The Effect of Highway Gradient on Passenger Car Equivalents (PCE) of Two-Lane Highways in Thailand

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

***Index Terms*— Highway gradient, Two-lane highway, Passenger car equivalent, Lagging time headway, Uninterrupted traffic**

I. 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.

In this study, the two-lane highways were focused because the highest proportion compared to the others. In 2017, Department of Highways (DOH) declared that two-lane highways were 34,325.562 kilometers out of the total 51,781.162 kilometers (66.29 percent) [1]. 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 two-lane highways.

II. Literature Review

A. PCEs Used in Thailand [2]

Satthamnuwong, Chaichannawatik, and Petchan [2] point out that PCE factors that were used in the past 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 imprecision of level of service (LOS) analysis.

After that, during the past two decades, the Department of Highways (DOH), Thailand had studied PCEs in many highway projects in order to gather actual traffic characteristics on specific sections. Examples of PCEs value in past studies in Thailand are shown in Table I.

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TABLE I. PCEs IN THE PAST STUDIES OF DOH, THAILAND. [2]

Type of Vehicle	Passenger Car Equivalent Factor				
	Highways[1]	Motorway[2]	ay no.201	Motorway[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
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

Currently, many organizations responsible for highways and transportation 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 II.

TABLE II. CURRENT PCEs USED IN RELEVANT AGENCIES IN THAILAND. [2]

Type No.	Type of Vehicle	PCE values			
		DOH[6]	OTP[7]	EXAT[8]	DRR[9]
1	Bike	0.20	20.0	-	-
2	Motorcycle, MC	3.03	25.0	-	0.25
3	Motor-tricycle, TC	1.00	00.1	-	-
4	Passenger Car <7 pax, PC	00.1	00.1	00.1	1.00
5	Passenger Car >7 Pax, PC-L	00.1	00.1	00.1	
6	Light Truck, LT	00.1	00.1	00.1	
7	Light Bus, LB	50.1	50.1	50.1	
8	Medium Bus, MB	50.1	2.00	50.1	2.00
9	Medium Truck, MT	10.2	00.2	10.2	
10	Heavy Bus, HB	10.2	00.2	10.2	
11	Heavy Truck, HT	50.2	5.20	50.2	2.50
12	Full Trailer, FT	50.2	5.20	50.2	
13	Semi-Trailer, ST	50.2	5.20	50.2	

[1] DOH. (2000). The study of reserved highway development to the south: Hua Hin - Bang Saphan District. Final Report. Ministry of Transport. Thailand. (In Thai)

[2] DOH. (2002). The Study of Inter-city motorway construction project between Chiang Mai and Chiang Rai. Final Report. Ministry of Transport. Thailand. (In Thai)

[3] DOH. (2004). The Study of Highway route no. 12 construction projects: Nhong Ruea - Highway no.201. Final Report. Ministry of Transport. Thailand. (In Thai)

[4] DOH. (2004). The Study of Inter-city motorway construction project: Chonburi - Pattaya. Final Report. Ministry of Transport. Thailand. (In Thai)

[5] DOH. (2001). The study on The Strengthening of DOH's Management and Updating of The Long-Term Strategic Investment Plan. Final Report. Ministry of Transport. Thailand. (In Thai)

[6] DOH. (2018). Travelled-Vehicle Kilometer on Highways Report in 2017. Ministry of transport. Thailand. (In Thai)

[7] Office of transport and traffic policy and planning. (2011), Transport Data and Model integrated with Multimodal Transport and Logistics (TDL) project, Final report, Ministry of Transport, Thailand. (In Thai)

[8] EXAT. (2016). Feasibility Study on the Engineering, Economic, Financial and Environmental Aspect of the Udonratthaya-Ayutthaya Expressway Project. Final report. Ministry of Transport, Thailand. (In Thai)

[9] DRR. (2013). Traffic and Accident on Rural Road Annual Report in 2012. Ministry of Transport. Thailand. (In Thai)

B. *Factors Affecting PCE Value [3]*

According to the review of factors affecting PCE values from various researches can be classified into 3 main groups,

1) Geometric of highway factors such as number of lane, lane width, percent grade and length of grade, etc.

2) Efficiency of vehicle factors such as type of vehicle, size, weight, power and braking efficient, etc.

3) Traffic factor such as percentage of truck, speed, Level of Service (LOS), etc.

The 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 two-lane highways in the uninterrupted traffic conditions.

