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Developing Methodology for Calibrating Vehicle-Following Models on Intercity Expressways Using Vehicular Trajectories

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Abstract

The research work is originated with an intent of studying traffic flow characteristics on intercity in-depth with wide variation in traffic flow levels. For this purpose, two expressway sections: (i) Pune-Mumbai Expressway and (ii) Ahmedabad-Vadodara Expressway were selected, as these are the best available roads in category of intercity expressways, in India. In order to model the vehicle-following behavior on these roads, traffic data was collected using high quality video camera on both study sections, in such a way that maximum possible variation in traffic flow characteristics is captured in traffic data. Macroscopic characteristics such as speed, density and flow, were evaluated using video graphic data collected from the study sections. Based on empirical data observations, it was realized that, data may not be fully adequate to develop Measure of Effectiveness (MOEs) thresholds. Consequently, simulation-based approach is to model the traffic flow on selected study sections. With this motivation, simulation model, namely, VISSIM-9.0 was calibrated using newly developed methodology for mixed traffic conditions. In particular, driving behavior parameters were optimized using high-quality vehicular trajectories and further also validated to a satisfactory extent, using hysteresis plots. A well-calibrated simulation model was then applied for developing speed-flow-density fundamental diagrams, and thereby determining capacity and Level-of-Service (LoS) thresholds using density and V/C ratio. It was found that the capacity value for six-lane divided expressway (three-lanes in each direction) is determined as about 7500 PCU/h/direction, which actually reasonably matches with the US-HCM (2010) guidelines. The derived LoS thresholds using traffic density is expected to act as read-reckoner reference for practitioners for monitoring traffic operations on expressways. It is anticipated that, the proposed method of calibrating vehicle-following driving behavior using high-quality trajectory data is transferable to other mixed traffic conditions.

Keywords: Expressways, simuation, Hystersis, Driving behavior

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1. Background

Expressways are the highest class of roads in the Indian road network and it makes up around 1,455 km in road network, which is operational in India. There are 26 Expressways are being currently in operational and 26 others has been proposed. By the year 2022, the National Highways Development Project by Government of India aims to expand the highway network and plans to add an additional 18,637 km of expressways. But, in the present context no indigenous guideline is available for monitoring the performance of these road sections. These road-sections are similar to freeways in the United States, Autobahns in Germany and expressways in China. This topic is very well researched in developed countries. Many researchers have brought out interesting observations on traffic flow characteristics for these kind of roads. Daganzo, Lin, and Del Castillo 1997 analyzed the freeway sections using numerical simulation of traffic low characteristics on freeways to study the usage of lanes by the vehicles. The study added good understanding about lane-based behavior, prevailing in developed countries like USA. Zhao et al.(Zhao et al. 2009), investigated the traffic characteristics on ring road sections and mid-block sections of freeways. The study concluded that vehicular behavior is similar in both the cases. While, these studies are focused on basic understanding of traffic flow parameters on freeways, there are quite a few studies focused on use of simulation models for assessing traffic management schemes on freeways. To understand the impact of exclusive truck facility on performance of urban freeway, shockwave analysis was conducted using simulation under varying traffic states (Abdelgawad et al. 2011). Vadde et al. 2011 assessed the performance of traffic management schemes using simulation and quantified the performance in terms of delays. Zhao and Yu 2011 studied the physical properties and formulated a model in expressing the traffic behavior on the expressways. Geistefeldt et al. 2014 in their work, developed LoS thresholds for freeways, using simulation and compared with the available guidelines. Finally, the authors have given a methodological frame work in simulating the road sections on freeways with different simulation tools such as VISSIM, PARAMICS, and MITSIM. To develop robust simulation under freeways (Durrani, Lee, and Maoh 2016), (Chitturi and Benekohal 2008) calibrated the psychophysical car following models with the help of vehicular trajectory data sets and given a frame work in developing the robust simulation models and highlighted the importance of driving behavior in modelling freeways. From the literature available for developed countries, it can be inferred that for developing expressway capacity and LoS related estimates, use of simulation model can be one of the approaches in absence of huge amount of loop-detector data over wider range of traffic flow conditions. Simulation models can be calibrated and validated for the observed conditions reasonably well, which then may be deployed to develop macroscopic speed-density-flow relationships in order to get accurate capacity estimates. This approach is adopted in the present study, as there is neither loop-detector nor any other automated traffic surveillance data source available to researchers in India. This can be also true for other developing countries, where there may be limited or no automated or sensor-based data source available for modelling.

Under prevailing mixed traffic conditions in India, general practice is to collect traffic data using video graphic survey and traffic data is extracted manually or using semi-automated tool. This necessitates analyzing traffic flow, using approaches (i) theory-based modelling, (ii) empirical data modelling, and (iii) semi-empirical hybrid approach, using empirical as well as simulated data. Use of simulation models warrants high-quality trajectory data base development for the roadway and traffic conditions under consideration. Out of these, the authors have adopted semi-empirical approach of calibrating simulation model using field observed data in this research work. In connection to this, very few studies are reported in explaining the performance of expressways in India. (M S Bains, Ponnu, and Arkatkar 2012) used VISSIM for modelling traffic flow on Pune-Mumbai Expressway. The study reported a value of 7200 PCU/hour/direction. The authors calibrated Wiedemann74 car-following parameters using combination of primary and secondary data source. The limitation of this study is that the authors have not given the logic of optimizing values of vehicle-following parameters. Likewise few more studies (Bharadwaj et al. 2016),(Manraj Singh Bains, Ponnu, and Arkatkar 2012) and (V. Thamizh Arasan and Arkatkar 2010) are reported on use of simulation models for estimating PCU, capacity and effect of variation in traffic conditions, such as traffic flow and composition through sensitivity analysis. Ponnu et al. (Ponnu et al. 2015) worked on the behavior of vehicles on the Delhi-Gurgaon expressway and modelled behavior of vehicle in terms of lane usage, following time and gap acceptance behavior. Even the authors (Shirke et al. 2017) modelled the behavior of vehicles and in terms of their lane choice using mathematical models. Chandra(Chandra 2015) used empirical observations to develop capacity estimates for interurban high-speed roads. Similarly the authors (Singh, Ponnu, and Arkatkar 2012) in the previous study, worked on Delhi Gurgaon expressway section and evaluated the effect of traffic compositions on passenger car equivalents

(PCU). From the literature, it can be inferred that in case of Freeways, Autobahns many studies have reported about prominent use of simulation models for assessing systems performance and other related applications. Whereas, under mixed traffic conditions in India, some studies are reported regarding usage of simulation models in modelling traffic flow on different roadway sections, although there are very few for expressways. After review of literature available on simulation studies on expressways in India, it can be inferred that there are following research gaps: (i) researchers have used mostly traffic data in calibrating simulation models, mainly 1-min or 5-minute interval data on traffic flow variables, (ii) parameter calibration procedures are not clearly stipulated, (iii) there is no use of high-quality vehicle trajectory data in calibrating car-following parameters, (iv) models are validated using mostly macroscopic parameters such as flow, speed and density, but not based on microscopic parameters such as vehicle-based driving patterns, (v) there is no comparison of using lane-based and non-lane based approaches within simulation framework, although real traffic flow pattern is likely to follow reasonable lane-discipline on expressways. Keeping in view these research gaps, objective of this research work was framed to develop a methodology for calibrating vehicle-following models using high-quality trajectory data and validating simulation model VISSIM 9.0 using micro-level driving patterns observed on expressways. The well-calibrated model was then used to estimate capacity and LoS thresholds. Further, the simulation modeling was also evaluated using two schemes: non-lane based and lane-based approaches, in VISSIM.

