Estimation of Stream Equivalency Factor at Signalized Intersection Under Mixed traffic conditions in Ahmedabad City

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Abstract: In order to bring a heterogeneous traffic stream into a homogeneous one consisting of passenger car, the concept of Passenger Car Unit (PCU) factor was introduced. Historically, several methods have been developed for the estimation of PCU values. The present study computed PCU values with area occupancy method for different vehicle categories present at signalized intersections under heterogeneous traffic condition using regression method shows unrealistic PCU values for certain vehicle categories at approaches. Consequently, the study introduced the concept of Stream Equivalency Factor (SEF) to avoid the profound understanding of the PCU estimation. It is a ratio of traffic volume in PCU per hour and volume in vehicles per hour. This factor is related to traffic composition and volume on road through the regression analysis. Multiple linear regression model consists of the flow ratio and percentage of vehicle ratio. For doing so, traffic flow data of some signalized intersections of Ahmedabad is collected using Videography during the peak hours. The data is extracted from the videography with the use of AVIDEMUX software. The PCU values of different vehicles obtained by area occupancy method during the peak hours. This data used for developing SEF model with the use of multiple linear regression technique.

I. INTRODUCTION:

Traffic pattern in developing countries like India is different than traffic in developed countries. The cities of the world including those in the Europe and united states has heterogeneous traffic conditions but the degree of heterogeneity is different. India has a variety of vehicles like cars, light commercial vehicles, heavy commercial vehicles, two-wheelers, three-wheelers, and non-motorized vehicles in its traffic stream. While roads in developed countries have dominating traffic of cars with very low proportions of light and heavy commercial vehicles. The main portion of national and state highways in India is composed of two-lane roads. These roads have both direction traffic movements. The traffic in the opposite direction influenced to drivers for lane changing and overtaking behaviors. When the traffic volume increases, the demand for such maneuvers also increases, and passing opportunities decrease. When the same facility is used by various categories of vehicles problem gets more complicated, starting from slow-moving vehicles to fast-moving vehicles, with differences of their static and dynamic characteristics. Indian urban road has the proportion of cars may be as low as 30% in the traffic stream. The wide variety of mixed traffic and change in their size and speed creates a number of problems to traffic engineers. Speed, acceleration, capability, maneuverability these four major aspects associated with several types of vehicles in the traffic mix responsible for the problems to traffic engineer. Careful consideration of these aspects needed because it is difficult to develop traffic stream models for estimation of capacity under mixed traffic conditions.

The analysis of a mixed traffic flow for different vehicles is simplified if the relative effect of each vehicle type can be expressed in common unit. The second edition of the Highway Capacity Manual of the United States (HCM 1965) introduced the concept of the passenger car unit (PCU) as a measure to convert all types of vehicles in a traffic stream into an equivalent number of passenger cars. It helped bring a non-uniform traffic stream with all types of vehicles down to a uniform traffic stream consisting of passenger cars only. Since then, many studies have been carried out for estimation of PCU values for different vehicle classes in different parts of the world. IRC – 1990 gives static PCU of ten categories of vehicles that found on Indian road conditions. Since that several research has been held on the PCU of several vehicles categories. Based on vehicle area and speed concept (Chandra et al, 1996) gave a methodology for the estimating of dynamic PCU. According to that given method, PCU values for different vehicles under mixed traffic condition is inversely proportional to the area occupancy (AO) ratio and directly proportional to the clearing speed. (Mathew sonu et al,2016) for PCU of vehicles on four legged roundabout Time occupancy concept was used. Instead of considering clearing speed ratio, ratio of time occupancy of subject vehicle to occupancy time of standard car is taken. Chandra et. Al. (1996) gave a methodology for the estimating of dynamic PCU. According to that given method, PCU values for different vehicles under mixed traffic condition is inversely proportional to the area occupancy (AO) ratio and directly proportional to the clearing speed. Mathew sonu et. Al. (2016) for PCU of vehicles on four legged roundabout Time occupancy concept was used. Instead of considering clearing speed ratio, ratio of time occupancy of subject vehicle to occupancy time of standard car is taken. New concept of area occupancy has been introduced by Arasan V T and Dhivya G in 2010 for the study of the mix traffic condition (P. Preethi and R. Ashalatha; 2016) worked on the topic of estimation of dynamic PCU using the area occupancy concept at signalized intersection.

