Study on Traffic Flow Characteristics using Probe Vehicles

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Abstract

Large scale transport infrastructural enhancements are carried out in urban areas. Metrorail Construction has led to creation of work zones on major roads in many cities including Chennai in India. The already congested road network due to road width restrictions on certain stretches is further strained due to the construction activities. The study on traffic flow characteristics at work zones helps to plan traffic management and is a useful resource for planning future work zone activities. Traffic flow at work zones were studied using videography and probe vehicles (GPS fitted). Videography was used to record classified volume count of vehicles entering the work zone and the speed of vehicles at work zones. GPS fitted probe vehicles were run along the work zone sections to obtain the speed variations. To study the behavior of heterogeneous traffic, GPS fitted cars were run and the probe vehicles formed 1-3% of the vehicular flow. Speed and capacity reduction at work zones on urban roads for heterogeneous traffic was estimated and reported in this paper.

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1. Introduction

The growth in economy in the past two decades has induced higher traffic growth in the range of 8 to 10% per year. There is a need to meet the growing travel demand of the increasing population. The rapid growth of India's urban population has put enormous strain on all transport systems. People prefer to use private modes rather than public mode. In order to increase the public transport ridership and reduce congestion, Transit projects are being planned and implemented in many metropolitan cities. Rail transit projects like Metro rail/ Mono rail systems involve large scale construction and the construction duration is expected to last for 3 to 5 years. During the period of construction, handling traffic in work zones is challenging because the work activity presents an abnormal and often disruptive environment to the motorist. Geometric conditions in work zones might be more restricted compared to a normal urban road sections. Due to this, the capacities of urban work zones are normally lower than the capacity of basic urban road sections. This causes queuing, increased delay, increased accident rates and higher vehicle operating cost. Work zones have been a noticeable source of accidents and congestion, and there have been significant efforts to enhance safety and improve mobility in work zone areas. Quantifying the traffic and safety impact at work zones will be an effective tool in selection of particular work methodology with due consideration to impacts, assessing the economic value of work zone impacts, and selection of types of work zones etc. Traffic flow at work zones due to metro rail construction was studied and the impact in terms of speed and capacity reduction was analysed.

2. Background

Speed measurement is an important task in work zone capacity estimation. The use of GPS for speed measurement has been explained by many researchers and some of them are discussed here. (Yi Jiang and Shuo Li 2001) had studied the traffic flow characteristics at various types of work zones such as crossovers and lane closure type. They have estimated the reduction in the speed of the work zone by means of the GPS. From the speed and the distance plots they identified that there is reduction in the speed at the entry and exit end of the work zones and they have concluded that GPS is an effective tool in estimating the speed reduction in work zones. Irum Sanaullah et al., (2012) studied the travel time estimation along a link road using Probe vehicle fitted with GPS. The GPS data were

collected for a total of 73 vehicles over a period of 6 hours from the Interstate I-880 (California, USA). The evaluated travel time was then validated against reference travel time data collected from high resolution video cameras. (Mudge et al., 2013) studied the performance of work zone sections using Probe vehicle. The applicability of different types of probe data to manage the different work zones was studied and found that the probe vehicle fitted with GPS was suitable for measure the performance of work zone sections at metropolitan and regional level. (Sumeet Gupta et al., 2013) had studied the speed reduction at work zones sections and lidar gun was used to collect the speed data. The vehicle speed was compared with the posted speed limit in Advance Warning Zone (AWZ), Working Zone (WZ) and Terminal Transition Zone (TTZ) on NH-8 in India. (Vidya.R et al., 2012) had measured the speed details for different type of work zones created along the section of National Highways 67. The spot speed survey was conducted to assess the speed range at work zone sections.

(Darcy M. Bullock et al., 2009) studied the traffic delay in the work zones by means of blue tooth probe technique. They collected automatic Bluetooth probe data for travel time estimation from numerous sites and found the travel time delay due to the installation of the work zones in that site. (Zoltan A. Nemeth and Ajay K. Rathi 1981) had studied the impact of fixing the speed limit in the work zone area using simulation technique. They reported that due to the internal friction between the vehicles in the merging area there is a great reduction in the speed of the vehicles.

