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Measuring Heterogeneous Traffic Density

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***Abstract*—**Traffic Density provides an indication of the level of service being provided to the road users. Hence, there is a need to study the traffic flow characteristics with specific reference to density in detail. When the length and speed of the vehicles in a traffic stream vary significantly, the concept of occupancy, rather than density, is more appropriate to describe traffic concentration. When the concept of occupancy is applied to heterogeneous traffic condition, it is necessary to consider the area of the road space and the area of the vehicles as the bases. Hence, a new concept named, 'area-occupancy' is proposed here. It has been found that the estimated area-occupancy gives consistent values irrespective of change in traffic composition.

***Keywords*—**Density Measurement, Heterogeneity, Occupancy, Traffic Flow.

I. INTRODUCTION

STUDY of the various characteristics of road traffic is immensely useful for planning and design of roadway systems and operation of road traffic. Understanding the real traffic behavior requires quantification of some of the basic traffic flow characteristics such as speed, flow and density. Generally, motorists perceive lowering of the quality of service when the traffic density on the road increases. In other words, for a given roadway, the quality of flow, changes with the traffic density on the road. Thus, the measure 'density' provides a clear indication of both the level of service being provided to the users and the productive level of facility use. Hence, there is a need for in-depth understanding of traffic flow characteristics with specific reference to density.

Traffic density is defined as the number of vehicles occupying unit length of roadway at any instant of time. The length and width of roadway, usually considered for measurement of density are 1 km and one traffic lane, respectively. Also, due to difficulty in the field measurement, density can be calculated from field measured values of traffic volume and speed as

$$k = \frac{q}{u} \quad (1)$$

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where, k = density in vehicles per lane per km; q = flow rate in vehicles per hour; u = space mean speed in km per hour. This relationship will hold good only in homogenous traffic flow, where the speed variation among the vehicles is less and the sub streams have constant spacing and constant speed.

The density, expressed as number of vehicles per unit length of roadway, is valid only under highly homogeneous traffic condition, wherein the difference in individual vehicle speeds and vehicle dimensions are negligible. In practice, however, even under homogeneous traffic conditions, there are significant differences in the said two characteristics (speed and dimension) of vehicles. The measure, density, hence, becomes inapplicable for conditions with variation in the speed and dimensions of vehicles in the traffic stream. Hence, there is a need to redefine the measure, density to make it appropriate for traffic conditions, wherein, there are significant variations in the dimensions and speeds of vehicles in traffic streams.

The road traffic in countries like India is highly heterogeneous comprising vehicles of wide ranging static and dynamic characteristics. Due to the widely varying vehicular dimensions and speeds, the measure, density, as indicated earlier, is inappropriate for measuring traffic concentration on roads carrying heterogeneous traffic. Here, the aim is to develop an appropriate alternative measure to represent traffic density with potential for application to heterogeneous traffic conditions such as those prevailing on Indian roads.

II. EARLIER STUDIES

Realizing the need for development of an appropriate measure to represent traffic density, there were several research attempts made on the subject matter in the past. First, an attempt was made to compute density based on the number and speeds of vehicles, measured at a point [1] and this computed factor, named, 'Occupancy' was used as surrogate for density. Then, as a refinement of the concept, occupancy was defined as a non-dimensional variable which can be measured directly by the proportion of time during which a single point on a roadway is covered by all vehicles [2]. It is calculated as,

$$Occupancy = \frac{\sum t_i}{T} \quad (2)$$

where, t_i = time during which a single point on a roadway is covered by vehicle i and T = total observation period.

Several researchers have studied the concept of occupancy and found a relationship between density and occupancy, either as linear or non linear, under homogeneous traffic conditions [2]–[7].

III. Concept of Occupancy

The measure occupancy is a function of speed and length of individual vehicle and thus, it could consider the effects of varying vehicle length and speed. Hence, it can be considered as a logical substitute of density [8].

Based on the definition of occupancy (2), it can be inferred that vehicle is detected while passing a point or line across the roadway. In practice, however, one is no longer dealing strictly with a point measurement, but with measurement along a short section of road using detectors. In other words, occupancy, based on practical consideration, is defined as the percentage of time the detection zone is occupied by the vehicles [9]. Therefore, occupancy measured using detectors depends on the length of the detection zone, each detector type has a differing zone of influence (detector length) and the zone of influence is effectively added to the vehicle length. Hence, the measured occupancy may be different for different detection zones even for the same site having identical traffic, depending on the size and nature of the detectors [10]. This implies that it is necessary to consider length of the road section also in the formulation in order to standardize the measurement of occupancy.

