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CAPACITY ESTIMATION UNDER HETEROGENOUS TRAFFIC CONDITIONS USING MICROSCOPIC SIMULATION

¹Shashank Deshmukh, ²Mr. Yusuf Sultan

¹Post Graduate Research Scholar, ²Assistant Professor

¹Department of Civil Engineering and Applied Mechanics

¹SHRI G.S. INSTITUTE OF TECHNOLOGY AND SCIENCE, Indore (M.P.), India

Abstract -: Road network in India plays important role in the economic development of the country, specially interconnection between urban corridors. In India percentage of such interurban highways is very less and carries more traffic than any other road transportation system. For the operating interurban, multilane divided highway assessment of Level of Service is very important. In the sequence of assessment of the level of service, capacity estimation is very important. To estimate capacity efficiently microscopic simulation model developed for interurban multilane divided state highway SH-27 which connects two important cities of M.P. To obtain space mean speed, classified traffic volume count, the projected area of vehicles, and free-flow speed traffic data was collected using videography in the field and extracted using traffic data extractor. The first capacity was estimated using the traditional method for SPCU and DPCU and also estimated capacity using Indo-HCM method and in last using microscopic simulation model microscopic simulation software VISSIM-21. To check the validity of the developed simulation model, simulated traffic parameters and field traffic parameters were compared and also given static validation to the model. Capacities estimated from various methods were compared. Differences between capacities are not significant so this validated model used for capacity estimation of SH-27, subsequently Level of Service can be assessed using capacity estimated by the microscopic simulation model.

Keywords – Capacity estimation, microscopic simulation, interurban highways, VISSIM, heterogenous traffic.

Introduction

For the economic development of countries, traffic infrastructure of that country plays an important role, among them road network is very important. A developing country like India has extremely heterogeneous traffic and causes loss to the economic development of the country in terms of Road User Cost. The interconnected highway between cities or interurban highways in the country is most important in all traffic systems in India for the movement of freights and passengers. In the existing road network in the country, Inter-Urban Highways are 1.8% - 2% in length and carry more than 40% of traffic. The major problem for the operation of the interurban highway is highly heterogenous. For design, planning, and operation of the Interurban Highways speed-flow study and capacity building are very important which further assess the Level of Service of road. Roadway capacity is estimated using the free-flow speed of roads and vehicles present in the traffic flow. The capacity of the roadway is the maximum traffic flow that can be accommodated in a highway facility in a given time under prevailing conditions. Initially, IRC:64-1996 provided the guidelines for the capacity of highways in the rural area which is expressed in PCU/hr/direction. IRC:64-1996

(Guidelines for capacity estimation in rural areas) provides standard static passenger car unit (SPCU) values for ten different types of vehicles. The government of India recently developed its highway capacity manual Indo-HCM (2017) for capacity estimation in which dynamic passenger car unit (DPCU) is used as the traffic condition, roadway condition, and composition of vehicles affect the passenger car unit values. Capacity estimation of highway can be done most accurately using microscopic simulation models which is more is than the physical modelling and mathematical modelling. In recent years this technique became very popular as it reduces the efforts and time for evaluation of various traffic parameters. Indore-Ujjain Highway (SH-27) connects to major developing cities of the state (Indore and Ujjain) and also provides interstate connectivity for Maharashtra, Madhya Pradesh, and Rajasthan is important for passenger and goods movement.

The microscopic simulation technique is widely used in academics, consultancies, and transportation agencies. which is based on theories, probability and statistics, differential equations, and numerical methods. Various types of models used for simulation such as the Monte Carlo method, Cellular Automata model, car-following models, etc, these models are classified into mesoscopic, macroscopic, and microscopic models. For this study, a microscopic simulation model is used in which individual elements of the transportation system can be analysed. Driving behaviour of individual vehicles in the road networks simulated using these traffic models. In this study, Wiedemann99 car-following model is used because it is modern and suitable for the modelling of the traffic conditions of rural areas for multilane highways and expressways. Weidemann99 car following model consists of driver behaviours parameters CC_0 to CC_9 which are for different driving situations such as free driving, approaching, following, and braking. Out of these parameters, CC_0 (standstill distance) and CC_1 (headway time) are important parameters that govern the safety distance between two vehicles.

Objective of the Study

- The main objective of the study is to “develope microscopic simulation model for capacity estimation”.
- Comparison of the capacities evaluated using the traditional and microscopic approach for SPCU and DPCU value.
- Capacity with the capacity of four-lane inter-urban highways of INDO-HCM.

Literature Review

Satish Chandra et. al (2003) introduced new methods for estimation of passenger car units under mixed traffic conditions. In this method PCU values can be calculated using speed of vehicles and projected area of vehicle, also established conceptual model for estimation of dynamic passenger car unit. Influence area of vehicle, speed of vehicle lateral clearance and headway was considered for estimation of PCU values. In this study author also established a second-degree curve between road way capacity and lane width and found that as lane width increases the capacity increases but increase in the freedom of movement causes reduction in the capacity.

