SIMULATION OF HIGHLY HETEROGENEOUS TRAFFIC FLOW CHARACTERISTICS

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ABSTRACT

Simulation models are mathematical/logical representations of real-world systems. Microscopic traffic simulation models have been playing an important role in traffic engineering and particularly in cases, in which field studies, involving extensive data collection, over a wide range, is difficult or expensive to conduct. As the available simulation models can only replicate homogeneous traffic flow, a model of heterogeneous traffic flow, named, HETEROSIM was developed to simulate heterogeneous traffic flow. In this model, a dynamic stochastic type discrete event simulation is adopted in which the aspects of interest are analysed numerically with the aid of a computer program. The model was validated using field observed data of traffic flow. Then, the model was applied to measure one of the fundamental charactertistics of traffic flow, namely concentration. It is a broader term encompassing both density and occupancy. Occupancy takes into account the traffic composition and speed, and hence, occupancy is more meaningful than density. The concept of occupancy can not be directly applied under heterogeneous traffic conditions, as the traffic has no lane discipline. In this paper, a new concept named, 'area-occupancy' is proposed to measure traffic concentration.

INTRODUCTION

Simulation models are mathematical/logical representations of real-world systems, which take the form of software executed on a digital computer in an experimental fashion. The user of traffic simulation software specifies a "scenario" as model inputs. The simulation-model results describe system operations in two formats: (1) statistical and (2) graphical. The numerical results provide the analyst with detailed quantitative descriptions of what is likely to happen. The graphical and animated representations of the system functions can provide insights so that the trained observer can gain an understanding of why the system is behaving this way. However, it is the responsibility of the analyst to properly interpret the wealth of information provided by the model to gain an understanding of cause-and-effect relationships.

Simulation models may also be classified as being static or dynamic, deterministic or stochastic, and discrete or continuous. A simulation model, which does not require any random values as input, is generally called deterministic, whereas a stochastic simulation model has one or more random variables as inputs. Random inputs lead to random outputs and these can only be considered as estimates of the true characteristics of the system being modeled. Discrete and continuous models are defined in an analogous manner. The choice of whether to use a discrete or continuous simulation model is a function of the characteristics of the system and the objectives of the study (Banks et al. 2004). For this study, a dynamic stochastic type discrete event simulation is adopted in which the aspects of interest are analysed numerically with the aid of a computer program.

As this study pertains to the heterogeneous traffic conditions prevailing in India, the available traffic simulation models, such as CORSIM, MITSIM, VISSIM, etc. which are based on homogeneous traffic conditions, where clear lane and queue discipline exists, are not applicable to study the heterogeneous traffic flow characteristics. Also, the research attempts made to model heterogeneous traffic flow (Katti and Ragavachari 1986; Marwah 2000; Kumar and Rao 1996; Khan and Maini 2000) are limited in scope and do not address all the aspects comprehensively. Hence, there was a need to develop appropriate models to simulate heterogeneous traffic flow. Accordingly, a model of heterogeneous traffic flow, named, HETEROSIM was developed (Arasan and Koshy 2005). The application of the model to study the traffic flow characteristics, at micro level, is dealt with, after a brief description of the important features of the model and its validation, in this paper.

MODELLING HETEROGENEOUS TRAFFIC FLOW

The framework of the heterogeneous traffic flow simulation model, HETEROSIM, is explained briefly here to provide the background for the study. For the purpose of simulation, the entire road space is considered as single unit and the vehicles are

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represented as rectangular blocks on the road space, the length and breadth of the blocks representing, respectively, the overall length and the overall breadth of the vehicles (Figure 1). The entire road space is considered to be a surface made of small imaginary squares (cells of convenient size - 100 mm square in this case); thus, transforming the entire space into a matrix. The vehicles will occupy a specified number of cells whose co-ordinates would be defined before hand. The front left corner of the rectangular block is taken as the reference point, and the position of vehicles on the road space is identified based on the coordinates of the reference point with respect to an origin, chosen at a convenient location, on the space. This technique will facilitate *identification* of the type and location of vehicles on the road stretch, at any instant of time, during the simulation process.

