Modelling the area occupancy of major stream traffic

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Abstract

The U-turns at median openings interrupt the movement of approaching through vehicles. This results an overall reduction in speed and flow along with increase in density. It is difficult to measure density from field observations and it doesn't consider any heterogeneous characteristics of traffic stream. Alternatively, area occupancy takes into account the flow, speed, and the dimension of each vehicle. Therefore area occupancy is a much better measure to study the performance of a road as compared to traffic density. This concept assumes that the vehicles must move at a uniform speed while entering and exiting the test section which may be practically impossible to maintain for all the vehicles. Therefore, to overcome this assumption, a modified technique has been proposed in this study. Besides, the change in area occupancy at various segments of slow down section across different U-turning traffic volumes has been assessed. Finally, a regression equation has been modelled to estimate area occupancy at every segment of road section corresponding to any U-turning volume. This model has been validated by comparing the estimated values with the values obtained from field data and the MAPE is found to be less than 10%.

*Keywords:*Area occupancy, U-turns, median opening, regression analysis, density.

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1. Introduction

To meet the demand of vehicular traffic, most of the urban roads are now constructed as multilane roadsor existing two lane roads are being widened to multilane roads. The multilane roads are generally constructed with raised median in order to segregate the opposing traffic movements (Cooner et al., 2009). Openings are provided in the raised median for the vehicles to make U-turns and reverse their direction of movement; before finally merging with approaching through traffic stream in the opposing lane (Mohapatra et al., 2016). Due to this U-turning movement the approaching through vehicles get affected in an adverse manner as they progressively travel towards median opening and these vehicles are found to start decelerating. Therefore, a possible slowdown section exists for the vehicles approaching towards the median opening and this slowdown section is found to start at a distance of 40-50

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meters in the upstream of start of median opening and ends near the center of median opening (Mohanty et al., 2017; Mohanty and Dey, 2017).
Understanding this real traffic behaviour of approaching through vehicles require quantification of some of the basic traffic flow characteristics like speed, flow and density. Study of the various characteristics of road traffic is immensely useful for planning and design of roadway systems and operation of road traffic (Arasan and Dhivya, 2008). On Indian roads, it is difficult to measure microscopic characteristics, as the flow patterns are complex with no lane discipline. To study the traffic behaviour, speed and flow are widely used in India (Mallikarjuna and Rao, 2006). 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 (Arasan and Dhivya, 2008). It is also difficult to measure density from field observations and therefore, it is usually calculated from measured field values of traffic volume and speed ($k = q/v$). Furthermore, this fundamental relationship ($q= v*k$) 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 (Arasan and Dhivya, 2008). Also, the traffic density does not consider any heterogeneous characteristics of a traffic stream. Therefore, occupancy which is being used recently in place of density that takes the vehicle length into consideration.However, 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 different lengths (Mallikarjuna and Rao, 2006). Moreover, while dealing with traffic comprising of vehicles having different static and dynamic characteristics it is thus essential to include area of the vehicle to represent the realistic traffic behaviour (Arasan and Dhivya, 2008). Therefore, to overcome the difficulties associated with the estimation of occupancy, Mallikarjuna and Rao (2006) proposed a new measure of occupancy called "Area Occupancy" to measure the performance of vehicles in heterogeneous traffic conditions. This is modified by Asaran and Dhivya (2008). The measurement of area occupancy assumes that the entry and exit speed of a vehicle in the test section must be uniform. However, this assumption may not be always true. This study modifies the technique of measuring area occupancy where assumption of maintaining the uniform speed at entry and exit of a test section need not to be followed. The present study aims to assess the area occupancy at different segments of slow down section across different U-turning volumes.

2. Methodology

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 (Arasan and Dhivya, 2008). Thus, area occupancy can be expressed as follows:

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

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 timet_i in m^2; A = areaof the total road stretch in m^2, and T = total observation period in s.
The concept of area occupancy introduced by Mallikarjuna and Rao (2006) and Asaran and Dhivya (2008) assumes that the speed of the vehicle while entering and exiting the

test section must remain unchanged. To overcome this assumption, the concept of estimating area occupancy has been modified as explained in the successive section.
Considering two reference lines, X_1 and X_2 (start and end of the test section respectively) on a stretch of a road, four times (t_0, t_1, t_2, t_3) are to be noted for each and every approaching through vehicles. t_0 refers to the time when the front bumper touches the test section (X_1). Similarly, t_1 refers to the time when the rear bumper of the same vehicle just leaves X_1. Likewise, t_2 refers to the time when again the front bumper touches the test section at X_2 and t_3 is the time when the rear bumper leaves X_2. This is shown in Figure 1 below.

