MICROSCOPIC HEADWAY METHOD OF ESTIMATING PASSENGER CAR EQUIVALENTS*

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1. Introduction

Capacity analysis procedures are based on the Level-of-Service (LOS) concept, which is described in terms of ideal conditions. Prevailing conditions on motorway facilities rarely approach the ideal conditions. Various adjustment factors are used to account for the prevailing conditions, that multiply calibrated flow under ideal conditions to yield an equivalent flow under prevailing conditions. One of such ideal conditions is the presence of passenger cars only in the traffic stream, which is least likely to occur in practice.

2. Formulation to Passenger Car Equivalent

As described in the Highway Capacity Manual[1] (HCM), the adjustment factor for heavy vehicle (f_{HV}) converts flow in passenger car per hour (basic flow, q_B) to an equivalent flow in vehicles per hour (mixed flow, q_M) for a specified percentage of heavy vehicle (p). The passenger car equivalent (PCE) is an intermediate factor to determine the adjustment factor for heavy vehicle. Conceptually, PCE is the number of passenger cars displaced by each heavy vehicle in the flow. Thus,

$$f_{HV} = \frac{q_M}{q_B}\ ;\ PCE = \frac{1}{p}\left(\frac{1}{f_{HV}} - 1\right) + 1$$

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

If the flow rates are converted to headways (h), then,

$$h(sec) = \frac{3600}{q(vph)}$$

$$\therefore\ PCE = \frac{1}{p}\left(\frac{h_M}{h_B} - 1\right) + 1 \qquad ..(2)$$

Four pairs of headway types occur in the mixed stream. If the sequence of headway types in the mixed stream is assumed to be random, the average headway (h_M) in the mixed stream can be expressed as[2),3)],

$$h_M = (1-p)^2 h_{M_{PP}} + p(1-p) h_{M_{PT}} + p(1-p) h_{M_{TP}} + p^2 h_{M_{TT}} \qquad ..(3)$$

where, $h_{i_{jk}}$ is the headway (lagging in this study) of four pairs of headway types in which i is either mixed (subscript M) or basic (subscript B), j is the vehicle type of interest (P for passenger car and T for heavy vehicle) and k is the leading vehicle type. h_B is the average headway in basic stream without any heavy vehicle, such that, $h_B = h_{BPP}$. Substitution of h_B and h_M in equation (2) results the following equation for PCE,

$$PCE = \frac{1}{p}\left[\frac{(1-p)^2 h_{M_{PP}} + p(1-p) h_{M_{PT}} + p(1-p) h_{M_{TP}} + p^2 h_{M_{TT}} - h_{B_{PP}}}{h_{B_{PP}}}\right] + 1 \qquad ..(4)$$

If the headway data is collected for a certain period of time (for example 15 min), then the headway values of four headway types in the mixed stream can be obtained from the same data set. However, the value of h_{BPP} in equation (4) does not correspond to the same data set as of the mixed stream. The value of h_{BPP} has to be calculated from the flow condition that will correspond to the same level of service as that of mixed flow. Due to this difficulty, some researchers[2),3)] suggested that average lagging time headway of a P-P pair in basic stream is equal to the headway of a P-P pair in the mixed stream. Thus,

$h_{B_{PP}} = h_{M_{PP}}$ and after simplification,

$$PCE = \frac{(1-p)\left(h_{M_{PT}} + h_{M_{TP}} - h_{M_{PP}}\right) + p\, h_{M_{TT}}}{h_{M_{PP}}} \qquad ..(5)$$

