VEHICULAR INTERACTIONS AND TRAFFIC FLOW ESTIMATION

by

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1.0 INTRODUCTION

The phenomenon of traffic congestion and the concern being voiced for it around the world are normally correlated to the rapid population growth and the unprecedented growth in vehicle registration. However, the most striking factor in India is the complex heterogenity of traffic flow or the 'mixed traffic flow' in India.

Till to date no comprehensive work has been carried out to rationally assess the amount of traffic for which the traffic flow facilities be designed, to cater to the equivalent of this mixed traffic flow. On Indian roads, as many as 13 incompatible types of vehicles comprising of bicycles, pedal rickshaws, scooters, hand-carts, to heavy automobiles of various types moves in the aggregated flows, and occupy the same right-of-way.

No system of any kind can be expected to function satisfactorily till the basic design inputs are properly planned and rationally assessed. The work in this direction did not start in the developed west, for the simple reason that such a problem did not exist there; and in the absence of any authentic basic work the work has not taken up in India.

This paper, therefore, describes an approach which could form the rational basis for the planning and design of traffic flow systems in India.

With the above objective, the experimental programme was designed and carried out, in two phases (i) for undivided typical Indian city roads, and (ii) the divided major urban arterials of typical Indian metropolitan areas roads and highway. The methods of data collection and experimental programme were so adjusted, so to serve the needs of the data requirement for this specific research programme; as well as, it may serve as a guide for field-studies in similar programmes in future.

2.0 FIELD DATA REQUIREMENTS FOR THE STUDY

The requirements of the basic field data, which guided the design of the experimental programme have been divided in two distinct groups, in accordance with the objective and scope of the present research programme.

2.1 UNDIVIDED ROAD SECTIONS-TYPICAL CITY ROADS AND STREETS

Typical roads and streets in Indian cities vary in their geometric standards with regard to the pavement width or the total right-of-way, which varies normally from standard one lane width to 2-lane wide roads. These undivided roads carry the local traffic, which is highly heterogeneous in character, between various landuses, which are often mixed, in the absence of a proper land-use planning or the urban planning. The major portion of trips are home-based-work trips which constitute between 60-80% of total traffic(1). However, the basic characteristics of the traffic stream remain typically similar in nature. It has been estimated (7) that almost 66% of the total undivided roads in India have single lane wide pavements with or without adequate shoulders.

Thus, two features become significantly important, i.e.,(i) the pavement width and the total width available for two directions of flows, (ii) the composition of traffic stream and nature of flow during critical or peak periods.

Apart from the above features of roads and traffic flow, the additional requirements are, the parameters of traffic flow which govern, represent and predict, the behaviour, amount and consequences of the vehicular interactions in the traffic stream and should be recorded.

2.2 DIVIDED HIGHWAYS-TYPICAL MAJOR URBAN ARTERIALS

Major urban arterials in large towns and specifically in metropolitan areas of India like Bombay, Calcutta, Delhi and Madras are different in characteristics with regards to roadway and the traffic flow. The basic difference visible macroscopically relates with the number of lanes, the total right-of-way, and the separated directions of traffic flow. The difference in traffic flow characteristics and the vehicular-interactions can normally be appreciated through microscopical mathematical analysis.

One common characteristic on both the divided and undivided roads of major towns and typical small cities alike, is the complex heterogenity of the traffic stream. Besides, the geographical variations of the traffic stream, actual composition and the vehicle types do vary in the above two categories. The real content of the problem is however, unchanged. The composition of traffic on major arterials of Bombay and Delhi vary but the complexity of the traffic situation in both the metropolis is unaffected.

A general description of the divided major arterials in large towns, which makes them significantly different from the typical undivided city roads is as follows:

(i) The major urban arterials are normally 4-6 lane wide and cater to heavy intracity urban traffic, and normally, have divided right-of-way between two directions of flows, having 2-3 lanes for each direction

It is significant to mention here, that as per IRC(7,12) recommendations, and the Highway Capacity Manual(20), normally two lane wide right-of-ways are not divided and separated in two directions of flow.

3.

