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Microsimulation Modelling in VISSIM on Short-term and Long-term Improvements for Mangalore City Road Network

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Abstract

The problems due to traffic congestion require continuous monitoring of movement of vehicles in the road network. In this connection, the study of speed and flow characteristics of roadways assists in developing strategies for efficient management of traffic. The focus of the present investigation was on suggesting short-term and long-term improvements at selected locations in the road network for Mangalore City. A VISSIM model which was previously calibrated and validated for vehicle, driver, and roadway characteristics based on vehicular flows across 18 mid-block sections was used for this purpose. The calibration was performed iteratively using the *GEH* statistic as an indicator, where the simulated vehicular volumes and speeds at 18 mid-block sections of the city were compared to the observed values. The validation of the model was then performed on a separate set of video-graphic data. Using the VISSIM model developed, it was possible to predict that significant improvements in vehicular flows and speeds could be attained which reduced the travel time of trip-makers.

Keywords: microsimulation; volume; speed; delay; VISSIM

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1. Introduction

A proper understanding of vehicular movements over the urban road network, traffic handling efficiencies at mid-blocks and junctions, and identification of bottlenecks in the road network will be helpful in formulating policies for traffic management. The evaluation of speed and flow characteristics of a road network in particular, is important in decision making, as it assists in identifying the short-term and long-term improvements to be undertaken for the existing road network of a city.

Traffic volume and vehicular speed are important inputs required for the performance evaluation of roadways. Software generally employed in performing analysis related to movement of vehicles in road networks include

VISSIM, VISUM, TRANSYT, PARAMICS, HETROSIM, CORSIM, SimTraffic, SCOOT, SYNCHRO, OSCADY, ARCADY, PICADY, SISTM and so on. The microsimulation software VISSIM employed in this study provides the necessary flexibility for modelling mixed traffic flow conditions for Indian roads where vehicular movement is not strictly lane based.

Presently, Mangalore is a fast developing city in India located at 12.87° N latitude and 74.88° E longitude (MCC, 2018), having a very strong industrial base. Mangalore has emerged as the industrial and commercial hub of Dakshina Kannada District in Karnataka. The population in Mangalore City population is estimated to be 499,487 as per Census (2011). The Municipal Corporation includes 60 wards spread over approximately 132.45 square km of area (MCC, 2018), and is surrounded by 12 upcoming urban agglomerations. The total length of the road network within the Corporation limits is about 1170 km as on 2015 (MCC, 2015).

The scope of the present study is focused on performing a microsimulation-based modelling using VISSIM with special emphasis on attaining a proper understanding of traffic flow characteristics of Mangalore City for heterogeneous traffic composition. The focus of the present investigation was on suggesting short-term and long-term improvements at selected locations in the road network for Mangalore City using a previously calibrated and validated VISSIM model. The model was calibrated for vehicle, driver, and roadway characteristics based on video-graphic data on vehicular flows across 18 mid-block sections in the city. The validation of the model was then performed on a separate set of video-graphic data.

A major road network of the city connecting Hampankatta Junction, Navabharat Junction, PVS Junction, Bunt’s Hostel Junction, Jyothi Junction, Bendoorwell Junction, Balmatta Junction, and St. Theresa’s School Junction is considered for the analysis. The VISSIM model for the road network was calibrated iteratively using the *GEH* statistic invented by Geoffrey E. Havers, a transport planner, in the 1970s as documented in DMRB (1996) as an indicator. The VISSIM model was later validated using a separate set of data to evaluate the performance of the simulated road network. The vehicle and driver characteristics were thus finalized.

Subsequently, simulation experiments were performed using the validated VISSIM model to assess the impact of widening of the road section between Karangalpady Junction and Bunt’s Hostel Junction for movement of vehicles from Karangalpady Junction to Kadri Junction and to Jyothi Junction via Bunt’s Hostel Junction. A similar exercise was performed to study the impact of widening of the road section at Bendoorwell Junction for movement of vehicles from Kankanady to St. Theresa’s School Junction and towards Balmatta Junction via Bendoorwell Junction. The outputs for simulated volumes and speeds were compared for the scenarios before and after implementing the improvements.

Additionally, the validated VISSIM model was used to analyze the impact of introducing a flyover for streamlining the flow of vehicles arriving from PVS Junction, moving towards Jyothi Junction and Kadri Junction via Bunt’s Hostel Junction. A similar exercise was performed to study the impact of introducing a flyover for streamlining the flow of vehicles arriving from Kankanady Junction, moving towards St. Theresa’s School Junction via Bendoorwell Junction. Here also, the outputs for simulated volumes and speeds were compared for the scenarios before and after implementing the improvements.

The above study is considered to provide a framework for traffic planners to perform microsimulation-based modelling of vehicle and driver characteristics. It also provides a road-map to traffic engineers on the methodology to be adopted to analyze the movement of vehicles in urban traffic and develop efficient traffic management strategies to mitigate traffic congestion.

2. Selected Studies on Application of VISSIM in Traffic Management

Fellendorf and Vortisch (2001) performed microsimulation-based modelling in VISSIM using data obtained from US and German freeways. The model developed was calibrated and validated, and the best characteristics defining driver-behavior were identified for US and German freeways. In the above study, the driver-characteristics were assigned to the model based on inputs from a probe vehicle.

Park and Schneeberger (2003) proposed a nine-step-methodology for development of a VISSIM model for the design of a coordinated signal in Virginia. The testing and calibration procedures were performed iteratively using a regression model. Five random seeds were tested in this study. The validation was then performed on a new set of data. Also, Velez et al. (2006) performed similar studies, and used the statistical analysis method, namely the *student's t-test*, to show that the results obtained from a micro-simulated model and the field data for the same road network in Puerto Rico are comparable.

Chu et al. (2004) performed calibration and validation for various micro-simulation models to evaluate traffic operations and management strategies over a road network in Irvine, California. Also, Park and Qi (2005) performed calibration studies on twenty-one characteristics using VISSIM in Virginia.

Lu et al. (2016) adopted a video-based method for calibration of car-following characteristics to obtain the predicted flows using VISSIM for studies performed in Waterloo, Canada. It was found that the video-based approach is more accurate and reliable compared to other conventional methods.

In the previously calibrated VISSIM model used in this study, vehicle characteristics such as the *minimum lateral clearances*, and the *acceleration and deceleration distributions* were assigned for each vehicle type based on values adapted and modified from Arasan and Krishnamurthy (2008), Manjunatha et al. (2013), Mathew and Radhakrishnan (2010), Bains et al. (2013), and Mehar et al. (2014). Additionally, the values for driver characteristics such as the *minimum look-ahead distance*, *minimum look-back distance*, *average standstill distance*, safety distances, and the *time-lag between lane/direction changes* were assigned based on values adapted and modified from Siddharth and Ramadurai (2013).

Furthermore, four random seeds were used in the testing phase while developing the VISSIM model used in this study in a manner similar to that demonstrated by Park and Schneeberger (2003) and Velez et al. (2006), The best random seed identified was used throughout in the calibration process to develop the VISSIM model. Calibration was performed iteratively using the *GEH* statistic as a benchmark to indicate the closeness of the predicted values to the actual values. The *GEH* statistic computed based on DMRB (1996), is an empirical approach for comparing actual and predicted values in simulations. This is expressed as,

$$GEH = [2(K - P)^2 / (K + P)]^{0.5} \quad (1)$$

where, K is the predicted or simulated value by the simulation model, and P is the observed value.

In the present investigation, the calibration of the VISSIM model was previously performed for a total of thirty-two characteristics which included separate characteristics for speed, acceleration and deceleration for each vehicle type in a manner similar to that demonstrated by Chu et al. (2004), and Park and Qi (2005).