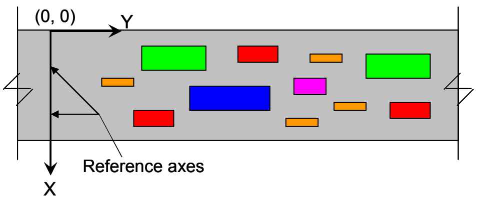


Figure 1: Reference Axes for Representing Vehicle Positions on the Roadway

The simulation model uses the interval scanning technique with fixed increment of time. For the purpose of simulation, the length of road stretch as well as the road width can be varied as per user specification. Due to possible unsteady flow condition at the start of the simulation stretch, a 200m long road stretch, from the start of the simulation stretch, is used as warm up zone. Similarly, to avoid the possible unsteady flow at the end of the simulation stretch due to free exit of vehicles, a 200m long road stretch at the end of the simulation stretch is treated as tail end zone. Thus, the data of the simulated traffic-flow characteristics are collected covering the middle portion between the warm up and tail end zones. Also, to eliminate the initial transient nature of traffic flow, the simulation clock is set to start only after the first 50 vehicles reached the exit end of the road stretch. The model measures the speed maintained by each vehicle when it traverses a given reference length of roadway. The output also includes, the number of each category of vehicles generated, the values of all the associated headways generated, number of vehicles present over a given length of road (concentration), number of overtaking maneuvers made by each vehicle, and speed profile of vehicles.

The logic formulated for the model also permit admission of vehicles in parallel across the road width, since it is common for smaller vehicles such as motorised two-wheelers to move in parallel in the traffic stream without lane discipline. The model was implemented in *C++* programming language with modular software design. The flow diagram illustrating the basic logical aspects involved in the program is shown as Figure 2.

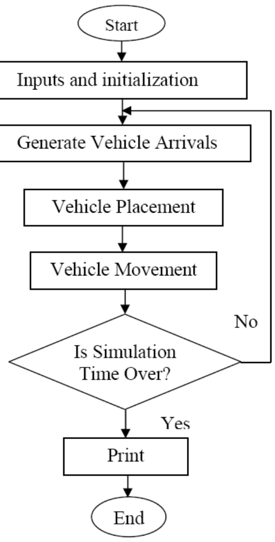


Figure 2: Major Logical Steps of the Simulation Model

Vehicle Generation

In a stochastic traffic simulation process, the vehicles arrive randomly, and they may have varying characteristics (e.g. speed and vehicle type). Traffic-simulation models, therefore, require randomness to be incorporated to take care of the stochasticity. This is easily done by generating a sequence of random numbers. For generation of headways, free speed, etc., the model uses several random number streams, which are generated by specifying separate seed values. Whenever a vehicle is generated, the associated headway is added to the sum of all the previous headways generated to obtain the cumulative headway. The arrival of a generated vehicle occurs at the start of the warm-up road stretch when the cumulative headway equals the simulation clock time. At this point of time, after updating the positions of all the vehicles on the road stretch, the vehicle-placement logic is invoked.

Vehicle Placement

Any generated vehicle is placed at the beginning of the simulation stretch, considering the safe headway (which is based on the free speed assigned to the entering vehicle), the overall width of the vehicle and lateral clearances. If the longitudinal gap in front is less than the minimum required safe gap (space headway), the entering vehicle is assigned the speed of the leading vehicle, and once again the check for safe gap is made. If the gap is still insufficient to match the reduced speed of the entering vehicle, it is kept as backlog, and its entry is shifted to the next scan interval. During every scan interval, the vehicles remaining in the backlog will be admitted first, before allowing the entry of a newly generated vehicle.

