Analysis and Development of Traffic Speed-Flow-Density Relationships for Urban Roadway

Thasneem Nadirsha, Archana S

Abstract*: India is a developing country containing heterogeneous traffic, which is characterized by wide variations in traffic characteristics. The new technologies offer the greatest challenge and hope for improving the quality of traffic system. The ability to apply traffic flow fundamentals is an essential ingredient in working toward improving the transportation system. The present study is concerned with macroscopic traffic flow characteristics observed on 4-lane divided carriageway [Thrissur-Kunnamkulam (SH-69)]. The intention of this paper was to analyse traffic flow, density, and speed for developing a model that provide the exact character of traffic flow. Traffic flow fundamental diagrams are used to characterize the relationship between these parameters. Study of traffic flow involves selection of location, videographic survey, analysis of video recordings, statistical analysis and calculation of basic parameters of traffic flow. Data extracted are compiled for each direction. Scatter diagrams were plotted by using the collected data. The relationship between parameters was developed based on regression analysis using statistical software SPSS 21. The speed-density function obtained was compared to macroscopic models such as Greenshield's model and Greenberg's model. By using speed-density model, flow-density and speed-flow relationships are predicted for the given highway. Further validation of the predicted model is done using graphical residual analysis. This succeeded to develop new models enabling theoretical determination traffic parameters for a given urban roadway.

Index Terms: Fundamental diagrams, Heterogeneous traffic, Macroscopic parameters, Scatter diagrams.

I. INTRODUCTION

Traffic flow represents the traffic load on the transportation system and the interaction between these loadings and the facility capacity determines the operational performance of the system. Hence it is extremely important to know the flow rates, their temporal, spatial and modal variations, and the composition of the traffic stream. Speed and travel time are the fundamental measurements of traffic performance of the existing highway system, and speed is a key variable in the redesign or design of new facilities.

Density is an important characteristic that can be used in assessing traffic performance from the point of view of users and system operators.The traffic stream models determine the fundamental relationships among macroscopic parameters for uninterrupted flow conditions.

The traffic stream characteristics include flow, speed, and density. The relationships are for free-flow and congested-flow conditions away from flow interruptions such as at intersections.

II. LITERATURE REVIEW

J Roux [1] tested the relevance of overseas models to South African conditions, a number of models have been investigated with data obtained from South African freeways. Models obtained from three separate freeway sections were compared to overseas models as well as models obtained from local studies. P. Balaji [2] in his paper vehicle class-wise speed volume model for three-lane undivided urban road found that multi-class speed flow equations are more relevant to these types of facilities rather than single class flow speed models. D. Ashish [3] developed speed density relations for different vehicle type on urban arterial roads under mix traffic conditions in Chandigarh, Jaipur and Delhi using a set of simultaneous equations and established speed prediction models. R.S. Dhapudkar [4] reviews the status of heterogeneous mixes worldwide, and what factors need to be considered in such mixes. He developed a macroscopic stochastic model of traffic movements at signalized intersection, to study macroscopic traffic parameters (flow, speed and density) and to establish new models for the Indian highway. XU Cheng [5] developed fundamental diagrams of traffic flow. 10 typical speed-density relation models are summarized and analyzed by parameter calibrations and fitting errors using Beijing Expressway data. Saurav B. [6] study among vehicular density measured from moving observer method in field and density predicted from theoretical speed-density models. Moving observer data were collected from nine test vehicle runs in a weekday. Vehicle counts with and against test vehicle, vehicle passing and over taking the test vehicles, journey time and travel distance were recorded. Parameters of traffic stream such as volume, speed and density were calculated from the collected data. Then Greenshield's model, Greenberg's model and Underwood's model were fitted in the graphical representation of speed-density relationship and corresponding parameters were determined using SPSS. Hashim and Wahidah [7] based on the functional relationships between flow, density and speed for the three major highways in Malaysia. The trans-logarithm function of density-speed model was compared to the classical models of Greenshield's, Greenberg's, Underwood and Drake et al.

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III. DATA COLLECTION AND EXTRACTION

A. Determination of Study Section

The initial step was the selection of the road stretch, from which the data were collected. The road selected was Thrissur-Kunnamkulam road (see Fig. 1). The next step was the selection of the study section on the selected road in which the entry point and exit point are marked. A pilot study was organized on the selected road which covers both free-flow and congested-flow conditions in order to determine the place were predictable to get the data more precisely. The distance enclosed by the entry and exit point is noted as 1.4 km. The data were collected by videographic survey conducted on typical weekdays over peak and off-peak hour.