C. *Methods to Determine PCEs*

Shalini and Kumar [4] and Ingle [5] 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. The concept of LTH values are shown in Fig. 1. Hence, Passenger Car Equivalent (PCE) can be defined as equation 1.

$$PCE_{ij} = \frac{LTH_{ij}}{LTH_{PCj}} \tag{1}$$

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

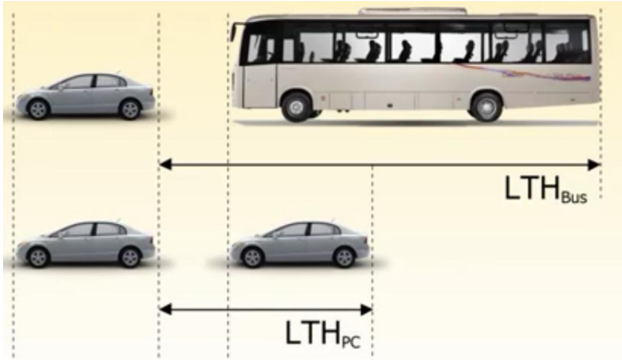

Figure 1. Lagging Time Headway (LTH) of interested vehicles under traffic condition j.,

III. DATA COLLECTION AND ANALYSIS

This research started with the review of literatures relating to PCE values. Then, 12 sections of two-lane highways representing characteristics of highway sections covering the areas from flat to hilly terrain were intentionally chosen for data collection. The example of two-lane highways sections data is shown in Fig. 2.

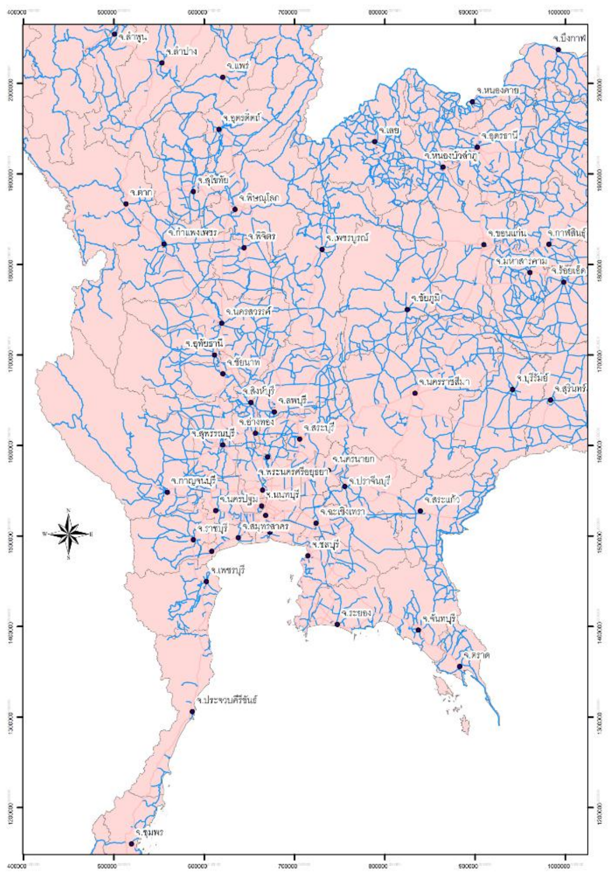

Figure 2. The candidate two-lane highway sections for data collection

Next, data gathering in each section was conducted for two days from 6:00 A.M. to 6:00 P.M. during 16-31 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 II. The example of software used for manual data decoding is represented in Fig. 3.

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. Table III shows the detail of the average 15-minute PCE analysis of each vehicle type on Highway Route No. 304 from Kilometers 216+260 direction to Prachinburi in Lane No. 1 from 6:00 A.M. – 6:00 P.M. of the first day of data collection.

Figure 3. Example of data decoding. [2]

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.

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

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 Highway Route No. 304 from Km. 216+260 direction to Sikhio. sections is shown in Table IV

