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Modeling Roadway Occupancy Under Varied Speed and Flow Values in Mixed Traffic Conditions

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ABSTRACT

Due to the significant increase in vehicle population over the recent decades, a high concentration of traffic on urban roads has been observed. In contrast, the area of the carriageway remained unchanged in urban areas during this time. Two important parameters, namely, density and occupancy, are encompassed by the "Concentration". The roadway occupancy is more important under mixed-traffic conditions where various types of vehicles share the same carriageway. Also, Occupancy is more critical than density because it accounts for traffic composition and speed. Despite its significance, few researchers have used data of simulated density to study area occupancy in mixed-traffic. As the density cannot be obtained directly, this paper employs simulated outcomes of density to present a novel approach for estimating roadway occupancy, considering varying speed and flow values on urban roads under mixed-traffic conditions.

Keywords – area occupancy, flow, mixed traffic, speed, VISSIM.

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I. INTRODUCTION

The prevalence of vehicles with varying sizes and speeds in mixed traffic circumstances has led to a noticeable escalation in traffic congestion over the past few decades. This situation significantly affects roadway occupancy. In order to have a comprehensive understanding of real-world traffic conditions, it is imperative to quantify the core traffic flow characteristics, namely speed, flow, and density. Typically, the calculation of density is derived theoretically by utilizing field measurements of traffic volume and speed, resulting in the equation $k = q/s$.

In this context, the variables are defined as follows:

k represents the "density of vehicles per lane per kilo-metre", q represents the" flow rate of vehicles per hour", and s represents the "speed of the traffic stream" in kilometres per hour.

It is observed that the above relationship is good in homogeneous traffic conditions, while less accurate in mixed traffic conditions. Therefore, the density, represented as the total number of vehicles per unit of a length of a specific roadway, is applicable in situations when the traffic exhibits a high level of homogeneity. In scenarios involving mixed traffic, speed and the physical dimensions of vehicles exhibit sudden variations, hence directly impacting the density measurements associated with a certain situation. As the size and speed of vehicles vary suddenly, it is very difficult to obtain density using the above relationship under such conditions. The simulation is required to overcome such a predicament. VISSIM is widely used and accepted as the output obtained through its simulation is accurate. In this study, the density is obtained through the simulation results of VISSIM, and the same results are validated by applying statistical parameters such as R^2, Normalized Root Mean Square Error (NRMSE), and p-value. In this research, roadway occupancy is referred to as the percentage ratio between the total surface area occupied by vehicles against the total surface area of a specific road segment.

Numerous investigations have been conducted for roadway occupancy as well as traffic stream characteristics in scenarios involving a combination of different traffic types and volumes. Khan S. and Maini performed a study with the aim of developing a model for traffic flow under varied conditions. The authors also investigated the distinctive attributes pertaining to traffic composition, the geometry of the given roadway, vehicular interactions, driver behaviour, and maneuverability for their study [1]. Chandra S. and Kumar U. conducted a study to exa mine the influence of the width of lane on carrying capacity of roads that accommodate a variety of vehicles in India. The researchers established adjustment factors, particularly for substandard lane widths [2]. Mallikarjuna C., and Rao K.R., have conducted a study on the area that is occupied by vehicles. In their study, they considered the dimensions of the vehicle's projection, specifically its length and breadth [3]. Arasan V.T. and Dhivya G. measured occupancy under diverse traffic situations using simulation techniques. They concluded in their study that the idea of occupancy cannot be applied directly to “mixed traffic conditions”[4]. For non-lane-based varied traffic at intersections, Mathew T.V. and Radhakrishnan calibrated “Microsimulation-Models” using VISSIM [5]. Geroliminis and Sun co nducted empirical experiments to examine the disper sion characteristics of "Macroscopic Fundamental Diagrams” (MFDs) by assessing flow and occupanc y patterns under congested traffic situations [6]. A comprehensive examination was conducted by Mallikarjuna C. and Rao K.R., wherein an investiga tion was carried out utilising the notion of area occu pancy, which resulted in the construction of a traffic model [7]. Park and Schneeberger have successfully developed a “Microscopic Simulation Model” to rep resent a “coordinated actuated signal system” [8]. M ahapatra G.and Maurya performed a study to assess the connection between vehicle longitudinal speed as well as lateral properties for conditions in Indian traf fic [9]. In order to compute the “Dynamic Passenger Car Unit” (PCU) using the idea of area occupancy, an estimation method was given by Preethi and Ash alata [10]. Kumar et al. conducted a study that was in tended to determine the values of “Passenger Car Un its (PCU)” in mixed traffic situations and utilised ar ea occupancy as a fundamental metric for vide variety of vehicles [11]. Mishra et al. suggested a unique methodology f orestimating PCU values for heterogeneous traffic si tuations that utilises area occupancy [12]. A case stu dy was conducted by Roy et.al. to investigate impa ct of “Mixed Traffic” on capacity of Indian roads [13]. In the course of their research, George et al. employed Kalman filtering techniques to investigate area occupancy. They validated their findings by comparing them with simulated density and assessing the performance accordingly under various traffic scenarios, like congestion and non-recurrent traffic situations [14]. In another study, George et al. suggested a strip-based strategy on the density-occupancy relation [15]. Bandi M. and Geor ge V. created a microsimulation model in VISSIM to analyse effect of the short-term and long-term improvements for a road network of Mangalor e City [16]. Singh et.al., conducted a study to examin e the characte-ristics of traffic flow, specifically focu sing on the three main parameters: speed, flow rate, and area occupancy. The study took into account the circumstances of heterogeneous traffic[17]. The suit ability of the area occu-pancy concept in MFDs as o pposed to traditional MFDs was examined. The rese archers reached the conclusion that assessing area oc cupancy in field was a more straightforward process in comparison to evaluating traffic density.