The paper is organized in total 8-sections including the present section. Data collection procedure is explained in the section-2, along with details of study sections. Section-3 explained the calibration of driving behavior and presents the development of simulation model in a comprehensive manner. Section-4 describes the simulation strategy (lane-based verses non-lane based schemes) in modelling traffic flow. Section-5 gives details about development of macroscopic fundamental diagrams, followed by section-6 describing micro-level simulation based trajectories interaction evaluations. Section-7 labels the findings from the study from the research work. This is then followed by summary and conclusions in section-8.

2. Study area

For the present study, mid-block road sections on two intercity Expressways, namely Ahmedabad-Vadodara Expressway (AVE) and Pune-Mumbai Expressway (PME) (situated in the western part of India) were selected with sections of trap length 100 and 120 m, respectively. Ahmedabad-Vadodara Expressway is a 4-lane divided roadway section with 2-lanes on each side including hard paved shoulder of 2.6 m width (width 11.0 m), on either side, as depicted in Figure 1(a). The vehicular movement over the sections was captured using video-graphic survey for a duration of 8 hours during day time on a bright sunny day. The traffic video data was then manually extracted to deduce different macroscopic traffic flow characteristics, which then used to develop macroscopic fundamental traffic flow diagrams. As indicated in one of the research gaps, to sense the real vehicle type driving behavior on selected study sections, a time duration of 20 minutes of the video data was used. This duration was selected in such a way that maximum variation in traffic flow could be captured. Moreover, duration of 20 minutes was adequate, as vehicular trajectory data was developed using Traffic Data Extractor developed by IIT Bombay, India in which the longitudinal and lateral position of vehicles were tracked for a time interval of 0.5 sec manually. This procedure was followed for tracking 407 vehicles on Ahmedabad-Vadodara Expressway. The second study section, Mumbai-Pune Expressway, with a trap length of 120 m and width 12.5m, was selected for the present work and is shown in Figure 1(b). It is a 6-lane divided carriage way with a paved shoulder of 1.5 m on either sides. In this case also, a traffic video was captured for a duration of 8 hours. As previously followed, 20 minutes of vehicular trajectory data was developed from about 813 vehicles, by tracking them over the study section using same tool. Four different vehicle categories was observed on two study sections, namely Car, Bus, Truck and Light Commercial Vehicle (LCV). It was also observed that car composition is predominant on both the study sections with 92 and 83 % respectively, on Ahmedabad-Vadodara

Expressway (AVE) and Pune-Mumbai Expressway (PME). It may be noted that movement of small vehicles such as motorized two-wheelers and three-wheelers is banned in expressways.

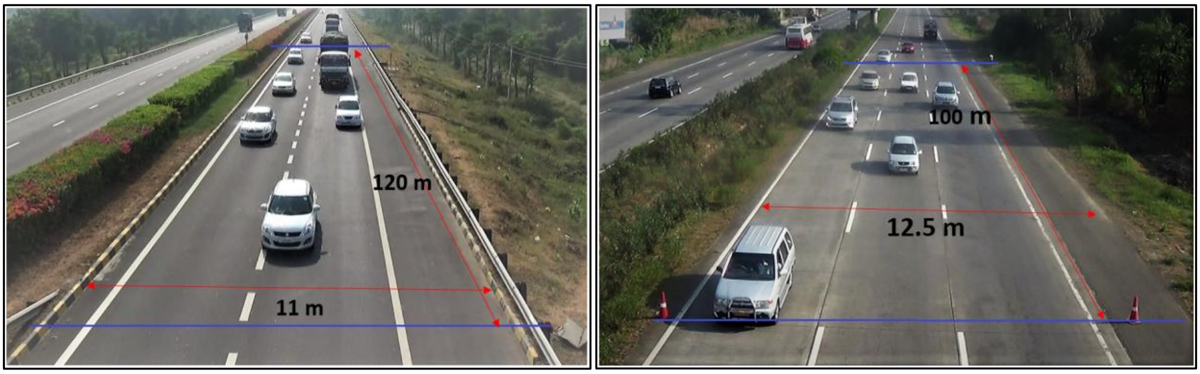

Fig.1. (a) Ahmedabad-Vadodara Expressway (b) Mumbai-Pune Expressway.

Based on the video graphic surveyed data, by means of manual extraction, the fundamental traffic characteristics in terms of PCU (Kumar et al. 2017) were evaluated for the road sections and speed-flow plots were presented in Figure 1(c). From the analysis, it can be observed that in most of the times, both the road sections are serving at a moderate traffic flow, ranging from 1000 to 4000 PCU/h on Ahmedabad-Vadodara section and 1500 to 7500 PCU/h in the case of Pune-Mumbai section. It was inferred that these data sets are not having enough variation in flow, which otherwise may require to estimate capacity and LoS thresholds. Even it was expected that capturing varied traffic flow on the study sections is dubious throughout all traffic states and congested regime in present situation. Hence, simulation based semi-empirical approach was adopted to study the traffic characteristics on expressways. But, in order to have the confidence on the output robust simulation models is to be developed and also model is to be validated from an aggregated macroscopic level to micro level, as explained in identified research gaps. On this basis, the study had been carried forward.

