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EFFECT OF AUTOMATED SPEED ENFORCEMENT SYSTEMS ON DRIVING BEHAVIOR AND ATTITUDES ON MOUNTAINOUS ROADS IN THAILAND

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ABSTRACT: Speeding is one of the leading causes of road traffic accidents in mountainous areas in Thailand. Recently, the government has been gaining attention to employ automated speed enforcement systems for monitoring speeding behavior on major highways. This study aims to evaluate the effectiveness of an automated speed enforcement system implemented along mountainous road sections in Thailand. Specifically, the study examines whether such system changes driving behavior and attitudes. The study has two thrusts. First, the study conducted the observational before-and-after speed study and performed the statistical analyses to evaluate driving behavior. Second, the study conducted the questionnaire surveys and applied the sequential equation modelling analyses together with the Theory of Planned Behavior concept to evaluate driving attitudes toward speeding and speed enforcement system. The study used the Highway No.118, one of the most hazardous mountainous corridors in Thailand as a case study. The results showed the changes in both driving behavior and attitudes. After implementing automated speed enforcement system. there were significant reductions in speed and the number of violators. Moreover, psychologically, drivers believe that they would increase the opportunity to perform overspeed if there is no speed control. Therefore, this study provides decision-makers better understand the characteristics of driving attitudes and behavior in Thailand and ensures the effectiveness of automated speed enforcement system.

Keywords: Safety, Speeding, Automated speed enforcement, Risk, Theory of planned behavior

1. INTRODUCTION

Like many other countries, speeding is one of the most leading causes of road traffic accidents on highway networks in Thailand. According to the 2009-2018 national accident statistics [1], speeding contributes 71% in road traffic accidents as shown in Fig. 1. Reducing speeding is now becoming a high-priority target for many road safety authorities. To this aim, proper and effective safety countermeasures have been proposed to reduce speeding lowering crash risk.

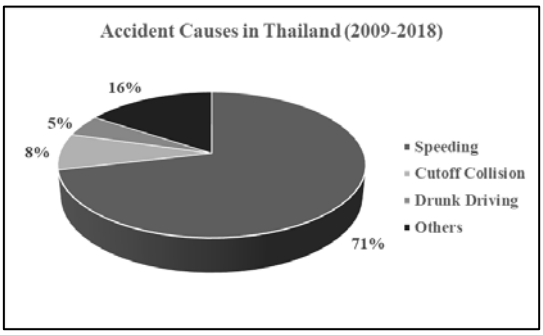

Fig.1 Causes of accident on highway network in Thailand between 2009 and 2018.

An automated speed enforcement system is one of emerging speed control technologies, which has been proved to be a success safety measures in many developed countries. Recently, Thai government has been gaining attention to employ automated speed enforcement systems for monitoring speeding behavior on major highways. The main objective of this study is to evaluate the effectiveness of the automated speed enforcement systems being implemented on mountainous roads in Thailand. The major contribution of this study is the examination of the changes in driving behavior and attitudes affected by the speed enforcement system on a high-risk mountainous corridor.

2. LITERATURE REVIEW

Various studies worldwide focused on evaluating the effectiveness of speed enforcement applied in different road functions and areas, such as freeways [2], arterial roads [3, 4], local streets [6], and residential streets and school zones [7, 8]. These studies measured the effectiveness of speed control in terms of speed reduction and the number of violators reduced. Table 1 lists some examples of research studies regarding the effectiveness of speed enforcement.

Table 1 Examples of Speed Enforcement Literature

Studies	Area	Measures of effectiveness
IIHS [3]	Freeways in Scottsdale, Arizona	Number of violators
Cunningham et al. [4]	14 corridors across Charlotte, North Carolina	Speed reductions and Crash reduction
Retting et al. [7]	Residential streets and school zones in Montgomery County, Maryland	Speed and Public attitude
D'Elia et al. [6]	Local streets in Melbourne and Victoria, Australia	Crashes, Casualty crashes,
Freedman et al. [8]	School zones in Portland, Oregon	Public awareness, Speed, Proportion of traffic exceeding the speed limit by 10 mph

The study by Lu [9] compared the effectiveness of different speed control measures. The study showed that the speed cameras have high efficiency and enhance the speed continuity of speed control. Moreover, the study by Marciano et al. [10] discussed the pros and cons of overt and covert speed cameras and suggested that the covert speed cameras (the drivers cannot notice) with the immediate feedback to the violators is the most efficient approach to motivate drivers to maintain their speeds.