3. Strategies Adopted for the Short-term and Long-term Improvements

Microsimulation techniques are used effectively in the field of modelling vehicular flows on urban road networks. These techniques provide the necessary basis for investigating traffic flow characteristics. Simulation-based approaches are cost-effective in modelling traffic flow, performing detailed analyses on the existing traffic scenario and in the study of impact of short-term and long-term improvements in the road network. The following sub-sections provide details on the methodology adopted for short-term and long-term improvements on the road network.

3.1. Simulation studies on minor widening of the road section between Karangalpady Junction and Bunt's Hostel to streamline flows towards Jyothi Junction and Kadri Junction

In the validated VISSIM model, the base network was modified to incorporate the proposed improvements mainly comprising minor widening of the road section between Karangalpady Junction and Bunt's Hostel Junction. Fig. 1 provides details on the existing layout of the road section between Karangalpady Junction and Bunt's Hostel Junction. The four-minute video-graphic data collected at this junction, previously set apart for the validation of the VISSIM model was used for performing the simulation study.

A 100m stretch of road extending from Karangalpady Junction to Bunt's Hostel Junction was considered for widening. The road section between Karangalpady Junction and Bunt's Hostel Junction was represented in VISSIM, in the form of three inter-connected links namely, Link 1, Link 2 and Link 3. All the links were assigned with vehicle flows along 2 lanes to accommodate the incoming traffic. Fig. 2 provides details on the assigning of links for the road section. Table 1 provides measurements of the lane widths for Link 1, Link 2 and Link 3 before and after widening.

The width of the road section between Karangalpady Junction and Bunt's Hostel Junction was proposed to be increased to a minor extent as part of the short-term improvement strategy. Here, it was considered to widen the narrow roads from the existing width of 3.1-3.3m to the standard minimum lane width of 3.5m based on the need to conform to road geometric standards as prescribed in IRC 86 (1983). In this road section, a full-fledged widening could not be performed due to limitations in availability of land. It was also required to reduce the existing width of the adjoining footpath from around 1.8-2.2m to a minimum width of 1.5m as per IRC 86 (1983) in order to increase the road widths. Additionally, the width of a road link close to Bunt's Hostel Junction was proposed to be widened from 4m to 5m to facilitate faster movement of vehicles. Further widening of the existing road could not be performed due to the presence of large commercial buildings in the vicinity.

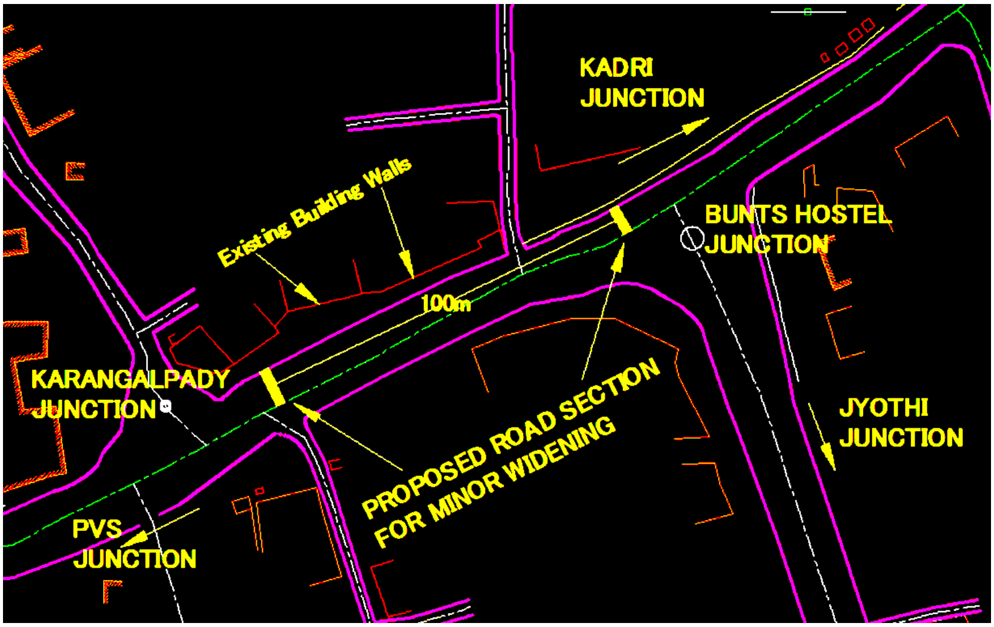

Fig. 1. Details on the Existing Layout between Karangalpady Junction and Bunt's Hostel Junction

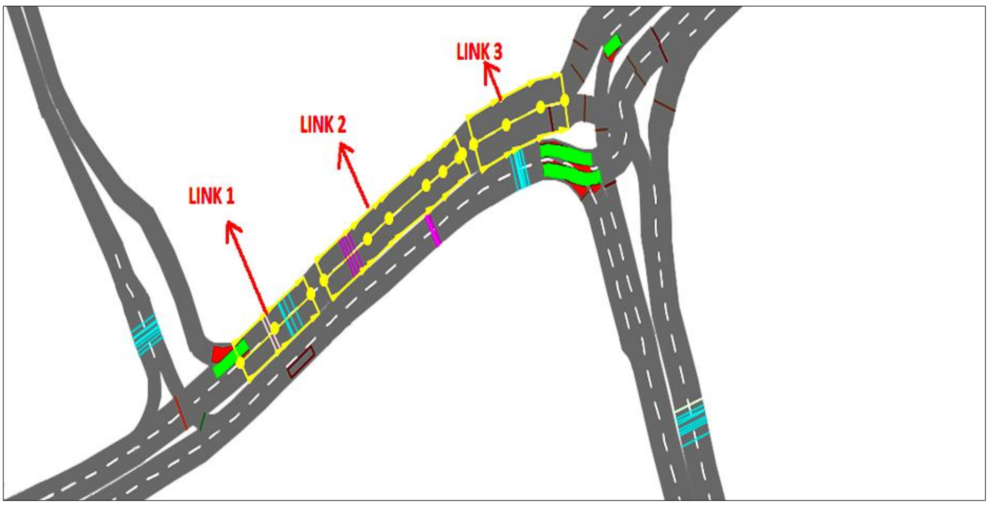

Fig. 2. Link 1, Link 2 and Link 3 between Karangalpady Junction and Bunt's Hostel Junction

Table 1. Lane Width Measured Before and After Widening

	Assigned Lane	Width before Widening (m)	Width after Widening (m)
Link 1	Lane 1	3.3	3.8
	Lane 2	3.3	3.8
Link 2	Lane 1	3.1	3.8
	Lane 2	3.1	3.8
Link 3	Lane 1	4	5
	Lane 2	4	5

3.2. Simulation studies on minor widening of the road sections at Bendoorwell Junction to streamline flows towards St. Theresa's School Junction and Balmatta Junction

In the validated VISSIM model, the base network was modified to incorporate the proposed improvements mainly comprising minor widening of the road sections at Bendoorwell Junction. Fig. 3 provides details on the existing layout of Bendoorwell Junction with details on the road section to be widened. The four-minute video-graphic data collected at this junction, previously set apart for the validation of the VISSIM model was used for performing the simulation study.

A 150m stretch of road at the junction from Kankanady towards Balmatta Junction was considered for widening. The road section was represented in VISSIM, in the form of two inter-connected links namely, Link 1 and Link 2. All the links were assigned with vehicle flows along two lanes to accommodate the traffic flow. Fig. 4 provides details on representations for interconnected links for the road section. Table 2 provides measurements of the lane widths for Link 1 and Link 2 before and after widening.

