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Safety effectiveness of an upgraded midblock pedestrian crossing on an urban arterial road

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Abstract

Pedestrians are vulnerable road users who have a high risk of being struck by vehicles; their dying accounts for 8% of all road fatalities in Thailand. Thus, this study investigated the effectiveness of midblock pedestrian crossing improvements, comparing (1) a typical zebra crossing (C1), (2) a zebra crossing with traffic markings and warning signs (C2), and (3) a crossing as in C2 but with pedestrian signals (C3). This current research investigated the traffic volume and speeds of motorcycles (MC) and passenger cars (PC) before and after the improvement. The findings indicated that the 85th percentile speeds and the estimated maximum speed of MC and PC decreased significantly after the C2 and C3 improvements. Consequently, fatality probabilities of pedestrians were also estimated. It was found that the fatality probabilities of the C2 crossing slightly decreased by 5% (compared to C1), whereas the fatality probabilities of the C3 crossing significantly decreased by 53% (compared to C1). Based on the results, midblock pedestrian crossings with traffic signals could promote safer conditions for pedestrians in mixed-traffic urban areas compared to traditional zebra crossings.

Keywords: Road safety, Pedestrian crossing, Traffic signal, Speed, Effectiveness

1. Introduction

Pedestrians are vulnerable road users who have a high risk of being struck by vehicles and dying. Increasing interactions between pedestrians and vehicles in urban areas, especially at midblock crossings, cause higher risks and more fatalities [1]. According to the global status report on road crash statistics [2], pedestrian fatalities account for more than 0.35 million deaths a year, which is approximately 23% of all fatalities. In addition, most pedestrian fatalities occur in urban areas (81%), many of which were at midblock sections (74%) [3].

A number of studies have shed light on vehicle-pedestrian collisions at midblock crossings. Olszewski P, et al [4] found that vehicle-pedestrian collisions were at midblock crosswalks (73%), unsignalized crosswalks (23%), and signalized crosswalks (4%), respectively. These results are consistent with the study of Soathong et al. [5], which demonstrated that the proportion of vehicle-pedestrian crashes was 89% at uncontrolled crossings and 11% at signalized crossings.

According to the recent situation in Thailand, the fatality rate from road crashes is approximately 26 deaths per 100,000 population, with pedestrian crossing tolls accounting for approximately 8% [2] of the deaths. With regards to road crash data on national highways from 2017 to 2021 [6], the number of pedestrian deaths rose from 111 to 139 (an increase of 6.3% per year). The main cause of vehicle-pedestrian collisions (70%) was vehicles speeding, going over the 80 kilometres per hour (kph) speed limit in urban areas [7]. This is much higher than the safe speed for a pedestrian crossing zone, which should be 20-30 kph [8].

Because of this, there has been an increasing trend of pedestrian fatalities due to the development along roadside areas, especially cities along national highways [9]. This may be due to the relatively high accessibility of such areas often giving rise to high traffic volumes, roadside activities, and local communities. Also, urban arterial road sections usually have a variety of road users, including bus passengers, pedestrians, and various types of vehicles in mixed traffic conditions [10]. Moreover, mismatched street hierarchies, for instance, roadway sections with multiple-lanes and overly wide lane widths (more than 3.0 meters) in urbanized areas, could lead to an increased risk of pedestrian crashes and injury severity [9]. Furthermore, some urban areas lack safety-related infrastructure for pedestrian crossings, especially in midblock sections.

Based on the aforementioned research, traffic speed control and engineering measures are essential tools in terms of reducing the risk and severity of pedestrian collisions. Various road authorities have put great effort into utilizing different types of safety-related measures for pedestrian crossings, e.g., zig-zag lines, installation of pedestrian crossing approaches [11], 3D zebra crossings [12], pre-timed signalized pedestrian crossings [13], and actuated signalized pedestrian crossings [14]. However, there are several questions about the effectiveness of those types of equipment.