The aforementioned occupancy concept is specific to lane based traffic flow. Under heterogeneous traffic condition like in India, the traffic do not follow traffic lane and for maneuvering, vehicles occupy any location along the width of road depending on space availability. Hence, to analyze the characteristics of the heterogeneous traffic, it becomes necessary to consider the whole of the width of road as single unit. Hence, when the occupancy concept is applied to heterogeneous traffic, it becomes necessary to consider the area (length and width) of the road space and the area of vehicles as the bases.

IV. Concept of Area-Occupancy

Considering all the said issues related to occupancy, a modified concept of occupancy, named, 'Area-Occupancy', appropriate for heterogeneous traffic condition, is proposed here, which considers the horizontal projected area of the vehicle, without any restriction on the length of detection zone and width of road (treating the whole of the width of road as single unit without consideration of traffic lanes). It may be noted that the area-occupancy concept can be applied to any traffic condition, from highly homogeneous to highly heterogeneous, by considering any length of the detection zone. Considering a stretch of road, area-occupancy is expressed as the proportion of time the set of observed vehicles occupy the chosen stretch of a roadway. Thus, area-occupancy can be expressed as follows;

$$AreaOccupancy = \frac{\sum_i t_i a_i}{TA} \quad (3)$$

where, t_i = time during which a stretch of a roadway is occupied by vehicle i in s (occupancy time); a_i = area of the road space occupied by vehicle i during time t_i in m^2; A = area of the whole of the road stretch in m^2 and T = total observation period in s.

A. Measurement of Area-Occupancy

In the case of measurement of occupancy using vehicle detection loops, the time, t_i is the time interval from the instant the front of a vehicle enters the detection zone to the instant the rear of the vehicle leaves the detection zone. This method, however, cannot be applied to measure area-occupancy. The reason is as follows.

Considering two reference lines, (one at the start and the other at the end) on a stretch of a road, the occupancy time of a vehicle can be split into three different time components, namely, t_1, t_2 and t_3, where t_1 is the time during which the vehicle crosses its own length at the first reference line at the start of the road stretch, t_2 is the time from the instant the rear end of the vehicle touches the first reference line to the instant the front end of the vehicle touches the second reference line at the end of the road stretch and t_3 is the time during which the vehicle crosses its own length at the second reference line. The principle is depicted, using the trajectories of the front and rear ends of a vehicle, in Fig. 1.

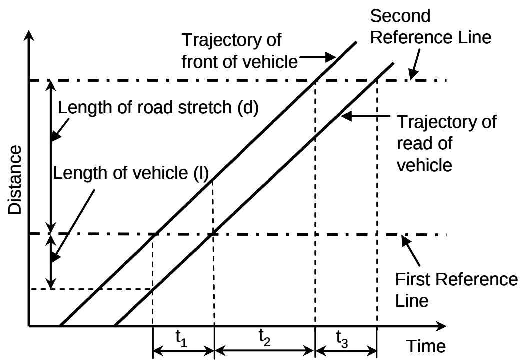

Fig. 1 Principle involved in the measurement of area-occupancy

It can be seen that during the time t_2, the whole of the area of the vehicle will be present on the section of the road considered and the area of the road space occupied by the vehicle, at any instant of time, will be equal to the area of the vehicle itself. On the other hand, during the times t_1 and t_3, the section of the road under consideration is occupied by the vehicle only partially. Hence, for the time durations t_1 and t_3, the area of the road space occupied by the vehicle progressively varies and it is always less than a_i. Due to this, during the time t_1 and t_3, in the formulation of area-occupancy, $t_i a_i$ (with t_i being considered to be $t_1+t_2+t_3$) will overestimate the occupancy of the vehicle.