Satish Chandra, A. Mehar and S. Velmurugan et. al (2014) This paper mainly focuses on the estimation of the capacity of four-lane and six-lane highways using VISSIM software. Calibration of driving behaviour parameters CC_0 and CC_1 was done in the study which became input parameters for a car-following model in VISSIM software for Indian multilane divided highways. To check the effect of traffic composition on the capacity of multilane highways they developed speed flow relations for a different combination of standard class and one of remaining class and results were combined to get the capacity of the individual vehicle or all vehicle present in traffic.

Yadav, Anamika et el. (2014) In this paper, the author estimates the capacity for the multilane interurban highway. For this study author selected a 60m stretch on four lanes multilane highway two study section of 50m on NH-2 which connects the two cities Delhi and Mathura. Data was collected on a normal weekday on this road for 8-10 hours and to cover the effect of morning and evening peak hours. Using the data from the videography survey author developed the speed flow equation and from spot speed data and other data collected author developed a microscopic simulation model for dynamic passenger car units. Capacities obtained from the microscopic simulation were 4488 PCU/hr/dir towards Mathura and from the traditional method was 4161 PCU/hr /dir towards Mathura. The capacity obtained using these two methods was compared later.

C. Munigety et. al (2014) For traffic data collection, extraction, and analysis on a microscopic level for different traffic conditions semiautomated tool is developed. This tool is used for trajectory data extraction, speed of moving vehicles and to get a classified volume of vehicles. The efficiency of the tool and the procedure for operating is given in this paper. The camera calibration technique is also discussed in this paper. Use of trajectory data for heterogeneous traffic flow modelling discussed in this paper from which lateral clearance, headway, and projected area of the vehicle can be obtained.

Man raj Singh Bains et al. (2014) In this study author did modeling of traffic for expressway he found the estimated the capacity for 6lane expressway is 7595 PCU/hr/direction. Also shown PCU value of all categories of vehicles decreases when their proportion increases in the traffic stream. This paper also gives the idea of defining the input parameters in VISSIM.

Mohammad Firoz et. al (2018) In this study author estimated the capacity of a four-lane highway (NH-44) on which two sections of 60m length were selected. This study involves steps for capacity estimation of NH-44 such as speed flow studies, dynamic passenger car unit study, free flow studies. The paper also discusses the various model adopted for traffic flow modeling. The capacity estimated for NH-44 was 4100 PCU/hr/direction.

Prateek Raj et. al (2016) After investigation of previous researches author concluded that the width of the road increases the saturation, flow rate also increases under heterogeneous traffic conditions. The traffic simulation tool VISSIM can simulate heavily populated road corridors and identify the performances. Signalized and non-signalized intersections can also be optimized and study by using VISSIM. The author also estimated the capacity for traffic forecast using a microscopic simulation tool, also established a relation between the width of the road and flow rate which is a second-degree curve. Capacity estimated using microscopic simulation on NH-6, 3733 PCU/hr/direction and against the field capacity of 3688 PCU/hr/direction also plotted the speed flow equations for capacity estimation in the year 2030.

Indo-HCM (2017) (Indian Highway Capacity Manual) This is India's first highway capacity manual which is developed by CSIR-CRRI Scientists this manual gives a methodology for highway capacity estimation for all types of roads in India for heterogeneous traffic conditions along with data collection strategy. For interurban multilane divided highway equations for capacity estimation developed between observed free-flow speed and capacity. Based on studies of scientists an equation between free-flow speed and roadway capacity was established for multilane divided interurban highway in India which estimates the base capacity. Adjusted capacity can be calculated giving adjustment for free flow speed based on the condition of the surface of road, curvature, and for gradient also an adjustment to base capacity for paved and unpaved shoulder width.

Research Methodology

Based on extensive literature study methodology was prepared for this work. First step was selection of study section for data collection on the multilane interurban highway (SH-27). Data was collected in the field using videography method. Desired space mean speed, classified traffic volume, and vehicle characteristics were extracted using Traffic Data Extractor (TDE) which was developed by IIT-Bombay.

Using extracted traffic data dynamic PCU values were calculated using concept given by Chandra and Kumar (2003) and speed distribution was given to each vehicle class in which free flow condition occurring. Capacity was estimated using traditional method for static PCU and dynamic PCU values. There after capacity was estimated using Indo-HCM guidelines and microscopic simulation. Speed-flow data obtained from validated microscopic simulation model was used for capacity estimation.

Data Collection and Extraction

A section on SH-27 was selected for data collection and trap length of 50m was marked in both the direction of traffic flow, description of selected site given in table 1.

