

## AREA OCCUPANCY CHARACTERISTICS OF HETEROGENEOUS TRAFFIC

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Increasing congestion due to rapid urbanization in developing countries like India necessitates the study of traffic flow for effective traffic management. Most of the traffic studies conducted in this regard were on the lines of methods used in developed countries. These studies were able to represent the traffic behavior only in a very limited manner. In developing countries traffic is composed of several types of vehicles ranging from cars with high speeds to low speed non-motorized vehicles. Microscopic traffic characteristics such as time headway and space headway are difficult to measure due to the heterogeneous nature (no lane discipline, and two or three small vehicles occupying one lane in lateral direction) of the traffic. Even using some of the macroscopic traffic characteristics such as density or occupancy, to study this kind of traffic may lead to erroneous results. Thus it is desirable to have a metric that can represent the heterogeneous nature of traffic in these conditions. Since varying vehicle dimensions are attributed to the lack of lane discipline, a modified measure of occupancy termed as Area occupancy is proposed in this paper. Like occupancy, area occupancy is also measured over time. This measure would also be able to consider the varying vehicle dimensions of the traffic. Based on field observations it is shown that area occupancy is more meaningful in representing the heterogeneous traffic when compared to occupancy.

KEYWORDS: Occupancy, heterogeneous traffic, passenger car unit

### 1. INTRODUCTION

Any study related to traffic requires a good understanding of the real traffic observed. On Indian roads, it is difficult to measure microscopic characteristics (time-headways, space-headways etc.), as the flow patterns are complex with no lane discipline. In India to study the traffic behavior, speed and flow (passenger car units/hr) are being used. Characteristics of different vehicles which are commonly found are represented through the value of Passenger Car Unit (PCU). Every vehicle other than car is quantified into equivalent number of passenger cars. The PCU value in general is calculated based on length of the vehicle, weight/horsepower ratio, and some other road factors like terrain, shoulder conditions etc. PCU values are calculated based on different performance measures such as headways, speed, delay, density, and vehicle-hours. Among these performance measures, traffic density is a good indicator of the driver's freedom to maneuver and proximity to other vehicles, and is consistent with the measure of effectiveness for freeways used in the Highway Capacity Manual. Since PCU value also depends on the traffic stream characteristics such as volume, and speed, the determination of correct PCU value for each type of vehicle under dynamic traffic conditions is a difficult task (Highway Capacity Manual, 2000).

Density is defined as the number of vehicles per unit length of the road and it is not considering any of the heterogeneous traffic characteristics. Occupancy which is being used recently in place of density takes the vehicle length into consideration. Since occupancy is a function of the vehicle length, this characteristic could be used in describing the traffic which consists of vehicles occupying the full lane width with

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different lengths. While dealing with traffic comprising of different vehicle types such as motorized two wheelers, motorized three wheelers and non-motorized vehicles, it is thus essential to include area of the vehicle to represent the realistic traffic behavior. Since motorized two wheelers and three wheelers are having widths of 0.8 m and 1.4 m respectively, which are considerably less than the standard lane width (3.5 m), it results in no-lane discipline. In these conditions two or three small vehicles can travel shoulder-to-shoulder in one lane. Since occupancy does not consider the vehicle widths, it is also inadequate in representing heterogeneous behavior of the traffic. Hence a modified measure of occupancy termed as area occupancy is proposed in this paper. This measure will give the percentage time the vehicle-area spent on the detector. This proposition is validated based on the data collected from National Highway-1 (Delhi to Amritsar), India, using a digital video camera. A detailed description of the data collection procedure is given in the following sections. Due to the complexity in extracting data from video film, occupancy and area occupancy values were compared for only a period of 30 minutes, during which flow is considerably high. It is found that there is a significant difference between the variations of these two values when the traffic is composed of two-wheelers and heavy vehicles.

The organization of this paper is as follows. In the second section a review of the traffic characteristics and their significance is presented. The third section deals with formulation of area occupancy and its basis. Data collection part is discussed in fourth section. In the fifth section, a detailed analysis of results is presented. Conclusions and further scope are given in the final section.

## 2. LITERATURE REVIEW

It is important to consider all the vehicle characteristics when studying traffic related problems. While dealing with homogeneous traffic it is easy to collect and extract microscopic traffic characteristics such as time headways and space headways, and macroscopic characteristics such as flow, speed and density. In heterogeneous traffic conditions due to lack of proper data collecting techniques and the complexity involved, very few have studied these characteristics (Gupta and Khanna, 1986; Palaniswamy et al., 1985). Some of these studies are reviewed here.