The purpose of this study was to evaluate the effectiveness (in terms of safety) of pedestrian crossing improvement progressing from a typical zebra crossing to a zebra crossing with traffic markings and warning signs, and a zebra crossing with pedestrian signals. The midblock pedestrian crossing on the Kanjanavanich Road (Highway No. 407 Sta.24+700) passing through a growing urban area was selected as a case study. This road section is classified as an urban arterial road serving major traffic moving between Songkhla city and other areas. The results from this study could promote safer conditions for pedestrians in mixed-traffic in transition zones between suburban and urban arterial roads in Thailand, where there is a high proportion of motorcycles.

This paper is comprised of five sections. Following this introduction (Section 1), a review of previous research is presented in Section 2. The methodology is explained in Section 3. Then, the key findings are presented and discussed in Section 4. Finally, conclusions and recommendations are clarified in Section 5.

2. Materials and methods

This study investigated the effectiveness of pedestrian crossing improvements from a typical zebra crossing to a zebra crossing with traffic markings and warning signs and a zebra crossing with pedestrian signals in terms of speed change and the likelihood of pedestrian fatality. The scope of the study, data collection, and methods of data analysis are, therefore, explained in the following sub-sections.

2.1 Scope of the study

2.1.1 Study area

An urban arterial road section of Highway No. 407 (Kanchanavanit Road), Section 0102, Sta. 24+700, in Mueang District, Songkhla Province, was selected. As shown in Figure 2, the road section was approximately 400 meters long and both roadside areas had a mix of commercial shops, convenience stores, banks, and residential estates. Two bus stops were also located on both sides. The road section consisted of four traffic lanes (two lanes per direction) with a raised median. The traffic lane width was approximately 3.5 meters, and the shoulder width was 2.0 meters. There was a pedestrian refuge on the raised median, which was approximately 3.3 meters wide. This road section is representative of urban arterial road sections found in growing transit cities.

2.1.2 Types of pedestrian crossings

The three types of pedestrian crossings considered in this study are as follows:

• Typical zebra crossing (C1): as shown in Figure 2A is a crossing in which white stripes are painted on the pavement surface together with thick white stop lines across the road.

• Zebra crossing with traffic markings and warning signs (C2): as shown in Figure 2B is an upgrade of C1 by adding OSBs, zig-zag lines, and flashing warning lights before the zebra crossing. A red area is also painted to increase the visibility of the zebra crossing.

Zebra crossing with traffic markings, warning signs, and pedestrian signals (C3): as shown in Figure 2C is a further upgrade of C2 by installing an intelligent pedestrian signal system that can detect both the traffic flow of vehicles entering the crossing and the movement of pedestrians crossing the road, and automatically adjust the traffic lights' timing for pedestrians and vehicles following set safety rules [20]. Note that the posted speed limit on the study road section was 70 kph with an average daily traffic (ADT) of 13,270 vehicles per day with 145 pedestrians per hour crossing the road. These figures surpass the mi nimum criteria for traffic signal warrants as shown in Figure 3.

