Asia-Pacific Journal of Science and Technology: Volume: 28. Issue: 01. Article ID.: APST-28-01-14. Research Article

APST

Asia-Pacific Journal of Science and Technology

https://www.tci-thaijo.org/index.php/APST/index

Published by the Research and Graduate Studies,
Khon Kaen University, Thailand

Effectiveness of automated red-light running control using closed-circuit television cameras in Thailand

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Received 30 July 2021
Revised 7 December 2021
Accepted 26 December 2021

Abstract

In developing countries, insufficient road-hierarchy planning, and control result in signalized intersections along mixed-traffic highways. Motorcycles' red-light running (RLR), along with insufficient enforcement, are the major causes of collisions at these intersections. The objective of this study was to determine the efficacy of automated RLR control in this scenario. Signalized intersections along Thailand's Friendship Highway, which runs through Khon Kaen City, were used as research locations. For evaluating changes, this study used an observational before-after design with a group comparison. The study collected data on the RLR behavior, RLR tickets, as well as frequency of collisions and injuries, both before and after the RLR control implementation. The results suggest the RLR reduced by 33.3%. Crash and injury rates decreased by 17.5% and 13.6%, respectively. However, long-term studies are necessary for evaluating the impact on the rate of fatal outcomes. These results demonstrate the effectiveness of the RLR control for traffic regulation and accident prevention in the context of a developing country.

Keywords: Crash, Developing country, Injury prevention, Red-Light Running control

1. Introduction

In developing countries, insufficient road-hierarchy planning and control translate into significantly more road safety-related issues. Signalized intersections on city-bound highways are notable examples. These intersections must accommodate both local road users and high-speed traffic. As a result, more crashes and serious injuries are associated with these intersections, particularly involving motorcycle riders who ride alongside larger vehicles.

The safety of motorcyclists is a global issue. Globally, motorcycle riders account for approximately 30% of all road-user fatalities. In Southeast Asia, this rate is approximately 50%, while in Thailand specifically it reaches 75%. As a result, Thailand ranks first among countries with most motorcycle-related fatalities [1]. Owing to the affordability of small-sized motorcycles, low-income families living in regional regions are more likely to own 100-125 cc motorcycles. The number of motorcycle registrations has recently reached 21 million, accounting for more than half of all registered vehicles in Thailand [2].

Motorcycle riders are particularly vulnerable to red-light-running (RLR) collisions. In Thailand, the two major causes of motorcycle-related deaths are collisions with other vehicles (58.4%) and loss of control (28.2%) [3]. RLR crashes are typically associated with the former. Right-angle and rear-end crashes are typically associated with RLRs, and often fatal when they occur at high-speed intersections. This is particularly true for motorcyclists, who are more vulnerable than other road users. Apart from the fact that they are physically susceptible, their rule-violating behavior has been widely recognized. Motorcycles are involved in more RLR accidents than other vehicles [4]. In addition, RLR is one of the top ten causes of road crashes in general [5]. The number of RLR-related road crashes has increased in recent years, and the associated safety concerns require further attention.

Lessons learned from developed countries demonstrate how enforcement technologies can be used for addressing RLR-related concerns; in particular, red-light cameras (RLCs) are often used. Recent research on the safety implications of RLCs is summarized in Table 1. According to the literature review, RLCs increased safety by reducing the overall number of collisions in Canada [6], number of injury/fatality-associated collisions in Belgium [7], and number of injury/fatality-associated collisions in the United States [8-10]. In contrast, in South Korea [11], the use of RLCs resulted in an increase in the number of total and injury crashes.

Of note, the safety profile of RLCs appears to vary by region, with a concentration in developed countries. To our knowledge, information on the impact of RLCs in developing countries is currently scarce. Only one study [12] used closed-circuit television (CCTV) cameras to develop a program for automatically detecting red-light running. Apart from the lack of data on RLCs in developing countries, there is a lack of research on the impact of RLCs on specific vehicle types, most notably motorcycles. Only a few studies [13,14] found that motorcycle crashes were significantly less frequent at RLC-equipped intersections in Singapore, compared to those without RLCs. Most of the existing research has been conducted in developed countries.

