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Assessment of Operational Quality of Traffic Flow on Indian Highways

Parimal Godse
Assistant Professor
Department of Civil Engineering
Priyadarshini Indira Gandhi College of Engineering, Nagpur, India

Vishrut Landge
Associate Professor
Department of Civil Engineering
VNIT, Nagpur, India

Sanket Amle
Assistant Professor
Department of Civil Engineering
Priyadarshini Indira Gandhi College of Engineering, Nagpur, India

Abstract

In the present study, quantification of level of service for four-lane divided highway has been performed by using simulation technique. For the purpose, three operational service measures are proposed in the study namely traffic stream speed and platoon parameters like average platoon size and percentage following. The criteria or range for each measure to define particular LOS has been compared with criteria in Highway capacity manual (HCM) and reviewed literature. The significant difference in criteriawasobserved due to frequent lane change and undefined lateral behavior of the traffic on multilane highways. Sucha realistic Indian traffic scenario on multilane highway has been modeled and studied through micro-simulation tool 'PASSIM' developed by the authors. The study has been carried on particular section of uninterrupted flow facility which is designated here as 'Rurban' highway hasdistinctly identified between rural highway and urban roads in terms of prevailing traffic condition and driver behavior. The result presented in the form of proposed LOS stratification table based on both quantitative and qualitative operational service measures which practically and indirectly represent road user perceptions too.
Keywords: Platoon; Microscopic Simulation; Multi-lane Highway; Mixed Traffic; Lane-changing; Car-following; Level-of-Service

I. Introduction

As per directives from Ministry of Road Transport & Highways (MORTH), Government of India, all two-lane highways should be upgraded to four-lane highways with paved shoulder when traffic volume is triggered around 10000 pcu/day in plain terrain. The ministry also directed to construct or re-strengthen any highway at least with two-lane paved shoulder here onwards. The criteria for widening under traffic volume limit earlier from 15000 pcu/day, has been now drop up to 10000 pcu/day, keeping in view of quality of service in terms of safety, comfort and convenience to road-users. How to quantify the quality of service based on travellers' perception? Which performance measures should be taken into consideration in the level of service analysis? Theseare the subject of present study. Authors emphasized that widening of carriageway should be assessed, based on both quantitative and qualitative performance analysis under present and projected traffic scenario. A wide road-network in India carries different types of vehicles with varying static and dynamic characteristics. Same road space in undefined manner leads to complex behavioural analysis to study the operational characteristics of traffic flow. Simply temporal and spatial density or volume properties do not specify the quality of service for Indian highways. Capacity augmentation based on such traffic demands would be inadequate to carry any decision of highway project investment and execution. It is need to judge the performance of system qualitatively along with capacity-demand analysis. It would help in taking decision and deciding time-frame of service life for particular highway under widening process.

Level of service (LOS) is stratification of quantitative measures which defines the quality of service [1].

Selected performance measures describe quality of service defined as service measures. It should be measurable in the field and can be quantitatively used in different analysis of transportation system. The service measures defining the operational quality of service of highway facility are important in framing planning and traffic management strategies and policies. In the present paper, average stream speed of traffic stream, v/c ratio and platoon parameter, average platoon size on multilane (four-lane) divided highways in plain terrain under mixed traffic condition have been considered as operational service measures to quantify the level of service. Various models and field methodologies are available to estimate the operating speed on highway for different vehicles. But it is empirically very difficult to measure the platoon parameters. Multilane highways with mixed and non-lane based nature of traffic flow are very much susceptible to formation of platoon in the same traffic direction under different flow levels and traffic stream compositions. Author developed micro-simulation tool PASSIM- Passing simulation by implementing time continuous discrete longitudinal traffic model enhance intelligent driver model (eIDM) and lane-changingmodel MOBIL as per realistic Indian highway traffic conditions in plain terrain.Microscopic simulation proved to be efficient analytical technique to capture vehicular interaction and analysis of traffic flow dynamics. Through simulation, platoon behaviour has been modeled and studied in depth on multilane highways. The model is capable to establish relationship among various operational parameters.

