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Capacity Estimation of Multilane Highways under Heterogeneous Traffic Conditions using Micro-Simulation Technique

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Abstract

The behavior of a driver of any vehicle is important in estimating heterogeneous traffic conditions with no strict lane discipline. In the present study, a micro-simulation model is used to analyze the mixed traffic condition with different drivers' behavior parameters. The field data collected on traffic flow characteristics of multilane highways are used in the calibration and validation of the simulation model. Out of the ten coefficient of correlation (CC) parameters in the simulation model, five are used in the present study to make a model of simulation for heterogeneous traffic; the other five parameters are not considered for testing their influence on simulated capacity values as they represent very typical behavior of a driver, either in car-following, or in free-flow conditions. Two separate simulation models are made by changing the CC (CC0, CC1, CC2, CC7, and CC8) parameters, each for a four-lane divided and a six-lane divided highway as the geometric conditions of the roads, and the traffic flow is different for both the cases. These models are then applied on two other sections of a four-lane divided and a six-lane divided highway to validate the parameters of the model developed earlier for other sections.

Keywords: Behavior, Calibration, Capacity, Heterogeneous, Parameters, Traffic.

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Introduction

In developing countries, the traffic includes numerous vehicle classes that interact in a disorderly manner with no lane discipline, forming an imprecise mixed traffic condition. The nature of the traffic condition is exceedingly diverse as several vehicle categories with changing features, both statically and dynamically move or operate on a common road width without any physical segregation. The traffic operations are affected as the vehicles with smaller dimensions pierce the gaps formed between larger dimension vehicles. Unrestricted movement of vehicles makes the traffic situation further multifaceted in comparison with standardized traffic situations. Aimed at the persistence of better preparation and organization of highways, the determination of roadway capacity of various highways and expressways is the utmost serious matter under consideration. For the execution of a proper plan, design, and operations of roads, the information of the capacity of a roadway is crucial. Underneath diverse traffic circumstances, the volume of traffic along with the composition is important to estimate roadway capacity concerning the vehicles moving through a particular section in a unit amount of time. The simulation represents a mirror or projection of actual traffic behavior, which is difficult to observe in real-world situations. So, it is very much essential for the usage of a minuscule model of traffic simulation to generate the mixed traffic flow after calibrating its influencing model parameters affecting the longitudinal behavior of a driver or vehicle.

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Literature Review

The progress of any efficient traffic system requires all basic and detailed information regarding macroscopic and microscopic parameters of the traffic course, and the consequence of the prevailing traffic, roadway, and control conditions on these parameters. Gomes *et al.* (2004)[1] worked on a congested freeway micro-simulation model by the use of VISSIM. A comprehensive practice was carried out on the creation and standardization of a model on imitation of a freeway having a unidirectional approach with an on-ramp controller. From work, it can be deduced that with some logical adjustments, the simulation tool was well matched to be used in freeways with multifaceted traffic connections. Madhu and Velmurugan (2011)[2] worked on estimation of traffic capacity of an expressway having eight lanes with diverse traffic by developing a model on minuscule simulation with the consideration of entrance restricted alienated expressway. The creation of computer-generated paths by vehicles was approximately scrutinized for its influence on traffic capacity, and it was detected that the said capacity of expressway without any virtual paths got decreased by a certain amount along with a decrease in vehicle speed. Bains *et al.* (2012)[3] worked on demonstrating the movement of vehicles on the expressways in India by means of simulation practice. The work assessed the traffic capacity on expressways by considering the consequence of proportions of vehicles on the passenger car equivalencies and also got decreasing values for the rise in the ratio of traffic volume to traffic capacity regardless of the class of vehicles. Li *et al.* (2015)[4] worked on the classification of the nature of vehicle driving along with standardization of model on minuscule simulation. It was observed that the standardization of minuscule simulation tool was required for the evaluation of detailed features of vehicular traffic along with the behavior of varied vehicle drivers in realism previous to perform an investigation of vehicular traffic. The evaluability of the classification of various sorts of driving for standardization of the model was totally anticipated. Asaithambi *et al*. (2016)[5] studied the physiognomies of vehicular flow by the use of diverse vehicle-ensuing prototypes on varied traffic circumstances. The outcomes demonstrated that the exclusion of auto rickshaws and heavyweight vehicles had encouraging insinuations for highway traffic capacity and passenger car unit assessment along with the investigation of different service standards of the highway.