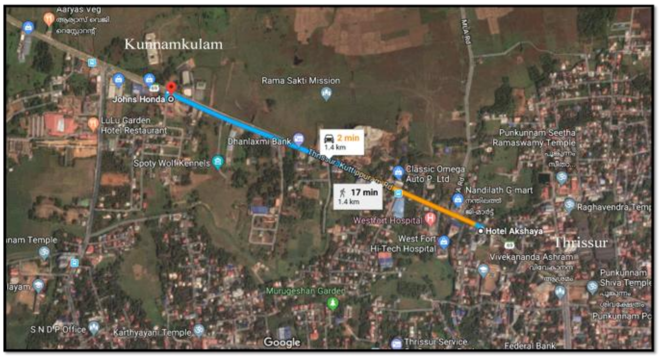

Fig.1 Study Section (Thrissur-Kunnamkulam Road)

B. Data Processing

Video recordings were processed by tracing vehicle movement crossing the specified study section. The flow data is calculated at entry and exit points in such a way that the vehicles which are passing through the section in every five-minute interval. The speed data is done by calculating the time by which vehicle which enters and exit the rectangular section. Initial density is determined using photographic technique along the entire section. By using initial density, the density is calculated at every five-minute interval using Eqn. 1 as follows:

$$k_t = k_{t-1} + N_{entry} - N_{exit} \qquad (1)$$

Where,

k_t is the density at time t

N_{entry} is the number of vehicles entered the stretch during the time from t-1 to t

N_{exit} is the number of vehicles going out the stretch during the time from t-1 to t

The collected data from the video recordings were gathered in Excel sheets, and then processed in order to obtain the macroscopic traffic stream parameters such as flow, speed, and density.

IV. DATA ANALYSIS

A. Determination of Speed-Density Relationship

The speed-density curve is plotted using Greenshield's, Greenberg's and Exponential models, where density is independent variable and speed is dependent variable (see Fig. 2 and Fig. 4 towards Thrissur and Fig. 3 and Fig. 5 towards Kunnamkulam). Greenshield's and Greenberg's models could predict the traffic condition when velocity equals zero (v=0). The Greenshield's model is linear while the Greenberg's model non-linear. Both of them have the highest point of traffic congestion when velocity is zero. These highest points cannot represent the maximum congestion levels because the classical functions are either linear or exponential.

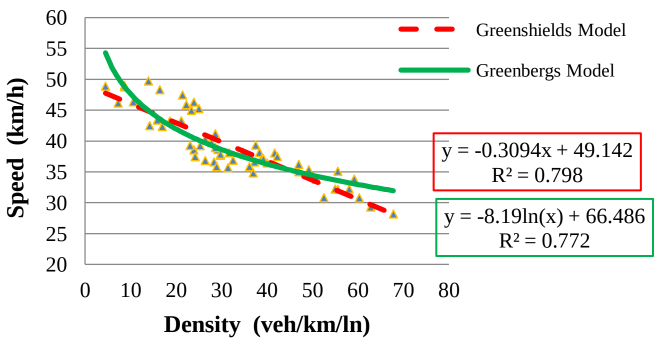

Fig.2 Speed-Density Relationship using Greenshield's and Greenberg's Models (Towards Thrissur)

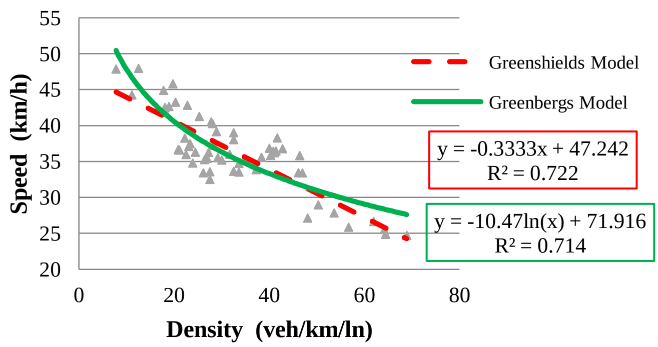

Fig.3 Speed-Density Relationship using Greenshield's and Greenberg's Models (Towards Kunnamkulam)

