Intermediate Public Transport
— Analysis in Madras —

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1. Introduction:
The cities in the developing countries have exhibited a radically different character during the past few decades from those in the developed countries in terms of Urban expansion and Urban renewal. The pace of socio-economic development being rather slow in the third world countries, the urban magnate has been able to create and maintain an illusive image of higher employment potential and other socio-economic benefits. The one way migration resulting from this urban pull has only aggravated the complexities of urban living. In terms of transportation demand, the peripheral expansion of the urban settlements and concentration of activities in the core areas have given rise to increased trip length and expensive commutation. On one hand, while the car ownership is seen increasing in the developing world it is apparent that the use of public transport is also increasing. Any real increase in the income level of the people has the effect of revealing this demand. Unlike the situation in most developed world, the urban public transport sector of the developing world is a growth industry. Further more it is an industry about which little is known because it comprises more than just the conventional buses and trains of developed cities. Urban transport is often greatly dependent on this sector as the conventional mass transport system do not render service in commensurate with the growing transport demand. Many third world countries have their own unique forms of non conventional transport system which are mostly private operated and may not fall within the definition of the organised sector.

This paper is intended to bring out the general urban transport scenario of Madras and the salient features of case studies on the characteristics of the Intermediate Public Transport system and the congestion effect of Auorickshaw, a unique form of Intermediate Public Transport (I.P.T) in India.

2. The Growth Pattern of Madras:
Madras is the fourth largest city in India, situated on the Eastern sea board of the sub-continent with a Harbour that caters for a fifth of the country's import and export. It is well located in relation to Rail, Water and Air transport with the rest of the country. It has an International Airport to cater to International travel demands. Madras has a

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relatively static base of large scale formal Industry and commerce, including shipping and banking. Nevertheless, the Madras Metropolitan Area (M.M.A) is experiencing acute problems of rapid urban growth and expanding outwards rather than upwards because of ready availability of land. While there has been steady increase in population, the economy is not expanding at an equal rate and there is growing pressure on the limited utility services that exist, resulting in degradation of living environment. The M.M.A encompassing an area of 1167 square kilometers has a population of 4.3 million with an annual growth rate of about 2.2 percent.

The Master Plan prepared for M.M.A provides for a Ring and Radial pattern of development (Fig. 2) synchronising Landuse and Transport. The new developments are guided along the routes radiating from the city. The main transportation corridors are designed for rapid Transit System.

Madras has grown from the gradual development and later coalescence of a number of settlements (Fig. 3).
As there were few physical constraints (apart from inundation) the city grew in a dispersed low density pattern, leaving large pockets of vacant or under utilized land within itself. Though the city limits have been extended as corporate boundaries in tune with the outward expansion of the urban area, the corresponding provision of utilities and facilities to meet the needs of the growing population has not kept pace.

The Northern part of the city has a great deal of new industrial development while residential development is increasing in the southern part of the city. The main built up area extends beyond the city limits in the North along railway line, in the west along the central railway line and in the South along the trunk Highway. Sparse development along the fringes is also noticeable. Three characteristically different areas can be distinguished: the main built up area, comprising the city and its contiguous development; and the predominantly rural area.

2.1 Direction of Growth:

The highest rates of population growth (though not the highest increase) are found in the areas peripheral to the city and along the main transportation corridors. Present trends indicate that while development is taking place in the transportation corridors, a considerable amount of growth is taking the form of gradual accretion on all the landward sides of the city.
(1) Density:

The available evidence (Fig. 4) suggests that substantial increase of density are occurring as intensification of use takes place in previously developed areas. However it is seen that it is the area which are already densely built up which are becoming even more dense.
(reflecting their desirable locations) more than, under utilized areas becoming more efficiently used. This trend is likely to increase and such intensification may take two forms, overcrowding and increase in building bulk.

(2) Industry:

After independence the city experienced a large growth in population and economic activity owing to the emphasis on industrialization in the Five year Plans. New industries were setup in the South and central part of the city in both private and public sector which helped to emphasize the development along the corridors. Between 1964 and 1974 there was significant increase in industry both within the city where, 370 ha, of land were developed and outside the city within M.M.A, where 400 ha. were developed.
2.2 General Characteristics Of Movement Of People In The City:

The movement of commuters between Home and Work presents the major transportation problem in M.M.A. About 50 percent of the daily passenger trips in the city are being performed during the peak hours, of which about 50 to 60 percent are journey to work and back. The majority of intra-urban trips in the city is being catered to by the existing public transport systems namely Buses and Trains. About 1.2 million passengers are carried by them in the proportion of 80 to 20. The over dependence on public transport system is due to inadequate living space at affordable costs in the city and periphery, particularly for people who can not afford to keep personal vehicles and depend entirely on the public transport systems. At present there are three railway lines carrying about 0.44 million commuters daily along the North, Central and Southern corridors. All the three lines use Electric traction. Introduction of High Capacity Rapid Transit system along the dense North- South- Eastern corridor is under construction.

