PASSENGER CAR EQUIVALENTS FOR TRUCKS AND BUSES ON HIGHWAYS IN THAILAND

Sompong SIRISOPONSILP
Assistant Professor
Department of Civil Engineering
Chulalongkorn University
Bangkok 10330
Thailand
Fax: +66-2-251-7304
E-mail: Sompong.Si@chula.ac.th

Wirach HIRUN
Former Graduate Student
Department of Civil Engineering
Chulalongkorn University
Bangkok 10330
Thailand

Wisoot SANGARUNLERT
Former Graduate Student
Department of Civil Engineering
Chulalongkorn University
Bangkok 10330
Thailand

Abstract: This study attempts to determine the PCE values that accurately represent the effects of trucks and buses on highway traffic in Thailand. The analysis separates highways into two distinct types namely, two-lane highways and multilane highways, in light of the indisputable difference in traffic and driving behavior experienced on the two types of facilities. The PCE values for trucks and buses on multilane highways are analyzed on the basis of the lagging headways formed in front of each type of vehicles in the traffic stream. In the case of two-lane highways, the PCE values are estimated from the relative impacts of each vehicle type on speed reduction and in terms of platoon leaders and followers. The finally adopted PCE values appear to increase with vehicle size and highway grade. The effect of the gradient on the PCE values is more evident on two-lane highways than on multilane facilities.

Key Words: Passenger car equivalents, Multilane highways, Two-lane highways, Truck PCE, Bus PCE.

1. INTRODUCTION

Trucks and buses normally have greater adverse effects on traffic flow quality than passenger cars, primarily for three reasons. Firstly, they occupy more road spaces due to their larger sizes. Secondly, they generally have poorer operating capability, resulting in the formation of larger gaps in the traffic stream that creates inefficiency in the use of roadways. Thirdly, they are more difficult to overtake because of their larger sizes often blocking the sight of the drivers following them. The relative impedance effects of trucks and buses compared to passenger cars are typically expressed as the Passenger Car Equivalents (PCEs). In the design and analysis of highway capacity, the PCE values have been used to convert flows of mixed traffic into equivalent flows of passenger cars only. The 1994 edition of the U.S. Highway Capacity Manual (TRB, 1994) defines the term "Passenger Car Equivalent" as "The number of cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic, and control conditions". This definition remains essentially unchanged from that first introduced in the 1965 Highway Capacity Manual.

The impacts of trucks and buses vary from location to location depending on inherent traffic characteristics and driving behavior. Consequently, the PCE values estimated under particular situations may not be directly transferable to other environments. Due to the absence of locally acceptable PCE values for trucks and buses, the planning, design, and operational analysis of highways in Thailand have long "borrowed" the PCE values derived from the observation taken in other countries, particularly those values proposed in the U.S. Highway Capacity Manual. These PCE estimates, however, may not be the proper values to represent traffic situations in Thailand and have probably lead to "sub-optimal" highway investment plans or highway designs, especially in the places where heavy vehicles are prominent.

This study was carried out with the primal objective to analyze the PCE values for trucks and buses that truly reflect the traffic conditions and driving behavior generally experienced on highways in Thailand. It has been widely accepted that the PCE values of a particular vehicle type can be influenced by numerous factors pertaining to roadway geometry and traffic characteristics. This study, however, focused solely on the effect of roadway gradients on PCE values because the highway grade has been the design element receiving the greatest attention in the planning and design of highways in Thailand. In our study, highways were classified into two-lane highways and multilane highways, viewing that the impacts of heavy vehicles on the two types of highways being significantly different. Heavy vehicles of interest were classified into 6 wheel trucks, 10 wheel trucks, combination trucks, and buses. This classification is consistent with that adopted by the Department of Highways (DOH) of Thailand except that the DOH classification combines 10 wheel trucks and combination trucks into the "large truck" category.