The width of the road section at Bendoorwell Junction was proposed to be increased as part of the short-term improvement strategy. Here, it was proposed to widen the existing lane width of 3.5m and 4m to 5m to facilitate faster movement of vehicles at the junctions. However, in order to accommodate the widening of the road section, it was required to reduce the width of the adjoining footpath from around 1.8-2.2m to a minimum width of 1.5m as per IRC 86 (1983). Here too, a full-fledged widening could not be performed due to the presence of large commercial buildings in the vicinity.

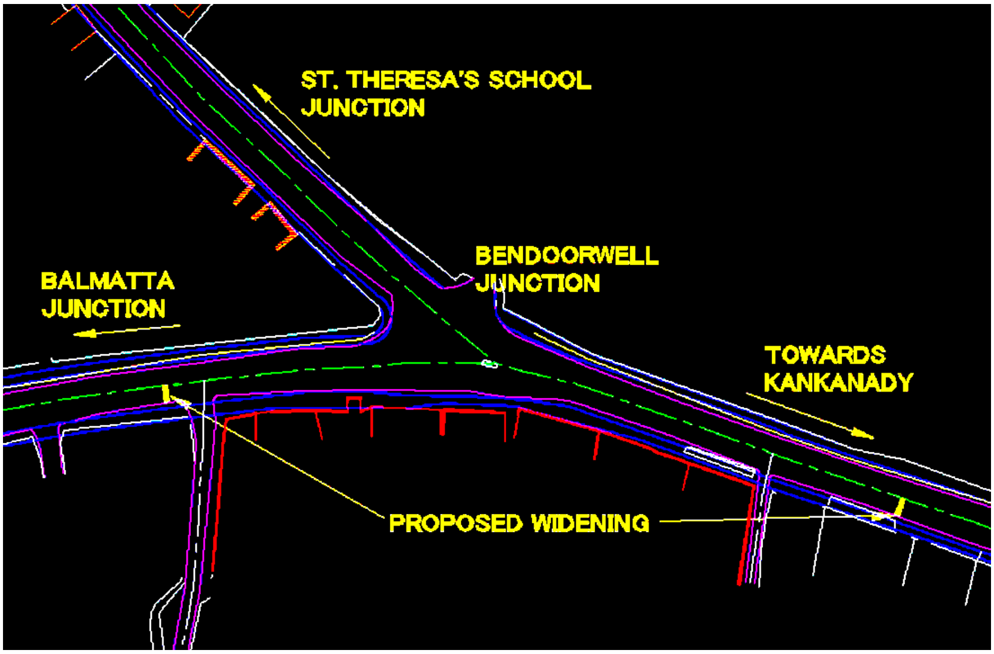

Fig. 3. Details on the Existing Layout at Bendoorwell Junction

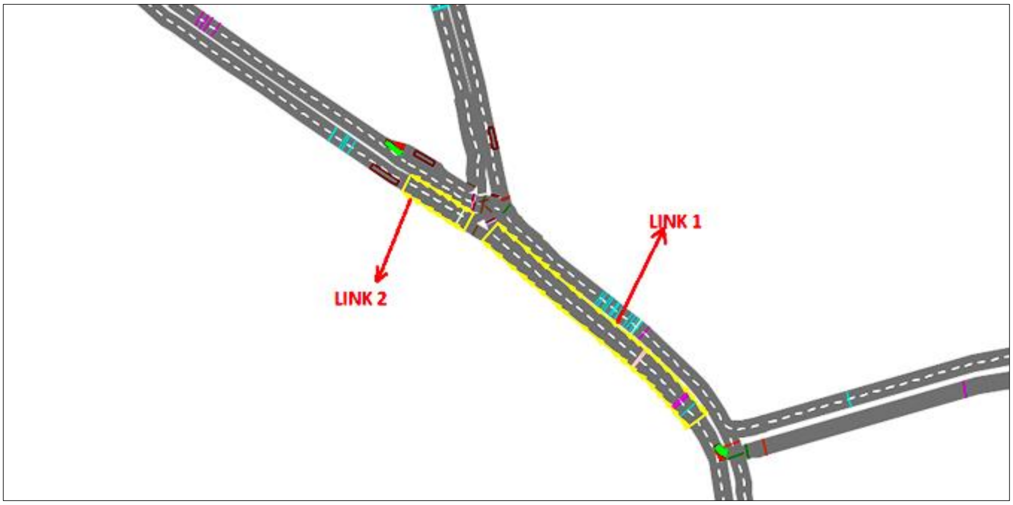

Fig. 4. Link 1 and Link 2 at Bendoorwell Junction from Kankanady towards Balmatta Junction

Table 2. Lane Width Measured Before and After Widening

	Assigned Lane	Width before Widening (m)	Width after Widening (m)
Link 1	Lane 1	4.0	5.0
	Lane 2	4.0	5.0
Link 2	Lane 1	3.5	3.5
	Lane 2	3.5	5.0

3.3. Simulation studies on introduction of a flyover to streamline flows arriving from PVS Junction moving towards Jyothi Junction and Kadri Junction

In the validated VISSIM model, the base network was modified to incorporate the addition of a flyover considering the traffic arriving from PVS Junction, moving towards Jyothi Junction and Kadri Junction. Fig. 1 referred above provides details on the existing layout of Bunt's Hostel Junction. The four-minute video-graphic data collected at this junction, previously set apart for the validation of the VISSIM model was used for performing the simulation study.

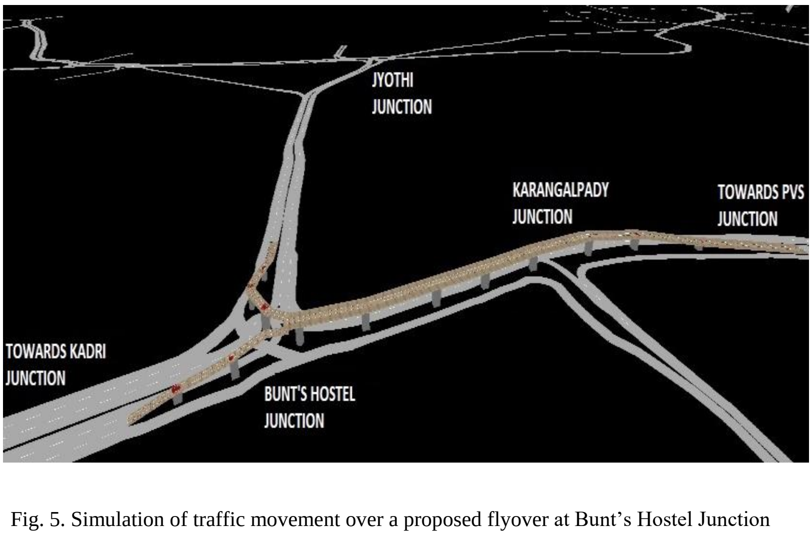

Fig. 5. Simulation of traffic movement over a proposed flyover at Bunt's Hostel Junction

The flyover at Bunt's Hostel Junction was proposed as part of a long-term improvement strategy to reduce the congestion at Bunt's Hostel Junction and at Karangalpady Junction which are about 100m apart. The volume of flow from Bunt's Hostel Junction to Jyothi Junction, and from Bunt's Hostel Junction to Kadri Junction together constitutes 36.44% of the total traffic arriving at Bunt's Hostel Junction. The use of a flyover will ease the turning movements at the nearby Karangalpady Junction to a large extent.

Before performing the simulation, the base network was modified to incorporate the links for handling the traffic arriving at Bunt's Hostel moving towards Jyothi Junction, and Kadri Junction. The flyover of approximately 300m length was proposed to be constructed for a double lane width of 7m upto Bunt's Hostel Junction, bifurcating to single lane widths in two different directions, one towards Jyothi Junction, and the other towards Kadri Junction with a gradient of 3%, which was lesser than maximum permissible gradient of 4% as per IRC 86 (1983). Fig. 5 provides details on simulated movement of vehicles on the flyover at Bunt's Hostel Junction.