Table 1 - Typical Traffic Composition as Observed on Major Urban Arterials by Time-Lapse Photographic Study

Typical Composition during Peak-Periods

	Vehicle Type	Observed percentage	Observed variations manually recorded
Slow Moving Non-automobiles	Cycles	60%	10%
	Animal drawn carts and hand carts, etc. including rickshaws	4%	20%
Fast Moving automobiles	2-wheeler scooters motor-cycles	12%	10%
	Three-wheelers (Tempos) automobiles (Auto-rickshaws)	8%	15%
	Cars, Jeeps, Light-Vans	10%	10%
	Buses, Trucks, Tractors, Trailors, and other heavy automobiles	6%	20%

3.0 ANALYTICAL TECHNIQUE AND MATHEMATICAL MODEL

3.1 PROBABILITY AND INTERACTION CONSIDERATIONS

It has been observed that the speeds of all vehicles in traffic stream are affected by the interactions and at higher volumes the interactions amongst the groups of vehicles also increase and the amount of effect on speeds of all the vehicles in the compositions may be taken to be similar and evaluated.

However, the probability of the vehicular interactions depends upon the presence of a given vehicle type at a given location (14). To evaluate the speed interactions, the interaction results are correlated in terms of free-flow speed, and the developed equations are presented elsewhere. However,

$$\text{Interaction} = f_1 \text{ (free flow speed, operating speed, vehicle types present)}$$

Different vehicles present at given location = f_2(volume of traffic, composition, probability of arrival)

Probability of arrival = f_3(number of vehicles of a given category, composition)

The various trials based on the above logic were made, which initially had

$$EPCV = (\frac{VV}{VC})\ (\frac{AV}{AC}).P(x).I$$

Where VV = speed of the vehicle under consideration, kmph,

VC = speed of the passenger car under identical conditions, kmph

AV = area of the vehicle, sq.m.

AC = area of the car, sq.m.

P(x) = probability of arrival of same vehicle type

$$P(x) = (\frac{\text{No. of vehicles of the category in the composition}}{\text{No. of cards in the composition}})$$

I = interaction

$$\text{Inerraction} = (\frac{\text{Headway of the vehicle at a given speed}}{\text{Headway of the car at the same speed}})$$

Various attempts through computer analysis did become essential to evaluate the interactions more rationally and logically based on certain trials and available guidelines (16,17,24,25) made for other more homogeneous traffic flow situations, and allied research.

The interaction (8,9,10) was further improved upon incorporating the free flow speeds, and operating or travelling speeds of the standard unit of measurement, the passenger car and the vehicle under consideration. Therefore, the rate of interaction was thus:

Rate of interaction = f(VFV, VFC, OPS, HWV, HWC, OPS)

$$IR = \frac{HWV}{HWC}.(\frac{VFV/VV}{VFC/VC})$$

Where EPCU = Equivalent passenger car value

HWV = Headways of vehicles at travelling speed, m

HWC = Headway of passenger car at the same speed, m

VF(V & C) = Free flow speeds of the vehicle and the car, kmph

VV, VC = Travelling speeds of the vehicle and the car, respectively, kmph (all headways considered are space-headways)

3.2 OPERATING SPEEDS AND PAVEMENT OCCUPANCY

The most striking difference in homogeneous traffic flow stream and the mixed vehicular traffic of the type attempted herein, is the difference in operating speeds of the individual vehicles, and the amount of projected area the vehicles occupy on the pavement, which obviously varies with the speeds and the vehicle size. Depending upon the work done earlier (3,7,8) the concept of the pavement occupancy was incorporated into the analysis in relation to the average pavement width or the lane width. The initial trial included was of the form:

$$EPCV = \frac{VFV}{VFC} \times \frac{AV}{AC} \times \frac{HWV}{HWC} \quad \frac{PAV - WV}{PAV - WC}$$

Where, PAV = average pavement width for single lane roads and average lane width in general, m,

WV = width of the vehicle, m

WC = width of the average standard passenger car (Standard Unit) m.

This concept in its initial form does include the basic effect in variation and on numerous successive trials through computer analysis programme the data inputs were made for the fast and slow moving vehicles of all the categories considered.

