestion on the entire facility.

8 Development of scenarios

In order to obtain the satisfactory performance of the entire network (congesting index must be within the acceptable values), various scenarios have been created

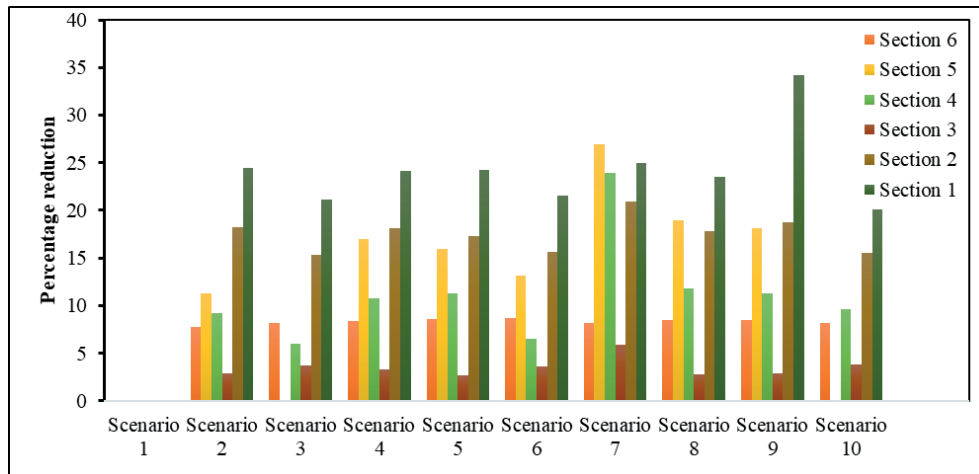


Figure 8 Percentage reduction of the speed performance index for generated scenarios

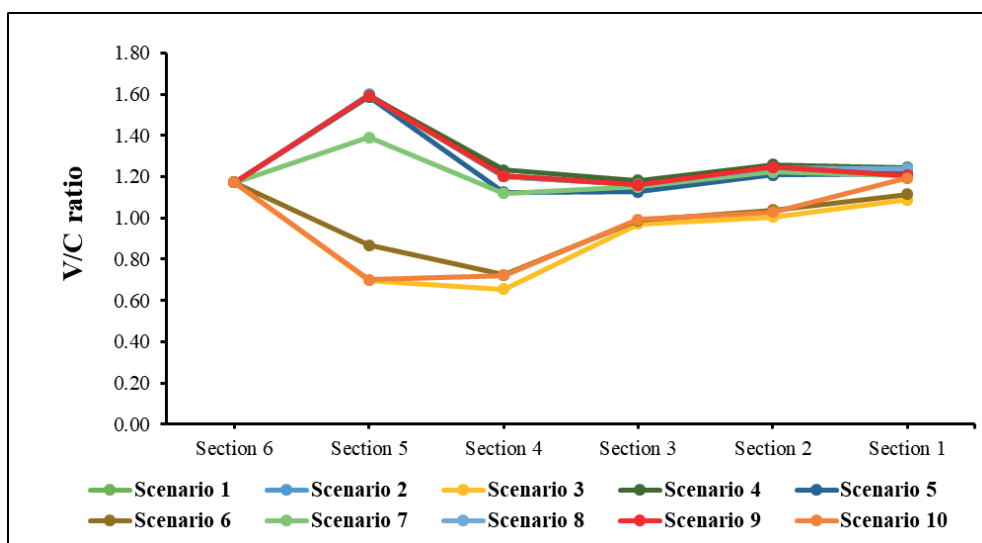


Figure 9 Graph of the v/c ratio for different scenarios

in VISSIM and compared to the existing scenario. The geometric developments were made in all the scenarios by providing channelized intersection or providing signalized intersection in the study stretch. The development made in each scenario is shown in Table 3.

The channelized intersection is provided by providing free left turn in rotaries. Signal timing for signalized intersection is adopted by calculating it with Webster's Method [31]. Signal timing is adopted in two phases, in the direction of a minor road and another in the direction of a major road. Scenarios are generated in VISSIM software with the help of the scenario management tool. Scenario 1 is an existing scenario. Nine scenarios are generated by providing a signal at the intersection and channelized intersection at intersections 4 and 5.