Table 1 Description of study section

Width of Carriageway	Type of Shoulder		Median Width	Type of Pavement Surface
	Paved Shoulder width	Unpaved Shoulder width		
6.8 m /Direction	1.5m	2m	5m	Bituminous

For data collection video camera was installed at the height of 16 ft. in middle of the median. The video graphic data was collected for the period of 9 hours in morning (8:00am–11:00am) three hours in afternoon (1:00pm–4:00pm) and three hours in evening (5:00pm–8:00pm) on normal week day.

With the aid of semiautomated tool (TDE-IIT Bombay) required traffic flow characteristics such as classified traffic volume, space mean speed obtained for every five-minute interval. Vehicles were classified into seven classes namely Car, Two-Wheeler (T.W.), Three-Wheeler (Th.W.), Bus, Light Commercial Vehicles (LCV), Heavy Commercial Vehicles (HCV) and Multi Axel Vehicles (MAV). Composition of each vehicle class present in the traffic given in the figure 1. Projected area of each vehicle class calculated trajectory extraction facility of Traffic Data Extractor; projected area of each vehicle class shown in table 2.

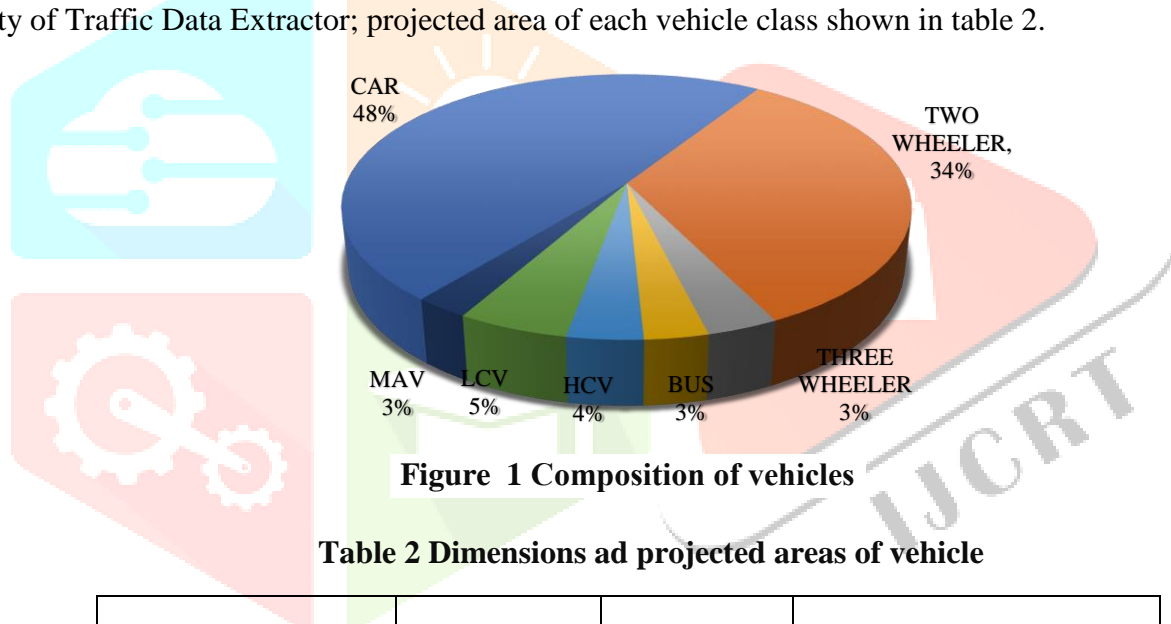


Figure 1 Composition of vehicles

Table 2 Dimensions ad projected areas of vehicle

Vehicle Category	Length (m)	Width (m)	Projected area in (m ²)
CAR	4.1	1.55	6.355
TW	1.86	0.62	1.1532
THW	3.2	1.45	4.64
BUS	11.4	2.5	28.5
HCV	13.6	2.42	32.912
LCV	6	1.9	11.4
MAV	13.75	2.5	34.375

Free Speed Study

Free speed of any vehicle, is the speed adopted by driver when there is no restriction to freedom of maneuver because of the presence of other vehicles in the stream. The study of free speed required for the estimation of DPCU values and as desired speed distribution in VISSIM. Percentage cumulative frequency curve plotted for the spot speeds of free flow occurring hours (1.00 PM- 4:00 PM) for each class of vehicle. From curve percentile speeds (85th, 50th and 15th), and Spread Ratio (SR) is obtained. SR is the check for distribution of speed, SR must be unity for the well distribution of data. Typical speed distribution of car shown in fig. 2 and results obtained from free speed study shown in table no. 3.

