Level of Service Classification for Urban Heterogeneous Traffic: A Case Study of Kanapur Metropolis

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ABSTRACT

The *Highway Capacity Manual* (HCM, 1985) has defined level of service mostly for the developed countries having predominant contribution of motorized vehicles. There are very fewer number of models to simulate the urban heterogeneous traffic flow having significant proportion of non-motorized vehicles. These types of flows are mostly observed in the countries of Asia-Pacific region. The flow of heterogeneous traffic on urban roads is highly complex and the existing analytical models cannot be used to predict the flow behavior on urban corridors. A traffic simulation model, which can replicate the movement of heterogeneous traffic, has been developed to analyze the various environment of the road system. Traffic studies have been conducted on different roads of Kanpur metropolis. It includes parameter estimation of different sub-models of the simulation system and traffic and driver behavior modeling. After development of traffic simulation model, model has been successfully calibrated and validated for the urban heterogeneous traffic flow conditions on the Kanpur roads. The simulation model has been further applied for experiments under different road, traffic, and operating conditions.

For level of service experiments a two-lane (7 m) wide-level tangent road section (Road – I) is selected for simulation runs. As based on the observed traffic composition in Kanpur a benchmark traffic composition (Level I) is selected for simulation runs. This benchmark composition has 35 percent of motorized vehicles and 65 percent of non-motorized vehicles. Road stretch of 500 meter length with additional warming up zone of 300 meter length is adopted in this study for simulation experiments. Simulation runs are planned at increasing flow levels (8–10 flow levels) until flow approaches unstable state. It is planned to simulate 1600 vehicles for each run. To eliminate the effect of transient state, the statistics of the first one hundred vehicles are ignored. In the present study, level of service (LOS) is defined as composite of several operating characteristics that are supposed to measure the quality of service as perceived by the user at different flow levels. During analysis operating characteristics considered to define LOS are journey speed of cars, journey speed of motorized two wheelers, concentration, and road occupancy. Based on the simulation results of benchmark road (Road – I) and traffic composition (Level I) level of service is classified into LOS I, LOS II, LOS III, and LOS IV. Level of service criteria developed in this study may also help to identify the deficiencies of an urban road system and to plan for alternative improvements to attain a desired level of service.

1. INTRODUCTION

After successful calibration and validation of simulation model for urban heterogeneous traffic flow conditions (Singh, 1999), the simulation model is applied for experiments under different road, traffic, and operating conditions. Analysis of the simulation results is used to estimate the level of service under different operating conditions. Level of service criteria developed in this study may also help to identify the deficiencies of an urban road system and to plan for alternative improvements to attain a desired level of service. Level of service criteria developed in this study may also help to identify the deficiencies of an urban road system and to plan for alternative improvements to attain a desired level of service. Level of service criteria may also be used to determine the maximum service flow under different road, traffic, and operating conditions.

2. OVERVIEW OF SIMULATION MODEL SYSTEM

The formulated Traffic Simulation Model System consists of various component sub-models, which are assembled into a realistic structure of the system. The various sub-models, the activities associated with them, and their linkages are shown in Figure 1.

The heart of the system is the development of traffic simulation model, which simulates the flow of vehicles. Road and traffic sub-models are developed to generate the road and traffic input respectively for the simulation model. To understand the working of the simulation model, animation program system is developed to have the graphic display of the simulated traffic. The model output is analyzed through traffic results processing program to get the statistics of different performance measures. Some parameters of traffic flow are estimated through analysis of the field traffic data. Calibration of model parameters and decision thresholds is attempted by estimated traffic flow parameters and also through simulation experiments. The simulation model is validated for a number of measures of effectiveness (MOE). The validated simulation model is used to conduct a series of simulation runs to judge the sensitivity of some road and traffic characteristics.

3. CALIBRATION AND VALIDATION OF SIMULATION MODEL SYSTEM

The formulated traffic simulation model consists of a series of sub-models. The realistic estimate of various parameters and decision thresholds is attempted in the calibration process in three sequential stages.

The experimental simulation runs are made on the road for which the field observations are available. A short road stretch is selected and traffic is simulated for different flow levels. Comparison of the observed and simulated values of journey speeds for different vehicle types are made.

The model is validated for various measures of effectiveness such as journey speeds, time headways, traffic density, and number of overtakings performed. Simulation runs are made