II. MODELLING APPROACH:

PCU is a measure of relative interaction caused by a vehicle to a traffic stream compared to a passenger car under a specified set of roadway, traffic, and other conditions. This interaction will depend on traffic, roadway, and environmental conditions. For a given facility, roadway and environmental conditions remain almost unchanged during field observation time, and therefore traffic characteristics like traffic composition, traffic volume, speed of each category of the vehicle, and physical size of the vehicle must be able to explain all variations in PCU values for a vehicle type. The composition accounts for any change in the traffic and changing degree of damaging effect at different volume levels. The vehicular interaction and all other geometric influences culminate in the speed of the vehicle and the physical size of a vehicle is supposed to indicate manoeuvrability, acceleration or deceleration capability, and space occupancy on the road, which are crucial in the measurement of density. Considering all these factors, Area occupancy method developed by Arasan V T, Dhivya G; 2010

Area occupancy is the proportion of the time set of observed vehicle occupy the chosen stretch. It is non dimensional parameter and its value ranges from 0 to 1. Area occupancy of an individual vehicle category is the sum of area occupancy of that category vehicles during the observed time which shown in the following equation. In this study observed time taken 5 second.

$$\mathrm{AO} = \sum_i (AO)\, i$$

$$AO_i = \frac{ai \sum_n t_i}{TA}$$

Where, AO_i = the area occupancy of "i" category vehicle, a_i = horizontal projected area of "i" category vehicle, ti = time occupancy of "i" category vehicle, T = observed period in second, A = area of study stretch

Let $(A_{eq})_i$ be total standard car horizontal projected area equivalent to "i" category vehicle clearing the observation area during observed green time and t_s be the average occupancy time of the all vehicles available during the observation green time in the intersection area. So that equivalent standard car occupancy corresponding to the observed area occupancy is $(A_{eq})_i t_s$/ TA Total occupancy of a vehicle category "i" can be converted to standard car area occupancy as shown in equation.

$$N_{(CS)i} = \frac{(Aeq)_i}{a_{sc}}$$

Where, a_{sc} = the horizontal projected area of standard car in m^2

The number of standard car spaces obtained through above equation can be considered as the equivalent number of passenger cars to the total number of "i" category. Take ni be the number of vehicles in the "i" category then the dynamic PCU value of "i" category vehicle can be calculated out using following equation.

$$PCUi = \frac{N_{(cs)i}}{n_i}$$

Where, n_i is number of vehicle of "i" category whose time occupancy are used for the calculation of PCU.

The methodology in this study divided in five stages. In first stage, different approaches of intersections in Ahmedabad have been identified by pilot survey. And inventory survey of selected stretches included in first stage. Second stage contain data collection by videography. Videography at selected stretch done in peak hours of morning and evening time for two to three hours at selected approaches. Camera position have been set in the way that can cover 50 to 100-meter stretch in the video footage steady shoot can be done for selected approaches without camera movement. In, third stage data extraction part done. Data extraction done by playing the recorded video in AVIDEMUX software and with screen marker 50-meter stretch have been marked on screen the video played on large screen projector to count the volume count, and clearance time of individual vehicle type in 5 sec slice of green phase. Fourth stage contains analysis part in analysis of extracted data from the footage dynamic PCU for individual vehicles by area occupancy method and SEF values have been calculated. In fifth stage model development of PCU for individual vehicular category and SEF by regression technique have been done. Effect of different vehicle composition and flow on derived model values has been checked with various graph plots with different composition and different flow values.

III. STUDY AREA PROFILE:

Three intersections of Ahmedabad have been selected for the study based on selected criteria that have four Legged Signalized Intersection, Free Left Turning lane, Appropriate Approach Width, Vehicle Composition Variation, Flat Gradient, Nearby Buildings for Videography. Swastik intersection, C.G. road, Parimal intersection, Ushmanpura intersection, Ashram road selected as study approaches.