The Capacity of work zones have been estimated for the car only traffic by many researchers (Maze et al., 2000) observed a work zone on a rural IOWA interstate highway to measure the volume of vehicles that can pass through a work zone lane closure prior to and during congested operations and to better understand the related driver behaviors. The capacity was suggested based on the average of the 10 highest vehicle volumes passing through the work zone before and after the queue formation. They have reported that the vehicle volumes varied between 1400 and 1600 pcus per hour. (Darrell W. Borchardt et al., 2009) had established the capacity and analysed the road user cost of selected freeway work zones in Texas. To estimate the capacity, field data were collected at work zones using manual count. The capacity of each study site was estimated based upon the field data collection and the maximum observed volume throughput of the work zone. It was observed that the roadway capacity is reduced by about 20 percent within a work zone.

(Rahim F. Benekohal et al., 2010) has studied the formation of Queue and user cost at Highway work zones. They proposed a four regime model for the capacity estimation of the work zones. (Kivanc A. Avrenli et al., 2011) investigated the distinct effects of Police enforcement and ITS implementation on work zone speed flow curve and capacity. According to the results, both the police car and Speed Photo Enforcement (SPE) van reduced the speeds in the upper branch (uncongested) of the work zone speed-flow curve, a slight capacity reduction of around 50 pcphpl and 100 pcphpl respectively were identified in their study. (Mayank Prakash Jain 2008) studied the effect of arterial work zones in Florida using simulation models. Simulation of arterial work zones showed that the distance from the work zone to the downstream intersection affects the capacity of the entire arterial work zone. In this study, an arterial work zone capacity was compared with the arterial roads having no work zones.

Only few attempts have been made to assess the work zones impact of work zones in India. The traditional speed measurement methods such as, spot speed measurement and radar gun has been used to study the speed reductions at work zone section. In this study, a new attempt was made to measure the speed at work zone sections using Probe vehicle. GPS probe data is one of the most advanced techniques for quantifying speed reductions at work zone sections.

3. Study Work Zone

The work zone selected for the study was located on Grand Southern Trunk (GST) road in Chennai. GST road is a six lane divided road passing through, institutional, commercial and residential areas. GST road connects, Central Business District of Chennai to airport and the southern suburbs. Due to the Metro rail construction, the carriageway width on GST road for a distance of 400 meters was reduced from 3 lanes to two lanes between Pallavaram intersection and Cargo intersection. At the work zone section chosen carriageway width was reduced on the far side lane (figure 1). The total length of the stretch was 3300 meters and the work zone was between 2400 meter and 2800 meter chainage. The capacity of the work zone section was compared with an ideal six lane divided road (Rajiv Gandhi road) in Chennai.

Fig.1 View of Work Zone Section with Reduced Width along GST Road

4. Methodology

The extent of speed reduction and capacity reduction along work zones was measured. The speed reduction in the work zone was estimated using GPS probe vehicle data and the capacity was estimated with the help of videographic survey conducted for a period of 4 hours. A camera was fitted at the road side and focused on a trap section of length 20 m on the road, which is demarcated using adhesive tapes. The recorded video was imported into an application developed for video data extraction, in which the entry and exit time of vehicles entering and leaving the trap section were keyed by the enumerators. The capacity of work zone was compared with an ideal section (Six lane divided road) to understand capacity reduction.

4.1Capacity reduction at work zone

Work zone configurations are normally different than basic road sections and number of available lanes might be reduced in a particular section of an urban road. The capacity of work zones is normally less than the capacity of basic sections, and may cause queuing. To estimate the capacity, videographic surveys were conducted for a period of 4 hours during the morning peak hour on the selected stretches. Two cameras were deployed one at the entrance of the work zone and the other one was placed to cover

a trap length of 30m of road in work zone where there is reduction in the width of the carriageway. The position of the cameras deployed in the work zone is shown in figure 2.