2. THEORECTICAL FRAMEWORK

A good number of techniques and approaches developed specifically for determining the PCE values for trucks and buses have been discussed in the literature. One may group available techniques according to the types of data from which PCE values have been derived. A particular group of techniques has calculated the PCEs using empirical data observed directly in the field while another group has derived the PCEs from the data provided by the microscopic simulation models of traffic flow under various controlled experimental settings. The application of such simulation models provides the analysts with the luxury to comprehensively investigate the PCEs under a great variety of roadway, traffic, and operating conditions. However, prior to useful application these simulation models must be thoroughly calibrated and validated for actual driving behavior and vehicle characteristics, implying that a large amount of effort and resources must be invested in the model development. Due to the time and financial constraints, our study elected to derive the PCE values from the field-measured data.

In our study, existing techniques for estimating the PCE values were examined and selected with consideration given to both theoretical and practical viewpoints. Ideally, one would prefer to derive the equivalency between cars and other vehicle types using the same criterion as that adopted in measuring flow performance. This, unfortunately, has proven difficult in practice, particularly for deriving PCE values from empirical data (McLean, 1989). Nevertheless, every possible attempt was made in this study to identify and employ the techniques that in certain ways relate the concept of passenger car equivalency to some surrogate measures of traffic flow performance. In the absence of automatic data collection equipment, the techniques selected for our study were limited to those requiring the data that would easily be collected manually or with the aids of generally available equipment such as video recorders. The techniques eventually applied in the determination of the PCE values for each highway type are briefly discussed in the following sections.

2.1 Multilane Highways

The 1994 Highway Capacity Manual defines the level of service for multilane highways in terms of density, representing the proximity of vehicles to each other and the degree of maneuverability within the traffic stream. Roess and Messer (1984) indicated that average spacing and density are related on a one-to-one basis, and spatial headway could be argued to be an appropriate surrogate parameter for density. Krammes and Crowley (1986) supported the application of the headway approach by pointing out that the headway approach would estimate the PCE values based on actual measurements of the relative position maintained by drivers in the traffic stream. The determination of PCEs from headway measurements is therefore appropriate because it estimates PCEs based on the driver's perception of equivalent densities.

A number of formulations have been derived for estimating PCE values from headway measurements. However, most formulations have been developed assuming that traffic stream consists of only two types of vehicles including passenger cars and a single type of trucks, and cannot be directly applied to handle multiple types of trucks or heavy vehicles. A formulation particularly suitable for analyzing multiple truck types is the most simplistic one that simply derives the passenger car equivalency based solely on the ratio of lagging headways as follows:

$$E_x = \frac{H_x}{H_c} \tag{1}$$

where E_x denotes the PCE value for vehicles of type x, H_x refers to average lagging time headway measured from the rear of the leading vehicle to the rear of vehicle type *x*, and H_c is average lagging headway associated with passenger cars in traffic stream.

McShane and Roess (1990) suggested three alternative approaches for determining headways and applying the equivalency relationship of Equation (1). In the first approach, referred to as "Driver-Determined Equivalence", the PCE values are easily computed by simply substituting into Equation (1) the corresponding average headways observed during each 15-minute period. By collecting headway data at various occasions for numerous 15-minute intervals, one would be able to explore the presence of the relationship between the PCE values and other explanatory variables such as percentages of heavy vehicles in the traffic stream and traffic volumes.

The second approach determines the equivalent headways based on constant spacing by plotting for each vehicle type the observed headways of individual vehicles against their corresponding spacings. Given a value of spacing, the corresponding relative headways are determined as shown in Figure 1, and the passenger car equivalents at equal spacing are subsequently estimated by applying Equation (1).

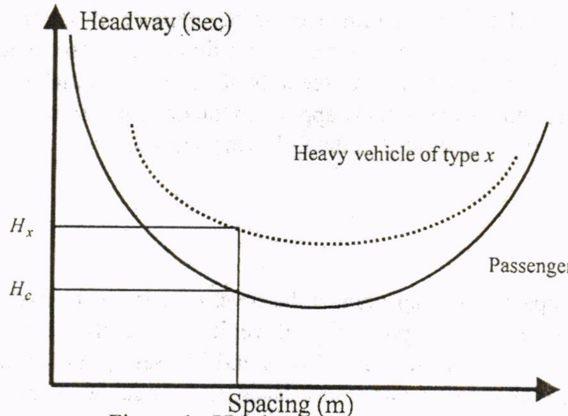

Figure 1. Headways at equal spacing.
Adapted from Roess and Mcshane (1990).

