Study of Flow Characteristics and Traffic Stream Modelling on Indian Expressway: A Case Study of Mahatma Gandhi Expressway

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Abstract: Proper understanding and analysis of traffic stream characteristics is necessary for design, analysis, operation and management of roadway facilities. An attempt has been made in this paper to analyze the traffic stream characteristics and to model traffic flow by taking Ahmedabad and Vadodara connecting four-lane divided, Mahatma Gandhi expressway. The selected road stretches are basic expressway segments in plain terrain. Vehicles are classified as Small Car, Big Car, Light Commercial Vehicle (LCV), Bus and Truck. Traffic data is collected using video graphic method. Data on traffic volume, vehicle composition, speed of different vehicle categories, lane utilization etc. has been manually extracted from video files. The results show that more than 97% of vehicles are following lanes under free-flow conditions. The results show diffrent speed-density relationships along with parabolic relationships between speed-flow, flow-density. The capacity of expressway is found to be approximately 4377 PCE/hour/direction for a traffic stream having about 25% of heavy vehicles. The results of the present study are expected to highlight the existing scenario of traffic flow on Mahatma Gandhi expressway.

Keywords: Expressway; Mixed traffic flow; Traffic flow characteristics; Traffic flow models

1. INTRODUCTION

The Expressways, National Highways, State Highways and Rural roads together comprise the road network in India. Among this, Expressways are the highest class of road in India and which is a controlled-access highway, designed for fast traffic, with entrance and exit at designated points. Currently, expressways in India measure 600 km approximately and around 18,637 kms more expressways will be added to the Indian Road Network by the year 2022. Traffic characteristics on expressways are different from all other roads in India. It’s mainly because Expressway facilities carry only relatively large fast moving vehicles such as cars, buses and trucks and the vehicles such as bullock carts, cycles, two-wheelers, and three wheelers have no access at all on such roads. Expressway is designed for high speed, high volume traffic flow and is expected to play an important role in the development of country. Study of traffic flow on expressways in India is necessary to analyze traffic behavior on such facilities, which is yet not studied adequately. The design speeds on expressways are high and in the absence of slow moving vehicles, both motorized and non-motorized, the traffic flow characteristics such as traffic composition, speed, lateral and longitudinal gaps between the vehicles are significantly different as compared to those on other multilane highways. Thus it is necessary to understand the traffic flow characteristics on expressways and develop relationships among fundamental characteristics and also to determine the capacity and level-of-service (LoS) that are essential in planning, design, and operation of roadway facilities. Detailed study of different traffic flow characteristics is better done by modelling the system using appropriate analytical techniques, which will enable the study of the characteristics over a wide range of the influencing factors. In the 11th Five Year plan (2007-2012) report, it has been mentioned that as a matter of fact, no systematic study has ever been undertaken to determine the capacity of expressways in India. Thus, there is a need to initiate a study on the capacity and LoS criteria of expressways depending upon the carriageway/roadway widths and other relevant parameters. This type of study will provide basis for planning, designing as well as operation management of expressways in future. In view of this, Ahmedabad-Vadodara Mahatma Gandhi expressway is selected for studying traffic flow characteristics. This study is aimed to model traffic flow on Indian expressways with specific reference to an intercity expressway, Mahatma Gandhi expressway and further also to estimate its capacity using the simulation model named, VISSIM.

Traffic data collection is done through video recording because of its ability to collect data of all the traffic flow characteristics simultaneously and facilitate data extraction at both microscopic as well as macroscopic levels. Data extraction is the process of retrieving data from unstructured or poorly structured data sources for further data processing, storage and analysis. In the present study, data is retrieved from video by converting them into frames followed by manual observation and counting and are further properly stored in MS excel for further analysis. Data extraction is carried out with the help of Xilisoft video converter and IrfanView software. Using these softwares, video is converted into frames at a rate of 25 frames per second and the required data is noted down from the frames which is entered in MS excel. Data analysis is carried out using MS excel and SPSS platforms. Speed-flow-density models are developed through traffic characteristics in terms of PCE per hour per direction.

2. LITERATURE REVIEW

It is important to understand the different approaches adopted by various researchers in the past with respect to their objectives, in order to formulate an appropriate approach for the study. The literature related to expressways and traffic flow characteristics which have been used for the study is presented here. Breman et al. (1977) analyzed the statistical properties of freeway traffic on expressway situated in California. The data base consists of trajectories constructed from aerial photographs of the Long Island Expressway. They concluded that the headways, both space and time, are usually independent and also, speeds and headways are independent except at the highest flow rates. Elefteriadou et al. (1997) studied the impact of variables such as traffic flow, truck percentage, truck type (length and weight/horse power ratio), grade, and length of grade on PCUs using simulation technique. Fellendorf and Vortisch (2001) presented the possibilities of validating the microscopic traffic flow simulation model VISSIM, both on a microscopic and a macroscopic level. Gardes et. al. (2002) applied the Paramics traffic micro-simulation model, and assesses its ability to serve as a tool for evaluating potential freeway improvement strategies that include ramp metering, auxiliary lanes, and HOV lanes. Helbing et al. (2002), have shown that all the presently known macroscopic phenomena of freeway traffic, including (i) the fundamental diagrams, (ii) the characteristic parameters of congested traffic and (iii) the transitions between free traffic and other congested traffic states can be reproduced and explained by microscopic and macroscopic traffic models based on plausible assumptions and realistic parameters. Roux and Bester (2002) studied speed-flow relationships on Cape Town freeways and presented a model to state the merit of representing the whole range of speed-density data with two separate curves ; uncongested regime and congested regime. Models were more optimistic with regards to flow on freeways during congested conditions. The authors also stated that, the models obtained were not readily applicable to other freeways as freeway conditions differ significantly from one to another. Zhizhou et. al. (2005) applied VISSIM platform for traffic flow simulation using field data obtained from Traffic Information Collecting System (TICS) on North-South (NS) Expressway in Shanghai, China. Matsuhashi et. al. (2005) assessed the traffic situation in Hochiminh city in Vietnam, using image processing technique and traffic simulation model (VISSIM). It was found that the high number of motorcycles in the network interfere with other vehicles which reduces their average speed drastically. Wang et al. (2009) proposed a stochastic speed-density relationship and developed a stochastic fundamental diagram of traffic as traffic flow is a many-car system with complex and stochastic movement. They found that, deterministic speed-density relationship models can explain physical phenomenon's underlying fundamental diagrams and the stochastic model is more accurate and suiTable to describe traffic phenomenon. Ardekani et al. (2011) have developed macroscopic speed-flow models for characterization of freeway and managed lanes. Nine different speed-density models (four conventional models and five modifications of these models) were calibrated for a freeway site in Texas. The study reports that the Drake model is best among all 9 models.