9 Results

Level of Congestion is analyzed for each scenario. Congestion is described as an excess of vehicles on

a portion of the roadway at a particular time resulting in slower speeds. Congestion can be measured using average speed, flow/density, delay and travel time variability.

9.1 Speed performance index

Vehicle speed is an essential indicator for measuring the road traffic state. Here, the speed performance index is used to measure the level of congestion. The speed performance index is as calculated by:

$$R_v = \frac{v}{V_{\max}} * 100, \quad (2)$$

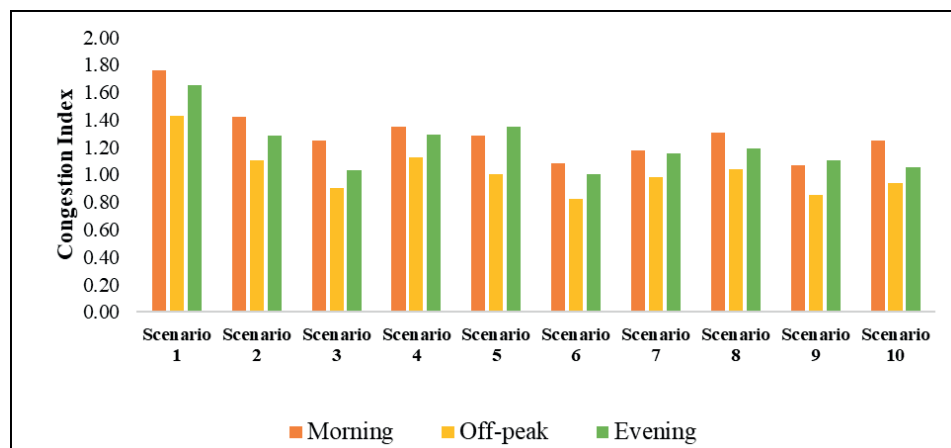
where:

R_v denotes the speed performance index,
 v represents the average travel speed, km/h,
 $V_{\max}$ indicates the maximum permissible road speed, km/h.

The value of the speed performance index lies between 0 to 100. Value 0 indicates heavy congestion, while value 100 shows very smooth traffic. As the

Table 4 Reduction in travel time (in %) compared to Base Scenario (Scenario-1) for the best result scenarios

Scenario	Scenario-3	Scenario-6	Scenario-9
Small Car			
Morning-peak	25.30	22.50	22.58
Off-peak	25.47	20.16	22.00
Evening-peak	22.12	22.19	16.89
Three Wheeler			
Morning-peak	21.15	23.68	26.17
Off-peak	19.84	23.14	23.34
Evening-peak	23.44	23.90	22.69
Two-wheeler			
Morning-peak	7.44	26.68	26.45
Off-peak	26.22	28.03	25.89
Evening-peak	28.29	28.21	21.45
Big car			
Morning-peak	19.54	24.79	25.34
Off-peak	16.12	27.87	23.70
Evening-peak	19.45	22.89	21.49

**Figure 10** Congestion index based on the travel time for different scenarios

value increases from 0 to 100, congestion is reduced. In this study, the speed performance index for midblock between segments is found out. From Figure 8, it can be observed that the maximum speed performance index is for scenario 9. The average percentage increased by 15.6% for this scenario.

9.2 Volume-to-capacity ratio

The volume to capacity (v/c) ratio measures the level of congestion on the road. The v/c ratio can vary from 0 to 1 and as the value of v/c increases, congestion increases. For each road segment, volume is collected from the simulated run and the volume to capacity ratio is thus evaluated. For determining the v/c ratio, the capacity of the urban road is adopted from the recently developed Indian Highway Capacity Manual. From Figure 9, for scenario 3, scenario 6 and scenario 10, the

v/c ratio is minimum. Scenarios 3, 6 and 10 provided channelized intersection so the vehicle could take a free left turn, minimizing the chance of queues and delays. Hence, volume on the road is less and provides better performance.