The third approach is relatively similar to the earlier approach except that the plots of headways versus speeds of individual vehicles are developed instead, and the PCE values at equal speed will be subsequently derived. All three approaches described above were employed in our study.

2.2 Two-lane Highways

Traffic engineers have long recognized that traffic operation on two-lane highways is unique. Lane changing and passing are possible whenever there are sufficiently large gaps in the opposing traffic stream. In the 1994 Highway Capacity Manual, service quality of traffic flow on two-lane highways is described by average travel speed, percent time delay, and capacity utilization. Percent time delay defined as the average percent of the total travel time that all motorists are delayed in platoon while traveling a given section of highway is regarded as the primary measures of service quality while speed and capacity utilization are secondary measures.

Consistent with the above definition of level of service, McLean (1989) clearly indicated that "for two-lane traffic, the larger average headways for trucks resulting from the difference in unimpeded speeds between cars and trucks and the difficulty in overtaking trucks. Hence, trucks are more likely to be platoon leaders, with large headways to the next downstream vehicle. While the headway difference is clearly indicative of the degree of additional impedance produced by trucks, it cannot be directly related to the usual measures of flow performances on two-lane highways." Following this line of argument, it becomes apparent that the traditional headway approach that measures the relative space occupied by vehicles is no longer applicable in the case of two-lane highways.

Among the techniques proposed for two-lane highways, we found that the three approaches used by Van Aerde and Yagar (1984) were most relevant to two-lane highways. The first approach, named the "Speed Reduction" technique, estimates passenger car equivalents from the relative sizes of the speed reductions caused by equal volumes of each vehicle type. Passenger car equivalent estimates are derived using the following linear regression model:

$$Speed = Free\ Speed + a_{6w}V_{6w} + a_{10w}V_{10w} + a_{tr}V_{tr} + a_bV_b + a_cV_c + a_{op}V_{op} \quad (2)$$

where V_x denotes the number of vehicles of type x, coefficient a_x reflects the extent to which a vehicle of type x would cause a reduction in the speed of traffic stream, and subscripts *6w*, *10w*, *tr*, *b*, *c*, and *op* represent 6 wheelers, 10 wheelers, combination trucks, buses, passenger cars, and opposing vehicles respectively. The PCE value of a vehicle type x will subsequently be estimated as follows:

$$E_x = \frac{a_x}{a_c} \quad (3)$$

The second technique derives equivalents in terms of platoon leaders. Typically, platoons on a two-lane facility are formed because fast vehicles catch up with slower vehicles and are not being able to pass. As trucks and buses often have lower operating speed, they are more likely to be caught by faster vehicles than are passenger cars. In other words, heavy vehicles have greater likelihood of becoming platoon leaders than do passenger cars. The investigation of PCEs in terms of platoon leaders begins with the estimation of the probability of a subject vehicle being platoon leaders. The leader propensity associated with a vehicle type x, b_x, is mathematically expressed as the ratio of percent leads to percent of total traffic as illustrated in Equation (4). The PCE value for a particular vehicle type is simply determined by comparing the leader propensity of the subject vehicle to that of passenger car as given in Equation (5).

$$b_x = \frac{Percent\ of\ platoons\ having\ vehicle\ type\ x\ as\ the\ leaders}{Percent\ of\ total\ traffic} \quad (4)$$

$$E_x = \frac{b_x}{b_c} \quad (5)$$

The third technique shifts the attention from platoon leaders to platoon followers by recognizing that it is principally the followers who are delayed by the formation of platoons. The equivalency is established on the basis of additional platoon followers resulting from the presence of a subject vehicle in the traffic stream. The passenger car equivalency was derived by first determining additional platoon followers likely produced by the presence of a vehicle of interest using the following regression equation:

$$Number\ of\ Followers = Constant + d_{6w}V_{6w} + d_{10w}V_{10w} + d_{tr}V_{tr} + d_bV_b + d_cV_c + d_{op}V_{op} \quad (6)$$

where d_x is the coefficient reflecting additional platoon followers caused by the presence of a vehicle of type x. The PCE value for vehicles of type x was subsequently estimated from the relative effects on the number of platoon followers compared to passenger cars as follows:

$$E_x = \frac{d_x}{d_c} \quad (7)$$

3. DATA COLLECTION

Few considerations were attended to in selecting the sites for field data collection. Firstly, it was considered that the geometric features of the survey sites should meet certain "desirable" conditions including three-and-a-half meter minimum width of travel lanes, two-meter minimum lateral clearance, no side friction, and no direct access points located nearby. Secondly, to reduce the need for long survey periods the sites should have experienced relatively moderate-to-high percentages of trucks and buses. Thirdly, to ease the mobilization of the survey teams and to minimize the data collection expenses the survey sites should not be far from Bangkok where our office was located. Furthermore, the attempt to determine the influence of roadway grade on the PCE values demanded multiple sites with different gradients for each highway type. After a tedious selection process, the collection of traffic data on multilane highways was chosen to take place at three separate locations on the four-lane Chonburi-Rayong section of Highway 36, situated about 150 kilometers from Bangkok. A total of five sites were selected on the Pattaya-Rayong section of Highway 36 for the study of traffic on two-lane highways. Tables 1 and 2 provide information about the exact location, percent grade, section length, and median type of each selected survey site. Sections 3.1 and 3.2 present the procedures for data collection and data reduction for multilane highways and two-lane highways respectively.

Table 1. Survey sites on multilane highways.

Station	% grade	Section Length (m)	Total
11+000 – 13+000 (EB)	0	---	Divided
14+725 – 14+925 (EB)	1.85	200	Divided
17+575 – 17+950 (EB)	4.24	375	Divided

Table 2. Survey sites on two-lane highways.

Station	% grade	Section Length (m.)	Type of median
35+000 – 25+210 (EB)	0	---	Undivided
17+700 – 17+885 (EB)	1.95	185	Undivided
43+200 – 43+400 (WB)	1.96	200	Undivided
21+700 – 21+950 (WB)	2.78	250	Undivided
26+300 – 26+470 (WB)	2.98	170	Undivided

3.1 Multilane Highways

The three techniques chosen for the estimation of the PCE values for heavy vehicles on multilane highways require information about lagging headways, speeds and spacings of individual vehicles. At each selected study location, observations were undertaken over a single day during the hours of 9:00-12:00 and 13:00-17:00, using a team of three observers equipped with a video recorder and three stopwatches. All data required by the "Driver-

Determined Equivalence" approach were recorded using a video camera which was carefully positioned on a good vantage point that permitted unimpeded view of the traffic over the concerned highway section. A simple in-house computer program was developed to facilitate the extraction of data from the videotapes. Observers manually observed the videotapes that were played back at one-fifth the normal speed, and pressed a designated key on the keyboard whenever the rear bumper of a vehicle crossed the reference line. With the internal clocks installed in the computer, the program automatically counted the number of each vehicle type, recorded the exact time to the tenth of a second as the keys were pressed, and subsequently determined the lagging headways.

The three observers collected information needed in evaluating the PCE values based on headways at constant spacings and at constant speeds. For any randomly selected pair of vehicles in traffic stream, the first observer observed the elapsed time the leading vehicle traveled over a specified highway section, the second observer recorded the travel time taken by the following vehicle, and the third observer noted the time headway between the two vehicles. The measured travel times were analyzed later to estimate individual speeds. Given the observed time headways and the estimated speeds, individual spacings were then determined. It is noteworthy that headways exceeding seven seconds were excluded from the consideration because they represented the situations in which vehicles were traveling at free will without interacting with other vehicles.

3.2 Two-lane Highways

The analysis of PCE values for two-lane highways required information about volumes by vehicle type, traffic speed, platoon leaders by vehicle type, and number of platoon followers. At each study location, a team of three observers, equipped with seven handheld counters and a stopwatch, was employed to collect data during the 9:00-17:00 hours over two days. As far as speeds were concerned, we viewed that to individually record the speed of every vehicle would be prohibitively expensive, therefore elected to measure vehicle speeds using the approach proposed by Yagar and Van Aerde (1982). This particular approach divides traffic into platoons and assuming that speeds of vehicles in a platoon are virtually identical. The average speed of the platoon can be estimated directly from the observed speeds of few sampled vehicles in the platoon.