Arasan and Dhivya (2010) observed that, the traffic density expressed as number of vehicles per unit length of roadway, cannot be appropriate for accurate measurement of traffic concentration as length and speed of the vehicles in a traffic stream varies significantly and suggested a new methodology named, "area-occupancy" and validated the same using simulation technique. Arkatkar et al. (2013) developed a traffic flow model in India for eight-lane divided Delhi-Gurgaon urban Expressways and derived its capacity. It was found that the capacity level critical speed reduces linearly and capacity value decreases non-linearly with increase in percentage of trucks from 10% to 100%. Bains et al.(2012) modeled traffic flow on Mumbai-Pune Expressway (six-lane expressway, 10.5m wide per direction) to evaluate capacity of expressways. They reported that, the PCU value of all categories of vehicles decreases when their proportion increases in the traffic stream. Bains et al.(2013) found that speed limit compliance have effect on roadway capacity and with increasing driver compliance level for a given posted speed limit there is an increase in roadway capacity along with a marginal decrease in the travel times at flow levels near capacity. Puvvala et al. (2013) developed a traffic flow model for Delhi–Gurgaon expressway and derived capacity using dynamic PCU. They suggested treating PCU as dynamic quantity instead of fixed PCU values. Vagadia and Joshi (2013) carried out a study on dynamic characterization of mixed traffic on arterial roads in India. Study reports that, PCU of various vehicles mainly depend on traffic composition, traffic volume and road geometry beside their size and speed characteristics. Based on the review of literature the following important points have been identified:

1. Most of the researchers in India in the past aimed at aimed at assessing the roadway capacity based on empirical and combination of empirical and simulation approaches, for varying carriageway widths including single lane, intermediate lane, two-lane bi-directional, four-lane and six-lane (multilane) divided carriageway widths covering different terrains have been carried out during the last two decades. But, only a limited number of studies have been carried out to determine the capacity of expressways in India.
2. In most of the countries, researchers have applied the combination of field and simulation studies to study traffic flow characteristics both at microscopic and macroscopic levels to develop capacity over a wider range of roadway and traffic conditions.

In view of the above points and considering the fact that a huge network of expressway has been planned in future, there is a need to determine the capacity of expressways in India.

3. OBJECTIVES OF THE STUDY

To understand traffic characteristics on expressways, it is necessary to study, at micro level, the influence of roadway and traffic characteristics by taking into account all the important influencing factors. Accordingly, an expressway traffic-flow simulation model can be applied to study the traffic flow characteristics for varying roadway and traffic conditions on expressways. The proposed research is mainly concerned with the development of capacity estimates through modeling of heterogeneous traffic flow on expressways in India. The specific objectives of the research work are as follows:

1. To study the traffic flow characteristics on expressways for in-depth understanding and to quantify the influencing factors for modeling heterogeneous traffic flow on expressways.
2. Application of VISSIM to stimulate traffic flow on expressway and to validate the model with field data.
3. To estimate Passenger Car Equivalent (PCE) values of different categories of vehicles for studying their variation due to changes in traffic conditions.
4. To derive capacity estimates for expressways carrying heterogeneous traffic.

4. DATA COLLECTION

Three basic freeway segments with flat straight stretches on four-lane divided Mahatma Gandhi Expressway are selected for traffic flow analysis. The Survey details of the selected study stretches are shown in Table 1.

Table 1. Study sections and survey details

S. No.	Name of the Test Section	Date of Survey	Duration of Survey (along with Time and Hours)	Recorded Traffic Direction
1	Chainage: 30.181km (near ROB 9, between Nadiad and Ahmedabad)	19-10-2013 Saturday	8.15 am-12.20 pm & 2 pm -5.56 pm (8:00:51)	Ahmedabad to Vadodara
2	Chainage: 35.620km (Near ROB 12, between Nadiad and Ahmedabad)	19-10-2013 Saturday	7.20 am-11.20 am & 2.30 pm-6.30 pm (7:59:57)	Vadodara to Ahmedabad
3	Chainage: 54.805km (Near ROB 17, between Vadodara and Nadiad)	18-10-2013 Friday	7.50 am-11.17 am & 3 pm- 6.27 pm (6:54:49)	Vadodara to Ahmedabad

The study stretches were selected after conducting a reconnaissance survey to satisfy the following conditions: (1) The stretch should be fairly straight, (2) Width of Roadway should be uniform, and (3) There should not be any direct access from the adjoining land uses. Flat straight study stretches are identified by giving consideration to traffic direction and presence of interchange at Nadiad. As per Indian norms, a total of six study stretches are selected and collected data for study of expressway. But in the present study, as data extraction is a time consuming process, data analysis and modelling attempt could done only for three study stretches. As shown in table 1, stretches of both the traffic directions, before and after the interchange at Nadiad are considered. Traffic will remain same trough out the expressway except near interchange as vehicle may access or leave the expressway through the interchange. So, the selected three section is considered as enough as traffic volume and composition are not varying in other possible study sections. Selected stretches are shown in Figures 1(a) through 1(c).

Figure 1 (a) Google earth image of (b) Google earth image of (c) Google earth image of . chainage: 30.181km; chainage: 35.620 km; chainage: 54.805 km.

Inventory survey was carried out for the selected study stretch to gather details of roadway geometry. The expressway is having 11 m wide dual carriage way including side shoulder of 2.6 m with a central median width of 5.9 m. These dimensions of lanes are same for all the selected stretches. For analysis purpose two lanes are designated as median side lane (MSL) and shoulder side lane (SSL) in this study. Here, field surveys are carried out on the selected stretch using video graphic technique by fixing high resolution camera on ROB (road over bridge) above the center of a one direction carriageway accordingly to covers marked 100m longitudinal section, which helps to collect the data regarding speed, classified volume count, vehicle composition, and lane utilization. Speed is also measured using radar gun for all categories of vehicles mainly to check the accuracy of speed obtained from the video.

5. DATA RETRIEVAL

Data extraction for classified vehicle count, speed, traffic composition and lane utilization is carried out manually from images developed from video. Xilisoft video converter is used as supporting software. This software helps to convert the video into .avi format and to set the frame rate of video (25 frames for a second) and screen size (640 *480 vga). Later, images (frames) are extracted from video at a rate of 25 per seconds with the help of Irfan View software. Frames are opened in Irfan View software and run in forward and backward direction to mark the entry and exit of each vehicle in each section followed by noting down the frame number while vehicle touch the entry and exit line respectively. Along with, vehicle category, lane type and lane changes (over the selected 100 m) are also noted down in MS Excel sheet. Later, space mean speed for each vehicle is calculated using equation 1.

$$v = \left(\frac{l * n}{f_x - f_e}\right) * 3.6 \quad (1)$$

where,

v : speed in kmph

l : length of study stretch,

n : number of frames per second,

f_e : frame number while entering the study stretch, and

f_x : frame number while leaving the study stretch

6. DATA ANALYSIS

6.1 Traffic Composition

The vehicle categories present on the expressway are small car (<1200cc- as per Indo HCM guideline), big car, light commercial vehicle (LCV), bus and trucks. For analysis, trucks are categorized into two types- single and tandem- axle trucks together forms one category and multi axle trucks constitutes the other. Figure 2 shows average representative vehicle composition on the expressway whereas Figure 3.a and 3.b shows an example of vehicle composition over a section near ROB 9 (chainage: 30.181km) during different time of the day.

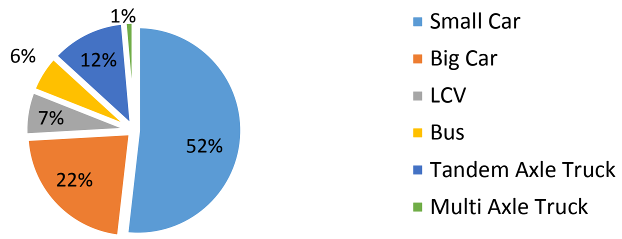

Figure 2 Percentage Vehicle composition on expressway

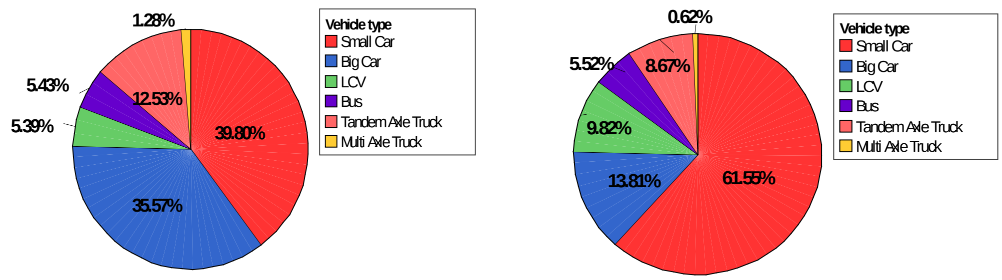

Figure 3 (a) Vehicle composition at ROB 9: morning hours; (b) evening hours

In the traffic composition, small car is the highest contributor (52 %) followed by big car, Tandem-axle trucks, LCV, bus, and multi-axle trucks. Contribution of small car and big car together is around 74% for all the three sections. Multi axle trucks are always $\leq$ 2% of total traffic. The results also show that truck and big car proportion is high during morning hours and less during evening hours. At the same time LCV and small car proportion is increasing from morning to evening. Hence, it is expected that in the absence of smaller vehicles, the traffic flow characteristics such as traffic composition, speed, lateral and longitudinal gaps between the vehicles are significantly different as compared to other multilane highways.