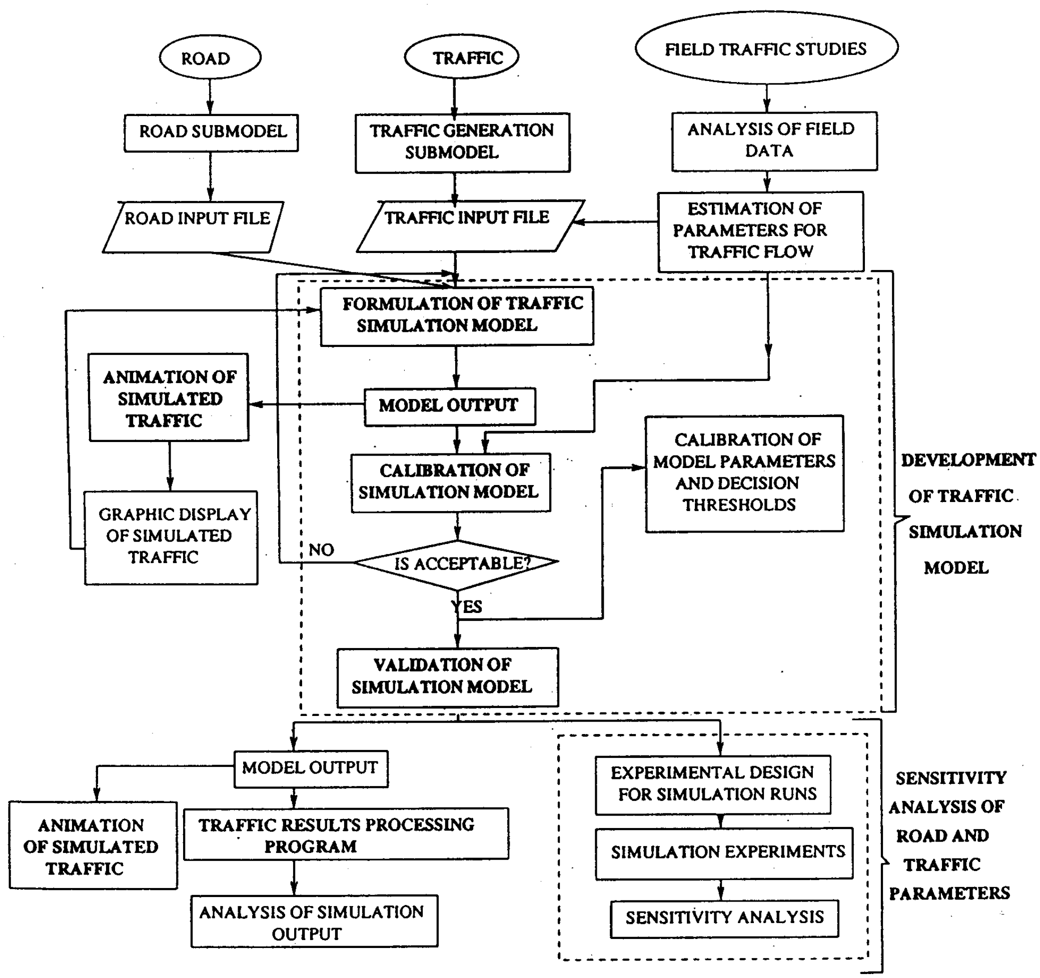

FIGURE 1 Overview of Traffic Simulation Model System.

at flow level different from one used for calibration. This helps to test the capability of model under different conditions. Simulation run is made for an hourly volume of 2332 vph (vehicles per hour) observed during the peak period. Comparison of simulated and observed output indicates the capability of the simulation model to realistically represent the complex heterogeneous traffic flow.

4. DESIGN OF SIMULATION EXPERIMENTS

4.1 Road Characteristics

A two-lane (7 m) wide-level tangent road section (Road – I) is selected for simulation runs. As this is the road for which data were collected for calibration and validation of the simulation model, this is the benchmark road on which simulation experiments are done for different traffic flow rates.

4.1.1 Length of road sections

For unbiased estimation of traffic flow characteristics, a certain minimum road length should be simulated. The roads have intersections at closed space in urban areas. Road stretch of 500 meter length along with warming up zone of 300 meter length is chosen in this study for simulation experiments. The length is appropriate to study the traffic interactions and to estimate traffic flow parameters.

The simulation model requires the following traffic input for each vehicle at entry to the road section: vehicle type and its dimensions, entry coordinates, free speed, power mass ratio, entry time, entry speed, and lateral position at entry.

First five parameters are generated based on traffic flow and composition. However, it is not possible to estimate the entry speed and lateral position at entry. For the simulation experiments conducted for calibration and validation, the observed data for entry speed and lateral position was available. But for experiments of sensitivity analysis, these inputs need to be generated. The entry speed and lateral position of the vehicle depends upon the flow level and its interaction with other vehicle in close vicinity. Due to these factors a simple generation is not appropriate. To have a realistic generation of entry speed and lateral position, an additional warm up road section is included before the actual road stretch is to be simulated. The vehicles are generated and moved in the warm-up section as per the simulation model. The vehicle characteristics at the end of warm-up section are given as input for the actual road stretch and the simulation is continued. In this manner entry speed and lateral position will be quite realistic as it is output of the simulation flow process.

4.2 Traffic Characteristics

4.2.1 Traffic composition

Based on the observed traffic composition in Kanpur a benchmark traffic composition (Level I) is selected for simulation runs. This benchmark composition has 35 percent of motorized vehicles and 65 percent of non-motorized vehicles. The proportion of individual vehicle types is given in Table 1.

TABLE 1 Traffic Composition for Simulation Runs

Vehicle Type	Proportion in Percent (Level I)
Cars/Vans/Jeeps	5.0
Buses/Trucks/LCVs	2.5
Tempos/Auto Rickshaws	12.5
Motorized 2-Wheelers	15.0
Non-Motorized 2-Wheelers	50.0
Non-Motorized 3-Wheelers	14.5
Non-Motorized Other Traffic Entities	0.5
Motorized Vehicles	35.0
Non-Motorized Vehicles	65.0

LCV: Light Commercial Vehicles.
Tempo/Auto Rickshaw: Motorized Three Wheelers.

4.2.2 Traffic flow level

Simulation runs are planned at increasing flow levels until flow approaches unstable state. For road section simulation runs are made at unidirectional flow levels of (600, 900, 1200, 1800, 2400, 3000, 3600, 4200, and 4800 vph).

4.2.3 Free speed distribution

Free speed distribution is one of the most important characteristics affecting the operating speed of vehicles. Mean and standard deviation of free speeds for different vehicle types are given in Table 2.

4.3 Strategies for Simulation Runs

4.3.1 Length of simulation experiments

It is planned to simulate the traffic of 1600 vehicles, which results in adequate sample size for analysis. Duration of simulation runs varies depending upon flow rate to be simulated.

4.3.2 Starting conditions

When simulation is started with an empty road system, first few vehicles move under free flow condition, without any interactions with other vehicles present in the road system (transient state). To eliminate the effect of this transient state, it was decided to ignore the statistics of the first one hundred vehicles moving over the road stretch. The remaining sample size of 1500 vehicles is sufficiently large enough to draw conclusions and inferences.

5. STRATEGY FOR ANALYSIS OF SIMULATION RUNS

Performance measures considered for analysis at each simulation run are:

- Journey speed distribution of different vehicle types.
- Mean acceleration noise for different vehicle types. Acceleration noise of a vehicle is defined as the standard deviation of the variation about the mean acceleration.
- Road concentration: This is studied in three different ways:
    - Number of vehicles in the road section.
    - Road occupancy expressed as total vehicle area in relation to the road area.
    - Vehicle influence area expressed as proportion of road area.
- Overtaking/passing maneuvers executed by different combinations of overtaking and overtaken vehicle types.

6. ANALYSIS OF RESULTS FOR BENCHMARK ROAD (ROAD – I) AND TRAFFIC COMPOSITION OF LEVEL I

To estimate the flow level, which results in unstable flow condition resulting into platoon formation, the simulation results for high flow levels are studied along time at 100 second intervals. Figure 2 shows the variation of mean journey speeds of cars along time at flow level of 3000, 3600, 4200, and 4800 vph. It is observed that for flow levels of 3000 and 3600 vph there is no variation of journey speed along time except for minor random fluctuations. For flow levels of 4200 vph and 4800 vph, the mean journey speed reduces with time. This indicates that the flow may be in an unstable state.