Ramanayya (1980) used 'Equivalent Design Vehicle' in place of passenger car unit to model the traffic observed on urban roads in India. This study is the first of its kind in measuring the flow using a metric other than PCU values. From this study it was shown that PCU value of the passenger car itself is not constant due to heterogeneous traffic conditions. In this model an attempt was made to convert all vehicles including car into "equivalent design vehicle unit". Subsequently this was not validated in any of the future studies. Chari and Badarinath (1983) made an attempt to quantify density under these conditions using area density. This is the first study that considered vehicle areas in measuring the density. Area density is defined as sum of the total vehicle area projected on the ground per unit area of road way. A time lapse camera with a 1-sec interval between successive exposures of the film was used for data collection. Madhava Kumar (1994) used traffic characteristics such as speed, flow and density to study the traffic observed on National Highways in India. In this study, four persons were employed on each end of the road stretch to collect vehicle data such as time of entry, registration number, and type of vehicle simultaneously. Later from the collected field data, for every one minute interval, total number of vehicles located on the road stretch is calculated. Observed number of vehicles divided with the length of the road gives the

density value. Singh (1999) used concentration as traffic characteristic, for validating the simulation model, which is defined as proportion of road space occupied by vehicles at an instant. In this study video graphic technique was used to collect concentration data at 15 second intervals. Bham and Benekohal (2004) used percent space occupancy in their work to represent congested traffic conditions in a better way when traffic is composed of vehicles with different lengths. According to them, space occupancy provides a better feel for the state of traffic since it incorporates length of each vehicle when compared to average length used in density. Jiang and Wu (2004) extended speed gradient model to incorporate different types of vehicles. It was used to study the steady state of mixed traffic flow. Some researchers have tried to incorporate different vehicle characteristics in macroscopic models (Wong and Wong, 2002; Zhu et al., 2003; Chanut and Buisson, 2003). Lan and Chang (2005) developed a cellular automata based traffic flow model to model the mixed traffic including two wheelers. Khan and Maini (1999) have done an extensive review of heterogeneous traffic flow modelling studies and concluded that for mixed type of vehicles, linear density measurements are inadequate, and there should be a measure which includes the vehicle area. It was also concluded that the uniform definition of passenger car equivalent is not applicable and the values of equivalency depend on traffic composition, degree of saturation and location.

From the review of literature it is evident that density cannot adequately describe heterogeneous traffic conditions, since it is not considering vehicle size. On the other hand occupancy, which considers vehicle length, adequately represents the traffic stream containing vehicles of different lengths (Transportation Research Board, 1997). However occupancy too falls short in representing the traffic that consists of vehicles having different widths. In this context we propose a new measure of occupancy termed as area occupancy. This measure includes vehicle width besides its length and seems to be a better measure in representing the heterogeneous traffic.

### 3. DENSITY, OCCUPANCY AND AREA OCCUPANCY

Here we describe the macroscopic traffic flow characteristics such as density, occupancy and area occupancy. We need to define some aspects of vehicular mix and lane discipline before proceeding any further to distinguish the features unique to the traffic behaviour with varying vehicle size and lane discipline.

#### *3.1 Homogeneous and heterogeneous traffic*

Homogeneous traffic means that the composition of vehicles with similar characteristics (dimensions, and performance features) and follow lane discipline, this we term as 'Ideally Homogeneous' (IHO). However the real traffic is never homogeneous and the variations exist between vehicle sizes (length only is considered be varying) and drivers, this is termed as 'Real Homogeneous' (RHO). This is sometimes referred to as 'Heterogeneous' in some literature (Logghe, 2003). Traffic in these conditions however follows the lane discipline. Real heterogeneous traffic is defined as that which comprises of varying vehicle sizes and operating characteristics (Khan and Maini, 1999). Here the traffic does not have a lane discipline and one or more vehicles are placed laterally in the same lane. Thus we designate this kind of traffic state as 'Real Heterogeneous' (RHE).

### 3.2 Density

Density or occupancy is useful in getting an idea about how crowded a certain section of the road is. Because density is essentially defined as a spatial measurement, it is one of the most difficult quantities to obtain. Under IHO (same type of vehicles), stationary (speed is constant over space and time) traffic conditions density can be estimated either from the fundamental relation of traffic characteristics (speed, flow and density) or from occupancy which is a temporal measurement.

Traffic density ( $k$ ), measured over space and is defined as number of vehicles observed on a specified length of road at a given time instance. If  $N$  vehicles are observed in a photograph taken at a given time instance and the covered distance is  $L$ , then

$$K = N / L . \quad (1)$$

The density value obtained from the above gives the number of vehicles over a stretch of road. It neither considers the length nor width of the vehicle. If similar types of vehicles are travelling on the road, density gives fairly accurate measure of traffic quality.