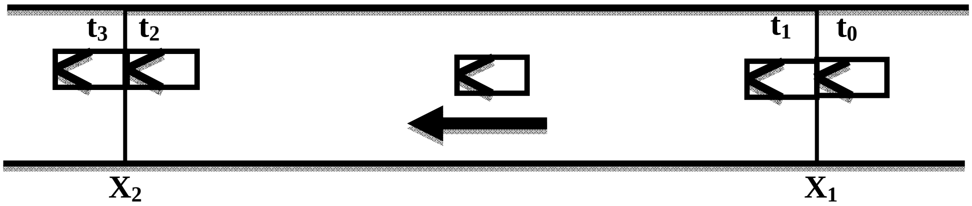

Figure 1. Entry and exit of vehicle at a test section

It can be observed from the figure that during time ($t_1$to t_2) the total area of a vehicle will be present on the test section. During this interval, at any instant of time, the road space occupied by a vehicle is equal to area of the vehicle itself. Generally, during time (t_0 to t_1) and (t_2 to t_3)a vehicle gradually occupies or leavesthe section. During these times the test section is occupied by a vehicle partially and the area of test section occupied by the vehicle progressively increases during (t_0 to t_1) and decreases during (t_2 to t_3). However, Asaran and Dhivya (2008) assumed the speed maintained by a vehicle to be constant within the stretch of the road and therefore the contribution of the vehicle to occupancy during both the time intervals (t_0 to t_1) and (t_2 to t_3) are same. However, this may not be always possible that vehicles maintain a constant speed specifically when they are approaching median opening or moving in slowdown section. Therefore, this study overcomes this assumption and the procedure of gradually occupying the area of test section is shown in Figure 2 and the steps for calculation of area occupancy is explained in detail.

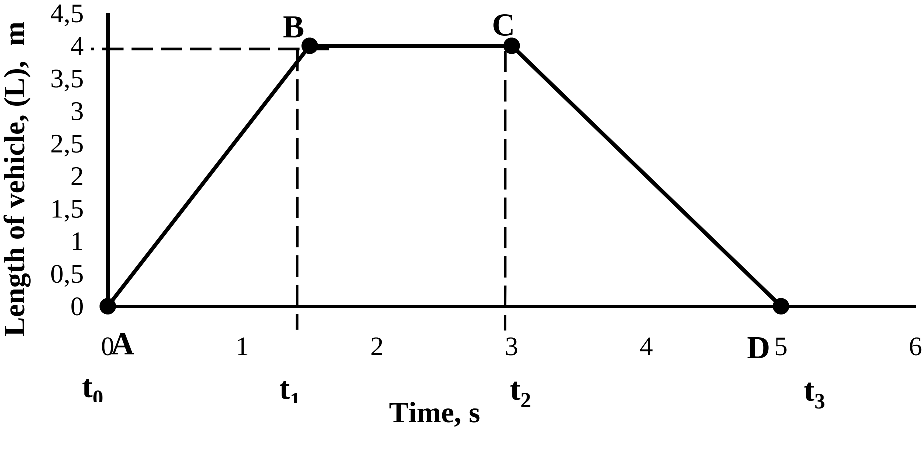

Figure 2. Occupancy of vehicle in the test section with respect to time

I. At t_0 the length of the vehicle within the test section is zero. However, at time (t_0 to t_1) the vehicle length within the test section gradually increases from zero to L (Length of vehicle) and represented by line AB. At any instant of time during time interval (t_1 to t_2), the length of vehicle within the test section is constant and represented by line BC. Likewise line AB, the gradual departure from the test section is represented by line CD.

II. The area under ABCDA gives the length of vehicle occupied within the test section in terms of $t_i L_i$ (meter*second).

$$t_i L_i = [\{0.5(t_1 - t_0)L\} + \{(t_2 - t_1)L\} + \{0.5(t_3 - t_2)L\}]$$

III. Subsequently, $t_i L_i$ when multiplied with the width of the vehicle gives the total area occupied by the vehicle in terms of $t_i a_i$ (meter^2 * second).

$$t_i a_i = t_i L_i * w_i$$

IV. This $t_i a_i$ is determined for all the vehicles crossing the test section at a definite time period, T.

V. Finally Area occupancy for the test section for the time period is calculated by using Equation (1).

The above mentioned procedure has been used in the present study to calculate the area occupancy of vehicles.