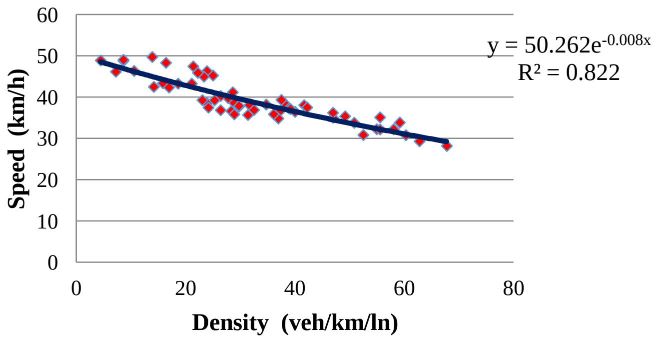

Fig.4 Speed-Density Relationship in Exponential Scale (Towards Thrissur)

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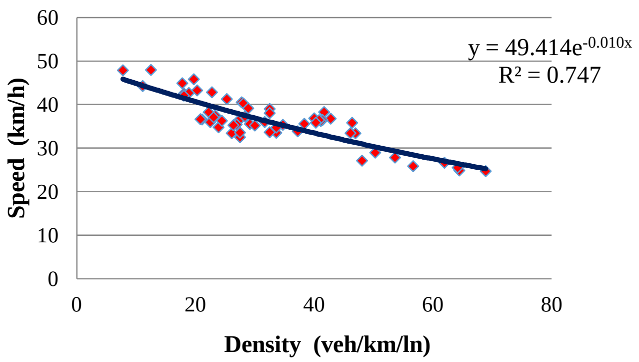

Fig.5 Speed-Density Relationship in Exponential Scale (Towards Kunnamkulam)

B. Speed-Density Model

The final form of speed-density relationship model is presented as follows:

Towards Thrissur:

$$u = 50.262e^{-0.008k} \tag{2}$$

Towards Kunnamkulam:

$$u = 49.414e^{-0.010k} \tag{3}$$

Where,

u is the speed (km/h) and k is the density (veh/km)

C. Flow-Density Model

The flow density relationship can be derived as follows:

$$q = u * k \tag{4}$$

Towards Thrissur:

$$q = (50.262e^{-0.008k})k \tag{5}$$

Towards Kunnamkulam:

$$q = (49.414e^{-0.010k})k \tag{6}$$

Then obtained flow-density model are plotted, where density is independent variable and flow is the dependent variable. The best fit logarithmic curve is drawn over the observed data for two lanes (see Fig. 6 and Fig. 7).

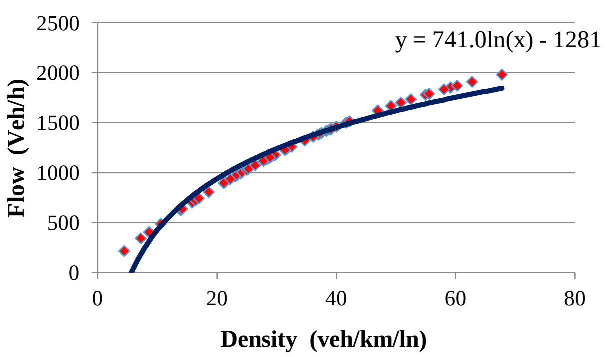

Fig.6 Flow-Density Relationship (Towards Thrissur)

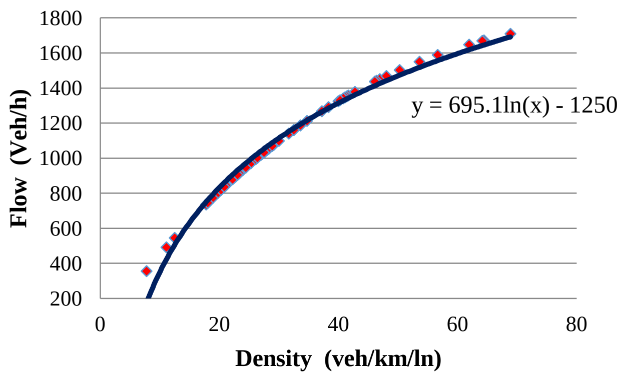

Fig.7 Flow-Density Relationship (Towards Kunnamkulam)

D. Speed-Flow Model

Flow is chosen as the dependent variable and speed as the independent variable because a variation in vehicle's speed is responsible for the variations in flow. The flow-speed function can be mathematically illustrated by the exponential function.

Towards Thrissur:

From Eqn. 2

$$u = 50.262e^{-0.008k}$$

Therefore

$$k = -\frac{1}{0.008}\log\frac{u}{50.262} \tag{7}$$

Substituting value of k in Eqn.5

$$q = \left(50.262e^{-0.008(-2.870\log u)}\right)(-2.4870\log u) \tag{8}$$

Towards Kunnamkulam:

From Eqn. 3

$$u = 49.414e^{-0.010k}$$

Therefore

$$k = -\frac{1}{0.010}\log\frac{u}{49.414} \tag{9}$$

Substituting value of k in Eqn.6

$$q = \left(49.414e^{-0.010(-2.0237\log u)}\right)(-2.0237\log u) \tag{10}$$

Then obtained speed-flow model curve are plotted. The best fit linear curve is drawn over the observed data for two lanes (see Fig. 8 and Fig. 9).