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* Keywords: headway, passenger car equivalents, level of service
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This assumption does not clarify that under what condition h_{BPP} is equal to h_{MPP}. In other words the meaning of this assumption in terms of macroscopic flow variables is not clear. Gwynn[4)] found that the average headway of a P-P pair in a lane with 80% truck was significantly larger than the average headway of the P-P pair in a lane with 0% truck. It had also been suggested that the presence of trucks in a lane may have an appreciable influence on increasing the headways between all types of vehicle pairs in the lane. Although a slightly larger average headway for P-P pair was observed in a lane with 38% truck than for P-P pair in a lane with 0% truck, no significant difference was observed from statistical tests. Gwynn concluded that the percentage of truck in a lane had an effect on the average headway of all types of vehicle pairs. For these reasons, though the assumption that $h_{BPP} = h_{MPP}$ makes it possible to use the data from the mixed-flow-only, the effect of this assumption in the PCE value should be studied in detail first. For simplicity sometimes the passenger car equivalent is estimated as the ratio of the headway between T-T pair and P-P pair. This is just a corollary from equation (5) with the assumption that the size of the headway depends primarily on the type of following vehicle only. Thus,

$h_{M_{PP}} = h_{M_{PT}}$; $h_{M_{TT}} = h_{M_{TP}}$ and substitution in equation (5) results,

$PCE = \frac{h_{M_{TT}}}{h_{M_{PP}}}$ which is independent of percentage of heavy vehicle also.

Before introducing various assumptions it should be understood well that all the formulation on PCE from headway approach is based on the basic definition of PCE from equation (1) that is traditionally based on the level of service concept of capacity analysis. Besides, it is very important that the microscopic approach should also consider the importance from the macroscopic view points such that the results from the two approaches are in harmony to each other and should allow the direct comparison.

3. Formulation based on V/C ratio approach

The estimation of PCE is usually based either on macroscopic or on the microscopic approach of traffic flow. The macroscopic approach of PCE estimation considers the relationships of macroscopic traffic variables. Sthapit and Okura[5)] have discussed about the macroscopic methods of PCE estimation and have proposed the V/C ratio approach. PCE in V/C ratio approach is estimated with the assumption that the relative level of service of basic flow and the mixed flow are identical at same V/C ratio. Thus, for the same V/C ratio,

$\frac{q_B}{q_{oB}} = \frac{q_M}{q_{oM}}$ where, q_{oB} and q_{oM} are capacity for basic and mixed flow conditions. After rearranging and substituting in equation 1,

$$PCE = \frac{1}{p}\left(\frac{q_{oB}}{q_{oM}} - 1\right) + 1 = \frac{1}{p}\left(\frac{h_{oM}}{h_{oB}} - 1\right) + 1$$

$$\therefore\ PCE = \frac{1}{p}\left[\frac{(1-p)^2 h_{oM_{PP}} + p(1-p)h_{oM_{PT}} + p(1-p)h_{oM_{TP}} + p^2 h_{oM_{TT}} - h_{oB_{PP}}}{h_{oB_{PP}}}\right] + 1 \qquad ..(6)$$

The value of h_{oBPP} is calculated at the capacity of basic flow. Other four types of headway in mixed flow are calculated during capacity flow condition of mixed stream and at various percentage of heavy vehicle.

4. Data used

The data from the twin loop detector in Tomei expressway have been used for the analysis. The detector has two traffic sensors each of 1.5 m width separated at 5.5 m. The site for the data collection has two lanes in each direction and is at 45.97 kp in the inbound direction for the traffic coming towards Tokyo. The data include the entry and exit time of each vehicle both at the first and the second sensor. The headway and the speed of each vehicle were calculated and vehicles longer than 5.5 m were classified as heavy vehicles. The data contain a total of about 70 hours collected along the day and the night. However only the data for the day time were used for analysis. Although a comparison of results between two lanes was possible, currently, only the data for faster (median) lane were used for the results presented in this study. Unfortunately, higher volume data were available for percentage of heavy vehicle less than 20% and greater than 50% up to 70% only. High volume flow conditions were not observed for percentage of heavy vehicle about 20% to 50%.