TABLE III. AVERAGE PCE OF EACH VEHICLE TYPE ON LANE NO.1 DAY NO.1

No.	Time	Average 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	2.2	1.5		2.4	2.6	3.2		4.6			6.2	5.3	0.68	0.00	1.09	1.18	1.45	0.00	2.09	0.00	0.00	2.82	2.41
2	06.15-06.30	2.3			2.5	2.3	3.4		3.8		4.1	5	5.4	0.00	0.00	1.09	1.00	1.48	0.00	1.65	0.00	1.78	2.17	2.35
3	06.30-06.45	2.2			2.4	2.2			3.9		4	5.5	6.1	0.00	0.00	1.09	1.00	0.00	0.00	1.77	0.00	1.82	2.50	2.77
4	06.45-07.00	2.2			2.6	2.4			3.5	4.3	5	6.3	5.7	0.00	0.00	1.18	1.09	0.00	0.00	1.59	1.95	2.27	2.86	2.59
5	07.00-07.15	1.9			2.2	2.4								0.00	0.00	1.16	1.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	07.15-07.30	2			2.3	2.5								0.00	0.00	1.15	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	07.30-07.45	2			2.4	2								0.00	0.00	1.20	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	07.45-08.00	1.9			2.3	2								0.00	0.00	1.21	1.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	08.00-08.15	2	1.8		2.5	2.3			4		4.8	4.3	5.3	0.90	0.00	1.25	1.15	0.00	0.00	2.00	0.00	2.40	2.15	2.65
10	08.15-08.30	2.2	1.6		2.2	2.4							5.4	0.73	0.00	1.00	1.09	0.00	0.00	0.00	0.00	0.00	0.00	2.45
11	08.30-08.45	2.1	1.2		2.1	2.4			4.2		5	5.8	6.2	0.57	0.00	1.00	1.14	0.00	0.00	2.00	0.00	2.38	2.76	2.95
12	08.45-09.00	2.1			2.3	2			3.9			4.7	6	0.00	0.00	1.10	0.95	0.00	0.00	1.86	0.00	0.00	2.24	2.86
13	09.00-09.15	2.2	2.2		2.2	2.6	4			5	6.1		5.8	1.00	0.00	1.00	1.18	1.82	0.00	0.00	2.27	2.77	0.00	2.64
14	09.15-09.30	2.2	1.7		2.5	2.5					5.1		6.2	0.77	0.00	1.14	1.14	0.00	0.00	0.00	0.00	2.32	0.00	2.82
15	09.30-09.45	2.2			2.4	2.2								0.00	0.00	1.09	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	09.45-10.00	2.1	2		2.5	2.4		4.3			5		5	0.95	0.00	1.19	1.14	0.00	2.05	0.00	0.00	2.38	0.00	2.38
17	10.00-10.15	2.2	1.4		2.4	2.5			4.8		5		4.7	0.64	0.00	1.09	1.14	0.00	0.00	2.18	0.00	2.27	0.00	2.14
18	10.15-10.30	2.1	1.7		2.2	2.5			3.9					0.81	0.00	1.05	1.19	0.00	0.00	1.86	0.00	0.00	0.00	0.00
19	10.30-10.45	2.3	1.6		2.1	2.4			4.6		6			0.70	0.00	0.91	1.04	0.00	0.00	2.00	0.00	2.61	0.00	0.00
20	10.45-11.00	2.1	1.2		2.4	2.2	3.8					4.6	5.2	0.57	0.00	1.14	1.05	1.81	0.00	0.00	0.00	0.00	2.19	2.48
21	11.00-11.15	2.1	1.1		2.5	1.9			4.9		4.9		6.3	0.52	0.00	1.19	0.90	0.00	0.00	2.33	0.00	2.33	0.00	3.00
22	11.15-11.30	2.1	1.4		2.3	2.3			4.7		5	6.4		0.67	0.00	1.10	1.10	0.00	0.00	2.24	0.00	2.38	3.05	0.00
23	11.30-11.45	2.1			2.4	2							6.4	0.00	0.00	1.14	0.95	0.00	0.00	0.00	0.00	0.00	0.00	3.05
24	11.45-12.00	2.2	1.6		2.3	2.2		3.8	5.1	5.2	4.3	6.2		0.73	0.00	1.05	1.00	0.00	1.73	2.32	2.36	1.95	2.82	0.00
25	12.00-12.15	2.1	1.5		2.3	1.7			4			5.7	6.1	0.71	0.00	1.10	0.81	0.00	0.00	1.90	0.00	0.00	2.71	2.90