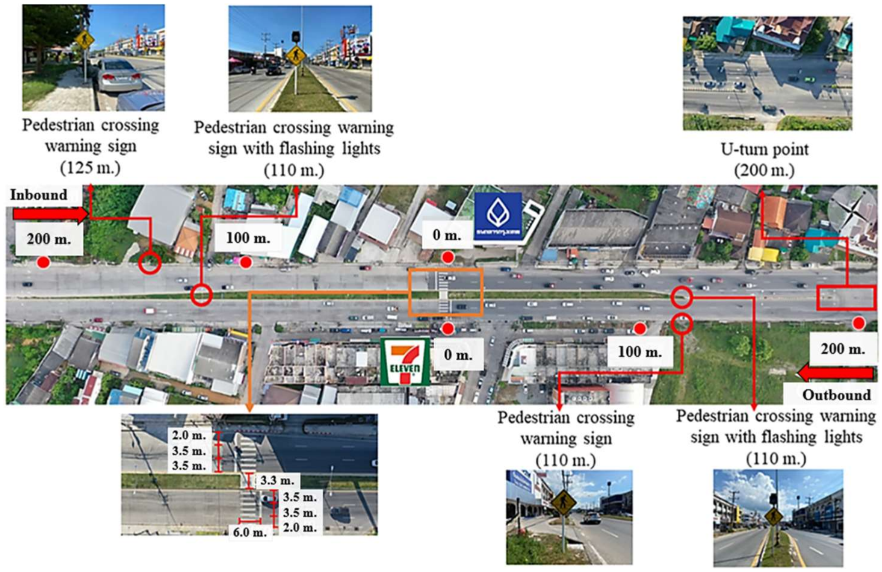

Figure 1 The study area.

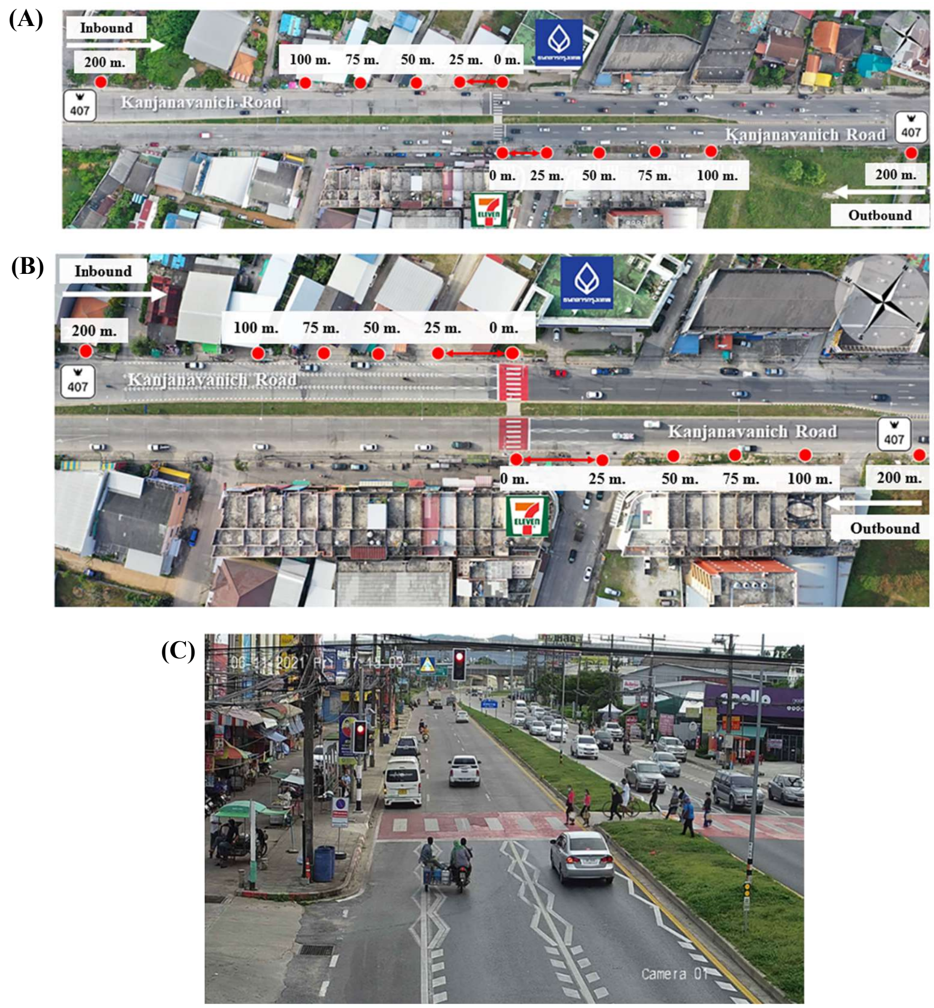

Figure 2 Three types of pedestrian crossings in this study: (A) Typical zebra crossing (C1), (B) Zebra crossing with traffic markings and warning signs (C2), and (C) Zebra crossing with traffic markings, warning signs, and pedestrian signals (C3)