5. Analysis and results

Equations (4) through (6) involve the microscopic headway pairs, but these were originally derived from flow rate relationships. If the PCE values were estimated from equation (1) by macroscopic approach, the data of five minutes or fifteen minutes averages would have been used. Averaging for longer duration will not reflect the adequate situation for percentage of heavy vehicle to be used in those equations. Again, averaging several hours data may not give enough information for comparison of results from microscopic and macroscopic approaches. Conversely, if shorter duration is used, the number of data in each type of headway pair will be too small to take an average. With these things in mind, the average values of headway were calculated at 15 min with 3 min moving interval.

It is also of some concern about what should be the maximum value of headway to be included in averaging. After examining the results near high volume, 20 sec was considered as the maximum value of headway to be included, because the mean headway becomes nearly constant after this value. An example has been shown in Figure (1).

The average headway of the four pairs of headway types are then calculated for 15 min with 3 min moving interval as stated earlier. The example of headway types against the average headway of the mixed flow is shown in figure (2) for about 50% to 70% of heavy vehicle.

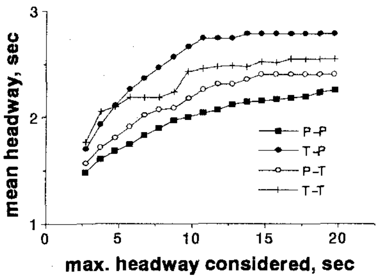

Figure 1: Mean headway

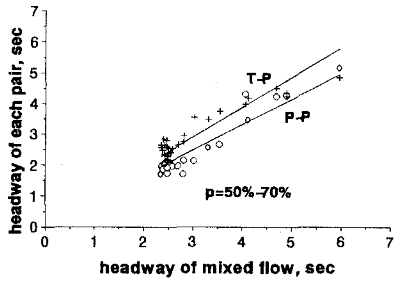

Figure 2: headway of different pairs

The results for all pairs of headway types for different percentage of heavy vehicles are given in Table 1. A linear relationship as in Figure (2) was considered for regression.

Table 1: Four pairs of headway types

% of heavy vehicle, p	Headway pair	Coefficient A ($h_{M_{ij}} = A \times h_M$) Fig.2	No. of data	R^2 value
5%-10%	P-P	0.972	82	0.97
	P-T	0.996		0.62
	T-P	1.264		0.61
	T-T	1.158		0.50
10%-20%	P-P	0.947	52	0.97
	P-T	0.992		0.78
	T-P	1.064		0.86
	T-T	1.132		0.70
50%-70%	P-P	0.828	27	0.92
	P-T	0.889		0.77
	T-P	0.968		0.83
	T-T	1.001		0.95

The average headway for P-P pair was the least in all three percentage of heavy vehicle class. The average headway for T-P pair was the highest for very low percentage of heavy vehicle, but it slowly changes and the headway for T-T pair becomes higher as percentage of heavy vehicle increases. As mentioned earlier, the data for percentage of heavy vehicle between 20% and 50% did not include the high volume condition. The data for these low volume cases were scattered more and may have some effect in the estimation. However, the analysis is based on the high volume data and should have little effect. Furthermore, for these very low volume cases the headway for T-T pairs were sometimes lesser than that for P-P pairs. This may be due to the fact that heavy vehicles travel in a platoon more often and travel closer to each other than P-P pair even at low volume because of relatively lesser speed.

The relationships between mixed speed and the inverse of headway of each pair have been illustrated in Figure (3) for percentage of heavy vehicle 5%-10%. The optimum values of each headway pair are then calculated from these relationships for different percentage of heavy vehicle. Figure (4) shows the comparison of the average headway $h_{B_{PP}}$ (p=0%) with the average headway $h_{M_{PP}}$ at p=50%-70%. The result for p=5%-10% lies slightly below p=0%, but has not been shown deliberately because the figure becomes unclear with overlapping data otherwise. The figure clearly shows that the headway of P-P pair is affected by percentage of heavy vehicle as concluded by Gwynn[4], such that, with the increase in percentage of heavy vehicle the headway for P-P pair increases. At none of the points in high flow region the two headways become equal. Very unfortunately the results could not be checked for other intermediate percentage of heavy vehicles due to the unavailability of data. The results for low volume cases for other intermediate percentage of heavy vehicles were very scattered and overlapping to each other to draw any conclusions.