The position of the camera is fixed to find out the maximum flow in five minute intervals before and after queue formation. The video records from second camera were used to obtain the spot speed of the vehicles and the first camera was used to detect the time of queue formation. The maximum volume of vehicles observed during the period at which the queue formation starts was defined as the capacity of the work zone.

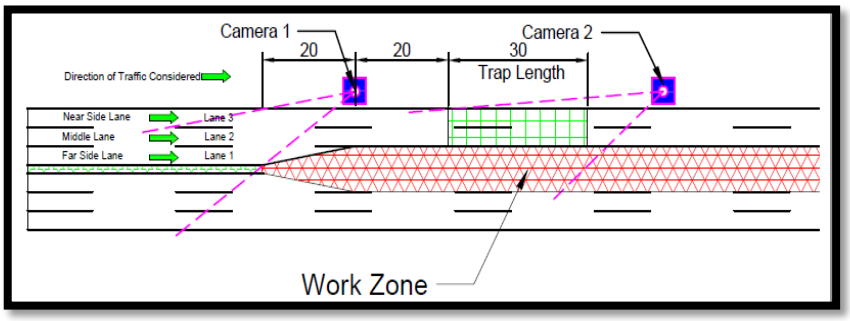

Fig. . 2 Arrangement of Camera in Work zone for Videographic Survey

The Capacity of the ideal urban road section was estimated by Greenshields method by adopting the concept proposed by Dhamaniya and Chandra (2014).

4.2 Speed reduction at work zone

The probe vehicles fitted with GPS were run on the road section in which work zone was a part and the speed reduction was estimated.

A set of 5 cars fitted with GPS were run repeatedly for obtaining the speed data from both the ideal section as well as in the work zones. The GPS fitted vehicles were run for 4 hours when video recording was performed. The polling frequency of the GPS was set at 10 seconds. The probe vehicles were run in a loop around the work zone to increase the sample size. The speed of the vehicles was transferred by GPRS technique at a frequency of 10 seconds and it was recorded in the server along with the position of the vehicle in terms of latitude and longitude. A sample of data recorded in the server is shown in the figure 3.

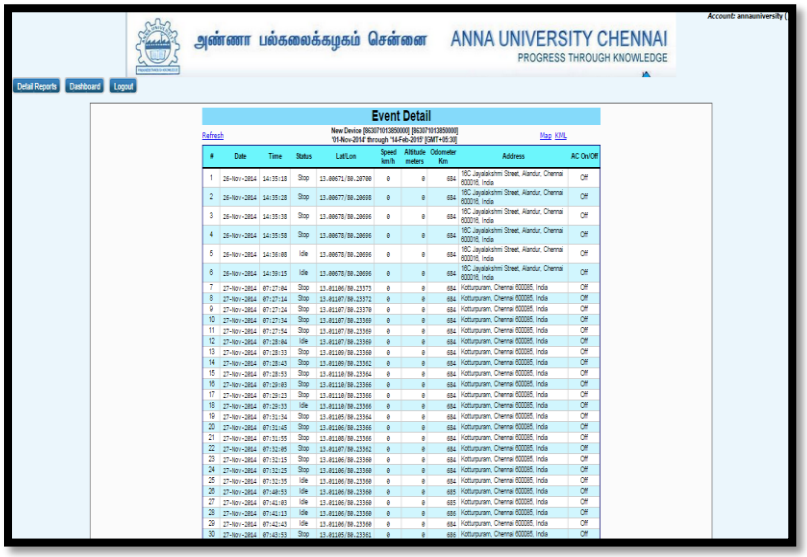

Fig. . 3 Display of GPS Data in the Server Monitor

The average, maximum and minimum speed in the section before the work zone and at the work zone were analysed.

5. Traffic Flow Characteristics

On GST road the video was recorded for a period of four hours at two locations. The cameras were mounted in the nearby scaffolding arrangements. The second camera was mounted to cover a trap length of 30m in the work zone. The snapshots of the videographic recording of the two cameras are shown in the figure 4.

The data from the video was extracted using a data extraction software developed using C# which needs human intervention for the identification of the vehicles. In the video records lines to delineate the trap length were drawn. Then the video was run to extract the type of vehicle and time of entry & exit. With the data recorded the category wise five minute flows and the speed of the vehicles were computed.