Vehicle Movement

This module of the program deals with updating the positions of all the vehicles in the study road stretch sequentially, beginning with the exit end, using the formulated movement logic. Each vehicle is assumed to accelerate to its free speed or to the speed limit specified for the road stretch, whichever is minimum, if there is no slow vehicle immediately ahead. If there is a slow vehicle in front, the possibility for overtaking the slow vehicle is explored. During this phase, the free longitudinal and transverse spacing available for the subject vehicle (fast moving vehicle), on the right and left sides of the vehicle in front (slow vehicle), are calculated. If the spacing is found to be adequate (at least equal to the movable distance of the vehicle intending to overtake plus the corresponding minimum spacing in the longitudinal direction and the minimum required lateral spacing in the transverse direction), an overtaking maneuver is performed. If overtaking is not possible, the fast vehicle decelerates to the speed of the slow vehicle in front and follows it.

The model is also capable of displaying the animation of simulated traffic movements through mid block sections. The animation module of the simulation model displays the model's operational behavior graphically during the simulation runs. The snapshot of animation of traffic flow, obtained using the animation module of HETEROSIM, is shown in Figure 3. The model has been applied for a wide range of traffic conditions (free flow to congested flow conditions) and has been found to replicate the field observed traffic flow to a satisfactory extent through an earlier study (Arasan and Koshy 2005). It may be noted that though the model is primarily intended for simulating heterogeneous traffic flow, it can also be used to simulate homogeneous traffic condition by suitably changing the input data with regard to roadway and traffic conditions.

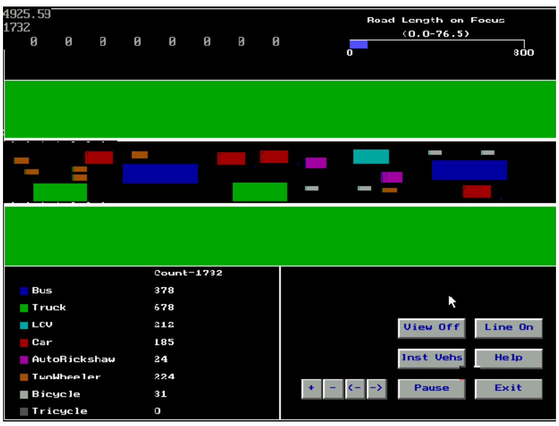


Figure 3: Snapshot of Animation of Simulated Heterogeneous Traffic Flow

Though the model is generally validated, it was decided to check for the appropriateness of the model for the specific requirements of this study by revalidating the model. Field data collected on traffic flow characteristics such as free speed, volume, composition, etc. were used in the validation of the simulation model. The simulation runs were made with different random number seeds and the averages of the values were taken as the final model output.

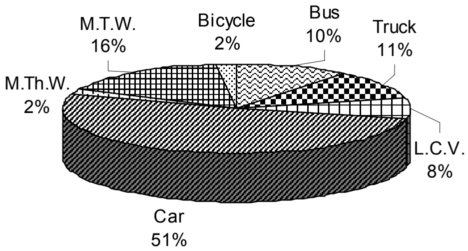
DATA COLLECTION

Study Stretch

The stretch of intercity roadway between km 99.4 and km 99.7, of National Highway No. 45 between the cities, Chennai and Chengalpet, in the southern part of India, was selected for collection of traffic data for the study. The study stretch is a four-lane divided road with 7.5 m wide main carriageway and 1.25 m of paved shoulder for each direction of movement. The stretch is straight and level with no side road connections. Also, the traffic flow on the study stretch was unhindered by the road side land uses.

