ARPN Journal of Engineering and Applied Sciences

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THE DEVELOPMENTOF A PREDICTION MODEL OF THE PASSENGER CAR EQUIVALENT VALUES AT DIFFERENT LOCATIONS

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ABSTRACT

This article is focused on determining the Passenger Car Equivalent (PCE) values at different location that divided into road segment and locus. The PCE values are needed to analyse the traffic flows of roads in mixed traffic condition, and differing geometric or environmental conditions. Traffic conditions consist of type and dimension of vehicles, number and percentage of vehicles, time headway, speed and delay. Generally, environmental condition is discussed together with the geometric. These conditions are related to types of road, alignment, characteristics of lanes, design speed, road surface, weather, roadside activities (pedestrians walking and crossing, traders, parking, buses stopping, and slow vehicles). This study aims to develop the model of the PCE values at different segment and locus, and to find the significance of the differences of those values. The basic hypothesis is that the difference will be significant if too different conditions of locations, but it will not be significant if nearly the same conditions. This study is part of the research carried out at nine urban road segments in three cities in Indonesia. Each road segment was divided into four loci corresponding to the locations of camcorder, namely Locus B (before), Locus Z (at zebra crossing), Locus A (after) and Locus O (outside area). The PCE values were analysed by using multi linear regression model that consist of the speed ratio, dimension ratio, percentage of vehicle ratio, and side friction factoras independent variables. Finding so far shows that the standard deviation is nearly same each locus, but there is very noticeable difference each road segment. This is indicated that group data per locus tend to have the same or insignificant difference mean, while group data per road segment, either same or different mean is possible occurred.

Keywords: passenger car equivalent, location of survey, significant difference.

INTRODUCTION

Generally the performance of each vehicle influences the performance of the traffic stream in terms of road capacity, traffic congestion and air pollution (Sugawara, 1995; Ajgaonkar, 1974). Lee (2007) wrote that motorcycles can be travelling alongside other vehicles in the same lane, following in an oblique position, with a small gap and a short time headway compared to vehicles which influence the performance of other vehicles in the stream. Traffic conditions are measured in terms of average flow, speed, etc., and traffic analysis for mixed traffic is conducted by comparing values of different vehicles, with a passenger car as the standard vehicle. The vehicular unit is named a Passenger Car Unit (PCU), and the conversion value is Passenger Car Equivalent (PCE) (TRB, 2000).

Many factors have been used in PCE analyses, such as time headway, speed, traffic flow, and the percentage of trucks. Vehicle percentage is sometimes used together with time headway, delay or speed, and vehicle size is used together with speed, to anticipate if there are similar speed values between two different vehicles of different sizes (Craus *et al*., 1980). This research was conducted in some cities of Indonesia that used the vehicle speed as the main factor to determine the value of PCE. It was because generally the impact of different condition of roads (including physical road side facilities) would be directly felt by driver on the vehicle speed (fast or slow moving). Also, it was difficult to define and measure headways in Indonesia, where motorcycles could create unique movement patterns and had a high percentage, and low awareness of drivers on discipline of the traffic lane.

This article is part of author research that aimed to determine the effect of physical facility of ZoSS (Zona Selamat Sekolah or School Safety Zone) to the PCE values for mixed traffic condition in several road segments of Indonesian urban road. Indonesian mixed traffic conditions are related to the high proportion of motorcycles and the presence of non-motorised in traffic flow and various roadside activities. Beside different road segments, each segment was divided into four loci with different condition. Therefore, this article aims to determine the PCE values at different segment and locus, and to find how significant the difference.

PASSENGER CAR EQUIVALENTS

Factor affecting passenger car equivalent (PCE)

PCE values are also used to analyse the performance of road network in term of road segment capacity and intersections saturation flow. There are similar factors affecting PCE values and road capacity or saturation flow, such as vertical and horizontal alignment, lane width, shoulder width, traffic conditions and side friction conditions. For road capacity, traffic condition is viewed in terms of traffic distribution per direction, but for intersections, saturation flow is viewed in terms of percentage of turning movement (DGoH 1997).