The variation of road occupancy along time is also shown in Figures 3 and 4 for high flow levels of 3000, 3600, 4200, and 4800 vph. Road occupancy is observed at every 100 second interval until entry of last vehicle. As the number of vehicles being simulated is same for simulation experiment, the entry time of the last vehicle depends upon the flow level. These results show that at highest flow level of 4800 vph, the road occupancy is increasing with time while it has only minor random fluctuations at flow level of 3000 vph.

The above results have demonstrated that the simulated traffic flow is in an unstable state at higher flow levels. For a stable flow condition, the number of vehicles on the road stretch will have only random variations along time. Figures 5 and 6 show separately the cumulative number of vehicles entering and leaving at different times. The difference between these two curves represents the number of vehicles present on the road section (density). For the flow level of 3000 vph (Figure 5), the two curves are almost parallel and the system is in a stable state. The cumulative number of vehicles entering and leaving at different times are shown in Figure 6 for three flow levels of 3600, 4200, and 4800 vph. It is observed that number of vehicles leaving the road stretch at different times is almost identical for flow levels of 4200 and 4800 vph. This demonstrates that the flow is in an unstable state with concentration is increasing over time. Above study of simulation results along time clearly indicates that the traffic flow starts approaching the unstable state at flow level of 4200 vph. At flow levels of 4800 vph the system is in an unstable state. The capacity of this road could be around 4200 vph. Mean and standard deviation of journey speeds for different vehicle types are presented in Table 2 for different traffic flow levels. Figure 7 shows the journey speed-flow relationships for different vehicle types. Journey speeds reduce with flow and the level of speed reduction depends upon the vehicle type. Vehicles of high free speed, i.e., cars and motorized two wheelers have high speed reductions even at low flow levels as these vehicles encounter more interaction in the traffic stream. Journey speed of non-motorized vehicles has minor variations with flow level. These slow moving vehicles significantly affect the speed of faster vehicles, but they themselves keep moving at close to the free speed. At low flow levels, the journey speeds of motorized vehicles (i.e., car, tempo) are significantly higher than those of non-motorized vehicles. But as flow increases, this difference reduces and at very high flow levels the speeds of motorized and non-motorized vehicles are very close indicating that flow is moving in platoons and the speed is being dictated by the non-motorized vehicles.

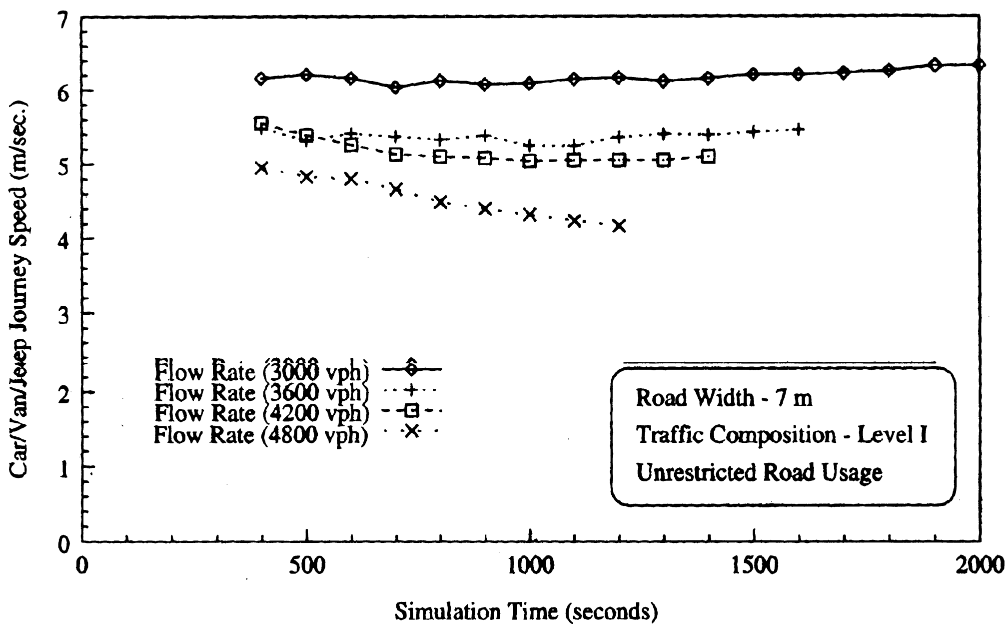

FIGURE 2 Mean journey speed–time relationships.

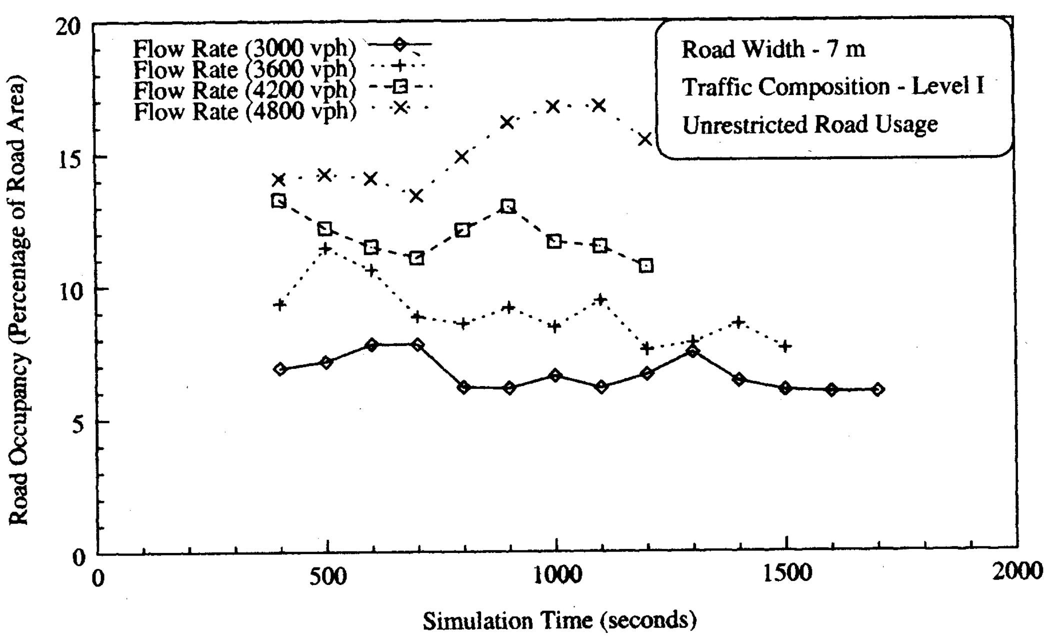

FIGURE 3 Road occupancy–time relationships.