3. Field study and data collection

In order to determine the area occupancy, field data were collected from different median openings on six-lane divided urban roads. The road sections were identified so that the vehicular movements at these sites are unaffected by horizontal curvature, presence of upstream or downstream intersection, bus stop, parked vehicles, pedestrian movements or any kind of side friction. All the road sections have raised kerb on both side and carriageway width in the range of 9.4 m to 9.8 m in each direction of travel of the road. At each test section, data were collected by video recording technique on typical weekdays. The geometrical details of all the seven median openings has been shown in Table 1.

Table 1. Geometric details of different test sections

Sectionno.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Width of median opening, m	20	15.7	19.8	14.8	20	20.3	20.1
Width of raised median, m	1.3	1.0	1.2	1.2	1.3	1.2	1.3
Width of carriageway, m	9.6	9.6	9.8	9.5	9.4	9.5	9.4

Due to the limited priority situation, the approaching through vehicles are usually found to start decelerating in the upstream of the median opening. Therefore, a possible slowdown section exists for the vehicles approaching towards the median opening. Ma et al. (2013) concluded that the possible slowdown section starts 40 m before the starting of intersection. Nevertheless, the traffic conditions are totally different in Indian scenario. Thus, an isolated speed profile study was made to recognise the possible slowdown section.

The speed profile of around 2000 vehicles was studied and the slowdown section is found to start at a distance of 40-50 m in the upstream of start of median opening and ends near the center of median opening (Mohanty et al., 2017). From the start of median opening, 50 m in the upstream direction is divided into equal segments of 10 m each. The median opening portion is divided into two equal halves. Two cameras (C_1 and C_2) were used in the field to record the traffic data as shown in Figure 3.

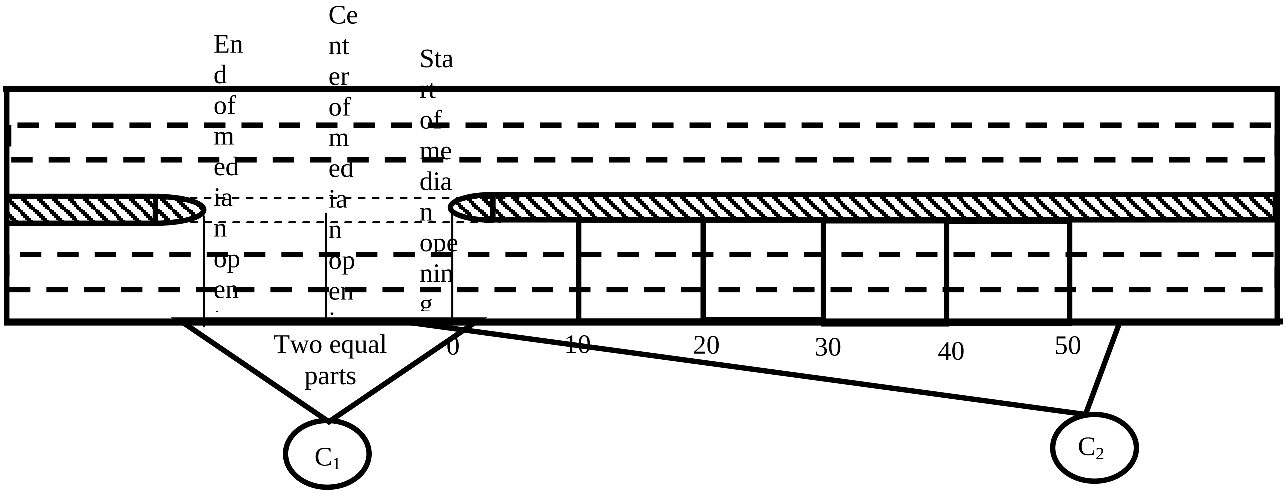

Figure 3. Camera setup for data collection

As explained in the methodology, times (t_0, t_1, t_2, t_3) is noted for each vehicles crossing different segments of the test section in every 60 seconds. The length and width of every vehicle is also noted down.