Therefore, the factors affecting passenger car equivalent can be classified into three conditions (Hidayati, 2013):

1) Traffic conditions, such as vehicle type and size, number and percentage of vehicles and non-passenger cars, time headway, speed and delay.

2) Geometric conditions, such as number and width of lanes, directional distribution, length and percentage of grade, alignment, width of kerbs and shoulders, and median and highway access.

3) Environmental and general conditions, such as weather, surface of pavement, number of pedestrians walking, parking areas, bus stop facilities, road markings and traffic signal. These factors not only affect passenger car equivalents but also influence capacity and saturation flow

Methods for measuring passenger car equivalents

Many methods have been used to determine passenger car equivalent values, including the time headway ratio method, delay method, speed method, flow rate or volume method, and travel time method.

Generally, time headway method is based only on time headway parameter. The composition of vehicle type *i*(e.g. passenger car, truck, bus, and motorcycle)is used in the model to make the result more accurate if there are different compositions in the traffic stream. Rongviriyapanich and Suppattrakul (2005) have made variations to the headway method related to the position of motorcycles in traffic flow. There was a relationship between delay method and speed method, where both of them are related to the travel time.

The following presentation showsexamples of equations that can be used to calculate the PCE values each method.

1) Time headway ratio method

Kimber *et al.* (1985) defined the time headway method of measuring the PCE of trucks as the ratio of the average time headway of the type of vehicle *i* and the average time headway of a car (see Equation.1). They researched the PCE values of motorised vehicles at two-phase signalised intersections and used the traffic flow variables, the percentage of vehicles, the time headway, saturation flow, and traffic signal settings in their analysis.

$$PCE_h = \frac{\bar{h}_{LV-i}}{\bar{h}_{LV-LV}} \qquad (1)$$

Where, $\bar{h}_{LV-i}$is the mean time headway between a passenger car and another vehicle type i, while $\bar{h}_{LV-LV}$ is the mean time headway between two successive passenger cars.

On the other hand, Craus *et al.* (1980) modified this method by using the ratio of the time headway reduced by the proportion of cars and then comparing it with the proportion of other vehicles (trucks) (see Equation.2).

$$PCE_{(h)Tr} = \left(\frac{\bar{h}_v}{\bar{h}_{LV}} - P_{LV}\right) \Big/ P_{Tr} \qquad (2)$$

Where, $\bar{h}_v$ is average time headway for all vehicle type samples, $\bar{h}_{LV}$is average time headway for passenger car only sample, $P_{LV}$is proportion of passenger cars, and $P_{Tr}$is proportion of trucks.

2) Delay method

Craus *et al.* (1980) defined the delay time method of the PCE of truck as the ratio of average delay time caused by one truck in the stream and the average delay time caused by one passenger car (see Equation. 3). They researched the PCE values of trucks and buses of two-lane rural highways. They made three assumption on their analysis: each direction traffic was in free flow condition; the main traffic flow was balanced, and the opposing direction had a relative speed equal to the sum of the average speed and the speed of the overtaken vehicle; and passing manoeuvres were responsive to opposite traffic speed. Although, this method was also affected by traffic volume and percentage of heavy vehicles, so that it can be defined as "the ratio of delay caused by a heavy vehicle to the delay of a car in an all-passenger car traffic stream" (Benekohal and Zhao 2000).

$$PCE_{(d)Tr} = \frac{\bar{d}_{Tr}}{\bar{d}_{LV}} \qquad (3)$$

3) Speed method

Referring to the general equations of the time headway method Equation. (1) and the delay method Equation. (3), the speed method of measuring the PCE also can be defined as the ratio of two different average speed values as in Rahman and Nakamura (2005) who determined the PCE values of non-motorised vehicles using Equation.(4).

$$PCE_{(V)UM} = 1 + \frac{V_b - V_m}{V_b} \qquad (4)$$

Where, $PCE_{(V)UM}$is the passenger car equivalent of non-motorised vehicles based on speed of vehicle, while V_b is the average speed of passenger cars in the base flow (km/h), and V_m is the average speed of passenger cars in the mixed flow (km/h)

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4) Flow rate method

The following equations can be used to estimate the PCE value based on flow rate:

$$q = \sum_{i=1}^{n} q_i PCE_i \quad (5)$$

Where, q is the flow rate in PCU/hour, q_i is the flow rate of vehicle type i per hour, and PCE_i is passenger car equivalent for vehicle type i.

