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PASSENGER CAR EQUIVALENTS IN UNCONGESTED FLOW REGIME FOR LEVELLED, STRAIGHT MOTORWAY SECTION.

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A macroscopic method of estimating Passenger Car Equivalent for uncongested flow regime has been discussed. Straight line Greenshield's model of traffic flow has been considered for uncongested flow regime. For a two lane (each direction) motorway section, the Passenger Car Equivalent is first estimated for each lane and also for day and night time conditions separately. By using the distribution of flow and the percentage of heavy vehicle by lane, the Passenger Car Equivalent is calculated for the whole roadway section in one direction. The result for day time and for the night time conditions has also been compared.

1. INTRODUCTION

The heavy vehicles reduce the total number of vehicles that can use the motorway system. The effect of heavy vehicles in the traffic stream can be evaluated by estimating the reduction in total number of vehicles due to the presence of heavy vehicles. In the macroscopic model of traffic flow, the effect of heavy vehicles can be described by the effect in the flow rate. From the estimated effect, Passenger Car Equivalents (PCE) of the heavy vehicle can be calibrated.

The concept is thus to estimate PCE by comparing flow rate without heavy vehicles (basic flow) and flow rate with certain percentage 'p' of heavy vehicles (mixed flow) at *similar traffic flow conditions.* As the capacity analysis procedures are based on Level of Service (LOS) concept, the traffic flow conditions are considered to be similar at same level of service. The basic equation of Highway Capacity Manual (HCM)[1] with the same notations is rewritten as,

$$SF_i = MSF_i \times N \times f_w \times f_{HV} \times f_p$$

Applying the number of lanes, lane width and other factors, if q_B is the flow rate per lane with LOS_i for ideal condition (basic flow) and q_M is the flow rate per lane with same LOS_i for mixed flow condition with percentage 'p' of heavy vehicles, then,

$$q_M = q_B \times f_{HV}$$

$$f_{HV} = \frac{1}{1 + p(PCE - 1)}$$

where, f_{HV} is the heavy vehicle factor. The PCE value can be calculated as,

$$PCE = \frac{1}{p}\left(\frac{q_B}{q_M} - 1\right) + 1 \quad ...eq.(1)$$

The macroscopic estimation of PCE from this concept is generally accepted, but there seems to be no general agreement on what condition is to be applied at which the two flow rates q_B and q_M produce the same level of service. There have been different approaches suggested. As discussed by Sthapit and Okura[3], Huber[2] suggested equal average speed or equal density criteria. In equal average speed criteria, the difference in flow rate for basic and mixed flow is measured at equal average speed for both cases and hence the difference in two flow rate is due to the difference in density alone. Conversely, in equal average speed criteria, the difference in two flow rates is due to the difference in speed alone. But more practically, the difference in flow rate due to the presence of heavy vehicles is

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caused by the reduction in average speed (heavy vehicles travel with lower speed) as well as change in density.

As shown in Fig.1, considering two traffic flow streams, one with passenger cars only and the other with mixed vehicles, the free flow speed, the capacity or the jam density of mixed stream will never reach to the free flow speed, capacity or jam density of passenger car stream. Now, the assumption is that a mixed vehicle in mixed stream at free flow condition will feel the same level of service as that of a basic vehicle in basic vehicle stream at free flow condition. So is the case at jam condition and capacity condition. This assumption as shown in Fig.2, implies that the level of service in passenger car stream and in mixed stream are identical when the normalized density as well as the normalized speed of the two flows are equal.

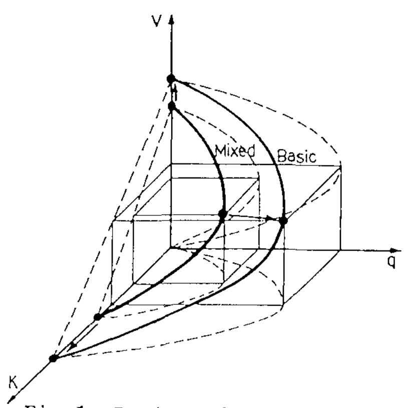


Fig.1, Basic and Mixed Streams

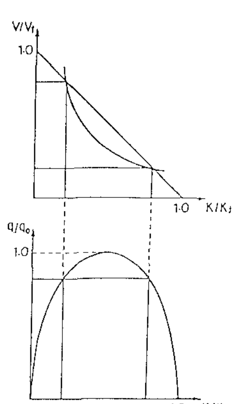


Fig.2, Normalized Flow

Thus,

$$\frac{k_B}{k_{jB}} = \frac{k_M}{k_{jM}} \; ; \quad \frac{U_B}{U_{FB}} = \frac{U_M}{U_{FM}}$$

$$or, \; \frac{k_B}{k_M} = \frac{k_{jB}}{k_{jM}} \; ; \quad \frac{U_B}{U_M} = \frac{U_{FB}}{U_{FM}}$$