### 3.3 Occupancy

In the recent past, many of the traffic studies are using either induction loops or image processing techniques to collect the data. It is convenient to collect flow and occupancy data by using these techniques.

Occupancy is defined as the percentage time the road section is occupied by a vehicle over a given period of time. Occupancy is equivalent to density under equilibrium conditions but only somewhat related to density under non-equilibrium conditions (Transportation Research Board, 1997).

$$\rho = \frac{\sum_{i=1}^N O_i}{T} , \quad (2)$$

$$O_i = \frac{l_i + d}{v_i} , \quad (3)$$

where  $\rho$  is occupancy;  $O_i$  is the time the  $i$ th vehicle occupied the detector;  $l_i$  is the length of the  $i$ th vehicle; and  $v_i$  is speed of  $i$ th vehicle; and  $d$  is detector's length.

When both density and occupancy are measured over a general measurement region (over time and space) they can be related in the following manner (Daganzo, 1997);

$$\rho(A) = k(A) \times l(A) , \quad (4)$$

where occupancy, density and average vehicle length are measured over time and space.

Occupancy measured over time, is related to the density and average vehicle length measured over space as follows

$$\rho \approx k \times \bar{l} , \quad (5)$$

where  $\rho$  is measured over time,  $k$  and average vehicle length  $\bar{l}$  are measured over space. In case of traffic with different vehicle lengths it is apparent that occupancy is more meaningful than density (useful for RHO class). Even this improved traffic measure is not suitable when the traffic is RHE. In RHE traffic most of the time vehicles will be travelling on the central portion of the road for different reasons. Since occupancy is a function of length and speed of the vehicle, in case of IHO or RHO traffic it could consider the effect of large slow-vehicle's impedance by means of its length (generally long vehicles are wide-bodied vehicles). In case of RHE traffic (observed on Indian

Roads), traffic is composed of some short vehicles whose weight to horsepower ratio is more. Effects of these vehicles are more pronounced when these vehicles are obstructing the vehicles behind while travelling on the middle portion of the road. In order to represent RHE traffic, we propose to modify the formula for occupancy. This formula would incorporate vehicle area and total road width, is discussed in detail in the following section.

### 3.4 Area occupancy

The above discussed traffic characteristics may not exactly depict the collective traffic behavior moving in a 3-D region, including 2-D for the roadway (longitudinal and transverse) and 1-D for the time (Lan and Hsu, 2006). To overcome these difficulties, in estimating this new metric, absolute width of the road is considered irrespective of number of lanes. If this is the case, at any time instance there can be more than one vehicle depending on the vehicle size, across the road width. This term is also considering the size of the vehicle, which has a significant bearing on the traffic behavior in RHE conditions. For example, a truck moving with the same speed that of a two-wheeler will cause a bigger deterioration in the level of service due to its size, limited maneuverability and acceleration/deceleration characteristics than the two wheeler. When considering a small section (e.g. detector) of the road, Area occupancy expresses for how long a particular size of the vehicle is moving on that section of the road. Like occupancy, area occupancy is also measured over time (Temporal Area occupancy, the term area occupancy is used through out this paper to refer this quantity) and is formulated as follows;

$$\rho_A = \frac{\sum_{i=1}^N O_i \times w_i \times d}{T \times W \times d}, \quad (6)$$

where  $\rho_A$  is area occupancy;  $O_i$  is occupancy time of the  $i$ th vehicle in seconds;  $w_i$  is width of the  $i$ th vehicle;  $W$  is road width;  $d$  is the length of the road section under consideration; and  $T$  is observed time period in seconds.

In the above formula, the numerator value takes care of the occupancy time (similar to occupancy); the amount of time a vehicle with a given area is spending on the road section under consideration. Its value will depend on the composition of traffic and speeds of the vehicles.

Figure 1 gives the graphical representation of area occupancy measurements over a short section (e.g. induction loop) of the two-lane road. It is assumed that there are two vehicles on the road at a time instance  $T_1$  and both vehicles are travelling at same speed. Figure 1(a) shows the top view of a two lane road on which two vehicles (vehicles shown with solid lines) are just entering into the detection area at the time instance  $T_1$  and their respective positions at the time instance  $T_2$  (vehicles shown with dotted lines). From the definition of occupancy, the difference between  $T_1$  and  $T_2$  gives the occupancy time of the large sized vehicle. Occupancy time for small vehicle is not same. As discussed earlier in this kind of situations (RHE traffic), representing time-space evolution of vehicles in a 2-Dtime-space diagram may not help in identifying the real traffic conditions. Figure 1(b) shows the 3-D time space evolution of the vehicles is. In addition to the time and space, road width is represented in the third dimension. The volume (time  $\times$  road width  $\times$  detector length) in between the two horizontal planes shown in Figure 1(b) represents the total control volume. Two vertical planes which are shown in the figure represent the time instances at which the large sized vehicle enters