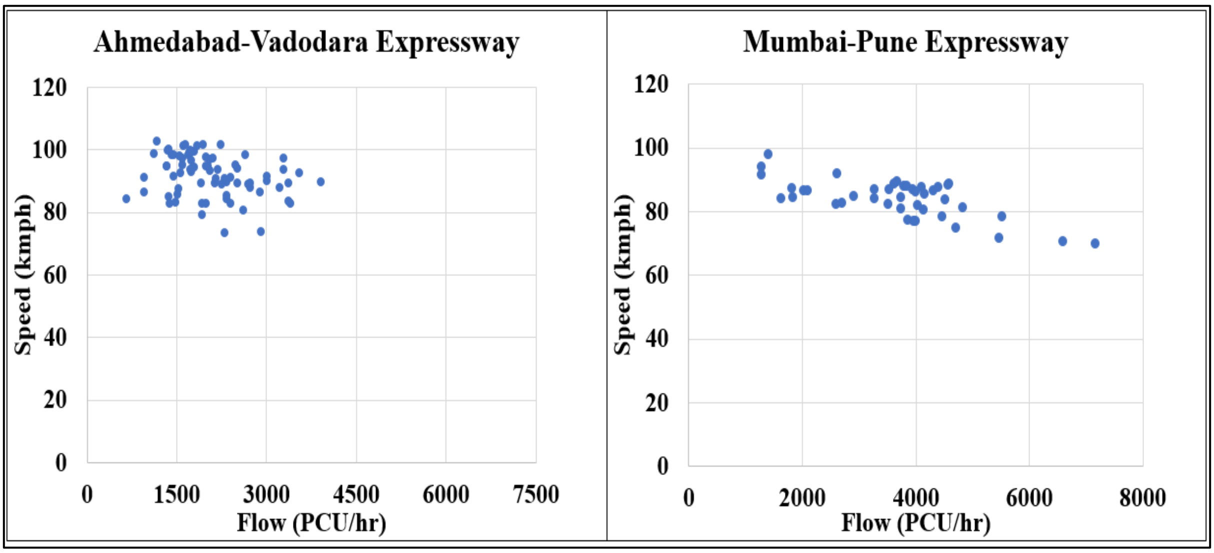

Fig.1(c) Speed flow plots from the study sections

3. Simulation Model Development

From the literature, it was inferred that many studies in past had applied traffic simulation tools in solving the critical problems and assessed the optimal solutions. Considering this in the present study, simulation approach had been attempted in studying the traffic characteristics on the expressway sections, but the application of simulation tools in Indian traffic context are less due to the complexity involved in modelling driving behavior. Similarly, very few studies had been carried in this direction in quantifying the driving behavior due to unavailability of trajectory data. Considering this in the present study microsimulation tool VISSIM 9.0. is used in simulating the road sections. But, in order to have confidence on the outputs from simulation, requires robust simulation models and should show a good correlation with field behavior. It was inferred that driving behavior plays a major role in this direction. In the present study to develop the robust simulation models driving behavior had tweaked, on this lines under Indian traffic (Mathew and Radhakrishnan 2010) had calibrated driving behavior in behavior in VISSIM by means of Genetic Algorithm. Even the authors (S. Arkatkar 2016) had given a vehicular trajectory level frame work in calibrating the driving behavior for the mixed traffic conditions. in the present case, the trajectory level frame work had applied in modelling the driving behavior for the two study sections for modelling robust simulation models.

3.1. Driving Behavior

The key element in studying the driver behavior is the identification of leader-follower pairs in different traffic conditions. In homogeneous traffic condition, it is easy to spot leader-follower vehicle pairs because of the lane based traffic movement. But under mixed traffic conditions the driving interactions among the vehicles are much more complex. In the present study to capture the following behavior initially, time space plots of vehicles were plotted on a given lane as shown in Figure 2(a), through visual inspection, the trajectories in following are assumed as leader-follower pairs. But under Indian context, there exists an influence of the vehicles from adjacent lanes, to study the influence of such vehicles, relative distance versus relative velocity (subject follower minus leader) is plotted for 3 combinations: (i) Assumed leader versus vehicle in other lane, (ii) Vehicle in other lane versus assumed follower and (iii) Assumed leader versus assumed follower. From these combinations, the pairs which are showing hysteresis phenomenon (representation of following behavior) are considered as true leader-follower pair. All such pairs are aggregated based on vehicle category wise for both the study sections for calibrating following behavior as shown in Figure 2(b).

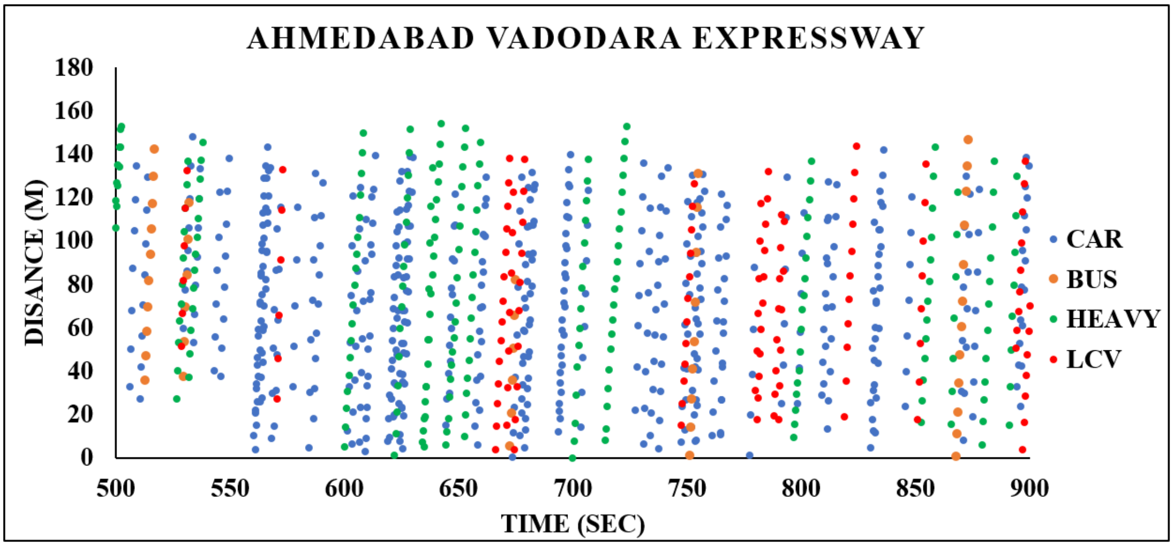

Fig. 2(a). Time space plots of vehicles on the study section.

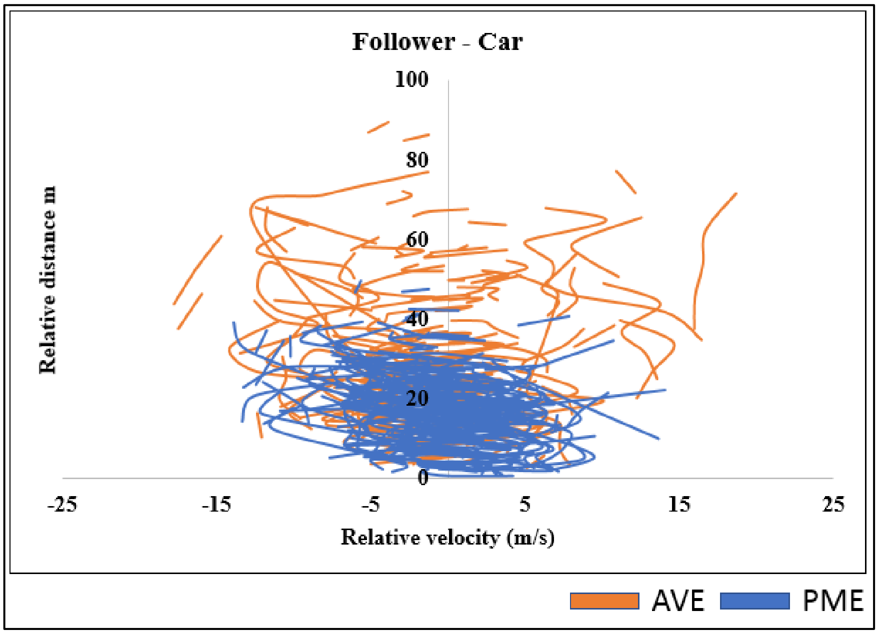

Fig. 2(b). Aggregated hysteresis plots of car on the study sections

3.2. Modelling Following Behavior

It was inferred that in microscopic simulation tool VISSIM, the following behavior of vehicle was expressed in terms of Wiedemann models, namely Wiedemann74 and Widemann99 out of these two Wiedemann 99 is the upgraded version and the core logic involved in these models remains same. In these models, the driver behavior is explained through thresholds of relative distance and relative velocity of the leader vehicle along with four driving regimes namely: free flow, following, approaching, and decelerating as shown in Figure 3(a). In the present case from the vehicular trajectory sets, it was observed that on Ahmedabad-Vadodara Expressway traffic flow was observed around 1200 veh/hr, which falls under moderate flow and for Mumbai-Pune Expressway it was around 2400 veh/hr, which represents a medium flow. So, in order to model the following behavior comprehensively, the hysteresis plots were aggregated for both sections for each of the following vehicle category. On this basis, the Wiedemann models were calibrated.