26	12.15-12.30	2.2	1.6		2.4	2.3			4.8		5.1		6.2	0.73	0.00	1.09	1.05	0.00	0.00	2.18	0.00	2.32	0.00	2.82
27	12.30-12.45	2.1	1.6		2.3	2.7			4.1		5.5	4.8	5.1	0.76	0.00	1.10	1.29	0.00	0.00	1.95	0.00	2.62	2.29	2.43
28	12.45-13.00	2	1.3		2.2	2.4		3.9	4.5		6.1	5.2	5.6	0.65	0.00	1.10	1.20	0.00	1.95	2.25	0.00	3.05	2.60	2.80
29	13.00-13.15	2	2.2		2.3	2.2			4		5.2	6.6	5.2	1.10	0.00	1.15	1.10	0.00	0.00	2.00	0.00	2.60	3.30	2.60
30	13.15-13.30	2			2.2	2.3			3.9	5.6	5.3		4.8	0.00	0.00	1.10	1.15	0.00	0.00	1.95	2.80	2.65	0.00	2.40
31	13.30-13.45	2.1	1.6		2.3	2.1		4.8		4.4		6.2	6.4	0.76	0.00	1.10	1.00	0.00	2.29	0.00	2.10	0.00	2.95	3.05
32	13.45-14.00	2.1	1.9		2.1	2.2			4.3	5	4.7	5.4	5.8	0.90	0.00	1.00	1.05	0.00	0.00	2.05	2.38	2.24	2.57	2.76
33	14.00-14.15	2	1.9		2.1	2.6			4.7	5.6	6.1		6.2	0.95	0.00	1.05	1.30	0.00	0.00	2.35	2.80	3.05	0.00	3.10
34	14.15-14.30	2.1	1.3		2.3	2.1			4.5	5.7			5.9	0.62	0.00	1.10	1.00	0.00	0.00	2.14	2.71	0.00	0.00	2.81
35	14.30-14.45	2	1.4		2.2	2.5			4.5		5.6		6.4	0.70	0.00	1.10	1.25	0.00	0.00	2.25	0.00	2.80	0.00	3.20
36	14.45-15.00	2.1	1.4		2.3	2.2			5	5.3			5.2	0.67	0.00	1.10	1.05	0.00	0.00	2.38	2.52	0.00	0.00	2.48
37	15.00-15.15	2.1			2.3	2.3			4.1	4.6	5.3		6.4	0.00	0.00	1.10	1.10	0.00	0.00	1.95	2.19	2.52	0.00	3.05
38	15.15-15.30	2	1.6		2.3	2.5		4.5	3.9				6.6	0.80	0.00	1.15	1.25	0.00	2.25	1.95	0.00	0.00	0.00	3.30
39	15.30-15.45	2.2	1.8		2.2	2.5			3.9		5		5.3	0.82	0.00	1.00	1.14	0.00	0.00	1.77	0.00	2.27	0.00	2.41
40	15.45-16.00	2.3	1.5		2.5	2.3		4.7			4.8		5.7	0.65	0.00	1.09	1.00	0.00	2.04	0.00	0.00	2.09	0.00	2.48
41	16.00-16.15	2			2.3	2.4			4.1		5.2	5	5.2	0.00	0.00	1.15	1.20	0.00	0.00	2.05	0.00	2.60	2.50	2.60
42	16.15-16.30	2.1	1.7		2.1	2.5			4.2	4.9	5.3	5.6	6.2	0.81	0.00	1.00	1.19	0.00	0.00	2.00	2.33	2.52	2.67	2.95
43	16.30-16.45	2			2.3	2.3			4.8		5.6	5.6	6.5	0.00	0.00	1.15	1.15	0.00	0.00	2.40	0.00	2.80	2.80	3.25
44	16.45-17.00	2.1	1.4		2.3	2.5			4.2	5.5	4.9	5.1	6	0.67	0.00	1.10	1.19	0.00	0.00	2.00	2.62	2.33	2.43	2.86
45	17.00-17.15	2.1	1.7		2.3	2.1		5	4.6		5.7		5.2	0.81	0.00	1.10	1.00	0.00	2.38	2.19	0.00	2.71	0.00	2.48
46	17.15-17.30	2	1.3		2.3	2.5	2.7	4.9	4.6		5.9		5.6	0.65	0.00	1.15	1.25	1.35	2.45	2.30	0.00	2.95	0.00	2.80
47	17.30-17.45	2.1	1.6		2.4	2.4		4.3	4.5		4.5	5.3	5.9	0.76	0.00	1.14	1.14	0.00	2.05	2.14	0.00	2.14	2.52	2.81
48	17.45-18.00	2	1.3		2.4	2	2.6	4.8	5				5.6	0.65	0.00	1.20	1.00	1.30	2.40	2.50	0.00	0.00	0.00	2.80
	Average PCE of each vehicle type on Lane no.1 Day no.1													**0.75**	**N.A.**	**1.10**	**1.10**	**1.54**	**2.16**	**2.07**	**2.42**	**2.45**	**2.61**	**2.73**