6.2 Traffic Flow

Traffic flow is the number of vehicles passing a specified point during a stated period of time. From 5 minute aggregate classified counts, hourly flow rate is derived. Figure 4 shows that, flow is fluctuating and maximum flow is observed at morning 9:08:30 am (1104 vehicles/hour and evening at 5:06 pm (1056 vehicles/ hour). In figure 5, the average traffic flow in different sections at different time are compared.

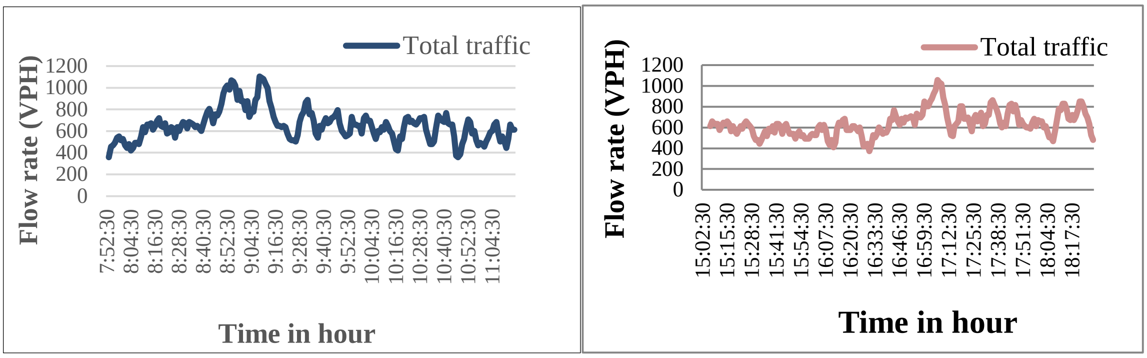

Figure 4 (a) Hourly traffic flow at Chainage: 54.805km - Morning hours; (b) Evening hours

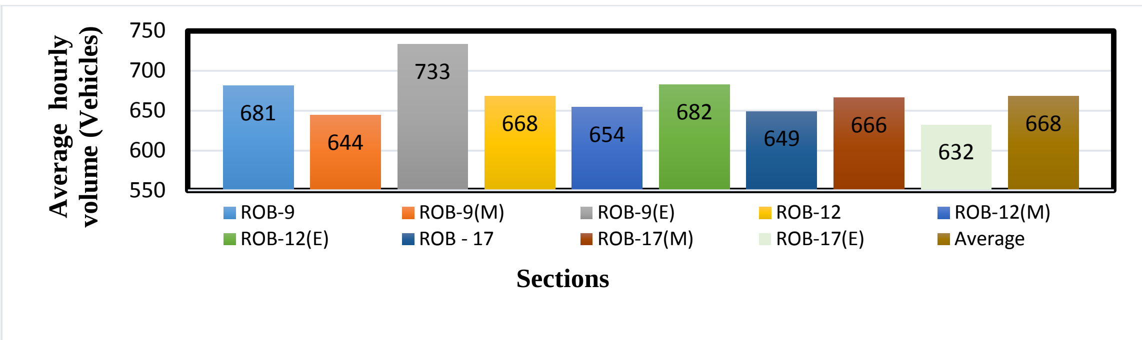

Figure 5 Average traffic flow in different sections at different time

The average hourly volume is higher for evening hours than morning hours for the sections located between Nadiad- Ahmedabad and lower for evening hours for section located between Vadodara and Nadiad. It may be due to the influence of interchange at Nadiad or due to the difference in traffic at weekday (Friday) and weekend (Saturday).

6.3 Vehicle Distribution over Carriageway and Lane Changes

Lane utilization and distribution represents how the rate of traffic flow is distributed among the available number of lanes in a given section. This utilization or split is affected by several factors including traffic flow rates as well as the presence and composition of heavy vehicles such as trucks, buses, Light Commercial Vehicles, etc. within the traffic. The importance of studying lane utilization comes from the fact that it is one of the input parameters for any traffic simulation models which are increasingly being used in order to assess and suggest solutions for traffic problems. Figure 6 are showing the vehicle distribution over carriageway and lane changes at different sections on the expressway.

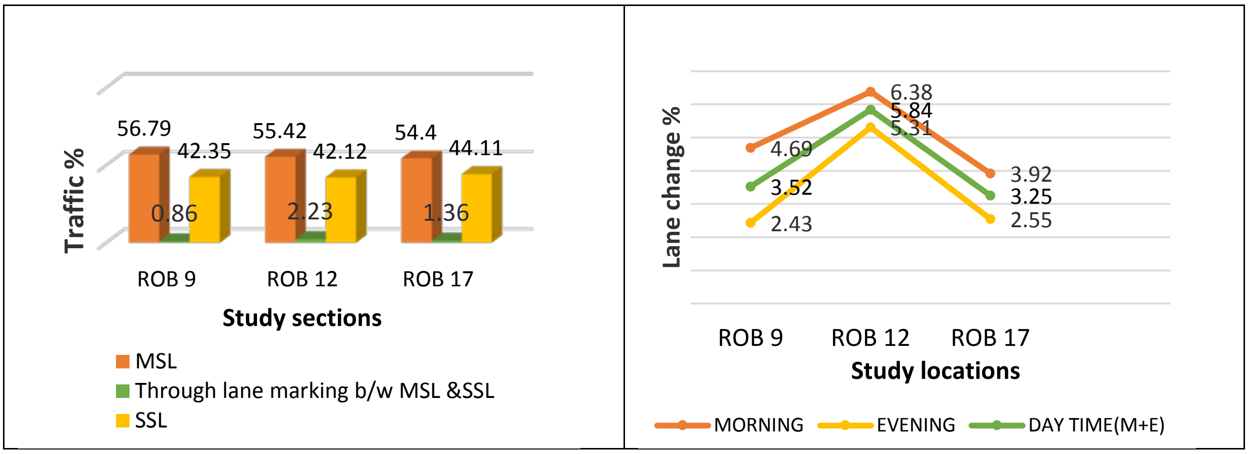

Figure 6 (a) Vehicle distribution over carriageway; (b) Lane changes on different sections

While analyzing the distribution of vehicles in lanes (Figure 6.a), it is found that more than 97 % of vehicles are following lanes and remaining vehicles are not following one particular lane. They are found to move across the lane marking between two lanes on roadway sections. From the graph, it is clear that lane change is more on location near ROB 12- chainage: 30.181km (5-6.5%) than the remaining 2 sections (2 to 5%). In all sections, it was found that the lane changing behaviour is more during morning hours and less during evening hours.