A new term is also coined in this paper i.e. 'Rurban' highways. A designation has been made up of two words; Rural and Urban, assigned to approaching highways to the (second tier) cities in plain terrain of India. A 20 to 25 km long highway segmentfrom the outer municipal boundary of cities designated here as 'Rurban' highway segment which exhibits all together distinct features compared with purely rural and exclusively urban road-network. These highway segments carry daily commuter traffic along with long trips. It provides accessibility for nearby areas and serves the purpose of mobility for rest of the highway traffic. Also rurban highways traffic stream compositions are shared with significant percentage of motorised two-wheelers as being a low cost means of personal transport. A developed microscopic simulation tool describes the interaction and impact of different composition of vehicles on overall performance of rurban four-lane divided highway with paved shoulder.

II. Background Literature

A traffic density (pcu/mi/lane) has been suggested as a performance measure for quantifying LOS for automobile modes on multilane highways in United States [9]. On the other hand, performance under heterogeneity of traffic on Indonesian multilane divided carriageways has been defined through two service measures; degree of saturation and mean operating speed considering headway of 5 seconds as a platoon forming criterion [3]. A quality of service on Japanese multi-lane expressways is defined based on three platoon parameters; platoon rate, platoon size and percentage of follower in various flow regimes *viz.*, free, partial constrained, constraint and congested flow [8]. For Indian multi-lane highway, author proposes a follower density as the most suitable service measure to derive threshold values for LOS stratification [1].No specific criteria to define LOS for rural Indian highways are available in the official guidelines. A design service volume of 35000 pcu/day represent LOS B for four-lane divided carriageway in plain terrain as per code [2]. An author has suggested PCU values for different categories of vehicles under varying percentage share of particular type of vehicle with all cars situation in a capacity analysis study on multi-lane highways under mixed traffic conditions in India. Author also classified level of service from grade A to E based on service volume range estimated through speed-flow relationship [7]. The evaluation of service level for urban expressway in China was carried out by selecting three traffic flow performance indices; average speed, time occupancy and flow rate [10].

III. Field Studies

Field data for the present study was collected at a section of four-lane divided highway with paved shoulder in India.The sections were selected on long straight four-lane National highways, NH-6 and NH-7, approaching Nagpur City (a 20 km stretch) in Vidarbha region of India (plain terrain). Both these sections were away from influence of bus stops, intersections, road side parking, pedestrians, other side friction, curvature or gradient. Traffic on these segments represent the characteristics of rurban highway as the composition of motorcycles during peak hours was observed around 50 percent in overall traffic. A longitudinal section of 50 m length was made on the highway (in one direction of traffic movement) using white self- adhesive cloth tape and video recording of the sections was done for 4 hours on a typical weekday. The video film was later replayed on a wide screen monitor in the laboratory and data on classified volume count was decoded and collected along with speed distribution for each category of vehicle. All vehicles were divided into three categories as presented in Table 1.

Table - 1
Vehicle type, average dimensions and plan area.

Type of Vehicle	*Notation*	*Average dimension (length X width)*	*Physical rectangular area (m^2)*
Car	*CR*	*4.0 m X 1.6 m*	*6.4*
Heavy vehicle/Truck	*HV*	*8.0 m X 2.5 m*	*20.0*
Motorized Two-wheeler/Bike	*TW*	*2.0m X 0.75 m*	*1.5*

Acceleration characteristics were studied and related model parameters were estimated considering different combinations offollower-leader pair by installing 'Android device' having GPS based Accelerometer app. A 10 kilometres long straight stretch of rurban highway was selected and several runs of test vehicles were made during peak hours to obtain all required combinations of traffic behavior. Field data is used to calibrate and validate proposed simulation tool.