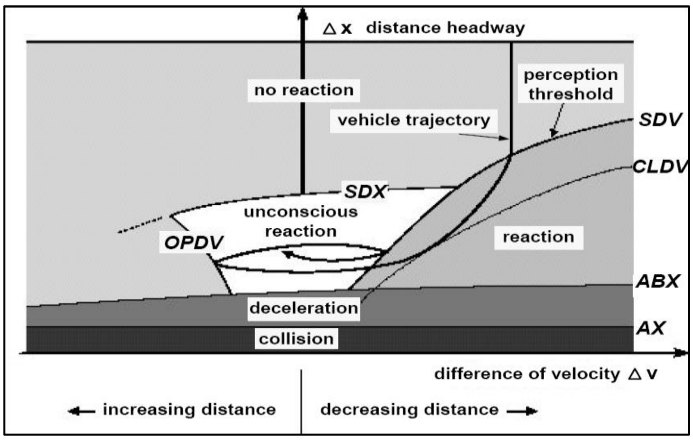

Fig. 3(a) Following-behavioural thresholds in Wiedemann model (PTV 2016)

3.3. Wiedemann 74

From literature (Menneni, Sun, and Vortisch 2009), it was inferred that Wiedemann 74 model is the earliest model and it was given in a simple mathematical formulation involving the parameters and is given as

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

After identifying the leader follower pairs, the parameters bx_add, and bx_mult were calibrated using the values of ABX, which is the desired minimum following distance threshold identified from hysteresis plots and Vslower which is the minimum of speed among the leader follower pair and AX as the minimum relative distance maintained between the leader-follower pairs. In this study, the value of N is assumed as 0.5. Based on the equation (1) the optimized values of parameters were calculated using simple solver tools. On the basis, the parameters were calculated the study sections as reported in Table 1(a)

Table 1(a) Calibrated parameters for Wiedemann 74

Sr. No	Following Vehicle category	Wiedemann 74 parameters		
		AX	bx_add	bx_mult
1	Car	1.05	0.219	0.559
2	Bus	1.703	0.471	1.370
3	Truck	1.703	0.471	1.370
4	LCV	1.65	0.819	1.159

3.4. Wiedemann 99

Wiedemann 99 model is the second implication of car following model, in which following behavior had expressed by means of ten parameters, in which each parameter has its significance in explaining the following behavior as given in Table 1(b)

TABLE 1(b) Definition of Wiedemann 99 parameters

Parameters	Implication in following behavior
CC0	Desired rear bumper-to-front bumper distance between vehicles in standstill conditions. *AX=CC0*
CC1	Defines the time (in seconds) the following driver wishes to keep. The VISSIM manual (PTV 2016) reports this as headway time, $ABX = Lead\ vehicle\ length + CC0 + CC1 * v_{slower}$
CC2	Defines, rather restricts the longitudinal oscillation during following condition $SDX = ABX + CC2$
CC3	Defines the perception of subject vehicle (in seconds) to leader
CC4	The maximum negative relative velocity during the following process
CC5	The maximum positive relative velocity during the following process
CC6	Defines the influence of distance on speed oscillation during following condition
CC7	Defines actual acceleration during oscillation in a following process
CC8	Defines the desired acceleration when starting from a standstill.
CC9	Defines the desired acceleration when at 80km/hr.

In the present study, the methodology adopted by (S. Arkatkar 2016) was used in calibrating the Wiedemann 99 models. On this basis, the parameters were calibrated as follows, CC0 was related to psychological safe distance that a driver maintains in order to avoid collision and so it had no significant variation and was equal to AX, which was equal to the value used in Wiedemann 74. The value of CC1 was calculated by means of the equation in table. CC2 was evaluated as a zone of following in which 50th percentile and 25th percentile of relative distances were calculated from the hysteresis plots. The 25thpercentile value was yielding good result in both the road sections. Even though it was concluded that at 25th percentile value was the threshold of following. this frame work had to be adopted over varying traffic conditions on the road sections for fixing the threshold limit from the hysteresis plots. CC3 was taken as the slope of the line as shown in Figure 3(b), by assuming it as a straight line. For finding CC4 and CC5, 95th percentile values of relative velocity were tried. There was no proper explanation for finding CC6 and default value defined in the model was adopted. CC7 was calculated for each following vehicle category by taking the average of acceleration values during the following process. CC8 was the acceleration value corresponding to the standstill condition. In the present study, default value was used. CC9 was the average acceleration at 80 KMPH as these speed ranges were not available in the extracted trajectory data set, default values were adopted for the study and the calibration frame work were given in figure 3(b) along with observed data and calibrated parameters were reported in table 2(a).

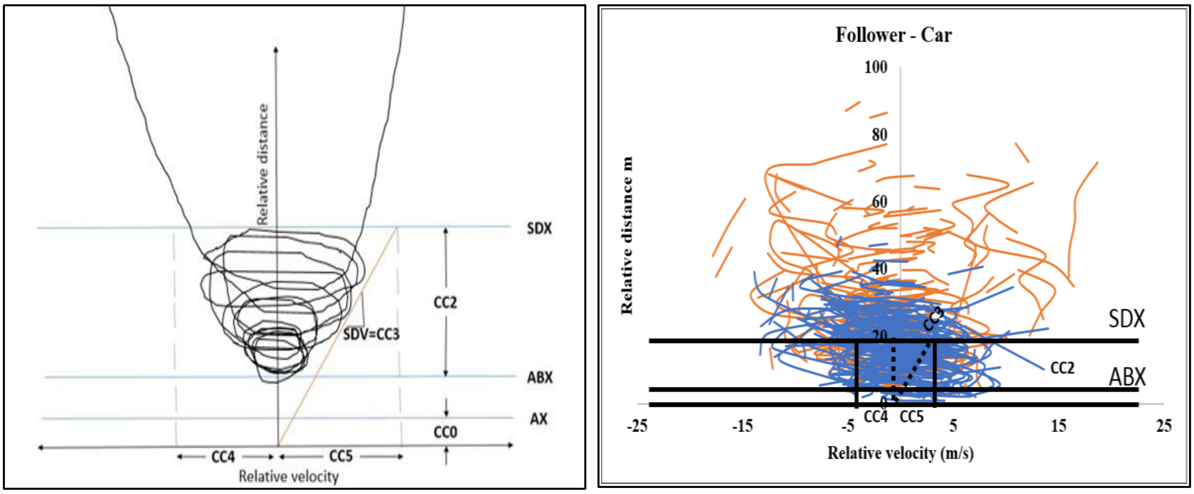

Fig. 3(b). Pictorial representation of relative distance versus relative velocity

TABLE 2(a) Calibrated parameters of Wiedemann 99 for the study sections.