Table 2 Lane preferences of vehicles on different study sections

Max % on	Median side lane(MSL)		Shoulder side lane (SSL)			
Vehicle type	Small Car (%)	Big Car (%)	LCV (%)	Bus (%)	Tandem axle Truck (%)	Multi axle Truck (%)
ROB 9	71	70	86	71	93	94
ROB 12	71	70	79	65	90	92
ROB 17	69	66	80	77	95	93

In Indian expressways, mostly cars are moving with a speed limit of 100-120kmph. But in few cases speed are reaching 160kmph. MSL is designed for fast moving vehicles like cars and SSL is for comparatively lesser speed vehicles like trucks. But in mahatma Gandhi expressway, it is clear from Table 2 that nearly 30 % of cars are moving with the trucks through SSL. 65 % of buses, 79% of LCV and 90 % of trucks preferred shoulder side lane (SSL) for their traffic movement. Also, it was observed that within the study area 2.4-6.4 % of vehicles changed their line and maximum of 2.3 % of vehicles are moved exactly above the line marking without following a particular line. Lane changes are present for both the lanes. These factors are likely to affect the capacity, safety and level of service like speed and performance. So, further modelling is done for one direction flow (2 lanes) without considering the line marking.

6.4 Free-Flow Speed

The mean speed of passenger cars that can be accommodated under low to moderate flow rates on a uniform expressway segment under prevailing roadway and traffic conditions [HCM, 2010]. Free Flow Speeds may be measured for given vehicle, when the traffic flow is such that the time gap between two consecutive vehicles is more than 8 s. Speed analysis shows that, cars have highest speed and trucks are moving at lowest speed. The relative frequency distribution curve of speed for different vehicles at three locations is shown in Figure 8.a. The curves exhibit a similar fluctuating trend at all the three locations. Cumulative plot (Figure 7.b) of speed at different locations are showing similar trend. Curves for small car and big car are observed to coincide. The lowest speed is for trucks and it increases for LCV, bus and car, respectively.

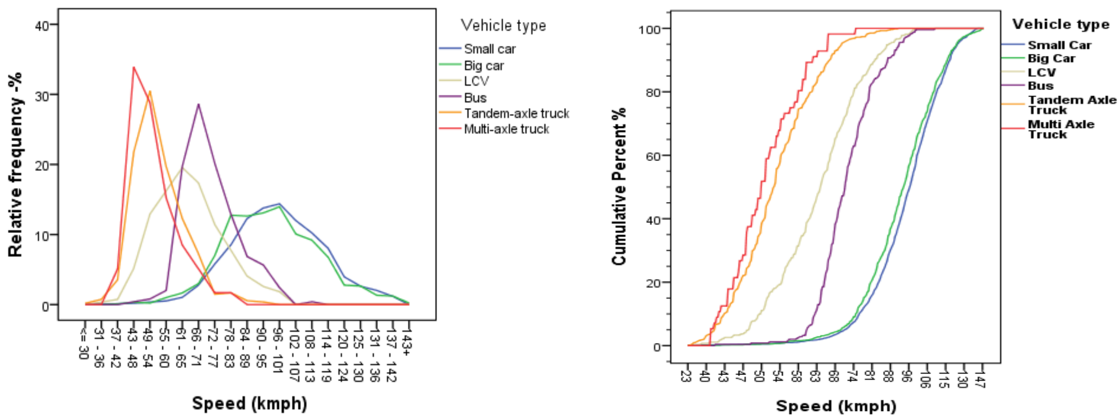

Figure 7 (a) Relative Frequency distribution of speed; (b) Cumulative plot of speed

Table 3 shows mean, minimum and maximum values of time mean and space mean speeds including speed ratio for different vehicles particularly at ROB 17 (chainage: 54.805 km). The various parameters given in the Table are employed for testing the normality of the speed data for different vehicle categories.

Table 3 Comparison of space mean speed & time mean speed-ROB 17

	Space mean speed (kmph)				Time mean speed (kmph)			
Vehicle category	Speed ratio	Minimum speed	Maximum speed	Mean speed	Speed ratio	Minimum speed	Maximum speed	Mean speed
Small car	1.1	23	139	94	1.1	53	134	97
Big car	1.2	39	148	92	1.2	62	135	98
LCV	1.1	35	100	62	0.7	37	86	65
Bus	1.8	42	110	72	1.3	48	104	73
Tandem axle Truck	1.4	27	92	52	1.3	33	88	55
Multi axle Truck	1.6	41	75	50	1	33	74	51

All the study sections are showing more or less similar values. The results show that, speed ratio is varying between 0.6-1.8 while considering all the study stretches. For all the vehicles, Chi-square tests are satisfactory as value is lesser than Table value of $\chi 2$ t =14.0671 for α

=0.05 and df =7. Hence, it is inferred that the collected spot speed data are normally distributed. This data may also further can be useful for developing simulation model.

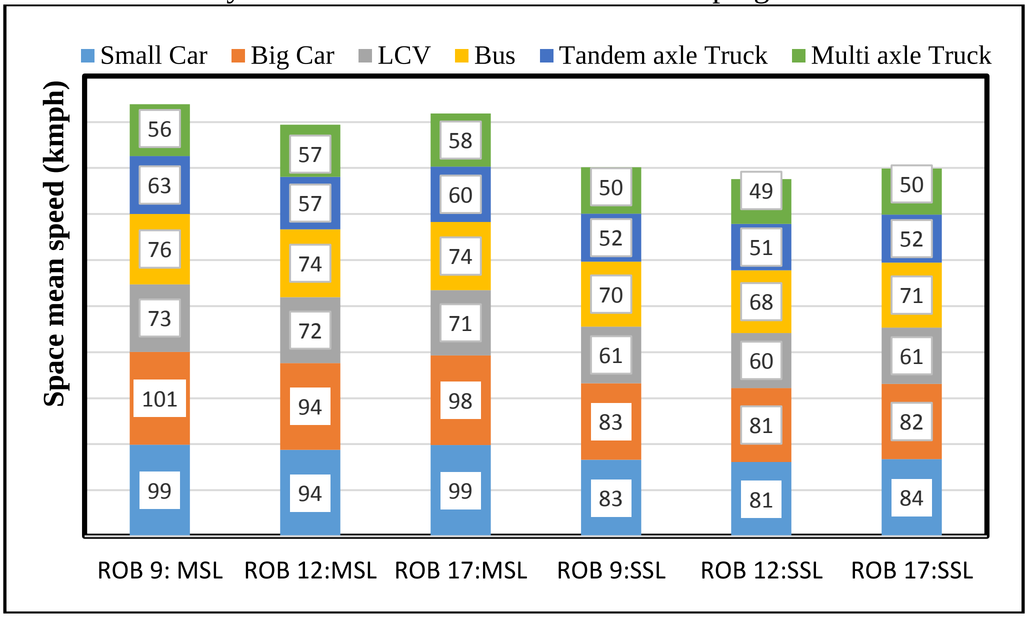

Figure 8 Lane wise space mean speed of different vehicles on different sections

Lane wise analysis of vehicular speed (Figure 8) shows that, speed is higher in median side lane for all categories of vehicles. Average speeds of same vehicle category on different locations are almost same for a particular lane. It is noticed that, speed of all categories of vehicle on ROB 12 (chainage: 30.181km) is slightly less than other two locations, which may be due to the higher lane change presence over there.