Fig. . 4 View of the Video Records before the Start and at Work Zone

The composition and the hourly variation of traffic flow are shown in the figure 5 & 6. Two Wheelers were 65 % of the total flow. Cars were classified as Car small (Sedan and Hatchback) and Car Big (SUVs) and cars were 27 % of the total traffic flow. Two wheelers (motorized) is the most preferred mode in Indian cities due to its low cost and ease of parking. The peak hour flow was observed between 09:00 and 10:00 hours with a total traffic flow of 9200 Vehicles/Hour/Direction. During peak hour both the lanes of work zone was utilized equally and during other time period the utilization of far side lane was higher than the near side lane.

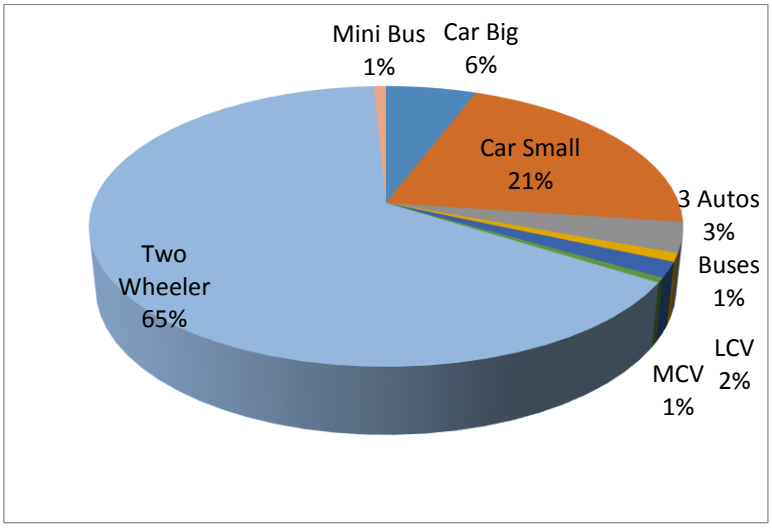

Fig. . 5 Vehicle Compositions on GST Road

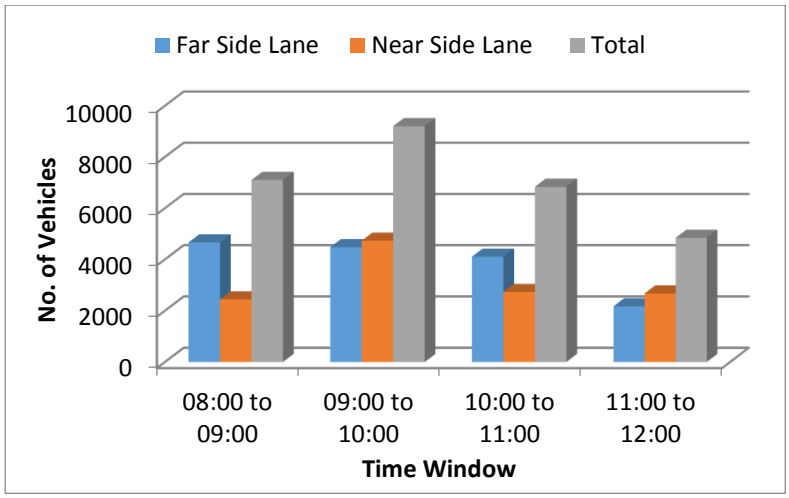

Fig. . 6 Variation of Traffic Flow on GST Road

6. Travel Speed Measurements

Travel speed was obtained from the GPS polling of the five cars that were run repeatedly along the work zone section. The work zone is about 400m in length and the probe vehicles traversed for a length of 3.3 km for a period of four hours from 08:00 to 12:00 hours in order to assess the reduction in the speed at the work zones. The entire stretch on which the speed measurement was carried out is shown in the figure 7. Eighty Eight runs were performed with the probe vehicles along the GST road in the four hour period.