9.3 Congestion index based on travel time

Congestion index based on the travel time is a performance measure of the road network, indicating congestion on the road. The average value of the Congestion Index (CI) is calculated for the whole road stretch as:

$$CI = \frac{T^L/V_F}{L/V_F}, \quad (3)$$

where:

T is the average of the travel times as computed by the

model on the validation dataset,
 L is the segment length,
 V_f is the free-flow speed

Using Equation (3), the congestion index is calculated based on the travel time. Table 4 shows the vehicle class wise travel time reduction in percentage for three best scenarios of all. From Figure 10, it is observed that the congestion index is small for scenarios 6, 9 and 3. The average reduction of travel time congestion index is 35%, 39.64% and 38.56%, respectively, for scenarios 3, 6 and 9. Furthermore, along with the congestion index, a significant reduction in travel time is observed for scenarios 3, 6 and 9. The results show that channelized intersection has an advantage over signalized intersection for the studied road section

as for signalized intersection, even if there was no congestion, the driver has to wait until the signal turns green.

9.4 Traffic congestion representation using geographic information system (GIS)

Geographic Information System (GIS) provides visualization of the congestion, which can be easily recognizable for the traveler. The traffic conditions were displayed using ArcGIS software and the volume to capacity ratio and travel time congestion index were used to analyze the road segment congestion. As the congestion level reduces, a delay gets reduced and hence exhaust emission decreases. For all the scenarios, the