The Pallavan Transport Corporation (PTC) is the sole operator of Bus service in M. M.A. It has a fleet of 2100 buses catering to 2.7 million passenger trips per day in 303 routes. The fleet utilization of PTC is about 94 percent. In addition to railway and buses the Intermediate Public Transport (IPT) also contribute to the city transport system. There are about 550 Taxis, 8000 Autorickshaws and 7500 Cyclerickshaws, about 30000 cars, 38000 Motorcycles Scooters account for personal transport besides 560,000 bicycles.

While the Mass transport services the major portion of work trips, education trips etc the IPT an unique form to the developing world uncommon in Developed countries, services other trips like, recreational trips and social trips. These form of transport play a vital role in the overall urban transport scenario. In this paper an attempt has been made to bring out the salient features of the IPT, their role in the urban transport scenario in general and the studies carried out by the Author for the first time in this sector to identify the congestion effect of one of the most common form of IPT, namely the Autorickshaw in the urban traffic stream of Indian city so as to effect sound traffic control, regulatory and management measures.

2.3 Need for the study:

In harnessing the available transport modes for optimal utilization in conformity with the city and regional functions and the socio-economic structure, a study of this kind was carried out not only to suggest improvements to the transport system of the city or region but also in view of the following:

The objective of a transportation facility is to accommodate a quantity of demand with an acceptable quality of service. This quality is apparent to the user in terms of his freedom to follow a path and speed of his choice, the ease and the physical and mental comfort of his operation. Although not directly of these factors, the driver is affected also by the degree of hazard to which he is subject, the probability of failure to meet his
transportation objectives and the total cost of the service. An acceptable quality of service to accommodate a quantity of traffic depends on the capacity of road network that is, capacity of open road sections and of road intersections. Obviously this ability depends greatly on the physical features of the roadway itself. Yet there are other factors not directly related to roadway features that are of major importance in determining the capacity of the highway. Many of these factors relate to variations in the traffic demand and the interactions of the vehicles in the traffic stream.

If all the vehicles in the traffic stream were identical in performance determination of capacity would have been a simple matter. However, composition of traffic on road network is seldom homogeneous in nature and the traffic stream consists of vehicles of different performance characteristics, determination of capacity becomes a complex task. The heterogeneity of traffic stream in developing countries is especially large compared to the developed countries. In Japan for instance, the average traffic composition of flow with regard to motor vehicles only shows that the majority of motor vehicles on the road are commercial vehicles. However the traffic composition is of large variety of fast and slow moving vehicles like, cars scooters, motorcycles, autorickshaws, buses and trucks, cyclerickshaws and animal drawn vehicles in India. In short anything that moves or can move occupies the road space.

Vehicles of different types require different amounts of road space because of variations in size and performance. Hence Autorickshaws basically a power drawn vehicle differs in size (comparatively smaller) and performance in the urban traffic stream. Though there is a general agreement on the role of Autorickshaw can play in the overall urban transport facility, the wide spread contentions are;

(a) The number of Autorickshaws in the traffic stream cause congestion.
(b) The smaller Autorickshaws introduce greater accident hazard on Urban roads because of reduced visibility from within and greater difficulty by other drivers in seeing through it to other vehicles in the stream.
(c) Another school of thought is that small vehicles are safe or safer because of greater manoeuvrability and because other drivers can see over them to other vehicles in the traffic stream.

However there were no studies undertaken to identify the behavioural characteristics of Autorickshaws and their congestion effect in the traffic stream on increasing their number. For sound transport planning and effective use of the available road space, a study of this nature was of paramount importance.

2.4 Objective of the study:
A study of this kind was undertaken with many objectives in mind, however the major objective of the study was to determine the behavioural characteristics of Autorickshaws and their congestion effect in the traffic stream and frame recommendations for effective traffic control, regulation and management measures.
3. IPT In Indian Cities:

Besides the conventional forms of public transport system like buses and trains all the cities of any description in India have inherited the IPT forms of Public Transport namely Autorickshaws, Cyclerickshaws and animal drawn vehicles called "JUTKA" OR "TON-GAS". The growth of population as also that in number of vehicles have outpaced the planned growth of the cities.

In many cases the transport network has remained practically static with marginal and adhoc improvements which have been proved to be highly inadequate to combat the growing needs of modern transportation. A clear gap has therefore been left between the aspiration of the people seeking more economic safe and efficient transportation systems on one hand and the supply of such facilities on the other. To fill in the gap there has been a mushroom growth of these forms of IPT vehicles. While the general growth rate of other vehicles was 7 to 8 percent the growth rate of Autorickshaws, the important forms of IPT was 11 to 12 percent. The general description of these two forms of IPT are as follows.

