# PASSENGER CAR EQUIVALENTS OF HEAVY VEHICLES ON MOTORWAYS FROM MICROSCOPIC HEADWAY METHOD*

by Izumi OKURA** and Naresh STHAPIT***

## 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 equivalent (PCE) is an intermediate factor to determine the adustment 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 in 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,

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

The assumption that the sequence of headway pairs in mixed stream is random, has been checked as shown in Figure 1 for lane2 (median lane) case. The result shown that, for a particular percentage of heavy vehicle the actual percentage of like pairs (P-P and T-T) are slightly higher than those given by equation (3). In corollary, the actual percentage of unlike pairs (P-T and T-P) are slightly lesser than those given by equation (3).

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 mixed stream can be obtained from this single observation. However, the value of $h_{BPP}$ in equation (4) does not correspond to the same observation. The value of $h_{BPP}$ has to be calculated from flow condition without any heavy vehicle 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.

* Keywords headway, passenger car equivalents, Level of Service

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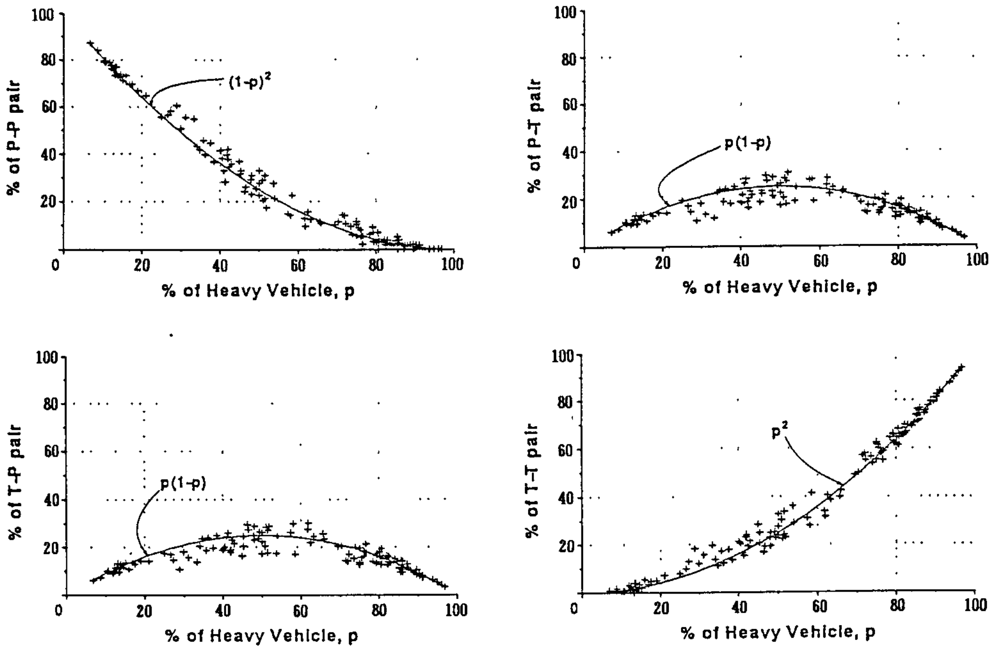


Figure 1: Percentage of Each Pairs of Headway Types

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

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

This assumption does not clarify that under what condition $h_{BPP}$ is equal to $h_{MPP}$. The meaning of this assumption in terms of macroscopic flow variables is not clear. In other words, whether this assumption is valid for same speed, density or V/C ratio, which are the parameters for LOS. 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. In this study, 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 the reasons, though the assumption that $h_{BPP} = h_{M_{PP}}$ 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. The absolute speed and density for both flows may not be the same, however the relative speed and the relative density for the two cases will be the same[6]. 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 site for the data collection has two lanes in each direction and is at 45.97 km in the inbound direction for the traffic coming towards Tokyo. The data include the entry and exit time of each vehicle. 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. 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 to 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 date 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 and, at the same time, stability of flow should also be considered. With these things in mind, the average values of headway were calculated at 15 min with 3 min moving interval. In our study, analytical works have been done for both cases of lane1 and 2. Since the phenomena occurred in the lane2 are more complicated, the analytical results of lane2 are mainly explained in this paper. An example of headway distribution7-10) for all four pairs of headway types is given in Figure 2 for lane2 case. The mean, standard deviation and the number of data in each case are also shown in the figure. A total of about five hours data have been used. From the figure, it seems that the median of P-P and P-T pair is close, however the mean values are affected by the larger headways. Similarly, the median of T-T pair seems to be larger than that for T-P pair, however the mean is opposite.

So, it is of some concern about what should be the maximum value of headway to be included in averaging. The possible effect of this consideration in PCE values should thus be clarified. After examining the data 20 seconds 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 3.

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 4 for about 50% to 70% of heavy vehicle.

The results for all pairs of headway types for different percentage of heavy vehicles are given in Table 1 for lane2 (median lane). A linear relationship as in Figure 4 was considered for regression.