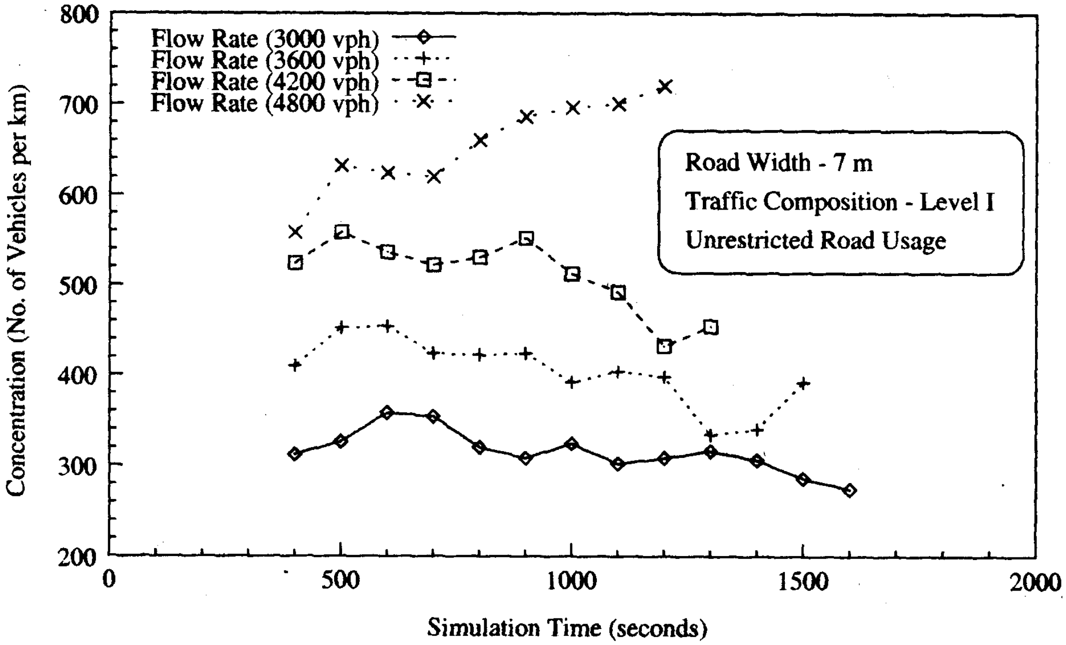

FIGURE 4 Density–time relationships.

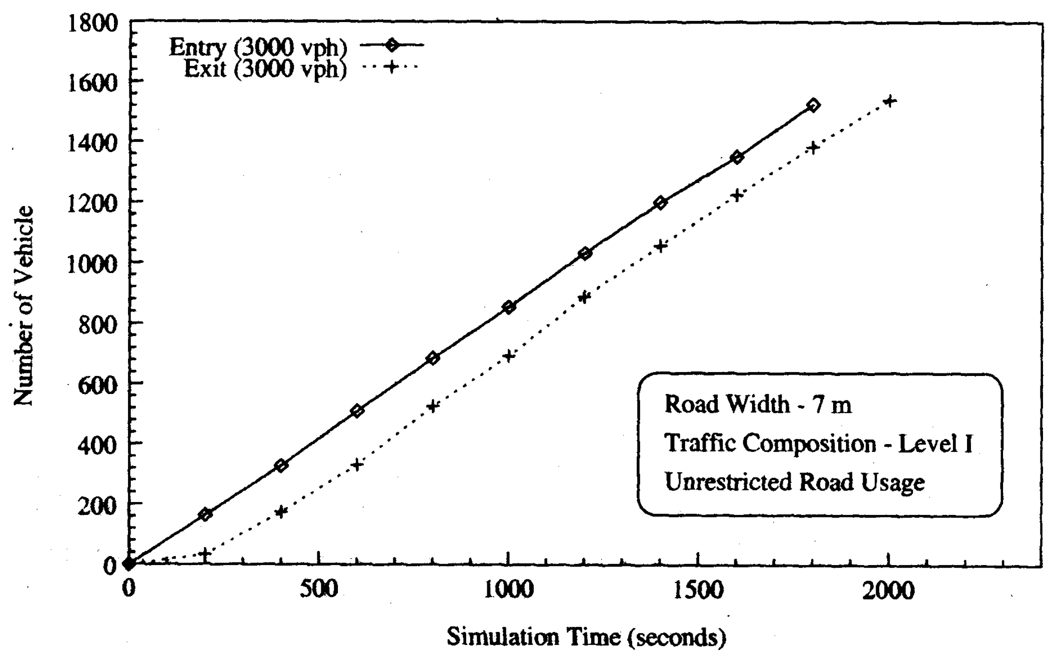

FIGURE 5 Entrance and exit flow rates–time relationships.

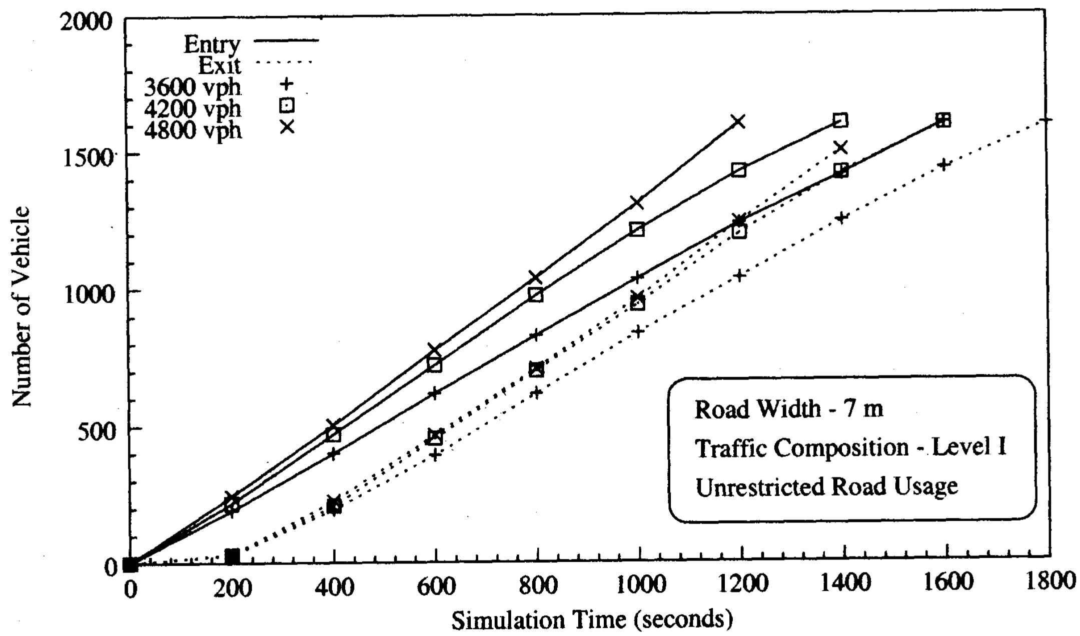

FIGURE 6 Entrance and exit flow rates–time relationships.