and left the detection zone. The volume which is common to the vertical and horizontal planes  $((T_1-T_2) \times \text{vehicle width} \times d)$  represents the time spent by the large sized vehicle – area in the detection zone. Extending this to the total vehicles which may have crossed the detection zone during the observed period, the formulation of area occupancy is obtained as shown below:

$$\rho_A = \frac{\sum_i (T_2 - T_1)_i \times w_i \times d}{T \times W \times d} = \frac{\sum_i \frac{(l_i + d)}{v_i} \times w_i \times d}{T \times W \times d} = \frac{\sum_i O_i \times w_i \times d}{T \times W \times d} \tag{7}$$

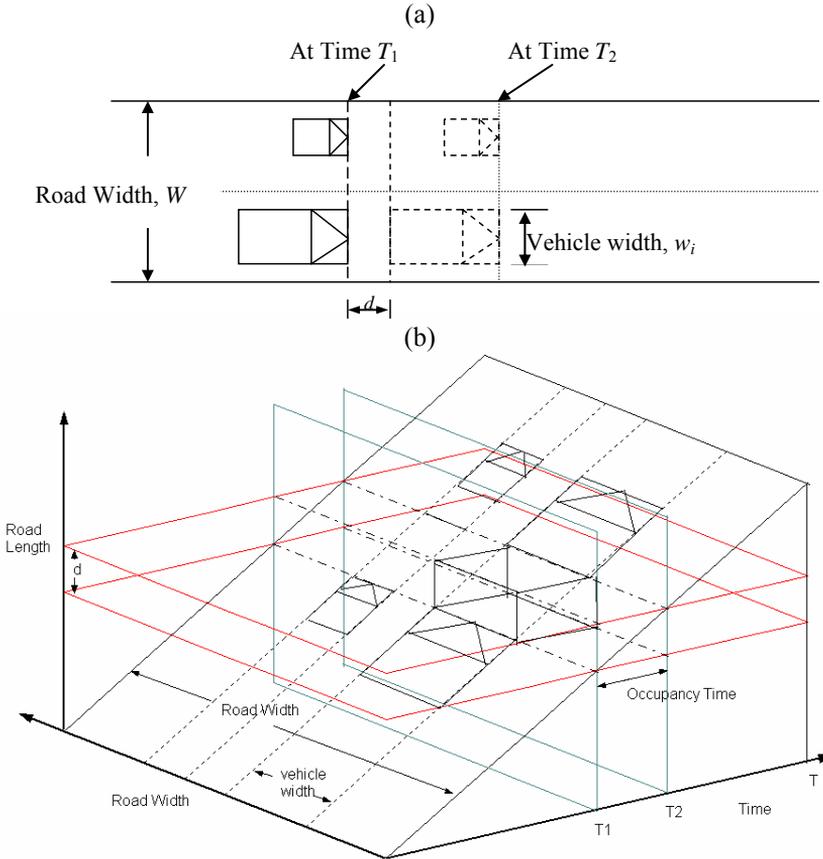


FIGURE 1: Graphical representation of factors considered in area occupancy measurements

In formulating the area occupancy it is assumed that vehicles are travelling with constant speeds over the detection zone. It is also assumed that at the beginning and at the end of the observation period there are no vehicles located in the detection zone. Area occupancy measured over space is defined as the ratio of sum of the all vehicle areas to the road area.

$$\rho_A(s) = \frac{\sum_i a_i}{W \times L} \tag{8}$$

where  $a_i$  is the vehicle area;  $L$  is the length of the road section under consideration. In the following example it is shown that temporal area occupancy ( $\rho_A$ ) measure (length of the vehicle  $\gg$  detector's length) converges to area occupancy measured over space ( $\rho_A(s)$ ) under stationary traffic conditions.

*Example.* In this example it is assumed that only cars are travelling at 80 km/h speed on a two-lane road having a width of 7 m. It is also assumed that vehicles are maintaining a time-headway of 2 seconds and flow is under equilibrium conditions (stationary and homogeneous). Then the volume of the cars travelling on a two-lane road will be 3600 vehicles/hr. Length and width of the car are taken as 4.7 m and 1.7 m respectively. Detector lengths are neglected assuming that it is too small when compared with vehicle lengths. Observation period is taken as 1 minute.

$$\rho_A = \frac{\sum_i \frac{(l_i)}{v_i} \times w_i}{T \times W} \Rightarrow 5.14\% .$$

Since flow is homogeneous and stationary, the fundamental relationship between traffic characteristics (flow = density  $\times$  speed) is valid and the value of density can be estimated from the available flow and space-mean speed. From this relationship, considering the above traffic characteristics, 45 cars will be occupying a two - lane road and the resulting area occupancy (here the area occupancy is different and it is equals to the ratio of sum of the vehicle areas and the road area) is exactly equals to 5.14%.