TABLE IV. THE EXAMPLE OF WEIGHT AVERAGE OF PCES ON HIGHWAY NO.304 KM.216+260 DIRECTION TO PRACHINBURI

Detail	Type of vehicle										
	MC	TC	PC-L	LT	LB	MB	MT	HB	HT	FT	ST
Average PCE of vehicle type i on route r of day no.1	0.75	-	1.10	1.10	1.54	2.16	2.07	2.42	2.45	2.61	2.73
Number of vehicle type i on route r of Day no.1	34.00	-	48.00	48.00	6.00	10.00	35.00	12.00	31.00	21.00	39.00
Average PCE of vehicle type i on route r of day no.2	0.71	-	1.07	1.11	1.37	1.73	1.70	2.21	2.45	2.54	2.54
Number of vehicle type i on route r of Day no.2	43.00	-	48.00	48.00	8.00	22.00	38.00	4.00	23.00	15.00	42.00
Weighted Ave PCE of vehicle type i on route r	**0.728**	-	**1.088**	**1.104**	**1.439**	**1.864**	**1.880**	**2.368**	**2.451**	**2.582**	**2.632**

Consequently, the analysis, the average Passenger Car Equivalent (PCEs) of each vehicle type on 12 sections is shown in Table V

TABLE V. 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. 201 KM. 31+000	Dan Khun Tod	-1.202	0.608	0.870	1.187	1.182	1.409	1.517	1.520	1.630	1.969	2.027	2.043
Hw. 201 KM. 31+000	Sikhio	1.202	0.605	0.870	1.162	1.212	1.445	1.525	1.528	1.909	2.038	2.089	2.080
Hw. 201 KM. 27+500	Dan Khun Tod	2.655	0.640	0.940	1.150	1.320	1.530	1.590	1.520	1.750	1.830	1.940	2.001
Hw. 201 KM. 27+500	Sikhio	-2.655	0.650	0.880	1.170	1.440	1.560	2.020	1.620	1.900	1.990	2.040	2.030
Hw. 2256 KM. 47+000	Lopburi	3.809	0.641	0.985	1.110	1.171	1.357	1.560	1.646	1.802	2.134	2.166	2.417
Hw. 2256 KM. 47+000	Nakhonrachasima	-3.809	0.701	1.048	1.137	1.187	1.400	1.673	1.674	2.068	2.177	2.120	2.392
Hw. 304 KM. 216+060	Nakhonrachasima	5.208	0.660	0.960	1.080	1.140	1.290	1.530	1.590	1.900	2.090	2.280	2.390
Hw. 304 KM. 216+060	Prachinburi	-5.208	0.682	N.A.	1.100	1.144	1.332	1.660	1.613	N.A	2.358	2.303	2.457
Hw. 304 KM. 216+260	Nakhonrachasima	5.935	0.767	N.A	1.108	1.129	1.524	1.721	1.880	2.162	2.398	2.622	2.533
Hw. 304 KM. 216+260	Prachinburi	-5.935	0.728	N.A	1.088	1.104	1.439	1.864	1.880	2.368	2.451	2.582	2.632
Hw. 2256 KM. 39+325	Nakhonrachasima	6.693	0.709	1.006	1.171	1.196	N.A	N.A	1.690	1.841	1.917	2.011	2.314
Hw. 2256 KM. 39+325	Lopburi	-6.693	0.794	1.043	1.165	1.236	1.310	N.A	1.527	2.089	1.965	2.017	2.113

The empty PCE values of some vehicles in Table V were occurred due to the lacking in number of vehicles and characteristic of the non-platoon following.

IV. PCE OF TWO-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. The example of relation of PCE and gradient of MC and TC on two-lane highway section are shown in Fig. 4.

Moreover, PCE of almost all vehicles on two-lane highways is likely to increase along the slope of the highway. From the relationship above, the PCE based on the slope of the two-lane highways can be summarized as shown in Table VI.

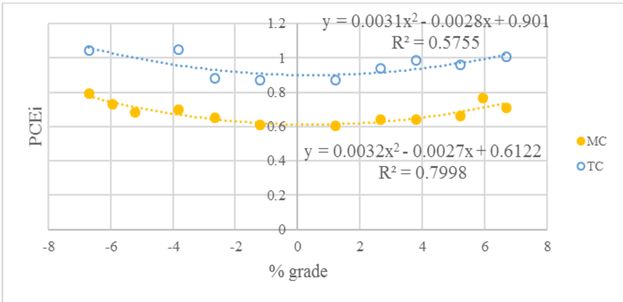

Figure 4. The example of relation analysis of PCE of each vehicle and gradient on two-lane highway section

TABLE VI. PCE OF EACH VEHICLE TYPE BASED ON GRADIENT OF THE TWO-LANE HIGHWAYS.