6.5 Model Development

The proposed study aims to arrive at empirical (using field observed data) relationships among different traffic characteristics on different sections of expressways in Indian traffic conditions and to develop a simulation model for the same. Based on the results of these analyses (empirical and simulation), capacity estimates will be developed for expressways. For this purpose, models are developed using traffic characteristics in terms of PCE per hour using Excel curve fitting technique. The observed traffic flow rate and weighted average stream speed are used to find the traffic density for every five-minute interval using fundamental traffic flow equation (Q=k*v). Taken the present low traffic situation on the expressway in mind, here the data of all the three sections are combined without considering direction as it will help to get the maximum possible situations on the expressway. This 23 hour traffic data is used for the modeling purpose and which produces 276 data points. Using the extracted data on speed, flow and density, speed-density, flow-density and flow-speed relationships were plotted as shown in Figures 9, 10 and 11, respectively.

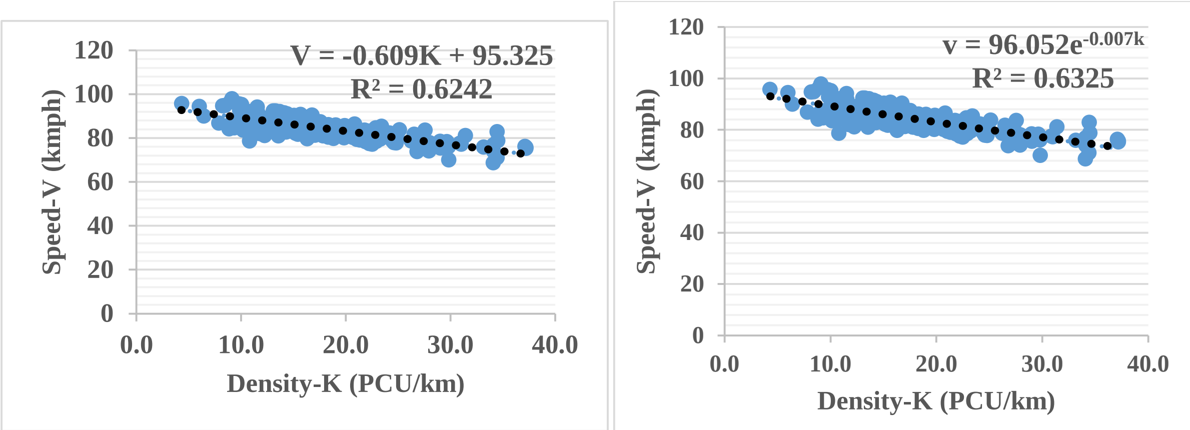

Figure 9 Speed-Density Curve

Various functions (Greenshild, Greenberg and Underwood) were fitted to this data and the reasonably fitted relationship was taken for further analysis. The linear relationship was found to be fitting reasonably well for speed-density data with co-efficient of determination (R^2) as 62.42 %. Equation 2 is a linear Greenshild model which is assumed to reprenst field observed data in two boundary conditions (uncongeesed and congested traffic state) well.

$$V = -0.609K + 95.325 \; (R^2 = 0.6242) \quad (2)$$

$$V = 96.052 * e^{-0.007\,k} \; (R^2 = 0.6325) \quad (3)$$

This relationship (equation 3) is similar to the Underwood's exponential speed-density relationship of the form, $V = V_f * e^{-K/Km}$. Where, *V is* the speed at density K, V_f the free speed and K_m represents the density at which flow experiences its maximum with respect to density. [Ardekani, S.et al., 2011]. Therefore, the results show that, free flow speed is about 95 km/h for the section on the expressway under present study. All these functions forms are also explained very well by May (1990).

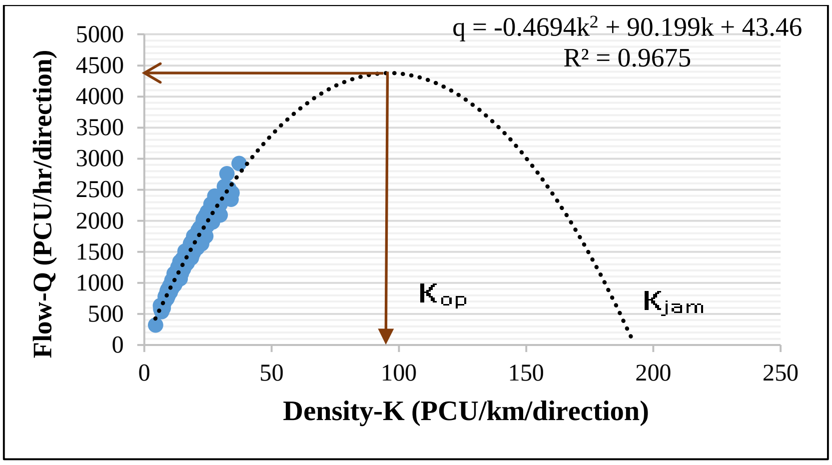

Figure 10 Flow-Density Curve

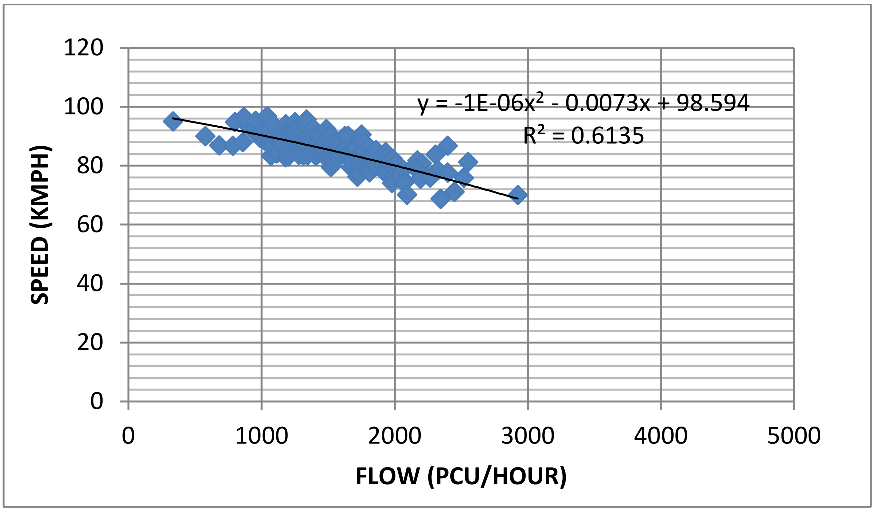

Figure 11 Speed- Flow Curve

In both speed-flow curve & flow-density curve, observed data points are at free flow regime. The field observed data points are represented in blue color, whereas yellow color depicts the points of speed obtained using flow-density model data points which are found by putting different values of density (K) in the flow equation obtained from the graph. Speed-flow curves are showing parabolic relationship (equation 3) and Speed at capacity was found as 47 kmph. Similarly flow – density also shows parabolic relationship (equation 4).

$$V = -3E\text{-}06Q^2 - 0.0018Q + 94.957 \ (R^2 = 0.5922) \quad (3)$$

$$Q = -0.4694K^2 + 90.199K + 43.46 \ (R^2 = 0.9675) \quad (4)$$

Accordingly, optimum density is found by equation K_{opt} = 96 PCE/km. Maximum flow discharge (Capacity) is, Q_{max} (C) = 4377 PCE /hour/direction and jam density is approximately about K_j = 193 PCE/km/direction for 8.4m carriageway excluding the space of emergency lane in one direction of traffic flow.

7. MODEL VALIDATION USING VISSIM

The approaches to traffic flow modeling may be microscopic or macroscopic. To accomplish the objectives of the proposed research work, a microscopic study approach of vehicular interactions under traffic conditions prevailing on expressways can be better suited. To arrive at speed-flow characteristics and establish capacity estimates through microscopic simulation, one has to model the flow of individual vehicles in a detailed manner for which established simulation packages may be used. Traffic flow data can be collected at selected locations of expressways in different parts of India and would be analyzed to study the speed, placement, arrival, acceleration, deceleration and overtaking characteristics of different types of vehicles. The collected data pertaining to these traffic flow characteristics from field will be incorporated in the simulation model. The model will then be calibrated and validated for the selected stretches of expressways in India using the observed traffic data collected over a wider range. The validated model further will be applied to derive capacity estimates for varying roadway and traffic conditions.