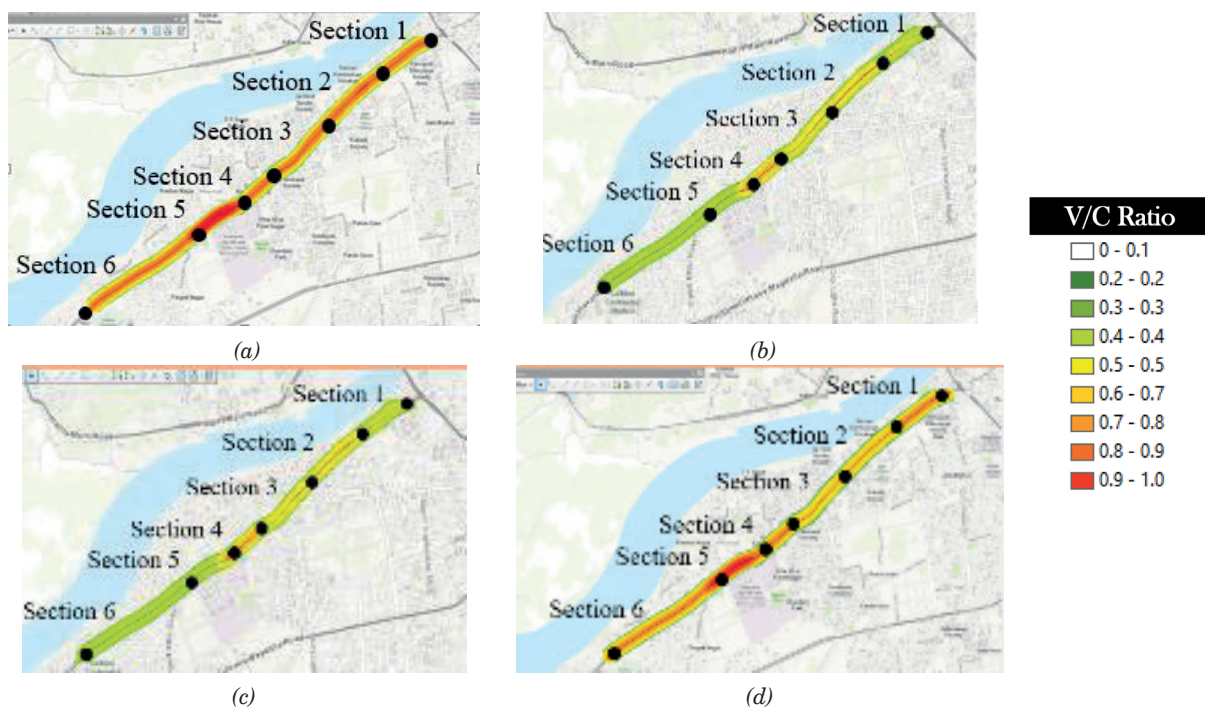


Figure 11 ArcGIS Model for Different scenario

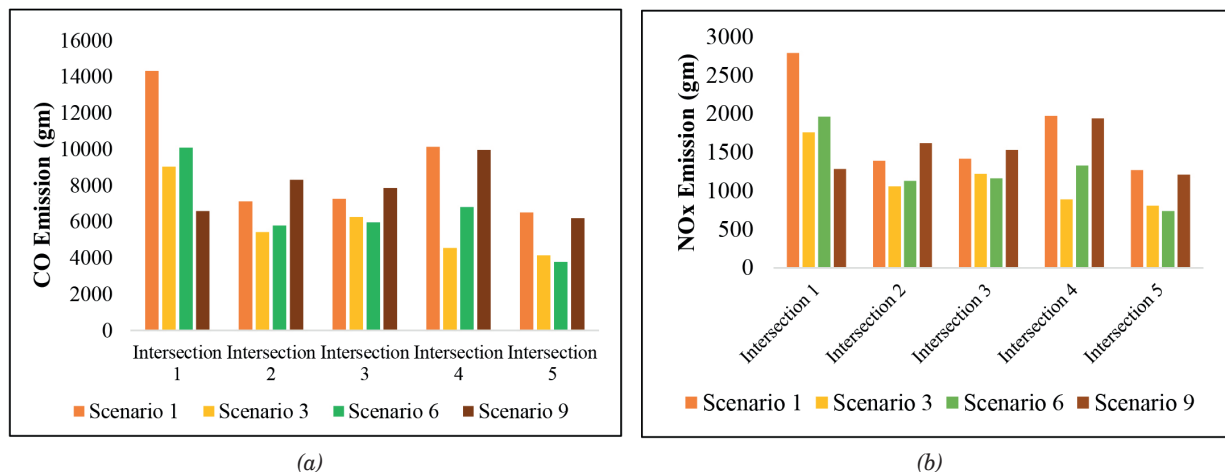


Figure 12 Emission Observed for different scenarios (a) CO Emission (b) NOx Emission for scenarios

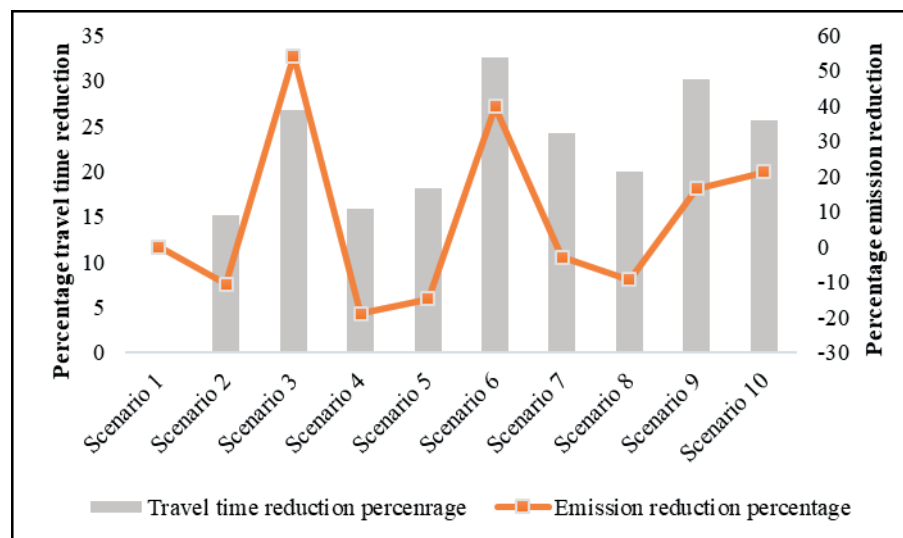


Figure 13 Relation between delay and emission

congestion is shown by the v/c ratio because it is used as the primary measure for the planning purpose.

Figure 11 shows the four different scenarios presented using the GIS platform taking the v/c ratio as the measure of effectiveness. Figure 11 (a) shows the existing field condition, which is observed to have large v/c values. Figures 11 (b), 11 (c) and 11 (d) show the GIS representation for scenarios 3, 6 and 9, respectively. It is observed that the congestion relaxes with a maximum decrease in the v/c ratio from 1.27 (for the base scenario) to 0.81 (for scenario 3).

9.5 Emission of gases

In terms of sustainable and energy-efficient transport system options, fuel consumption and air pollution are other vital performance measures. Therefore, the vehicle emission regarding carbon dioxide (CO_2), nitrogen oxides (NO_x) and Volatile Organic Compounds (VOCs) and fuel consumption were measured. Reducing the value of this measure of effectiveness reflects a significant increase in the traffic flow efficiency and safety along the road. As congestion reduces, emissions of these gases are also reduced. The reduction patterns of CO_2 and NO_x are shown in Figure 12, respectively.