Understanding the safety implications of RLCs is critical in developing countries, given the vulnerability of motorcycle riders in RLR-related collisions. However, research on the effectiveness of RLCs in Thailand and other developing countries is lacking, despite the fact that numerous road crash and road safety studies have been conducted recently to address Thailand's critical road crash-related problems. Examples include statistical analysis and forecasting of road crashes in Thailand [15,16], and a study of the motorcycle riders' risky behavior in Thailand [4,17-19].

Despite this lack of information about the accidents involving motorcycle riders in developing countries, a series of meta-analyses have indicated that RLCs exert an increasing safety impact [20-22]. Two previous meta-analyses [20,21] assessed the effectiveness of RLCs for reducing the number of crashes. These studies found that while RLCs may potentially reduce the number of right-angle crashes, they may increase the number of rear-end crashes. These studies were unable to demonstrate the spillover effect (effect in the same area) and cast doubt on the efficacy of RLCs for promoting overall safety. According to a recent meta-analysis study [22], RLCs reduced the number of total crashes by 12%, with a tendency to decrease the number of right-angle crashes while increasing the number of rear-end crashes. The research concluded that the safety benefits of camera-equipped intersections and spillover effects tend to increase over time [22]. Despite the lack of conclusive evidence, RLCs have been highlighted as a potential tool, owing to their growing safety implications [22].

Table 1 Recent studies on safety impact of RLCs.

Location	Method	Crashes		References
		All	Injury	
Singapore	Hierarchical Poisson	37-55%[1]		[13]
Belgium	Before-after Empirical Bayes	-	-14%[4]	[7]
Florida, USA	Before-after Empirical Bayes	-	-	[23]
Canada	Before-after Empirical Bayes	-26%[4]	-	[6]
South Korea	Before-after Empirical Bayes	+51%[4]	+53%[4]	[11]
Missouri, USA	Before-after Empirical Bayes	+2%[4]	-7%[4,*]	[8]
Chicago, USA	Before-after Empirical Bayes	-	-16%[4]	[9]
USA	Poisson regression	-	-14%[4,*]	[10]
Developed cities	Meta-analysis	+6%[4]	-13%[4]	[20]
Developed cities	Meta-analysis	-2%[4]	-20%[4]	[21]
Developed cities	Meta-analysis	-12%[4]	-	[22]

Note: * includes Fatality, vehicle type: motorcycle[1], light vehicle[2], heavy vehicle[3], all vehicle types[4].

Taking into account the above information, the objective of this study was to determine the safety impact of automated RLR control at signalized intersections along urban highways in developing countries. This paper is divided into four sections: an introduction, materials and methods, results and discussion, and conclusions and recommendations.

2. Materials and methods

2.1 Study area

The studied intersections were in Khon Kaen City, Thailand. In November 2016, the Khon Kaen province's road safety committee launched the "14-kilometer safety drive corridor" along a section of the Friendship Highway through this city, with the goal of reducing the number of traffic fatalities. This corridor is a major urban arterial road, with a high volume of motorcycles sharing space with other high-speed and large vehicles. The project's first phase established and enforced an urban speed limit along this corridor. Automated speed cameras were installed for speed regulation. The Safer Roads Foundation (SRF), based in the United Kingdom, provided financial support for this project. As a result, both the average speed and number of collisions were significantly reduced [24].

In July 2017, the committee and SRF launched the second phase of the RLR control project to create a safer corridor. Police has never previously enforced RLR in this corridor, owing to the lack of enforcement equipment. At dangerous signalized intersections, CCTV cameras equipped with automatic RLR detection programs have been installed. As shown in Table 2, three signalized intersections that experienced fatalities over a five-year period (2012-2016) were selected for the RLR enforcement. They were the Mordindang intersection (No. 1), the Phatumuang intersection (No. 3), and the Charoensri intersection (No. 5). Their locations are shown in Figure 1. Warning signs indicating the presence of the RLR enforcement via CCTV cameras were installed at these intersections, as shown in Figure 1B.

This study extended a previous study's [12] program for automatically detecting RLR and sending the data to the Thai police ticket management system (PTM). As shown in Figure 2, the program was created to monitor an area within the video frame captured by a wide-angle CCTV camera. After identifying a vehicle and the red light of the traffic signal, the area around the vehicle was analyzed, for determining the presence of RLR. If the latter was discovered, the program used a zoom CCTV camera to record video frames and the license plate of the RLR vehicle. The PTM stored photographs of RLR vehicles and their license plates in a database, and later used them as evidence.

Table 2 Number of crash-related deaths at the studied intersections.