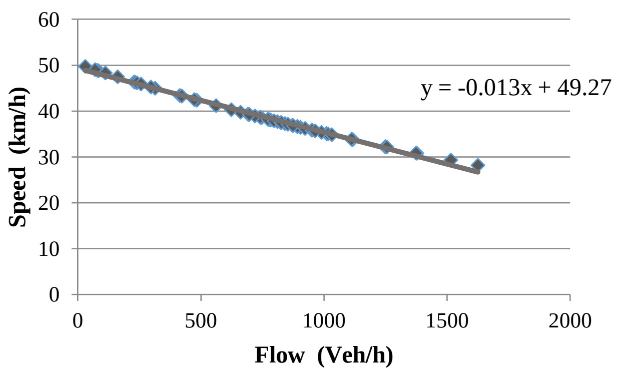

Fig.8 Speed-Flow Relationship (Towards Thrissur)

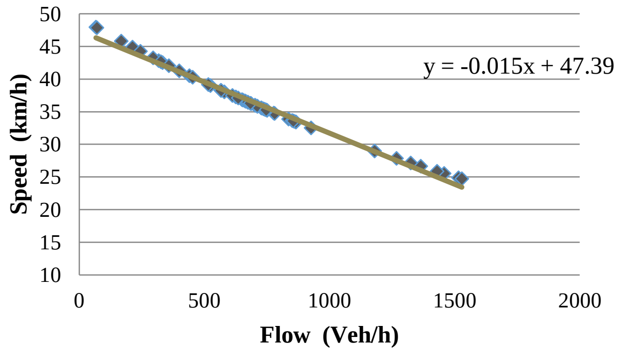

Fig.9 Speed-Flow Relationship
(Towards Kunnamkulam)

V. MODEL VALIDATION

Graphical Residual Analysis: The basic tool for statistical modeling is graphical residual analysis. The acceptability of various phases of the model is provided by different plots of the residuals from a fitted model. Numerical methods like R^2 statistic for model validation are also useful, but usually to a small extent than graphical methods. Graphical Residual Analysis for the given lanes (see Fig. 10 and Fig. 11).

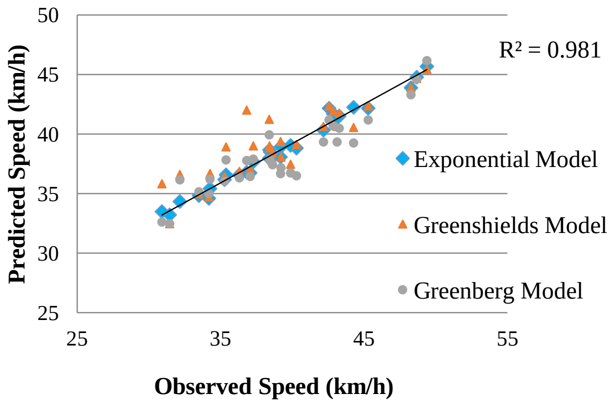

Fig.10 Graphical Residual Analysis (Towards Thrissur)

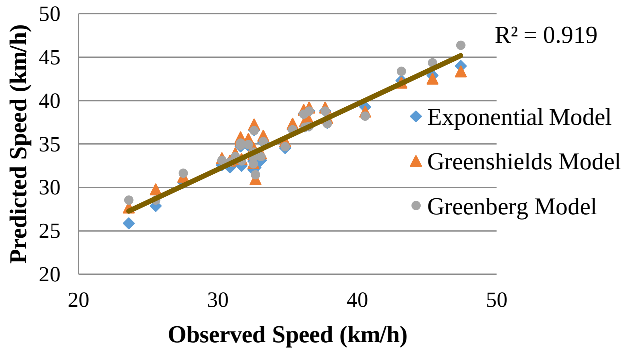

Fig.11 Graphical Residual Analysis
(Towards Kunnamkulam)