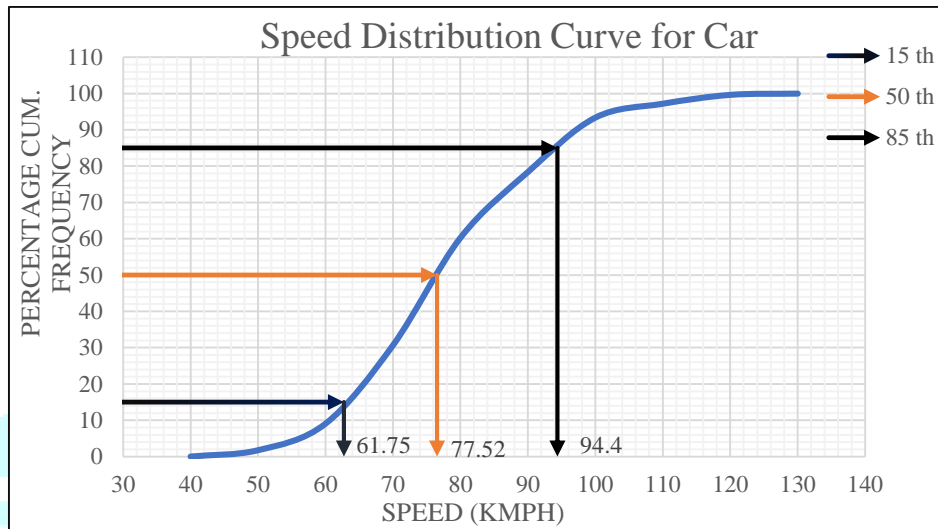


Figure 2 Speed distribution of car

Table 3 Free Speed Study

Vehicle Class	Sample Size	Average Speed	Maximum Speed	V ₁₅	V ₅₀	V ₈₅	Standard Deviation	Spread Ratio
Car	300	77.96	120.6	61.75	77.53	94.407	14.6	1.069518
2W	108	59.81	101.8	47.08	58.78	71.03	12.08	1.047009
3W	90	53.34	80.9	42.12	52.36	63.46	10.93	1.083984
Bus	140	64.23	110.2	48.59	63.33	79.09	14.01	1.069199
LCV	157	61.05	100.6	46.29	59.76	74.32	13.8	1.080921
HCV	180	54.34	90.92	42.01	52.21	63.29	12.01	1.086275
MAV	93	52.48	80.55	41.68	52.06	62.4	10.24	0.996146

Spread Ratio range is (.9961-1.086) which is around one, showing well distribution of speeds for all vehicle classes.

Dynamic PCU and Static PCU study

Passenger car unit value is very important factor in the estimation of capacity. By using these values vehicle which interacting with traffic stream can be converted into equivalent passenger car. **Indian Road Congress** provided standard static passenger car unit for capacity estimation in IRC:64-1990 (Guidelines for estimating capacity of roads in rural areas). Dynamic Passenger Car Unit concept was brought by Chandra & Kumar in 2003 in which PCU value is estimated based on influence area of vehicle, traffic composition, speed of each category of vehicle, headway and lateral clearance of vehicles.

$$PCU_i = \frac{\text{Speed Ratio of car to the vehicle } i}{\text{Area Ratio of car to the vehicle } i}$$

$$PCU_i = \frac{V_c/V_i}{A_c/A_i}$$

Where, PCU_i is dynamic passenger Car Unit, A_c is projected rectangular area of car, A_i is projected rectangular area of Vehicle I, V_c is clearing speed of car, V_i is clearing speed of vehicle i.

Dynamic PCU values and Static PCU values given in the table 4.1 and table 4.2

Table 4.1 DPCU Values

Vehicle Type	Dynamic PCUs
CAR	1
TW	0.3
THW	1.2
BUS	5.45
HCV	7.42
LCV	2.3
MAV	8.1

Table 4.2 SPCU Values given by IRC

Fast Vehicles Type	Static PCUs
Motor cycle or scooter	0.5
Passenger car, pickup, van, auto	1
Agricultural Tractor, L c v	1.5
Truck or Bus	3
Truck trailer, Agricultural, Tractor Trailer	4.5

Estimation of Capacity Using Traditional method

Various speed flow models are used for estimation of capacity by making plot between speed and flow such as linear, exponential, logarithmic, power, polynomial, akcelik and bureau of public road (BPR). For Capacity estimation data of three hours (5:00 PM to 8:00 PM) was considered. To plot speed flow curves, every 5minute vehicle counts of each vehicle class, was converted in PCU values (SPCU and DPCU). These PCU values multiplied by 12 to get hourly flow in PCU/hr. Space mean speed of every 5minute interval was calculated by harmonic mean of spot speed data of all vehicles. Speed flow curves for SPCU and DPCU value given in the figure 3.1 and figure 3.2.