DATA COLLECTION

Type of data

There are two types of data used in the analysis: first data is any information relating to the study obtained from another party. These data include:

1) Information of road segments with School Safety Zone (ZOSS) facility and evaluation report of its implementation.
2) Percentage of each vehicle, average speed, road performance, and number of accidents in Indonesia.
3) Vehicle composition and number of accidents in several developing countries.
4) Other supporting data (such as: type of road, and city population)

The other data refers to any information collected through the field study in Indonesia. This data include:

1) Geometry (i.e. type of road, width of road, length of ZOSS area, and the distance between two camcorders).

2) Environment (i.e. type of land use, road markings, traffic signs).

3) Number of vehicles passing through the road segments.

4) Frequency of side friction items (i.e. pedestrian, vehicle stopped, vehicle in/out of side road, and street vendors).

5) Start and end time of sample vehicles passing through the marked areas using double lines on the road.

Main survey

Collection data was conducted at nine (9) road segments with ZoSS facilities located in Surakarta (2 segments), Yogyakarta (4 segments) and Sragen (3 segments). Each segment would be divided into four loci based on the condition of ZoSS facilities, and each locus equipped with a camcorder. First locus is named Locus O (outside of ZOSS), locus 2 is called Locus B (before zebra crossing), locus 3 is Locus Z (at zebra crossing), dan last locus is named Locus A (after zebra crossing).

ZOSS areas are operated only at certain times of the day, i.e. at the beginning and end of the school activities. Both times are during peak hour sessions. In order to know the traffic pattern out of ZOSS operation time, this study has also collected data on off-peak hour. In this case, the survey time during 10:00-12:00 was considered as off peak hour time. Based on this matter, the data during off-peak hour can be considered as a comparison of data on peak hour. Therefore, the survey was carried out in wo sessions of 06:00-08:00 and 10:00-14:00.

The activities of main survey was divided into two steps, i.e. recording data at the site area, and transferring it into the laptop and/or removeable disk then compiling the data into Tables.

ANALYSIS OF PASSENGER CAR EQUIVALENT

As mentioned before, this article is part of the author's study related to passenger car equivalent values. The whole analysis consisted of: side friction analysis (Hidayati *et al*, 2012), speed analysis, flow rate analysis, and model of passenger car equivalent analysis. This article will only present the result of PCE analysis based on regression analysis.

Modified speed method

The method used in the PCE analysis is called modified speed method. It means beside the main parameter of speed of vehicle, the model would also used another independent variables. Even though the basic method will use the speed ratio between vehicle types i and car, the model would also used other independent variables. This method was divided into two steps of analysis, which were finding the PCE values each model and validating the result using the ANOVA. Figure-1 describes the process of the first step. In the first step, the analysis used the PCE value of vehicle type i from the Indonesian Manual (IHCM) o as an initial value (E_i^0) of dependent variable. The manual has classified the PCE values into only four types which are light vehicle, heavy vehicle, motorcycle and non-motorised vehicle (DGoH, 1993). While this study has divided vehicles into ten types. Therefore, ten values will be derived from the four values.

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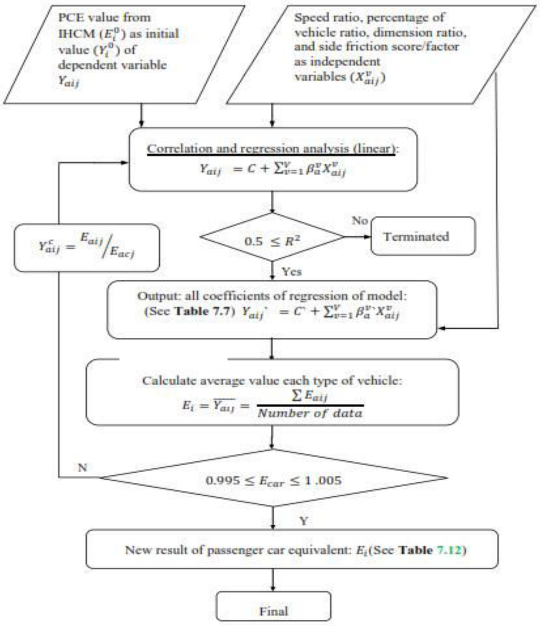

Figure-1. Regression analysis process (Hidayati, 2013).