2.2 Data collection and data analysis

2.2.1 Physical characteristics of the study road section

Physical characteristics of the road section under study were investigated. The investigation consisted of the width of the traffic lanes, median, and shoulders, the conditions of the surface and road marking conditions, the width and length of the pedestrian crossing, and the condition of the stop lines, pedestrian crossing lines, warning signs, and speed limit signs. Aerial photographs of the study area were also taken to account for the travel behaviors of road users on both sides.

2.2.2 Data collection on traffic volume

The traffic volume of motorcycles and passenger cars was collected as they were main vehicle groups passing through the road section being studied. The collection of traffic volume data was conducted in both directions.

In the case of C1, the traffic volume was collected on weekdays from the 15^{th} to the 16^{th} of July 2020 and the weekends of the 18^{th} and 19^{th} of July 2020. Then, the traffic volume passing C2 on weekdays was collected on the 19^{th} of January 2021 and for the weekend of the 23^{rd} of January 2021. Finally, in the case of C3, the traffic volume on weekdays was collected on the 17^{th} and 18^{th} of June 2021 and for the weekends on the 19^{th} and 20^{th} of June 2021. Each day, the data was collected continuously for two hours in the morning (7-9 a.m.) and two hours in the afternoon (4-6 p.m.).

2.2.3 Speed data collection

The speeds of motorcycles and passenger cars were randomly collected during the traffic volume surveys. The spot speed of any vehicle traveling within a distance of 25 meters from the stop line to a marked line (as shown in Figure 2A was measured during congested traffic conditions so that potential unsafe speeds approaching the crossing areas for C1, C2, and C3 could be obtained. This speed is likely to be influenced by to the physical characteristics of the road section. In the case of C3 (a zebra crossing with traffic signals), the speeds were recorded when the traffic signal was changing from green to yellow (a four-second interval). This was to measure the potential risk speed of a vehicle entering the pedestrian crossing.

It should be noted that in this study the distance of 25 meters was defined to measure the spot speed of each vehicle because, beyond this distance, there are some entrances/exits and roadside activities that could affect the vehicle's speed.

2.3 Data analysis

2.3.1 Determination of speed differences

The average speeds and the 85^{th} percentile speeds related to the different types of pedestrian crossings (i.e., C1, C2, and C3) were calculated. The absolute value and the percentage of speed changes from the improvement from C1 to C2 and to C3 were also determined.

In addition, the t-test [15] was utilized to determine if there was a significant difference between two sets of speed data, i.e., C1 vs C2 and C2 vs C3. The statistical t value can be determined by using Equation 1.

$$t = \frac{|\mu_1|\mu_2}{\sqrt{\frac{SD^2}{n_1}+\frac{SD^2}{n_2}}} \quad (1)$$

In Equation 1, μ_1 and μ_2 are the average speeds of pedestrian crossing type 1 and type 2, respectively. SD_1 and SD_2 are the standard deviations of pedestrian crossing type 1and type 2, respectively. Finally, n_1 and n_2 are the number of speed samples of pedestrian crossing type 1 and type 2, respectively.

The research hypothesis was that the average speeds of two types of pedestrian crossing would be significantly different. Thus, the null hypothesis (H_0) and research hypothesis (H_1) are described in Equations 2 and 3, respectively.

$$H_0: \mu_1 = \mu_2 \quad (2)$$

$$H_1: \mu_1 \neq \mu_2 \quad (3)$$

Once means $H_0: \mu_1 = \mu_2$ that the average speeds of pedestrian crossing type 1 (μ_1) and type 2 (μ_2) would not differ significantly, and $H_1: \mu_1 \neq \mu_2$ means that the average speeds of pedestrian crossing type 1 (μ_1) and type 2 (μ_2) would differ significantly.