Assuming the speed maintained by the vehicle to be constant within the stretch of the road, the contribution of the vehicle to occupancy, during the time interval t_1, is equal to the occupancy contribution during the time interval t_3. Then, the problem of over estimation of occupancy value can be avoided if the time interval t_i is considered as the elapsed time from the instant the front\ rear end of the vehicle crosses the first reference line to the instant it crosses the second reference line ($t_i = (t_1+t_2)$ or (t_2+t_3)). Thus, area-occupancy can be estimated by simply measuring the time taken by all vehicles to cross the road stretch considered. The correctness of the area-occupancy concept can be verified by estimating the area-occupancy value for a wide range of roadway and traffic conditions and checking for the logical validity of the results.

For estimation of area-occupancy, it is necessary to measure accurately the characteristics of heterogeneous traffic flow and the other relevant factors on vehicular movement over a stretch of roadway. Measurement of these complex characteristics in the field is difficult and time consuming. Also, it may be difficult to carry out such experiments in the field covering a wide range of roadway and traffic conditions. Hence, it is necessary to model road–traffic flow for in depth understanding of the related aspects. The study of these complex characteristics, which may not be sufficiently simplified by analytical solution, can be done using appropriate modeling technique like computer simulation. Simulation is already proven to be a popular traffic-flow modeling tool for applications related to the traffic flow on roads. Hence, simulation technique has been used here to validate the concept of area-occupancy here. A simulation model of heterogeneous traffic flow, named, HETEROSIM, developed by the first author of this paper [11] is used here to study the heterogeneous traffic flow characteristics covering a wide range of roadway and traffic conditions, with specific reference to the measurement of occupancy.

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 vehicle characteristics and traffic flow characteristics such as free speed, classified volume count, traffic composition, occupancy time, etc. are used in the validation of the simulation model. The validated simulation model can then be used to estimate the area-occupancy over a wide range of traffic flow conditions.

V. Data Collection

The input data required for the model, pertaining to vehicle characteristics, were adopted from an earlier study [12] and the details are shown in columns (2) to (5) of Table 1. The free speeds of the different categories of vehicles were measured on the study stretch of the road during lean traffic periods and the details are given in columns (6) and (7) of Table1.

The traffic data used in this study was collected by video capturing the traffic flow on the Maraimalai Adigalar Bridge (having a divided road with 12 m wide road space for each direction of traffic flow), in Saidapet area in Chennai city, India, during morning peak hour. The traffic flow pertaining to one direction (towards Parry's Corner) was considered for this study. A total of 7082 vehicles were observed to pass through the study section in one hour and the composition of the traffic is as given in Fig. 2. The headway data was also collected and then classified with a class interval of 0.3 s resulting in 14 classes with lower limit for the first and the last classes being 0 and 3.9 respectively. The data was fitted into negative exponential distribution and the goodness of fit was tested using chi-squared test. It was found that the observed chi-square value was 15.229 against the critical value from chi-squared table, for 13 degrees of freedom at 5% level of significance, of 22.362. Thus, the observed headway distribution fitted well into the assumed negative exponential distribution.

TABLE I
Data of Vehicle Characteristics and Free Speed

Vehicle Type	Overall Dimensions in m		Lateral Clearance-allowance in m		Free Speed in km/h	
	Length	Width	Min.	Max.	Mean	S.D.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Bus	10.3	2.5	0.3	0.6	67	7
Truck	7.5	2.5	0.3	0.6	62	9
L.C.V.	5.0	1.9	0.3	0.5	61	7
Car	4.0	1.6	0.3	0.5	72	7
M.Th.W.	2.6	1.4	0.2	0.4	48	8
M.T.W.	1.8	0.6	0.1	0.3	61	10
Bicycle	1.9	0.5	0.1	0.3	15	2

Note:L.C.V.- Light Commercial Vehicle, M.Th.W. - Motorised Three Wheelers, M.T.W. - Motorised Two Wheelers