Researchers have conducted several studies in past, as is obvious from the literature referenced above. However, very few researchers have conducted a study to analyse the area occupancy using simulation techniques. The present research aims to contribute to this literature using simulation techniques to model occupancy of the area for different speed and flow values in “mixed traffic conditions.”

Materials and Methods

(a) Study area:

This study focused on the road segment connecting Kalupur circle and Kalupur railway station of Ahme dabad city. The segment considered was 380 m long and had 3 lanes with a total carriageway width of 11.5 m. The condition of the pavement was good, and no gradient was observed.

(b) Collection of data:

Videography was employed to conduct a traffic surv ey during morning peak hours, off-peak hours, and e vening peak-hours. During the survey, two full HD v ideo cameras were strategically positioned, with one camera situated at the entry point and another camer a positioned at the exit point. This arrangement ensu red comprehensive coverage of the whole traffic are a. The flow rate was measured for each class of vehi cle at a 5 minute period. The speed of various vehicl es was determined by calculation using the equation:

s=d/t, which represents the connection bet-ween spe ed (s) and time (t) in the context of vehicles, where s is the speed of the vehicles measured in kilometres per hour (km/h). The variable "d" represents the dist ance traveled, measured in kilometres. The variable "t" represents the amount of time taken to travel the aforementioned distance. The actual measurements of different vehicles were taken, and the average sizes are tabulated as per Table-1. These values are considered as input value parameters to obtain simulation results using VISSIM.

Table-1 Size of different vehicles

Type of vehicle	**Size**
Two-wheeler	1.95 m X 0.80 m
Three-wheeler	2.80 m X 1.48 m
Car	3.70 m X 1.53 m
Bus/Truck	9.70 m X 2.50 m
LCV	4.10 X 1.75 m

(c) Generation of VISSSIM Model:

For this research work, the parameters required to simulate the traffic scenario as real in VISSSIM were speed, flow, and plan areas of different vehicles. The length of a road segment, name of the road, number of lanes, and each lane width were given as input as per observed data. Before each simulation, the following input, values were entered:

1. Vehicle input:(i.e., number of "vehicles").
2. Vehicle composition, including relative flow.
3. Desired speed of each type of vehicle.
4. 2D/3D model properties including size (static properties and dynamic properties).
5. Link behaviour.
6. Driver behaviour.

To obtain simulation results as per real-time traffic scenarios, above mentioned values were edited before each simulation. The results of the speed value and flow value obtained from the simulation were then compared with the observed speed value and flow values.

II. RESULTS AND DISCUSSION

Fig.1 shows the correlation between observed and si mulated speed values for the Kalupur road stretch, w hile Fig. 2 illustrates the connection between observe d and simulated flow values. Statistical variables including Normalised RMSE ("Root Mean Square Error"), p-value, and R^2 were used to verify the simulation model's accuracy. The findings shown in Figures 1 and 2 demonstrate that the simulated model correctly captures speed and flow data as the Normalised Root Mean Square Error (NRMSE), p-value, and modified R^2 value are within acceptable bounds.