IV. Microscopic Simulation Tool

The PASSIM (Passing Simulation - Estimating the Vehicle Passing Rate I.e. Rate of change of Lane changing behavior of the system)tool is used to estimate the LOS of the system depending on the mixed traffic conditions on Indian multi-lane highways. PASSIM tool is developed in Canvas of html 5 with the help of javascript and jquery as a scripting language in which code has been written. (Javascript Framework). The Core PHP code is used to provide the authorized access to the users and various dynamic combinations of the test cases as per the realistic traffic conditions in India. The PASSIM tool focuses on the mid-long segment of the non-urban roads. In the present study, a four-lane divided highway 7m wide with paved shoulder of 1.8m on either side carrying broadly three types of vehicles; car (CR), two-wheelers (TW) and heavy vehicles (HV) havebeen included.The animated graphical user interface (GUI) of the tool is shown in Figure 1. It consists of 4 sub panels. Left panel describes the basic capabilities of tool along with selection of facility. Middle panel shows the real time traffic flow scenario in animation mode. One can easily visualise and interpret the current traffic flow situation under different variables selection and the general status of operational behaviour. Right most panel works as a control board where model parameters like scale ratio, time steps and other input variables like compositions, desired speed, *etc.*can vary as per study objectives. Outputs of current simulation run generate in the tabular format at the bottom panel. These results can be exported to .xls format for further analysis and conclusions.

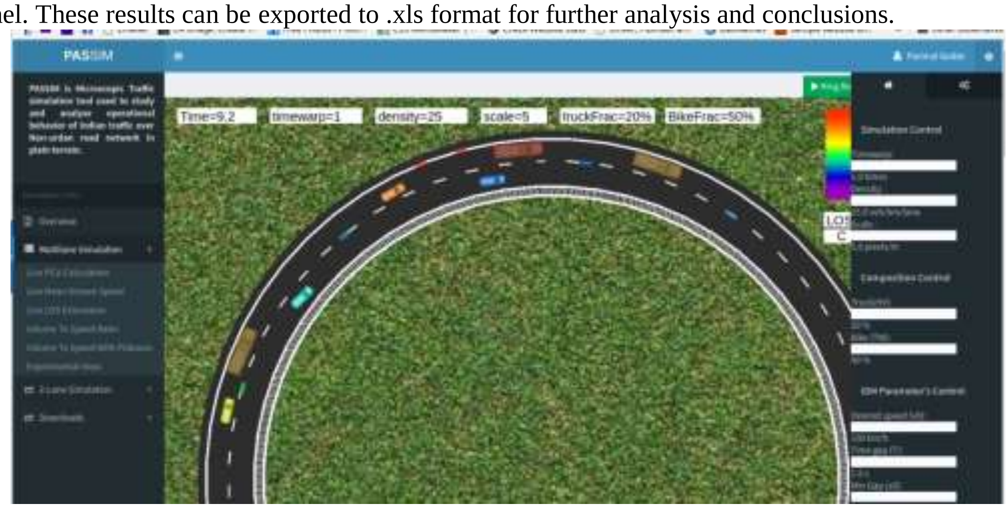

Fig. 1: Simulation Overview

A. Longitudinal Traffic Model- eIDM

The Intelligent Driver Model (IDM) is a discrete time continuous car-following model represents single lane dense traffic flow dynamics. In such models, the decision of any driver to accelerate or to brake depends only on his or her own Speed (v), and on the position and speed of the "leading vehicle" immediately ahead [11]. For smooth controlling of the rate of acceleration and deceleration of the follow vehicle under critically lower relative velocity and smaller gap with leading vehicle, the Adaptive cruise control (ACC) has been implemented in IDM extended as 'Enhanced IDM (eIDM)' or sometimes 'ACC Model'[5] [12].An ACC is the radar sensor equipped system installed in front side of vehicles which maintain the safe gap with leading vehicle automatically through gradual deceleration rate. It avoids the rear end collision even in critical condition when sudden brakes applied by the lead vehicle. This algorithm is used in PASSIM tool to plot the movement and working of the vehicle objects in to simulated scenario which is very much relevant to Indian traffic condition.