While speed camera programs seem to be success in many countries today, the use of enforcement cameras is certainly contentious. It is found that several international programs were initially met with public resistance. There were a number of public concerns, which road safety professionals should consider when implementing a speed camera program. They include ticket procedures, how ticket revenues will be distributed, and whether or not automated enforcement results in reduced accident rates. [11]

3. RESEARCH APPROACH

This section is divided into three parts: the study area, the method to analyze driving behavior, and the method to analyze driving attitudes.

3.1 Study Area

Chiang Mai is the major city in the northern region of Thailand. About 89-percent of the area is mountainous terrain. Most of the roads connected to other neighboring cities are mountainous roads. One of the most dangerous roads is Highway No.118 (Chiang Rai - Chiang Mai) connected between Doi Nangkaew district in Chiang Rai Province and Doi Saked district in Chiang Mai Province. This road corridor has more than 7% grades and continuous curvy roads 3 kilometers or more. It has numerous road accidents in each year, and most of them are caused by speeding and unfamiliarity of drivers. Drivers fail to control the vehicles and the accidents result in massive loss of life and property. The average daily traffic along this corridor is 11,982 vehicles per day (both directions) in 2015 and the percent share of vehicle type is 11% of motorcycles, 39% of passenger cars, 36% of light trucks or pick-ups, 9% of heavy trucks, and 5% of buses. Fig. 2 shows the example of road section on Highway No.118.

Fig. 2 Example of road section in a study area

Highway No.118 in Chiang Mai was built in 1984. It is a 52-kilometer two-lane or four-lane undivided road with asphalt pavement. At the end of 2016, five automated speed cameras were installed along this corridor at the following station locations as shown in Fig. 3:

- Location 1: km 50+400 (Baan Nam Thu)
- Location 2: km 43+050 (Baan Pang Fan)
- Location 3: km 35+800 (Coffee Shop)
- Location 4: km 21+700 (Saan Pieng Ta)
- Location 5: km 15+600 (Doi Saket Junction)

Fig. 4 shows one of the automated speed camera system being installed in the study area.