In this present study, traffic is never reaching congested condition. Based on the available data equations are made using curve fitting techniques with reference to previous traffic flow model studies. The model showing better relation is considered for estimation of jam density, free flow and capacity. As traffic is not reaching the congested condition, model has to be validated using other techniques. For this purpose simulation software VISSIM were used. In this software, observed field conditions are given as input parameters for generating data for both uncongested and congested conditions. Speed-flow curve of VISSIM generated data plotted along with the observed field data curve shows both are coinciding for the observed traffic in uncongested traffic conditions. So, it was assumed that few points which are found to be lying just below capapcity condition also may represent the actual field. These points are obtained based on the situation when the vehicles are in queue and hence represent the traffic state in queue discharge which is also an indicative of system capacity. The capacity obtained using the curve fitting technique is near to the one using VISSIM simulation model. The VISSIM input parametes, validation of its generated data and modeling are explained in following sections.

7.1 Base Model Development in VISSIM and Capacity Estimation

A model which accurately represents the design and operational attributes of the study stretch in the simulation software is known as the ‘base model’. The base model development involves the following steps: (a) Development of Base Link/Network. (b) Defining Model Parameters. (c) Calibrating the Network. (d) Validating the Model. Development of a link/network that accurately depicts the physical attributes of a test site is an important stage in the modeling process. The basic key network building components in VISSIM are links and connectors. In the present simulation model, a unidirectional two lane test section link spanning 1000 m was created representing the study stretch located on the mahatma Gandhi expressway. Additionally, extra links of length 200 m each were provided at the beginning and end of the main stretch for buffering process. The test section and the buffer links were joined using the connectors. The buffer links provided the spatial warm up sections for vehicles entering and exiting the test section thereby ensuring accurate results. Figure 12 shows a snapshot of simulation runs in VISSIM with reference to location and simulation is done for one direction (2 lanes).

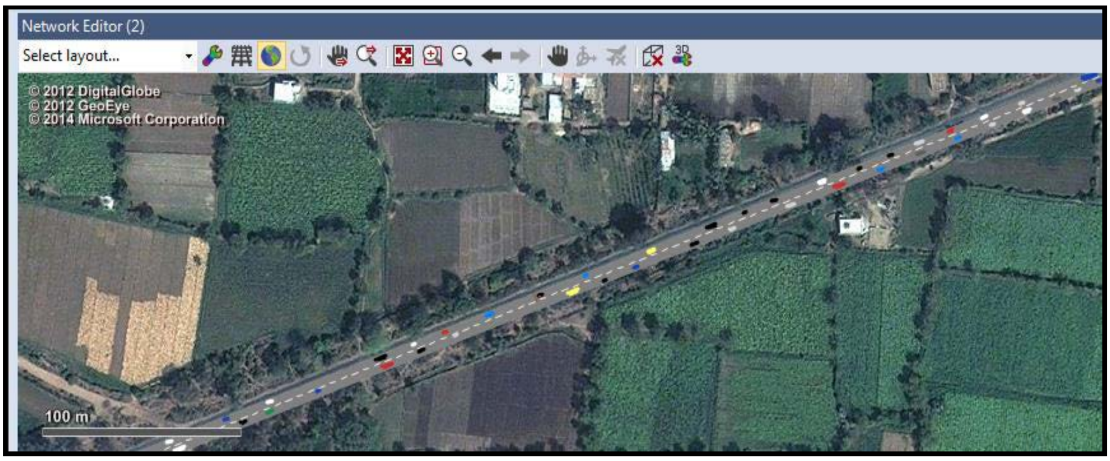

Figure 12 Snapshot of simulation runs in VISSIM with reference to location

Defining model parameters includes a) vehicle model, b) desired speed distribution, c) Vehicle composition and Vehicle Flow, and d) Driving behavior characteristics. Vehicle model deals with defining the dimensions of each vehicle type that are plying on the test stretch. It is also used to define the acceleration values of vehicles. The desired speed distribution for each vehicle category was given as input for the simulation model in VISSIM. The maximum& minimum values of the speeds and distribution between these values were defined in the model. Vehicle composition and vehicle flow based on field observations is given as an input for the given time interval. The driving behavior is also given and its characteristics mainly include these two features viz. car following behaviour and lateral distance. This various input parameters are given in VISSIM are based on field observed data and the various studies conducted before on Indian expressways. [P-TV VISSIM Manual (2012); Mathew and Radhakrishnan (2010); Arkatkar et al. (2014), Bains et al. (2013)]. Table 4 and 5 are shows values of various parameters inputed in VISSIM for simulation.

Table 4 Input parameters given in heterogeneous traffic flow simulation

Vehicle type	**Composition (%)**	**Observed speeds(kmph)**				**Vehicle dimensions(m)**		**Lateral-clearance share (m)**	
		Max. speed	**Min. speed**	**Mean speed**	**Std. deviation**	**Length**	**Width**	**Min.**	**Max.**
Small car	0.52	125	80	96	7.19	3.72	1.44	0.5	1.0
Big car	0.22	127	80	98	7.79	4.58	1.77	0.5	1.0
LCV	0.07	90	52	65	8.01	6.1	2.1	0.4	1.0
Bus	0.06	95	65	72	5.98	10.1	2.43	0.4	1.0
Tandem-axle truck	0.12	75	50	60	4.57	7.5	2.35	0.4	1.0
Multi-axle truck	0.01	70	45	55	7.14	10.1	2.43	0.4	1.0

Table 5. Acceleration values given in VISSIM model for different vehicle categories.

Vehicle type	**0-30 km/hr (m/s^2)**	**30-60 km/hr (m/s^2)**	**Above 60 km/hr (m/s^2)**
Small car	2.20	1.7	1.00
Big car	2.20	1.7	1.00
LCV	1.3	0.90	0.60
Bus	1.00	0.70	0.50
Tandem-axle truck	1.10	0.58	0.34
Multi-axle truck	0.80	0.60	0.30

In the present simulation model, the outputs were the traffic flows and average speeds of the vehicles for 5 different random seed values. All the simulations were run for a total time of 3900 s including a temporal warm-up period of 300 s to ensure accurate simulation results. From previous studies and calibration, the standstill distance is taken as 1.00m, headway time is 0.8s and traffic volumes inputted are 200,500 to 5000 at an interval of 500 vehicles. Vehicle speeds, flow and composition are validated by comparing values obtained using simulation model with field observation. Figure 13 shows a comparison of field observed speed and simulated speed for all selected vehicle categories and Table 6 shows composition of vehicles in simulation resembles field vehicle composition which is used to check the need of caliberation.