### 3.5 Area occupancy measured over space and time

Like the other traffic characteristics, area occupancy can also be measured over space and time (general measurement region). Instead of considering finite road length such as induction loop, a considerably large section of the road is considered in measuring the area occupancy. It is formulated in the similar way described in Figure 1, where  $d$  is replaced with  $L$  length of the large road section.

$$\rho_A(A) = \frac{\sum_{i=1}^N \frac{L - x_i}{\bar{v}_i} \times w_i \times l_i}{T \times W \times L} , \quad (9)$$

where  $\rho_A(A)$  is area occupancy measured over space and time;  $L$  is the length of the road section under consideration;  $\bar{v}_i$  is the space mean speed of the  $i$ th vehicle when travelling over the road section under consideration;  $x_i$  denotes the distance between the vehicle and any of the two ends of the detection zone, measured along the road length. When the vehicle could manage to traverse part of the road section under consideration (this is the case when vehicles are entering onto the road section just before the end of the observed time)  $x_i$  denotes the distance between the front-end of the vehicle to the end of the detection zone. The same vehicle will be in the detection zone at the starting of the next observed period and in this case  $x_i$  denotes the distance between the starting point of the detection zone and the front of the vehicle. The value of  $x_i$  is zero when vehicle has traversed the entire detection zone during the observed period;  $(L-x_i)$  denotes the distance traveled by the  $i$ th vehicle over the road section under consideration, this is true only if the  $i$ th vehicle has no lateral movement;  $w_i$  is the width of the  $i$ th vehicle;  $W$  is the width of the road and it is assumed to be constant for the entire road section.

While measuring this quantity it is assumed that the all vehicles are travelling in a straight line path over the observed road section. If it is possible to measure the total distance traveled by any vehicle (in case it is not equals to  $L$ ), in the above formula  $L$  can be replaced with the measured distance. If the time spent by the  $i$ th vehicle on the road section is known,  $(L - x_i)/\bar{v}_i$  can be replaced with this time.

As can be seen in the formulation, the crucial part in measuring the area occupancy values is how effectively the vehicle width can be estimated. With the help of dual loop detectors or by using image processing based traffic data collection techniques, vehicle lengths can be estimated which in turn can be used in estimating vehicle width (Lan and Kuo, 2002). The length of the vehicle can be estimated using the vehicle speed measured from the dual-loop detectors and the detector-on time from either of the loops. Under free flow conditions vehicle lengths can be found with fair amount of accuracy. To overcome the errors observed in forced-flow conditions in measuring vehicle lengths, (Zhang et al., 2005) proposed new dual-loop algorithm which can handle erroneous raw loop actuation signals. Under heterogeneous traffic conditions, since vehicle composition is playing a significant role in understanding the traffic behavior, it is necessary to have proper methodology to collect the vehicle lengths and a lot of work needs to be done in this area.

Since taking measurements over space is very difficult, in reality, it is difficult to measure area occupancy over time and space. In the present study, the term area occupancy refers to the temporal measurement only.

#### 4. DATA COLLECTION

Data collection part is one of the main hurdles when studying the real heterogeneous traffic behavior. Induction loops are used widely to collect traffic data such as classified traffic flow, speed, and occupancy. This technique has been tried in India too but with little success. The main reason for the failure of this technique is the no-lane disciplined traffic and the presence of large number of two wheelers and heavy vehicles. For example, any heavy vehicle which is travelling on the middle portion of a two-lane road activates both the detectors placed on the two lanes. In case of two two-wheelers travelling side by side on one lane will activate the detector only once. Image processing based data collecting technique which is under development seems to overcome these problems even under dense RHE traffic conditions.

In India at present video graphic technique is widely used to collect the traffic data. In most of the cases it is limited to collect classified traffic volumes. For research purposes, the same technique is also being used to collect the speed data with the help of some auxiliary soft wares. In the present study also video graphic technique is used to collect the classified traffic volume and speed data. Though it is tedious to collect data by using this technique, every detail of the observed traffic can be extracted. This technique has got some advantages over the other data collection techniques, though it is time consuming and labor intensive. Data regarding vehicle characteristics such as length and width, and classified traffic volumes which are important traffic characteristics under RHE traffic conditions, can be collected with 100% accuracy. For the present study data was collected on the National Highway – 1 (NH-1), connecting New Delhi and Amritsar. Brief description of the data collection procedure is described below.