3.1 Cyclerickshaw:

It is basically a slow moving vehicle, similar to the wheels of a big tricycle, operated by human energy. The seating capacity of the vehicle is two and often used for light goods transport also. This form of IPT is predominantly used in many cities particularly in areas where the road network pattern is narrow and not conducive for the modern motorised transport. The trip length of these IPT vehicle is also very short. More recently motorised forms of cyclerickshaws are also seen in a few cities. However the stability of the vehicle at higher speed, safety etc are yet to be taken stock of. In general the operation of this form of IPT is mostly confined to a small area of operation.

3.2 Autorickshaw:

This form of IPT is also triwheeled however power driven. It can be compared to small three wheeled car with a seating capacity of three. The vehicle has a peculiar shape with wind screen glass in the front alone and the rest of the body of the vehicle is completely covered with openings for the passengers to get in and out of the vehicle. The design of the body is such that there is no rear view also. This vehicle is considered to be a fast moving vehicle with a maximum economic speed of 45 kilometer per hour (Kmph) and these vehicles are also more comparable to buses of trains in terms of their trip length. The most predominantly used form of IPT is the Autorickshaws.

3.3 Intermediate Public Transport System-Definition and Characteristics:

3.4 Definition:

Intermediate Public Transport system, otherwise called as Para Transit is defined to
be that form of Public Transport falling between the conventional buses and Taxi transport systems. This is the most commonly recognized definition although there are many other forms of definition offered to suit to the circumstances. Hence forth the Intermediate Public Transport shall be mentioned as IPT in short for convenience.

3.5 Characteristics:
The schematic representation of the characteristics of IPT are as shown in Fig. 5 which illustrates the following:

i. IPT is between Private and Public transport.

ii. It is less flexible than individual private transport.

iii. Off shoot of public modes become most demand responsive ie adjust their operation to cater to individual requirements.

v. Certain modes developed along with the city form using slow moving vehicles.

3.6 Role of IPT in Urban Public Transport:
A care study carried out by the Author in Indian cities on the objective assessment of the role of IPT in Urban Public Transport during 1978 revealed the following:

i. The supply of Mass Public Transport in satisfying the ever increasing transport demand is in short supply and not commensurate with the pace of developments and therefore the gap is filled by these IPT modes of transport.

ii. The various activities in the cities and the travel characteristics of the people revealed that there is a latent demand for usage of IPT, as the Mass transport facility however efficient it may be, can not satisfy all the travel demand with their fixed time and route operation system.

iii. While a homogeneous and efficient Public Transport for a city is the objective
of any Public Transport planning exercise, considering the socio-economic pattern, the physical pattern of the city, it is desirable not to replace one mode by another. Therefore the existence of IPT in cities and towns is inevitable.

iv. The city of any description in India has grown around a core area, the old quarters of the city with narrow road network pattern not conducive for motorised transport vehicles operation, for uniform transport facility massive redevelopment scheme will involve huge financial investment and therefore the continuance of IPT service is essential.

v. The greatest advantage of IPT lies in its more personalised form of public transport providing door to door service. The travel characteristics of the people indicate that for many trips like social trips, recreation trips, health service trips and business trips the IPT is preferred.

vi. More often luggage carrying facility in Mass Public Transport facilities is either not possible or difficult therefore IPT is preferred for such purposes by the people.

vii. The flexible route and time of operation of IPT is another major advantage for its high demand and it provides a wide variety of choice in availing the most suitable form of transport to suit to the need, nature and purpose of the journey and purse of the traveller.

viii. Wider income disparity prevailing in India is not conducive for a uniform transport policy and the regimentation in favour of particular mode of transport may rather deter development than promoting it.

ix. The IPT is an Industry by itself. It provides a vast employment potential in various spheres of its existence, therefore in a situation where promotion of gainful employment is of paramount importance there is a large scope in the sector of IPT.

4. Case studies:

4.1 Case study-1: Behavioural characteristics of Autorickshaws:

The study methodology is as shown in Fig. 6 and the study location and simple analysis grid are shown in Fig. 7

(1) General:

It is been recognized that the composition of the traffic stream, ie proportion of Cars, Buses, Trucks, Autorickshaws etc is a major factor in determining the total number of vehicles which can be transported through a section of roadway. Different types of vehicles exhibit widely different behaviour in traffic stream. Such a variation in behaviour can materially affect the character of the traffic stream as a whole.

On the normal multi-lane facility the effect of difference in operating behaviour of vehicles is minimized so long as sufficient freedom exists for drivers to change lanes. However, at facilities where lane changing is not permitted, traffic will tend to be governed by those vehicles which are least able to respond to change in traffic speed and volume. Consequently, it is important that as much as possible be understood about the behaviour
Towards this end the present study is undertaken to study the behavioural characteristics of Autorickshaws in relation to buses and cars as there is heavy demand from these vehicles for road space utilization on Urban roads of India.