Vehicle Type	Relationship equation	R^2	Slope (%)								
			-7	-5	-3	-2	Flat	+2	+3	+5	+7
MC	$y = 0.0032x^2 - 0.0027x + 0.6122$	0.7998	0.8	0.7	0.6	0.6	**0.6**	0.6	0.6	0.7	0.8
TC	$y = 0.0031x^2 - 0.0028x + 0.901$	0.5755	1.1	1.0	0.9	0.9	**0.9**	0.9	0.9	1.0	1.0
PC-L	$y = -0.0007x^2 - 0.0005x + 1.1519$	0.1117	1.1	1.1	1.1	1.2	**1.2**	1.1	1.1	1.1	1.1
LT	$y = -0.0025x^2 - 0.0019x + 1.2584$	0.1898	1.1	1.2	1.2	1.3	**1.3**	1.2	1.2	1.2	1.1
LB	$y = -0.0023x^2 + 0.002x + 1.4634$	0.1651	1.3	1.4	1.4	1.5	**1.5**	1.5	1.4	1.4	1.4
MB	$y = 0.0033x^2 - 0.0181x + 1.6096$	0.2974	1.9	1.8	1.7	1.7	**1.6**	1.6	1.6	1.6	1.6
MT	$y = 0.0039x^2 + 0.0023x + 1.5562$	0.2525	1.7	1.6	1.6	1.6	**1.6**	1.6	1.6	1.7	1.8
HB	$y = 0.0074x^2 - 0.0192x + 1.8002$	0.5253	2.3	2.1	1.9	1.9	**1.8**	1.8	1.8	1.9	2.0
HT	$y = 0.004x^2 - 0.0097x + 2.0224$	0.1602	2.3	2.2	2.1	2.1	**2.0**	2.0	2.0	2.1	2.2
FT	$y = 0.0056x^2 + 0.0002x + 2.0611$	0.1637	2.3	2.2	2.1	2.1	**2.1**	2.1	2.1	2.2	2.3
ST	$y = 0.0076x^2 + 0.0018x + 2.1197$	0.3087	2.5	2.3	2.2	2.1	**2.1**	2.2	2.2	2.3	2.5

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.

V. 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 analyzing 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 behavior of the bike, which generally runs along the shoulder of a highway.

According to Table VI, the results show that appropriate uninterrupted PCE values for a two-lane highway in Thailand should range from 0.60 to 2.10 for a flat terrain depending on types of vehicle as follows: 1) motorcycle (0.60 PCU); 2) motor-tricycle (0.90 PCU); 3) sedan or passenger car (less than 7 passengers) (1.00 PCU); 4) passenger car (more than 7 passengers) and passenger van (1.20 PCU); 5) light truck or pick-up (1.30 PCU); 6) light bus (1.50 PCU); 7) medium bus or 6-wheeled bus (1.60 PCU); 8) medium truck or 6-wheeled truck (2 axles) (1.60 PCU); 9) heavy bus or 10-wheeled bus (1.80 PCU); 10) 10-wheeled truck (2.00 PCU); and other trailers (more than 3 axles) (2.10 PCU).

Additionally, the analysis results show that the most of PCE values relatively varied with highway gradients. When the absolute value of a slope is higher, the PCE value has a tendency to increase except $PCE_{PC.L}$, PCE_{LT} and PCE_{LB}.

Finally, there are some important points to be discussed. Firstly, the PCE of Motorcycle (PCE_{MC}) increased from 0.25-0.33 to 0.60. This reflects that the motorcycle mode makes more impact on two-lane highway capacity than we ever realized. Secondly, the underestimated PCE of the large Passenger Car (more than 7 passengers) or Passenger Van ($PCE_{PC.L}$) and Light Truck (PCE_{LT}) are 20 and 30 percent, respectively. 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 19 percent overvalued PCE of the Heavy Truck of 10 or more wheeled-vehicles, the analysis has been reduced from 2.50 to 2.10, 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 two-lane uninterrupted flows highways. Hence, the further study on other types of highways and traffic conditions is recommended.

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