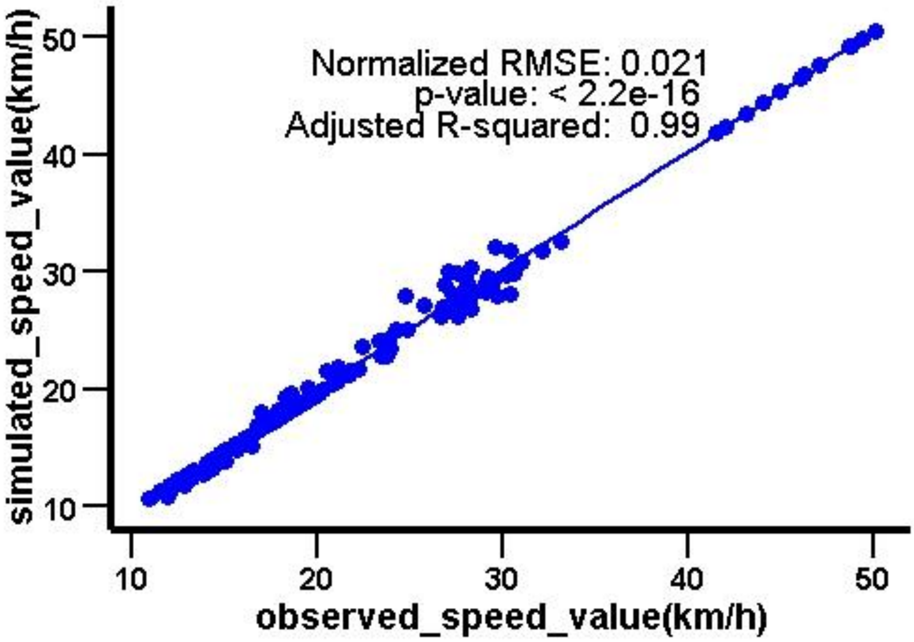

Figure 1 Plot of observed speed value v/s simulated speed value.

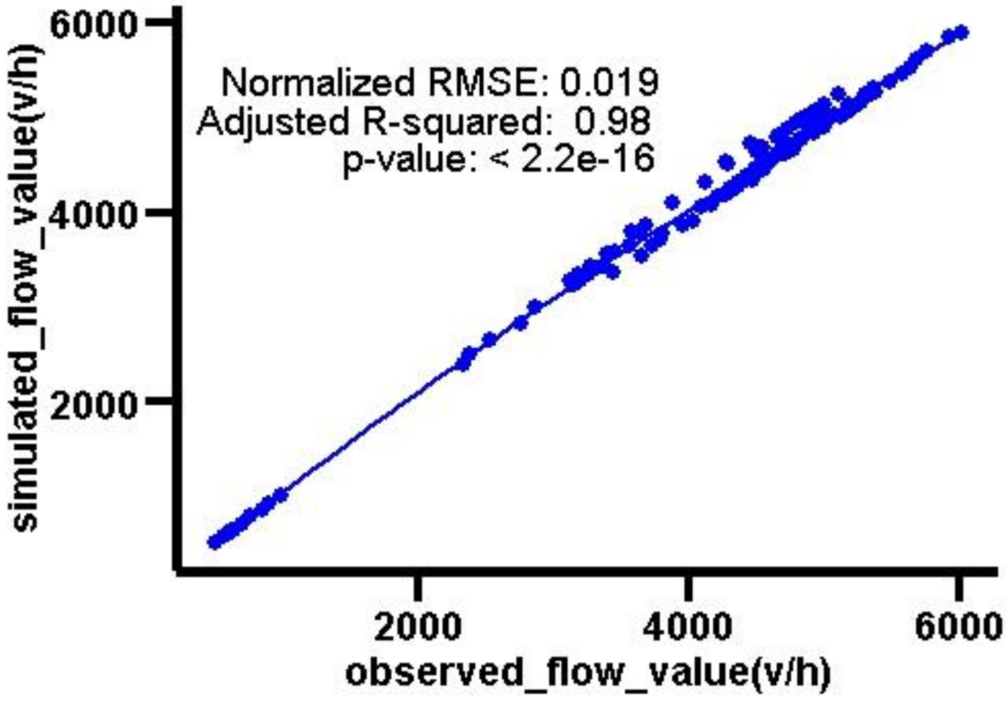

Figure 2 Plot of observed flow value v/s simulated flow value.