In the present study, with the help of two reference lines (similar to the speed trap) the time instances at which the vehicles are entering and leaving the road section are noted

down. With the help of these time instances and length of the road section, speeds are calculated for all the vehicles. From the speeds, time taken by each vehicle to traverse a distance of 3 m (d, detector length) i.e. occupancy times are estimated for all vehicles. Since every vehicle can be seen, the corresponding vehicle length can be obtained which is used in calculating the occupancy times. Though this is not the correct procedure to collect occupancy times, as the traffic is under free flow regime (Figure 2), this method will give a reasonably correct occupancy times. For the same time period, classified traffic flow values are obtained for every one minute interval. The observed traffic falls into free flow regime (with minor fluctuations in speed, see in Figure 2). The composition of traffic can be seen in Figure 3 and different vehicle characteristics (sizes) are listed in Table 1. A detailed analysis of the collected data is presented in the following section.

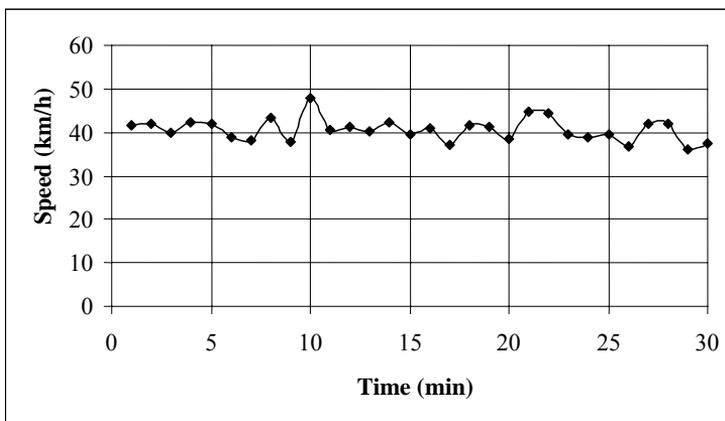


FIGURE 2: Variation of speed over time

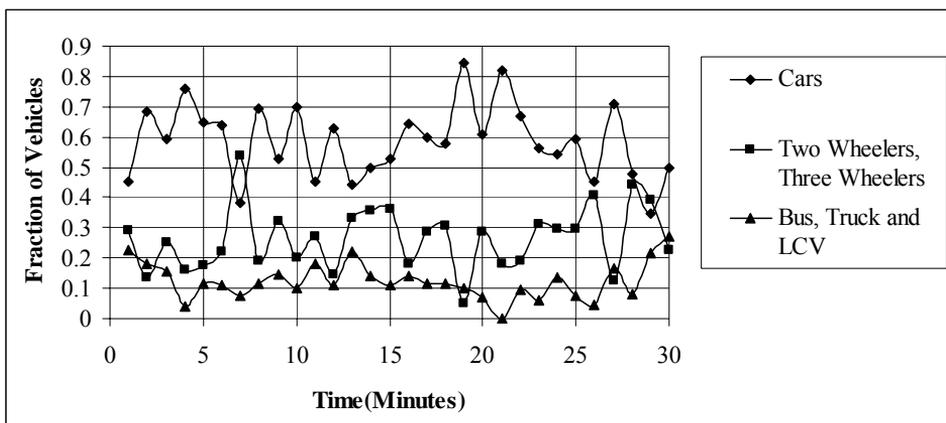


FIGURE 3: Vehicle composition observed

TABLE 1: Vehicle characteristics observed

Vehicle Class	Length (m)	Breadth (m)	Area (m <sup>2</sup> )
Bicycle	1.9	0.5	0.95
Rikshaw <sup>a</sup>	2.5	1.3	3.25
Two Wheeler <sup>b</sup>	1.8	0.6	1.08
Three Wheeler <sup>c</sup>	2.6	1.4	3.64
Car	4.7	1.7	7.14
LCV <sup>d</sup>	5.0	1.9	9.50
Truck	8.4	2.5	21.00
Bus	10.3	2.5	25.75
Tractor	7.2	1.9	13.68

<sup>a</sup> Three wheeled non- motorized vehicle

<sup>b</sup> Two wheeled motorized vehicle including Bike, Scooter, Moped

<sup>c</sup> Three wheeled motorized vehicle

<sup>d</sup> Light Commercial Vehicle

## 5. RESULTS AND ANALYSIS

For analysis purposes, data collected from 10:30 AM to 11:00 AM was used. For the 30 minute duration considered, detailed traffic data is obtained. From the speed data it can be seen that the fluctuations are minimum during this period and flow is falling under free flow regime (Figure 2).