9.6 Comparison between delay and vehicle emissions

As vehicle travel time is reduced percentage of emission is also reducing. However, the proportions of reduction of emission and travel time are not similar. Figure 13 shows the comparison of the travel time reduction and emission reduction for all the scenarios. For scenario 3, the reduction of travel time is by 26% and emission reduction by 54%. Meanwhile, for scenario

6, travel time reduction is 32% and emission reduction is 39%.

The overall simulation analysis results of three congestion indexes, based on speed, travel time and the v/c ratio, are used to quantify and assess the congestion. Thus, it is observed that scenario 3 (i.e. provide channelized intersection at Intersection 5), scenario 6 (i.e. the channelized intersection at Intersection 4 and Intersection 5) and scenario 9 means (change the signal time for Intersection 1 signal) are performing better than the remaining scenarios. Further, considering the emission reduction and the travel time reduction, scenario-3 can be given as the rank-1 due to consideration of sustainability. Moreover, for scenario-3, only one intersection has to change, which will be more economical than making the other improvements. It is recommended that scenario-9 be implemented in the field as it deals only with the signal timings that will be easy to deal with.

10 Conclusions

The traffic congestion is the biggest challenge of the current era, especially on urban road networks. The problem of congestion becomes very tedious in heterogeneous non-lane-based traffic streams. An arterial road network is considered in the present study, where the frequent traffic congestion has been observed in the recent past. In order to provide mitigation measures for congestion, geometrical improvements of various nodes have been suggested. Therefore, the entire network has been simulated in VISSIM microscopic simulation software that is calibrated for heterogeneous non-lane-based traffic movement by collecting field data on the study stretch. The geometric improvement has been suggested and hence 10 different scenarios have been generated in VISSIM and various congestion measures

have been determined. After a comprehensive analysis of the congestion measures, such as the speed performance index, congestion index by travel time and the v/c ratio, it is observed that the channelized intersection is performing better for most indexes' values than a signalized intersection. Out of 10 scenarios generated, it is observed that 3 scenarios give favorable results of the less congestion on the road. These three scenarios are respectively for providing channelized intersection at intersection 5, providing channelized intersection at intersection 4 and intersection 5 and providing a signal at intersection 4; channelized intersection at intersection 5 and interstation 2. The results show that providing channelizing intersection at two of the point elements (intersection) would reduce the travel time congestion index from 1.61 to 0.97. It has also been observed that the speed performance index has improved by 8.88%

while providing channelized intersection at one of the point elements and 11.52% when the two-point elements have converted to channelizing intersection. The whole outcome, in terms of the congestion measures, has been graphically shown in the GIS environment. The GIS-based outcome is easy to understand the scenarios and effective countermeasures provided to reduce congestion.

Acknowledgment

The authors would like to thank TEQIP-III, a Government of India initiative, for sponsoring this project. The project is entitled "Operational Efficiency of Urban Roadway Links using Performance Box" (Project number SVNIT/CED/AD/TEQIPIII/2119/2019). The present study is a part of the project.