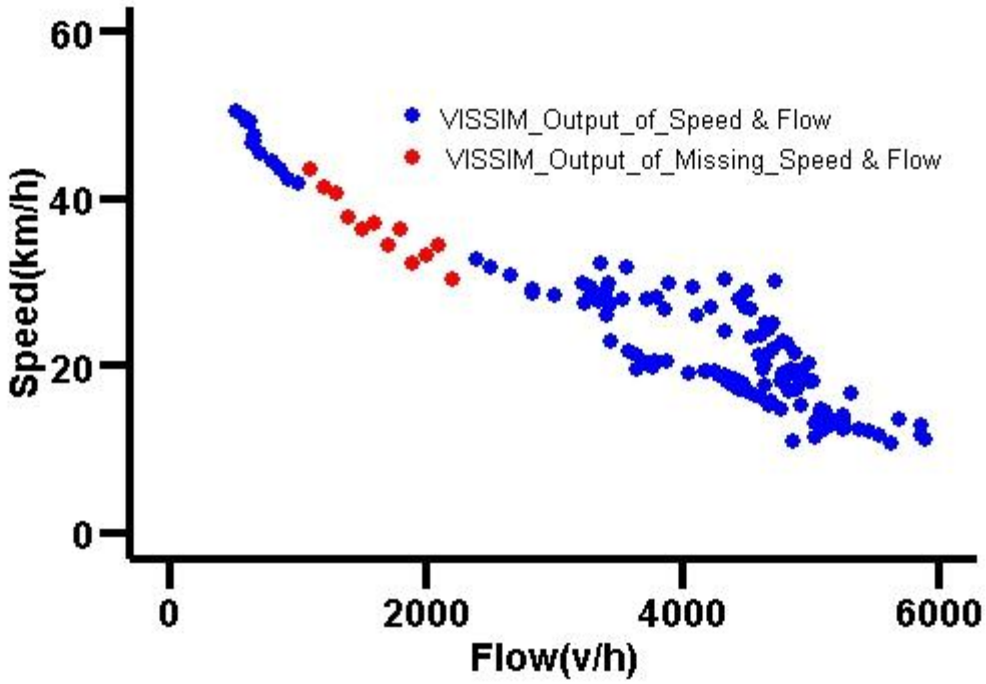

Figure 3 Plot showing the relationship between speed and flow with missing values.

However, it was discovered that certain data points were missing, which caused the dataset to be inconsistent. To address this, flow values were predicted using a simulation technique for given input speed values between 33 and 42 km/h. Figure 3, which depicts the link between speed and flow while taking into consideration the missing values in the dataset, shows the outcomes of this prediction. Density values were produced from the VISSIM output following the validation of the simulation results and the prediction of missing data. The connection between (i) speed and roadway occupancy and (ii) flow and roadway

occupancy was then established using these density values. The ratio of the total surface area of a specific road segment that is occupied by vehicles to the entire surface area of the segment was utilised to calculate the roadway occupancy. Figure 4 shows how speed and roadway occupancy are related, whereas Figure 5 shows how flow and roadway occupancy are related.