The developed equations, have an identification that as the homogeneity of the traffic stream decreases i.e. the traffic stream becomes increasingly heterogeneous, the inter-vehicular interactions increase. The final form of relationship may be represented as

$$\text{Equivalent demand} = \frac{VFC}{VFV} \times \frac{HWV}{HWC} \times \left(\frac{PAV-WC}{PAV-WV}\right) + \frac{WV}{WC} - \frac{HWV}{HWC} \times \left(\frac{PAV-WC}{PAV-WV}\right)$$

This relationship is further improved incorporating the effect of variations in headways and operating speeds.

3.3 AN ALTERNATIVE SIMULTANEOUS APPROACH

During the process of the analysis it was discovered that there was an alternative approach possible which could incorporate fundamental concept of level-of-service through volume and capacity ratio (14,19,15). The inherent advantage of using V/C ratio is the explicit limits of 0 and 1 which accommodates all the flow conditions.

This simultaneous development also provides a possible procedure for model validation. The model validation in the present case being complex due to the conceptual involvements, has been achieved through an alternative approach developed simultaneously.

The use of the present approach of simultaneous development is made for model validation. The overall development is presented through the (1) Analysis and development of level-of-service criterion through volume-capacity ratio. (2) Level-of-service and critical operating speeds through traffic density.

3.4 ANALYSIS AND DEVELOPMENT OF LEVEL-OF-SERVICE CRITERION THROUGH VOLUME-CAPACITY RATIO

To incorporate the effect of volume-capacity ratio and to obtain effect of level-of-service in the analysis, it is through the use of this ratio into the interaction factor, which comprises the effect of, initially, volume and composition changes. Thus the interaction factor, in the equations in article 3.2 is converted as a function of volume-capacity ratio as incorporated in Figure 1. These effects are built into the equation, as follows:

IF = f(VCR, OPS, VV, VC)

Where, VCR = volume-capacity ratio

OPS = critical operating speed of the traffic stream

VV,VC = travelling speeds of the vehicle and the car

It may be observed that the operating speed of the vehicle and the traffic stream have a marked effect on the effective demand values. This could be expected as the volume-capacity ratio and operating-speeds together define the level-of-service (19, 20,22, 23, 24) of the traffic flow system. Hence, it became essential as well as very significant to incorporate the effect of level-of-service through critical operating speeds by the incorporation of traffic-density which essentially defines the operating speeds within the explicit limits of free-flow speeds and halts or stoppages corresponding to zero velocity.

3.5 CRITICAL OPERATING SPEEDS AND TRAFFIC DENSITY

The travelling speeds as obtained from the field data for different categories of vehicles may be used as an input into the developed model as explained earlier. However, as has been discussed and developed earlier, the operating speeds could also be predicted in terms of the free-flow speeds and the reduction caused due to the interactions from the surrounding vehicles. The speeds, thus derived are called as critical operating speeds of the vehicles (OPSC) or the critical operating speeds for the traffic stream (OPS).

The use of traffic density is also made to predict the critical operating speeds and to some extent acts as a in-built mechanism to check the adequacy of predicted operating speeds used in the