As can be seen from the definitions, occupancy ( $\rho$ ) and area occupancy ( $\rho_A$ ) are functions of speed. In addition  $\rho$  depends on the vehicle length and  $\rho_A$  depends on the vehicle area. When more short vehicles with low vehicle area or vehicles with large areas, are traveling on the roads, there shall be some difference between the values of  $\rho$  and  $\rho_A$ . The same is evident from Figure 4 and Figure 5 which are showing the fluctuations of  $\rho$  and  $\rho_A$  over the thirty minute duration under consideration.

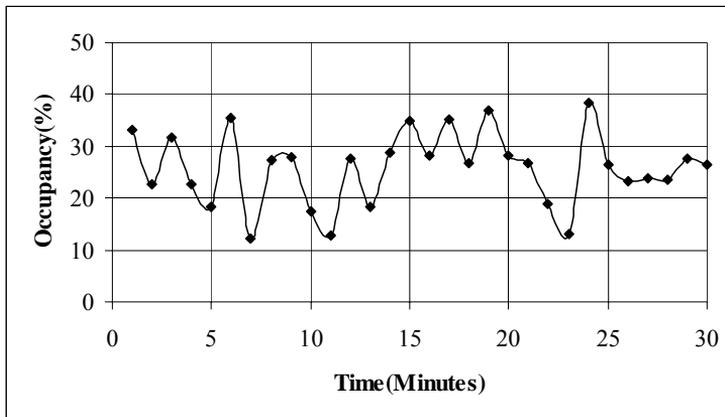


FIGURE 4: Variation of occupancy over time

If we observe the variations in  $\rho$  and  $\rho_A$  for 4th to 5th minute, for 10th to 11th minute and for 15th to 17th minute of the observed period, there is a clear difference between variations of these two values. From 4th minute to 5th minute the values of  $\rho$  is decreasing whereas the values of  $\rho_A$  are almost same. From Table 2, it is evident that from 4th minute to 5th minute there is a considerable change in the percentage of cars and an addition of one more truck. Since the percentage reduction of cars is more  $\rho$

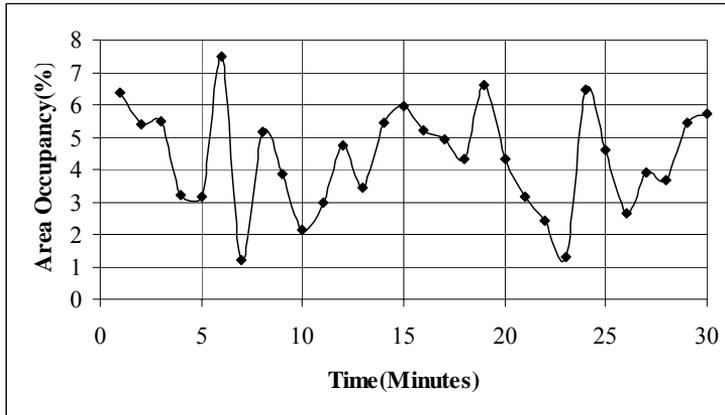


FIGURE 5: Variation of area occupancy over time

TABLE 2: Number of vehicles observed during each one minute interval

Observed minute	Bus	Truck	Car	Two wheeler	Three wheeler	LCV	Cycle	Tractor
1	2	1	14	7	2	4	0	1
2	3	1	15	2	1	0	0	0
3	1	2	19	7	1	2	0	0
4	1	0	19	4	0	0	1	0
5	1	1	11	3	0	0	1	0
6	2	2	21	7	1	1	0	0
7	0	0	5	7	0	1	0	0
8	3	0	18	5	0	0	0	0
9	0	2	18	11	0	3	0	0
10	0	0	14	4	0	2	0	0
11	0	2	5	2	1	1	0	0
12	3	0	14	10	0	0	0	0
13	1	1	8	5	1	2	0	0
14	3	1	14	10	0	0	0	0
15	3	1	19	11	2	0	0	0
16	2	1	18	5	0	1	0	1
17	0	2	21	9	1	2	0	0
18	1	1	15	8	0	1	0	0
19	1	1	33	2	0	2	0	0
20	0	2	17	8	0	0	0	1
21	0	0	23	2	3	0	0	0
22	1	0	14	4	0	1	0	0
23	0	0	9	5	0	1	1	0
24	2	0	15	8	0	1	0	0
25	1	0	8	8	2	0	1	0
26	1	0	10	7	2	0	2	0
27	1	0	17	3	0	3	0	0
28	1	1	12	11	0	0	0	0
29	2	1	8	7	2	2	0	1
30	2	3	11	5	0	1	0	0