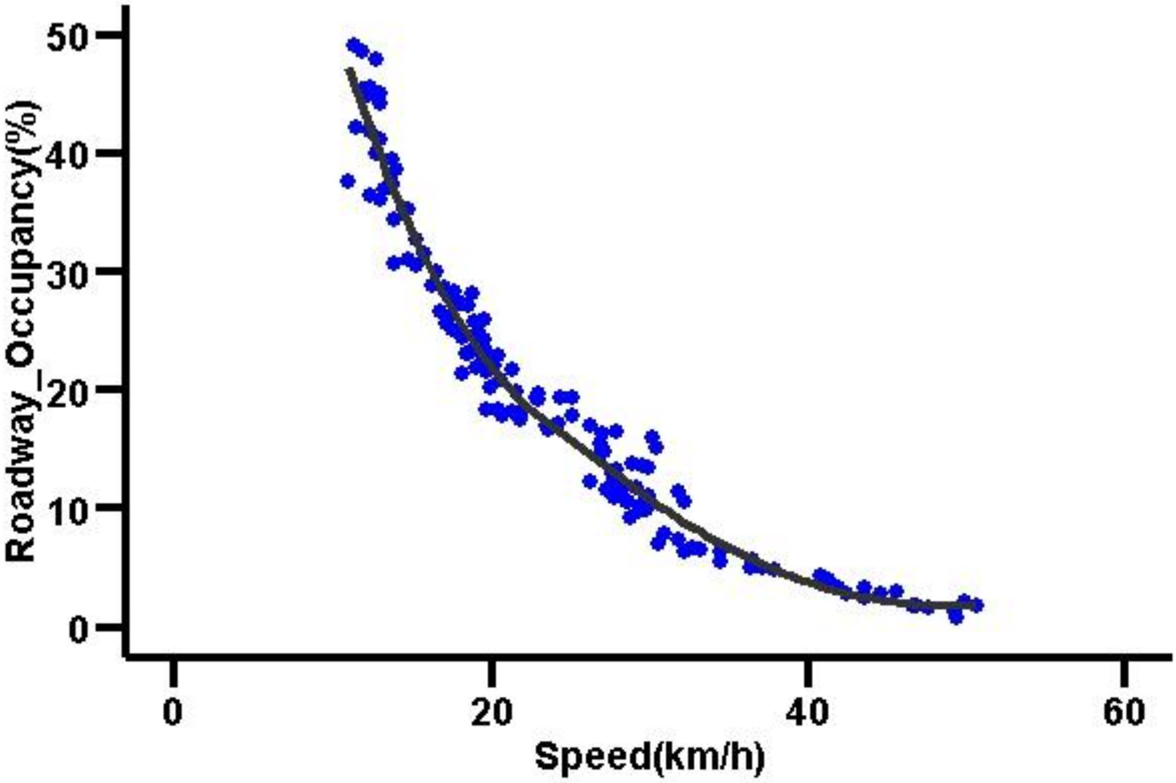

Figure 4 Plot of speed and roadway occupancy.

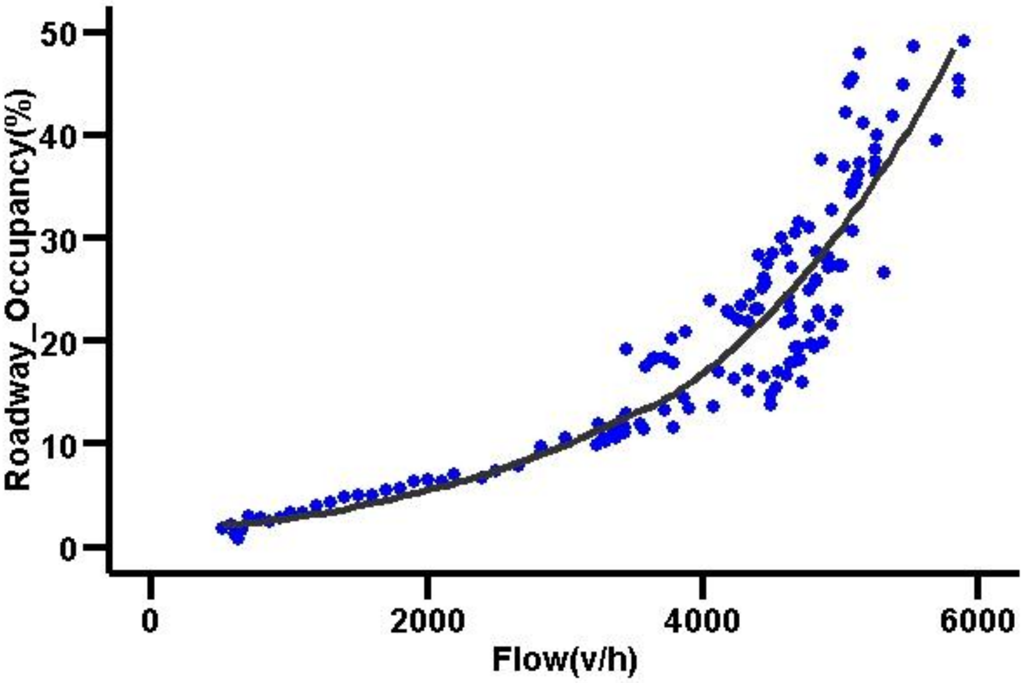

Figure 5 Plot of flow and roadway occupancy.

Results obtained through simulation output using VISSIM for speed and flow are considered acceptable to obtain density values as the same existed very close to real traffic scenarios. The following regression equations (i) & (ii) are obtained for speed versus roadway occupancy and flow versus roadway occupancy.

$$Y_1 = - 0.0013*X^3 + 0.1544*X^2 - 6.4562*X + 100.31 \quad \text{---(i)}$$

$$Y_2 = 5E\text{-}10*X^3 - 3E\text{-}06*X^2 + 0.0088*X - 2.7669 \quad \text{---(ii)}$$

III. CONCLUSIONS

The regression model equations derived in this study can precisely predict the roadway occupancy (%) depending on provided speed (km/h) or flow (v/h) values. For example, a speed of 40 km/h corresponds to a roadway occupancy of 5.90%, whereas a flow of 2000 v/h results in a roadway occupancy of 6.83%. The estimates provided by these regression equations are deemed acceptable for this research. It was observed that roadway occupancy reaches its peak at lower traffic speeds and lowest at higher traffic speeds. Conversely, occupancy is lowest at lower flow values and highest at higher flow values. Furthermore, buses, trucks, and LMVs take up more road space for extended periods of time than two-wheelers, three-wheelers, and cars.

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