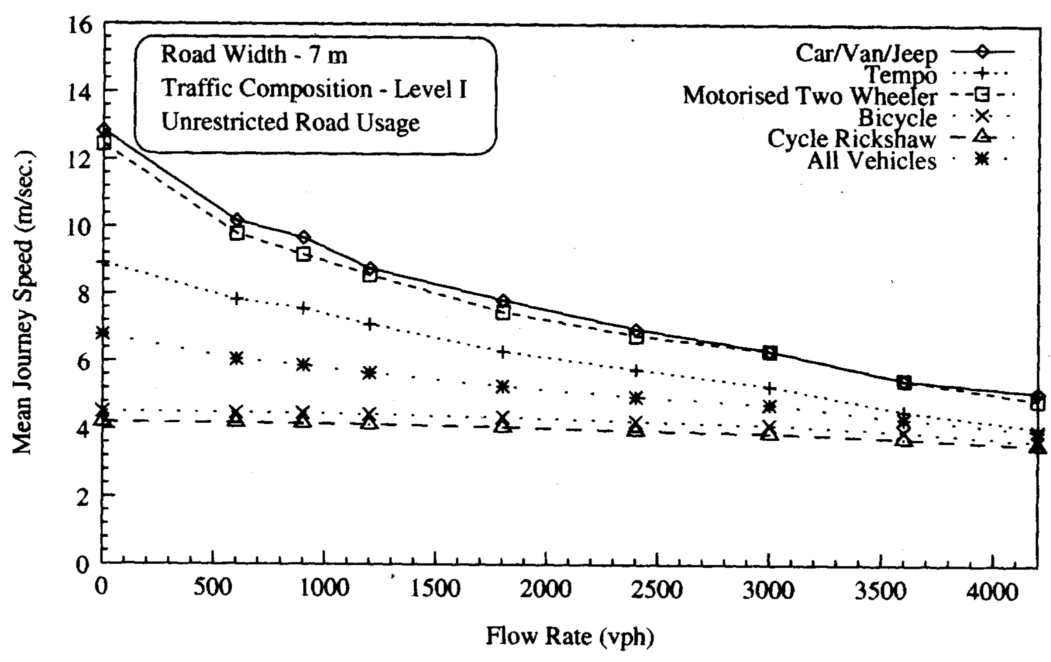

FIGURE 7 Mean journey speed–flow relationships.

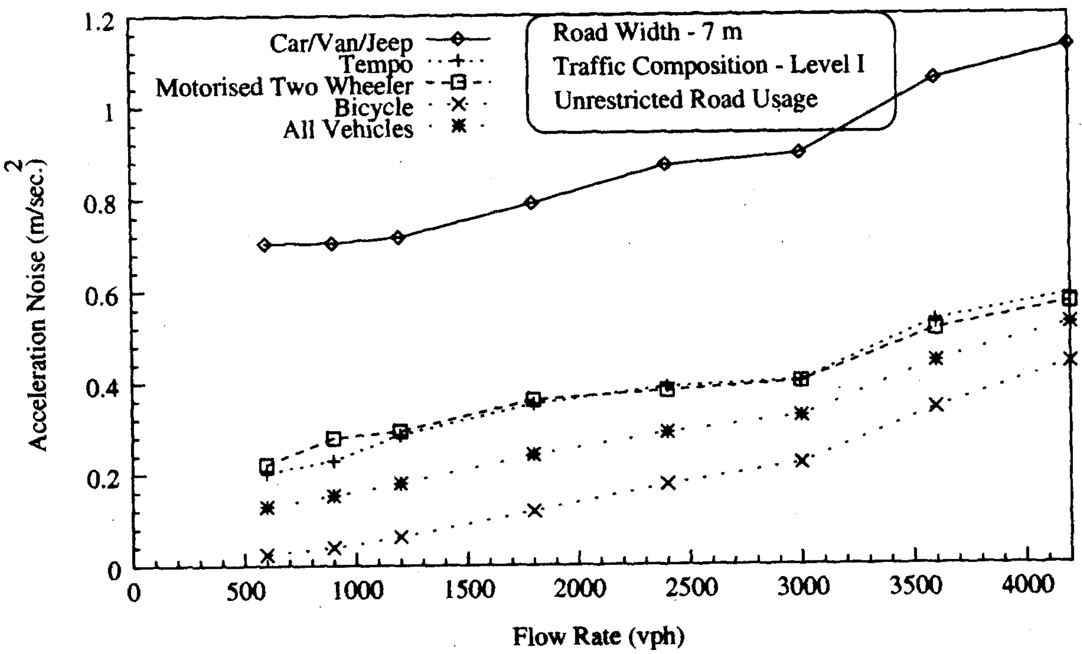

FIGURE 8 Acceleration noise–flow relationships.

