PASSENGER CAR EQUIVALENTS (PCE) OF HETEROGENEOUS VEHICLES ON FOUR-LANE HIGHWAYS IN THAILAND

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ABSTRACT

This paper is aimed to introduce Passenger Car Equivalent (PCE) values on four-lane highways in Thailand. The study began with a literature review of PCEs, and then 12 sections of four-lane highway were intentionally selected and data collected by using digital video cameras during 6:00 A.M. to 6:00 P.M. for two days for each site for a total of 12 sites. After that, the process involved decoding video signals from IP cameras to identify traffic volumes, speeds, and time headways for 13 different vehicle types. Next, the Lagging Time Headway (LTH) method was applied and analyzed to find PCE values in 15-minute intervals. The results showed that a highway gradient is a significant factor related to the PCE value. Moreover, the recommended PCE value of a four-lane highway according to the highway gradient was proposed in this study.

KEYWORDS: Department of Highways, Four-lane highway, Passenger car equivalent, Lagging time headway, Highway gradient.

1. Introduction

In the traffic engineering analysis, the conversion of other vehicle types into passenger car unit (PCU) is one of the important techniques for the simplification of the analysis and evaluation. Regarding this method, the Passenger Car Equivalent (PCE) factor is considered as a specific value varied by each vehicle type that will be used for multiplying with the observed number of each vehicle type to obtain the result of a homogeneous unit. In the past, PCE values, using to convert heterogeneous traffic in Thailand, were referred or adopted from abroad where driving environments such as the vehicle type classification, and the capacity and size of vehicles completely differed from those of Thailand. Although the fact that PCEs were partially studied by other organizations in the country, such works focused only on specific scopes for their projects. Therefore, the PCE values could not be used as representative values of vehicles in all cases. Furthermore, the previous studies were performed a long time ago and vehicle characteristics are not similar to the present conditions. Hence, this study is aimed to gather and analyze current traffic data to find the appropriate PCE of each vehicle type suitable for Thailand's four-lane highways.

2. Literature review

2.1 PCEs used in Thailand [1-5]

In general, PCE factors that were used in the analysis, planning, and design of highways in Thailand were mostly based on research and development in foreign countries. However, due to the differences in general characteristics of roads and vehicles, especially trucks and buses, and other factors, the foreign PCEs do not correlate to the actual traffic conditions of Thailand and the use of the foreign PCEs may result in inaccuracy of level of service (LOS) analysis.

During the past two decades, the Department of Highways (DOH), Thailand [1-5] had studied PCEs in many projects in order to gather actual traffic characteristics on highways. Examples of PCE factors in past studies are shown in Table 1.

Table 1 PCEs in the past studies of DOH, Thailand. [1-5]

Type of Vehicle	Passenger Car Equivalent Factor				
	DOH[1]	DOH[2]	DOH[3]	DOH[4]	DOH[5]
1. Motorcycle (MC)	0.25	-	0.30	0.25	-
2. Motor-Tricycle (TC)	0.25	-	-	0.75	-
3. Passenger Car (PC), Van, Pick-up	1.00	1.00	1.00	1.00	1.00

Table 1 (continued) PCEs in the past studies of DOH, Thailand. [1-5]

Type of Vehicle	Passenger Car Equivalent Factor				
	DOH[1]	DOH[2]	DOH[3]	DOH[4]	DOH[5]
4. Light Bus (LB)	1.50	1.25	-	1.00	1.60
5. Normal Bus (HB)	2.00	2.00	2.00	1.75	1.60
6. 4-wheeled truck (LT)	2.00	1.50	2.00	2.00	-
7. Medium Truck)6-wheels: MT(	2.00	1.75	2.00	2.50	1.30
8. Group of heavy truck)10-wheels: HT(, Semi-Trailer (ST) and Full-Trailer (FT)	2.00	2.00	2.00	2.50	2.00

From Table 1, each project had different patterns of the PCE value. However, such values were not much different within each group of vehicles.

Currently, many agencies such as the Department of Highways (DOH), Office of Transport and Traffic Planning and Policy (OTP), Expressway Authority of Thailand (EXAT), and Department of Rural Roads (DRR) have defined and used certain PCEs, which are different based on traffic characteristics on the routes of each agency, as shown in Table 2.