Fig. . 7 Section along GST Road with Work zone for Travel Time Survey

The information stored in the server was date, time, location in terms of latitude and longitude, speed etc. The view of the vehicle path at the road section including work zone for a typical run of probe vehicles is shown in the figure 8. The details of speed recorded for the direction Pallavaram intersection to Cargo intersection was segregated and used for further analysis.

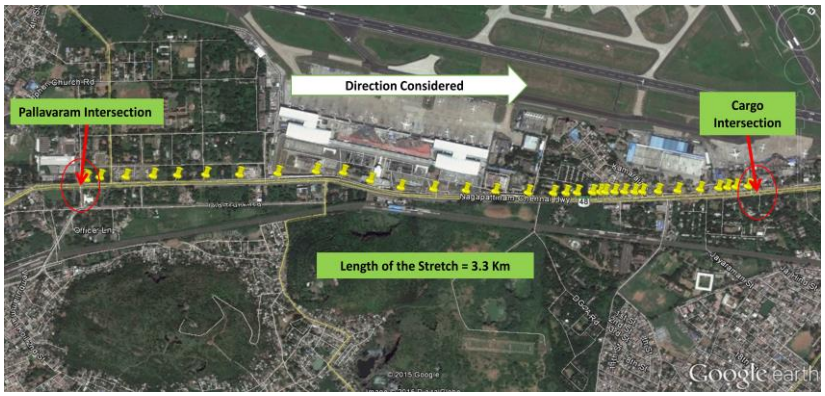

Fig. 8. Plot of GPS Polling Points of a Typical Run

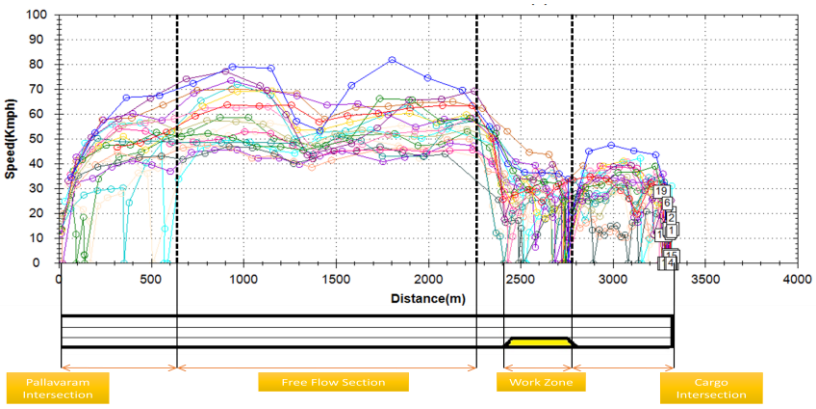

Figure 9 Speed Distance Plot of Probe Vehicle Trips along Pallavaram to Cargo Intersection

The speed data of the 88 runs were plotted with the distance for the direction Pallavaram – Cargo intersections (figure 9). The work zone starts from 2400m chainage. Vehicles travelled at higher speeds from 0 to 2400m chainage and, the speed on entry to the work zone and at the work zone. The minimum, average and maximum speed recorded is shown in

figure 10. The dip in maximum speed was due to the horizontal curve in the alignment between 1200 to 1700 meter chainage.