Itcomprises of different types of vehicles right from slow moving vehicles, motorized two-wheeler to cars and heavy vehicles with variety of static and dynamic characteristics using same road space at a time without any lane discipline. An aggressiveness of an Indian driver always seeks gaps to move forward from following state, keeping critical space headway ahead and ignoring the follower status in current lane or adjacent lane (or changed Lane). Equation 1 and Equation 2 give the acceleration (deceleration in case) rate for following vehicle based on free flow traffic condition or congested flow regime.

$$\frac{dv}{dt} = a\left[1 - \left(\frac{v}{v_0}\right)^{\delta} - \left(\frac{s^*(v,\Delta v)}{s}\right)^2\right] \quad (1)$$

Where,

$$s^*(v,\Delta v) = s_0 + \max\left[0,\ \left(vT + \frac{v\Delta v}{2\sqrt{ab}}\right)\right] \quad (2)$$

Where, s is space headway, v is actual speed of subject vehicle (following), Δv is relative velocity (velocity difference), s* is desired gap, T is desired time gap, vo is desired speed, a is maximum acceleration, so is minimum space headway which varies significantly under Indian traffic condition, it becomes least with motorised two wheelers, b is comfortable deceleration and ∂ isacceleration gradient component. Table 2shows all the calibrated model parameters of eIDM for study section.In literature, authors demonstrates that the Gamma distribution is the best to model the desired space gap during the steady-state car following situation under mixed traffic conditions. The desired time gap is described by the lognormal distribution with a mean of 1.548 s [13].Accordingly different sets of input data were estimated for three categories of vehicles and shown in Table 2.

Table - 2
eIDM calibrated parameters.

Model Parameters	*Car (CR)*	*Truck (HV)*	*Two wheeler (TW)*
Desired speed v0 (kmph)	*100*	*60*	*65*
Free acceleration exponent	*4*	*4*	*4*
Desired time gap T (seconds)	*1.5*	*2*	*1*

Jam distance (m)	*2*	*3*	*1*
Maximum acceleration a (m/s²)	*1*	*0.5*	*0.75*
Desired deceleration b (m/s²)	*3.96*	*3.96*	*3*
Coolness factor c (ACC system)	*c=1*		

B. Passing and Lane-Changing Model MOBIL

In the proposed simulation tool, a lane-changing model MOBIL (Minimizing overall breaking induced by lane-change) [6] has been incorporated with underlying longitudinal car-following model eIDM.

Frequent lane-changing manoeuvre is a distinct characteristics of multi-lane highways carrying mixed nature of traffic. Non-lane based movement, speed differential, vehicle width variations and undefined pattern formations among different categories of vehicles impose restrictions to free movement of faster vehicles in the traffic stream [4]. When a vehicle moving with its desired speed comes up against a relatively slower vehicle in front, it will pass immediately if there is sufficient lateral gap in the adjacent lane. In absence of required gap, formation of platoon will be observed on roads. PASSIM- passing simulation, a tool is developed to assess the passing opportunity available all the time under mixed and non-lane based traffic flow on Indian highways. In view, lane-change and lateral behaviour are reflected to be significant events in the analysis of operational performance of traffic.

MOBIL works on two criteria *viz.* safety criteria and incentive criteria. eIDM applied to following vehicle in the target lane satisfies no eIDM. Incentive criteria checks the overall advantage in terms of acceleration gain to the system during lane-change maneuver and it should be at least balance with the threshold value of user-perception acceleration rate of system (a_{thr}). Here, as in Indian traffic conditions, as stated earlier, the drivers are aggressive and ignore the status of the following vehicle and seek forward for the desired gap to move on. So, in MOBIL we propose the condition where the politeness factor kept zero and the vehicle will change the lane without considering the following car behavior in target lane.Table 3 shows all the calibrated model parameters of MOBIL for study section.