2.3.2 Estimation of maximum speeds

The greatest chance of a pedestrian being killed by a vehicle is when s/he is hit by a maximum speed of the vehicle. A motorist would travel with a maximum vehicle speed if there was no congestion or other adverse conditions. Thus, in this study the maximum speeds of motorcycles (MC) and passenger cars (PC) were estimated from the free-flow speeds during which the traffic flow was very low under uncongested conditions.

In this study, the relationships between traffic flow rate (v) and speed (u) of C1, C2, and C3 were investigated by applying Greenshields's macroscopic stream model [16]. Figure 3 demonstrates the relationship between traffic flow rate (in vehicles/h) and speed (in kph) in a parabolic shape. In order to estimate the free-flow speed (the microfarads (u_f)), the traffic flow rate and speed data collected under uncongested conditions were used to investigate the traffic flow rate and speed relationship under uncongested regimes (which leads to a high risk of pedestrian crashes and injury severity). However, for more accuracy, the data under congested conditions can be used to investigate the relationship under both uncongested and congested regimes.

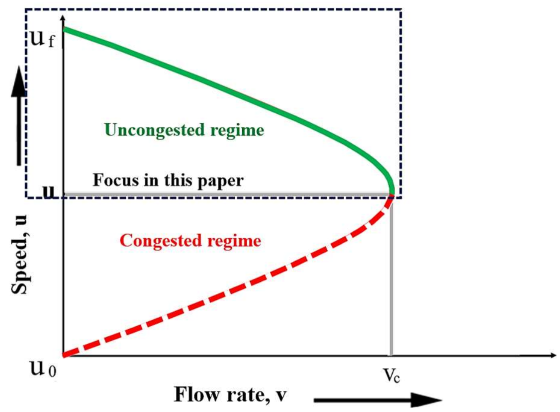

Figure 3 The relationships between traffic flow and speed. [16]

2.3.3 Prediction of pedestrian fatality probability

The maximum speeds estimated from the previous subsection were then used to predict the likelihood of pedestrian fatality if s/he were hit by a vehicle traveling at the estimated maximum speed. In this study, the Scott and Mackie model [17] was adopted to predict the effect of maximum speed on the fatality probability of a pedestrian crash. This fatality probability model has been extensively used as the aspirational criteria for safe speeds in a safe system approach [8].

Figure 4 illustrates the relationships between impact speed and risk (fatality probability) of different crash types. Regarding the pedestrian crash, for example, if a pedestrian were hit by a vehicle at a speed of 30 kph, the chance of him/her being killed is at most 10%; if the collision speed is at 60 kph, the chance of him/her being killed is at most 30%. But if the collision speed is at 100 kph, the likelihood of being killed is almost 100%. It should be noted that the upper bound of pedestrian fatality risk was applied to predict the pedestrian fatality probability in this study.

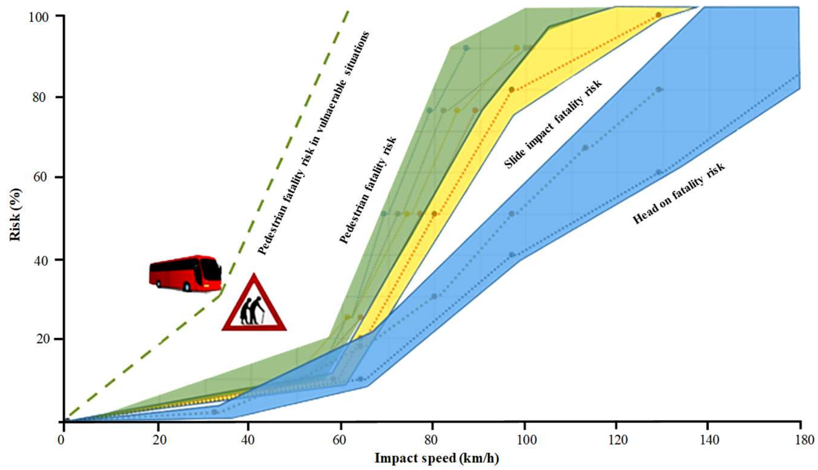

Figure 4 Scott and Mackie model for fatality probability vs. vehicle collision speeds [35].