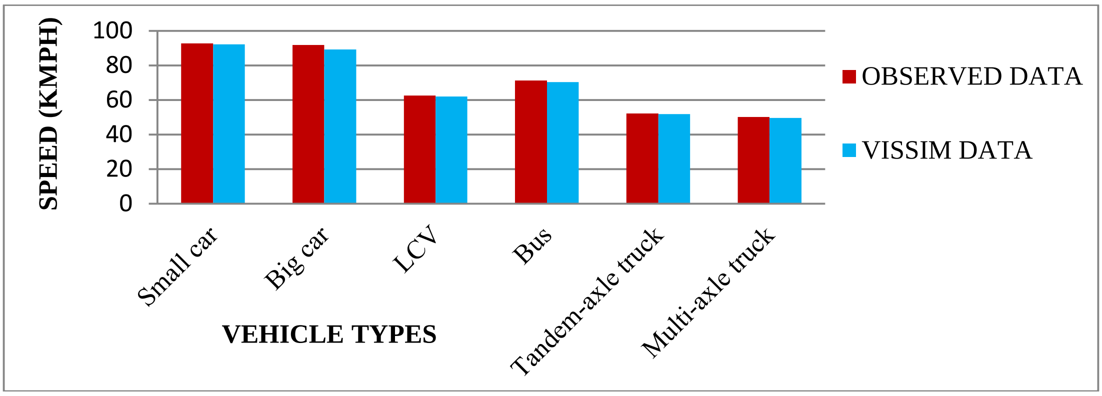

Figure 13 Comparison of field observed mean speeds and VISSIM mean speed

Table 6 Comparison of field observed and VISSIM generated flow

	Field observation		VISSIM output	
Vehicle type	**No. of vehicle**	**composition**	**No. of vehicle**	**composition**
Small car	1196	0.52	1204	0.52
Big car	506	0.22	508	0.22
LCV	161	0.07	167	0.07
Bus	138	0.06	144	0.06
Tandem-axle truck	276	0.12	288	0.12
Multi-axle truck	23	0.01	24	0.01
total	2300	1.00	2335	1.00

As shown in figure 13, the generated VISSIM speeds and the field observed speeds are almost same. Also, while comparing the number of vehicles generated while giving the field capacity as input, the generated traffic in VISSIM are near to the field value and also, their composition are exactly similar to the field composition. So, from the calibrated model, the traffic flow was simulated starting from a very low volume level to the capacity-level and the speeds of vehicles corresponding to each of the volume levels were recorded as output. In this regard, it may noted that when simulation runs are made with successive increments in traffic volume (input), there will be commensurate increase in the exit volume at the end of the simulation stretch. When the simulated volume reaches the capacity level, the increments in the input traffic volumes will not result in the same amounts of increase in the exit volume, and will result in a decrease in the rate of traffic flow. A few successive decreases in the exit volume (in spite of increase in the input) indicate that the roadway has reached its capacity. The speed-flow relationship obtained, using the outputs of the simulation process, is depicted graphically in Figure 14 in terms of vehicle per hour. It is clear from the Figures that the VISSIM generated speed-flow curve is exactly coinciding and just above the field observed speed flow curve for the observed traffic. So, it is assumed that the trend will be same for high congested condition while field experiences higher volume of traffic. The model is validated as the curves follow the field condition. The blue color points in graph are representing uncongested conditions and yellow shows congested condition. Congested and uncongested curves will be meeting at capacity.

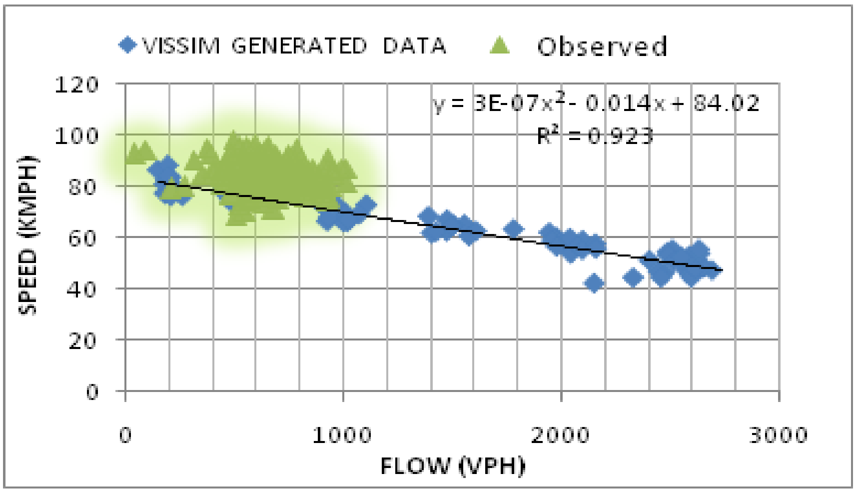

Figure 14 Speed – Flow curve in terms of vehicles per hour

7.2 Calculation of PCE and Capacity Estimation In terms of PCE

As explained in the introduction, capacity of a highway facility with heterogeneous traffic flow with vehicles of widely varying static and dynamic characteristics is best expressed in terms of PCE/hr. Different vehicle categories such as buses, light commercial vehicles, trucks, motorized two-wheelers and motorized three wheelers are expressed into equivalent PCE. This necessitates an accurate estimation of PCE, which varies dynamically with various traffic flow parameters such as stream speed, vehicle composition and volume-capacity ratio. Chandra (2004) proposed the concept of dynamic PCE considering the various traffic interactions and flow characteristics. The PCE for a vehicle are calculated using equation (5).

$$PCEi = \frac{VC/_{Vi}}{Ac/_{Ai}} \quad (5)$$

Where,

PCE_i : PCE of the subject vehicle i,
V_c : Average speed of cars in the traffic stream,
V_i : Average speed of subject vehicles i,
Ac : Projected rectangular area of a car as reference vehicle and
A_i : Projected rectangular area of the vehicle type i.

For the purpose of this study, the projected rectangular area of the car, (Ac) (reference vehicle) was considered as the average value of the rectangular area of big cars and small cars. The average speed (V_c) of the car (reference vehicle) for the given flow level, was estimated as the weighted average of the speeds of big cars and small cars, based on their composition in the traffic composition. The PCE values of different vehicle types were estimated using Eq. (5), based on the average speed and flow values, derived through the output of five random runs. Variation of PCE values with vehicle categories are shown in figure 15.