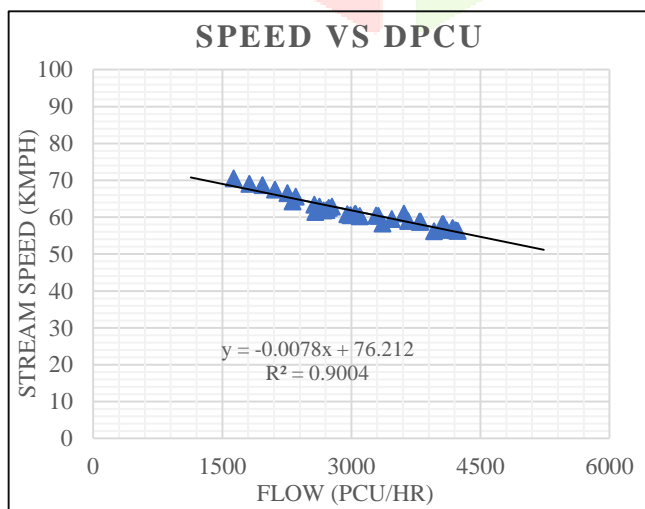


Figure 3.1 Speed flow graph for capacity estimation using SPCU

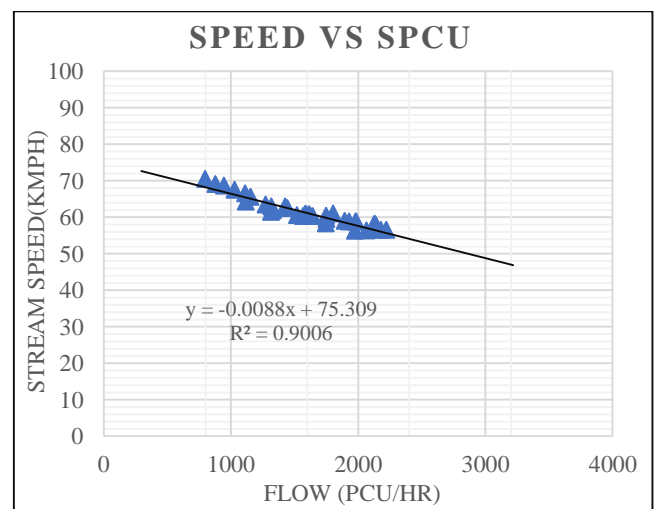


Figure 3.2 Speed flow graph for capacity estimation using SPCU

Using obtained linear equation at half of the velocity intercept flow rate is calculated for SPCU and DPCU which are the two capacities using static PCU values and dynamic PCU values. Capacity obtained using SPCU values is 4279 PCU/hr/direction and DPCU values is 4886 PCU/hr/direction.

Capacity Estimation Using Indo-HCM (2017)

Indian Highway Capacity Manual provided equations for capacity estimation of multilane divided inter-urban highways. The equation for the capacity of a four-lane divided interurban highway given below.

$$C = 30 * V_{os} + 1540 \dots\dots (1)$$

Where, V_{os} is observed free flow speed (85th percentile speed of standard car).

According to field conditions adjustment is given to the observed speed and capacity in above equation.

$$V_{osadj} = V_{osbase} - 4.7 \times IRI - 0.6 \times GR - 0.03 \times CU \dots\dots (2)$$

$$C_{adj} = C + 188 \times PSW + 170 \times UPSW + 74 \dots\dots (3)$$

Where, V_{osbase} is observed free flow speed (85th percentile speed of standard car) in base condition, V_{osadj} is adjusted observed free flow speed, C_{adj} is adjusted capacity, PSW is paved shoulder width and $UPSW$ is unpaved shoulder width.

Effect of roughness of the road surface, gradient and curvature is not considered therefore adjustment only given based on shoulder conditions. For $V_{os} = 94.4$, $PSW=1.5m$ and $UPSW= 2m$, capacity obtained using above equations is 4872 PCU/hr/dir.

Capacity Estimation Using Microscopic Simulation

In the process of capacity using this technique first step was developing a simulation model based on some input parameters than the developed simulation model calibrated for the replication of field conditions and validated by comparing two output parameters i.e. speed and flow with the parameters obtained in the field. Development of simulation model involves following steps-

Development of Road Links on Study Stretch

For the development of a microscopic simulation model link of 700 m on either side of the road is created each link consists of two lanes of 3.4 m and a paved shoulder of 1.5 m. For avoiding congestion at the entry of the vehicles buffer links of 150 m were provided on both sides of the study links. Data collection points were given in the middle of links in both directions.

Desired Speed Distribution

Speed distribution results obtained in free speed study for each category of vehicle given input as desired speed distribution to VISSIM for each vehicle class.

Desired acceleration and deacceleration

This Input was given directly to the model from a previous study by Chandra and Shukla (2011) he suggested a single value of maximum acceleration or deceleration and desired acceleration and deceleration. Desired acceleration and deceleration values are given in the table below.

Driving Behaviour Parameters

Weidemann99 car following model consists of driver behaviour parameters CC_0 to CC_9 which are for different driving situations such as free driving, approaching, following, and braking. Out of these parameters, CC_0 (standstill distance) and CC_1 (headway time) are important parameters, these parameters govern the safety distance between two vehicles.