3.4. Simulation studies on introduction of a flyover to streamline flows arriving from Kankanady moving towards St. Theresa's School Junction

In the validated VISSIM model, the base network was modified to incorporate the addition of a flyover considering the traffic arriving from Kankanady, moving towards St. Theresa's School Junction. Fig. 3 referred above provides details on the existing layout of Bendoorwell Junction. The four-minute video-graphic data collected at this junction, previously set apart for the validation of the VISSIM model was used for performing the simulation study.

The flyover at Bendoorwell was proposed to handle right turning traffic moving towards St. Theresa's School Junction as a long-term improvement measure since the proportion of traffic moving along this direction was around 45% of the traffic reaching Bendoorwell Junction from Kankanady Junction. The right turning vehicles also constituted 20.8% of the total traffic arriving at Bendoorwell Junction from various directions. The use of the flyover was expected to eliminate the need to use traffic signals for other turning movements at this junction.

Before performing the simulation, the base network was modified to incorporate the links for handling the traffic movement from Kankanady towards St. Theresa's School Junction via Bendoorwell Junction. The flyover of approximately 200m length was proposed to be constructed for a single lane width of 4.5m with a gradient of 3%, which was lesser than the maximum permissible gradient of 4% as per IRC 86 (1983). Fig. 6 provides details on simulated movement of vehicles on the flyover at Bendoorwell Junction.

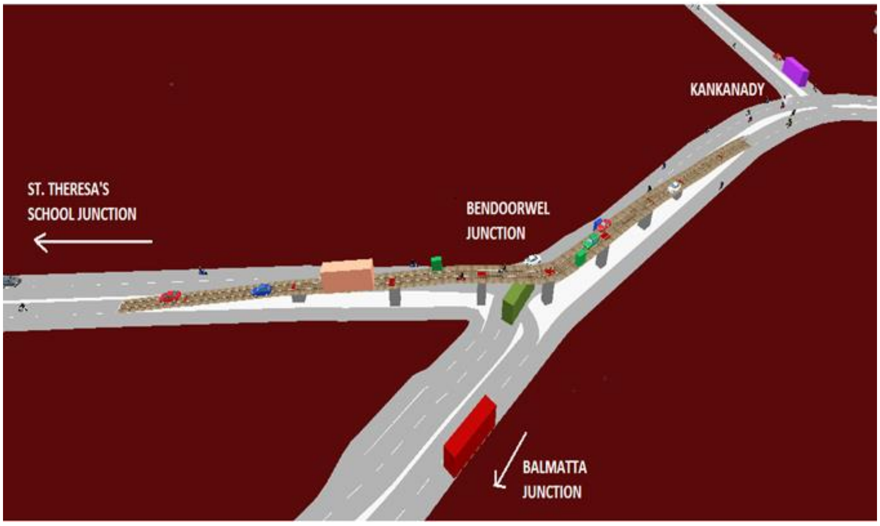

Fig. 6. Simulation of traffic movement over a proposed flyover connecting Kankanady and St. Theresa's School Junction

4. Results on Microsimulation-based Experiments, and Discussions

This section provides details on the results and discussions on microsimulation studies performed on the movement of vehicles in the city based on experiments performed as described in the previous section for short-term and long-term improvements proposed to be undertaken.

4.1. Results on minor widening of the road section between Karangalpady Junction and Bunt's Hostel Junction to streamline flows towards Jyothi Junction and Kadri Junction

A summary of the observations for traffic flows from Karangalpady to Jyothi Junction via Bunt's Hostel Junction with respect to simulated volume, speeds and stopped delays is provided in Table 3. Here, it is observed that the overall stopped delays have reduced from 25.06s to 12.08s resulting in a savings of 52% in fuel loss due to idling of vehicles. The level of improvement in stopped delays for auto-rickshaws, buses, cars, light commercial vehicles (LCVs), and motorized two-wheelers were observed to be 37%, 78%, 53%, 41%, and 47% respectively.

Table 3. Comparison of simulated volumes, speeds and stopped delays between Karangalpady Junction and Jyothi Junction before and after providing minor widening between Karangalpady and Bunt's Hostel Junction

Volume and Percentage of Vehicles			
Vehicle Types	*Before Widening of Road Geometrics	*After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	43 (100.00%)	71 (100.00%)	65%
Auto	9 (20.93%)	9 (12.68%)	0%
Bus	3 (06.98%)	5 (07.04%)	67%
Car	7 (16.28%)	10 (14.08%)	43%
LCV	2 (04.65%)	3 (04.23%)	50%
Two-Wheelers	22 (51.16%)	44 (61.97%)	100%
Space Mean Speed (KMPH)			
Vehicle Types	*Before Widening of Road Geometrics	*After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	8.19	24.53	200%
Auto	7.18	21.06	193%
Bus	8.15	20.66	153%
Car	7.50	26.58	255%
LCV	7.27	19.96	175%
Two-Wheelers	9.53	25.52	168%
Stopped Delay			
Vehicle Types	*Before Widening of Road Geometrics	*After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	25.06	12.08	52%
Auto	29.48	18.44	37%
Bus	23.63	5.11	78%
Car	29.02	13.72	53%
LCV	21.96	13.02	41%
Two-Wheelers	20.67	10.91	47%

* The percentages for each vehicle-type are shown in parenthesis.

Fig. 7 provides a pictorial representation of the comparison between the observed delays for various vehicle types before and after widening of the road for the above-mentioned direction of traffic movement.

The reduction in the stopped delays can be attributed to a minor widening and streamlining of the existing carriageway as indicated earlier by about 1m. This has facilitated faster movement of motorized two-wheelers that characteristically possess lesser road-space, higher accelerations and speeds as displayed in the simulation runs. This is also evident from the increase in the simulated volume of motorized two-wheelers by 100%. The faster movement of motorized two-wheelers consequently opened up the road-spaces for the movement of buses, cars, and LCVs resulting in increase in simulated volumes by 67%, 43%, and 50% respectively.

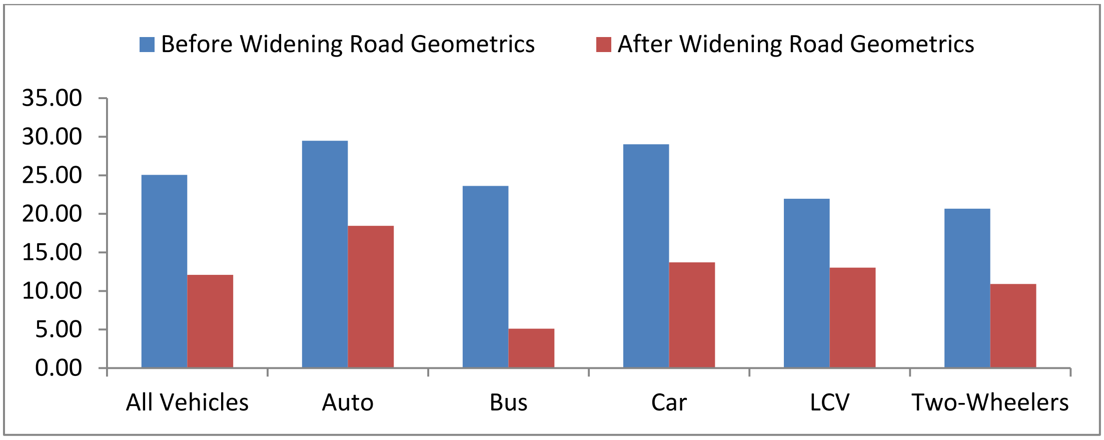

Fig. 7. Comparison between simulated stopped delays for various vehicle types moving from Karangalpady Junction and Jyothi Junction before and after providing minor widening

However, in the case of auto-rickshaws, there has been no increase in the simulated volume although the stopped delay of these vehicles improved by 37%. This is due to the reason that the volume of auto-rickshaws generated for the simulation had already passed through the road section. Fig. 8 provides a pictorial representation of the comparison between the observed volumes of various vehicle types before and after widening the road for the above-mentioned direction of traffic movement.