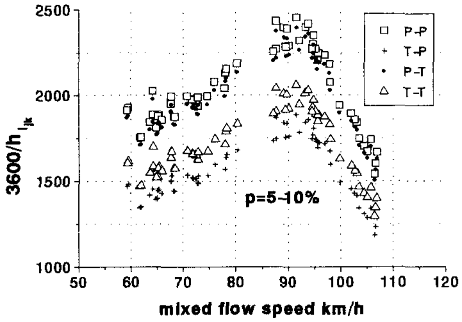

Figure 3: headway vs. speed

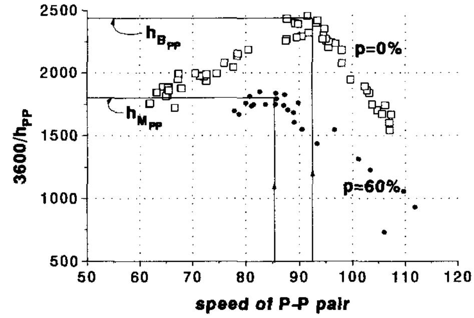

Figure 4: headway of P-P pairs

The optimum values of headway for all pairs of headway types were calculated from Figure (3) for three different percentage classes as given in Table (1) and also for the case at p=0%. These optimum headways for each pair of headway types are used in equation (3) to calculate optimum headway of mixed flow, which is shown in Figure (5). The optimum value of h_M for a particular percentage of heavy vehicle is calculated for the same values of average headways of each pair in that percentage class, but only changing the exact values of percentage. For example, values for p=15% and p=18% are calculated with same values of average headways of each pair as for p=10%-20% class, but with p=15% and 18% respectively in equation (3). Finally, PCE values were estimated from equation (6) and are shown as in Figure (6).

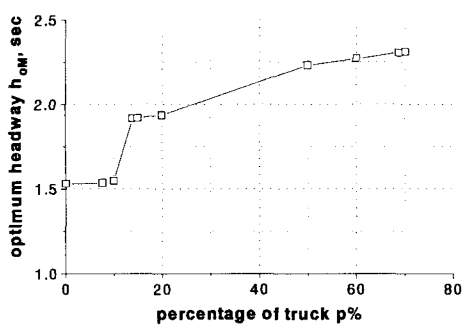

Figure 5: Optimum headway for mixed flow

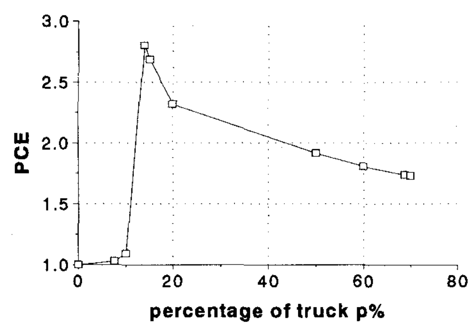

Figure 6: Estimated PCE values

6. Conclusions and recommendations

At lower flow rates, the headways for T-T pair are sometimes lesser than that for P-P pair, which is may be because the heavy vehicles travel in platoon more often even at low flow rate. Near the free flow region, there is more concern of decrease in speed than decrease in flow rate (or increase in headway) due to the presence of heavy vehicles. So, the PCE values from headway approach may be better near capacity or high flow region.

The average headway of each pair of headway types are affected by the percentage of heavy vehicle and should be studied in detail for all range of percentage of heavy vehicle.

The estimated PCE values increase with the increase in percentage of heavy vehicle to some maximum and decrease afterwards for median lane. PCE values should also be estimated for other lane positions and should be compared. The effect of day and night time conditions in PCE values is also of some interest and should be investigated.

Finally, it is very important that the estimated PCE values from microscopic and the macroscopic approaches should be comparable and be in harmony to each other, and is further planned to be investigated in detail.

References

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