Table 2 Current PCEs used in relevant agencies in Thailand. [6-9]

Type No.	Type of Vehicle	PCE values			
		DOH[6]	OTP[7]	EXAT[8]	DRR[9]
1	Bike	0.20	0.20	-	-
2	Motorcycle, MC	0.333	0.25	-	0.25
3	Motor-tricycle, TC	1.00	1.00	-	-
4	Passenger Car <7 Passengers, PC	1.00	1.00	1.00	1.00
5	Passenger Car >7 Passengers, PC-L	1.00	1.00	1.00	
6	Light Truck, LT	1.00	1.00	1.00	
7	Light Bus, LB	1.50	1.50	1.50	

Table 2 (continued) Current PCEs used in relevant agencies in Thailand. [6-9]

Type No.	Type of Vehicle	PCE values			
		DOH[6]	OTP[7]	EXAT[8]	DRR[9]
8	Medium Bus, MB	1.50	2.00	1.50	2.00
9	Medium Truck, MT	2.10	2.00	2.10	
10	Heavy Bus, HB	2.10	2.00	2.10	
11	Heavy Truck, HT	2.50	2.50	2.50	2.50
12	Full Trailer, FT	2.50	2.50	2.50	
13	Semi-Trailer, ST	2.50	2.50	2.50	

2.2 Comparison of PCEs with other countries. [6-15]

In general, the configuration of PCEs is also different across countries. Hence, the PCEs in various countries including Malaysia, Indonesia, China, the UK, and the United States, and the ASEAN Highway Standard are reviewed in order to understand the use of passenger car equivalents (PCEs) in each country. The comparison of PCEs is shown in Table 3.

Table 3 PCEs used in other countries. [6-15]

Type No.	Type of Vehicle	PCE values of each country						
		THA. [6-9]	MAS. [10]	IDN. [11]	AHS. [12]	CHN. [13]	UK. [14]	USA. [15]
1	Bicycle	0.20	-	-	0.50	-	0.20	-
2	Motorcycle, MC	0.25 - 33.03	0.22 - 0.33	0.20 - 0.50	0.50	0.30 - 60.0	0.40	-
3	Motor-tricycle, TC	1.00	-	-	-	1.40	-	-
4	Passenger Car<7, PC	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	Passenger Car>7, PC-L	1.00	1.00 - 1.75	-	-	-	1.00	-
6	Light Truck, LT	1.00	-	-	1.00	-	1.00	-

Table 3 (continued) PCEs used in other countries. [6-15]

Type No.	Type of Vehicle	PCE values of each country						
		THA. [6-9]	MAS. [10]	IDN. [11]	AHS. [12]	CHN. [13]	UK. [14]	USA. [15]
7	Light Bus, LB	1.25 - 50.1	-	-	-	-	-	-
8	Medium Bus, MB	1.50 - 2.00	-	-	-	1.20 - 60.1	-	-
9	Medium Truck, MT	1.75 - 10.2	1.19 - 1.75	1.30 - 70.1	-	1.20 - 60.1	1.50	-
10	Heavy Bus, HB	2.00 - 10.2	2.08 - 2.25	1.50	2.00	1.40 - 00.2	2.00 - 3.20	1.50
11	Heavy Truck, HT	2.00 - 50.2	2.25 - 2.27	1.30 - 2.50	2.00	1.40 - 00.2	2.30	1.50
12	Full Trailer, FT	2.50 - 3.00	-	-	3.00	2.00 - 50.2		
13	Semi-Trailer, ST	2.50 - 3.00	-	-	3.00	2.00 - 50.2		
14	Recreational Vehicle, RV	-	-	-	-	-	-	1.2

Note: "THA" (Thailand), "MAS" (Malaysia), "IDN" (Indonesia), "AHS" (Asian Highway Std.), "CHN" (China), "UK" (United Kingdom), "USA" (United States of America).

2.3 Factors affecting PCE value [16]

According to the review of factors affecting PCE values from various researches [16], 4 main factors that will affect PCE are a) Gradient, b) Percentage of Truck, c) Number of Lane, and d) Level of Service. However, this study is focused only the gradient factor and ignored other factors by study on four-lane highways in the uninterrupted traffic conditions.

2.4 Methods to determine PCEs

Shalini and Kumar [17] and Ingle [18] have reviewed and summarized the existing methods to determine PCEs, which can be grouped as follows: a) PCEs Based on Flow

Rates and Density, b) PCEs Based on Headways, c) PCEs Based on Queue Discharge Flow, d) PCEs Based on Speed, e) PCEs Based on Delays, f) PCEs Based on V/C Ratio, g) PCEs Based on Vehicle-Hours, and h) PCEs Based on Travel Time. However, the headway method, Lagging Time Headway (LTH), is selected for this study because of the clear concept that headway is a measure of the space occupied by the vehicle of interest and the ease of field data collection.