IV. DATA COLLECTION AND EXTRACTION:

All approach width of selected intersection, number of lanes and signal and cycle timing have been collected in inventory survey. Paldi approach, Gujarat university approach, stadium road, income tax approach has 3 lanes and 7.5-meter width, 2 lanes and 8.8-meter width, 2 lanes and 9.1-meter width, 3 lanes and 10-meter width simultaneously. Cycle time of these approaches are 115 second, 109 second, 109 second and 112 second in order. Videos were taken with the help of camera from the top of building near at the intersection. Traffic data collected at selected intersection include various parameters like steady recording of minimum 2 hours during peak period from suitable height with an aim to cover the entire intersection. More than one camera also used if suitable point is not available. With the help of the videography of the peak hours following traffic studies will be carried out. Traffic data collected at the intersection had encompass the various parameters like Traffic flow rate per cycle in veh/sec, Clearance time of vehicles. Camera was set in such a location from that whole clearance area of intersection and up to 10 meter from the stop line approach should be visible so that clearance time of straight and right turning movement can be counted.

The Data (classified vehicular volume and time occupancy measurement for individual vehicular category) is extracted manually by using Avidemux (version 2.6) Software from the recorded video. The Screen is marked by using the Screen Marker (Version 1.0.0.1) Software. To ensure accuracy vehicles were counted at five second interval and after completion of vehicle count for five seconds time occupancy of sampled vehicle for the same five seconds vehicles are measured. For the measurement of time occupancy (difference between the time when vehicle enters in the intersection from stop line and time when vehicle exit from the inter section from the stop line of exit approach) of vehicles video was rewind for every single vehicle reading. To ensure the validity of results, a representative and a statically accepted sample was chosen in which data of following vehicles were rejected and excluded from the analysis the vehicles which discharging from the queue before green signal start and Vehicles impeded by pedestrians or turning vehicles.

The data was recorded in to seven vehicle type namely Small car (car having four passenger capacity), Big car (car having more than four passenger capacity), Two wheeler, Three Wheeler, Light commercial vehicle (LCV), BUS, Heavy commercial vehicle (goods vehicles). To obtain the time occupancy of every individual vehicle from the video, in-time and out-time is noted. By these data set, time occupancy of individual vehicles is determined.

V. DATA ANALYSIS:

4.1 PCU CALCULATION:

Dynamic PCU are calculated for Parimal intersection using area occupancy method. Table given below shows the PCU calculation by area occupancy method at Parimal inter section for different vehicle category.

Green Phase	Calculated PCU by Area Occupancy Method						
	TW	Auto/ 3W	Small Car	Big Car	LCV	Bus	HCV
1	0.21	0.71	1.10		2.29		
2	0.20	0.75	1.09	1.74			
3	0.22	0.72	1.11		1.77		
4	0.20	0.75	1.17		2.29		
5	0.20	0.77	1.12		1.73		
6	0.21	0.78	0.96				
7	0.20	0.77	1.10				
8	0.19	0.69	1.11	1.93			
9	0.20	0.63	1.10	1.48		5.80	
10	0.21	0.82	1.14				

Table 1 Calculated PCU by AO Method

After comparing PCU values given by different researchers by using different methods following results are derived. Using time headway method PCU can be calculated for those vehicles who are coming successive at the approach. In mixed traffic condition like India only Two wheelers and small car coming successive one behind other so that PCU can be calculated for Two wheelers and Three wheelers only. With the regression method PCU cannot be evaluated for that vehicles, whose percentage are negligible compare to other vehicles. With the help of the time occupancy and area occupancy method PCU can be calculated for all category of vehicles inn specific time interval so these two methods can be used to find PCU of Vehicles in mixed traffic condition like India. From the comparison PCU values with different researchers PCU values derived by various methods it is clearly visible that Area occupancy is more helpful in mixed traffic condition, so the PCU of other approaches are calculated with Area occupancy method.