The model and values of PCE

This model combined the speed ratio with other ratios, including dimension ratio, percentage of vehicle, and side friction factor. These independent variables v will be used as X_{aij}^v, while the PCE values each vehicle type i of IHCM will present as dependent variable Y_i^0. In general form, the basic equation for this model can be written as

$$Y_{aij} = C + \sum_{v=1}^{V} \beta_a^v X_{aij}^v \qquad (6)$$

Where,

Y_{aij} Dependent variable vehicle type i at location a, during time period j represented the value of E_{aij} with initial value Y_i^0 taken from IHCM, $\overline{Y_{aij}}$ is the average value of the $Y_{aij}`$ model, and Y_{aij}^c is the new value for the next iteration

Y_{aij} Independent variable v of vehicle type i, at location a, during time period j, for example in this model X_{aij}^0 is constant, X_{aij}^1 is R_{aij}^V, X_{aij}^2 is R_i^A, X_{aij}^3 is R_{aij}^P and X_{aij}^4 is F_{faj}^t

β_a^v Coefficient of regression each variable v at location a

Based on equation 6 and by using SPSS 19, the PCE values each location and each type of vehicle can be seen in Table-1.

Table-1. Passenger car equivalent values - final iteration, average per type of analysis (Hidayati, 2013).

Type of analysis	E_{1j}	E_{2j}	E_{3j}	E_{4j}	E_{5j}	E_{6j}	E_{7j}	E_{8j}	E_{9j}	E_{10j}
1.1. Analysis per location all vehicles, Separate analysis per road segment	1.00	1.01	1.15	0.40	0.96	1.14	1.43	1.44	0.91	0.86
1.2. Analysis per location all vehicles, All roads together	1.00	0.97	1.15	0.62	0.93	1.13	1.58	1.51	0.94	0.89
2.1. As No. 1.1 without MC-3W, Big Bus and Big Truck	1.00	1.00	1.18	0.44		1.17			0.90	0.84
2.2. As No. 1.2 without MC-3W, Big Bus and Big Truck	1.00	0.93	1.25	0.52		1.22			0.91	0.84
3.1. Separate analysis per locus per road segment all vehicles (Locus O)	1.00	1.02	1.16	0.38	0.96	1.14	1.43	1.41	0.91	0.86
3.2. Separate analysis per locus per road segment all vehicles (Locus B)	1.00	1.01	1.17	0.39	0.96	1.15	1.43	1.42	0.90	0.86
3.3. Separate analysis per locus per road segment all vehicles (Locus Z)	1.00	1.00	1.17	0.41	0.92	1.16	1.51	1.43	0.93	0.86
3.4. Separate analysis per locus per road segment all vehicles (Locus A)	1.00	1.02	1.08	0.38	0.94	1.14	1.35	1.42	0.91	0.87
4.1. Analysis per locus all roads together all vehicles (Locus O)	1.00	0.95	1.17	0.69	0.94	1.15	1.65	1.57	0.97	0.92
4.2 Analysis per locus all roads together all vehicles (Locus B)	1.00	0.96	1.16	0.69	0.92	1.13	1.63	1.43	0.97	0.92
4.3 Analysis per locus all roads together all vehicles (Locus Z)	1.00	0.95	1.15	0.68	0.91	1.15	1.63	1.56	0.97	0.91
4. 4 Analysis per locus all roads together all	1.00	0.97	1.15	0.62	0.89	1.13	1.56	1.50	0.93	0.89