At each survey site, the first observer counted traffic volumes by vehicle type moving in the principal traffic stream and total traffic in the opposing direction, and recorded the counts in 5-minute intervals. During each 5-mintue interval, the second observer noted for each platoon the type of the vehicle being the platoon leader and counted the number of platoon followers while the third observer recorded the elapsed times taken by selected vehicles in traveling over a specified roadway section. In recording the travel times, for a small platoon only the first and the last vehicles of the platoon were selected. For a large platoon, additional few vehicles moving in the middle of the platoon were also observed. The recorded travel times of selected vehicles were later analyzed to estimate the average speeds of all vehicles in the corresponding platoons. It should be noted that the three observers were instructed and extensively trained to perform their duties in total synchronization to assure that the observed data contained in each 5-minute interval were absolutely consistent.

4. ANALYSIS RESULTS

Tables 3 and 4 show traffic volumes observed at all study sites. Traffic volumes were relatively light to moderate, with flow rates ranging from 1,300 to 1,450 vehicles per hour on multilane highways and from 400 to 600 vehicles per hour on two-lane highways. Heavy vehicles were prevalent at the study sites, accounting for about 30% of total traffic in most cases.

Table 3. Traffic volumes by vehicle type observed on multilane highways.

% grade	Average hourly volumes					
	Passenger cars	6-wheel trucks	10-wheel trucks	Combin. Trucks	Buses	Total
0	1,057 (72.8%)	119 (8.2%)	126 (8.7%)	120 (8.3%)	30 (2.1%)	1,452 (100%)
1.85	911 (69.6%)	118 (9.0%)	138 (10.6%)	117 (8.9%)	25 (1.3%)	1,309 (100%)
4.24	961 (72.5%)	107 (8.1%)	115 (8.7%)	115 (8.7%)	28 (2.0%)	1,326 (100%)

Table 4. Traffic volumes by vehicle type observed on two-lane highways.

% grade	Average hourly volumes					
	Passenger cars	6-wheel trucks	10-wheel trucks	Combin. Trucks	Buses	Total
0	385 (69.9%)	26 (4.7%)	77 (14.0%)	57 (10.3%)	6 (1.1%)	551 (100%)
1.95	402 (68.5%)	28 (4.8%)	84 (14.3%)	65 (11.1%)	8 (1.4%)	587 (100%)
1.96	350 (84.1%)	16 (3.8%)	27 (6.5%)	12 (2.9%)	11 (2.6%)	416 (100%)
2.78	340 (67.2%)	30 (5.9%)	64 (12.6%)	64 (12.6%)	8 (1.6%)	506 (100%)
2.98	289 (66.1%)	26 (5.9%)	58 (13.3%)	58 (13.3%)	6 (1.4%)	437 (100%)

The estimation of the PCE values for each highway type is presented in detail in the following sections.

4.1 PCE Values for Multilane Highways

Although field data were observed by traffic lane, the PCE values for multilane highways were estimated for all lanes combined. The determination of the overall PCE values across the two traffic lanes did account for the dynamics of interaction among vehicles traveling on the two adjacent lanes, truly reflecting the fairly high degree of freedom passenger cars have in making lane changes on multilane highways to maintain their desired position relative to other vehicles. The headway data extracted from the videotapes were grouped into 15-minute time intervals and the PCE values for each vehicle type corresponding to each time interval were estimated using Equation (1). Given the PCE values estimated for many intervals, the influence of traffic flow rate and percentages of heavy vehicles on the PCE values were thereafter explored but we were not able to establish any solid relationship between the PCE values and these two variables. As a result, for each type of heavy vehicle the simple average of PCE values over all time intervals was obtained instead and is shown in Table 5.

Table 5. Average PCE values by vehicle type based on the headway approach.

% grade	Passenger Car Equivalents			
	6-wheel trucks	10-wheel trucks	Combination trucks	Buses
0	1.25 (0.15)	1.34 (0.17)	1.54 (0.20)	1.30 (0.30)
1.85	1.22 (0.16)	1.36 (0.22)	1.58 (0.24)	1.15 (0.42)
4.24	1.46 (0.29)	1.55 (0.21)	1.83 (0.19)	1.39 (0.40)

Note: The standard deviations of derived PCE values are shown in the parenthesis.