(2) Physical Situation:

The most important aspect of this kind of study was to select a suitable site where there is heavy flow of traffic with desirable composition of the type of vehicles under study, least possible traffic interruptions like pedestrian crossings, bus stops and other traffic control signals, road signs and road markings and finally having a suitable vantage point (a tall building) to fix the Camera and take photographs, a four lane divided carriage way was selected. The details of the site conditions are shown in Fig. 7.

(3) Experimental Procedure:

To identify the behavioural characteristics of Autorickshaws in relation to buses and cars, it was necessary to know for each vehicle its Headway Time (HWT) and velocity or the speed. The instrument used in collecting the necessary data was a Time Lapse Photography Camera.

Fig. 6 Study methodology flow chart.
(4) Time Lapse Photography:

Off all the available methods and instruments, Timelapse photography has been proved to be the best suited for Headway Time measurements and prediction of behavioural characteristics of vehicles as Time Lapse Photography exhibits the field situation as it is and provides a permanent record of the data on Headway, Speed, Density and Volume.

For the purpose of the study a 16 mm Cine camera was used. The camera was set at the vantage point on the terrace of a thirteen story building facing the four lane divided carriage way. The camera was set up perpendicular to the flow of traffic. The Fig. 3 explains the position of the camera and other relevant details. The lamp posts on the central median of the road acted as reference points. The time interval between each frame was maintained at one second. Photographs were taken of the traffic in the morning and evening peak hours for thirty five minutes. During the process of photographing a blank frame was shot at every fifteen seconds interval so as to have a number of sets for analytical purposes which will give the required results. About thirty such sets were prepared using film editing equipment.

(5) Method of Analysis:

To obtain data on Headway Time (HWT) and speed of individual vehicles a suitable scale was constructed on a transparent medium and fixed on the editing screen. The scale
was so constructed to represent the exact field conditions. From the number of photographs in which an individual vehicle has occurred over the section is identified and the speed of that individual vehicle was calculated as follows.

\[ V = \frac{d}{n} \cdot t \cdot 3.6 \text{ kmph} \]

Where,
- \( V \) - Speed of the vehicle in kmph
- \( d \) - The displacement of a vehicle in meters
- \( n \) - Number of frames (photographs) in which the vehicle has crossed
- \( t \) - The speed of the camera ie. one frame per second.

The Time Headway has been measured using the lamp posts as reference marks. The time interval between the two successive vehicles just crossing the reference mark has been calculated. The typical scale constructed for the purpose of analysis is shown in Fig. 3.

The HWT was calculated as follows; “Time interval between the fronts of the vehicle crossing a particular reference line when following one another (measured in terms of number of frames) or

\[
\text{Headway Time} \ 't' = \frac{\text{Speed}}{\text{Spacing in (m)}}
\]

(6) Analysis:

For the purpose of the study, Four kinds of vehicle relationships were examined which are as follows;

1. Autorickshaw Following Car (AFC)
2. Car Following Autorickshaw (CFA)
3. Bus Following Autorickshaw (BFA)
4. Autorickshaw Following Bus (AFB)

Each of the pertinent data subsets were further segmented in to 5 kmph class intervals. Mean Headway times were calculated for every increment of each of the four sets. Table 1 to 4 given below illustrate the mean Headway Time and sample size by velocity class for

<table>
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<th>Speed kmph</th>
<th>Mean Headway secs</th>
<th>Sample size</th>
<th>Estimated volume (VPH)</th>
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<tr>
<td>15-20</td>
<td>2.65</td>
<td>3</td>
<td>1358</td>
</tr>
<tr>
<td>20-25</td>
<td>2.40</td>
<td>5</td>
<td>1500</td>
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<tr>
<td>25-30</td>
<td>2.30</td>
<td>8</td>
<td>1565</td>
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<tr>
<td>30-35</td>
<td>2.45</td>
<td>16</td>
<td>1469</td>
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<tr>
<td>35-40</td>
<td>2.50</td>
<td>11</td>
<td>1440</td>
</tr>
<tr>
<td>40-45</td>
<td>2.60</td>
<td>4</td>
<td>1384</td>
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<td>2.90</td>
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<td>55-60</td>
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each type of traffic. Variation in observed flow values and estimated flow values was not significant and therefore in order to indicate the variation in the maximum flow values corresponding to the Headway secs, the estimated flow values are given in the tables.

The plot of mean versus speed for the four traffic types mentioned above is shown in
Fig. 8. After considering the general shape of the HWT speed data in Fig. 4 it seemed possible to fit smooth curves to the data. Upon consideration a variation of the theoretical model proposed by Greenberg appeared to be a likely possibility.