4. Analysis of data

The area occupancy at different segments of road section is studied with a large amount of data at various traffic volume levels. The variation in area occupancy of approaching through vehicles was studied at every 10 m intervals from the start of the slowdown section (50 m on the upstream from the start of median opening) to the end of median opening. A change in area occupancy is observed as the approaching through vehicles approach towards the median opening. The presence of U-turns generally compels the approaching through vehicles to reduce their speed which leads to spent more time in the slow down section. The effect of U-turns is more prominent as the vehicles comes close to median opening area. Moreover, the frequency of U-turns (i. e. hourly volume of U-turns) also greatly influence the movement of approaching through vehicles. More frequent the U-turns during the movement of an approaching through vehicle in the slow down section, more will be the time spent by the approaching through vehicles within the slow down section. This results in an increase in area occupancy. Therefore, the variation in area occupancy at different segments of slow down section under different U-turning traffic volumes is estimated and presented in Table 2. From Table 2 it can be seen that the area occupancy increases with increase in U-turning volume. This is obvious that with an increase in flow, the interaction between U-turning vehicles and approaching through vehicles increases. This causes to spend more time which in turn increases the area occupancy. The variation in area occupancy is also presented in Figure 4 and it can be observed that as vehicles movein the downstream direction and come close to median opening, there is an overall rise in the area occupancy values. However, this increase is not noticeable upto 900 vph U-turning volume whereas there is a substantial increase in area occupancy at higher U-turning volumes (more than 900 vph). At low traffic volume, the interaction among the U-turns and approaching through vehicles are comparatively less. The approaching through vehicles are mostly found to avoid the possibility of conflict with U-turns by changing their lanes without usually compromising their speed. At high U-turning volume, a near congestion situation develops which considerably disrupt the overall traffic movements (Malaya et al., 2017). Due to increase in traffic density, the approaching through vehicles find it very difficult to shift towards kerb to avoid the U-turns at the median opening area (Malaya et al., 2017). This forces the approaching through vehicles to reduce their speed and this speed reduction is more prominent as the vehicles come close to median opening area. Therefore, the rise in area occupancy near the median opening area is more prominent at higher U-turning volumes.

Table 2. Area occupancy at different segments

Segments on road section (m)		**50 to 40**	**40 to 30**	**30 to 20**	**20 to 10**	**10 to 0**	**0 to -10**	**-10 to -20**
U-turning Volume, vph	**300-600**	0.887	0.913	0.944	0.982	1.011	1.015	1.006
	600-900	2.265	2.402	2.575	2.8314	3.055	3.215	3.195
	900-1200	3.348	3.527	3.765	4.502	5.162	6.582	6.581
	1200-1500	4.706	5.198	6.291	6.545	7.151	10.710	10.727
	More than 1500	6.268	7.469	8.046	8.471	9.218	12.795	12.824