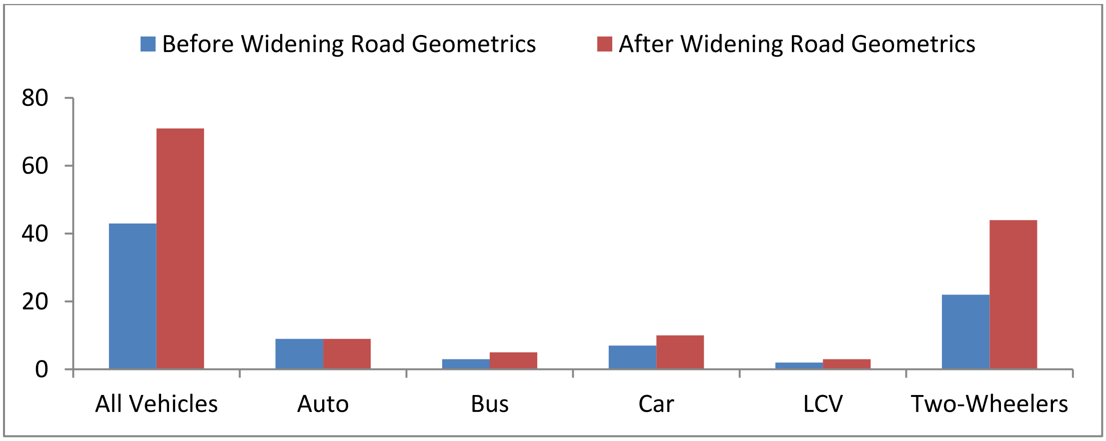

Fig. 8. Comparison between simulated volumes for various vehicle types moving from Karangalpady Junction and Jyothi Junction before and after providing minor widening

While examining the speeds, it can be observed that the space-mean speeds of all vehicles moving between Karangalpady Junction and Jyothi Junction have increased from 8.19kmph to 24.53kmph showing an improvement of 200%. It may be observed that the space-mean speeds of auto-rickshaws, buses, cars, light commercial vehicles (LCVs), and motorized two-wheelers have witnessed an increase by 193%, 153%, 255%, 175%, and 168% respectively.

Table 4 provides a summary of the observations for traffic flows from Karangalpady to Kadri Junction via Bunt's Hostel Junction with respect to simulated volume, speeds and stopped delays.

Here too, it is observed that the overall stopped delays have reduced from 16.08s to 0.03s resulting in a savings of 100% in fuel loss due to idling of vehicles. The level of improvement in stopped delays for auto-rickshaws, cars, and motorized two-wheelers were observed to be 99%, 100%, and 100% respectively.

The reduction in the stopped delays can be attributed to a minor widening and streamlining of the existing carriageway as indicated earlier by about 1m. This has facilitated faster movement of motorized two-wheelers as mentioned in the case of the previous road section analyzed. This is also evident from the increase in the simulated volume of motorized two-wheelers by 125%. The faster movement of motorized two-wheelers consequently opened up the road-spaces for the movement of buses, LCVs, cars, and auto-rickshaws resulting in increase in simulated volumes by 100%, 100%, 78%, and 19% respectively.

Table 4. Comparison of simulated volumes, speeds and stopped delays between Karangalpady Junction and Kadri Junction before and after providing minor widening between Karangalpady and Bunt's Hostel Junction

Volume			
Vehicle Types	*Before Widening of Road Geometrics	*After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	41 (100.00%)	74 (100.00%)	80%
Auto	16 (39.02%)	19 (25.68%)	19%
Bus	0 (00.00%)	1 (01.35%)	100%
Car	9 (21.95%)	16 (21.62%)	78%
LCV	0 (00.00%)	2 (02.70%)	100%
Two-Wheelers	16 (39.02%)	36 (48.65%)	125%
Space Mean Speed (KMPH)			
Vehicle Types	Before Widening of Road Geometrics	After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	8.46	39.33	365%
Auto	9.46	38.93	312%
Bus	0.00	35.57	0%
Car	10.20	37.39	266%
LCV	0.00	36.36	0%
Two-Wheelers	7.05	40.67	477%
Stopped Delay			
Vehicle Types	Before Widening of Road Geometrics	After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	16.08	0.03	100%
Auto	13.41	0.08	99%
Bus	0.00	0.00	0%
Car	14.18	0.02	100%
LCV	0.00	0.00	0%
Two-Wheelers	19.83	0.01	100%

* The percentages for each vehicle-type are shown in parenthesis.

While analyzing the speeds, it can be observed that the space-mean speeds of all vehicles moving between Karangalpady Junction and Jyothi Junction have increased from 8.46kmph to 39.33kmph showing an improvement of 365%. It may be observed that the space-mean speeds of auto-rickshaws, cars, and motorized two-wheelers have witnessed an increase by 312%, 266%, and 477% respectively. However, in the case of buses and LCVs, the speeds remained almost unchanged since the volume of flow of these vehicles have shown a significant increase replacing the free space made available by other smaller vehicles.

Considering the performance in the road sections for traffic flows from Karangalpady to Jyothi Junction and from Karangalpady to Kadri, described in Table 3 and Table 4, it can be seen that there is a considerable improvement in vehicular volumes, and vehicular speeds accompanied by a significant decrease in stopped delays for different types of vehicles.

4.2. Results on minor widening of road section between Kankanady and Balmatta Junction to streamline flows towards St. Theresa's School Junction and Balmatta Junction

A summary of the observations for traffic flows from Kankanady to St. Theresa's School Junction via Bendoorwell Junction with respect to simulated volume, speeds and stopped delays is provided in Table 5.

Here too, it is observed that the overall stopped delays have reduced from 8.42s to 5.16s resulting in a savings of 39% in fuel loss due to idling of vehicles. The level of improvement in stopped delays for buses, cars, and motorized two-wheelers were observed to be 61%, 58%, and 19% respectively. However, in the case of auto-rickshaws and LCVs, there has been no change in stopped delays.

Table 5. Comparison of simulated volumes, speeds and stopped delays between Kankanady Junction and St. Theresa's School Junction before and after providing minor widening at Bendoorwell Junction

Volume			
Vehicle Types	*Before Widening of Road Geometrics	*After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	60 (100.00%)	68 (100.00%)	13%
Auto	8 (13.33%)	9 (13.25%)	13%
Bus	3 (05.00%)	3 (04.41%)	0%
Car	16 (26.67%)	23 (33.82%)	44%
LCV	1 (01.67%)	1 (01.47%)	0%
Two-Wheelers	32 (53.33%)	32 (47.06%)	0%
Space Mean Speed (KMPH)			
Vehicle Types	Before Widening of Road Geometrics	After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	28.43	32.82	15%
Auto	30.73	31.91	4%
Bus	22.74	34.05	50%
Car	28.70	34.01	19%
LCV	22.67	32.21	42%
Two-Wheelers	28.14	31.90	13%
Stopped Delay			
Vehicle Types	Before Widening of Road Geometrics	After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	8.42	5.16	39%
Auto	2.61	2.60	0%
Bus	5.30	2.07	61%
Car	11.28	4.79	58%
LCV	0.00	0.00	0%
Two-Wheelers	8.35	6.80	19%

* The percentages for each vehicle-type are shown in parenthesis.

The reduction in the stopped delays can be attributed to a minor widening and streamlining of the existing carriageway as indicated earlier by about 1m. This has facilitated an increase in the simulated volumes of auto-rickshaws, and cars to 13% and 44% respectively.