Parameters	**Default**	**Car**	**Truck**	**Bus**	**LCV**
CC0	1.5	1.05	1.70	1.70	1.05
CC1	0.9	0.49	1.16	1.16	0.49
CC2	4	4.93	6.79	6.79	4.93
CC3	-8	-8.43	-13.60	-13.60	-8.43
CC4	-0.35	-0.34	-1.00	-1.00	-0.34
CC5	0.35	0.28	0.22	0.22	0.28
CC6	11.44	11.44	11.44	11.44	11.44
CC7	0.25	0.26	0.25	0.25	0.26
CC8	3.5	2.20	3.50	3.50	2.20
CC9	1.5	1.33	1.46	1.46	1.33

3.5. Lateral Behavior

From the preliminary analysis, it was found that lateral behavior of vehicles plays a major role in driving behavior along with following behavior in modeling the road sections. In the microsimulation tool VISSIM, the lateral behavior is modelled by means of lateral clearance share, for a given vehicle category the lateral clearance share at standstill conditions and at 50 kmph has to be given. From the trajectory data sets, it was observed that the vehicles are moving above the speed range (< 50 kmph). In the present study, lateral clearance were taken from the literature (Venkatachalam Thamizh Arasan and Arkatkar 2010) and (S. S. Arkatkar and Arasan 2010) which had reported on similar road way sections as shown in Table 2(b)

TABLE 2(b) Lateral clearance share adopted in the study (Venkatachalam Thamizh Arasan and Arkatkar 2010)

Sr. No	Vehicle category	Lateral clearance share (m)	
		@ standstill conditions	@80 kmph
1.	Car	0.3	0.5
2	Bus	0.4	0.7
3	LCV	0.3	0.5
4	Truck	0.4	0.7

Based on the calibration of Wiedemann 74 and Wiedemann 99 models, the following behavior of the vehicles had been captured, similarly the lateral behavior of the vehicles was also taken in to account. On this basis, the driving behavior of the vehicles were modelled and the study had been carried forward in modelling the road section.

4. Simulation Strategy

With the help of field data, the simulation of midblock sections were attempted in microscopic simulation tool VISSIM 9.0. From the literature (V Thamizh Arasan and Vedagiri 2006),(Metkari, Budhkar, and Kumar Maurya 2013) and (Barcelo 2010) it was observed that for under mixed traffic context, in simulation the entire road space had created in a single block (non-lane based) on this basis analysis were reported. But from the surveyed video graphic data it was observed that vehicles are showing some kind of lane wise movement. In this regard from the trajectory sets lateral placement of vehicles were evaluated as shown in Figure 4(a), it was observed that vehicles are having lane wise behavior over the road sections.

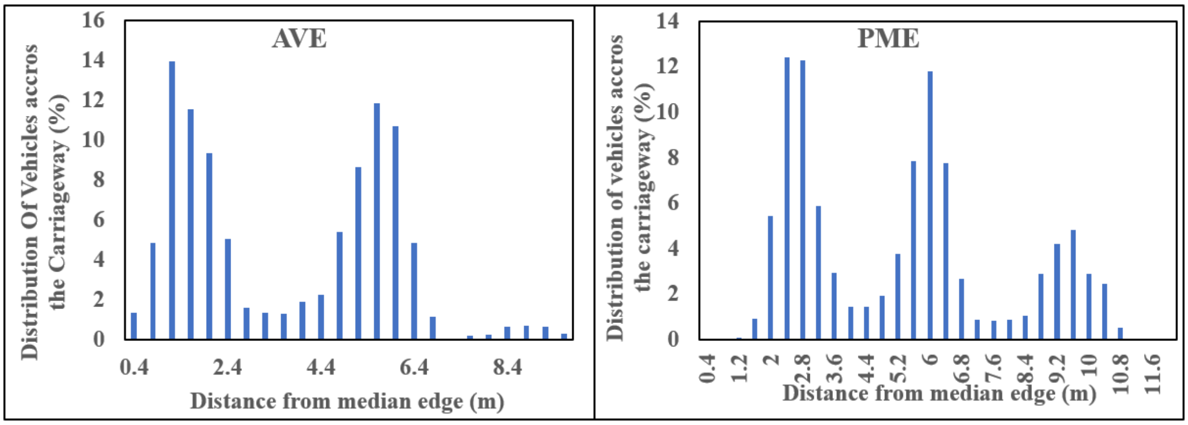

Fig. 4(a) Lateral placement of vehicles over the study sections

Even from the studies on Expressways under Indian traffic conditions (Shirke et al. 2017) had reported lane wise behavior of vehicles, considering this two kind of simulation networks were modelled, in the first case entire road width is modelled as a single entity (non-lane based) and in the second network was modelled in lane wise. On this basis in the simulation models, for a better replication of vehicles, the static dimensions and mechanical properties in the vehicle models are considered according to Indian traffic conditions (S. S. Arkatkar and Arasan 2010) . From the trajectory datasets desired speeds, calibrated following and lateral behavior were given as inputs to the simulation models, where in a case of lane wise approach, lane changing behavior adopted in (LEYN, Ulrike; VORTISH 2015) were given as inputs to the driving behavior.

5. Development of Macroscopic Plots

In the present study to develop the macroscopic plots for the midblock of road sections as discussed in earlier section were developed for a length of 1000m along with a buffer sections of 100m at the start and at the end. On this basis, simulation runs were carried out for a varying volume levels ranging from 500 vehicles/hour to 10000 vehicles/hour with an interval of 500 vehicles/hour for one hour each at 10 different random seeds and average of the ten seeds were taken for the analysis. This is very important to develop the complete macroscopic plots of the road section. Based on this methodology, the simulation runs were carried out by inputting the calibrated Wiedemann 74 and Wiedemann 99 parameters to the simulation models. On this basis speed, density and flow were evaluated in terms PCU (Kumar et al. 2017) for each 5 minute interval from the study section. Macroscopic plots were developed for the two study sections and speed flow plots are shown in Figures 4(b)and 4(c). It was found that simulation models from the both study sections were having a free flow speed around 100 kmph, which is the prescribed speed limit observed on the study sections during the video graphic surveys. Similarly, the characteristics such as capacity and free speeds were reported in the Table 3(a). From the speed flow plots it was observed that the simulated macroscopic plots were able to match the field data in the given range and the capacity of the sections were found to be around 7500 to 7750 PCU/hr for AVE and 7700 to 8000 PCU/hr. It was inferred from the results that both non-lane based and lane based simulation models were almost comparable in nature, but near the capacity, the variation in macroscopic plots were observed among non-lane based approach and lane based approach and had a difference in capacities which were within 200 PCU/hr in case on AVE and 250 PCU/h in case of PME. Similarly, variation in terms of follower behavior were checked in case of Wiedemann 74 model it is limited to 120 PCU/hr, with Wiedemann 99 it is in the range of 150 PCU/hr. It was concluded from the plots that both the non-lane based approach and lane based approach were performing in a similar way at the macroscopic aggregated level and variation among the outputs were insignificant other than near the capacity. From the simulation studies on freeways in the developed countries (Gomes, May, and Horowitz 2004b), (Gomes, May, and Horowitz 2004a) and (Woody 2006) it was observed that in most of the times Wiedemann 74 model is employed in modelling the urban traffic and in simulating high speed roads and freeways Wiedemann 99 model is used in expressing the following behavior. The main implication beyond this is that Wiedemann 99 is an upgraded model and able to express the closing up and giving up behavior of vehicles in following condition, whereas Wiedemann74 is more of a threshold model and good in modeling the stop and go conditions. Further in the research work Wiedemann99 model is used in the simulation models.