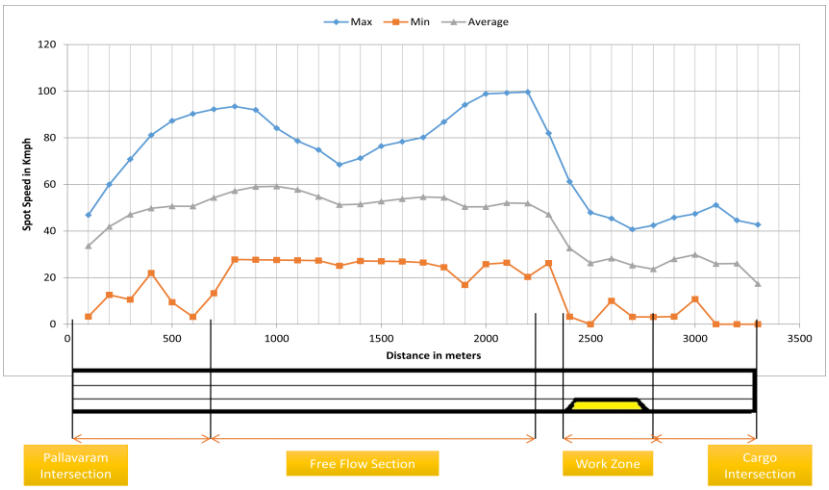

Fig. . 10 Observed minimum, average and maximum speed along the study stretch

The average speed on the stretch before start of work zone was 53kmph and the average speed at work zone region was 27 kmph. There was speed reduction of 49% at the work zone during the period.

7. Work Zone Capacity Estimation

The flow observed on urban roads in India is heterogeneous in nature and flow is expressed in Passenger Car Equivalents (PCEs). The PCE of each vehicle was computed based on Dynamic PCE method suggested by Chandra et al (1995). PCE of a vehicle would vary with the speed and plan area to that of car. The PCE value was computed using equation 1.

$$PCE_i = (V_c/V_i)/(A_c/A_i) \quad (1)$$

Where,

Vc = Speed of the Car,

Vi = Speed of the subject Vehicle

Ac = Plan Area of the Car

Ai = Plan Area of the subject Vehicle

The PCE values for different type of vehicles were estimated for the data collected and the range of PCE values for each vehicle category is given in Table 1. The PCE value of two- wheeler (motorized) varies from 0.18 to 0.27 as the plan area occupied by two-wheeler is less and it moves at lower speed when compared to car.

Table . 1 Estimated Dynamic PCE Values

Vehicle Types	Dynamic PCE Values
3 Wheeler Auto Rickshaw	1.03 - 1.48
Mini Bus	1.76 - 3.54
Buses	3.47 - 7.03
Car Small	1 – 1
Car Big	1.15 - 1.65
Two wheeler	0.18 - 0.27
Light Commercial Vehicles	0.94 - 1.40
Medium Commercial Vehicles	2.27 - 7.1

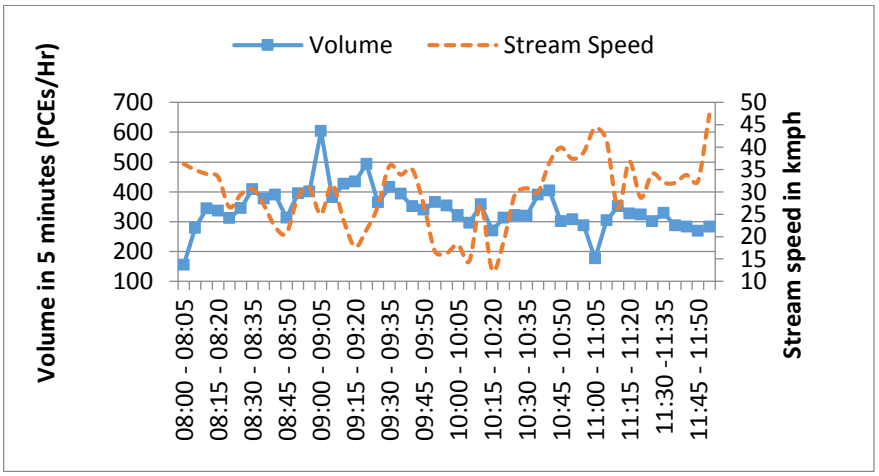

Fig. . 11 Flow and Stream Speed Variation

Flow rate in PCEs for every five minutes duration was calculated and plotted against the respective time windows. The stream speed of the vehicles was also plotted against the respective time interval and shown in the figure 11. From the camera records queuing was noted from 09:00 to 10:30 hours but lasted for short periods. Thus the ten highest flows observed for 5 minute duration were taken and the average of the values was considered as the capacity of work zone.

The estimated hourly flow rate for the maximum flow values on the GST road are shown in the table 2. The average of the highest flow rates is 5247 PCEs per hour. Hence the capacity of the work zone section based on the Maze et al. (2000) concept was 5247 PCEs per hour.