In the case of speeds, it can be observed that the space-mean speeds of all vehicles moving between Kankanady and St. Theresa's School Junction have increased from 28.43kmph to 32.82kmph showing an overall improvement of 15%. It may be observed that the space-mean speeds of auto-rickshaws, buses, cars, light commercial vehicles (LCVs), and motorized two-wheelers have witnessed an increase by 4%, 50%, 19%, 42%, and 13% respectively.

Table 6 provides a summary of the observations for traffic flows from Kankanady to Balmatta Junction via Bendoorwell Junction with respect to simulated volume, speeds and stopped delays. Here, it is observed that the overall stopped delays that were already close to zero and remained almost the same since traffic along this direction in this T-junction is given a free movement. The level of improvement in stopped delays in the case of traffic flow along the direction of simulation of traffic is 0% since there is no difference between the before and after scenarios.

Table 6. Comparison of simulated volumes, speeds and stopped delays between Kankanady Junction and Balmatta Junction before and after providing minor widening at Bendoorwell Junction

Volume			
Vehicle Types	*Before Widening of Road Geometrics	*After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	62 (100.00%)	85 (100.00%)	37%
Auto	11 (17.74%)	18 (21.18%)	64%
Bus	8 (12.90%)	8 (09.41%)	0%
Car	19 (30.65%)	26 (30.59%)	37%
LCV	0 (00.00%)	0 (00.00%)	0%
Two-Wheelers	24 (38.71%)	33 (38.82%)	38%
Space Mean Speed (KMPH)			
Vehicle Types	Before Widening of Road Geometrics	After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	20.87	33.72	62%
Auto	17.63	32.57	85%
Bus	20.60	34.04	65%
Car	19.02	32.38	70%
LCV	0.00	0.00	0%
Two-Wheelers	22.71	37.75	66%
Stopped Delay			
Vehicle Types	Before Widening of Road Geometrics	After Widening of Road Geometrics	Level of Improvement (%)
All Vehicles	0.0040 (Approximated to 0.0)	0.00	0%
Auto	0.0200 (Approximated to 0.0)	0.00	0%
Bus	0.0020 (Approximated to 0.0)	0.00	0%
Car	0.0100 (Approximated to 0.0)	0.00	0%
LCV	0.0000 (Approximated to 0.0)	0.00	0%
Two-Wheelers	0.0020 (Approximated to 0.0)	0.00	0%

* The percentages for each vehicle-type are shown in parenthesis.

The minor widening and streamlining of the existing carriageway as indicated earlier by about 1m has facilitated an increase in the simulated volumes of auto-rickshaws, cars, and motorized two-wheelers to 64%, 37%, and 38% respectively.

In the case of speeds, it can be observed that the space-mean speeds of all vehicles moving between Kankanady and Balmatta Junction have increased from 20.87kmph to 33.72kmph showing an improvement of 62%. It may be observed that the space-mean speeds of auto-rickshaws, buses, cars, and motorized two-wheelers have witnessed an increase by 85%, 65%, 70%, and 66% respectively.

Considering the performance in the road sections for traffic flows from Kankanady to St. Theresa's School Junction, and from Kankanady to Balmatta Junction, described in Table 5 and Table 6, it can be seen that there is a considerable improvement in vehicular volumes, and vehicular speeds for different types of vehicles.

4.3. Results on introducing a flyover connecting PVS Junction towards Jyothi Junction and Kadri Junction

A summary of the observations for traffic flows arriving from PVS Junction, moving towards Jyothi Junction with respect to simulated volumes and speeds is provided in Table 7. Here, it is observed that the overall vehicular volumes have increased from 25 to 45 vehicles resulting in an improvement of 80%. The level of improvement in volumes for auto-rickshaws, buses, light commercial vehicles (LCVs), and motorized two-wheelers were observed to be 100%, 50%, 100%, and 123% respectively. Fig. 9 provides a pictorial representation of the comparison between the observed volumes for various vehicle types before and after widening of the road for the above-mentioned direction of traffic movement.

Table 7. Comparison of simulated volumes and speeds for traffic between PVS Junction and Jyothi Junction before and after providing the flyover

Volume			
Vehicle Types	*Before providing the Flyover	*After providing the Flyover	Level of Improvement (%)
All Vehicles	25 (100.00%)	45 (100.00%)	80%
Auto	2 (08.00%)	4 (08.89%)	100%
Bus	2 (08.00%)	3 (06.67%)	50%
Car	8 (32.00%)	8 (17.78%)	0%
LCV	0 (00.00%)	1 (02.22%)	100%
Two-Wheelers	13 (52.00%)	29 (64.44%)	123%
Space Mean Speed (KMPH)			
Vehicle Types	Before providing the Flyover	After providing the Flyover	Level of Improvement (%)
All Vehicles	14.98	41.87	179%
Auto	12.83	41.51	224%
Bus	13.56	36.56	170%
Car	13.78	45.14	228%
LCV	0.00	40.74	0%
Two-Wheelers	16.56	41.72	152%

* The percentages for each vehicle-type are shown in parenthesis.

The increase in the traffic volumes can be attributed to the introduction of a flyover to facilitate vehicle movements towards Jyothi Junction. In the case of speeds, it can be observed that the space-mean speeds of all vehicles moving between PVS Junction and Jyothi Junction have increased from 14.98kmph to 41.87kmph showing an improvement of 179%. It may be observed that the space-mean speeds of auto-rickshaws, buses, cars, and motorized two-wheelers have witnessed an increase by 224%, 170%, 228%, and 152% respectively.

Table 8 provides a summary of the observations for traffic flows arriving from PVS Junction, moving towards Kadri Junction with respect to simulated volumes and speeds. Here too, it is observed that the overall vehicular volumes have increased from 18 to 23 vehicles resulting in an improvement of 28%. The level of improvement in volumes for auto-rickshaws, buses, light commercial vehicles (LCVs), and motorized two-wheelers were observed to be 100%, 100%, 100%, and 20% respectively.

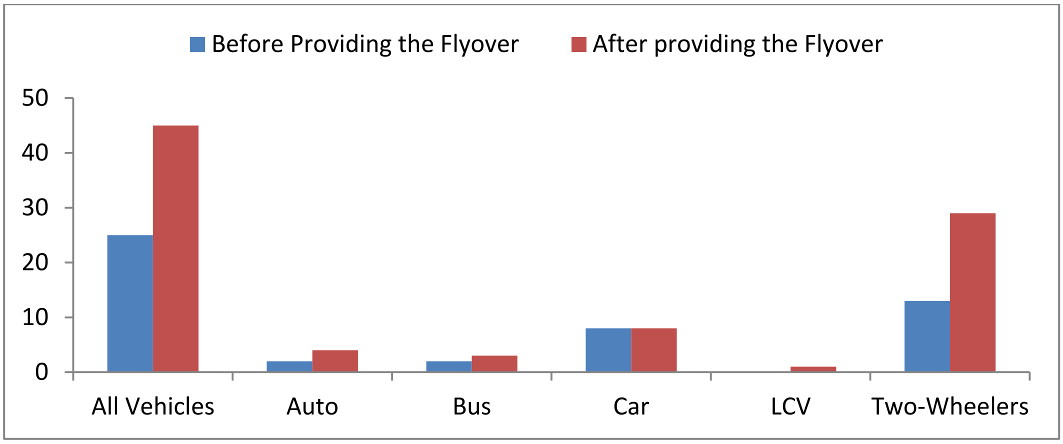

Fig. 9. Comparisons between simulated volumes for various vehicle types before and after providing the flyover between PVS Junction and Jyothi Junction

Table 8. Comparison of simulated volumes and speeds for traffic between PVS Junction and Kadri Junction before and after providing the flyover

Volume			
Vehicle Types	*Before providing the Flyover	*After providing the Flyover	Level of Improvement (%)
All Vehicles	18 (100.00%)	23 (100.00%)	28%
Auto	2 (11.11%)	4 (17.39%)	100%
Bus	0 (00.00%)	1 (04.35%)	100%
Car	6 (33.33%)	6 (26.09%)	0%
LCV	0 (00.00%)	0 (00.00%)	100%
Two-Wheelers	10 (55.56%)	12 (52.17%)	20%
Space Mean Speed (KMPH)			
Vehicle Types	Before providing the Flyover	After providing the Flyover	Level of Improvement (%)
All Vehicles	13.11	46.04	251%
Auto	13.62	37.67	177%
Bus	0.00	48.38	0%
Car	14.83	52.45	254%
LCV	0.00	0.00	0%
Two-Wheelers	11.92	45.43	281%

* The percentages for each vehicle-type are shown in parenthesis.