VI. RESULTS AND DISCUSSIONS

In the field, it is hard to find the linear relationship between speed and density as proposed by Greenshield. Greenberg's model is inadequate to predict the speed at lower densities. Because when density attains zero, speed readily increase to infinity. Traffic parameters obtained from Greenshield's and Greenberg's models are shown in Table I.Results of regression analysis of traffic speed against density are shown Figure 4 and Figure 5. Doubtless the exponential models are statistically adequate in determining speed-density relationships for the given road in uncongested regime. The higher R^2 coefficient for different lanes shows the best goodness of fit. The main drawback of the model is speed becomes zero only when density approaches infinity. Hence this cannot be used for predicting speeds at high densities. The model shows a better fit than Greenshield's and Greenberg's models for the uncongested condition. But it does not present a good fit to the congested condition. The density at maximum flow rate obtained is 125 veh/km and 100 veh/km towards Thrissur and Kunnamkulam. The free-flow speed obtained is 50.26 km/h and 49.41 km/h towards Thrissur and Kunnamkulam. The characteristics of the relationship between traffic flow and density in logarithm scale begin at the origin is shown in Figure 6 and Figure 7. At the initial section of the graph, traffic congestion accumulates at the highest level as exhibited by minimum flow and density. As the density rapidly increases, flow also begins to steadily increase. The speed-flow curves of different lanes for the given road are shown in Fig.8 and Fig.9. As the speed rapidly increases, the flow begins to steadily decrease. Therefore, the characteristics of the speed-flow relationship are determined by linear regression technique. The regression analysis was used to statistically evaluate the mathematical models. The obtained values of R^2 are 0.982 and 0.919 for the Exponential model in both lanes which implies the validity of the predicted model. Predicted Greenshield's model slightly overestimated and Greenberg's model slightly underestimates density for the lane towards Thrissur and the predicted Greenshield's and Greenberg's model slightly overestimated density for the lane towards Kunnamkulam.

I. Traffic parameters obtained from Greenshield's and Greenberg's models

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Traffic Parameter	Towards Thrissur		Towards Kunnamkulam	
	Greenshield's Model	Greenberg's Model	Greenshield's Model	Greenberg's model
A	49.14	66.48	47.24	71.91
B	-0.309	-8.19	-0.333	-10.4
u_f (kmph)	49.14	-	47.24	-
u_f/k_j	0.309	-	0.333	-
k_j (vph)	159	3352	142	1007
C	-	8.19	-	10.4
$C\ln k_j$	-	66.48	-	71.91
u_0	24.57	-	23.62	-
k_0	79.5	1233	71	370
q_{max}	1953	10099	1677	3853
R^2	0.798	0.772	0.722	0.714

VII. CONCLUSIONS

By conducting research on urban road the basic parameters of traffic flow have obtained. These parameters were used to develop diagrams for relations between flow, speed, and density in the un-congested regime. This made it possible to develop model equations, which can be used for theoretical determination of characteristics of the road in an urban road network in uncongested traffic conditions.

Further research should be done to incorporate heterogeneity and non-lane disciplined characteristics of Indian traffic and including more road types within different environments and cross-sections in order to gain more detailed relationship between specific conditions in which traffic flow operates and consequential relationship between basic traffic flow characteristics. Automatic counters and measuring tools should be used in order to minimize field work and reduce the measuring error possibility.

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REFERENCES

1. Roux, J. and Bester, C.J., 2002. Speed-flow relationships on Cape Town freeways. *SATC 2002*.
2. Ponnu, B., Thomas, J., Jha, K., Asaithambi, G. and Srinivasan, K.K., 2013. Vehicle Class-wise speed volume model for three-lane undivided urban roads. *Procedia-Social and Behavioral Sciences*, *104*, pp.468-476.
3. Dhamaniya, A. and Chandra, S., 2013. Speed prediction models for urban arterials under mixed traffic conditions. *Procedia-Social and Behavioral Sciences*, *104*, pp.342-351.
4. Dhapudkar, R.S., 2014. Analysis and Development of Traffic Stream Parameters of Heterogeneous Traffic at Signalized Intersection. *The International Journal Of Engineering And Science (IJES)*, *3*(5), pp.33-39.
5. Xu, C., Qu, Z.W. and Chen, X.M., 2014. Analysis of Traffic Flow Speed-Density Relation Model Characteristics. Journal of Highway and Transportation Research and Development (English Edition), 8(4), pp.104-110.
6. Barua, S., Das, A. and Hossain, M.J., 2015. Estimation Of Traffic Density To Compare Speed-Density Models With Moving Observer Data. International Journal of Research in Engineering and Technology, 4(08), pp.471-474.
7. Hashim, N., Mustapha, N., Wahidah, N.N. and Hashim, N., 2016. Outflow of traffic from the national capital Kuala Lumpur to the north, south and east coast highways using flow, speed and density relationships.

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