4.2 FIELD DATA ANALYSIS:

Composition on selected approaches for individual vehicle type is given below:

0bseved average traffic composition at different approaches								
Approach number	Approach Width in meter	Composition %						
		TW	3W	SC	CB	LCV	BUS	Truck
1	7.5	68.74	11.25	15.80	2.51	1.08	0.36	0.24
2	8.8	68.19	12.96	16.10	1.18	0.52	1.05	0.00
3	9.1	71.74	12.84	12.29	1.65	0.55	0.73	0.18
4	10	37.50	41.94	6.94	2.22	2.78	8.33	0.28

Table 2 Traffic Composition

4.3 DESCRIPTIVE STATISTICS OF PCUS:

Vehicle Type	PCU			
	Maximum	Minimum	Average	Standard deviation
2W	0.31	0.18	0.21	0.018
3W	1.6	0.51	0.75	0.140
CB	1.55	1.07	2.02	0.164
LCV	3.11	1.23	1.92	0.338
BUS	6.5	1.23	5.73	0.815
TRUCK	8.8	2.3	4.47	0.994

Table 3 Descriptive PCUs of all approaches

4.4 HISTOGRAM PLOTS FOR PCUS OF DIFFERENT VEHICLE TYPE:

Histograms of different vehicular type is also plotted using MINITAB software for understanding the distribution of PCUs and is shown in Figure 21. Figure 21 revealed that there was little variability in the sample distributions of the variables used in this study to develop prediction models.

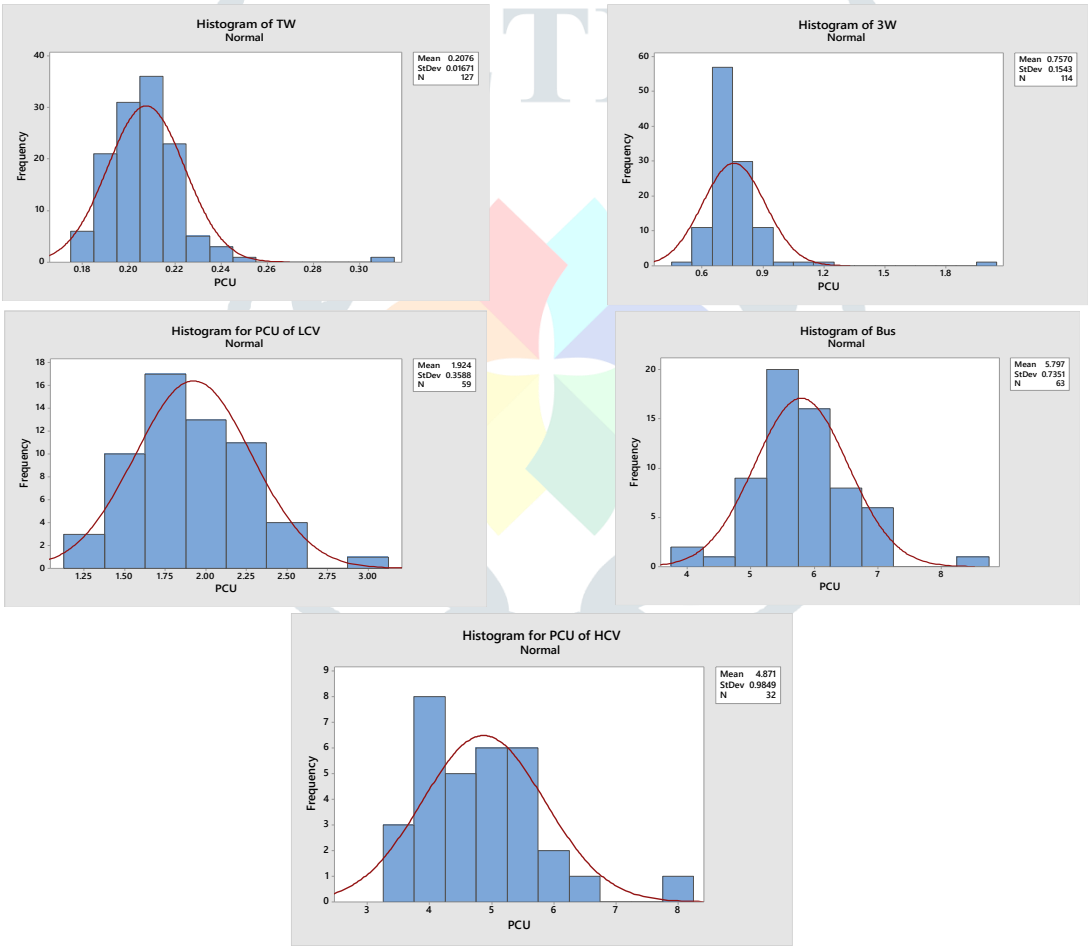

Figure 1 Histogram plots for different vehicle type

VI. MODEL DEVELOPMENT:

I.1 DEVELOPMENT OF SEF EQUATION BY REGRESSION TECHNIQUE:

Stream equivalency factor is the ratio of traffic volume in PCU per hour and volume in vehicles per hour. The stream stream equivalency factor is related to traffic composition and volume on a road. It is denoted by "K". Mixed traffic flow is often converted to equivalent flow in passenger car units (PCUs) by multiplying the number of each category of vehicles in the traffic stream by their respective PCU factors and then adding them up. PCU is a complex parameter and depends on multitude of factors. This is a simple method to convert a mixed traffic stream into a homogeneous equivalent without making use of PCU factors.

$$K = \frac{Flow\ in\ PCU\ per\ hour}{Flow\ in\ vehicle\ per\ hour}$$

A straight line relation with zero intercept (K should be zero for no flow condition) suggests the average value of K is 0.856. This is attributed to the varying traffic composition observed in different time intervals on different road sections. The K value will be higher for a traffic stream with high proportion of heavy vehicles and lower for a stream with high proportion of two-wheelers. Keeping in mind that the K value will depend on the proportion of traffic mix, a generalized equation relating K to the composition of traffic stream and traffic volume is developed using the multiple linear regression method. The mathematical form of this relation is given in Eq.

$$K = 1 + a_1 P_{cb} + a_2\, P_{HV} + a_3 P_{3W} + a_4 2_W + a_5 \frac{1}{N}$$

Equation 1

Where, Pcb = proportion of big cars in the traffic stream, Phv = proportion of heavy vehicles in the traffic stream, P3w = proportion of three-wheeler in the traffic stream, P2w = proportion of two-wheelers in the traffic stream, N = total flow in vehicles per hour.

The proportion of standard cars (Pcs) is not kept in the previous equation to avoid the problem of collinearity. The regression coefficients are a1–a5 and their values as estimated from field data.

After taking the proportion of 2W,3W, Big car, LCV, BUS, Truck and 1/N as independent parameter and K value as dependent variable for regression with 95% confidence level in excel following equation was generated. Summary output of regression P values of all independent variables are smaller than 0.05 for 5% level of significance, so that all variables are significant in the model. Coefficient of determination R – square value and adjusted R – square value of this model are 0.8759 and 0.8740 which shows that there is high correlation between independent and dependent variables.

$$K = 1 - 0.0073\, P_{2W} - 0.0047\, P_{3W} + 0.0020\, P_{CB} + 0.0047\, P_{LCV} + 0.0471\, P_{Bus} + 0.0337\, P_{Truck} + 0.2371\, \frac{1}{N}, R^2 = 0.92$$

Equation 2

Where, K = stream equivalency factor, P2W, P3W, PCB, PLCV, PBUS, PTRUCK are the percentage of 2W, 3W, CB, LCV, BUS and Truck, N is flow of the approach in veh/sec.

5.2 EFFECT OF TRAFFIC COMPOSITION AND VOLUME ON SEF:

It has been mentioned earlier that the Stream Equivalency Factor (K) depends on vehicles composition and traffic flow at the approach. The given Figure illustrates the variation of K for various vehicular traffic compositions at the study approaches. Proportions of one category of vehicles (small car) were kept constant at 25% and proportions of other Six categories of vehicles were varied in a complementary manner. In addition, different trend lines were drawn based on increasing two-wheeler proportion (increment) and decreasing heavy vehicles proportion (reduction) simultaneously in Figure. It is observed that K value is comparatively lower at higher flow values. K value is almost steady when flow is more than 3500 vehicles/h as shown in below figure. However, the percentage of error of K has reduced with the rise of flow rate. The proportion of the heavy vehicles increased the percentage of error of K, although an opposite trend is observed in the case of the two-wheelers.