Greenberg held that flow was related to concentration in the form of:

\[ Q = ck \frac{\ln(kj)}{(k)} \]

Where,  
- \( Q \) - Flow  
- \( c \) - Initial velocity  
- \( kj \) - Jamming concentration  
- \( k \) - Concentration

This results in the familiar q-k curve which rises from zero flow at zero density to some point of maximum flow and then flows off as the density builds up until the point of jam density (\( kj \)) where the flow is again zero.

Since the flow can be expressed as \( \frac{3600}{HWT} \), it can be seen that maximum flow is equivalent to minimum HWT. In addition, as velocity decreases HWT increases due to the extra time required for the vehicle to clear its own length past the point. As velocity approaches infinity flow approaches zero which fits the lower limit of Greenberg's model.
Rewriting Greenberg's equation to relate HWT to velocity it becomes:

\[ t = \frac{1000}{kj \cdot u} \frac{u}{c} \]

Where,
- \( t \) - HWT in seconds
- \( u \) - velocity (kmph)
- \( c \) - velocity at minimum HWT (kmph)
- \( kj \) - jam density in veh/km

This equation was fitted to the HWT-velocity relationship for each of the four traffic types.

(7) Interpretation of curves:

The fit of curves for the traffic type “Autorickshaw Following Car” (AFC) and Car Following Autorickshaw (CFA) are as shown in Fig. 9.

The lower curve indicates the relationship of Autorickshaw Following Cars while the upper curve also indicates the same relationship ie Car Following Autorickshaw. This is the homogeneous flow condition, a condition more possible to achieve when all the vehicles are of the same type. The AFC curve has minimum velocity of 25 kmph and HWT of 2.3 seconds. This represents a point of maximum flow of 1565 vehicles per hour (VPH). The curve CFA has its minimum velocity of 27.8 kmph and HWT of 3.38 seconds at a maximum flow rate of 1065 VPH. The two curves exhibit a considerable degree of

![Fig. 9 Fit of curves to headway-time speed data for CFA & AFC.](image-url)
similarity with a 2.8 kmph difference in speed at maximum flow.

The HWT offset between the two curves is quite constant within the normal range of operating speeds going from a difference of one second at 18 kmph to 1.6 seconds at 48 kmph.

The similarity in behaviour of these two types of traffic is most desirable as it indicates that control procedures which attempt to optimize traffic flow in terms of speed could be equally effective with either type of traffic.

(8) The fit of curves for the traffic type Autorickshaw Following Bus (AFB) and Bus Following Autorickshaw (BFA) is shown in Fig. 10. The AFB and BFA curves exhibit the non-homogeneous conditions wherein the minimum Time Headway is 2.7 seconds with a velocity of 26 kmph and flow rate of 1333 veh/hr. For BFA the minimum Time Headway is 2.58 seconds with a velocity of 35 kmph and flow rate of 1395 veh/hr. Thus the non-homogeneous flow exhibit definite similarity in maximum flow rate but at materially different velocity. This is quite opposite to the homogeneous flow experience. The difference in optimum speed of AFB and BFA poses a setback in traffic control measures. If, for example, speed is held at 26 kmph to optimize AFB, then the BFA segment will be operating at a less than optimum flow rate and vice versa. Hence a stream of large number of buses and Autorickshaws can not be optimized at any one speed. However a more possible velocity may be 30 kmph, But BFA would be required to operate at a sub-optimum velocity which might create unstable flow conditions.
(9) The fit of curves for the traffic flow type Car Following Autorickshaw (CFA) and Bus Following Autorickshaw (BFA) is as shown in Fig. 11.

The fit of curves indicates that when Car follows Autorickshaw, Car maintains a larger space behind Autorickshaw. This may be because Car drivers can not visualize the traffic ahead through the Autorickshaw as the body of the Autorickshaws are completely covered.

On the contrary when bus follows Autorickshaw Bus maintains a smaller spacing as the Bus drivers could visualize traffic ahead over Autorickshaws.

(10) The fit of curves for the traffic type Autorickshaw Following Car (AFC) and Autorickshaw Following Bus (AFB) is as shown in Fig. 12. The fit of curves indicate a situation that when Autorickshaw follows cars they maintain a smaller spacing behind the car as the visibility through the car is more clear than through the Autorickshaws when the cars follow them. At the same time when the Autorickshaws follow the Buses they maintain larger space as the size of the buses prevent the Autorickshaw drivers to visualize the traffic ahead.