Table 2 Highest Ten Flow Rates Observed

S.No	Flow (PCEs/5 minutes)	Hourly Flow Rate (PCEs/ Hour)
1	604	7242
2	493	5920
3	434	5213
4	426	5118
5	415	4984
6	409	4905
7	404	4846
8	400	4804
9	394	4730
10	393	4718

The Speed – Density and Speed - flow for the work zone was done. The hourly flow rate in PCEs was calculated with the 5 minute flow observed and the stream speed was calculated as the harmonic mean of the vehicle speeds recorded in the 5 minute duration. The total width of the carriageway at work zone i.e. two lanes was considered for the flow rate and stream speed calculation. The Speed flow relationship was considered to follow Green shields model. The Speed- Density plot (figure 12) indicated a linear relationship existed. The capacity found from the Speed – Flow plot (figure 13) was around 4888 PCEs. The speed flow plot indicates the flow at work zone was near to capacity and in congested region i.e. from LOS D to LOS F. The capacity of the work zone estimated by Maze et al. (2000) concept and that by Greenshields was close and the lower of the two was taken as the capacity of the work zone.

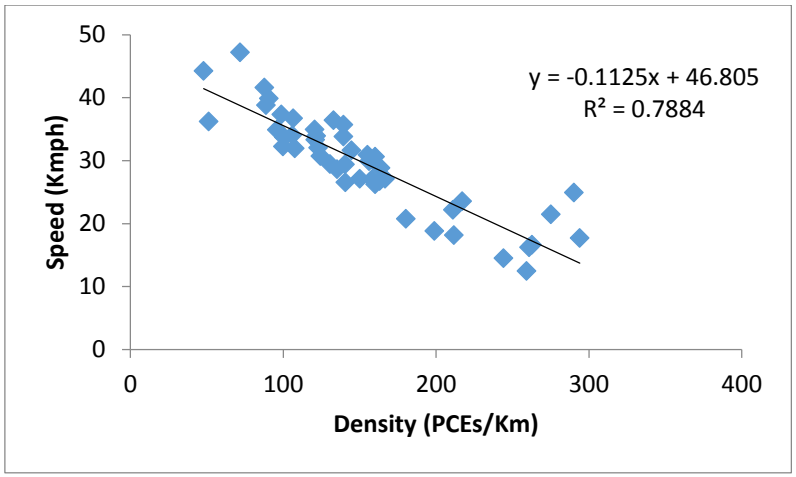

Fig. . 12 Speed – Density Relationship for GST Road

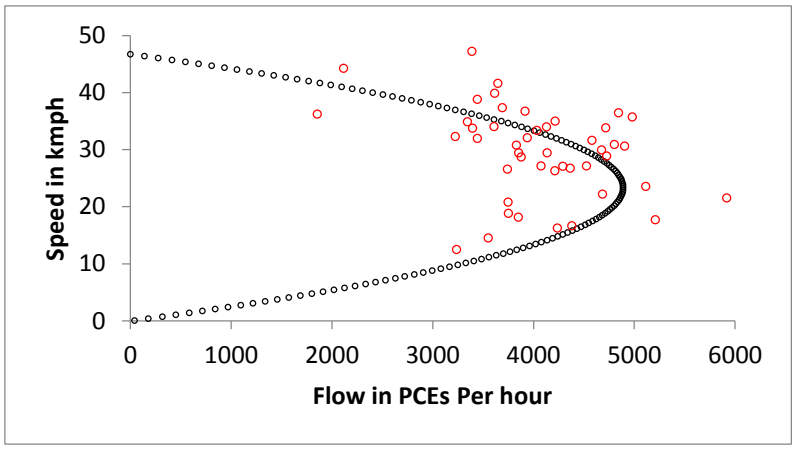

Fig. . 13 Speed – Flow Relationship for GST Road

8. Estimation of Capacity Reduction at Work Zone

To estimate the capacity reduction due to work zone was attempted by comparing capacity at an ideal section with that at work zone. A stretch on Rajiv Gandhi (RG) Road was taken as the ideal section. The RG Road is also a Six lane divided road with controlled access to the carriageway. Same methodology as adopted for work zone capacity estimation was followed. The Speed Flow relationship for the ideal section was developed based on the data collected for Rajiv Gandhi Road during the morning

peak hour. The Speed – Density (Figure 14) and Speed – Flow (Figure 15) relationships were established assuming the relationship to follow that proposed by Greenshield.