Therefore from eq.1,

$$PCE = \frac{1}{p}\left(\frac{U_B\,k_B}{U_M\,k_M} - 1\right) + 1$$

$$= \frac{1}{p}\left(\frac{U_{FB}}{U_{FM}}\,\frac{k_{jB}}{k_{jM}} - 1\right) + 1$$

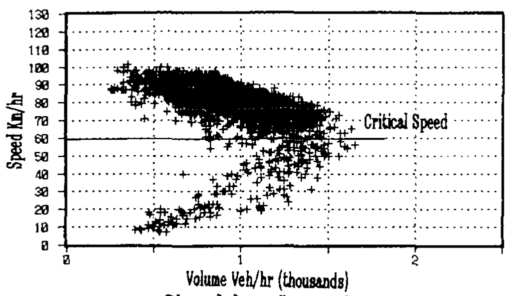
$$\therefore PCE = \frac{1}{p}\left(\frac{q_{oB}}{q_{oM}} - 1\right) + 1 \qquad \text{...eq.(2)}$$

2. DATA

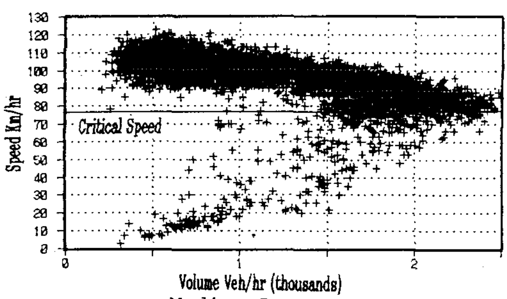
The vehicle detector data from Tomei Expressway with two lanes in each direction has been used. The data used is for the year 1990 and months of July, August and September. The site considered has almost ideal geometric conditions with horizontal curvature of radius 5000 m. and no vertical grade. The data includes 5 min. average of flow, percentage of heavy vehicles, occupancy and speed. Examining the scatter diagram, a significant difference in the pattern of scatterness in weekdays and holidays data was observed. So the data for weekend and the national holidays have been removed. Similarly, considerable difference was observed for the case of day time and for night time, as well as by lane. So the data was divided into four groups; day time median lane (will be named 'lane2 day' here after), day time shoulder lane (will be named 'lane1 day' here after), night time median lane (lane2 night) and night time shoulder lane (lane1 night). The scatter plots of q-v are shown in Fig.3. for the respective cases.

For each group, the data is further divided into several classes (about 12-15 classes) according to the percentage of heavy vehicles. The number of data in each class varied from 700 to 1300 points of 5 min. average. The data includes maximum upto 50-60% of heavy vehicles for day time conditions, where as for night time condition a full range upto 90-100% is also available.

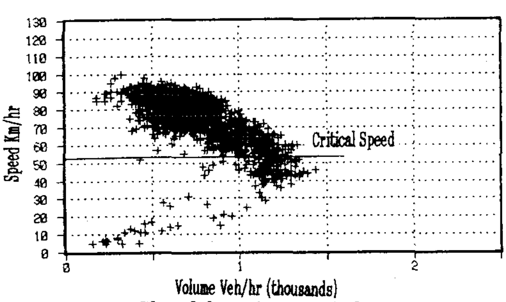
The interval of each class is not uniform and is chosen such that the number of data in each class does not differ much. After checking the results, it was found that some overlap between two classes was possible in order to increase the number of classes.



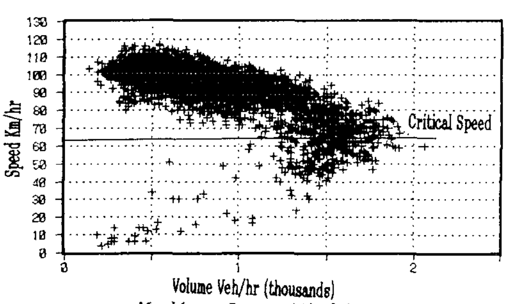
Shoulder Lane Day



Median Lane Day



Shoulder Lane Night



Median Lane Night

Fig.3, Scatter Plot of q-v

After examining the scatter plots of q-v, k-v, and k-q, proper critical speed value is chosen to separate the uncongested and the congested flow regime, as shown in Fig.3. *The data lying above this speed has been taken for analysis.* It may sometimes be necessary to consider the critical occupancy value as well depending on the nature of scatterness.