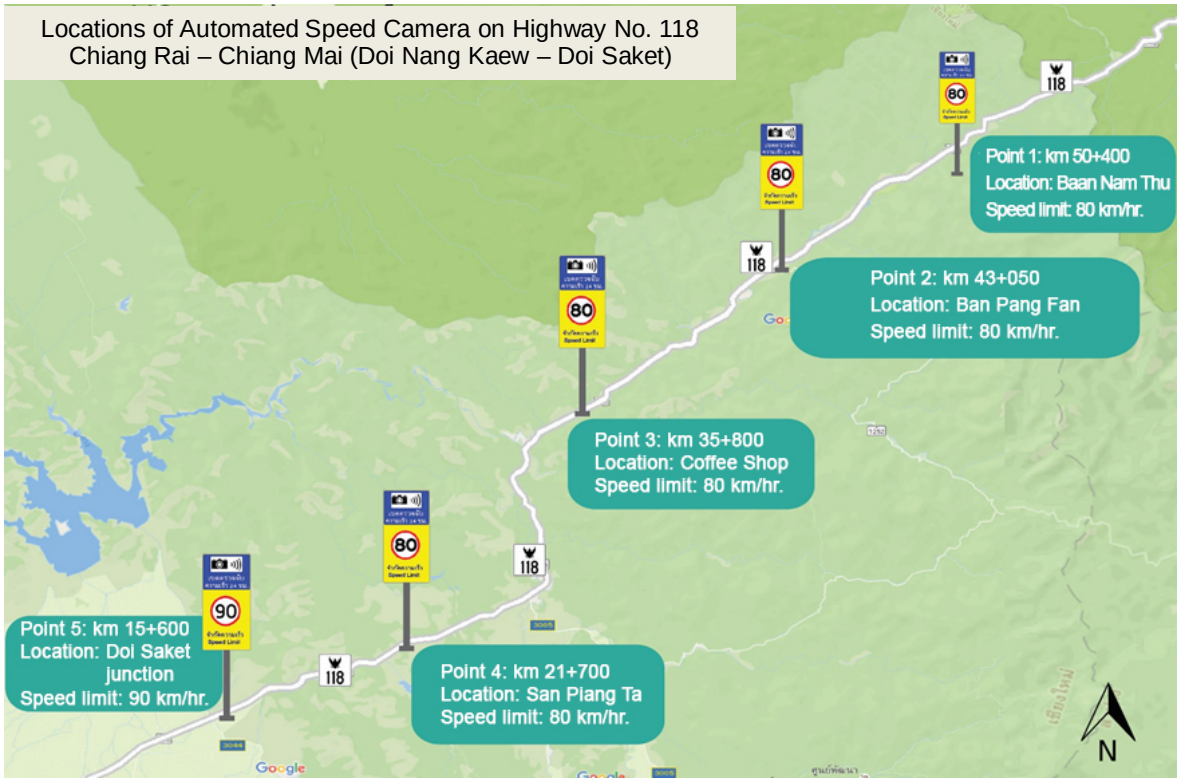

Fig. 3 Locations of automated speed camera

Fig. 4 Example of automated speed camera

3.2 Analysis of Speeding Behavior

The study examines the speeding behavior by comparing the speed data of road users before and after implementing automated speed enforcement. The observational before-and-after speed analysis is performed using the statistical *t*-test analysis. The hypothesis of the speed study is that there is difference between the vehicle speed data before and after implementing automated speed cameras along the corridor (H0). The t-test method calculates the *p*-value to find whether the difference between the means of two speed data groups is statistically significant within a specified confidence interval. The *t*-value is calculated using Eq. (1).

$$t = \frac{\overline{X_B} - \overline{X_A}}{\sqrt{\frac{S_B^2}{N_B} + \frac{S_A^2}{N_A}}} \quad (1)$$

where t is the value of statistical test, and $\overline{X_B}$ and $\overline{X_A}$ are the average speed of sample vehicles before and after installing automated speed camera, respectively. S_B and S_A are the standard deviation of sample vehicles before and after installing automated speed camera, respectively. N_B and N_A are the sample sizes of vehicles before and after installing automated speed camera, respectively.

3.3 Analysis of Speeding Attitudes

The study examines the speeding attitudes by using the statistical analysis of drivers' opinions. Questionnaire surveys are conducted by asking the opinions of drivers within the study area regarding speeding behavior, speed control measures, and factors affecting speeding behavior.

This study applies the Theory of Planned Behavior (TPB) to examine the psychological factors influencing the speeding behavior of road users. TPB firstly proposed by Icek Ajzen [12] in 1985 is one of the psychological theories explaining that the personal behavior is determined by three direct factors: attitude towards behavior (ATT), subjective norm (SN), and Perceived Behavioral Control (PBC), and one indirect factor: behavioral intention (IN) as shown in Fig. 4.

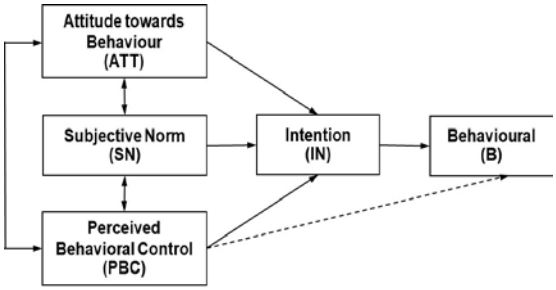

Fig. 4 Theory of planned behavior

Attitude towards behavior **(**ATT**)** is a personal belief accrued from individual attitude that a person favors or does not favor the behavior**.** It represents an individual**'**s good or bad, beneficial or harmful, pleasant or unpleasant, and likable or disgusting psychological evaluations. [12]

Subjective Norm (SN) is a personal belief accrued from the people who are important to him or her think he or she should or should not perform the behavior. It refers to the social pressures that an individual perceives for performing or not performing certain environmental behaviors. [12]

Perceived Behavioral Control (PBC) is a personal perception of the ease or difficulty of performing the behavior. It refers to an individual's perception as to whether performing a certain environmental behavior is difficult or easy. [12]

PBC can affect behavior in two ways. One is that it has implications on behavioral intention (I). The other is that it can directly predict behavior (B). PBC is affected by control beliefs and perceived strength. The former refers to factors that may prompt or impede an individual's performance of a certain behavior, and the latter refers to an individual's estimates of whether he or she has the capacity to control factors that may prompt or impede his or her performance of such behavior.

Intention (IN) is a willingness to perform the behavior. Behavioral intention refers to the determination of individual to possibly perform a certain behavior. Behavioral intention has prominent effect on the relationship between attitude toward behavior, subjective norm, perceived behavioral control.

4. RESULTS AND DISCUSSION

The analysis results are divided into two-fold.