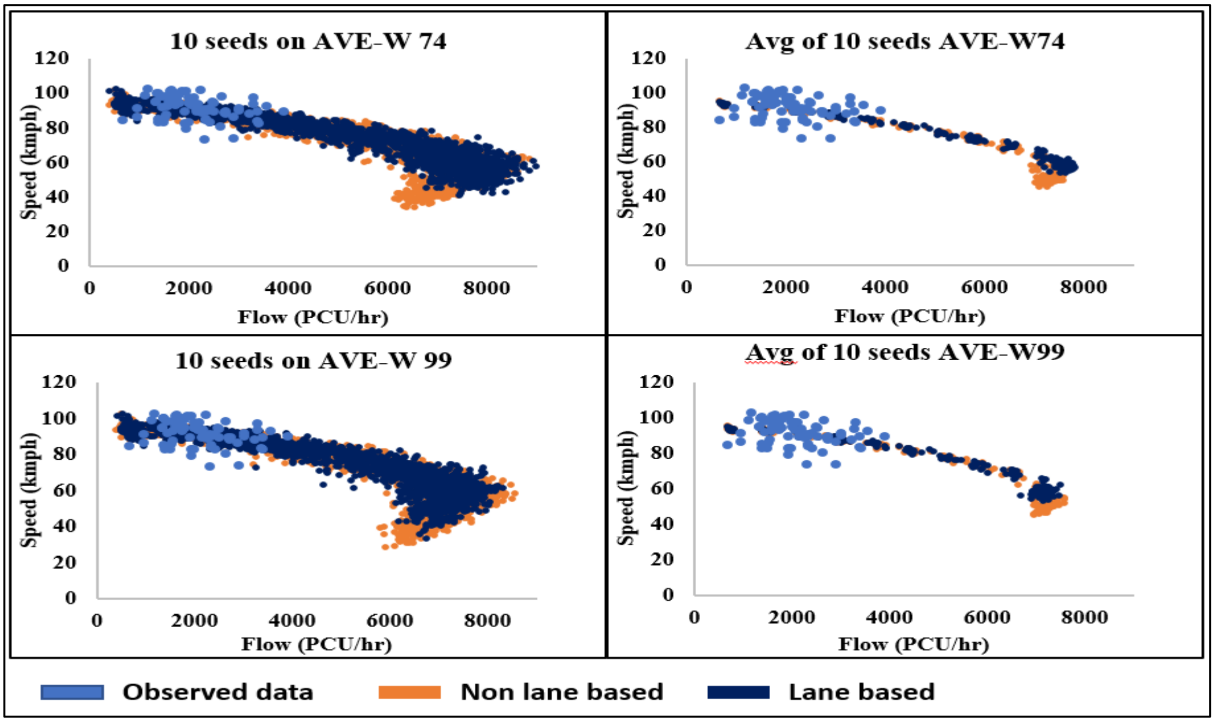

Fig. 4(b) Speed flow plots on Ahmedabad Vadodara Expressway

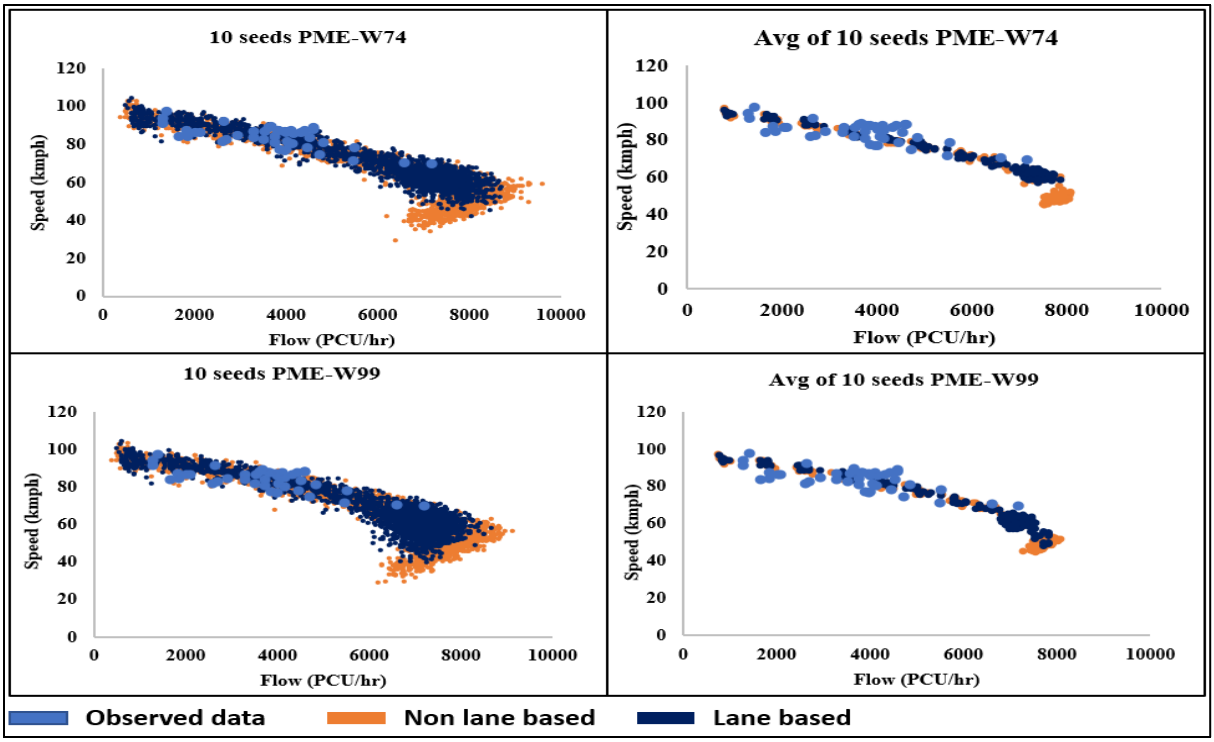

Fig. 3(a). Speed Flow plots on Pune Mumbai expressway

TABLE 3(a). Macro-level comparison of results among calibrated Wiedemann models

Study Area	Characteristics	Wiedemann 74		Wiedemann 99	
		Non-Lane Based	Lane Based	Non-Lane Based	Lane Based
Ahmedabad-Vadodara Expressway	**Capacity (PCU/hr)**	7598	7719	7564	7477
	Free flow speed (kmph)	105	105	105	105
Mumbai-Pune Expressway	**Capacity (PCU/hr)**	8038	7879	7822	7805
	Free flow speed (kmph)	103	103	103	103

6. Microlevel Investigation

Based on the macroscopic analysis, other than flow near the capacity, no significant variation was observed among the non-lane based and lane based simulation models. Further in order to understand the phenomenon to identify the variation near the capacity, vehicular trajectories were developed from the simulation models. On this basis, time space plots were plotted for the vehicles as shown in Figure 5(a). From the plots, it was identified that in case of non-lane based simulation models, continuous traffic shockwaves were observed in the stream and on the other side in lane based approach recurring partial perturbations were observed. From the microlevel examination, it was identified that in case of non-lane based approach, the subject following vehicle is aligned laterally skewed to its leader vehicle, due to this whenever the leading vehicle is slightly decelerating its speed in response, the follower vehicle also reducing its speed, as it is laterally skewed the subject follower effected the movement over the road space. These kinds of interactions had effected the movement on the road sections resulted in backward formation shockwaves. On the other hand, in case of lane based approach near the capacity, lane are almost operating independently and vehicle are maintaining necessary lateral clearance with the vehicle in the other lanes. From this it was concluded that in case on non-lane based approach the vehicles are behaving similar to the vehicles on the urban roads.