Table - 3
MOBILcalibrated parameters.

Model Parameters	*Typical Value*
Politeness factor p	*p=0*
Maximum safe deceleration b_{safe}	*4.0 m/s²*
Bias for right lane	*0.3 m/s²*
Threshold a_{thr}	*0.2 m/s²*

C. Platoon Criteria

The vehicle is said to be in platoon if the front vehicles’ speed in the current lane (cruise lane) is less than subject vehicles’ speed and it is not able to change the lane due to obstruction of vehicle in the adjacent (target) lane. In the situation, the ACC controlled deceleration rate of subject vehicle comes upto maximum of 4 m/s^2, induced lane-change realization in the longitudinal dynamics avoiding rear-end collision even at critical conditions. There after assessment of gap by subject vehicle has been taken up within ‘Judgement zone’ in the target lane. Existence of any vehicle within this zone discourages lane-changing manoeuvre and subject vehicle is queued behind lead vehicle forming a platoon. Untill clearing up of leader and immediate follower interaction, more and more vehicles are stacked up in queue. Figure 2 depicts Lane-change realization process.If both the above criteria are satisfied, lane-changing manoeuvre is executed as per MOBIL.

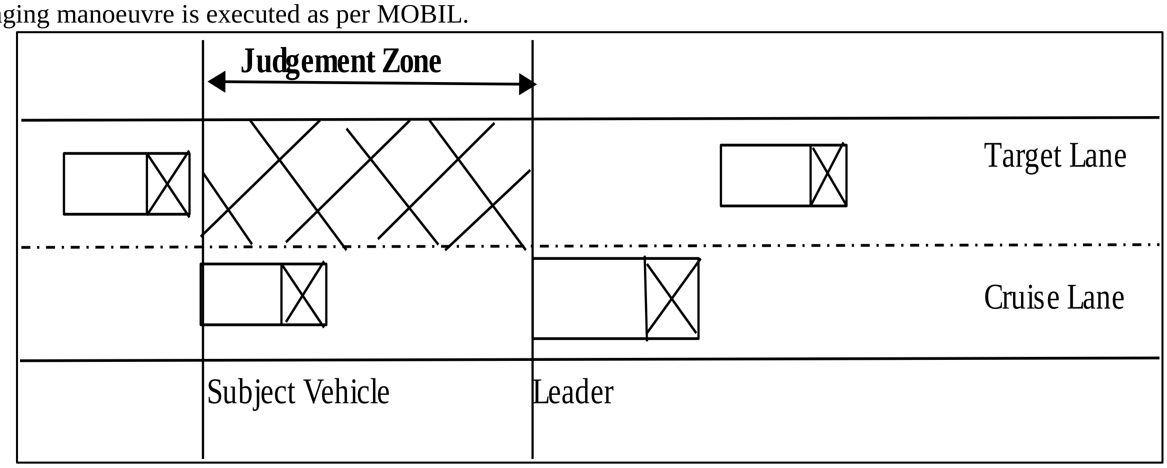

Fig. 2: Realization of Lane-change

V. SIMULATION OUTPUT AND DISCUSSION

In the present study, simulation is performed with the different traffic scenarios under varying compositions of vehicle types and flow levels. From previous studies, LOS were defined as given in Table 4.

Table - 4
LOS stratification as per HCM and literature.