- Analysis of driving behavior. The study measured the behavior in terms of average and 85th percentile speed of vehicles and number of violators
- Analysis of driving attitudes. The study measured the psychological factors of road users affecting speeding behavior.

The details of each analysis are presented as follows.

4.1 Results on Driving Behavior

The observational speed data were collected 2-month before and 2-month after introducing the speed cameras along a mountainous road in the study area. The sample size of 3,101 vehicles was observed at five station locations along the corridor. They were 1,606 and 1,495 vehicles before and after speed enforcement. Three vehicle types were classified including passenger cars, trucks, and buses.

Fig. 5 shows the frequency and cumulative frequency distributions of all speed data collected before and after the speed camera installation. The cumulative distribution of the observed "after" speed data is shifted to the left of the observed "before" speed data. The mean speed of all vehicles was reduced from 76.0 kilometers per hour to 70.4 kilometers per hour (or reduced by 8.0%). The 85th percentile speed of all vehicles was reduced from 93.0. kilometers per hour to 82.0 kilometers per hour (or reduced by 13.4%). It implies that most drivers lower their speed through the road sections in the study area.

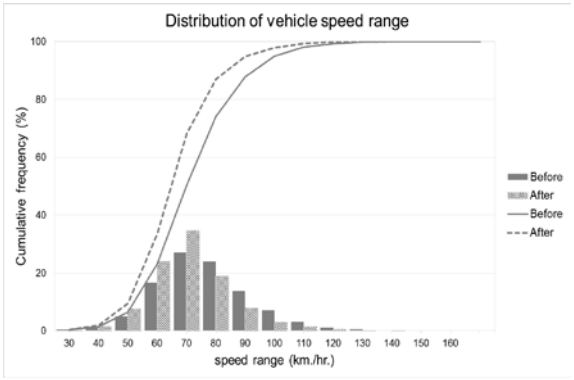

Fig**.** 5 Comparison of speed distribution

Table 2 summarizes the before-and-after speed data. The mean, 85th percentile, and the deviation of vehicle speed before and after the implementation at each automated speed camera location were presented. The statistical *t*-test showed the significant reduction on the average vehicle speeds at 95% confident interval ($\alpha = 0.05$) at each speed camera location.

Moreover, in this study, the numbers of violators before and after the implementation were also compared. The speed limits at Locations 1 to 4 are 80 km/h and that at Location 5 is 90 km/h. The number of violators was considerably reduced at all speed camera locations along the corridor. The percentage of violators was reduced at all locations: Location 1 from 31% to 11%, Location 2 from 19% to 7%, Location 3 from 53% to 19%, Location 4 from 12% to 3%, and Location 5 from 39% to 21% at Stations 1 to 5, respectively.

Table 2**:** Comparison of Driving Speed Before-and-After Implementation of Speed Enforcement System

Locations	Period	Speed Limit (km/h)	Sample Size	Speed (km/hr.)			*t*-value	Sig*
				Mean	85th percentile	Standard deviation		
Station 1: km 50+400	Before	80	244	72.9	84.0	12.1	4.90	0.00
	After		272	67.8	78.0	11.1		
Station 2: km 43+050	Before	80	258	68.7	82.0	11.8	4.24	0.00
	After		245	64.6	74.0	10.0		
Station 3: km 35+800	Before	80	267	80.8	94.0	13.0	8.39	0.00
	After		240	71.9	82.0	10.8		
Station 4: km 21+700	Before	80	321	68.3	77.0	9.0	5.89	0.00
	After		282	64.3	72.8	8.0		
Station 5: km 15+600	Before	90	516	83.5	103.0	19.7	4.60	0.00
	After		456	78.2	93.7	16.2		
All data	Before	-	1606	76.0	93.0	16.0	10.54	0.00
	After		1495	70.4	82.0	13.5		

Note: * Confident interval at 0.95

4.2 Results on Driving Attitudes

The questionnaire surveys were conducted for examining driving attitudes.

4.2.1 Basic Characteristics of Respondents

For the first part, the basic characteristics of 400 respondents are presented in Table 3.

Table 3**:** Basic Characteristics of Respondents

Characteristics		Number (Person)	%
Gender	Male	275	68.6
	Female	125	31.4
Age	Less than 23 years	21	5.2
	23-40 years	217	54.1
	More than 40 years	162	40.6
Occu-pation	Government officers	82	20.4
	Private employees	80	20
	Students	27	6.7
	Private business	93	23.2
	Contractor	100	24.9
	Other	18	4.7
Educa-tion	High school or lower	185	46.4
	Undergraduate	194	48.4
	Graduate or higher	21	5.2
Type of vehicle	Motorcycle	18	4.7
	Passenger car	272	67.8
	Van	37	9.2
	Bus	23	5.7
	Truck	50	12.5

4.2.2 Opinions on Automated Speed Enforcement

For the second part, the frequency analysis was performed. Some interesting statistics of drivers' opinions are summarized as follows.