Objective

The foremost motive of the current work is to evaluate the heterogeneous traffic capacity of multilane roads in India using the assistance of a micro-simulation model. The roadway capacity assessment chiefly hinges on vehicular maneuverability on any road network, so the vehicular interactions and psycho-physical behavior of the drivers can severely affect the traffic flow. Micro-simulation models on traffic are mainly used in cases where dynamics of the traffic system are involved, and detailed information on microscopic traffic measures is required. The simulation models contain various factors with default values that can also be changed according to the need of situations of the condition of traffic. A model on micro-simulation of traffic considers various factors like recognition of gap, adjustment of speed, shifting lanes, overtaking, and others that illustrate the precision of human driver conduct in traffic flow for better results of the simulation. In the current work, the minuscule, multi-modal time increment oriented and behavior-based simulation tool VISSIM[6] has been utilized to simulate the diverse traffic of the multilane highways of India. As driver's behavior is important for vehicle maneuverability in non-lane based mixed traffic flow, so the initiative is taken in the present study to calibrate driver behavior model parameters of the simulation software to emulate mixed traffic conditions of multilane highways.

Field Data Collection

The road sections were carefully chosen after conducting an inspection survey to gratify the circumstances, like straight stretched section, uniform roadway width, and no shortest admittance as of the contiguous land uses. The four sections chosen for the present study are national highway No. 6 (NH-6) at chainage 20 (towards Kharagpur), NH-45 at chainage 98 + 400 near Acharapakkam (Chennai-Villupuram highway), NH-8 at chainage 52 + 62 (towards Ahmedabad), and NH-8 at chainage 165 (towards Ahmedabad). The study sections NH-6 and NH-45 are four-lane divided national highway with every 3.5 meters wide lane, while the sections NH-8 (chainage 52 + 62) and NH-8 (chainage 165) are six-lane divided national highway with 12.48 and 12.35 meters width of the carriageway on either side, respectively. The geometry of the sections are straight and level with paved shoulder of 0.8-meter wide for NH-6 having chainage of 20 km, 1.5 meters paved shoulders along with 1-meter earthen shoulders for NH-45 at chainage of 98 km 400 meters, 1.1 meters paved shoulder along with 1.3 meters morrum shoulders for NH-8 at chainage of (52 + 62), and 1-meter paved shoulder along with 2 meters morrum shoulders for NH-8 at chainage of 165. The prevalent weather condition for data extraction was sunny without any rainfall. The speed-volume data was mainly collected for a trap length of 60 meters for NH-6, 75 meters for NH-45, and 100 meters for both the sections of NH-8, physically marked with the help of white paint and traffic cones. A video camera was then installed with the help of a tripod stand, and the camera was attuned by such means that the complete segment span was clearly visible to enable decoding of traffic volumes and space mean speed of different vehicle types. Video photographic data was collected on typical weekdays for NH-6, NH-45, and NH-8.