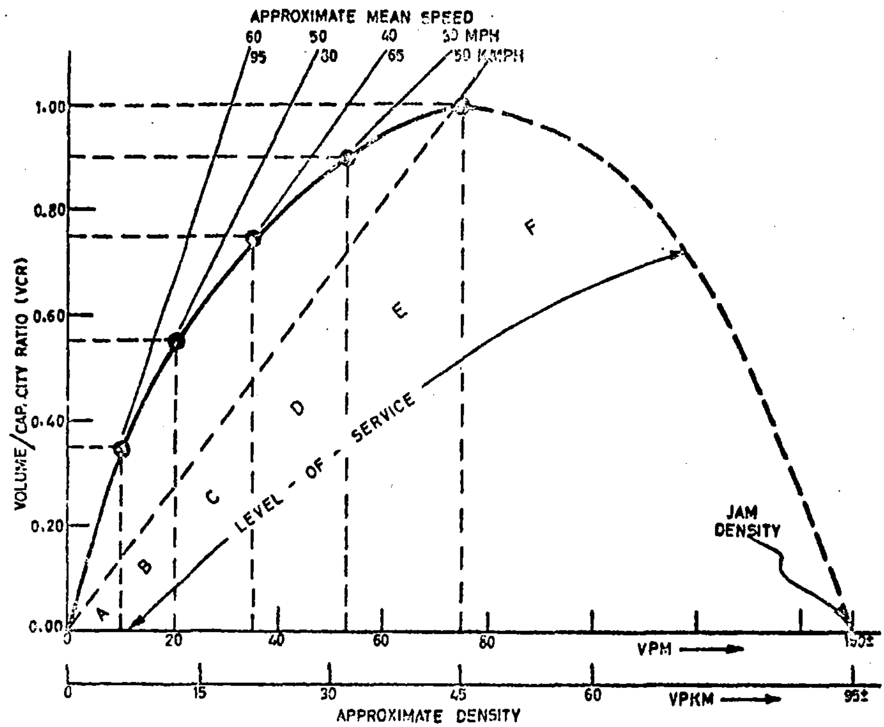

FIGURE 1 CONCEPTUAL RELATIONSHIP OF LEVEL-OF-SERVICE TO SOME MEASURES OF QUALITY UNDER UNINTERRUPTED FLOW CONDITIONS.

analysis for equivalent passenger car value of demand for each vehicle type. The concept of traffic density permits the explicit use of operating speeds of traffic streams within the specified limits,

- at zero traffic density – speed is free-flow speed
- at jam density or the maximum density – speed is zero

The variation in between are also well defined (19,20,15) and can be explained. As the relationship correlates the volume in passenger cars per hour, the density, the volume-capacity ratio and the level-of-service the prediction of volume, the travelling speeds i.e. the critical operating speeds of the traffic stream and each vehicle type or the category of the vehicle can also be found. As is clear from the figure; the following simple relations could be used,

$$\text{Volume} = \text{D.I.}\ (2\text{DAV} - \text{DI})\ \frac{\text{Capacity}}{(\text{DAV})^2}$$

Then the equations for critical operating speeds are of the form

$$\text{OPS} = f\,|\text{VCR, DAV}|$$

and $\text{OPSC} = f(\text{VCR, VFV, DAV})$

The volume and operating speeds could also be found out using the Table 2, as follows:

TABLE 2 VOLUME, OPERATING SPEED & DENSITY INDEX

Density Index	OPS kmph	Volume (p.c/hour)
0.0	VFV*	0.0
0.1	0.935 VFV	0.36 capacity
0.2	0.795 VFV	0.64 capacity
0.3	0.645 VFV	0.84 capacity
0.4	0.540 VFV	0.96 capacity
0.5	0.500 VFV	1.00 capacity
0.6	0.497 VFV	0.96 capacity
0.7	0.456 VFV	0.84 capacity
0.8	0.325 VFV	0.64 capacity
0.9	0.121 VFV	0.36 capacity
1.0	0.0	0.0

* VFV = Free Flow Speed, Kmph

3.6 MODEL VALIDATION

The development of an alternative simultaneous approach provided a built-in check on the values of critical operating speeds and for validation of the model for evaluating equivalent effective demand of each vehicle type as well as the total volume of the traffic stream as effective demand, under given conditions of the flow. Since, the conversion of the effect of large number of vehicle types is basically conceptual in nature and is not directly measureable; therefore, the comparison of the predicted operating speeds and volumes for a given volume-capacity ratio and other flow conditions; and the measured operating speeds in the field for same conditions, provided an ideal and perhaps, the only possible method of the model validation in the present case. The results of the model validation are presented in a representative manner. These show an excellent correlation of the validity of the model within the realism of the inherent shortcomings of the usual field-data collection programmes; as well as the realistic limits of accuracy desired in the programmes of traffic planning and design.

Further, as would have been expected, the predicted existing equivalent effective volumes (EEEV) for varying conditions by the generalized equivalent concept and the alternative approach through level-of-service concept also show an excellent correspondence and correlation. This is such, reinforces the model validation for the conditions described throughout the development of the programme.

4. RESULTS AND CONCLUSIONS

The basic objective of this research programme is to analyse and interpret the vehicular interactions under heterogeneous traffic flow and to explain the basic mechanism of flow through mathematical model. Such a model has been developed which is capable of estimating traffic demand of a mixed traffic flow stream in terms of passenger car volume or Effective Equivalent Passenger Car Volume along with other flow conditions. Within this broad framework the salient results as obtained and conclusions so derived are listed below:

(1) The experimental field programme designed and carried out has provided useful data and it could be used to advantage in the subsequent analysis.