Traffic Characteristics

Collection and analysis of data play a pivotal role in the development of successful simulation models. The field data inputs required for the model were collected at the selected stretch, which had a total carriageway width (including shoulder) of 8.75 m for each direction. A digital video camera was used to capture the traffic flow for a total duration of 1h. The video captured traffic data was then transferred to a Work Station (computer) for detailed analysis. The inputs required for the model to simulate the heterogeneous traffic flow are: road geometry, traffic volume, and composition, vehicle dimensions, minimum and maximum lateral spacing between vehicles, minimum longitudinal spacing between vehicles, free speeds of different types of vehicles, acceleration and deceleration characteristics of vehicles, the type of headway distribution and the simulation period. The required input traffic data for simulation purpose was obtained by running the video of the traffic flow at a slower speed (⅛th of the actual speed) to enable one person to record the data by observing the details displayed on the monitor of the computer. A total of 595 vehicles were observed to pass through the study section in one hour and the composition of the measured traffic volume on the study stretch is as depicted in Figure 4. It may be noted that Animal drawn vehicles and Tricycles, which may be present in small numbers on certain intercity roads, are not present on the study stretch. The free speeds of the different categories of vehicles were also estimated by video capturing the traffic under free-flow conditions. The speeds of the different categories of vehicles were measured by noting the time taken by the vehicles to traverse a trap length of 30 m. The observed mean, minimum and maximum free speeds of various classes of vehicles and their corresponding standard deviations are shown in columns (2), (3) ,(4) and (5) respectively of Table 1. The overall dimensions of all categories of vehicles, adopted from literature (Arasan and Krishnamurthy 2008), are shown in columns (2) and (3) of Table 2.



L.C.V. - Light Commercial Vehicles, M.Th.W. – Motorised Three-Wheelers, M.T.W. - Motorised Two-Wheelers

Figure 4: Traffic Composition at the Study Stretch

Table 1: Free Speed Parameters of Vehicles

Vehicle type (1)	Free speed parameters in km/h			
	Mean (2)	Min. (3)	Max. (4)	Std. Deviation (5)
Buses	70.0	55.3	84.3	8.9
Trucks	63.1	44.3	80.5	11.0
L.C.V.	66.8	54.9	83.4	8.2
Cars	85.1	58.6	118.0	17.3
M.Th.W	50.2	45.5	61.3	4.9
M.T.W	57.9	38.9	83.8	11.2
Bicycles	14.0	10	20	4.5

L.C.V. - Light Commercial Vehicles, M.Th.W. – Motorised Three-Wheelers, M.T.W. - Motorised Two-Wheelers

Table 2: Observed Vehicle Dimensions

Vehicle type (1)	Average overall dimension (m)	
	Length (2)	Width (3)
Buses	10.3	2.5
Trucks	7.5	2.5
L.C.V.	5.0	1.9
Cars	4.0	1.6
M.Th.W	2.6	1.4
M.T.W	1.8	0.6
Bicycles	1.9	0.5

L.C.V. - Light Commercial Vehicles, M.Th.W. – Motorised Three-Wheelers, M.T.W. - Motorised Two-Wheelers

Any vehicle moving in a traffic stream has to maintain sufficient lateral clearance on the left and right sides with respect to other vehicles/curb/ median to avoid side friction. These lateral clearances depend upon the speed of the vehicle being considered, speeds of the adjacent vehicles in the transverse direction, and their respective types. The minimum and maximum values of lateral-clearance share adopted from an earlier study (Arasan and Krishnamurthy 2008), are given in columns (2) and (3), respectively, of Table 3. The minimum and the maximum clearance-share values correspond to, respectively, zero speed and free speed conditions of respective vehicles. The lateral-clearance share values are used to calculate the actual lateral clearance between vehicles based on the type of the subject vehicle and the vehicle by the side of it. For example, at zero speed, if a motorized two-wheeler is beside a car, then, the clearance between the two vehicles will be 0.2 + 0.3 = 0.5m. The data on, acceleration values of different vehicle categories, at various speed ranges, taken from available literature (Arasan and Krishnamurthy 2008), are shown in Table 4.