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vehicles (Locus A)										
Indonesian Highway Capacity Manual	**1.00**	**1.00**	**1.00**	**0.25***	**0.25**	**1.00**	**1.20***	**1.20***	**0.80**	**0.80**

Note: *) the PCE value is 0.40 of motorcycle and 1.30 of heavy vehicle for low traffic flow (uncongested condition)

Analysis of variance (ANOVA)

Gray and Kinnear (2012) stated ANOVA is a multivariate analysis technique which functions to distinguish an average value of more than two groups of data by comparing their variance value. Before doing the analysis of variance, there are a few things need to be considered, i.e. 1) sample should be an independent group, 2) variants between groups should be homogeneous, and 3) data within each group has normal distribution.

The principle of ANOVA is to analyze the variability of the data into two sources of variation, namely: variation within groups (within) and between groups (between). If the variation of within and between group is the same, it means that there is no difference in the effect of the intervention, or in other words there is no difference between both means compared. Conversely, if the variation between groups is greater than the variation within the group, it means the intervention has an effect.

There are two types of ANOVA-One Way and Two Way ANOVA-that associated with the number of factors used in the analysis. This study compared the value of passenger car equivalent calculated in different locations and loci. As mentioned previously this study used ten types of passenger car equivalent values, but in this section each value will be analyzed separately.

The output of ANOVA analysis can be seen in Table-2. This table shows a summary table of ANOVA including sum and mean of square each type of variance, degree of freedom of between and within group, and the F value. Between group type of variance means the test is used only under one condition and is not a pairing the scores. For example, Type 1 is used only for Locus that consists of four loci, whilst Type 2 is used only for Location of nine road segments. For within group, the test is used for all values in the analysis, such as Type 1 is all values of separate analysis per locus of four loci per road segment of nine roads. Table-2 is used to determine whether there are differences in the values from each type of analysis. If the P-value of ANOVA table is less than the significance level (0.05), then it can be stated that the null hypothesis (H0) is rejected. It means there is a significant difference between the mean of the PCE values each group. As mentioned before, the ANOVA is only valid for homogeny variances, therefore, among three type of analysis (Type 1, Type 3, and Type 5) only Type 5 or pair of Analysis-Location has different mean of values. After finding this result, there is another test needed to be done for Type 5, namely Post Hoc Test.

Post Hoc Test is done to determine which groups have pairwise differences following the one-way ANOVA test. Before this test will be done, there is one step that needs to be clarified, which is to check whether the values of the variants are same or not. As mentioned earlier, the variant of Type 5 is same, therefore Duncan and Tukey are chosen as Post Hoc Tests that presented in Table-3. This table shows means of the PCE values of motorcycles that classified in three classes as subset. In addition, this table also shows the number of each type of data for analysis.

Table-2. Parameter of ANOVA process (Hidayati, 2013).

Type of analysis	Type of variance	Sum of squares	d_f	Mean square	F	Sig.
G_3-G_2, Locus, Motorcycle, Separate Analysis per Locus per Road All Vehicles	Between Groups	0.008	3	0.003	1.016	0.399
	Within Groups	0.084	32	0.003		
	Total	0.092	35			
G_2-G_3, Location, Motorcycle, Separate Analysis per Locus per Road All Vehicles	Between Groups	0.067	8	0.008	8.779	0.000
	Within Groups	0.026	27	0.001		
	Total	0.092	35			
G_3-G_2, Locus, Motorcycle, Analysis per Locus All Roads Together All Vehicles	Between Groups	0.032	3	0.011	1.126	0.353
	Within Groups	0.307	32	0.010		
	Total	0.340	35			
G_2-G_3, Location, Motorcycle, Analysis per Locus All Roads Together All Vehicles	Between Groups	0.287	8	0.036	18.284	0.000
	Within Groups	0.053	27	0.002		
	Total	0.340	35			
G_1-G_2, Data for Analysis,	Between Groups	1.044	7	0.149	15.592	0.000

Motorcycle	Within Groups	0.612	64	0.010		
	Total	1.656	71			
G_2-G_1, Location, Motorcycle	Between Groups	0.158	8	0.020	0.829	0.581
	Within Groups	1.498	63	0.024		
	Total	1.656	71			