3. METHOD OF ANALYSIS

3.1 PCE by lane

To calculate the passenger car equivalent from eq.(2), the optimum flow rates for different percentage of heavy vehicle classes are estimated by regressing the data assuming Greenshield's model of traffic flow. Flow rate is regressed against speed to minimize the error in estimating flow rate and the relationship is of the form,

$$q = A * v + B * v^2$$

where, A and B are constants and q and v are flow rate and speed respectively. After obtaining the optimum flow rate for various percentage of heavy vehicle classes, the PCE value for each percentage of heavy vehicle class is obtained. The PCE values are calculated with same procedure for shoulder lane and median lane independently and for day and night time conditions separately.

3.2 PCE for whole roadway section

The notations used are,

Q = total volume for both lanes (veh/hr)
q_1 = volume in lane 1, shoulder lane (veh/hr)
q_2 = volume in lane 2, median lane (veh/hr)
P = percent of heavy vehicle for both lanes
p_1 = percent of heavy vehicle for lane1 alone
p_2 = percent of heavy vehicle for lane2 alone
PCE_d = directional PCE for whole roadway section corresponding to P
PCE_1 = PCE for lane 1 corresponding to p_1
PCE_2 = PCE for lane 2 corresponding to p_2
$Q = q_1 + q_2$
$P*Q = p_1*q_1 + p_2*q_2$

The passenger car equivalents for the whole roadway section in one direction, PCE_d, with total percentage of heavy vehicle, P (considering both lanes) is calculated as follows.

(a) Relationships between total percentage of heavy vehicles P to p_1 and p_2 are established as,

$$p_1 = a_1 P - b_1 P^2$$
$$p_2 = (a_1 - 1) P + b_1 P^2$$

from which p_1 and p_2 can be calculated for a known percentage P in one direction. The plot of P against p_1 is shown in Fig.4. for night time condition.

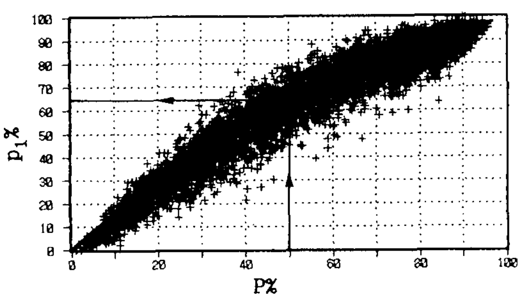


Fig.4, P vs p_1 Night Time

(b) The passenger car equivalents, PCE_1 for shoulder lane corresponding to p_1 and PCE_2 for median lane corresponding to p_2 are calculated independently as explained in section 3.1.

(c) PCE_d for the whole roadway section is then calculated from,

$$Q \times P \times PCE_d = q_1 \times p_1 \times PCE_1 + q_2 \times p_2 \times PCE_2$$

$$\therefore PCE_d = \frac{1}{P}\left[\left(\frac{q_1}{Q}\right) \times p_1 \times PCE_1 + \left(\frac{q_2}{Q}\right) \times p_2 \times PCE_2\right] \quad .eq.(3)$$

The values of q_1/Q and q_2/Q can be obtained from the plot of lane utilization rate against the total volume Q, Fig.5, (for day time condition) such that,

$$\frac{q_1}{Q} = \alpha \times Q + \beta \times Q^2 + \gamma = \left(1 - \frac{q_2}{Q}\right)$$

where, α, β, γ are cofficients.

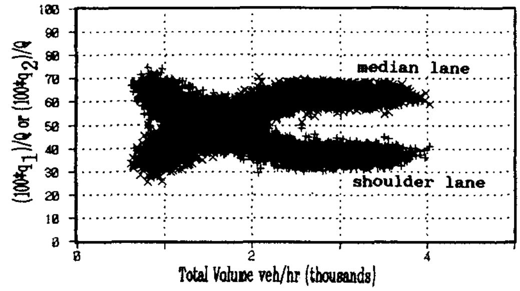


Fig.5, Distribution of Volume by lane

4. RESULTS AND DISCUSSIONS

4.1 PCE by lane

The site selected for the presentation of result is at 43.95 kilo-post from Tokyo and for inbound traffic coming in direction towards Tokyo. The distance from the nearest interchange is about 9 Km. which is at downstream of the site. The effect of geometry can be considered to be minimum. The horizontal curvature is of radius 5000 m. and there is no sharp horizontal curves in the vicinity of the site. The vertical terrain at the site is plain and there is a down grade of very mild slope (-0.3 %) at a distance of 500 m. upstream of the site and upgrade of +1.414 % at a distance of 200 m. downstream of the site.