Capacity Estimation Model

Model Methodology

The capacity of the four sections of multilane highways was initially estimated in the present study by using traditional methods.[7] The heterogeneous traffic volume measured at every five minutes interval was converted to homogeneous volume by utilizing the passenger car units (PCU) of diverse vehicular categories.[8,9] The speed of individual vehicles in 5 minutes volume count was determined, and the average stream speed was calculated. As the field data were not providing the complete shape of the speed-volume curve, so capacity was estimated with the help of a theoretical concept. Speed-volume data were converted to speed-density data by making use of the fundamental relationship between speeds, flow, and density. Various forms of equations, including Greenshield's model[7] (which became predominant with greater R^2 value), were tried to fit speed-density data. The best fit speed-density curve has been used to develop a complete profile of the speed-flow curve for assessing the roadway capacity. A micro-simulation model has been developed in the present study as it contains most of the design and operational attributes of roadway and traffic flow conditions, which are not possible to be considered in the traditional way of capacity estimation. The said simulation tool incorporates the two different sets of psycho-physical behavior-based car-following prototypes formerly established by Wiedemann in 1974 and 1999. The models follow separate rules and algorithms to execute the behavior of drivers passing through the network. The car-following behavior-based models in the simulation model consist of multiple numbers of parameters related to the speed and acceleration control of a vehicle with respect to the surrounding traffic and roadway conditions. The Wiedemann 99 prototype is added multifaceted depiction of car-following conduct of drivers as it contains ten different parameters related to action or reaction of the driver according to perceived traffic situations. This model is an improved variety of Wiedemann 74 model and was developed to represent behaviors of drivers on freeways, interurban highways, and expressways. The model contains ten different car-following behavior parameters termed as co-efficient of co-relation parameters (CC0 to CC9, as mentioned in Table 1). Each parameter is related to the behavior of a driver and its interaction among the vehicle population. The CC parameters given in the car-following model are very intrinsic to stationary and active features of vehicles moving on a road. The affectivity and sensitivity of each parameter are checked individually, and in a combination of other parameters, then the most important and influencing parameters are identified. In this study, traffic capacity is considered the degree of efficiency in the process of calibration and validation.

Selection of Driver's following Behavior Parameters

The sensitivity of the Wiedemann 99 model,[10-12] parameters are investigated by taking simulated capacity as a measure of effectiveness. The literature suggests that a small change in a parameter value may have a substantial effect on higher traffic volume and may alter the entire simulation results. Out of the ten CC parameters, five (CC0, CC1, CC2, CC7, and CC8) are selected in the current work to make a model of simulation for heterogeneous traffic. The other five parameters (CC3, CC4, CC5, CC6, and CC9) are not considered for testing their influence on simulated capacity values, as they represent very typical behavior of a driver either in car-following or in free-flow conditions. As far as highway capacity is concerned, it is a measure of macroscopic characteristics of traffic flow and is directly affected by the presence of external factors, like a roadway, traffic, and climate. So, these parameters are kept as default values in the entire calibration process.

Two separate simulation models are made by changing the CC (CC0, CC1, CC2, CC7, and CC8) parameters, each for a four-lane divided and a six-lane divided highway as the geometric conditions of the roads, and the traffic flow is different for both the cases. These models are then applied on two other sections of a four-lane divided and a six-lane divided highway to validate the parameters of the model developed earlier for other sections. The parameter CC0 is a clear halt amid two consecutive vehicles stopped in a line. This parameter is vital for the calculation of secured space anticipated by drivers in concurrence with CC1, which remains the distance in seconds that a vehicle driver desires

Table 1: Wiedemann 99 model parameters listed with changed values in VISSIM

Notation	*Name of parameter*	*Default value*	*Value for NH-6 (chainage 20)*	*Value for NH-8 (chainage 52 + 62)*
CC0	Standstill distance	1.5 m	1.4 m	1.44 m
CC1	Time headway	0.9 sec	1.2 sec	1.5 sec
CC2	Following variation	4 m	4.6 m	4.42 m
CC3	Threshold for entering "following"	-8	-8	-8
CC4	Negative following threshold	-0.35	-0.35	-0.35
CC5	Positive following threshold	0.35	0.35	0.35
CC6	Speed dependency on oscillation	11.44	11.44	11.44
CC7	Oscillation acceleration	0.25 m/sec^2	0.48 m/sec^2	0.35 m/sec^2
CC8	Standstill acceleration	3.5 m/ sec^2	2.6 m/sec^2	3.12 m/sec^2
CC9	Acceleration at 80 km/hr	1.5 m/ sec^2	1.5 m/sec^2	1.5 m/sec^2

to preserve at a convinced speed. Both CC0 and CC1 are changed from low to high values to get a set value for the simulated model in the current work.