No.	Intersection name	Design type	Deaths per five years
1	Mordindang	Treatment	4
2	Kanlapaphruek	Comparison	0
3	Phatumuang	Treatment	4
4	Bankok	Comparison	0
5	Charoensri	Treatment	2

Figure 1 (A) Locations of automatic RLR cameras along the urban arterial road and (B) Warning sign indicating RLR enforcement via a CCTV camera.

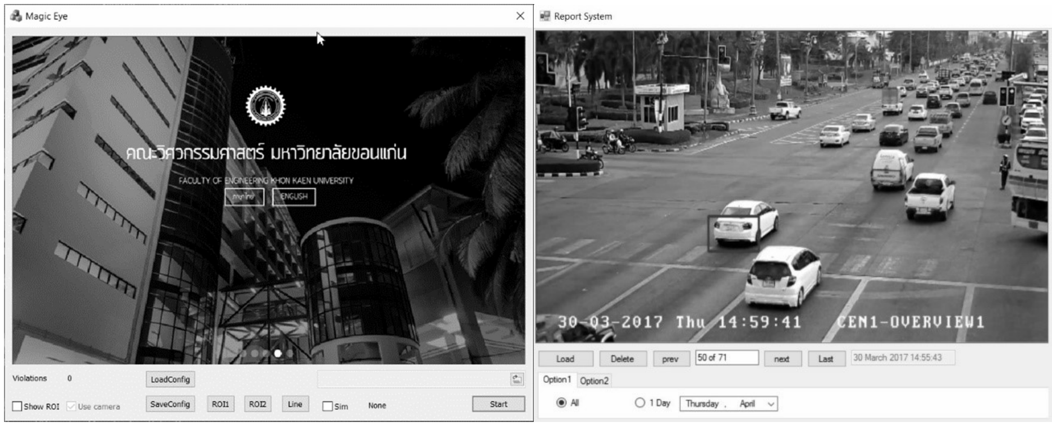

Figure 2 RLR detection program.

2.2 Study design

The empirical Bayes before-and-after method is one of the more reliable approaches for evaluating experimental interventions, because it accounts for the regression to the mean (RTM) bias. This is affected by the traffic volume and temporal effects. To account for the RTM bias, the number of crashes expected in the prior period without the treatment is considered as a weighted average of data from two sources: 1) the number of crashes observed in the prior period at the treated sites and 2) the number of crashes predicted at the treated sites (It is calculated by using a safety performance function (SPF), estimated by traffic volumes and physical characteristics of the untreated “reference” group) [25].

Owing to the limited amounts of traffic volume data for developing countries, this study used the observational before-after method with group comparison, for investigating the effect of the RLR control. The studied intersections consisted of five signalized intersections located along the highway that passed through Khon Kaen, as shown in Figure 1B. The treatment sites included the Mordindang intersection (No. 1), the Phatumuang intersection (No. 3), and the Charoensri intersection (No. 5), all of which had RLR-detecting CCTV cameras installed. The Kanlapaphruek intersection (No. 2) and the Bankok intersection (No. 4) were used for comparison sites because they lacked RLR-detecting CCTV cameras.

2.3 Data collection

Data were collected on the RLR behavior, crash records, and on the number of RLR tickets, both before and during the RLR control enforcement. The timeline for the data collection is shown in Figure 3.

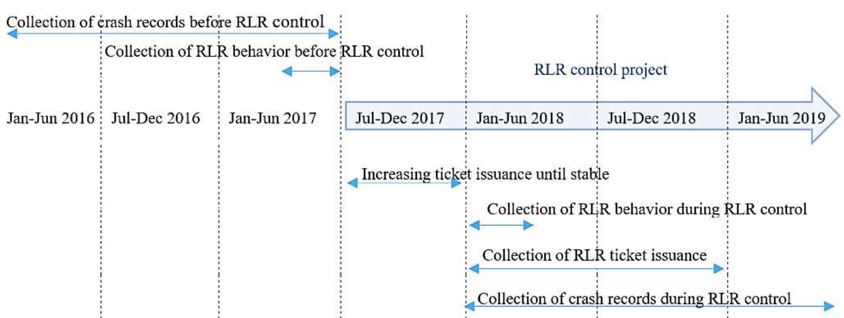

Figure 3 Timeline for data collection.