Fig. 10 provides a pictorial representation of the comparison between the observed volumes for various vehicle types before and after widening of the road for the above-mentioned direction of traffic movement.

The increase in the traffic volumes can be attributed to the introduction of a flyover to facilitate vehicle movements towards Kadri Junction. In the case of speeds, it can be observed that the space-mean speeds of all vehicles moving between PVS Junction and Kadri Junction have increased from 13.11kmph to 46.04kmph showing an improvement of 251%. It may be observed that the space-mean speeds of auto-rickshaws, cars, and motorized two-wheelers have witnessed an increase by 177%, 254%, and 281% respectively.

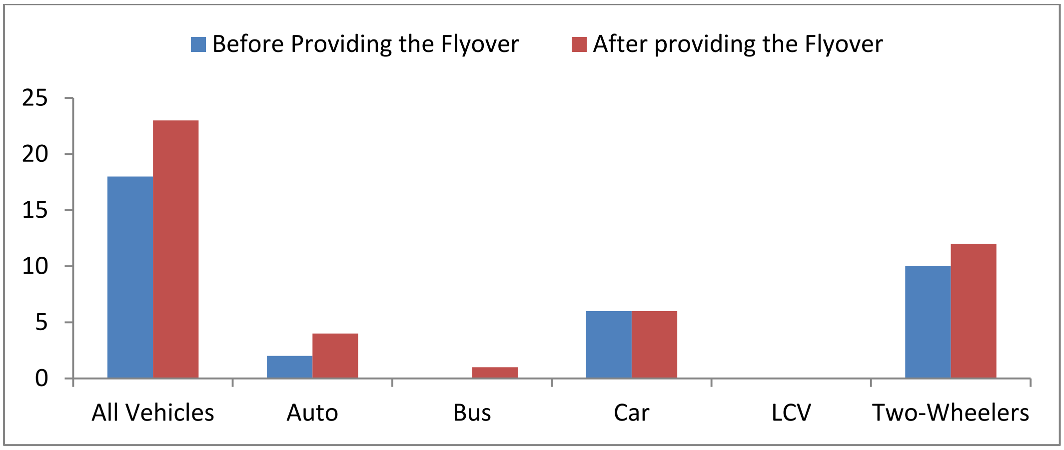

Fig. 10. Comparisons between simulated volumes for various vehicle types before and after providing the flyover between PVS Junction and Kadri Junction

4.4. Results on introducing a flyover connecting Kankanady and St. Theresa's school Junction

Table 9 provides a summary of the observations for traffic flows arriving from Kankanady Junction, moving towards St. Theresa's School Junction with respect to simulated volumes and speeds. Here too, it is observed that the overall vehicular volumes have increased from 60 to 74 vehicles resulting in an improvement of 23%. The level of improvement in volumes for auto-rickshaws, cars, and motorized two-wheelers were observed to be 63%, 6%, and 25% respectively.

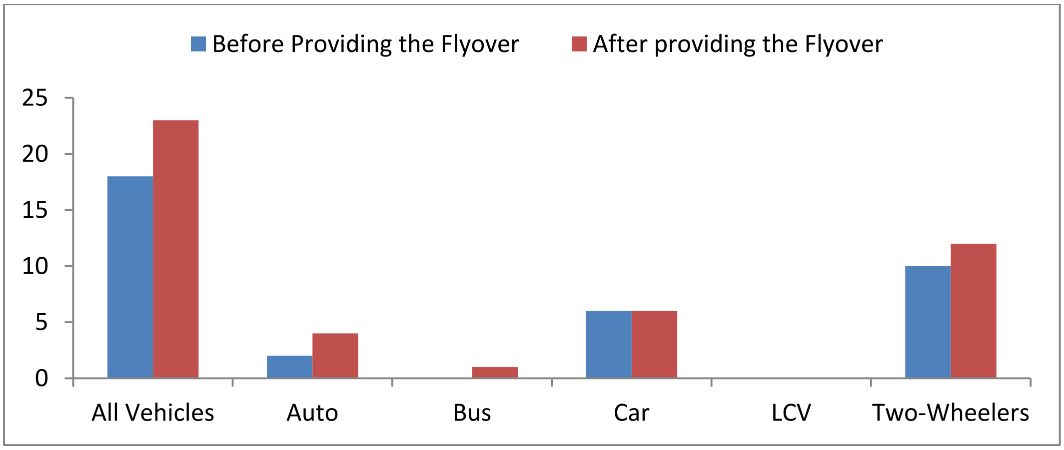

Fig. 11. Comparisons between simulated volumes for various vehicle types before and after providing the flyover between Kankanady Junction and St. Theresa's School Junction.

The overall increase in the traffic volumes can be attributed to the introduction of a flyover to facilitate the movement of vehicles from Kankanady going towards St. Theresa's School Junction. In the case of speeds, it can be observed that the space-mean speeds of all vehicles moving between Kankanady Junction and St. Theresa's School Junction have increased from 28.43kmph to 43.62kmph showing an improvement of 53%. It may be observed that the space-mean speeds of auto-rickshaws, cars, buses, LCVs, and motorized two-wheelers have witnessed an increase by 36%, 136%, 64%, 55%, and 51% respectively. Fig. 11 provides a pictorial representation of the comparisons between the observed volumes for various vehicle types before and after providing the flyover between Kankanady and St. Theresa's School Junction.

Table 9. Comparison of simulated volumes and speeds for traffic between Kankanady Junction and St. Theresa's School Junction before and after providing the flyover

Volume			
Vehicle Types	*Before providing the Flyover	*After providing the Flyover	Level of Improvement (%)
All Vehicles	60 (100.00%)	74 (100.00%)	23%
Auto	8 (13.33%)	13 (17.57%)	63%
Bus	3 (05.00%)	3 (04.05%)	0%
Car	16 (26.67%)	17 (22.97%)	6%
LCV	1 (01.67%)	1 (01.35%)	0%
Two-Wheelers	32 (53.33%)	40 (54.05%)	25%
Space Mean Speed (KMPH)			
Vehicle Types	Before providing the Flyover	After providing the Flyover	Level of Improvement (%)
All Vehicles	28.43	43.62	53%
Auto	30.73	41.84	36%
Bus	22.74	53.75	136%
Car	28.70	47.06	64%
LCV	22.67	35.04	55%
Two-Wheelers	28.14	42.53	51%

* The percentages for each vehicle-type are shown in parenthesis.

5. Conclusions

The present study focuses on suggesting short-term and long-term improvements at selected locations in the road network for Mangalore City. A microsimulation model developed using VISSIM which was previously calibrated for 32 characteristics including vehicle characteristics (such as minimum lateral clearances, and acceleration and deceleration distributions), driver characteristics (such as the minimum look-ahead distance, minimum look-back distance, average standstill distance, safety distances, and the time-lag between lane/direction changes), and roadway characteristics, was used in this investigation. The VISSIM model was also validated previously using a different set of video-graphic data. The conclusions on the study on short-term and long-term improvements at selected locations in the city are provided below.