LOS (HCM)	*Proposed LOS [8]*	*Avg Platoon Size*	*% of Free Vehicle*	*Stream Speed (kmph)*
A	*Free Flow*	*1 - 1.5*	*70 -100*	*100 -80*
B	*Free Flow*	*1.5 - 2*	*50 - 70*	*80 - 60*
C	*Partial Constrained Flow*	*2.0 - 3*	*33- 50*	*50 - 40*
D	*Partial Constrained Flow*	*3.0 - 4*	*25-33*	*40 - 30*
E	*Constrained - Flow*	*4.0 - 7*	*<25*	*30 - 20*
F	*Congested Flow*	*< 7*	*0*	*<20*

In test cases, percentage share of heavy vehicle vary by 10%, 20% and 30% share with balance share of cars. Impact of two-wheelers on traffic flow behavior was kept inactive with 0% share in stream compositions. Average platoon size, average stream speed and % followings were plotted under mentioned test cases of compositions and volume through intensive simulations. It was observed that increasing share of heavy vehicles degrade the performance of facility. Many times, two trucks occupy both the lanes in case of four-lane highway which restrict the free movement of cars. With increasing percentage of HV having comparatively lower acceleration capability, chances of complete blockage in highway increases which results in large numbers of platoons of different sizes.Overall speed of system is also affected due to interference of the cars with heavy vehicles. On the other hand, with increasing share of cars, there is a formation of platoon of fast moving cars which try to pass in single maneuver.

Figure 3 depicts relationship between traffic stream speed and the platoon size i.e. how many numbers of vehicles stranded in a platoon. As the percentage share of HV increases, the platoon size increases and average traffic stream speed decreases. Under all car situation, traffic stream speed achieved maximum speed of 100kmph and then decreases gradually while in case of increasing share of HV a drastic drop in speed observed even at lower platoon size (2-6). It represents strong presence of HV in traffic stream.A stream speed reached upto 20 kmph, where numbers of vehicles in platoon was 14.This indicates congested flow regime.