The RLR control project began in July 2017. However, owing to a shortage of police officers early during the RLR control study, police officers were unable to issue tickets consistently. Despite this, they boosted ticket issuance until it remained stable for six months, from July 2017 to December 2017. This study considered RLR tickets that were issued during 2018.

To monitor the RLR behavior changes, mobile cameras were installed at three treatment intersections: the Mordindang intersection (No. 1), the Phatumuang intersection (No. 3), and the Charoensri intersection (No. 5). The RLR behavior data were collected prior to and during the RLR control. For 24 h, the number of vehicles entering the intersections was counted. They were classified according to the vehicle type and engagement in the RLR events. Between April and June 2017, data about the RLR behavior prior to the RLR control enforcement were collected randomly on weekends and on weekdays (three months before the start of the project). During the months of January and March 2018, the RLR behavior data during the RLR control enforcement were collected randomly on weekends and weekdays (three months after the ticket issuance had stabilized).

This study compiled a list of all collisions at the studied intersections, as reported by local hospitals [26]. The hospitals recorded the number of crashes, the number of injuries and fatalities, and the location of crashes, but not the causes of all crashes (only lethal crashes were recorded). The hospitals recorded the crash locations using a GIS-based traffic accident database developed as part of a trauma management system [27]. Crash records prior to the RLR control enforcement were collected for 18 months, from January 2016 to June 2017. Crash records during the RLR control enforcement were collected for 18 months, from January 2018 to June 2019.

2.4 Data analysis

Prior to and during the RLR control enforcement, RLR behavior, RLR ticket, and RLR-related crash data were analyzed and compared between the treatment and comparison sites. Because the causes of the crashes were not recorded, this study analyzed all crashes at the studied intersections. Equation (1) was used for determining the crash rates, injury rates, and fatality rates, for all studied intersections [28]:

$$R = \frac{C \times 10^6}{365 \times N \times V} \quad (1)$$

where

R = Crash rate for intersection (crash per million entering vehicles)
C = Total number of crashes at the studied intersections during the study period
N = Number of years of data
V = Traffic volumes entering the intersection daily

3. Results and discussion

3.1 Reduction of the RLR Behavior

The percentages of RLR vehicles prior to and during automated RLR control enforcement are listed in Table 3. Evidently, motorcycles had higher RLR rates than other vehicles, both before and during the automated RLR control enforcement. This finding corroborates the findings of a previous study [4]. Automated RLR control decreased the RLR by 33.3% across all vehicle types. The RLR reduction was stronger on weekdays (53.8%) than on weekends (4.5%). At night, the RLR reduction was stronger (42.9%) than during the day (30.4%). Compared with other vehicle types, buses (70.8%) and public pickup trucks (67.3%) exhibited the highest RLR reductions. Motorcycles, on the other hand, had the smallest RLR reduction (19.6%).

Table 3 RLR behavior changes, before and after the RLR control enforcement.

	Before automated RLR control			During automated RLR control			RLR reduction
Day of week	RLR vehicles	Entering vehicles	RLR (%)	RLR vehicles	Entering vehicles	RLR (%)	(%)
Weekday	1,950	76,058	2.6	794	68,636	1.2	-53.8
Weekend	1,485	68,052	2.2	1,355	65,708	2.1	-4.5
Time of day							
Daytime	2,430	108,144	2.3	1,536	95,673	1.6	-30.4
Nighttime	1,005	35,966	2.8	613	38,671	1.6	-42.9
Vehicle type							
Motorcycle	986	19,369	5.1	669	16,251	4.1	-19.6
Passenger car	2,048	112,633	1.8	1,273	105,859	1.2	-33.3
Public pickup truck	286	5,234	5.5	88	4,780	1.8	-67.3
Truck	66	4,651	1.4	44	5,056	0.9	-35.7
Bus	28	1,168	2.4	8	1,197	0.7	-70.8
Trailer	21	1,055	2.0	13	1,201	1.1	-45.0
All vehicles	3,435	144,110	2.4	2,095	134,344	1.6	-33.3

Note: at treatment intersections: Mordindang intersection (No.1), Phatumuang intersection (No.3), and Charoensri Intersection (No.5).

3.2 Increased RLR Enforcement Efficiency

The RLR enforcement results are summarized in Table 4. The system detected an average of 3,526 RLR vehicles per month during the RLR control study period. However, owing to the shortage of police officers and owing to technical errors associated with the recognition of license plates, police only issued an average of 1,211 RLR tickets per month, accounting for 34.3% of detected RLR vehicles. Of note, prior to the implementation of the program, the police in the studied area never enforced RLR.