The estimated optimum flow values and the calculated PCE values with respective to percentage of heavy vehicle for each lane with day and night time conditions are as shown in Fig.7. and Fig.8. respectively. The highest optimum flow is observed for lane 2 day followed by lane 2 night, lane 1 day and lane 1 night correspondingly. It is to be clear that these values of volume do not represent the maximum observed flow rate but are calculated from the regression analysis. The estimated optimum flow is the capacity obtained by the regressed line as shown in Fig.6. The data with percentage of heavy vehicle lower than about 5 % for day time and about 10 % for night time were very few. So, from the shape of the curves it was assumed that the values remain constant below this percentage of heavy vehicle. This resulted in a convergence of all curves towards 0 % of truck in Fig.8. where as the actual PCE may be slightly higher than shown in the figure around this range.

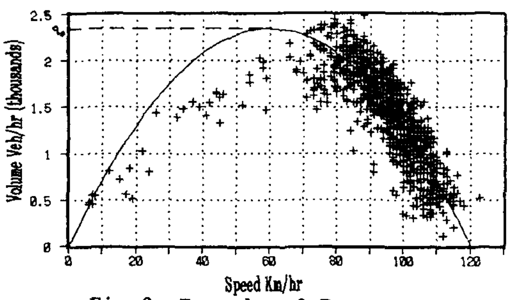


Fig.6, Example of Est. Capacity

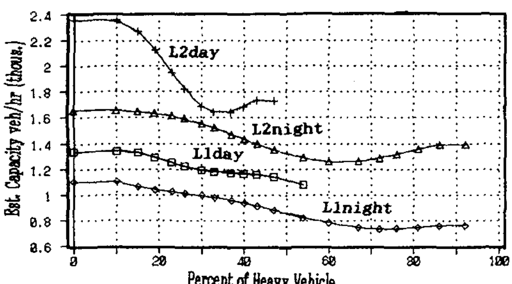


Fig.7, Estimated Capacity

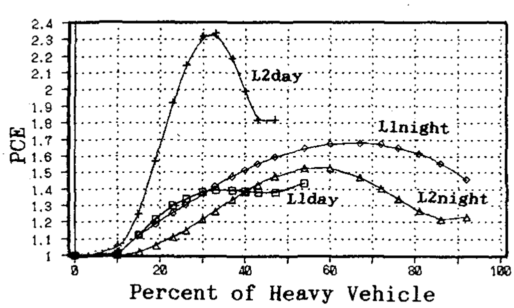


Fig.8, PCE Values

4.2 <u>PCE for whole roadway section</u>

The relationships between P and p_1 for day and night time conditions are given in eq.(4) and eq.(5) respectively.

$$p_1 = 1.5503458\ P - 0.0063598\ P^2 \qquad \text{...eq.(4)}$$
R squared = 0.90

$$p_1 = 1.5168218\ P - 0.0053925\ P^2 \qquad \text{...eq.(5)}$$
R squared = 0.94

Similarly, the plot of the lane utilization rate resulted eq.(6) for day time and eq.(7) for night time condition.

$$(100{*}q_1)/Q = 86.6 - 0.03154\ Q + 0.000004968\ Q^2$$
R squared = 0.82 ...eq.(6)

$$(100{*}q_1)/Q = 89.2 - 0.04077\ Q + 0.000008042\ Q^2$$
R squared = 0.74 ...eq.(7)

While obtaining eq.(4) through eq.(7) also, the data only in the uncongested flow regime has been taken. Moreover, when eq.(6) and eq.(7) were obtained separately for different percentage of heavy vehicle classes, the resulted equations for all classes were very close to each other and as the percentage of trucks changes, the maximum value of total flow rate available in each class also changes. Hence, eq.(6) and eq.(7) were obtained by combining the data for all available percentage of trucks.