value is reduced from 22.78% to 18.26% (Table 3). The addition of one truck which is having large area compared to car leads to the much less reduction of  $\rho_A$ . From 10th minute to 11th minute there is a reduction in the value of  $\rho$  and increase in  $\rho_A$ . Reduction in the occupancy can be attributed to the considerable reduction in number of cars as can be seen in the Table 2. Increase in the value  $\rho_A$  in this case affected by both increase in the number of trucks and their slow speeds. Speeds observed in the 11th minute for the

two trucks are 27.5 km/h and 26.05 km/h which are considerably less than the average speed observed (40.5 km/h) during that minute.

TABLE 3: Occupancy, area occupancy and flow details

Observed Minute	Occupancy ( $\rho$ ) (%)	Area occupancy ( $\rho_A$ ) (%)	Flow (vehicles/minute)
1	33.22	6.38	31
2	22.70	5.38	22
3	31.81	5.51	32
4	22.78	3.23	25
5	18.26	3.18	17
6	35.46	7.51	34
7	12.09	1.19	13
8	27.44	5.18	26
9	27.93	3.88	34
10	17.48	2.16	20
11	12.82	2.99	11
12	27.54	4.73	27
13	18.27	3.46	18
14	28.78	5.43	28
15	34.81	5.95	36
16	28.32	5.2	28
17	35.11	4.91	35
18	26.67	4.34	26
19	36.86	6.59	39
20	28.30	4.32	28
21	26.70	3.18	28
22	18.93	2.43	20
23	12.95	1.28	16
24	38.50	6.46	26
25	26.32	4.59	20
26	23.38	2.66	22
27	23.90	3.91	24
28	23.54	3.68	25
29	27.53	5.45	23
30	26.52	5.73	22

For the duration 15th to 18th minute  $\rho$  is decreasing and increasing alternatively. For the same duration  $\rho_A$  is decreasing continuously. From the traffic flow observations, it can be seen that during 16th minute flow comprises three heavy vehicles (Buses, trucks) and one tractor. During 17th minute flow is comprising of more cars and two-wheelers and total flow during this minute (Table 3) is more than the previous minute (16th minute). When measuring  $\rho$ , physical characteristics of these vehicles (widths) are not properly accounted for where as when measuring  $\rho_A$ , sizes of these vehicles are taken into consideration. Because of the above said reason  $\rho$  value during 16th minute is less than that of 17th minute even though there is more number of heavy vehicles during 16th minute, and  $\rho_A$  value during 16th minute is more than that of 17th minute which is considering vehicle areas.

From the above observations it is evident that  $\rho_A$  is representing vehicle characteristics in a better way under heterogeneous traffic conditions. Since  $\rho_A$  is encompassing area of the vehicle and its speed under prevailing traffic conditions its value is different from that of  $\rho$ . As can be seen from Figure 2, the data collected is falling under free flow regime and even under these conditions there is a significant difference between these two values. In congested traffic conditions differences between  $\rho$  and  $\rho_A$  would be more prominent due to the effect of large vehicles.

## 6. CONCLUSIONS AND FURTHER SCOPE

### 6.1 Conclusions

Due to the limitations in representing the RHE traffic behavior with the conventional traffic characteristics such as density and occupancy, in this work, a new metric called area occupancy has been proposed. The new metric considers 3-D time-space region, with road width as the third dimension, instead of the 2-D time-space region. Variations of the occupancy and area occupancy are studied over a short time period using observed traffic data. The following are the important conclusions drawn from this study:

1. Density and occupancy are inadequate in representing the RHE traffic behavior.
2. Varying vehicle width is the main reason behind the lack of lane discipline observed in RHE traffic.
3. Since area occupancy is considering vehicle width, besides the length it can thus adequately represent the heterogeneous nature of the traffic.
4. From the variations of occupancy and area occupancy, it can be concluded that the proposed new metric is representing the traffic behavior in a more realistic way.

### 6.2 Further scope

The study of area occupancy gives an insight into the behavior of heterogeneous traffic. The results obtained from this study have major ramifications on concepts of roadway capacity and level of service under RHE traffic conditions. The concept of area occupancy can also be used as a measure of performance in converting heterogeneous traffic stream into an equivalent homogeneous traffic stream. However, this measure needs further validation under various traffic regimes. Since vehicle dimensions are very crucial in realizing the area occupancy, there is a lot of work to be done in this direction. Image processing based data collection technique seems to be promising in acquiring this kind of traffic data.

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