The analysis results apparently indicate that the PCE values for truck increase with vehicle size. There is no marked difference between the truck PCEs derived for the level section and those for the 1.85% grade, implying that the traffic impacts of trucks on this range of roadway grades are virtually similar. The PCE values for all vehicle types associated with the 4.24% grade are notably higher than those with more modest grades.

In determining the equivalency at constant spacings, the relationships between individual headways and spacings were formulated under the following four alternative specifications:

(i) $Headway = \beta_0 + \beta_1 Spacing$

(ii) $Headway = \beta_0 + \beta_1 \boldsymbol{ln}(Spacing)$

(iii) $Headway = \beta_0 \boldsymbol{exp}(\beta_1 Spacing)$

(iv) $Headway = \beta_0 (Spacing)^{\beta_1}$

Judging from the t-statistics and the sum of squared errors associated with each specification, it appeared that the specification of type (iv) was the most favorable and was subsequently used in representing the relationships between individual headways and spacings for all vehicle types at all locations. The finalized headway-spacing relationships are summarized in Table 6.

Given the headway-spacing relationships as presented in Table 6, the PCE values for heavy vehicles were computed at different levels of service as defined by the 1994 U.S. Highway Capacity Manual and are shown here in Table 7. The resulting PCE values for trucks increase slightly with vehicle size but no definite conclusion could be drawn regarding the influence of service level and highway grade on the PCE values.

Table 6. Calibrated microscopic relation between individual headways and spacings.

% grade	Microscopic relation between headway (H) and spacing (S)				
	Passenger cars	6-wheel trucks	10-wheel trucks	Combination trucks	Buses
0	$H = 0.16S^{0.71}$	$H = 0.31S^{0.56}$	$H = 0.37S^{0.54}$	$H = 0.51S^{0.49}$	$H = 0.10S^{0.80}$
1.85	$H = 0.16S^{0.73}$	$H = 0.31S^{0.58}$	$H = 0.26S^{0.63}$	$H = 0.43S^{0.53}$	$H = 0.14S^{0.75}$
4.24	$H = 0.25S^{0.65}$	$H = 0.34S^{0.61}$	$H = 0.44S^{0.54}$	$H = 0.33S^{0.62}$	$H = 0.15^{0.77}$

Note: All estimated coefficients are statistically significant at 95% confidence level.

Table 7. Average PCE values by vehicle type and service level

% grade	LOS	Max. Density (veh/mi/ln)	Passenger Car Equivalents			
			6-wheel trucks	10-wheel trucks	Combination trucks	Buses
0	A & B	20	1.03	1.06	1.13	0.98
	C	28	1.12	1.22	1.35	0.98
	D & E	40	1.08	1.16	1.30	0.96
1.85	A & B	20	0.94	1.08	1.09	1.07
	C	28	1.05	1.08	1.25	0.97
	D & E	40	1.11	1.13	1.26	1.09
4.24	A & B	20	1.01	1.04	1.09	1.03
	C	28	1.20	1.07	1.22	0.98
	D & E	40	1.13	1.16	1.16	0.98

Similar procedures were applied to determine PCE values on the basis of relative headways at equal speeds. The same four types of specification presented in the earlier approach were examined to depict the relationships between headways and speeds of individual vehicles but the analysis did not reveal any meaningful headway-speed relationship. Consequently, no further investigation was exercised to derive the PCE values in this particular case.

4.2 PCE Values for Two-lane Highways

In the analysis of two-lane highways, the field data were aggregated into time intervals of varying lengths; 5 minutes, 10 minutes, 20 minutes, and 30 minutes. The determination of the PCE values under different levels of data aggregation allowed us to investigate the sensitivity of the derived PCE values to the ways the data were grouped. The techniques that produced relatively stable PCE values with respect to level of data aggregation would naturally be preferable.

Space mean speed was adopted in applying the speed reduction technique as mathematically presented in Equation (3). The analysis results showed that all estimated coefficients had the expected negative sign but those associated with six-wheel trucks and buses were not statistically significant in all cases. The PCE values for 10-wheel trucks and combination trucks appeared fairly stable and the averages of PCE values evaluated over four levels of data aggregation were obtained and are presented in Table 8.