4.2 Case study : 2 : - Speed Density Relationship of Autorickshaws in relation to Buses and Cars:

(1) General:
Congestion is the impedance of one vehicle on the other causing delay. In a situation (India) where the traffic is nonhomogeneous in character the impedance and consequent

Fig. 11 Headway time versus speed with autorickshaw as lead vehicle.
congestion is more. Hence the higher the heterogeneity the more the congestion. Since Autorickshaws have been increasing in number and forms considerable percentage composition of traffic, to find out the effect of Autorickshaws on the speed of other vehicles, registration plate method of observation for speed, density, volume and composition was adopted.

(2) Development of Speed-Density Relationship for Buses Cars and Autorickshaws:

Background Study

If traffic is sufficiently light, then the drivers of buses, cars and Autorickshaws have the freedom to do as they wish within certain limitations (i.e. speed limits if the drivers are law abiding, or certainly the technological limits of the vehicles.) Only occasionally will each driver slow down because of presence of other vehicles. As traffic increases to moderate level, encounters with other slow moving vehicles are more numerous. It is still not difficult to pass the slower moving vehicles and hence the driver's average speed is not appreciably less than the desired speed. However in heavy traffic, changing lanes become difficult and consequently the average speed of buses, cars and Autorickshaws get affected.

On the basis of these observations it is justified to use a simplifying assumption that at any point along the road, the velocity of a vehicle depends on the density of traffic.

Therefore,

$$V = v(k)$$  \hspace{1cm} (i)
Richards in Mid 1950's proposed this type of mathematical model of traffic flow. If there are no other vehicles on the road (corresponding to very low traffic densities) then the vehicles would travel at the maximum speed.

Therefore

\[ V(0) = V_{\text{max}} \]  

(ii)

\( v_{\text{max}} \) is sometimes referred to as the "mean free speed". However as the density increases, velocity would continue to diminish and at certain density, the vehicles would standstill. This maximum density is known as jam-density.

\[ \text{ie. } V(k_{\text{max}}) = 0 \]  

(iii)

The relationship between the vehicle speed and traffic density corresponding to values in between those given by equations i and iii may or may not be of a linear relationship. However it may be assumed to be linear.

(3) Study Methodology:

The study flow chart Fig. 13 explains the various steps followed for the purpose of the study.

(4) Data collection:

Study Location;
To find out the different values of densities and the corresponding values of Volume, spot speed and composition of Autorickshaws a stretch of road was selected on a four lane road in such a way that proper collection of data is ensured. The following were the criteria set for the study location and data collection:

i. Observers were located and data recorded in such a manner that the measurement did not attract the notice of the drivers.

ii. Accumulation of onlookers or anything unusual at the study location were avoided.

iii. Lines marked with the chalk on the road were made inconspicuous to the approaching drivers.

iv. The study locations were also away from the traffic control points (e.g. bus stops, intersections or right or left turns etc) so that speed is not affected due to their presence.

While the data relating to the spot speed, Classified volume count and density were collected using the conventional methods, the data relating to the jam density was collected at intersections as follows:

For the purpose of the data collection of length of the road near the traffic signal was marked lengthwise at an interval of one meter. The jam density was considered to exist at red light of the traffic signal. At red light both the number of different categories of vehicles and the length of the road occupied by these vehicles were noted. Fifteen observations were taken for jam density calculations.

(5) Data Analysis:

The data collected during peak and offpeak hours were analysed for spot speed, classified volume count, density and jam density and 34 data sets were established for detailed analysis as indicated below:

i. Spot speed, Space mean speed for various density values were established.

ii. The mean speed and their standard deviation for buses, cars and Autorickshaws were established.

iii. Two possible and measurable sources of variation for the speed of buses and cars were identified as:

   a) the time of the day and
   b) the traffic density

To determine whether part of the variability of the speed could be attributed to the identical sources namely the time of the day and the density of traffic an analysis of variance was performed on the data collected.

c) To determine the effect of the time of the day and the traffic density on the speed of buses, cars and Autorickshaws it was found that the number of observations were not the same from one cell to the other, therefore the method of Least squares was made use of.

d) To calculate the Threshold density i.e. density beyond which the speed of the Buses, Cars and Autorickshaws get significantly affected due to an increase in
density, a comparison between the means was done by analysing their difference by the "Student 't' test" as shown below:

\[
t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma} \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}
\]

Where,

- \( t \) - Value of statistics 't' for the density set compared.
- \( X_1 \) & \( X_2 \) - Mean speed of the buses, or cars or Autorickshaws for the two density sets to be compared.
- \( n_1 \) & \( n_2 \) - Number of observations in the two density sets to be compared.
- \( (n_1 + n_2 - 2) \) - Degree of freedom for the density sets compared.
- \( \sigma \) - Pooled standard deviation.

\[
\sigma = \left[ \frac{n_1 s_1^2 + n_2 s_2^2}{n_1 + n_2 - 2} \right]^{1/2}
\]

The 't' value has been calculated for the density sets 1 Vs 2, 2 Vs 3 and so on, and shown in tables corresponding to the vehicle under study for peak and off peak hours. The table value of 't' has been taken from Standard table of 't' distribution for \((n_1 + n_2 - 2)\) degree of freedom and at the level of significance of 0.05.