Table 3: Minimum and Maximum Lateral Clearances

Vehicle type (1)	Lateral-clearance share (m)	
	At zero speed (2)	At a speed of 60 km/h (3)
Buses	0.3	0.6
Trucks	0.3	0.6
L.C.V.	0.3	0.5
Cars	0.3	0.5
M.Th.W	0.2	0.4
M.T.W	0.1	0.3
Bicycles	0.1	0.3*

*- Maximum speed of these vehicles is 20 km/h

Table 4: Acceleration Rates of Different Categories of Vehicles

Vehicle type (1)	Rate of acceleration at various speed ranges (m/s^2)		
	0-20 km/h (2)	20- 40 km/h (3)	Above 40 km/h (4)
Buses	0.89	0.75	0.67
Trucks	0.79	0.50	0.43
L.C.V.	0.82	0.45	0.35
Cars	1.50	1.10	0.95
M.Th.W	1.01	0.45	0.30
M.T.W	1.35	0.80	0.60
Bicycles	0.10	-	-

L.C.V. - Light Commercial Vehicles, M.Th.W. – Motorised Three-Wheelers, M.T.W. - Motorised Two-Wheelers

MODEL VALIDATION

For the purpose of validation, the simulation model was used to replicate the heterogeneous traffic flow on a stretch of road. The total length of road stretch, for simulation purpose, was taken as 1,400 m. The simulation model was run with three random number seeds, and the average of the three runs was taken as the final output of the model. The observed roadway condition, traffic volume and composition were given as input to the simulation process. The inter arrival time (headway) of vehicles was found to fit into negative exponential distribution and the free speeds of different categories of vehicles, based on the results of an earlier study, (Arasan and Koshy, 2005) was assumed to follow Normal distribution. These distributions, then, formed the basis for input of the two parameters for the purpose of simulation. To check for the validity of the model, it was decided to consider the derived traffic flow characteristics at the micro level so that the validation is satisfactory. Accordingly, the field observed and simulated mean speeds of each of the categories of vehicles were compared to check for the validity of the model. The results of the experiment, for the observed traffic volume of 595 vehicles per hour, are shown in Figure 5. It can be seen that the simulated speed values significantly replicate the field observed speeds for all vehicle types.

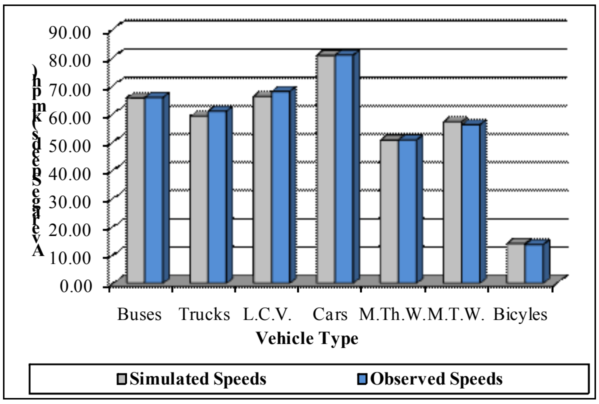


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Figure 5: Model Validation by Comparison of Observed and Simulated Speeds

A statistical validation of the model, based on observed and simulated speeds of different categories of vehicles, was also done by conducting t-test. The value of t-statistic, calculated based on the observed data (t_0), is 0.89. The critical value of t statistic for level of significance of 0.05 (95% confidence limit), at 6 degrees of freedom, obtained from standard t-distribution table is 2.97. Thus, it can be seen that the value of t statistic, calculated based on the observed data, is less than the corresponding table value. This implies that there is no significant difference between the simulated and observed means speeds.

MODEL APPLICATION

The 'HETEROSIM' model can be applied to measure the heterogeneous traffic flow characteristics on roads for varying traffic and roadway conditions. Here, the application of the model is specific to measure one of the fundamental charactertistics of traffic flow, namely concentration. Concentration is a road traffic measure which explains the extent of usage of road space by vehicles. It is a broader term encompassing both density and occupancy. Density is a measure of concentration over space and occupancy measures concentration over time of the same vehicle stream. Occupancy takes into account the traffic composition and speed, in its measurement and hence, occupancy is more meaningful than density. The concept of occupancy can not be directly applied under heterogeneous traffic conditions, as the traffic has no lane discipline. In this paper, a new concept named, 'area-occupancy' is proposed to measure traffic concentration of any roadway and traffic conditions (Arasan and Dhivya 2008). Considering a stretch of road, area-occupancy is expressed as the proportion of time the set of observed vehicles occupy the detection zone on the chosen stretch of a roadway. Thus, area-occupancy can be expressed as follows;

$$AreaOccupancy = \frac{a_i \sum_i (t_i)_{AO}}{AT} \quad (1)$$

where, $(t_i)_{AO}$ = time during which the detection zone is occupied by vehicle i and the subscript, $_{AO}$ stands for area-occupancy.