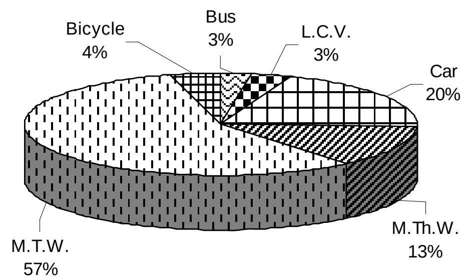

Fig. 2 Observed composition of traffic on the study stretch

VI. Model Validation

Model validation is the process of comparing model results with the corresponding field observed values to ensure that the simulated results realistically represent the real system (field conditions). For validating the simulation model, the traffic flow through a length of 1400 m of roadway (which excludes 200m on either side of the stretch for avoiding possible unsteady states in traffic flow), was simulated. The observed roadway condition, traffic volume and composition were given as input to the simulation process. The input vehicular composition for a traffic volume level of 7082 vehicles/h on the study stretch is as depicted in Fig. 2. Using the features of the simulation model, the time t_i ($t_i = t_1+t_2$, as depicted in Fig. 1) was recorded for each of the simulated vehicles. The simulation runs were made with three random number seeds and the average of the three values was taken as the final model output.

For the purpose of model revalidation, it was decided to compare the measured area-occupancy in the field with measured area-occupancy from simulation output. Accordingly, the field observed and simulated area-occupancy of each of the categories of vehicles were compared to check for the validity of the model. A comparison of the observed and simulated area-occupancy of the different types of vehicles is shown in Fig. 3. It can be seen that the simulated area-occupancy values significantly replicate the field observed area-occupancy for all vehicle types.

A paired *t*-test of null hypothesis of no mean difference was also performed to check for the match between simulated and observed area-occupancy of vehicles. The calculated value of t (t_0) is 0.03 against the critical value (from't' table) of 2.57 at 5% level of significance (95% confidence limit) indicating the statistical validity of the results.

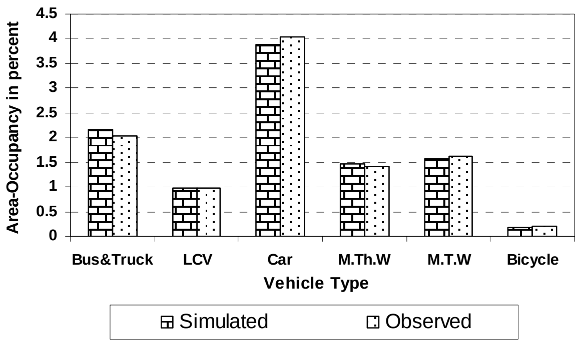

Fig. 3 Comparison of the simulated and observed area-occupancy

VII. Validation of Area-Occupancy Concept

To check the validity of the concept of area-occupancy, it was decided, as the first step, to study the relationship of area-occupancy with other traffic parameters such as speed and flow under homogeneous (cars-only) traffic condition. For this purpose, the validated simulation model was used for simulating the cars-only traffic on a single lane for a wide range of traffic volume levels. The traffic flow was simulated on one km long road stretch for one hour and three simulation runs, with different random number seeds, were made and the mean values of the three runs were taken as the final values of the relevant parameters obtained through the simulation process.

The average stream speeds, exit volume and area-occupancy of the homogeneous traffic, for the various volume levels were obtained using the simulation output. Then plot relating the estimated area-occupancy with stream speed is depicted in Fig. 4 and a similar plot relating flow and area-occupancy is shown in Fig. 5. It can be seen, in both the cases, the relationships are logical.

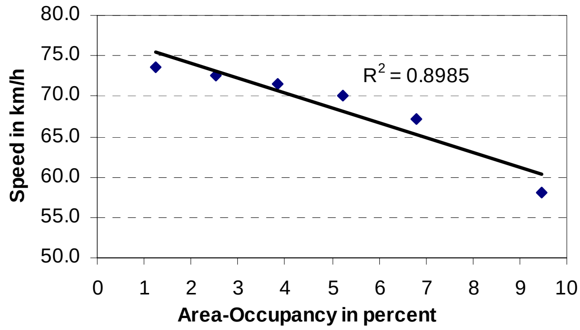

Fig. 4 Relationship between speed and area-occupancy of homogeneous traffic

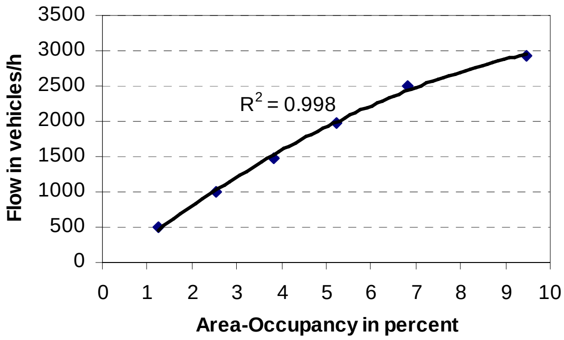

Fig. 5 Relationship between flow and area-occupancy of homogeneous traffic

After checking of the logical correctness of the relationship between speed, flow and area-occupancy of homogeneous traffic by simulating cars-only traffic flow on a single traffic lane, it is inferred that the concept of area-occupancy is valid and can be applied to measure accurately the extent of usage of road space by vehicles more reliably.