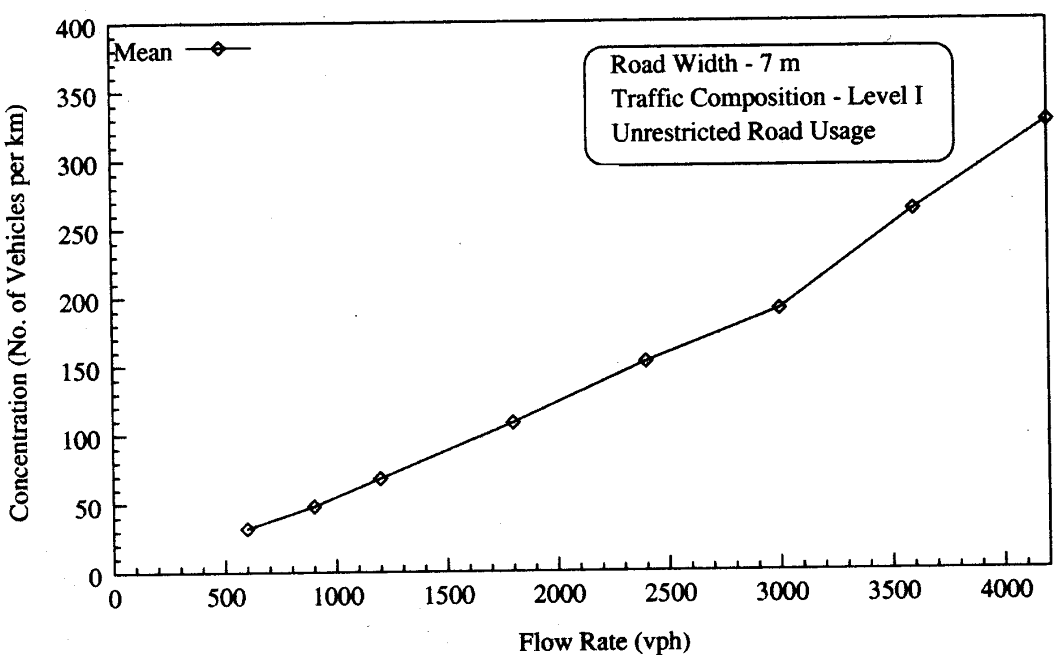

FIGURE 9 Density–flow relationships.

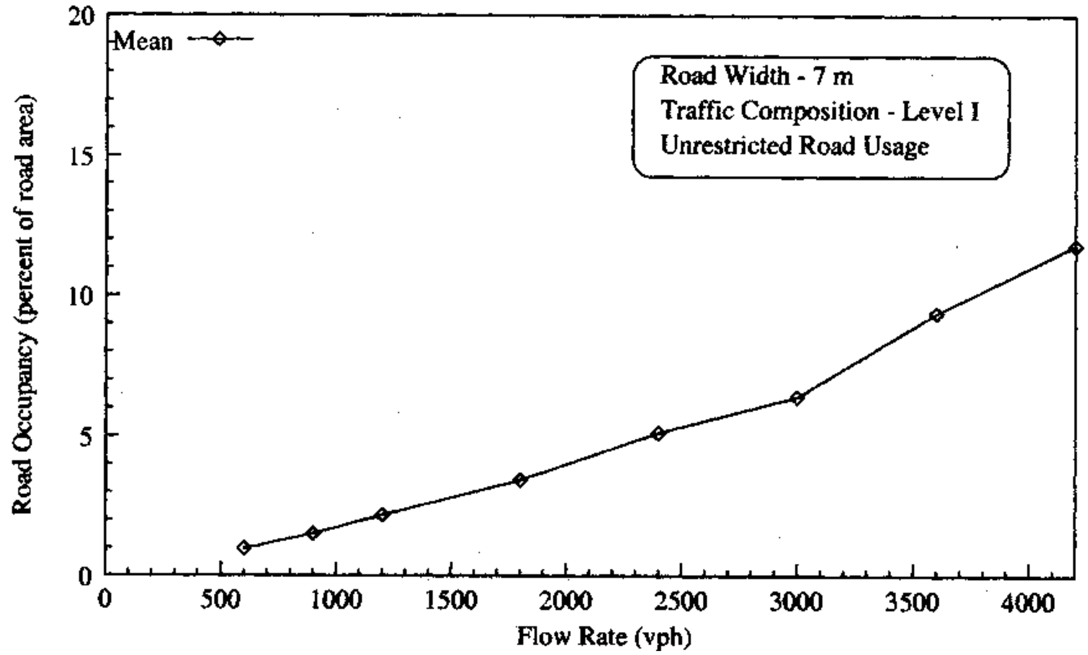

FIGURE 10 Road occupancy–flow relationships.

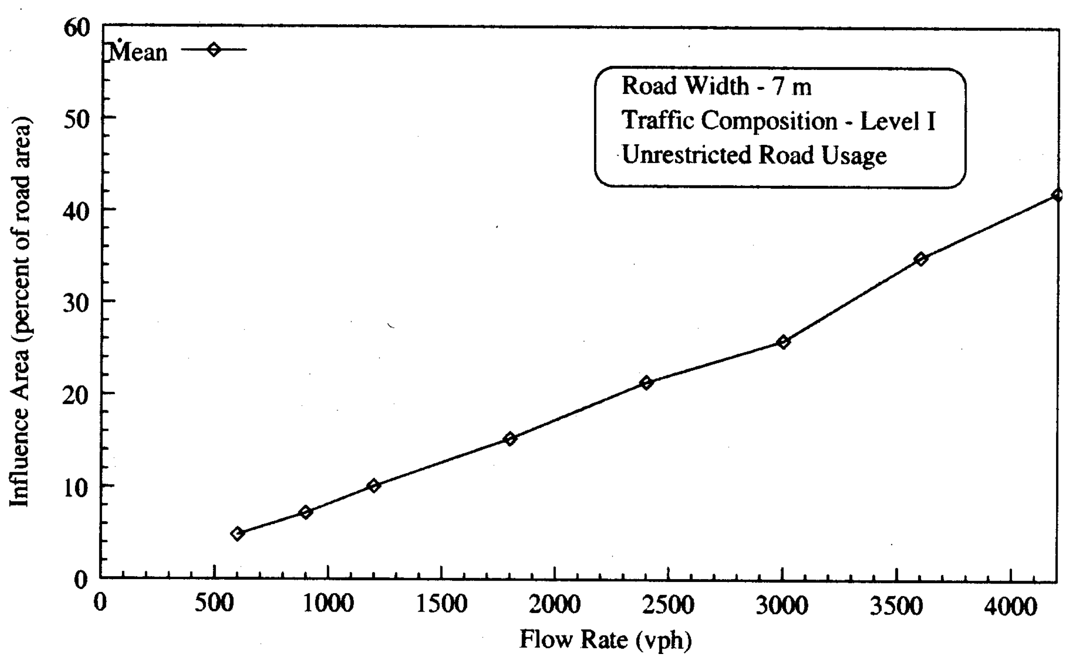

FIGURE 11 Influence area–flow relationships.