The standards of CC0 and CC1, in this case, is changed to 1.4 meters and 1.2 seconds for NH-6 (four-lane divided, chainage 20), and 1.44 meters and 1.5 seconds for NH-8 (six-lane divided, chainage 52 + 62) instead of the default values of 1.5 meters and 0.9 seconds. The parameter CC2 is the following distance variation that restricts the longitudinal oscillation of vehicles during the simulation. It is the distance incremental to the secured distance that a driver desires earlier to intentional movement nearer to the preceding vehicle. As CC0, CC1, and CC2 can have a combined effect on traffic simulation, so the parameter CC2 is augmented from lesser to greater standards for diverse values of CCO and CC1 and is finally obtained as 4.6 meters (NH-6) and 4.42 meters (NH-8) instead of the default value of 4 meters. The oscillation acceleration parameter CC7 is the actual acceleration rate desired by the driver of the following vehicle during the oscillation process (following driver accelerate or decelerate frequently with respect to leading vehicle) apart from capabilities of a vehicle type. This parameter shows the aggressiveness of a driver, so it is combined with the time headway parameter CC1 to see the effect on capacity. It is found that for the value of CC1 to be 1.2 seconds (NH-6) and 1.5 seconds (NH-8), the value of CC7 is 0.48 and 0.35 m/sec^2, respectively, getting a simulated value of capacity within a range of 5% from the traditional capacity value. The standstill acceleration parameter CC8 is the anticipated hastening of vehicles initiating from rest. The value for this acceleration may be higher than the average acceleration value. The values of CC8 can also be adjusted in maximum acceleration profiles for each assigned vehicle type. Thus, the value of standstill acceleration should depend on standstill distance (CC0). If the standstill distance between two vehicles is smaller, then a higher value of standstill acceleration of vehicles should not be provided from the view of safety. As the value of CC0 is selected as 1.4 meters (NH-6) and 1.44 meters (NH-8) in the model of the present study, which is lower than the defaulting worth of 1.5 meters, so the value of CC8 is kept lower than its default value of 3.5 m/sec^2. Thus, in combination with the parameter CC0, the value of CC8 is taken as 2.6 m/sec^2 (NH-6) and 3.12 m/sec^2 (NH-8) to get a realistic simulated capacity value. The changed standards of the selected parameters, along with the default values, are represented in Table 1.

Calibration and Validation of the Model

In the calibration procedure, the constraints of the present simulation tool are adjusted in such a way that it is capable of reproducing the traffic flow situations as detected in field conditions. As soon as the network is formed and typical involvements are given from the facts, the model is run with defaulting parameters that sometimes become unsuccessful to present results nearer to realism. Henceforth, sensitivity inspection through multiple constraints, along with the setting of their assortments for standardization, is done.[13,14] Separately, the specific possessions of the vehicle driver performance constraints on the traffic capacity of the link in simulation, their collective outcome is likewise ever so often noteworthy. The sensitivity of the driver's following behavior parameters is investigated by taking simulated capacity as a measure of effectiveness.

Five (CC0, CC1, CC2, CC7, and CC8) out of ten parameters have shown a significant effect on capacity estimation for both four and six-lane divided highways. So, the sensitivity of the parameters in combination is done by two-way analysis of variance (ANNOVA: two factors without replication) to see whether any change in parameter value from its default value affects simulated capacity at five percent level of significance. As already discussed earlier, the parameters are changed individually and in combinations from lower to a higher value to get a realistic simulated capacity. Two models are made with the changed CC parameters (five), one each for NH-6 (four-lane), and NH-8 (six-lane), and the level of significance is measured for the two sets of changed parameters against the default parameters of the Wiedemann-99 model. The p value of the two sets of parameters for NH-6 (four-lane) and NH-8 (six-lane) after comparing with the default value is found to be 0.0000016, which is lower than the critical value of 0.05. Thus, it indicates that the change in the default values of the parameters CC0, CC1, CC2, CC7, and CC8 provide a significant change in the value of simulated capacity as they are significantly different from newly considered CC parameter values, resulting in a realistic capacity estimation.