Finally, PCE values for the whole roadway section are calculated from eq.(3) for day time and night time conditions separately. The PCE value against the total volume (both lanes) is shown in Fig.9. for day time and Fig.10. for night time condition. The percentage of heavy vehicle shown is also a total for whole roadway section.

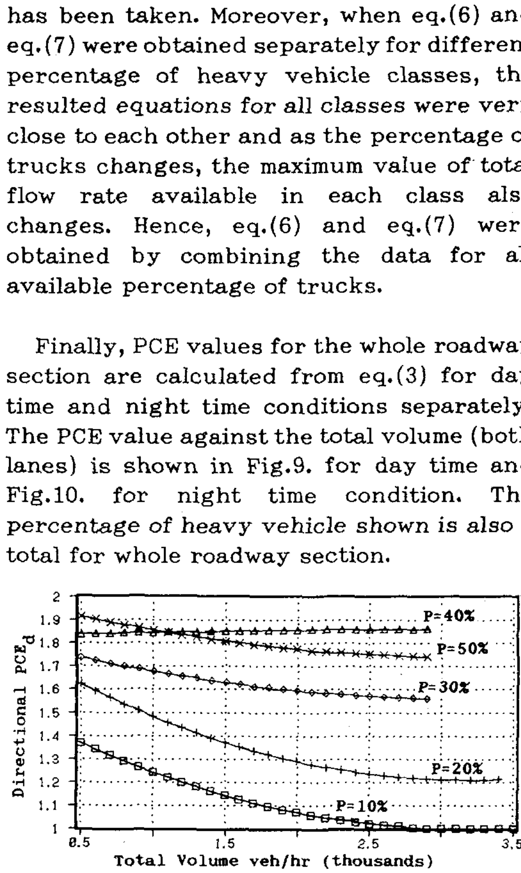


Fig.9, Directional PCE Day

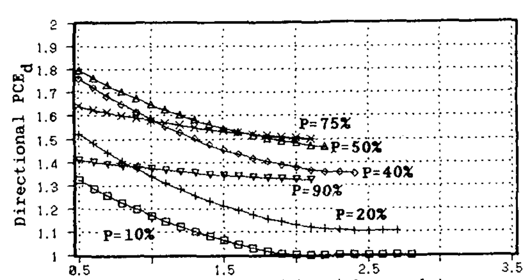


Fig.10, Directional PCE Night

5. CONCLUSIONS AND RECOMMENDATIONS

The conclusions from this study is given and the possible explanation has also been attempted.

1) From the results of the PCE for each lane, Fig.8, the PCE values increase with increase in percentage of truck to some maximum value and then decrease afterwards. The decrease in PCE value after certain percentage of truck is due to the increase in estimated capacity which may be caused by platooning effect where trucks can travel closer when the percentage is very high. This can be seen with the increase in the value of critical occupancy (at capacity) for higher percentage of truck.

2) The highest PCE value is observed for median lane day time and the PCE value reached maximum earlier for the day time condition than night time. The higher PCE value for lane2 day is because of the higher estimated capacity (Fig.7) at lowest percentage classes. Lower percentage of trucks means higher passenger cars and hence this flow condition can be expected to occur during peak hours where the driver population is regular user group who can travel faster with lesser headway. Whereas, during night time, due to light constraint, the vehicles can not travel faster relatively.

3) Comparing the directional PCE value for day and night time (Fig.9 and Fig.10), the PCE_d values for the same percentage class are slightly higher for day time. The effect of heavy vehicle is more for the day time, especially in the fast moving lane.

4) The directional PCE value for the same percentage class decreases with increase in total volume. It has also been observed that the rate of decrease in PCE is sharper near the lower flow rate than around the capacity. Holding the Percentage of truck constant, in lower flow rate region, when the density is very low, the difference in speed between passenger car and the truck is expected. Hence, larger effect is observed near lower flow rate. But, as the flow rate increases the difference in speed between passenger car and the truck gradually diminishes.

5) The decrease in directional PCE value with respect to increase in flow is sharper for night time condition than for day time. From Fig.3, for the uncongested region, the q-v relation is flatter for day time than for night time. So the decrease in speed with respect to increase in flow is higher for night time condition. This may have caused the sharper decrease in PCE with respect to increase in flow rate.

6) The PCE values have been calculated for the site with very little geometric effect. It would be more useful to compare the results for different geometric conditions. The effects of horizontal curvature and the vertical grades are further planned to be studied.

6. REFERENCES

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