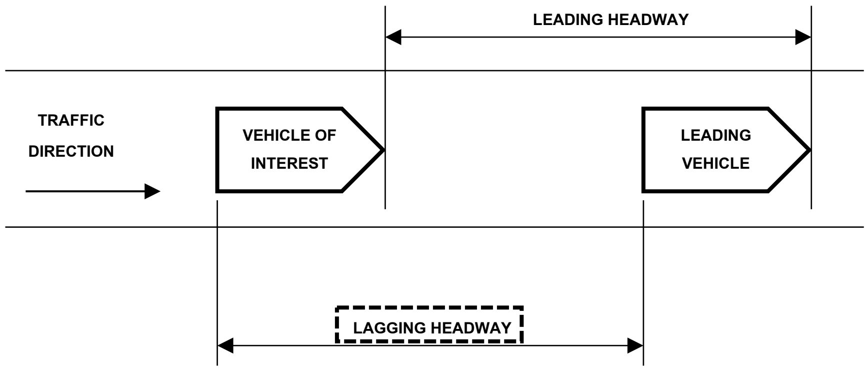

Figure 1 Lagging headway definition. (Adapted from Krammes and Croley [19])

Hence, Passenger Car Equivalent (PCE) can be defined as equation 1.

$$PCE_{ij} = \frac{LTH_{ij}}{LTH_{PCj}} \qquad (1)$$

When PCE_{ij} is Passenger Car Equivalent of vehicle type i under traffic condition j

LTH_{ij} is Average Lagging Time Headway of vehicle type i under traffic condition j

LTH_{PCj} is Average Lagging Time Headway of passenger car i under traffic condition j

3. Data Collection and analysis

This research started with the review of literatures relating to PCE values. Then, 12 sections of four-lane highways representing characteristics of highway sections covering the areas from flat to hilly terrain were intentionally chosen for data collection. Next, data gathering in each section was conducted for two days from 6:00 A.M. to 6:00 P.M. during 16-21 July, 2015. After that, the process involved decoding the video signals from the digital video cameras to identify the volume, speed, and lagging time headway of 13 different vehicle classes as described in Table 2. The software used for manual data decoding is represented in Figure 2 [16].

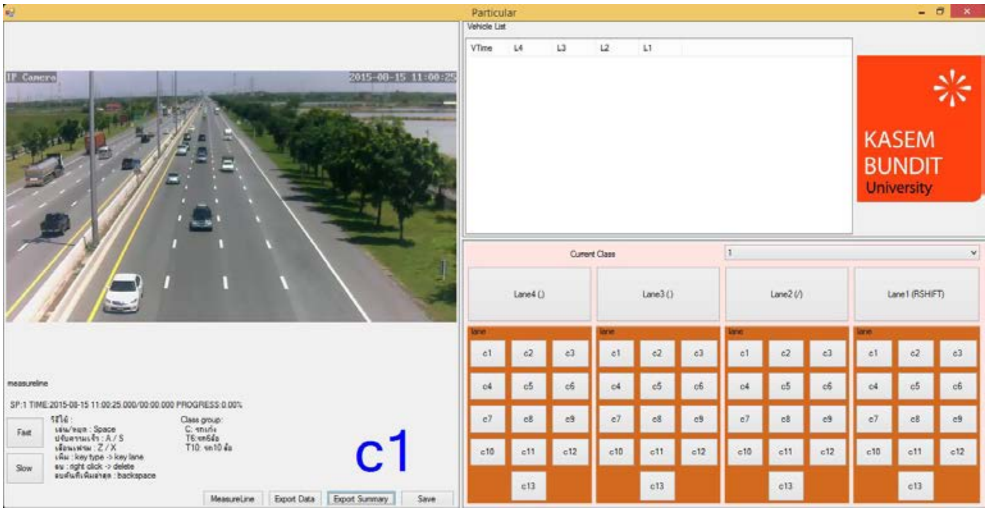

Figure 2 Software used for data decoding. [16]

Then, Lagging Time Headways (LTH), the representative values of size, velocity and freedom of movement of the vehicles of interest, were obtained from the videos every 15 minutes. After that, the process of data screening was done by filtering out the LTH value that was greater than 7 seconds because the particular vehicle did not follow in the same platoon. Moreover, all LTH data of each vehicle were plotted to determine the 20th-80th percentile level in order to eliminate the tailgating behavior and non-platoon state of vehicles.