5.1. Conclusions on minor widening of the road section at Bunt's Hostel Junction to streamline flows towards Jyothi Junction

In the case of traffic flows from Karangalpady to Jyothi Junction via Bunt's Hostel Junction, it is observed that the overall stopped delays have reduced from 25.06s to 12.08s resulting in a savings of 52% in fuel loss due to idling of vehicles. A visual inspection of the simulation performed in VISSIM indicates that the above mentioned reduction in the stopped delays due to a minor widening and streamlining of the existing carriageway by about 1m has resulted in motorized two-wheelers utilizing the available extra space to move forward. This consequently cleared the road spaces for other vehicles such as buses, cars, and LCVs to flow through more freely resulting in an increase in the overall simulated volumes considering all vehicle types from 43 to 71 vehicles during the simulation period of 4 minutes showing an improvement in vehicular flow by 65%. The above simulation experiment indicates that a minor increase of 1m in the width of the roadway can result in a significant increase in vehicular flow especially in heterogeneous traffic flow conditions where lane discipline is not strictly followed. The high increase in vehicular flow is also due to the reason that motorized two-wheelers constitute about 61.97% of the total vehicle vehicles passing through the road section. The above mentioned minor improvement has also resulted in an increase in the space-mean speeds of all vehicles moving along this direction from 8.19kmph to 24.53kmph indicating an improvement of 200%.

5.2. Conclusions on minor widening of the road section at Bunt's Hostel Junction to streamline flows towards Kadri Junction

In the case of traffic flows from Karangalpady to Kadri Junction via Bunt's Hostel Junction, it is observed that the overall stopped delays have reduced from 16.08s to 0.03s resulting in a savings of 100% in fuel loss due to idling of vehicles compared to the 'before' scenario. Here too, a reduction in the stopped delays due to a minor widening and streamlining of the existing carriageway by about 1m resulted in larger availability of road space for the movement of buses, LCVs, cars, and auto-rickshaws resulting in an increase in the overall simulated volumes considering all vehicle types from 41 to 74 showing an improvement of 80%. The high increase in vehicular flow is also due to the reason that motorized two-wheelers constitute about 48.65% of the total vehicle vehicles passing through the road section. It is also seen that the space-mean speeds of all vehicles moving along this direction have increased from 8.46kmph to 39.33kmph showing an improvement of 365%.

5.3. Conclusions on minor widening of the road section at Bendoorwell Junction to streamline flows towards St. Theresa's School Junction

In the case of traffic flows from Kankanady to St. Theresa's School Junction via Bendoorwell Junction, it is observed that the overall stopped delays have reduced from 8.42s to 5.16s resulting in a savings of 39% in fuel loss due to idling of vehicles. A visual inspection of the simulation performed in VISSIM indicates that the above mentioned reduction in the stopped delays due to a minor widening and streamlining of the existing carriageway by about 1m has resulted in motorized two-wheelers utilizing the available extra space to move forward. This consequently cleared the road spaces for other vehicles such as auto-rickshaws and cars to flow through more freely resulting in an increase in the overall simulated volumes considering all vehicle types from 60 to 68 vehicles during the simulation period of 4 minutes showing an improvement in vehicular flow by 13%. The above simulation experiment indicates that a minor increase of 1m in the width of the roadway can result in a significant increase in vehicular flow especially in heterogeneous traffic flow conditions where lane discipline is not strictly followed. The high increase in vehicular flow is also due to the reason that motorized two-wheelers constitute about 47.06% of the total vehicle vehicles passing through the road section. The above mentioned minor improvement has also resulted in an increase in the space-mean speeds of all vehicles moving along this direction from 28.43kmph to 32.82kmph indicating an improvement of 15%.

5.4. Conclusions on minor widening of the road section at Bendoorwell Junction to streamline flows towards Balmatta Junction

In the case of traffic flows from Kankanady to Balmatta Junction via Bendoorwell Junction, it is observed that the overall stopped delays that were already close to zero and remained almost the same since traffic along this direction in this T-junction is given a free movement. The level of improvement in stopped delays in the case of traffic flow along this direction is 0% since there is no difference between the before and after scenarios. Here too, a minor widening and streamlining of the existing carriageway by about 1m has resulted in larger availability of road space for the movement of auto-rickshaws, cars, and motorized two-wheelers with a consequent increase in the overall simulated volumes considering all vehicle types from 62 to 85 showing an improvement of 37%. It is also seen that the space-mean speeds of all vehicles moving along this direction have also increased from 20.87kmph to 33.72kmph showing an overall improvement of 62%.

5.5. Conclusions on introduction of a flyover to streamline flows arriving from PVS Junction moving towards Jyothi Junction

In the case of traffic flows on the proposed flyover connecting Karangalpady towards Jyothi Junction for flows arriving from PVS Junction, it is observed that the overall vehicular volumes have increased from 25 to 45 vehicles resulting in an improvement of 80%. A visual inspection of the simulation performed in VISSIM indicates that the above mentioned increase in the volume of vehicles along the direction from Karangalpady to Jyothi was attained by the introduction of a flyover that resulted in the streamlining of vehicular flows. The above mentioned long term improvement has also resulted in an increase in the space-mean speeds of all vehicles moving along this direction from 14.98kmph to 41.87kmph showing an improvement of 179%.

5.6. Conclusions on introduction of a flyover to streamline flows arriving from PVS Junction moving towards Kadri Junction

Considering the traffic flows on the proposed flyover connecting Karangalpady towards Kadri Junction for flows arriving from PVS Junction, it is observed that the overall vehicular volumes have increased from 18 to 23 vehicles resulting in an improvement of 28%. In this case too, the above mentioned increase in the volume of vehicles along the direction from Karangalpady to Kadri was attained by the introduction of a flyover that resulted in the streamlining of vehicular flows. The above mentioned long term improvement has also resulted in an increase in the space-mean speeds of all vehicles moving along this direction from 13.11kmph to 46.04kmph showing an improvement of 251%.

5.7. Conclusions on introduction of a flyover to streamline flows arriving from Kankanady moving towards St. Theresa's School Junction

In the case of traffic flows on the proposed flyover connecting Kankanady towards St. Theresa's School Junction. It is observed that the overall vehicular volumes have increased from 60 to 74 vehicles resulting in an improvement of 23%. A visual inspection of the simulation performed in VISSIM indicates that the above mentioned increase in the volume of vehicles along the direction from Kankanady Junction to St. Theresa's School Junction was attained by the introduction of a flyover that resulted in the streamlining of vehicular flows. The above mentioned long term improvement has also resulted in an increase in the space-mean speeds of all vehicles moving along this direction from 28.43kmph to 43.62kmph showing an improvement of 53%.

6. Policy Implications and Limitations of the study

The above study on implication of short-term and long-term improvements at selected locations in the road network indicate that, in heterogeneous traffic conditions vehicles do not necessarily follow lane discipline. This has resulted in higher operating capacities. The study indicates that the use of motorized two-wheelers is more popular on Indian roads. Due to the reason that these vehicles require lesser road space and can maneuver through available road spaces very easily when compared to private vehicles such as cars. The study also shows that the presence of cars, that typically have occupancy ratio of about 1.5 considering work trips during peak-hours occupy larger road space causing hindrance to the flow of public transport vehicles such as buses. The above findings indicate that the popular use of motorized two-wheelers in developing countries does not hamper with satisfying the travel demands of trip makers.

One of the major limitations in the above study was that some of the most preferred types of improvements could not performed due to unavailability of land resources especially in the built-up urban areas.

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