Comparison of any density sets will be called significant if the 't' value calculated is greater than the table value of 't'.

(6) Interpretation of the analysis:

The speed density relationship determined for Buses, Cars and Autorickshaws with respect to the time of the day and the traffic density are as shown in Figs. 14 to 16.

(A) The Fig. 14 shows the speed "V", Density "K" relationship for Autorickshaw using the Greenshield's Speed-Density model for peak and off peak periods and the observations are as follows:

---

Fig. 14  Speed density relationship for autorickshaws.
Peak period; 
\[ V = (48.16 - 0.291 K) \text{ for } K \geq 17 \]
and Off peak period; 
\[ V = (43.89 - 0.256 K) \text{ for } K \geq 17 \]

where, 
\[ V \text{ - Mean speed of Autorickshaw} \]
\[ K \text{ - Density (Veh/hr/lane)} \]

The Threshold density for Autorickshaws during
Peak period; 
17 (Veh/km/lane)
and Off peak period; 
17 (Veh/km/lane)

The maximum mean speed of Autorickshaws During
Peak period is 42.98 Km/h
Off peak period is 39.54 Km/h

(B) The Fig. 15 shows the speed “V” density “K” relationship for Buses using Greenshield’s Linear Speed Density Model for peak and Off peak period;
Peak period; 
\[ V = (51.40 - 0.308 K) \text{ for } K \geq 14 \]
and Off peak period; 
\[ V = (41.35 - 0.246 K) \text{ for } K \geq 14 \]
Table 5  Comparison of means of Autorickshaw speeds

<table>
<thead>
<tr>
<th>Value of 't' Statistics</th>
<th>peak hour Table value of 't'</th>
<th>Significance at 5% probability level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.38</td>
<td>1.978</td>
<td>Insignificant</td>
</tr>
<tr>
<td>0.98</td>
<td>1.960</td>
<td>Insignificant</td>
</tr>
<tr>
<td>2.35</td>
<td>1.960</td>
<td>Significant</td>
</tr>
<tr>
<td>2.52</td>
<td>1.960</td>
<td>Significant</td>
</tr>
</tbody>
</table>

Off peak period

| 1.55                    | 1.960                        | Insignificant                       |
| 2.32                    | 1.960                        | Significant                         |

Table 6  Comparison of means of speed of Buses

<table>
<thead>
<tr>
<th>Value of 't' statistics</th>
<th>Peak hour Table value of 't'</th>
<th>Significance at 5% probability level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.36</td>
<td>1.987</td>
<td>Insignificant</td>
</tr>
<tr>
<td>2.70</td>
<td>1.960</td>
<td>Significant</td>
</tr>
<tr>
<td>2.35</td>
<td>1.960</td>
<td>Significant</td>
</tr>
<tr>
<td>2.51</td>
<td>1.960</td>
<td>Significant</td>
</tr>
</tbody>
</table>

Off peak hour

| 1.55                    | 1.960                        | Insignificant                       |
| 2.32                    | 1.960                        | Significant                         |

where,

\[ V - \text{Mean speed of the Buses (Kmph)} \]

\[ K - \text{Density (veh/km/lane)} \]

The Threshold density for Buses during;

Peak period 14 (Veh/km/lane)

and Off peak period 14 (Veh/km/lane)

The maximum mean speed of Buses during

Peak period 47.40 Kmph

and Off peak period 37.80 Kmph

(C) The Fig. 16 shows the speed “V” Density “K” relationship for cars using Green-shield’s Linear Speed Density model for peak and and Off peak period;

Peak period;
Fig. 16 Speed density relationship for cars.

\[ V = (60.05 - 0.357 \ K) \text{ for } K \geq 17 \]

and Off peak period;

\[ V = (46.80 - 0.276 \ K) \text{ for } K \leq 14 \]

where,

\[ V \] - Mean Speed of Cars (Kmph)

\[ K \] - Density (Veh/km/lane)

The Threshold Density for Cars during

Peak period;

17 (Veh/km/lane)

and Off peak period;

14 (Veh/hr/lane)

The maximum Mean speed of Cars during

Peak period is 3.95 Kmph

<table>
<thead>
<tr>
<th>Table 7</th>
<th>Comparison of means of Car speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of ‘t’ statistics</td>
<td>Peak hour Table value of ‘t’</td>
</tr>
<tr>
<td>0.24</td>
<td>1.988</td>
</tr>
<tr>
<td>0.07</td>
<td>1.980</td>
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<tr>
<td>2.46</td>
<td>1.980</td>
</tr>
<tr>
<td>2.15</td>
<td>1.980</td>
</tr>
<tr>
<td></td>
<td>Off peak period</td>
</tr>
<tr>
<td>0.52</td>
<td>1.980</td>
</tr>
<tr>
<td>5.66</td>
<td>1.980</td>
</tr>
</tbody>
</table>
and Off peak period is 42.88 Kmph