References

- [1] SHI, G., SHAN, J., DING, L., YE, P., LI, Y., JIANG, N. Urban road network expansion and its driving variables: a case study of Nanjing city. *International Journal of Environmental Research and Public Health* [online]. 2019, **16**(2318), p. 1-16. ISSN 1660-4601. Available from: <https://doi.org/10.3390/ijerph16132318>
- [2] COHEN, B. Urbanization in developing countries: current trends, future projections and key challenges for sustainability. *Technology in Society* [online]. 2006, **28**, p. 63-80. ISSN 0160-791X. Available from: <https://doi.org/10.1016/j.techsoc.2005.10.005>
- [3] CLEVELAND, T., DEC, P., RAINHAM, D. Shorter roads go a long way: the relationship between density and road length per resident within and between cities. *Canadian Planning and Policy / Amenagement et Politique au Canada* [online]. 2020, **2020**, p. 71-89. ISSN 2562-122X. Available from: <https://doi.org/10.24908/cpp-apc.v2020i0.13406>
- [4] GLOVER, D. R., SIMON, J. L. The effect of population density on infrastructure: the case of road building. *Economic Development and Cultural Change*. 1975, **23**(3), p. 453-468. ISSN 0013-0079, eISSN 1539-2988.
- [5] KARTHIK, S., LOUI, T. R. Development of traffic congestion model to evaluate the level of congestion and its associative cost for an urban arterial road: a case study. *Journal of The Institution of Engineers (India): Series A* [online]. 2021, **102**(2), p. 623-632. ISSN 2250-2157. Available from: <https://doi.org/10.1007/s40030-021-00526-z>
- [6] RAO, A. M., RAO, R. K. Identification of traffic congestion on urban arterials for heterogeneous traffic. *Transport Problems* [online]. 2016, **11**(3), p. 131-142. ISSN 1896-0596. Available from: <https://doi.org/10.20858/tp.2016.11.3.13>
- [7] OLAYODE, I. O., SEVERINO, A., CAMPISI, T., TARTIBU, L. K. Prediction of vehicular traffic flow using Levenberg-Marquardt artificial neural network model: Italy road transportation system. *Communications - Scientific Letters of the University of Zilina* [online]. 2022, **24**(2), p. E74-E86. ISSN 1335-4205, eISSN 2585-7878. Available from: <https://doi.org/10.26552/com.C.2022.2.E74-E86>
- [8] JANDACKA, D., DURCANSKA, D., KOVALOVA, D. Concentrations of traffic related pollutants in the vicinity of different types of urban crossroads. *Communications-Scientific Letters of the University of Zilina* [online]. 2019, **21**(1), p. 49-58. ISSN 1335-4205, eISSN 2585-7878. Available from: <https://doi.org/10.1088/1757-899X/661/1/012152>
- [9] SAMAL, S. R., KUMAR, P. G., SANTHOSH, C. J., SANTHAKUMAR, M. Analysis of traffic congestion impacts of urban road network under Indian condition. *IOP Conference Series: Materials Science and Engineering* [online]. 2020, **1006**(1), 012002. ISSN 1757-899X. Available from: <https://doi.org/10.1088/1757-899X/1006/1/012002>
- [10] BARI, CH. S., NAVANDAR, Y. V., DHAMANIYA, A. Vehicular emission modeling at Toll Plaza using performance box data. *Journal of Hazardous, Toxic and Radioactive Waste* [online]. 2020, **24**(4), p. 1-19. ISSN 2153-5493, eISSN 2153-5515. Available from: [https://doi.org/10.1061/\(ASCE\)HZ.2153-5515.0000550](https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000550)
- [11] JI, W., WANG, Y., ZHUANG, D., SONG, D., SHEN, X., WANG, W., LI, G. Spatial and temporal distribution of expressway and its relationships to land cover and population: a case study of Beijing, China. *Transportation Research Part D: Transport and Environment* [online]. 2014, **32**, p. 86-96. ISSN 1361-9209. Available from: <https://doi.org/10.1016/j.trd.2014.07.010>