Following that, the average 15-minute LTH values were calculated and used for PCE analysis. Figure 3 shows the detail of the average 15-minute PCE analysis of each vehicle type on Highway Route No. 24 from Kilometers 5+200 direction to Sikhio in Lane No. 1 from 6:00 A.M. – 6:00 P.M. of the first day of data collection.

No.	Time	Ave. 15-min Time Headway (s)												Passenger Car Equivalent (PCE)										
		PC	MC	TC	PC-L	LT	LB	MB	MT	HB	HT	FT	ST	MC	TC	PC-L	LT	LB	MB	MT	HB	HT	FT	ST
1	06.00-06.15	2.7	2.2			2.7					5.2	5.7	6.1	0.81	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.93	2.11	2.26
2	06.15-06.30	2.7										5.7	5.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.11	2.11
3	06.30-06.45	2.5				2.6			4.1				5.2	0.00	0.00	0.00	1.04	0.00	0.00	1.64	0.00	0.00	0.00	2.08
4	06.45-07.00	2.5	1.7	2.5							4.8	5.8	5.2	0.68	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.92	2.32	2.08
5	07.00-07.15	2.6	1.5		3.1	3.6	4.2		4.5		4.7		6.2	0.58	0.00	1.19	1.38	1.62	0.00	1.73	0.00	1.81	0.00	2.38
6	07.15-07.30	2.4	1.6		3	2.7			3.2		5.6	5.8	5.6	0.67	0.00	1.25	1.13	0.00	0.00	1.33	0.00	2.33	2.42	2.33
7	07.30-07.45	2.6			2.8	3					4.9	5.9		0.00	0.00	1.08	1.15	0.00	0.00	0.00	0.00	1.88	2.27	0.00
8	07.45-08.00	2.6	1.9			3.2			4.2		6.4	5.4	6.2	0.73	0.00	0.00	1.23	0.00	0.00	1.62	0.00	2.46	2.08	2.38
9	08.00-08.15	2.6	1.7								5.1			0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.96	0.00	0.00
10	08.15-08.30	2.5	1.5		2.6	2.6			4.5		5.6	5.4	5.6	0.60	0.00	1.04	1.04	0.00	0.00	1.80	0.00	2.24	2.16	2.24
11	08.30-08.45	2.5				2.8			4.6			5.8		0.00	0.00	0.00	1.12	0.00	0.00	1.84	0.00	0.00	2.32	0.00
12	08.45-09.00	2.4	1.9		2.9	2.5					5.5	5.1	5.3	0.79	0.00	1.21	1.04	0.00	0.00	0.00	0.00	2.29	2.13	2.21
45	17.00-17.15	2.5	1.7		2.5	3		3.3	4.3		5.1	5.7	5.8	0.68	0.00	1.00	1.20	0.00	1.32	1.72	0.00	2.04	2.28	2.32
46	17.15-17.30	2.6	1.6		2.5	2.4			4.5		5.3	5.6	5.7	0.62	0.00	0.96	0.92	0.00	0.00	1.73	0.00	2.04	2.15	2.19
47	17.30-17.45	2.7			2.8	2.8				5.8	5.8		4.9	0.00	0.00	1.04	1.04	0.00	0.00	0.00	2.15	2.15	0.00	1.81
48	17.45-18.00	2.6			2.5	2.8			3.9			5.3		0.00	0.00	0.96	1.08	0.00	0.00	1.50	0.00	0.00	2.04	0.00
	Ave. of PCE of each vehicle type on lane: l, day:d													0.71	0.96	1.11	1.09	1.62	1.30	1.64	2.14	2.11	2.16	2.15

Figure 3 Example of the analysis of 15 min-LTH$_i$ of vehicles with 15 min-LTH$_{PC}$ on Highway Route No.24 KM.5+200 direction to Sikhio in Lane No.1, Day No.1

The data collection was done on two lanes in each direction and took a period of two days. Then the technique of weight average was applied in order to find the average PCE of each vehicle type. Equation 2 shows the concept of a 2-day weighted average of PCE values on Highway Route No. 24 from Km. 5+200 direction to Sikhio.