The simulation is run with the changed values of five (CC0, CC1, CC2, CC7, and CC8) parameters of the Wiedemann 99 model for each of a four-lane (NH-6) and six-lane (NH-8, chainage 52 + 62) highway, and a capacity value is obtained having a variation of ±5% with the estimated capacity of the traditional model,[7] proving a realistic estimation of capacity by traffic simulation. These two models are again used to estimate capacity for another four-lane (NH-45) and six-lane (NH-8, chainage 165) highway, respectively, and the simulated results are compared with the traditional capacity estimation result. It is seen that in this case, also the simulated capacity varies by ±5% with the estimated capacity of the traditional method. This proves the validation of the five driver's following behavior parameters, as they give a realistic value of simulated capacity in both the sections of four-lane and six-lane divided highway.

To check the temporal validity of the new simulation model, a comparison of the observed and simulation flow value has been made at 15 minutes interval of traffic flow. The details of the statistical validation through the paired t test are represented in Table 2. The estimated t statistic, p, and t critical values obtained from the standard t test are represented in Table 2 for a 5% level of significance, which is 95% confidence level, along with their respective degrees of freedom. From the results, it is seen that in all the cases,

Table 2: Comparison of observed and simulated flow for model validation

Road name	*Traffic parameter*	*Time interval (mins)*	*t-statistic value*	*t-critical value*	*p value*	*Critical p value*	*Degrees of freedom*
NH-8 (chainage 52 + 62)	Flow	15	1.194269	2.101	0.247874	0.05	18
NH-8 (chainage 165)	Flow	15	0.06171	2.1	0.951474	0.05	18
NH-6	Flow	15	1.42696	2.2281	0.18406	0.05	18
NH-45	Flow	15	1.15914	2.1009	0.261545	0.05	18

Table 3: Capacity of multilane highways

Road section	*Highway type*	*Directional capacity estimated by traditional method (PCU/hr)*	*Lane capacity (PCU/hr/lane)*	*Directional capacity estimated by simulation (VISSIM) method (PCU/hr)*	*Lane capacity (PCU/hr/ lane)*	*Capacity variation between traditional and simulation method*
NH-6 (chainage 20)	Four-lane divided	5,340	2,670	5,584	2,792	4.57(%)
NH-45	Four-lane divided	5,445	2,723	5,708	2,854	4.83(%)
NH-8 (chainage 52 + 62)	Six-lane divided	6,595	2,198	6,548	2,183	0.71(%)
NH-8 (chainage 165)	Six-lane divided	6,469	2,157	6,755	2,252	4.42(%)

the value of estimated t statistic is lesser than the t critical values for the t test, and the p value is more than the 5% level of significance. Thus, it can be concluded that there is no statistically significant difference between the observed and simulated traffic capacity of the four multilane highways considered for the present study.

Results

As discussed in the earlier sections that five parameters of the driver's car following behavior model are changed to get a realistic capacity value by the simulation method. The capacity analysis from the speed-density relationship (as per the Greenshield's linear model) for four different sections is done by plotting the speed-flow curves from the data generated from speed-density relation. The speed-flow curves are not presented in this paper due to the limitations of words. So, the capacity estimated by the traditional method and simulation method for four different sections of national highways in India in the present study is shown in Table 3.

Conclusion

From Table 3, the simulated capacity estimated for the four national highway sections NH-6 (chainage 20), NH-45 (chainage 98 + 400), NH-8 (chainage 52 + 62), and NH-8 (chainage 165) are found to vary by 4.57, 4.83, 0.71, and 4.42%, respectively, from the traditional capacity values. These values are all within the range of ±5% from the traditional capacity values, so the simulation values imply a realistic estimation of heterogeneous traffic data. It is also observed from the results that the simulated capacity values are not always more than the estimated capacity values by traditional methods, as in the case of NH-8 (chainage 52 + 62) section, where the simulated capacity is 15 PCU per hour per lane less than the traditionally estimated capacity value. Thus, we can conclude from Table 2 that the variation of ±5% in traditional and simulated capacity values is justified from the results of the estimated capacity in the present study. Thus, the two simulation models prepared for simulated capacity estimation provides realistic capacity values with only the change in five parameters of car following model, which proves the proper calibration and correct validation of the CC (CC0, CC1, CC2, CC7, and CC8) parameters of the Wiedemann 99 car following model present in the microscopic traffic simulation model used in the present study.

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