3. Results and discussion

3.1 Results of vehicle speeds

3.1.1 Characteristics of vehicle speeds

The speed distributions of MC and PC passing C1, C2, and C3 (inbound and outbound) on weekdays and weekends are plotted in Figure 5 and 6, respectively. Descriptive statistics of speed data, which included the minimum, average, standard deviation (SD), 85th percentile, and maximum speeds that were observed and then calculated, are presented in Table 2.

In the case of MC, on weekdays the range of the speeds between the minimum and maximum values in both directions were found from 60 kph to 83 kph for the case of C1, 54 kph to 76 kph for the case of C2, and 40 kph to 53 kph for the case of C3, respectively. The average speeds were slightly reduced from 67 kph to 56 kph after improvement to C2 (i.e., C2 vs C1) and relatively reduced to 42 kph after improvement to C3 (i.e., C3 vs C2). Correspondingly, the standard deviations were marginally changed from 5.62 kph to 5.52 kph after the C2 improvement, and comparatively decreased to 4.85 kph after the C3 improvement. Similarly, the 85th percentile speeds were slightly reduced, from 82 kph to 73 kph after the C2 improvement, and greatly lessened to 47 kph after the C3 improvement.

Likewise, on weekends the range of the speeds in both directions were found from 66 kph to 85 kph in the case of C1, 57 kph to 87 kph in the case of C2, and 40 kph to 59 kph in the case of C3, respectively. The average speeds decreased from 69 kph to 59 kph after the C2 improvement and were dramatically reduced to 45 kph after the C3 improvement. Consequently, the standard deviations were marginally changed from 3.44 kph to 4.06 kph after the C2 improvement, and slightly increased to 4.49 kph after the C3 improvement. The 85th percentile speeds were slightly reduced, from 82 kph to 76 kph after the C2 improvement, and significantly decreased to 54 kph after the C3 improvement.

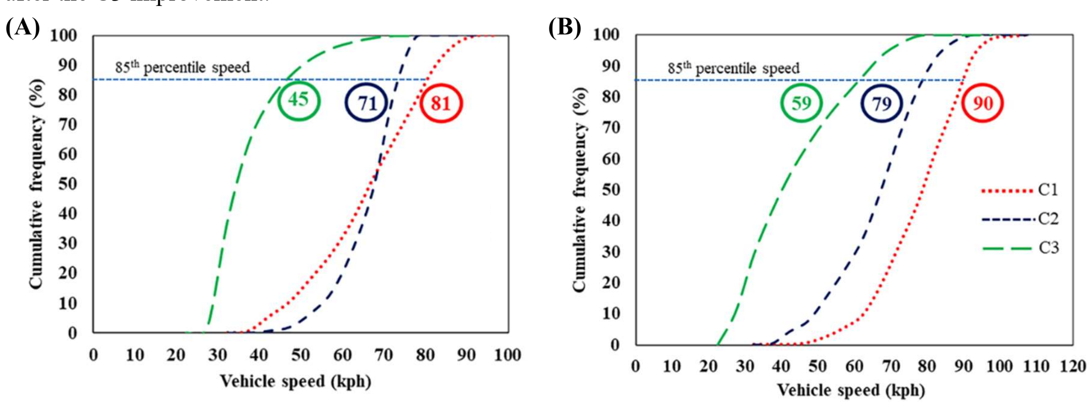

Figure 5 Speed distributions of inbound (A) motorcycles and (B) passenger cars on the weekdays.