- [12] TRIPATHI, S. Relationship between infrastructure and population agglomeration in urban India: an empirical assessment. *ADBI Working Paper Series*. 2017, **731**, p. 1-25. ISSN 1655-5252.
- [13] DINGIL, A. E., SCHWEIZER, G., RUPI, F., STASISKIENE, Z. Transport indicator analysis and comparison of 151 urban areas, based on open source data. *European Transport Research Review* [online]. 2018, **10**(58), p. 1-9. ISSN 1866-8887. Available from: <https://doi.org/10.1186/s12544-018-0334-4>
- [14] DAS, A., SAW, K. Traffic congestion modelling under mixed traffic conditions through fuzzy logic approach: an Indian case study of arterial road. 2004.
- [15] ASAITHAMBI, G., KANAGARAJ, V., SRINIVASAN, K. K., SIVANANDAN, R. Characteristics of mixed traffic on urban arterials with significant volumes of motorized two-Wheelers: role of composition, intraclass variability and lack of lane discipline. *Transportation Research Record* [online]. 2012, **2317**(2317), p. 51-59. ISSN 0361-1981. Available from: <https://doi.org/10.3141/2317-07>
- [16] HE, F., YAN, X., LIU, Y., MA, L. A traffic congestion assessment method for urban road networks based on speed performance index. *Procedia Engineering* [online]. 2016, **137**, p. 425-433. ISSN 1877-7058. Available from: <https://doi.org/10.1016/j.proeng.2016.01.277>
- [17] GAUTAM, L., JAIN, K. Study on mixed traffic flow behavior on arterial road. *International Journal of Engineering Research and Technology (IJERT)*. 2018, **6**(11), p. 1-7. ISSN 2278-0181.
- [18] WANG, W.-X., GUO, R.-J., YU, J. Research on road traffic congestion index based on comprehensive parameters: taking Dalian city as an example. *Advances in Mechanical Engineering* [online]. 2018, **10**(6), p. 1-8. ISSN 1687-8132, eISSN 1687-8140. Available from: <https://doi.org/10.1177/1687814018781482>
- [19] MADE, D., WEDAGAMA, P. The influence of mixed traffic on congestion level. *International Journal of GEOMATE*. 2019, **17**(64), p. 18-25. ISSN 2186-2982, eISSN 2186-2990.
- [20] AFRIN, T., YODO, N. A survey of road traffic congestion measures towards a sustainable and resilient transportation system. *Sustainability* [online]. 2020, **12**(11), p. 1-23. ISSN 2071-1050. Available from: <https://doi.org/10.3390/su12114660>
- [21] FELLENDORF, M., VORTISCH, P. Validation of the microscopic traffic flow model VISSIM in different real-world situations. In: 80th Annual Meeting of Transportation Research Board: proceedings. 2001. p. 1-9.
- [22] JIE, L., FANGFANG, Z., VAN ZUYLEN, H., SHOUFENG, L. Calibration of a micro simulation program for a Chinese city. *Procedia - Social and Behavioral Sciences* [online]. 2011, **20**, p. 263-272. ISSN 1877-0428. Available from: <https://doi.org/10.1016/j.sbspro.2011.08.032>
- [23] SUN, D. J., LIU, X., NI, A., PENG, CH. Traffic congestion evaluation method for urban arterials: case study of Changzhou, China. *Transportation Research Record* [online]. 2014, **2461**, p. 9-15. ISSN 0361-1981. Available from: <https://doi.org/10.3141/2461-02>
- [24] CELKO, J., KOVAC, M., HUSZAROVA, K. Influence of selected vehicle maneuvers on reduction of the urban roads capacity. *Communications - Scientific Letters of the University of Zilina* [online]. 2019, **21**(4), p. 81-89. ISSN 1335-4205, eISSN 2585-7878. Available from: <https://doi.org/10.26552/com.C.2019.4.81-89>
- [25] INDO-HCM. Indian Highway Capacity Manual (Indo-HCM). 2017.
- [26] CHARLY, A., MATHEW, T. V. Evaluation of driving performance in relation to safety on an expressway using field driving data. *Transportation Letters* [online]. 2020, **12**(5), p. 1-9. ISSN 1942-7875. Available from: <https://doi.org/10.1080/19427867.2019.1591075>
- [27] Racelogic Limited. Performance Box-III 100Hz GPS Data Logger User Guide. Unit 10, Swan Business Centre, Osier Way, Buckingham MK18 1TB. United Kingdom.: Racelogic Limited., 2014.
- [28] PAUL, G., RAJU, N., ARKATKAR, S., EASA, S. Can segregating vehicles in mixed-traffic stream improve safety and throughput? implications using simulation. *Transportmetrica A: Transport Science* [online]. 2021, **17**(4), p. 1-25. ISSN 2324-9935. Available from: <https://doi.org/10.1080/23249935.2020.1826595>
- [29] MITKAS, D. Z., POLITIS, I. Evaluation of alternative ramp metering scenarios on freeway on-ramp with the use of microscopic simulation software Vissim. *Transportation Research Procedia* [online]. 2020, **45**(2019), p. 483-490. ISSN 2352-1465. Available from: <https://doi.org/10.1016/j.trpro.2020.03.042>
- [30] BARI, CH S., GUPTA, U., CHANDRA, S., ANTONIOU, C., DHAMANIYA, A. Examining effect of electronic toll collection (ETC) system on queue delay using microsimulation approach at Toll Plaza -a case study of Ghoti Toll Plaza, India. In: 7th International IEEE Conference on Models and Technologies for Intelligent Transportation Systems: proceedings. 2021. p. 1-6.
- [31] MATHEW, T. V., RAO, K. V. K. Traffic signal design-II. In: *Introduction to Transportation Engineering*. NPTEL, 2007.