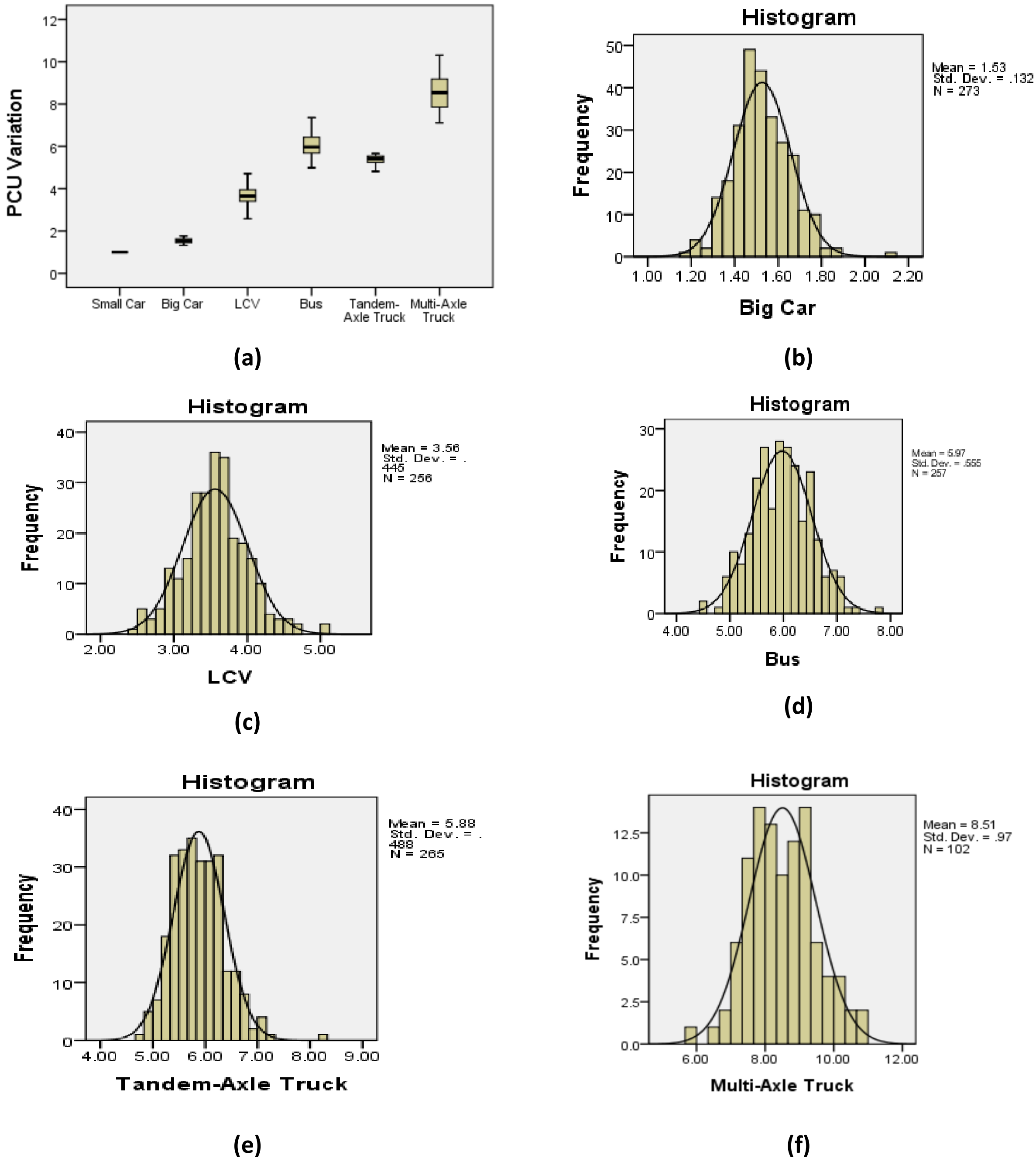

Figure 15 Variation of PCE Values for Different Vehicle Categories

Result shows that PCE values are changing according to the changes in vehicle speed and due to different speeds in different 5-minute intervals. It was noticed before that on the expressway, some vehicles are not following any specific lines and some are changing their lane of travel. This will surely affect the speed of vehicles and because of the present condition over there, speed of each vehicles are used without considering the lane of travel for the estimation of PCE value. This may be the reason behind Variation of PCE and the spread is higher for heavy vehicles as compared to cars. For all the vehicle categories, the PCE variation is found to be normally distributed. The speed-flow relationship developed using estimated PCE values for a four-lane expressway is shown (in terms of PCE per hour) in Figure 16.

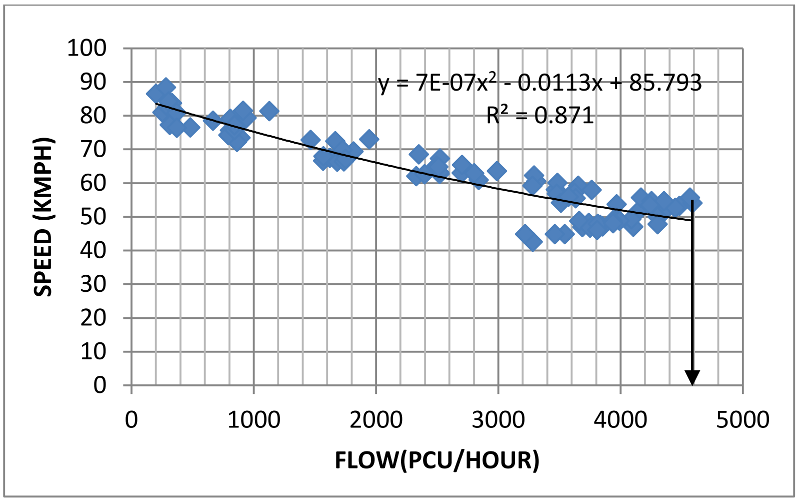

Figure 16. Speed–Flow curve in terms of PCE per hour

The value of capacity obtained from the simulation is 2700 vehicle per hour/direction for 8.4m carriageway excluding the space of emergency lane in one direction of traffic flow. It has also been used to quantify the relative impact of each category of vehicle on traffic flow by estimating their PCE values at different volume levels under heterogeneous traffic conditions prevailing on Indian expressways. Capacity obtained in simulation is 4600 PCE per hour/direction for 8.4m carriageway excluding the space of emergency lane in one direction of traffic flow. Whereas the field observation shows capacity is 4377 PCE per hour. The difference is less than 300 PCE/hour, which may be acceptable. As per HCM (2010), for four-lane expressway capacity is about 4800 PCE/h/direction (2400 PCE/h/lane) and the obtained result is reasonably close to this value using simulation. The difference may be attributed to the higher composition of heavy vehicles and also to the prevailing quasi-heterogeneous traffic conditions in developing countries like India. The Q-V curve is not exactly like US HCM. It may be because Indian traffic characteristics are vastly different from developed countries. Traffic movement on Indian Expressways may be said to be quasi-lane disciplined, with some vehicles following a lane-based driving and many others not. Moreover, the level of lane-discipline may change significantly based on the traffic flow level and its composition. Hence, expressways remain as a partially heterogeneous traffic characterized by a low level of lane-discipline. India is in the stage of Development of an Indian highway capacity manual (Indo-HCM) which is commissioned by planning commission of India and the present study is as part of it.

8. CONCLUSIONS

Expressways are the highest class of roads in the Indian Road Network. To be a truly developed country and to maintain that growth, it is very essential that the length of expressways, which are the best form of roads in a country, augment continuously. Analysis of traffic stream characteristics on expressways will provide basis for planning, designing, as well as operation management of expressways in future. In view of this, traffic data is collected by video graphic technique from three selected road stretches of Mahatma Gandhi expressway. For data extraction, frames are developed using IrfanView software with the help of Xilisoft video converter. The required traffic parameters are extracted from these frames manually for better accuracy. Traffic data analysis results showed that traffic flow is fluctuating and maximum flow rate observed is 1104 vehicles/hour. In traffic composition, small car is having highest share (52%) followed by big car, Tandem-axle trucks, LCV, bus, and multi-axle trucks. Always, contribution of total car is near to 75% and Multi axle truck is less than 2% of total traffic. Majority of cars are found to prefer median side lane and most of the trucks and LCVs are found to choose shoulder side lane. Median side lane is having high speed traffic. Lane changes on the 100 m stretches are high during the morning hours (5-7%) than in the evening hours (2.5-5%). Mean speed of car is more than 90 kmph, for LCV and bus is in the range of 60 to 75 kmph were as for truck is between 50 to 60 kmph. Except for bus, tandem axle trucks and multi axle vehicles speed ratio is seen in the range of 1.0 to 1.20 indicating speeds of cars and LCVs are normally distributed. All the traffic variables are measured without considering the traffic lanes. Developed traffic flow model showed linear and exponential speed-density relationships alongwith parabolic speed-flow and flow-density equations. The models indicated a free speed of about 96 km/h, optimum density of 96 PCE/km, jam density is K_j = 193 PCE/km and capacity of 4377 PCE /hour/direction having 8.4m carriageway excluding the space of emergency lane in one direction of traffic flow. In this study, the capacity obtained in simulation is found to be about 4600 PCE / hour/direction. Based on the results of these analyses (empirical and simulation), capacity estimates are proposed for Mahatma Gandhi four-lane divided Expressway. The results of the study may be very useful for the practitioners and also for the ongoing efforts to prepare an Indian Highway Capacity Manual (Indo HCM).

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