Calibration and Validation of the Model

To reflect field conditions in model calibration of some model parameters is required, for the calibration of model one hour (5:00 PM to 6:00 PM) of traffic data was used. To check the validity of developed simulation model, using above procedure. Entire 3 hrs (5:00 PM to 8:00 PM) of traffic data was used for validation.

Calibration of model

Already calibrated values of CC_1 and CC_0 were used from the study of S. Chandra et. al (2014). Other parameters such as look back and look ahead distance were calibrated using trial and error, overtaking behaviour overtaking from both the direction selected. After calibrating with those parameters, simulation was run with different seed number for 1st five-minute interval as 40,41,42, 45,43,44, 39,38,37,36 etc. Less variation between speed and volume between model and field data was observed at seed no 38, so the selected random seed no for the model was 38.

Validation of model

For validation of model two parameters speed and flow obtained in the field and microscopic simulation spatially compared, also speed simulated by individual vehicle class was compared. For the static validity of the model, a paired t-test was given for 5% level of significance i.e. 95% of confidence level paired t-test was performed in excel results from the test are shown in Table 5.

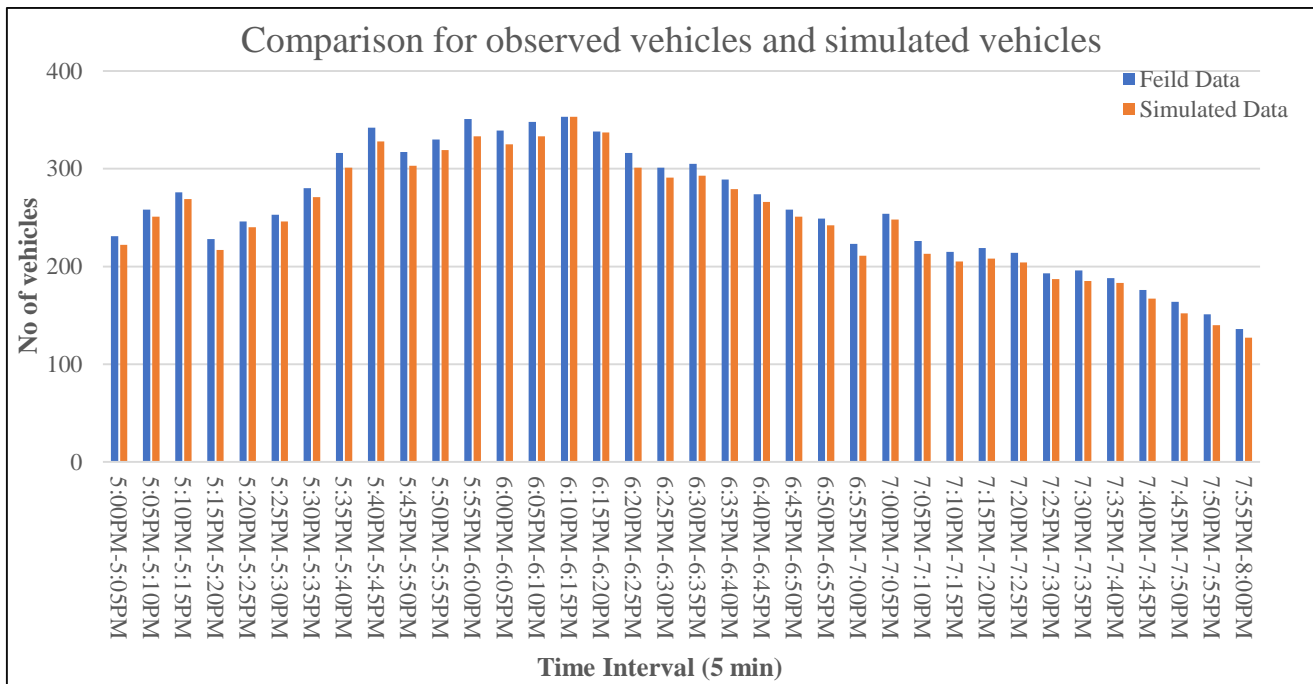


Figure 4.1 Comparison of number of vehicles in 5minute interval

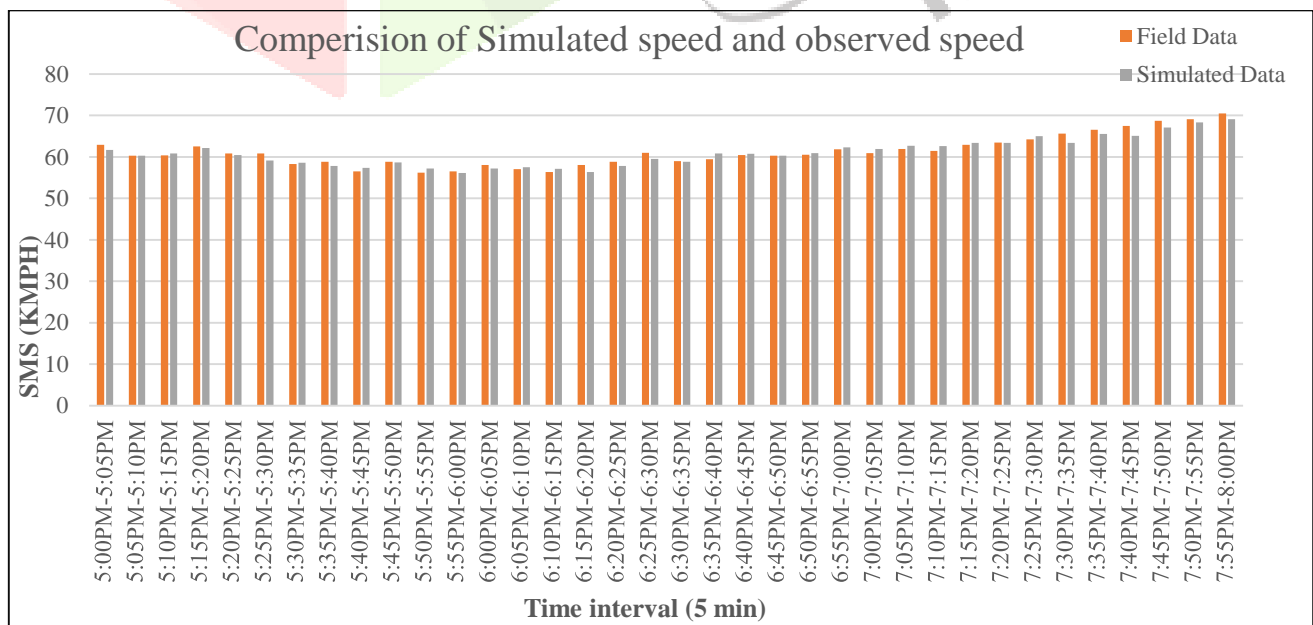


Figure 4.2 Comparison of SMS in 5minute interval

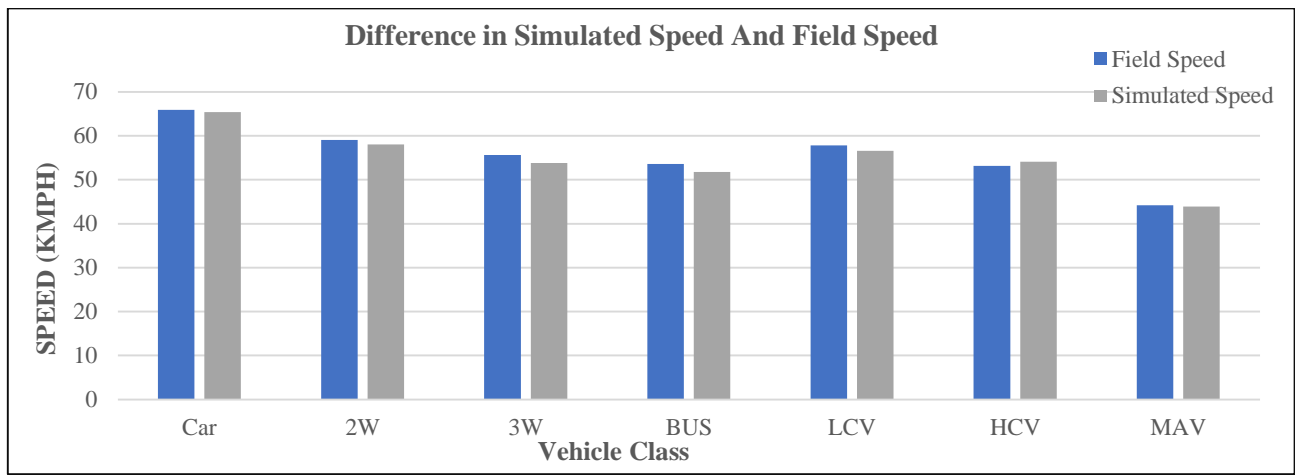


Figure 4.3 Comparison of SMS in 5minute interval

Spatial comparison between vehicle observed for five-minute interval in field and vehicles simulated in model shown in figure 4.1. Error between simulated vehicles and vehicles observed in the field for 5minute interval is ranging between (0%-7.3%). Again spatial comparison for simulated speed and field speed is shown in figure4.2, error between observed speed and simulated speed is ranging between (.01% to 3.3%). Simulated speed and speed observed in field of each vehicle class was also compared as shown in figure 4.3, error between space mean speed in field and from simulation is in between (.74%-3.3).

Table 5 t-test results

Parameter	Time Interval (min)	t-static value	t-critical value	p-value	p-critical value	Degree of freedom
Speed	15	0.3737	1.71	0.711	0.05	25
Flow	15	0.16673	2.06	0.8689	0.05	25

From the test t-static value is less than the t-critical value and p-value is greater than p-critical value which shows no significant statistical difference between field traffic data and simulated traffic data.