a_i = area of the detection zone occupied by vehicle i during time t_i

A = area of the whole of the road stretch

T = total observation period.

Validation of Concept of Area-Occupancy

The concept of area-occupancy can be said to be applicable for any traffic stream under both heterogeneous and homogeneous traffic conditions. To check for the validity of the concept of area-occupancy, as the first step, the density and area-occupancy of a homogeneous traffic stream are related independently to the speed and flow of a stream under homogeneous (cars-only) traffic condition. Since the scope of the experiment is to prove a fundamental relationship, uniform traffic flow on a single traffic lane was considered. Accordingly, the HETEROSIM model was used for simulating the cars-only traffic (100% passenger cars of assumed length 4 m and width 1.6 m) on a 3.5m wide road space - single traffic lane (with no passing). The traffic flow was simulated for one hour (T = 1h) over a stretch of one km. During validation of the model, it was found that three simulation runs (with three different random seeds) were sufficient to get consistent simulation output to replicate the field observed traffic flow. Hence, for model application also, the simulation runs were made with three random number seeds and the averages of the three values were taken as the final model output. The simulation was run with volumes varying from a low level to the capacity flow condition. Using the features of the simulation model, the times $(t_i)_{AO}$ were recorded for each of the simulated vehicles considering a detection zone length of 3m. The density *(k)* was calculated using the following equation, $q = ku$, where, q = flow of the traffic stream and u_s = space mean speed of the traffic stream. Also, area-occupancy was calculated using equation (1). To depict the validity of area-occupancy, the results of the simulation experiment were used to make plots relating (i) area-occupancy with speed and flow and (ii) density with speed and flow as shown in Figure 6and 7 respectively. It can be seen that area-occupancy and density exhibit similar trends of relationships with speed and flow. The trends of the curves relating area-occupancy with (i) speed and (ii) flow (Figure 6) are the same as those relating density with (i) speed and (ii) flow (Figure 7). Thus it can be concluded that area-occupancy is a valid measure which can be used to represent the concentration of road traffic.

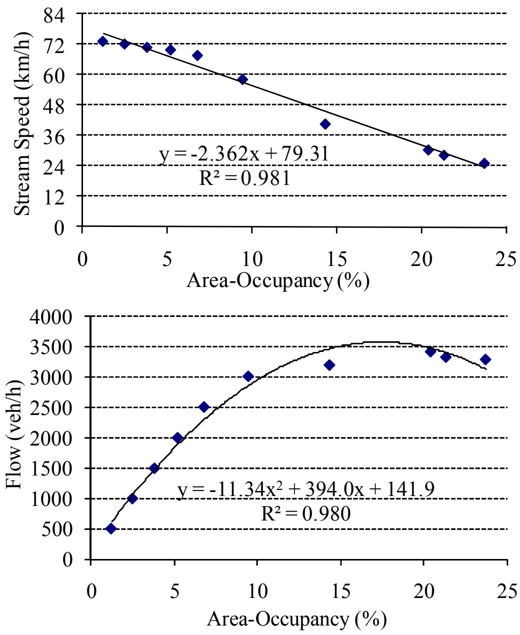
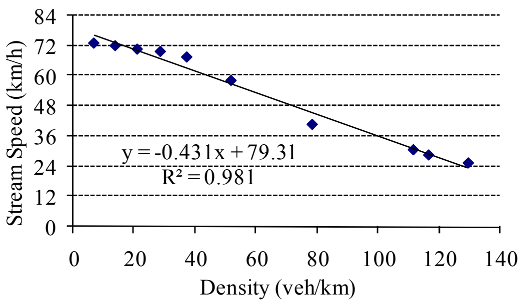