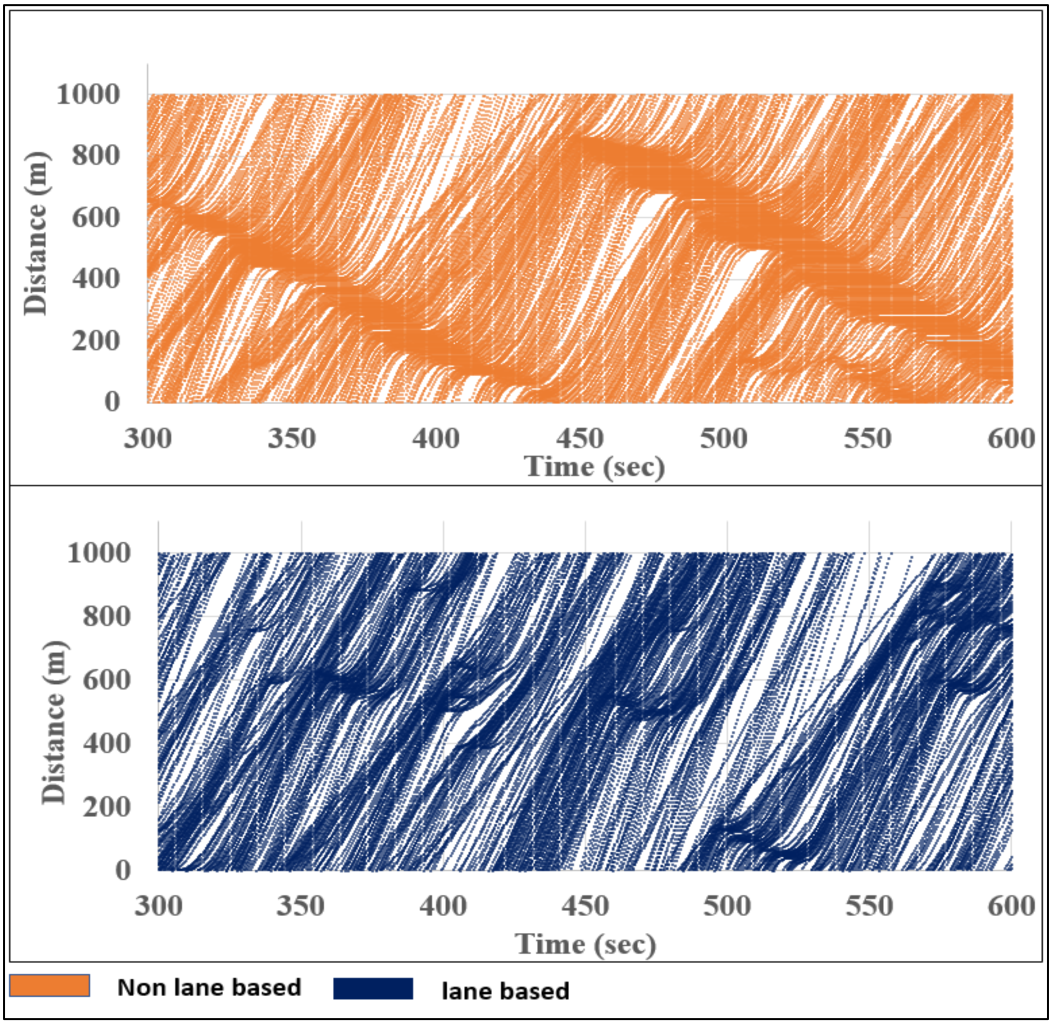

Fig. 5(a). Time space plots of vehicles in simulation network on AVE section

Further to understand the sense of the simulation models in replicating the field behavior at microlevel, relative longitudinal distance and relative velocities were computed among the successive vehicles (vehicle which are laterally skewed and they are within the width of leader) from the trajectory data and were evaluated in both the approaches and the relative distance vs relative plots were over laid with observed hysteresis as shown in Figure 5(b). From the analysis, it was observed that in the none-lane based approach, vehicles are interacting with laterally skewed vehicles, due to this the following transitions were found to be not that much smooth enough and resulted in high relative velocities. Whereas in case of lane wise approach good following up behavior among the vehicles were observed. It can be visualized that in case of lane based approach, the relative distance vs relative velocities are comparable with the observed hysteresis. On the other hand, in case of non-lane based approach the relative velocities are higher (due to backward formation shockwave) when compared with observed hysteresis. Finally, on this basis, it was concluded that lane based approach is the most suitable model for the expressways as the lane wise behavior of vehicles were more predominant and good in mimicking the observed driving behavior.