Based on Table-3, it can be seen that both methods (Tukey and Duncan) have more than one group located in the same column or subset. The first subset is intended for the groups with the low values, whilst the third subset is for intended for the groups with the high values. Besides that, there is a second subset that intended for the middle value between the first and third subset. The results from the Tukey method have five groups in the first column/subset, two groups in the second and three groups in the third. The range of means values are 0.3811-0.5144 for low value, 0.5155 - 0.6167 for the middle value, and 0.6167-0.6944 for high value.

Nevertheless, it can be seen that the means values in the second subset are also in the first and/or third subset. Therefore, based on Tukey's method, the groups can be classified in two subsets as low and high values. Similarly, the results from the Duncan method has four groups in the first column (range 0.3811-0.4433), two groups in the second (range 0.4433-0.5144), and three groups in the third (range 0.0.6167-0.6944). Based on the position of homogeneous subsets, it can be stated that groups of mean in the same column has same values or insignificant difference, and in the opposite the different column has significant difference of mean. For example, group of data per locus that used separately at Locus O (0.3811 of G_{131}) is same with at Locus Z (0.4144 of G_{133}), but both values are different from data all location used together in the analysis (0.6944 of G_{141} and 0.6789 of G_{143}).

Although not all types of above analysis produce the significant difference in the mean of group, but based on the R-square (see Table-7.9) it can be concluded that Model 1 can be used to determine the PCE values.

Table-3. Homogeneous subsets.

Type of data for analysis (G_1)		N	**Subset** (Means of the PCE values of motorcycles)		
			1	**2**	**3**
Tukey HSD[a]	G_{131}	9	0.3811		
	G_{111}	9	0.3989		
	G_{133}	9	0.4144		
	G_{121}	9	0.4433		
	G_{122}	9	0.5144	0.5144	
	G_{112}	9		0.6167	0.6167
	G_{143}	9			0.6789
	G_{141}	9			0.6944
	Sig.		0.0910	0.3560	0.6950
Duncan[a]	G_{131}	9	0.3811		
	G_{111}	9	0.3989		
	G_{133}	9	0.4144		
	G_{121}	9	0.4433	0.4433	
	G_{122}	9		0.5144	
	G_{112}	9			0.6167
	G_{143}	9			0.6789
	G_{141}	9			0.6944
	Sig.		0.2250	0.1280	0.1160

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 9.

CONCLUSIONS

The recommended model that has been chosen from this study for estimating the passenger car equivalent values follows the following formulation:

$$E_{aij} = C + \beta_a^1\left(\frac{V_{aij}}{V_{acj}}\right) + \beta_a^2\left(\frac{A_i}{A_c}\right) + \beta_a^3\left(\frac{P_{aij}}{P_{acj}}\right) + \beta_a^4(F_{faj}^t)$$

where, E_{aij} is the PCE value for vehicle type *i* at location *a*, during time period *j*, and β_a^v is the coefficient of regression each variable *v* at location *a*. The speed ratio $\left(\frac{V_{aij}}{V_{acj}}\right)$percentage of vehicle ratio $\left(\frac{P_{aij}}{P_{acj}}\right)$, dimension ratio $\left(\frac{A_i}{A_c}\right)$, and side friction factor (F_{faj}^t) are independent variables of vehicle type *i*, at location *a*, and during time period *j*.

According to Homogeneity and Post Hoc Test, only Type 7 (Group of Analysis-Location) has different mean PCE values, and the values between Type 1.1 (G_{111}) and Type 1.2 (G_{112}) were located at different column. This means that using separated data per location in the analysis has generated different mean PCE values to that using data from all nine segments together. Therefore, this study recommended the model that analyse data separated by location, not by locus.

ACKNOWLEDGEMENTS

The first author would like to thank the Directorate General of Higher Education (DGHE) of the Ministry of National Education of Indonesia that has provided the funding of this study and also to Universitas Muhammadiyah Surakarta (UMS) for their support.

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