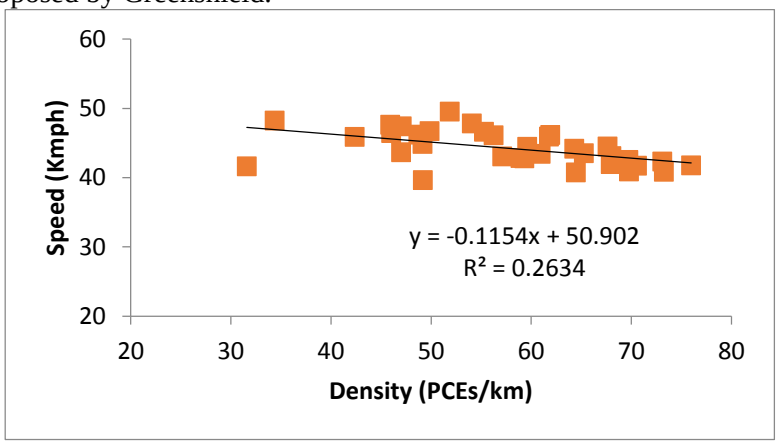

Fig. . 14 Speed - Density Graph developed for RG Road

The capacity estimated from the speed flow relationship for RG Road is 5613 PCEs per hour for the total width (3 lanes). The capacity of the work zone section was 4888 PCEs per hour (2 lanes). The Capacity at work zone was 12 % lesser than the ideal section.

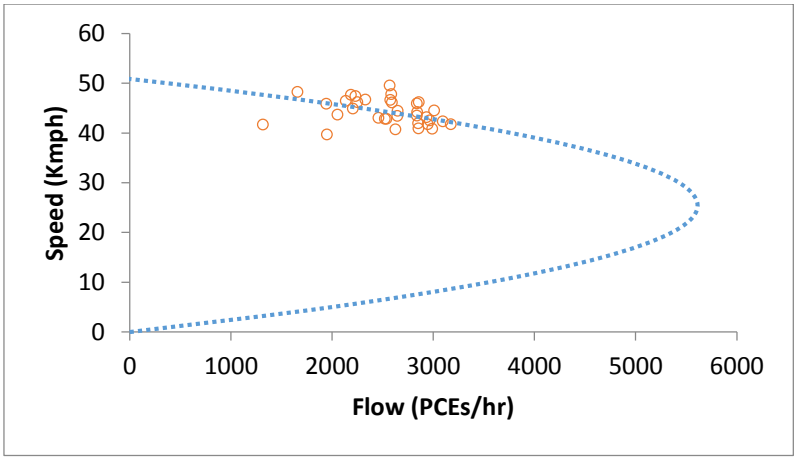

Fig. . 15 Speed – Flow Relationship developed for RG Road

On introduction of work zone on a six lane divided road by reduction of carriage way width by one lane the capacity gets reduced by 12 %. The vehicles adjust their speed, position and spacing when they enter a work zone. The speed reduction was nearly 50 % but the capacity reduction was 12% for a carriage way reduction of 33%. This may be due to higher proportion of smaller size vehicles i.e. Two-wheelers.

9. Conclusion

The work zone capacity estimation by Maze et al. (2000) concept and that of Greenshields yield closer values. The speed reduction at work zone is significant but the capacity reduction is marginal for heterogeneous traffic as smaller size vehicles especially two- wheelers are in large numbers. Deployment of GPS fitted probe vehicles provides an insight in speed reduction at work zones. Based on the average speed prevailing at work zone, capacity of the section could be estimated from established speed flow relationship.

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Acknowledgement

The authors are grateful to Center of Excellence in Urban Transport, Indian Institute of Technology, Madras for their financial support for the research study "Study on Safety at Work Zones in Urban Areas".