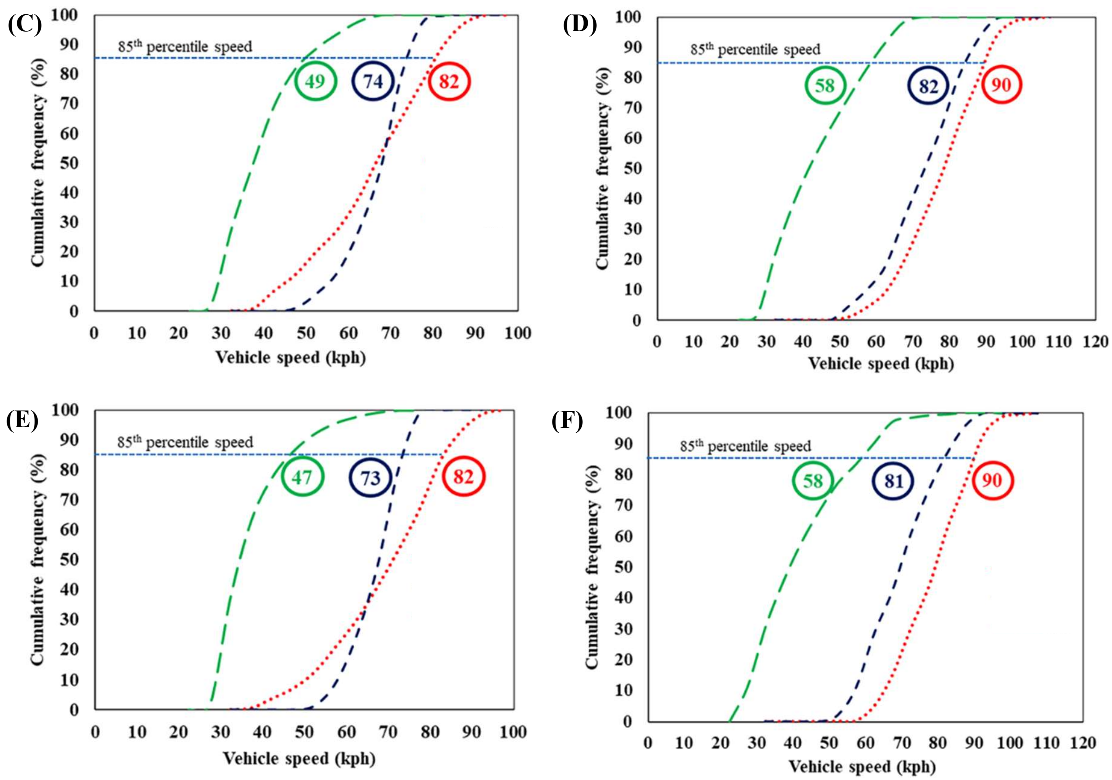

Figure 5 (Continued) Speed distributions of outbound (C) motorcycles and (D) passenger cars, both directions (E) motorcycles and (F) passenger cars on the weekdays.