As the concept of area-occupancy takes into account the variations in traffic composition and speed, the derived relationship between flow, speed and area-occupancy of heterogeneous traffic can be applied for any traffic condition irrespective of the composition of traffic. To confirm this, the model was used to simulate traffic with composition of 50% car and 50% bus, 70% car and 30% bus and 90% car and 10% bus. The area-occupancy, flow and speed were obtained for these three different traffic conditions. The value of area-occupancy of traffic with these three different traffic compositions were plotted against V/C ratio, and the same is depicted in Fig. 7. It can be seen that the values of area-occupancy of heterogeneous traffic with three different compositions are very close to each other and hence it can be concluded that the relationship between flow, speed and area-occupancy developed for particular roadway and traffic condition can be applied for any traffic condition under same roadway condition.

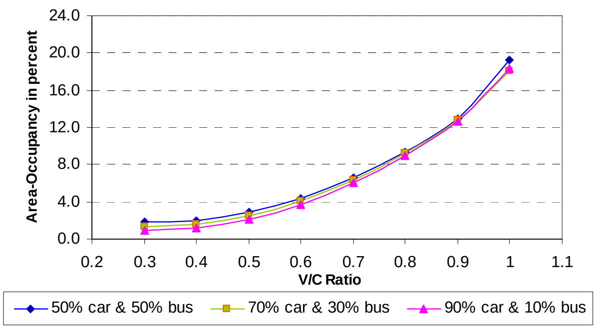

Fig. 6 Relationship between area-occupancy and V/C ratio

VIII. Summary and Conclusion

The review of the literature on traffic flow characteristics indicates that the traffic density, expressed as number of vehicles per unit length, can not be appropriate for accurate measurement of traffic concentration, due to variation in the dimension and speed of vehicles, even on a given traffic lane.

Hence, there is a need to find an alternative measure to quantify traffic concentration under different traffic conditions. Occupancy, defined as the proportion of time during which a single point on a highway is covered by all vehicles can help to remove the deficiencies of the concept of density to a significant extent. Occupancy thus, takes into account the variations in traffic composition and speed, in the measurement of traffic concentration, and gives a more reliable indicator of the extent of road being used by vehicles and hence, occupancy is more meaningful than density. Since, occupancy depends on the size of the detection zone, the measured occupancy, however, may be different for different detection-zone lengths, even for the same site having identical traffic, depending on the size and nature of the detector. Also, the concept of occupancy can not be directly applied under heterogeneous traffic conditions, as the traffic has no lane discipline and hence, it is necessary to consider the whole of the road as single unit to analyze the traffic flow. Hence, a new measure named 'area-occupancy' has been proposed, which considers the horizontal projected area of the vehicle, without any restriction on the length of the detection zone and width of road (treating the whole of the width of road as single unit without consideration of traffic lanes). Hence, area-occupancy concept is applicable for heterogeneous traffic with vehicles of wide ranging static and dynamic characteristics such as the one prevailing on Indian roads. When considering a section of road, area-occupancy is expressed as the proportion of time the set of observed vehicles cover the chosen section of a roadway. The logical correctness of the concept of area-occupancy is validated by comparing the area-occupancy with other two traffic flow parameters such as flow and speed under homogeneous traffic condition. It was found that the relationships are logical and hence it is inferred that the concept of area-occupancy is valid to measure accurately the extent of usage of road space by vehicles. Hence, area-occupancy, rather than occupancy, can be used as an indicator of road traffic concentration at any flow level because of its ability to accurately replicate the extent of usage of the road. It was found that the estimated area-occupancy gives consistent value irrespective of the change in traffic composition and it can be concluded that the area-occupancy can be used as a measure of traffic concentration for any traffic and roadway condition.

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