The free flow speed decreases with the increase in the roadway grade as one would expect. The PCE values for trucks appear realistic as they increase with both percent grade and vehicle size. On the other hand, the PCE values representing the opposing traffic do not correspond to our expectation as far as the effect of highway grade was concerned.

Table 8. Average PCE values by vehicle type based on speed reduction.

% grade	Free flow speed (kph)	Passenger Car Equivalents		
		10-wheel trucks	Combination trucks	Opposing traffic
0	88	1.67	2.14	0.34
1.95	74	2.42	3.01	0.61
1.96	72	2.71	3.19	0.14
2.78	69	3.15	3.55	0.35
2.98	65	3.11	3.84	0.44

To estimate equivalency in terms of platoon leaders, Equations (4) and (5) were applied to estimate the PCE values for each type of heavy vehicle under different levels of data aggregation. It was found that the derived PCE values were relatively stable with respect to the ways the data were aggregated. The resulting average PCE values across all levels of data aggregation are presented in Table 9.

Table 9. Average PCE values by vehicle type based on platoon leaders.

% grade	Passenger Car Equivalents			
	6-wheel trucks	10-wheel trucks	Combination trucks	Buses
0	2.49	3.20	3.94	1.67
1.95	2.65	3.61	4.28	2.18
1.96	2.63	3.76	4.46	2.06
2.78	2.76	4.12	5.31	2.45
2.98	2.86	4.34	6.17	2.43

The results presented in Table 9 look sensible in all respects. The PCE estimates increase with roadway grade and vehicle size and those for similar grades are basically comparable. It should also be noted that the PCE values computed on the basis of platoon leaders are substantially higher than those derived from the speed reduction technique.

The attempts to derive the PCE values on the basis of platoon followers using Equations (6) and (7) did not obtain meaningful results. The PCE values varied considerably with the manners in which observed data were grouped and many PCE estimates looked suspiciously incorrect.

5. CONCLUSIONS

Similar to the results derived by Van Arede and Yagar (1984) for two-lane highways, the findings of our study clearly reveal that the PCE values vary with the specific techniques used in the analysis. A careful review of the results for multilane highways indicates that the PCE values based on the headway approach as presented in Table 5 are more reasonable than those in Table 7 because they exhibit the expected influence of vehicle size and roadway gradient on the PCE values. For two-lane highways, we are in favor of the values analyzed on the basis of platoon leaders as presented in Table 9 over those reported in Table 8 since they provide PCEs for all vehicle types while portraying the anticipated effects of percent grade and vehicle size on the PCEs. It should be noted that the adopted PCE values for two-lane highways are roughly 2-3 times those for multilane highways, reflecting the fact that the effects of heavy vehicles are likely more severe on two-lane highways than on multilane highways which allow more passing opportunities.

Our PCE values for multilane highways appear relatively comparable with those proposed by the 1994 U.S. Highway Capacity Manual, but our selected PCE values for two-lane highways are significantly higher. This probably implies that heavy vehicles in Thailand generally have lower operating performance than their U.S. counterparts, but the effect of inferior performance is noticeable only on two-lane highways because drivers on multilane highways can avoid the delay caused by the presence of heavy vehicles by simply moving to a different lane.

Although this research work did not propose any new technique for determining the PCE values for trucks and buses, it is perhaps, to the best of the authors' knowledge, the first comprehensive study to apply local traffic data to examine PCEs for heavy vehicles actually operated on highways of varying geometry in Thailand. Nevertheless, it is well recognized that our research provides PCE estimates under few limited circumstances. Further research is definitely needed to estimate PCE values as a function of the full range of factors that have been found by earlier studies to have crucial effects on PCE. These factors include but are not limited to traffic flow rate, length of grade, vehicle performance characteristics, and percentages of heavy vehicles. The comprehensive study of PCE values based solely on empirical data would, however, require substantial time and financial resources to collect field data at numerous sites with varying physical and traffic characteristics. An appealing alternative approach would be to calibrate proper microscopic models of traffic flow that will be later applied to investigate the sensitivity of the PCE values to a variety of concerned variables.

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