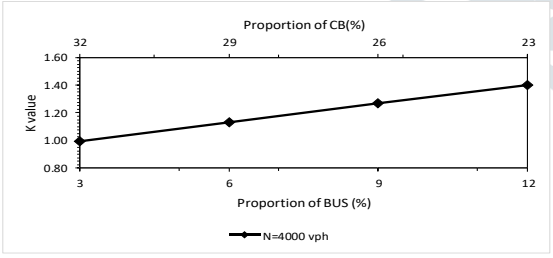

Figure 2 Effect of heavy vehicle proportion on K

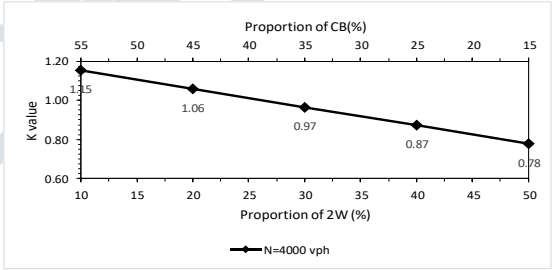

Figure 3 Effect of Two wheelers on K

I.2 MODEL VALIDATION:

Regression Statistics	
Multiple R	0.935913
R Square	0.875933
Adjusted R Square	0.874087
Standard Error	0.171706
Observations	952

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	196.7042	28.100606	953.1192	0
Residual	945	27.86123	0.0294828		
Total	952	224.5655			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2W	-0.0073	0.0002	-45.4982	0.0000	-0.007570212	-0.00694	-0.00757	-0.00694
3W	-0.0047	0.0004	-11.1267	0.0000	-0.005551529	-0.00389	-0.00555	-0.00389
CB	0.0020	0.0005	3.7107	0.0002	0.000949749	0.003082	0.00095	0.003082
LCV	0.0047	0.0012	3.9225	0.0001	0.002329343	0.006994	0.002329	0.006994
Bus	0.0471	0.0011	43.4014	0.0000	0.045013154	0.049277	0.045013	0.049277
Truck	0.0337	0.0018	19.1659	0.0000	0.030216197	0.03711	0.030216	0.03711
1/N	0.2371	0.1050	2.2595	0.0241	0.031174811	0.443109	0.031175	0.443109

Table 4 Summary output of model

R-squared (R^2) is a statistical measure that represents the proportion of the variance for a dependent variable that's explained by an independent variable or variables in a regression model and proportions range between 0 and 1. It is observed in Table 3. that R^2 value is closer to 1.

$$F\ 953.11 > F\alpha\ (p, n\text{-}p) = 2.02;$$

The null hypothesis is rejected if test statistic $F > F\alpha$ (p, n-p); the resulting F is significant. From the F distribution table with $F_{0.05}$, for p = number of independent variables and n = sample size.

The P value (*Sig*), which indicates the meaningful level to obtained coefficient for the model parameters. Generally, variables with *Sig* value of less than 0.05 are statistically meaningful in the model. For this model, parameters were found significant therefore it is statistically good.

VII. CONCLUSION:

This research proposes a new procedure for converting a heterogeneous traffic stream in to a homogeneous traffic stream by employing SEF instead of PCU values of individual vehicle types. Field data collected by videography at signalized intersection from the different location of Ahmedabad and Baroda region for deriving the relation between SEF and traffic composition and volume on road. The data extraction done by AVIDMUX software and speed data collected from video for each category of vehicles in stream is collected in excel sheets. The models developed in this study for SEF of vehicle are applicable to six-lane and four-lane divided urban roads. The effect of curvature and gradient will be different on the speed of cars and other categories of vehicles, and hence K-value for a traffic stream under the influence of these factors may be different and needs to be explored. Similar models may be attempted for other categories of roads also and variation in SEF with road width may be examined in future studies. The research data used to present a generalized method to obtain the value of SEF for any combination of vehicle categories and for any traffic volume on the road. The proposed method is simple and can be used to convert nonhomogeneous traffic stream volume measured in vehicle per hour to equivalent volume in PCU per hour without making use of PCU factors.

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