$$Ave.PCE_{ir} = \frac{(PCE_{ir1} * n_{ir1}) + (PCE_{ir2} * n_{ir2})}{(n_{ir1} + n_{ir2})} \qquad (2)$$

When $Ave.PCE_{ir}$ is average Passenger Car Equivalent of vehicle type i on route r

PCE_{ir1} is Average Passenger Car Equivalent of vehicle type i on route r of day no. 1

PCE_{ir2} is Average Passenger Car Equivalent of vehicle type i on route r of day no. 2

n_{ir1}, n_{ir2} is the number of vehicle type i on route r of days no. 1 and 2

According to the analysis, the average Passenger Car Equivalent of each vehicle type on 12 sections is shown in Table 4.

Table 4 Average PCE of each vehicle class on each sections.

Highway Section	Direction to	% Slope	Passenger Car Equivalent (PCE)										
			MC	TC	PC-L	LT	LB	MB	MT	HB	HT	FT	ST
Hw.24 km.7+950	Pak Thong Chai	-1.123	0.6892	0.8283	1.1016	1.1167		1.7062	1.5952	2.1764	2.0174	2.1974	2.1637
Hw.24 km.7+950	Sikhio	1.123	0.6585	0.8700	1.1054	1.0949	1.3745	1.6800	1.5883	2.1368	2.0574	2.1237	2.1299
Hw.24 km.5+200	Sikhio	-2.237	0.7193	0.7602	1.0775	1.0674	0.8077	1.2869	1.6637	2.2745	2.1951	2.2027	2.2140
Hw.24 km.5+200	Pak Thong Chai	2.237	0.6540	0.7044	1.0764	1.0779	1.0593	1.1498	1.6133	2.1643	2.2261	2.2323	2.1801
Hw.24 km.15+100	Pak Thong Chai	-3.638	0.6900	0.7300	1.1800	1.1800	1.2900	1.6100	1.5400	2.0900	2.1500	2.1600	2.2100
Hw.24 km.15+100	Sikhio	3.638	0.6400	0.9110	1.0840	1.1160	1.2860	1.3230	1.5730	2.1050	2.0100	2.0790	2.1182
Hw.11 km.134+500	Phrae	-4.719	0.7147	0.9200	1.0510	1.0655			1.6278	2.3740	2.3408	2.3282	2.3339
Hw.11 km.134+500	Uttaradit	4.719	0.7246		1.0643	1.0677		1.6505	1.6343	2.2279	2.2913	2.3415	2.2733
Hw.11 km.132+200	Phrae*	5.733	0.7667		1.0838	1.1094		1.7254	1.5657	2.2644	2.2606	2.4686	2.4506
Hw.11 km.132+200	Uttaradit	-5.733	0.7646		1.0657	1.1294		1.8200	1.6920	2.3296	2.2178	2.2310	2.2359
Hw.11 km.134+100	Phrae	6.385	0.7408	1.0689	1.0869	1.0767	1.1385	1.6356	1.6357	2.2837	2.2537	2.2584	2.3034
Hw.11 km.134+100	Uttaradit	-6.385	0.6654		1.0654	1.0876	1.1217	1.5351	1.5833	2.3780	2.2739	2.2895	2.3016

4. PCE of four-lane highway for Thailand.

In order to find the relationship between PCE (dependent variable: Y) and highway gradient (independent variable: X), the linear and polynomial regression analysis was applied. After that, the suitable equations were selected based on R^2 value. The results show that the polynomial is the better represent of the relationship between PCE and highway gradient. Moreover, PCE of almost all vehicles on four-lane highways is likely to increase along the slope of the highway. From the relationship above, the PCE based on the slope of the four-lane highways can be summarized as shown in Table 5.

Table 5 PCE of each vehicle type based on gradient of the four-lane highways.

Vehicle Type	Relationship equation	R^2	Slope (%)								
			-7	-5	-3	-2	0	+2	+3	+5	+7
MC	$y = 0.0015x^2 + 0.0008x + 0.6725$	0.2959	0.7	0.7	0.7	0.7	**0.7**	0.7	0.7	0.7	0.8
TC	$y = 0.0059x^2 + 0.0084x + 0.7715$	0.6436	1.0	0.9	0.8	0.8	**0.8**	0.8	0.8	1.0	1.1
PC-L	$y - = 0.0007x^2 - 0.0002x + 1.1012$	0.1130	1.1	1.1	1.1	1.1	**1.1**	1.1	1.1	1.1	1.1
LT	$y - = 0.0002x^2 - 0.0018x + 1.1026$	0.0648	1.1	1.1	1.1	1.1	**1.1**	1.1	1.1	1.1	1.1
LB	$y = -0.0001x^2 + 0.0076x + 1.1547$	0.0320	1.1	1.1	1.1	1.1	**1.2**	1.2	1.2	1.2	1.2
MB	$y = 0.0055x^2 - 0.0045x + 1.4549$	0.1701	1.8	1.6	1.5	1.5	**1.5**	1.5	1.5	1.6	1.7

Table 5 (continued) PCE of each vehicle type based on gradient of the four-lane highways.