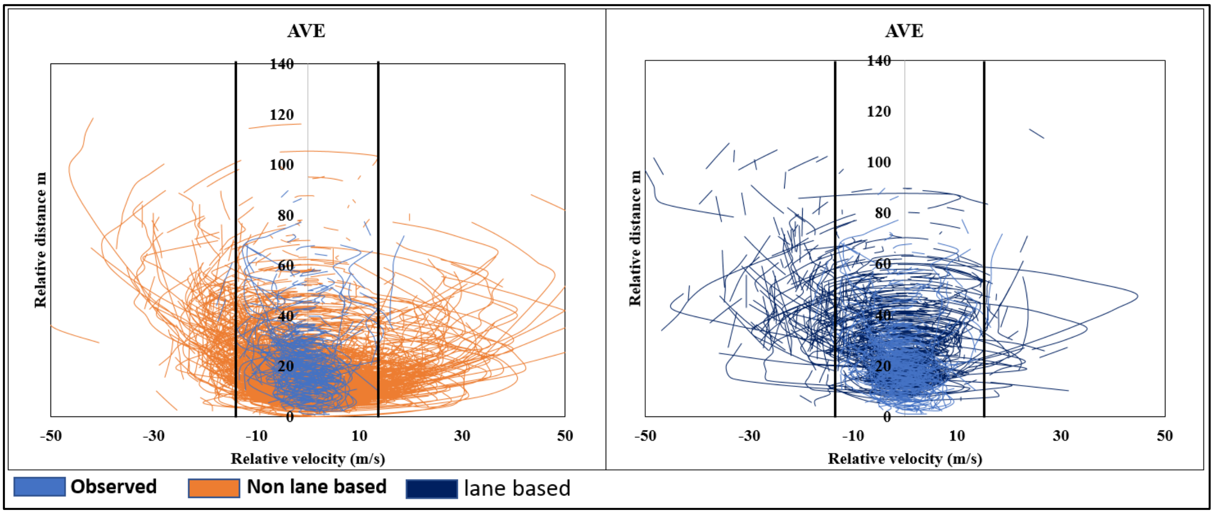

Fig. 5(b). Hysteresis comparison among the vehicles on the AVE

7. SIMULATION MODEL APPLICATION

Level-of-Service (LoS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to manoeuvre, traffic interruptions, comfort, convenience and safety. As expressways are new in Indian context, the level of service guidelines was not available in the present context and it was inferred that with the observed traffic data range from the macroscopic plots it was difficult to define the level of service thresholds for the road sections. considering this in the present study it was attempted to define the level of service guidelines, for that lane based simulation model with Wiedemann 99 model which is having good microlevel correction with observed driving behavior is taken up for the analysis and the macroscopic plots developed from the previous sections were used in this section. On this basis, the study had been carried forward. The methodology adopted, as per HCM (Dowling and Ostrom 2010), for developing level-of-service criteria for multilane highways, involves development of speed-flow relationship and delineation of various level-of-service boundaries on the speed-flow curves, based on density. Hence, with the help of simulation speed -flow curve was used developing the level-of service criteria for Expressways. Based on the relationships between speed, flow and density with the help of K mean clustering method (Sangalli et al. 2010) had employed in defining the level-of-service thresholds. To develop the LOS guidelines, speed, flow and density data for 5-minute interval were used these data sets are ranged from free flow condition to capacity condition and some few points lie even in congested state. For clustering, K-mean technique was adopted by using STATISTICA.10 software. From the data sets, clusters were defined based on speed, flow and density which represent LOS A to LOS F as shown in Figure 5(c). To get the better results for boundary delineation, 250 iterations were done with the help of software. After defining clusters, data points were plotted for speed-flow and flow density curves to define thresholds of LoS. On this basis, LoS anlalysis had been carried for both the road sections as reported in Table 3(b) along with V/C ratios for different LOS from HCM (National Research Council Transportation Research Board 2000) are compared with clustered data.

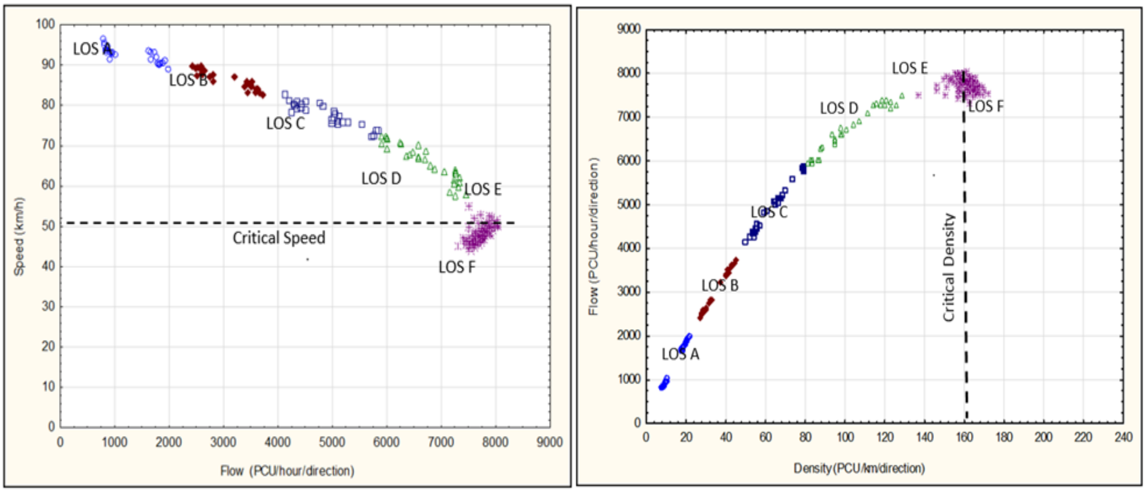

Fig. 5(c) Level of service thresholds on PME

TABLE 3(b) LOS thresholds for the study sections

Study section	LOS	Speed (km/h)	Flow (PCU/hr/direction)	Density (PCU/km/direction)	V/C ratio (clustering)	V/C ratio (HCM 2010)
Ahmedabad - Vadodara Expressway	A	>90	<1947	<23	0.26	0.3
	B	90-83	1948-3640	24-42	0.47	0.5
	C	82-71	3641-5565	43-75	0.73	0.71
	D	70-59	5566-6829	76-117	0.9	0.89
	E	58-52	6830-7613	118-147	1	1
Mumbai-Pune Expressway	A	>89	<1993	<22	0.25	0.3
	B	89-83	1994-3734	23-45	0.46	0.5
	C	82-74	3735-5858	46-80	0.73	0.71
	D	73-58	5859-7265	81-126	0.9	0.89
	E	57-50	7266-8045	127-161	1	1

8. FINDINGS

Based on the research frame work adopted in the present study, with the help of through validated simulation models, level of service thresholds were defined for the study sections. During this course, the following inferences were observed from this research work and are as following.

- From the observed data on the study locations, it is inferred that characteristics of the high-speed roads should not be studied with empirical observations alone, as variation in traffic volume will be less on these road sections, unlike the urban roads.
- From the micro-level observations, it was observed that the Expressway road sections are showing some kind of lane wise behavior, which is not predominantly observed in the Indian traffic context. It was attributed to the homogeneity in traffic as small vehicles (two-wheeler, auto etc.) were restricted in the expressways.
- It is also observed that vehicular trajectory data is indispensable source for simulating the road sections effectively in robust way, but at present, very few vehicular trajectory data sets are available under Indian conditions, as NGSIM data, which is hugely available and accessible in the US. Under Indian traffic conditions, only few studies had reported the usage of trajectory data, but this is the first study on Indian expressways.

- It was observed that the using the simulation approach, the capacities of the study sections are found to be around 7477 PCU/h/direction for Ahmedabad Vadodara expressway and 7805 PCU/h/direction for Pune - Mumbai expressway.
- The assessment of Level of Service was done by using micro simulation technique over a wide range of traffic volume with the help of clustering technique. LOS thresholds are further defined with the help of speed-flow and speed-density curve. From the study, it was concluded that the v/c ratios of different LOS are similar to the values specified in the guidelines suggested by HCM.

9. SUMMARY

Under Indian traffic conditions, it was perceived that most of the times non-lane-based movement of vehicles were observed due to heterogeneity involved in traffic. As expressways are different to Indian context and planned to offer a higher quality of service, smaller vehicles were access restricted on these road sections. But, it was observed that there are no proper guidelines available in monitoring the performance for these kind of road sections. In the present context, the variation in traffic volume is less in modelling the traffic characteristics. On this basis, simulation approach had been attempted in to model the traffic characteristics, to increase the simulation model validity, validation had carried at micro-level driving behavior. Based on this traffic characteristics were studied in terms of modelling the macroscopic fundamental plots. LoS thresholds defined in the study can be very useful in understanding the performance of the expressways. Similarly, the methodology developed for vehicle-following behavior based on trajectories can be transferable and useful to the researchers from other parts of world having similar traffic conditions.

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