Table 4 RLR enforcement in the studied area.

Month	RLR vehicles	Issued tickets
Jan 2018	3,059	0
Feb 2018	3,296	990
Mar 2018	5,543	1,417
Apr 2018	6,035	474
May 2018	3,324	1,148
Jun 2018	3,012	2,550
Jul 2018	3,394	1,167
Aug 2018	3,048	1,672
Sep 2018	2,514	948
Oct 2018	2,631	1,740
Nov 2018	3,327	1,270
Dec 2018	3,125	1,161
Total	42,308	14,537
Monthly average	3,526	1,211 (34.3%)

3.3 Reduction in the number of crashes

Table 5 summarizes the number of all crashes, injuries, and fatalities at the treatment and comparison intersections, prior to and during the RLR control enforcement. Prior to the RLR control implementation, the monthly averages of crashes at the treatment and comparison intersections were 1.74 and 1.08 cases/month/intersection, respectively, whereas the monthly averages of crashes at the treatment and comparison intersections were 1.46 and 1.14 cases/month/intersection, respectively, during the RLR control implementation. Monthly average crashes decreased by 16.1% at the treatment intersections but increased by 5.6% at the comparison intersections. This reduction in the number of collisions was comparable to the 12.0% average reduction in the number of collisions associated with recent RLCs in developed countries [22]. These effects are expected to vary according to area-specific factors, such as road hierarchy, traffic characteristics, access control, speed limits, and driving behavior.

Prior to the RLR control, the monthly averages of injuries at the treatment and comparison junctions were 1.85 and 1.19 case/month/intersection, respectively, whereas the monthly averages of injuries at the treatment and reference intersections were 1.63 and 1.31 case/month/intersection, respectively, during the RLR control. On a monthly basis, the number of injuries at the treatment intersections decreased by 11.9%. Meanwhile, the monthly average crashes at the comparison intersections increased by 10.1%.

Prior to the RLR control implementation, there were no death records at the studied intersections. However, two deaths occurred during the RLR control enforcement at the Charoensri intersection (No. 5), a treatment intersection, but these crashes were owing to drunk driving, and not owing to RLR. As a result, this study was unable to conclusively demonstrate the effect of automated RLR control on fatality crashes in the studied areas. Long-term studies are required for determining the effectiveness of the RLR control with respect to the reduction of the number of lethal accidents.

Table 5 Number of crashes and injuries before and during the RLR control enforcement.

Month	Treatment intersections[1,3,5]			Comparison intersections[2,4]		
	Crash	Injury	Fatality	Crash	Injury	Fatality
Before RLR control						
1) Jan 2016	7	8	0	0	0	0
2) Feb 2016	2	2	0	0	0	0
3) Mar 2016	8	9	0	3	3	0
4) Apr 2016	9	9	0	3	4	0
5) May 2016	6	7	0	1	1	0
6) Jun 2016	2	2	0	3	4	0
7) Jul 2016	5	6	0	2	2	0
8) Aug 2016	3	3	0	3	3	0
9) Sep 2016	7	8	0	1	1	0
10) Oct 2016	6	6	0	1	1	0

Table 5 Number of crashes and injuries before and during the RLR control enforcement. (Continued)