(7) Findings of the study:

i. For higher values of density the rate of reduction in the speed of Autorickshaw is very small and more for Cars and Buses.

ii. For every increase in density value of 10/veh/lane the rate of reduction in speed for

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Speed Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses</td>
<td>3.10 Kmph</td>
</tr>
<tr>
<td>Cars</td>
<td>3.60 Kmph</td>
</tr>
<tr>
<td>Autorickshaw</td>
<td>2.20 kmph</td>
</tr>
</tbody>
</table>

iii. The reduction in speed of Autorickshaws (ii. above) is very less when compared to Buses and Cars at varying density levels, for the observed reasons that the Autorickshaws, basically triwheeled vehicles have greater maneuverability in the traffic stream. Maintenance of certain level of speed by the Autorickshaw drivers, especially during peak period has greater relevance to the number of trips and the money earned as the demand for Autorickshaws is very high during peak period.

4.3 Congestion effect of Autorickshaw:

General;

Out of the well known mathematical expressions, regression analysis is the best and easy method of quantifying the effect of one or more independent variables on the dependent variable.

Taking advantage of the method of regression analysis the collected data was grouped for peak and off peak periods. The data subjected to various kinds of statistical tests in building the speed density relationship is made use of in the regression analysis also. The grouped data provided the information on space mean speed, density values at different percentage mix of Autorickshaws as well as buses.

(1) Multi linear regression analysis:

The basic form of the equation is;

\[ Y = a + bx + cz \]

Where; \( Y \) - dependent variable
\( x \) and \( z \) - independent variables.
\( a, b \) & \( c \) - regression coefficients or constants.

The form of equation relating to the study is as follows.

\[ Y = \text{The space mean speed of traffic in kmph.} \]
\[ x = \text{Loading rate Veh/km/lane.} \]
\[ z = \text{Percentage of Autorickshaw or Buses.} \]
\[ a, b \) & \( c = \text{Constants.} \]

The computed regression equation for Peak and Off peak periods at various percentage
composition of Autorickshaw is as follows:

For peak period:

\[ Y = 48.59 - 0.23x + 1.57z \]  \hspace{1cm} (i)

For off peak period:

\[ Y = 69.28 - 3.35x + 19.42z \]  \hspace{1cm} (ii)

where,

- \( Y \) - Traffic flow speed in kmph
- \( x \) - Load for a traffic lane in Ten minutes
  (as vehicles variable between 54 and 131)
- \( z \) - Percentage mix of Autorickshaws
  (variable between 0.1 to 0.25)

The equation in i and ii above indicate that the percentage mix of Autorickshaw increases the speed rather than decreasing the traffic flow speed and do not contribute to congestion of traffic as has been believed.

On the contrary when the traffic speed was analysed at various percentage mix of buses a different set of regression equations were formed which are as given below:

For peak period:

\[ Y = 47.58 - 0.067x - 1.75z \]  \hspace{1cm} (iii)

For off peak period:

\[ Y = 69.00 - 2.65x - 8.64z \]  \hspace{1cm} (iv)

The equations iii and iv above clearly indicate that the traffic flow speed is reduced when the percentage mix of buses increases. The regression coefficients when correlated showed a high degree of correlation at 97 percent.

(2) Conclusions of the study:

(a) The Autorickshaws do not contribute to the traffic congestion.

(b) The increase in the number of buses in the traffic flow speed decreases the traffic flow speed.

5. Recommendations of the study:

(i) The speed density mathematical model and regression analysis have clearly established that Autorickshaws do not impede other vehicles and cause congestion. Hence the introduction of more number of Autorickshaws in to the traffic stream on all arterial and radial roads will not affect the level of the facility.

(ii) The Headway speed analysis and regression analysis have shown that buses impede the other vehicles in the traffic stream and cause congestion. Hence there is a need to segregate buses on to separate lane on all arterial roads which converge towards the city centre to maintain better level of service.

(iii) Since the Autorickshaws have a maximum economic speed of 45 kmph, on all inter city Highways the Autorickshaws become a slow moving vehicle as the
normal speed maintained on the Highway is more than 60 kmph. Therefore the Autorickshaws should be segregated on to separate lanes on major Highways.

(iv) The Headway analysis has clearly shown that the present structural design of the body of Autorickshaws is a visual intrusion for the car drivers and that optimization of flow level suffers. Hence there is a need for improvement in the structural design of the body of Autorickshaws.

Acknowledgement:

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