Capacity Estimation using microscopic simulation data

For the capacity estimation, simulated vehicles converted to hourly flow in terms of SPCU and DPCU, then speed flow curve was plotted between hourly flow and space mean speed for SPCU and DPCU as shown in figure 5.1 and figure 5.2

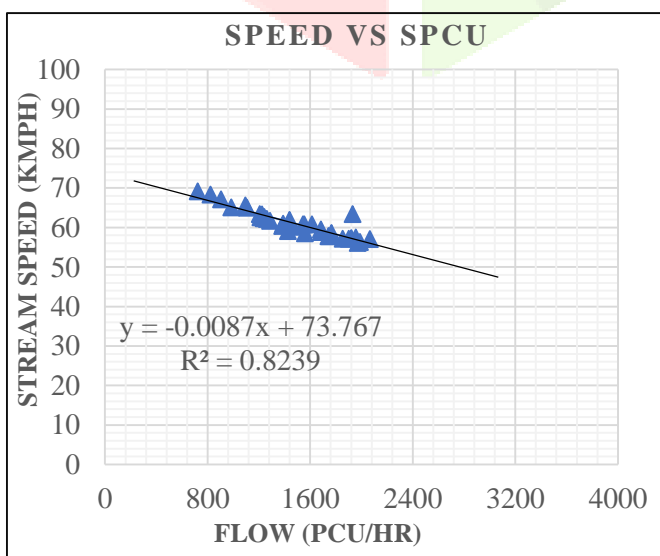


Figure 5.1 Speed flow graph for capacity estimation using SPCU

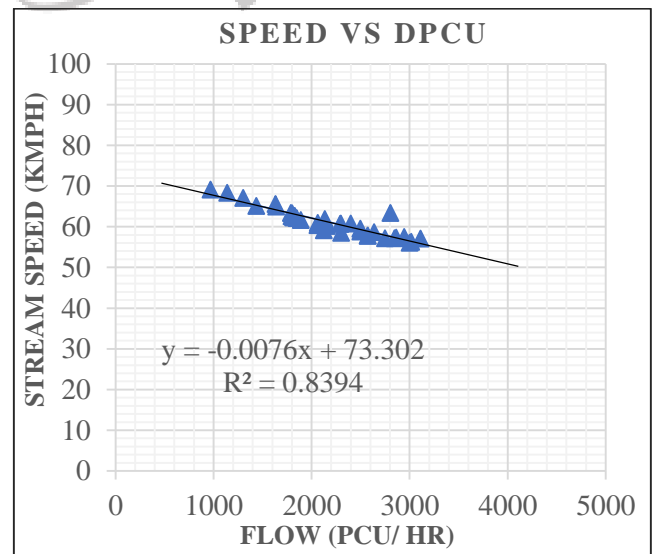


Figure 5.2 Speed flow graph for capacity estimation using DPCU

Capacity estimated using micropic simulation data for static and dynamic PCU values are 4231 PCU/hr/direction and 4822 PCU/hr/direction respectively.

Conclusion

Capacity estimated by IRC method in which static PCU values are used which does not incorporate the heterogeneous nature of traffic whereas estimation of capacity using dynamic PCU values covers the heterogeneous nature of traffic. This study using microscopic simulation as a model for capacity estimation and compared capacities which are estimated using various methods shown in table 6.

Table 6 Capacities obtained using various methods

PCU Values	Capacity		Capacity (Indo-HCM)
	Traditional Method	Simulation Model	
SPCU	4279 PCU/hr/dir	4231 PCU/hr/dir	4872 PCU/hr/dir
DPCU	4886 PCU/hr/dir	4822 PCU/hr/dir	

1. Analysis of traffic data was done by using traffic data extractor, by using analysis of spot speed data free-flow speed of the highway was estimated which is 94.4(km/hr).
2. By developing speed flow relationship capacity of SH- 27 is evaluated using a traditional and microscopic simulation model and compared these capacities. The difference between capacity using traditional model and simulation model for SPCU and DPCU are 1.12% and 1.31 % respectively.
3. Evaluated capacity using statically validated microscopic simulation model also compared with the adjusted capacity of SH-27 which is estimated according to Indo-HCM. The difference between capacity estimated using DPCU in the simulation model and adjusted capacity of interurban highway according to Indo-HCM is 1.02%.

Future Scope and Limitations

1. Yearly traffic growth in country is around 10%-15%, this model can be used for capacity estimation of roadway for traffic forecasted based on annual vehicle growths.
2. For desired capacity or LOS of SH27 width of roadway required can be calculated using this microscopic simulation model.
3. Effect of curvature, pavement conditions, gradient is not considered in estimation of capacity.
4. Only one section was considered for capacity estimation for more accurate results more than one section can be considered for the inclusion of effects of connected small roads to the highway.

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