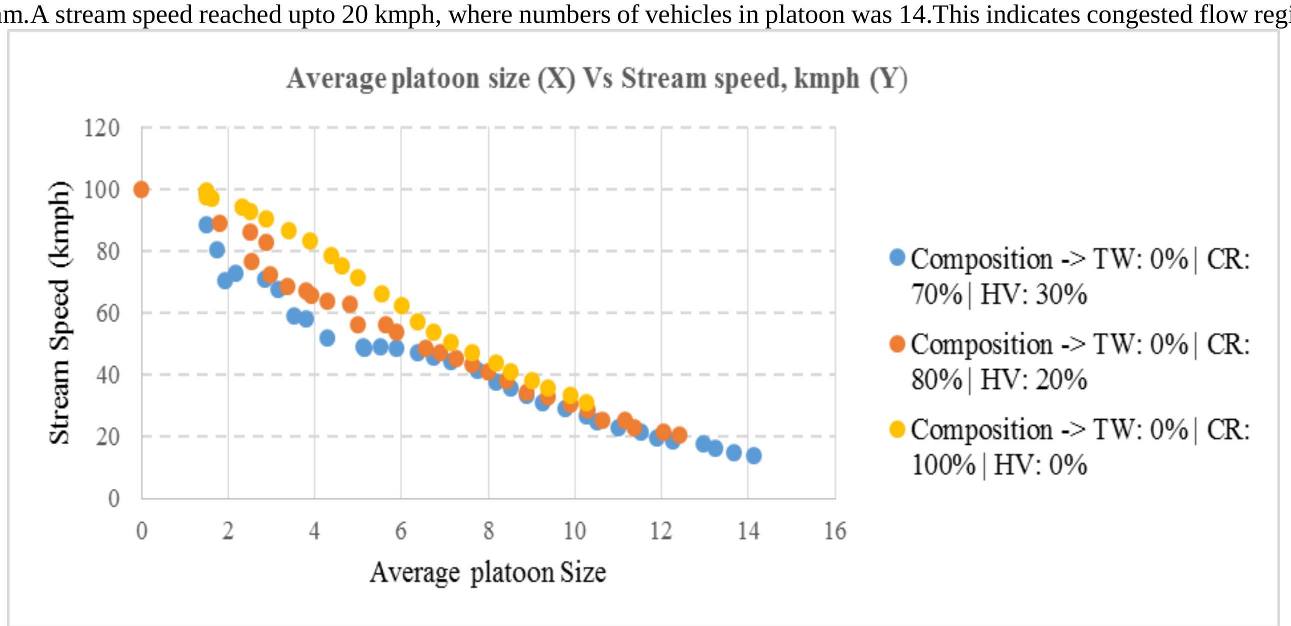

Fig. 3: Relationship between Speed and Platoon Size.

A relationship between platoon size with volume is shown in Figure 4. The platoon size increases linearly up to certain point with respect to volume and once volume is exceeds 4000pcu/hr which is near to directional capacity value for four-lane highway, the scenario changes and the scramble situation is formed as the system speed is degraded and the platoon size increases gradually. Under all car situation, the congestion stage achieved at lower volume level where number of vehicles in platoon was 6 or more. If the percentage share of HV increases, the peak volume level reaches upto 7000 pcu/hr and the platoon size becomes double. It shows, cars experience difficulties in finding lateral gaps and wait for lane-change opportunity which is responsible for larger platoon length.

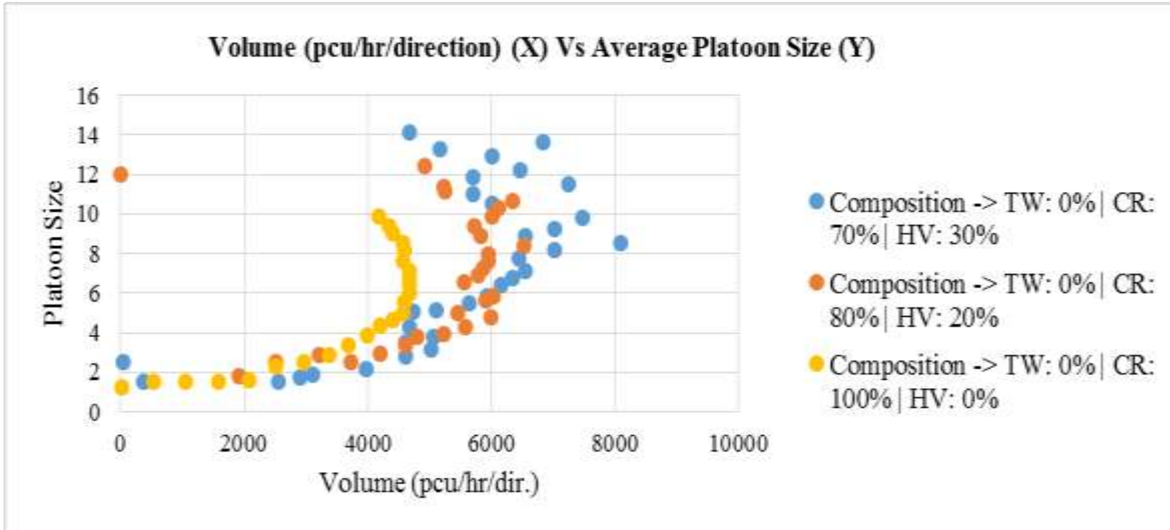

Fig. 4: Relationship between Volume and Platoon Size.

Figure 5 exhibitthe percentage of the following vehicles increase with increase in the volume. The peak is achieved at 5000vehicles with 50:50 share of HV and CR which concludes that the values received are validated with previous papers that refer to our current live scenario of the Indian traffic conditions.