Vehicle Type	Relationship equation	R^2	Slope (%)								
			-7	-5	-3	-2	0	+2	+3	+5	+7
MT	$y = 0.0005x^2 - 0.0016x + 1.6006$	0.0510	1.6	1.6	1.6	1.6	**1.6**	1.6	1.6	1.6	1.6
HB	$y = 0.0046x^2 - 0.0082x + 2.146$	0.6065	2.4	2.3	2.2	2.2	**2.1**	2.1	2.2	2.2	2.3
HT	$y = 0.0047x^2 - 0.0022x + 2.1005$	0.4177	2.3	2.2	2.1	2.1	**2.1**	2.1	2.1	2.2	2.3
FT	$y = 0.0041x^2 + 0.004x + 2.1641$	0.3632	2.3	2.2	2.2	2.2	**2.2**	2.2	2.2	2.3	2.4
ST	$y = 0.0047x^2 + 0.0022x + 2.1532$	0.5418	2.4	2.3	2.2	2.2	**2.2**	2.2	2.2	2.3	2.4

The above table showed that the relationship of PCE (Y's) and gradient (X's) was different in each type of vehicle. Moreover, with an increase in the absolute value of the gradient, the PCE value of heavy vehicle groups tends to increase. On the other hand, the PCE value of the light vehicle group is not so sensitive relative to the gradient.

5. Conclusions and Discussions

The literature review suggested that Passenger Car Equivalent (PCE) values were truly essential for traffic engineering studies, highway planning and design and traffic analysis. Moreover, the lagging time headway method was the most appropriate method for studying and analysing PCEs for this project. According to the analysis result, LTH and PCE of bicycle mode was negligible due to small sample size and the driving behaviour of the bike, which generally runs along the shoulder of a highway.

The results show that proper PCE values for a four-lane highway in Thailand should range from 0.70 to 2.20 for a flat terrain depending on types of vehicle as follows: 1) motorcycle (0.70 PCU); 2) motor-tricycle (0.80 PCU); 3) sedan or passenger car (fewer than 7 passengers) (1.00 PCU); 4) passenger car (more than 7 passengers) and passenger van (1.10 PCU); 5) light truck or pick-up (1.10 PCU); 6) light bus (1.20 PCU); 7) medium bus or 6-wheeled bus (1.50 PCU); 8) medium truck or 6-wheeled truck (2 axles) (1.65 PCU); 9) heavy bus or 10-wheeled bus (2.10 PCU); 10) 10-wheeled truck (2.10 PCU); and trailers (more than 3 axles) (2.20 PCU).

Moreover, the analysis results indicate that the values of PCE varied with highway gradients. When the absolute value of a slope is higher, the PCE value has a tendency to increase but is different depending on the type of vehicle.

Finally, there are some important points to be discussed. Firstly, the PCE of Motorcycle (PCE_{MC}) increased from 0.25-0.33 to 0.70. This reflects that the motorcycle mode makes more impact on four-lane highway capacity than we ever realized. Secondly, the PCE of the large Passenger Car (more than 7 passengers) or Passenger Van (PCE_{PC-L}) and Light Truck (PCE_{LT}) increased from 1.00 to 1.10. These reflect the real behavior of the vehicles, especially for 4-wheeled Trucks whose load capacity can be up to a total weight of 9.5 tons. Consequently, the mobility of Light Truck from this study should be less than that of Passenger Car. Next, the PCE of the Heavy Truck segment of 10 or more vehicles has been reduced from 2.50 to 2.10-2.20, which reflects the development of vehicle standards resulting in trucks that are more powerful with more braking efficiency. Lastly, the traffic conditions in this study were only the 2-day data collection on 12-sections of the four-lane uninterrupted flows highways. Hence, further study on other types of highways and traffic conditions is recommended.

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