Month	Treatment intersections[1,3,5]			Comparison intersections[2,4]		
	Crash	Injury	Fatality	Crash	Injury	Fatality
11) Nov 2016	3	3	0	1	1	0
12) Dec 2016	6	6	0	1	1	0
13) Jan 2017	6	6	0	3	3	0
14) Feb 2017	2	2	0	5	5	0
15) Mar 2017	7	8	0	4	5	0
16) Apr 2017	8	8	0	3	4	0
17) May 2017	4	4	0	4	4	0
18) Jun 2017	3	3	0	1	1	0
Total	94	100	0	39	43	0
Monthly average/intersection	1.74	1.85	0	1.08	1.19	0
During RLR control						
1) Jan 2018	9	9	1*	1	3	0
2) Feb 2018	7	9	1*	4	4	0
3) Mar 2018	6	7	0	7	9	0
4) Apr 2018	4	4	0	3	3	0
5) May 2018	3	3	0	2	2	0
6) Jun 2018	5	6	0	3	3	0
7) Jul 2018	4	8	0	3	3	0
8) Aug 2018	4	4	0	2	2	0
9) Sep 2018	7	7	0	3	5	0
10) Oct 2018	0	0	0	1	1	0
11) Nov 2018	3	2	0	1	1	0
12) Dec 2018	3	4	0	1	1	0
13) Jan 2019	5	5	0	3	3	0
14) Feb 2019	6	7	0	3	3	0
15) Mar 2019	1	1	0	2	2	0
Monthly average/intersection	1.74	1.85	0	1.08	1.19	0
During RLR control						
16) Apr 2019	7	7	0	1	1	0
17) May 2019	2	2	0	1	1	0
18) Jun 2019	3	3	0	0	0	0
Total	79	88	0	41	47	0
Monthly average/intersection	1.46	1.63	0	1.14	1.31	0
Difference before and during RLR control (%)	-0.28 (-16.1%)	-0.22 (-11.9%)	0	0.06 (5.6%)	0.12 (10.1%)	0

Note: 1 = Mordindang intersection, 2 = Kulapraphuk Intersection, 3 = Phatumuang intersection, 4 = Bankok Intersection, 5 = Charoensri intersection, *Drunk driving.

Table 6 lists the average crash and injury rates at the treatment and comparison intersections, prior to and during the RLR control enforcement. At the treatment intersections, the average crash and injury rates during the RLR control enforcement (0.95 crashes/million entering vehicles and 1.06 persons/million entering vehicles) were lower than before the RLR control enforcement (1.16 crashes/million entering vehicles and 1.23 persons/million entering vehicles). They decreased by 17.5% and 13.6%, respectively. At the comparison intersections, the average crash and injury rates during the RLR control enforcement (0.74 crashes/million entering vehicles and 0.85 persons/million entering vehicles) were higher than before the RLR control enforcement (0.72 crashes/million entering vehicles and 0.79 persons/million entering vehicles). They increased by 3.2% and 7.3%, respectively.

This demonstrates that while RLCs improved safety at the treatment intersections, they had no effect at the reference intersections in the studied area.

Table 6 Crash and injury rates prior to and during the RLR control enforcement.

Intersection type	Period	Average crash rate (crashes per million entering vehicles)	Average injury rate (persons per million entering vehicles)
Treatment intersections	prior to RLR control[1,3,5]	1.16	1.23
	during RLR control[2,4]	0.95	1.06
	difference	-0.20 (-17.5%)	-0.17 (-13.6%)
Comparison intersections	prior to RLR control[1,3,5]	0.72	0.79
	during RLR control[2,4]	0.74	0.85
	difference	0.02 (3.2%)	0.06 (7.3%)

Note: 1 = Mordindang intersection, 2 = Kulapraphuk Intersection, 3 = Phatumuang intersection, 4 = Bankok Intersection, 5 = Charoensri intersection.

4. Conclusion

The objective of this study was to determine the effect of the RLR control enforcement at signalized intersections along highways that pass-through cities in developing countries. The study hypothesis was that an automated RLR control system could facilitate the efficient enforcement of RLR vehicles in the study area. Although police issued RLR tickets to 34.3% of the detected RLR vehicles, the number of all RLR vehicles was reduced by 33.3%. Notably, RLCs had a smaller impact on motorcycles than on other vehicle types. Owing to the safety effect, the average crash and injury rates decreased by 17.5% and 13.6%, respectively. However, no spillover effect was observed in the studied area. These findings demonstrate the efficacy of the RLR control and the remaining enforcement limitations in the context of developing countries. Long-term studies should be performed, for evaluating the project in terms of the reduction of the number of lethal outcomes stratified by the vehicle type, especially focusing on motorcycles.

To significantly reduce the number of RLR-related accidents, the number of RLR tickets issued must be increased to encompass all RLR vehicles. The program for license plate recognition should be improved using artificial intelligence (AI) technology. The training data for AI development, such as the vehicle type characteristics, particularly motorcycles, and information about the road environment in the studied areas, must be collected.

Although the results of the automated RLR control in this study are rather promising, the number of crashes in the studied areas remained high. Control of the other types of risk-bearing behavior, such as drunk driving and illegal parking on roadways, should be enforced as well, particularly at night.

5. Acknowledgements

This research was supported by the Thai Health Promotion Foundation, Thailand.

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