Figure 6: Relationship between Area-Occupancy, Speed and Flow of Homogeneous Traffic



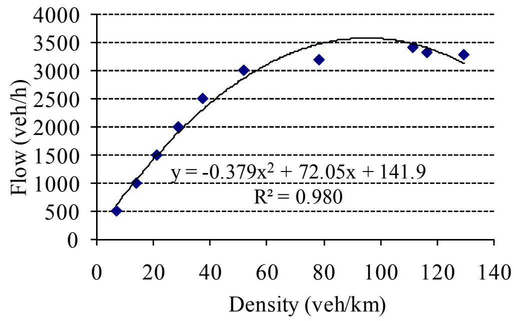


Figure 7: Relationship between Density, Speed and Flow of Homogeneous Traffic

Area-Occupancy of Heterogeneous Traffic

The concept of area-occupancy was applied to heterogeneous traffic condition and relationships were developed between flow, area-occupancy and traffic stream speed. The simulation model was used to simulate one-way flow of heterogeneous traffic on a six lane divided road, with 10.75m wide main carriageway and 1.5m of paved shoulder, for various volume levels with a representative traffic composition prevailing on Intercity roads (Figure 4). The traffic flow was simulated on one km long road stretch for one hour. Using the features of the simulation model, the time $(t_i)_{AO}$ was recorded for each of the simulated vehicles, considering a detection zone of length 3m. The area-occupancy was estimated using equation (1). The average stream speeds and flow of the heterogeneous traffic, for various volume levels were also obtained as simulation output. Then, plots relating the area-occupancy, speed and flow, were made as shown in Figure 8.

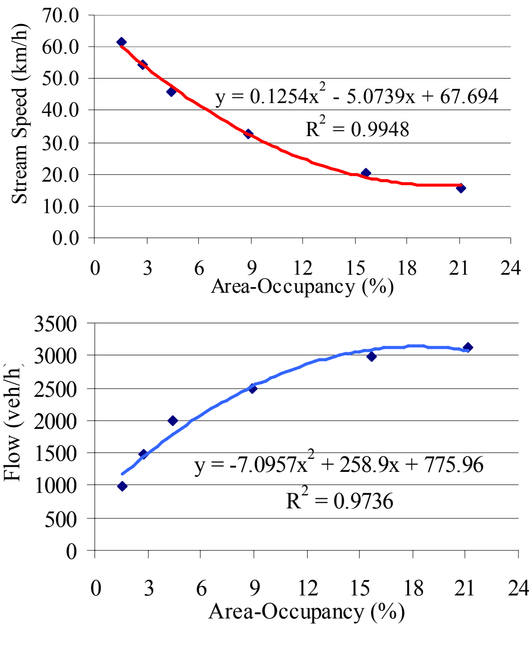


Figure 8: Relationship between Area-Occupancy, Speed and Flow of Heterogeneous Traffic

It may be noted that the decreasing trend of the speed with increase in area-occupancy and increasing trend of the area-occupancy with increase in traffic flow are found to be logical indicating the appropriateness of the area-occupancy concept for heterogeneous traffic.

CONCLUSIONS

The following are the important conclusions of the study:

1. The simulation model of heterogeneous traffic flow, named, HETEROSIM is found to be valid for simulating heterogeneous traffic flow on intercity roads to a satisfactory extent.
2. From the results of model validation, it is found that the simulation model significantly replicate the field observed traffic flow characteristics.
3. It is found, by using simulation model, that the new concept, area-occupancy is a valid measure which can be used to represent the concentration of road traffic under homogeneous traffic condition.
4. From the relationship developed between area-occupancy speed and flow, using the simulation model, it is found that, for the representative traffic composition, the trend of the curves are found to be logical indicating the appropriateness of the area-occupancy concept for heterogeneous traffic conditions.

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