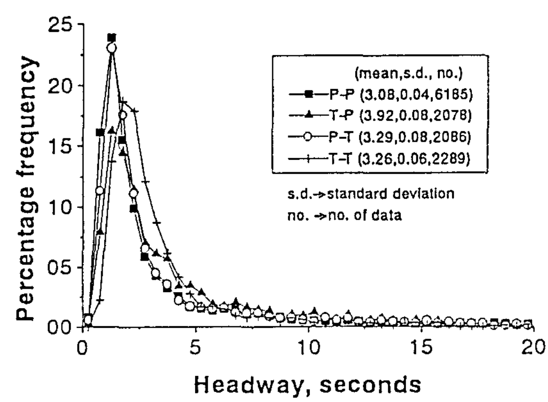


Figure 2: Headway distributions, lane2

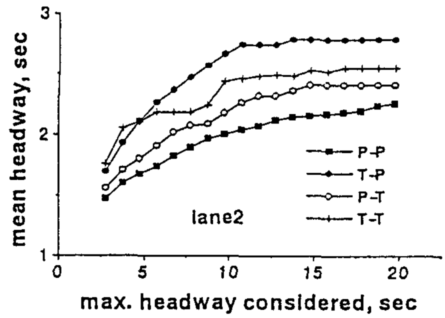

Figure 3: Mean headway

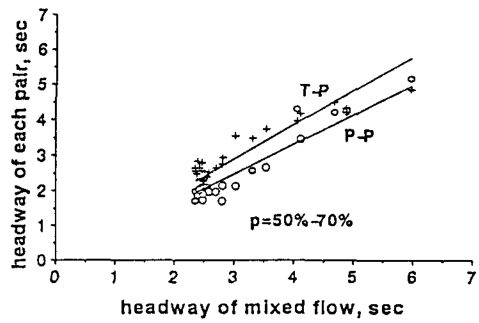

Figure 4: Headway of different pairs in lane2

Table 1: Four pairs of headway types, lane2 (median lane)

| % of heavy vehicle, p | Headway pair | Coefficient A ($h_{M_{ij}} = A \times h_M$) eg.Fig.4 | No. of data | $R^2$ value |
|---|---|---|---|---|
| 5%-10% | P-P | 0.972 (445.2) | 82 | 0.97 |
| | P-T | 0.996 (91.0) | | 0.62 |
| | T-P | 1.264 (54.3) | | 0.61 |
| | T-T | 1.158 (48.7) | | 0.50 |
| 10%-20% | P-P | 0.947 (126.6) | 52 | 0.97 |
| | P-T | 0.992 (42.2) | | 0.78 |
| | T-P | 1.064 (61.5) | | 0.86 |
| | T-T | 1.132 (40.7) | | 0.70 |
| 50%-70% | P-P | 0.828 (49.0) | 27 | 0.92 |
| | P-T | 0.889 (29.3) | | 0.77 |
| | T-P | 0.968 (49.3) | | 0.83 |
| | T-T | 1.001 (86.0) | | 0.95 |

Note: values in brackets are the t-values, which are significant for $\alpha < 0.001$

Average headway for P-P pair was the least in all percentage of heavy vehicle classes. Average headway for T-P pair was the highest for very low percentage of heavy vehicle, but it slowly changes and headway for T-T pair becomes relatively higher than headway for T-P pair as percentage of heavy vehicle increases. As mentioned earlier, data for percentage of heavy vehicle between 20-50% did not include high volume condition.

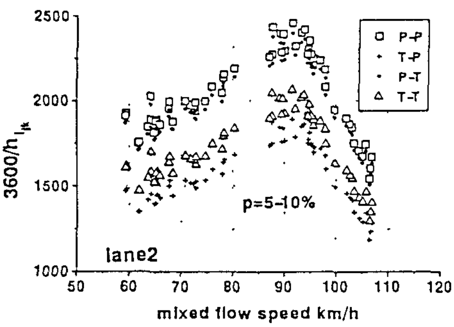

Figure 5: headway vs. speed

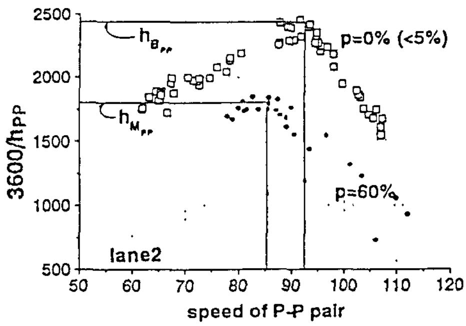

Figure 6: headway of P-P pairs

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 pair were sometimes lesser than that for P-P pair. 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 flow speed and the inverse of headway of each pair have been illustrated in Figure 5 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 6 shows the comparison of the average headway $h_{B_{PP}}$ (p=0%;<5%) with the average headway $h_{M_{PP}}$ at p=50%-70%. The result for 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 with other intermediate percentage of heavy vehicles were very scattered and overlapping to each other to draw any conclusions.