- Sixty-four percent (64%) of respondents were aware that speeding is the major cause of road traffic accidents on mountainous roads, followed by illegal overtaking, drivers' unfamiliarity with the roads, and slippery pavement condition.
- Sixty-nine percent (69%) of drivers were unaware of the speed limit of mountainous roads.
- Seventy-one percent (71%) of drivers agreed with the speed enforcement measure on mountainous roads, and seventy percent agreed with automated speed camera enforcement.

It implies that the majority of drivers accept the speed control on mountainous roads because they realize the consequences of speeding behavior.

4.2.3 Psychological Factors Affecting Speeding

For the last part of the questionnaire, the study uses Analysis of Moment Structure (AMOS) to perform the structural equation modelling (SEM) analysis. In the questionnaire, psychological factors are measured based on a seven-point Likert scale ranging from "Strongly Agree" to "Strongly Disagree". Each factor is measured by asking the respondents to rate different numbers of latent statements as follows: Attitude towards Behavior (ATT) factor group has four statements (ATT1 to ATT4). Subjective Norm (SN) factor group has four statements (SN1 to SN4). Perceived Behavioral Control (PBC) factor group has three statements (PBC1 to PBC3), and Intention (IN) factor group has three statements (IN1 to IN3). All the latent factors are listed in Table 4

The questionnaire was tested for its reliability using the Cronbach's alpha in the SEM analysis. The result shows that the Cronbach's alpha ranges

from 0.81 to 0.92, which represent the very high reliability of the questionnaire. Then the AMOS analysis was carried out and the TPB structure was constructed. The relationship among psychological factors and their latent factors were evaluated. The results of AMOS analysis are shown in Fig. 6.

Table 4**:** Latent factors in each factor group based on Theory of Planned Behavior

Factor Group	Question	Variable
Attitude towards behavior (ATT)	For me, in the next time I drive faster than the speed limit, I think it is …….	
	Bad – Good	ATT1
	Not useful - Useful	ATT2
	Unacceptable - Acceptable	ATT3
	Wrong – Not wrong	ATT4
Subjective Norm (SN)	I believe that my important people (e.g. family members/friends) think next time I should not/should drive over the speed limit.	SN1
	I believe that my important people (e.g. family members/friends) will disagree/agree when I drive over the speed limit.	SN2
	I believe that my important people (e.g. family members/friends) will not support/support me to drive over the speed limit.	SN3
	I believe that speeding behavior of my important people (e.g. family members/friends) is impossible/possible.	SN4
Perceived Behavioral Control (PBC)	In my next driving, I am unconfident/confident that I can drive over the speed limit.	PBC1
	It is difficult/easy for me to drive over the speed limit in my next driving.	PBC2
	I feel dependent/independent to drive over the speed limit in my next driving.	PBC3
Intention (IN)	"I intend to drive over the speed limit in my next driving" is very impossible/possible.	IN1
	"I have a tendency to drive over the speed limit in my next driving" is very impossible/possible.	IN2
	"I am willing to drive over the speed limit in my next driving" is very impossible/possible.	IN3