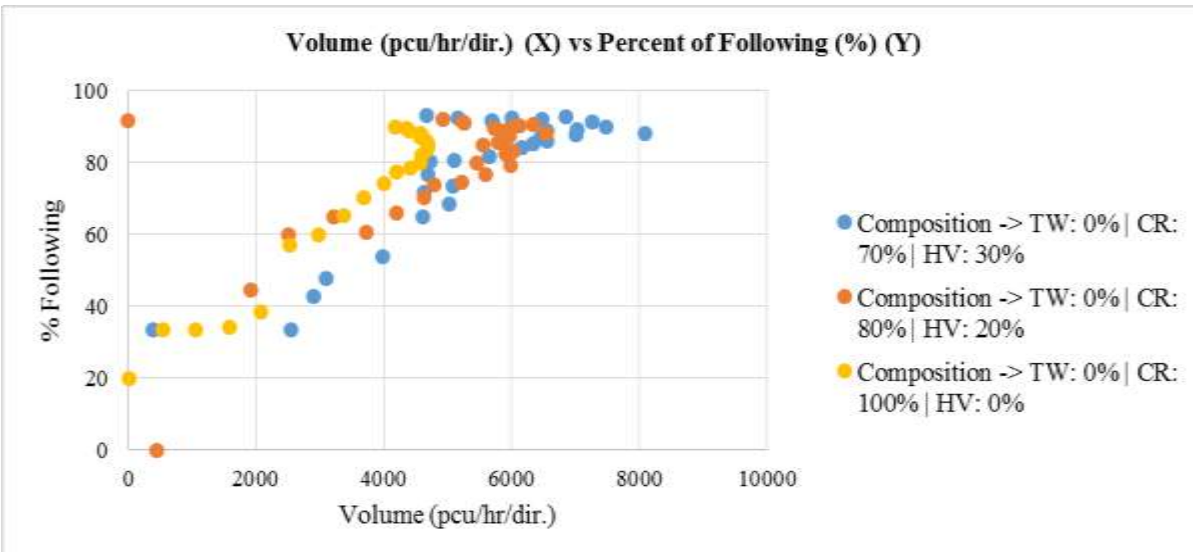

Fig. 5: Relationship between Volume and % of Following Vehicles.

The levels from A to F defined in HCM are considered to be standard in India too. But, the difference is that the values are defined for the homogeneous traffic conditions while India has mixed traffic condition with aggressive and dynamic traffic behavior. A frequent lane-change maneuver under varying compositions of vehicles at different flow levels influences performance measures on multilane highway traffic operation. Hence, new LOS is proposed to measure the system accurately. The average platoon size from 1 - 1.5 is considered as LOS A in HCM, where in our case it is considered as 0 - 2.0. This change or improvement in LOS is received or reached due to the mixed and non-lane based traffic behavior. Dynamic traffic behavior illustrates frequent lane changing behavior of the vehicles to find gap and maintain the higher average speed during its traversal. LOS criteria are proposed through simulation study presented in Table 5.

Table - 5
Proposedoperational LOS criteria

Avg. Stream Speed (kmph)	*Avg. Platoon Size (Mixed)*	*% Following (Mixed)*	*ProposedLOS*
100 -80	*0-2.0*	*0-33*	*A*
80 - 60	*2.0 - 3.5*	*33-50*	*B*
50 - 40	*3.5 - 7*	*50-65*	*C*
40 - 30	*7 - 8.5*	*65-75*	*D*
30 - 20	*8.5 - 10*	*75-100*	*E*
<20	*10+*	*100*	*F*

VI. CONCLUSION

In the present paper, level-of-Service (LOS) criteria for four-lane divided highway are defined on the basis of three performance measures which indirectly measure the user perception aspects like comfort and convenience. At the same time it represents the operational quality of traffic flow too.Proposed range of values for average stream speed, average platoon size and % following has been given for each LOS from A to F. Authors suggested to estimate simultaneously all three parameters at different compositions of traffic stream and flow levels and then using table a judgement should be given about the current status of LOS for the subject facility. The quantification has been done extensively by using self-developed simulation tool PASSIM which accurately embodies lateral, longitudinal, lane-changing and driver'sbehaviour on Indian context.

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