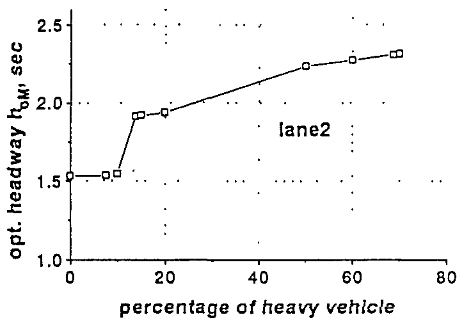


Figure 7: Optimum headway for mixed flow, lane2

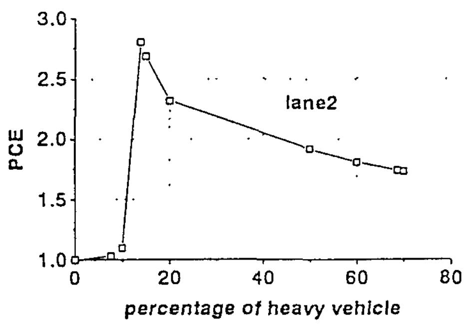


Figure 8: Estimated PCE values, lane2

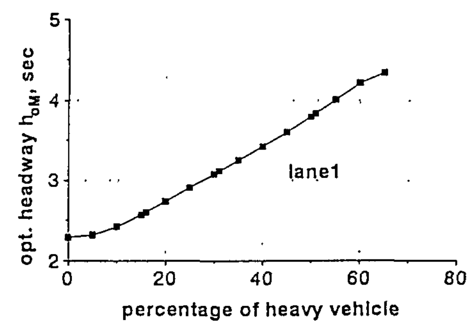


Figure 9: Optimum headway for mixed flow, lane1

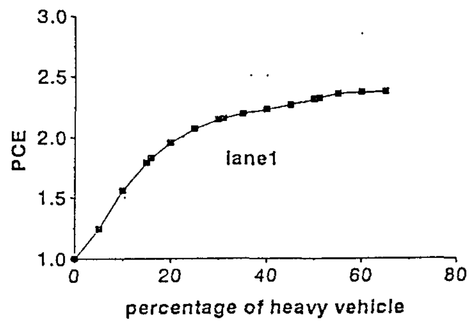


Figure 10: Estimated PCE values, lane1

The optimum values of headway for all pairs of headway types were calculated as from Figure 4 for 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 are shown in Figure 7 for lane2. 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 p=18% respectively in equation (3). Finally, PCE values were estimated from equation (6) and are shown in Figure 8 for lane2.

Based on the same analytical procedure, the optimum headway of mixed flow and the estimated PCE values for lane1 were also estimated and are shown in Figure 9 and 10 respectively.

## 6. Conclusions and Recommendations

At lower flow rates, the headways for T-T pair are sometimes lesser than that for P-P pair, which 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 for median lane increase with the increase in percentage of heavy vehicle to some maximum and decrease afterwards. PCE values for lane2 (median lane) increase very sharply near lower percentage of heavy vehicle. This is due to lesser percentage of heavy vehicle classes considered. If more classes are available the detail can be investigated. As for lane1 (shoulder lane), the estimated PCE values increase considerably sharply near lower percentage of heavy vehicle and increase with relatively smaller increasing rate afterwards. The effect of day and nighttime 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 macroscopic approaches should be comparable and be in harmony to each other, and further should be investigated in detail.

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## 高速道路における大型車の乗用車換算係数に関する微視的分析


大蔵　　泉・ナレッシュ　スタピット



この論文では大型車の乗用車換算係数（ＰＣＥ）を微視的状態量である車頭時間間隔に基づいて推定する方法について論じた。大型車・乗用車の２車種の組み合わせから成る４組の車種ペアの車頭時間を推定した上で、車種ペアの生起順序のランダムネスを仮定してこれらの車種が混合する実交通流の平均車頭時間の推定式を明らかにし、等交通量・容量比（等Ｖ／Ｃ比）基準によるＰＣＥ推定方法を提案した。東名高速道路における車両感知器によって収集された車頭時間データの１５分間平均値を用いて分析を行った結果、大型車のＰＣＥは、例えば第２車線の場合大型車混入率の増加に伴い増加し、ある混入率でピークに達して後減少すること等が知られた。


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## PASSENGER CAR EQUIVALENTS OF HEAVY VEHICLES ON MOTORWAYS FROM MICROSCOPIC HEADWAY METHOD


Izumi OKURA and Naresh STHAPIT



This paper discusses the microscopic approach of estimating Passenger Car Equivalents (PCE). The average headway of mixed flow condition with percentage of heavy vehicle p is expressed in terms of four typical headway types, assuming that the sequential occurrence of headway types is random. The formulation for estimating PCE is based on equal V/C ratio approach. The vehicle detector data of each vehicle from Tomei expressway have been used. Headways of each pair of headway types are averaged for fifteen minutes at three minutes moving interval. PCE for lane2 was found to increase with increase in percentage of heavy vehicle to some maximum value and then was found to decrease afterwards.


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