(2) The time-lapse photography along the traffic stream used in this research project is a first major work of its kind in a planned research programme; and the values provided through tedious and long data analysis are especially suited to a study of the present type and must be recommended for future studies, due to the following salient features:

(i) All features of vehicular interactions are recorded on a permanent basis for future analysis, as well as, in case of doubts in analysis, the data can be reproduced and re-analysed. Further a large number of variables can be simultaneously recorded from the data-roll of cinefilm. This could not be possible with any other form of data collection procedures. The additional cost involved in off-set by the additional benefits derived.

(ii) The specially developed attachments and other recording equipment are ideal for data analysis from time lapse photographic field studies. The grid used in this analysis is specially suited for the type of analysis mentioned herein.

(3) Following relationships for speed-interactions are established through linear-multiple-regression,

$$VV = (VFV - a_o) - a_1 N_i - a_2 N_2 - \ldots$$

Where, VV = operating speed of a vehicle under the vehicle interactions,

VFV = free-flow speed

a_o = intercept constant of regression analysis

and therefore

$$VV(I) = A_o - \sum_{i=1}^{6} A_i$$

Where, VV(I)= operating speed, kmph of Ith category of vehicles, and

$A_i = a_j N_k$

$j = 1-6$

$N_k = (0,1,2,3,4,5)$

a_j's are speed interaction factors

N_k's are numbers of interacting vehicles of jth category, (1-6) in this case.

Further,

$$A_o = (VFV(I) - a_o)$$

Where VFV(I) is the free-flow speed of ith category of vehicle, and

a_o is intercept constant of regression analysis.

The resulting speed interaction equations are:

VV(C) =(38.5-5.6 NC-5.9NB-1.42 NS-0.99NA-0.29NCY-4.1NR)

VV(B) =(42.0-2.6NC-6.7NB-2.3 NS-1.46NA-0.88NCY-2.7NR)

VV(S) =(36.0-5.6NC-2.11NB-1.0NS-1.33NA-1.92NCY-3.19NR)

VV(A) =(38.5-6.35NC-0.74NB-1.5NS-0.76NA-5.74NCY-2.2NR)

VV(CY)=(9.6-1.04NC-2.0NB-0.5NS-1.48NA-0.5NCY-1.54NR)

VV(R) =(8/15-2.2NC-1.3NB-0.19NS-0.21NA-0.1NCY-0.61NR)

Nomograms for speed-interactions are developed which can give the speed at any traffic situation.

(4) Lateral clearances amongst the vehicles have been recorded and presented in graphical analysis for (i) same direction of flow, and (ii) for opposite direction of flow and correlated to pavement occupancy and speed.

(5) Speed spacing relationship on undivided highways is

$$S = 0.065L + 0.082VL$$

Where, S = spacing, meters

L = vehicle length, m

V = operating speed, kmph.

(6) Spacing and speed relationship of car on divided highway is

$$S = 0.20+1.10V-0.04V^2-0.01V^3$$

S = spacing (clear) metres

V = speed kmph

(7) Space-Headway and speed relationships are:

CAR	HWR(C)	$= 11.97-0.52V-0.02V^2-0.01V^3$
	HWR(C)	$= 11.71-0.45V-0.02V^2$
BUS	HWR(B)	$= 7.30+0.80V-0.06V^2+0.01V^3$
	HWR(B)	$= 9.10-0.06V+0.01V^2$
THREE WHEELER	HWR(A)	$= 17.27-1.74V+0.06V^2$
AUTO RICKSHAW	HWR(A)	$= 0.40-0.95V-0.07V^2+0.01V^3$
SCOOTER	HWR(S)	$= 11.55-0.66V+0.02V^2$
	HWR(S)	$= 0.40+1.78V-0.18V^2+0.01V^3$

(8) The Equivalent Passenger Car Values (EPCV) can be determined in easy sequential form through the input of traffic stream characteristics e.g. the composition, operating speeds and flow levels. This has been shown that these values are corresponding to only the input data and as such are not generalized fixed values.

The Equivalent Passenger Car Volume of the mixed traffic flow can thus be determined.

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