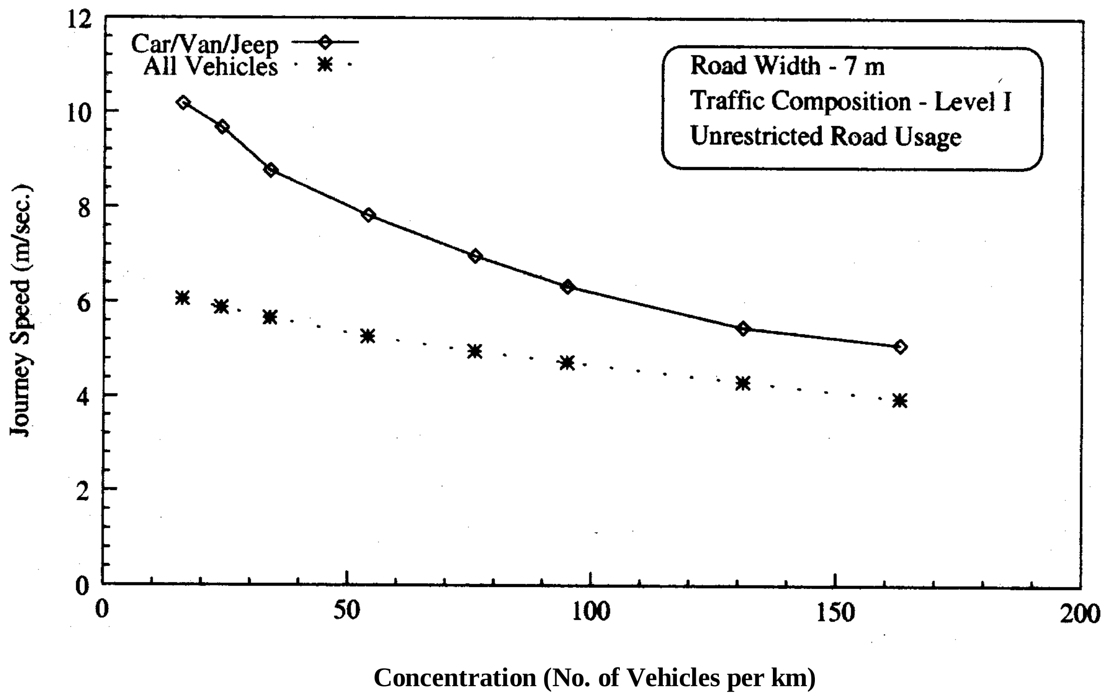

FIGURE 12 Mean journey speed–concentration relationships.

The variation of acceleration noise with flow level is shown in Figure 8. Acceleration noise is the standard deviation of mean acceleration. For faster vehicles like cars, the acceleration noise is very high as these vehicles interact with other vehicles and perform lot of acceleration and deceleration during the movement. The acceleration noise increases with flow level of all vehicle types indicating that model is realistically performing the interactions at low and high flow levels.

Road concentration is observed at every 100 second interval. The mean and maximum concentrations for different flow levels are shown in Figure 9. Results show that both concentrations increase almost linearly with flow level. As vehicles in the simulated traffic mix have wide variations in the dimensions, the concentration can be realistically expressed in terms of vehicle road occupancy and influence area with flow level is also shown in Figure 10 and Figure 11. It is observed that road occupancy increases at a certain rate up to 1800 vph and beyond this flow, the rate of increase is higher. The analysis of above results has demonstrated that speed and concentration are affected by flow level. The relations between speed and concentration are shown in Figure 12 for two cases, one for cars and the other for all vehicles. It is observed that mean journey speed of all vehicles varies almost linearly with concentration. However, for cars the speed variation is very high even at low concentration levels. It is observed that at flow level of 4200 vph, the mean concentration of the 500 meter long road stretch is 163 vehicles. As this is a two-lane road, the concentration per km per lane is also 163.

TABLE 2 Mean Journey Speeds of Vehicles for Different Flow Levels

Flow (vph)		Journey Speed: Car/ Van/ Jeep (m/sec)	Tempo/ Auto Rickshaw (m/sec)	Bus/ LCV (m/sec)	Motorized Two-Wheelers (m/sec)	Bicycle (m/sec)	Cycle Rick-Shaw (m/sec)	All Vehicles (m/sec)
Sample Size		80 *75	200 *186	40 *35	240 *226	800 *751	232 *220	1600 *1500
Free Speed	Mean	12.88	8.91	11.62	12.45	4.50	4.43	6.79
	St. Dev.	1.01	1.13	1.27	1.44	0.68	0.63	3.51
600	Mean	10.18	7.83	9.87	9.79	4.48	4.18	6.06
	St. Dev.	1.49	1.06	1.18	1.74	0.67	0.63	2.55
900	Mean	9.67	7.56	9.21	9.17	4.47	4.16	5.88
	St. Dev.	1.44	1.12	1.14	1.67	0.67	0.62	2.33
1200	Mean	8.76	7.10	9.00	8.56	4.43	4.13	5.66
	St. Dev.	1.43	1.07	1.28	1.58	0.66	0.62	2.07
1800	Mean	7.82	6.30	7.79	7.47	4.35	4.06	5.27
	St. Dev.	1.26	0.98	1.41	1.11	0.64	0.64	1.61
2400	Mean	6.97	5.77	6.88	6.78	4.32	3.96	4.96
	St. Dev.	0.89	0.80	1.05	0.90	0.62	0.57	1.34
3000	Mean	6.33	5.28	6.25	6.33	4.13	3.88	4.73
	St. Dev.	0.78	0.67	0.89	0.84	0.58	0.56	1.15
3600	Mean	5.46	4.54	5.18	5.47	3.93	3.73	4.31
	St. Dev.	0.67	0.59	0.68	0.73	0.54	0.51	1.15
4200	Mean	5.10	4.06	4.69	4.88	3.65	3.55	3.96
	St. Dev..	0.75	0.54	0.63	0.70	0.42	0.44	0.74

* After excluding statistics of first 100 vehicles.

TABLE 3 Number of Overtakings for Different Combinations of Vehicle Groups for Different Flow Levels

Flow (vph)	Number of Overtakings: Wide MV Ov. Wide MV	Wide MV Ov. Narrow MV	Narrow MV Ov. Wide MV	Narrow MV Ov. Narrow MV	Wide MV Ov. Wide NMV	Wide MV Ov. Narrow NMV	Narrow MV Ov. Wide NMV	Narrow MV Ov. Narrow NMV	Total
600	51	9	53	9	538	1481	491	1203	5064
900	61	20	58	24	732	2126	650	1722	7201
1200	91	12	111	16	942	2611	836	2219	9255
1800	140	41	142	40	1268	3432	1128	2941	12757
2400	220	46	218	64	1526	4192	1353	3641	16032
3000	279	55	324	72	1768	4372	1561	4160	18386
3600	367	65	524	125	1708	4279	1578	4402	19634
4200	506	108	680	167	1687	4374	1702	4731	20694

MV, motorized vehicle; NMV, non-motorized vehicle; Ov., overtakes.