** 0, -10, -20 indicate start, centre and end of median opening respectively.*

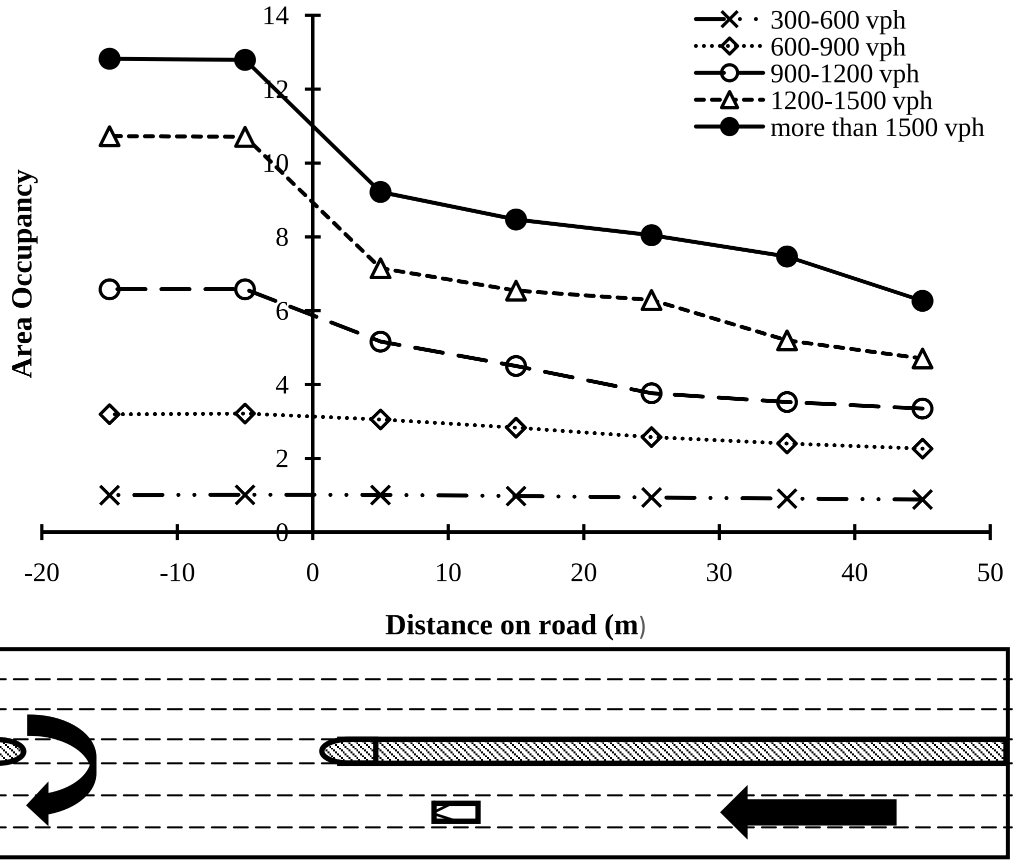

Figure 4. Trend of Area occupancy

From the above discussion it is clear that area occupancy at any segment in the slow down section is mainly influenced by three parameters; namely (i) U turning volume (V), (ii) speed of approaching through vehicles(v_{appr}) , and (iii) distance of the segment from median opening (D). Therefore, these three independent variables have been used for the estimation of area occupancy at different segments of the slowdown section under a particular U-turning volume. Prior to regression modelling, these variables were correlated to check the multicollinearity at 5% significance level and significant correlation was found in two cases; first between V and v_{appr} (Pearson correlation value = 0.76), and second between D and v_{appr} (Pearson correlation value = 0.84). However, no significant correlation was found between V and D. Therefore, a linear regression has been modelled by considering these two variables V and D. Around 1500 data points have been used to develop the following linear regression. The p-value of the variables are less than 0.05 which indicates about their statistical significance in the equation.

$$AO = 0.006V - 0.067D \qquad \text{(Adjusted } R^2 = 0.95)(2)$$

Where, AO is the area occupancy in 1 minute (60 s) at U-turning volume of 'V' vehicles per hour and 'D' distance of the centre of segment from the median opening, in m.

Table 3. Multiple linear regression table for estimation of area occupancy

Area occupancy	Coefficient	P>|t|	Adjusted R-square
V	0.006	0.000	0.96
D	-0.067	0.000	

The distance is measured on the upstream from the start of the median opening. Therefore, distances on upstream of median opening are always in positive whereas the distances on downstream from start of the median openings are always negative. The regression parameters of Equation (2) are shown in Table 3. It can be seen from Table 3 that the p-value for both the independent variables are less than 0.05 which shows about their statistical significance in the proposed equation. The accuracy of the proposed model has also been validated. For the validation purpose, a separate field study was conducted and data were collected from a different median opening of six-lane divided road. The data of this validation section have not been used for determining the area occupancy model. A random sample of around 30 minutes have been used for the validation purpose. The area occupancy computed by the proposed model have been compared to those obtained from the field data. The comparison was done at every segment (50 to 40, 40 to 30, 30 to 20, 20 to 10, 10 to 0, 0 to -10, and -10 to -20). Mean absolute percentage error (MAPE) is a good measure of prediction of accuracy while validating models related to traffic studies and capacity (Liu et al., 2008). MAPE is calculated by Equation (3) as given below.

$$M = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \tag{3}$$

Where,A_t is the actual value and F_t is the forecast value and n represents the number of data used for validation.

Usually, a MAPE value less than or equal to 10% is considered to be good enough (Liu et al., 2008). The highest MAPE value for all the cases of validation is 7.3%. Therefore, it can be concluded that the proposed model provides reasonable estimates of area occupancy.

5. Conclusion

This study modifies the procedure for measuring area occupancy which was introduced by Mallikarjuna and Rao (2006) and was further studied in detail by Arasan and Dhivya (2008). The modification has been done to overcome the assumption of maintaining constant speed by a vehicle at entry and exit of a test section. The present study attempts to estimate the change in area occupancy at different segments of regular 10 m interval within the slowdown section. The effect of U-turning volume on area occupancy has also been studied. It is observed that the area occupancy increases as the vehicles are close to the median opening area. However, this variation is not noticeable at low U-turning volume rather the variation is more prominent as the U-turning volume increases. Finally, a regression equation has been developed for estimating area occupancy at any distance from the median opening at any particular U-turning traffic volume. The proposed model is also validated by comparing the estimated values of area occupancy with the values obtained from field data and the calculated MAPE value is less than 7.5%.

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