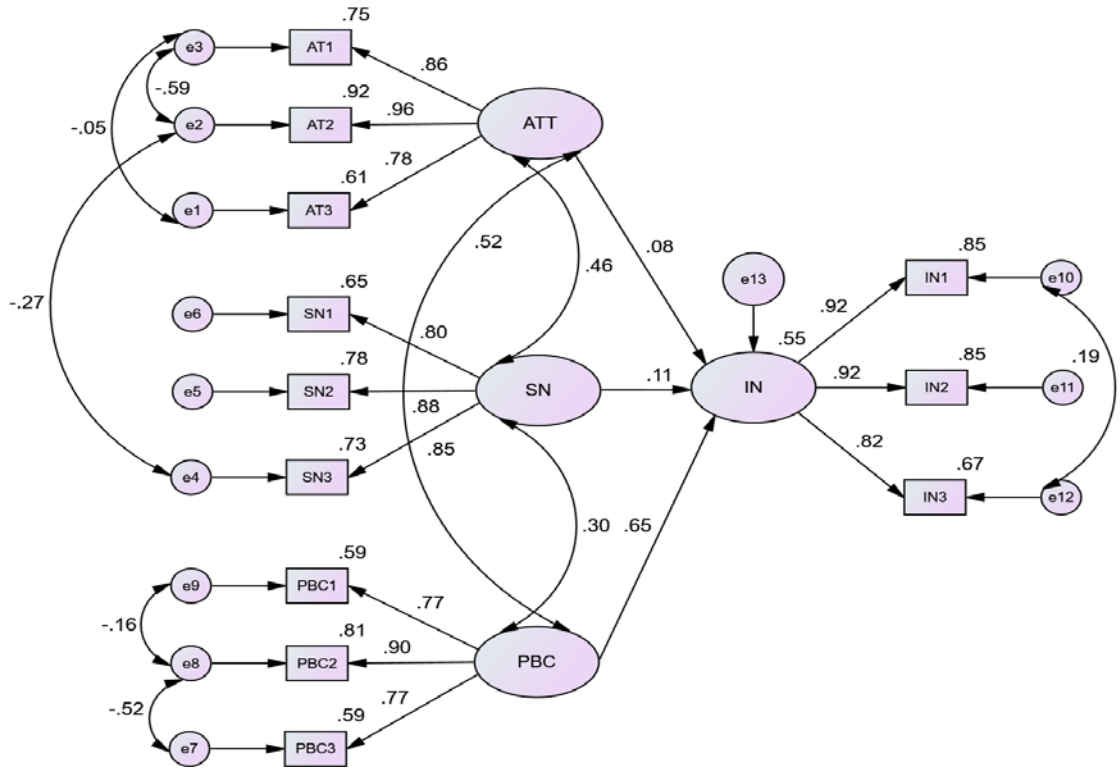

Fig**.** 6 The result of AMOS analysis

This diagram shows that three basic psychological factors: attitude towards behavior (ATT), subjective norm (SN), and perceived behavioral control (PBC) are highly influenced on intention (IN). All statistical indicators are accepted compared to their threshold values.

- Chi-square/df is 2.46 (recommended between 2 and 3), Goodness-of-fit indices (GFI) is 0.959 (recommended close to 1). It implies that the model closely replicates the observed population covariance.
- Comparative Fit Index (CFI) is 0.981 (recommended CFI ≥ 0.95), It indicates good fit of the model.
- Standardized Root Mean Squared Residual (SRMR) is 0.045 (recommended less than 0.05). This indicator also indicates good fit of the model.
- Root-mean square error of approximation (RMSEA) is 0.061 (recommended less than 0.08).

The diagram shows that among the three factors, PBC is the highest influential factor to the intention and to the speeding behavior. It implies that the speeding drivers are willing to drive fast whenever he or she has an opportunity to perform speeding. Therefore, breaking the opportunity to overspeed by introducing speed camera enforcement would affect the speeding behavior of drivers within the study area.

5. CONCLUSIONS

The paper presents the effect of automated speed enforcement system installed along the hazardous sections of mountainous roads in Thailand. Although the automated speed enforcement system has been successfully implemented in many developed countries, such system has not yet been widely introduced and comprehensively analyzed their effectiveness in Thailand. This study evaluated the effects in terms of the speeding behavior and drivers' perception and attitudes.

An automated speed camera enforcement system in this study becomes an effective speed control technology on mountainous roads because of three respects. First, the speed camera enforcement helps reduce the speed of vehicles significantly. The 85th percentile of vehicle speed is reduced by 13,4%, while the number of violators is reduced by 16%. Second, it helps increase public awareness of the risk of speeding behavior as the drivers perceive the speed limit more while driving on mountainous roads. In this study, the public resistance is minor because the drivers realize that the speed camera is a tool to enhance the speed regulation. Finally, the speed enforcement program helps minimize the opportunity of the drivers to perform overspeed. In other words, it enhances the safe driving speed and sustains the safe behavior.

This study has two further recommendations. One, this paper presents the 2-month before-and-after speed data. Data collection including speed data, speed tickets, and accident records should be carried out in a longer time period to ensure the sustainable speeding behavior and their positive consequences. Two, it should be noted that automated speed enforcement is one of the possible and practical safety countermeasures to improve the perceived behavioral control of drivers' speed on mountainous roads. More comprehensive studies on safety measures in other regards, such as engineering and education measures, should be emphasized in order to more effectively sustain the safe speeding culture.

6. ACKNOWLEDGMENTS

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