The overtakings/passings performed in the simulation model for different vehicle combinations are presented in Table 3 for different flow levels. These operations are with respect to 1500 vehicles for which statistics are studied. These overtakings/passings also include those operations where a vehicle may pass in the adjoining lane without any interaction. Results indicate that up to 3000 vph the overtakings performed on wide motorized vehicles (car, tempo, and bus) both by wide and narrow motorized vehicles are almost same. These overtakings are generally performed on tempos, which has low free speeds. Beyond flow levels of 3000 vph, narrow motorized vehicles perform more overtakings than wide motorized vehicles. This means that scooters perform more overtakings on tempos than cars/jeeps. At these high flow levels, the narrow motorized vehicles are able to perform more maneuvering than wide vehicles. It is also observed that overtakings of non-motorized vehicles both by wide and narrow motorized vehicles increase with flow level up to 3000 vph. Beyond this level, number of overtakings show a little downward trend. This happens because of close headways, the overtakings/passings are difficult to perform.

7. LEVEL OF SERVICE

The level of service (LOS) is a composite of several operating characteristics that are supposed to measure the quality of service as perceived by the user at different flow levels. For example one could consider travel speed, congestion level, freedom to maneuver etc. to be factors contributing to LOS. Based on the simulation results of benchmark road (Road – I) and traffic composition (Level I), the following operating characteristics may be considered to define the LOS.

Journey Speed of Cars: As cars have the highest free speed, they encounter lot of interactions. This speed is significantly affected by the flow level.

Journey Speed of Motorized Two Wheelers: The free speed of these vehicles is slightly lower than that of cars. As these vehicles are narrow they are able to perform more maneuverings in the heterogeneous traffic mix. Further the proportion of these vehicles is also significant in the traffic mix. The journey speed of non-motorized vehicles do not really define the quality of service as they are able to move at speeds closer to the free speeds.

Concentration: Concentration defined in terms of number of vehicles per kilometer defines the longitudinal spacing between the vehicles. Ability to overtake/pass depends upon the spacing between the vehicles in its neighborhood. Congestion is directly defined by the concentration level.

Road Occupancy: This is the physical area of the vehicles in the road section relative to the road area. This measure is adopted as the vehicles of heterogeneous traffic mix have wide variations in their dimensions.

Considering the nature of simulation results with reference to different operating characteristics, the performance can be classified into following four groups.

LOS I: This is the level for reasonably free flow conditions and operates up to a maximum service volume of 600 vph. The mean journey speeds of cars and motorized two-wheelers is up to 80 percent of their free speeds, i.e., cars 10.30 m/sec (37 km/h) and motorized two-wheelers 10.0 m/sec (36 km/h). The average longitudinal spacing is about 65 meters with a density of 30 vehicles per km. The vehicle area occupied (road occupancy) is just about 1 percent of the total road area.

LOS II: Flow conditions are stable and operate up to maximum service volume of 1800 vph. The average operating speed of cars and motorized two wheelers lies between 60–80 percent of their free speed, i.e., cars 7.7 m/sec (28 km/h) and motorized two-wheelers 7.5 m/sec (27 km/h). The average longitudinal spacing is just 20 meters with a concentration of 100 vehicles per km and the average road occupancy is 3.5 percent of the total road area.

LOS III: Increase in flow level significantly deteriorates the service. The difference in the operating speeds of car and non-motorized vehicles considerably narrows down. At the maximum service volume of 3000 vph, the operating speed of cars and motorized two-wheelers is only 50 percent of their free speeds, i.e., cars 6.4 m/sec (23 km/h) and motorized two-wheelers 6.2 m/sec (22 km/h). The maneuverability is seriously limited due to high proportion of constrained flow. The average longitudinal spacing is about 11 meters with a density of 180 vehicles per km. The vehicle road occupancy increases to 6.5 percent of road space.

LOS IV: Flow conditions are unstable and operate up to maximum volume of 4200 vph. The mean travel speed of cars and motorized two wheelers at maximum service volume is just 40 percent of their free speed, i.e., cars 5.20 m/sec (19 km/h) and motorized two-wheelers 5.0 m/sec (18 km/h). Maneuverability gets seriously affected, as gaps are small to allow overtakings and passings. Average longitudinal spacing is just about 6 meter, with density of 320 vehicles per km. The road occupancy level increases to 12 percent.

Table 4 summarizes the numerical value of operating characteristics for the four levels of service. The maximum possible flow for each LOS is also specified. Though the descriptions of LOS are specified with numerical values, it may be emphasized that a certain amount of subjectivity is involved because of large number of variables coming into play.

8. CONCLUSION

This paper has attempted to provide a classification of level of service for urban heterogeneous traffic condition. The level of service (LOS) is a composite of several operating characteristics that are supposed to measure the quality of service as perceived by the user at different flow levels. The operating characteristics considered to define the LOS are: journey speeds of cars and motorized two-wheelers; concentration; and road occupancy. Based on the simulation results of benchmark road (Road – I) and traffic composition (Level I) the levels of service are classified into the four groups (LOS I, II, III, and IV). LOS classification evolved in this study will be helpful to identify deficiencies of an urban road system and to plan for alternative improvement measures to attain a desired level of service. The study of the simulation results during analysis clearly demonstrates the capability of model to simulate urban heterogeneous traffic flow condition.

TABLE 4 Level of Service for 7-m Wide Road, Traffic Composition of Level I and Unrestricted Road Usage for Non-Motorized Vehicles

Level of Service (LOS)	**I**	**II**	**III**	**IV**
Maximum Service Flow (MSF) (vph)	600	1800	3000	4200
1.1.1 Cars				
Free Speed (m/sec)	12.88			
Travel Speed (m/sec) Travel Speed (percent of free speed)	10.30 ≥80	7.73 ≥60	6.44 ≥50	5.15 ≥40
1.1.2 Motorized Two Wheelers				
Free Speed (m/sec)	12.45			
Travel Speed (m/sec) Travel Speed (percent of free speed)	9.96 ≥80	7.47 ≥60	6.23 ≥50	5.0 ≥40
Density (veh/km)	≤30	≤100	≤180	≤320
Road Occupancy (percent of road area)	≤1.0	≤3.5	≤6.5	≤12.0

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