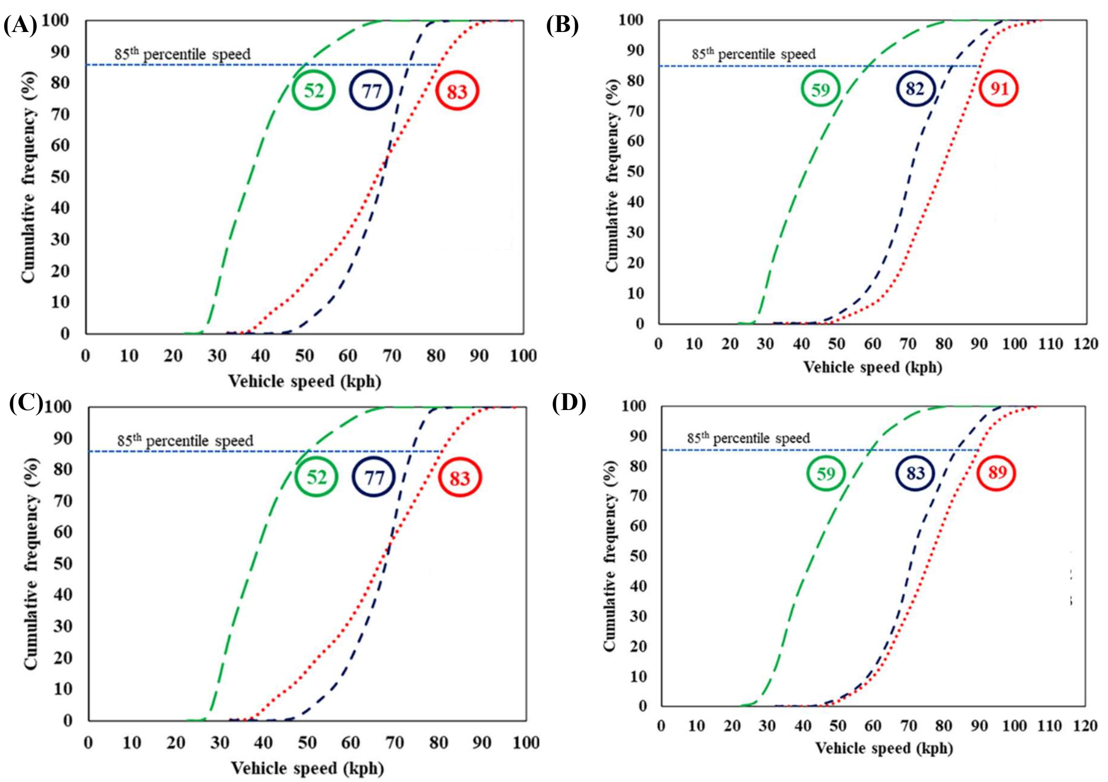

Figure 6 Speed distributions of inbound (A) motorcycles and (B) passenger cars, outbound (C) motorcycles and (D) passenger cars on the weekends.

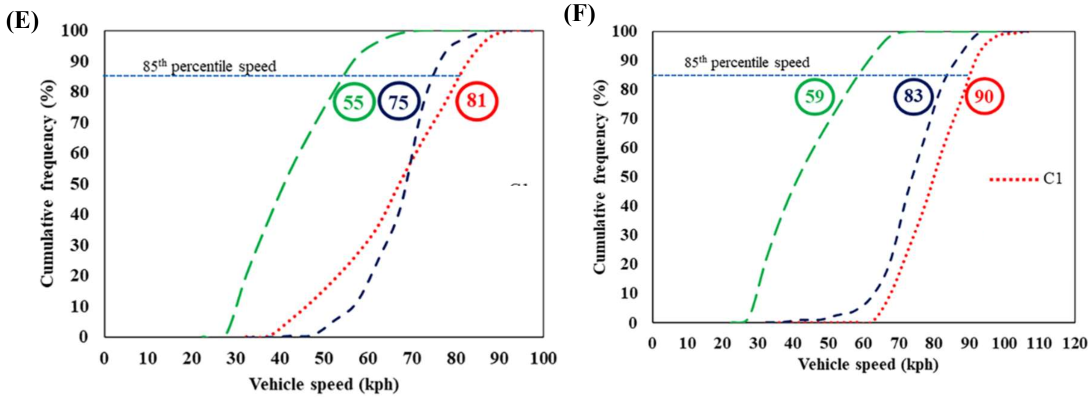

Figure 6 (Continued) Speed distributions of both directions (E) motorcycles and (F) passenger cars on the weekend.

Table 2 Descriptive statistics of speed data observed.

Day of week	Vehicle direction types		Minimum (kph)			Average (kph)			Standard deviation (kph)			85th percentile speed (kph)			Maximum (kph)			Number of samples		
			C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
Weekday	MC	Inbound	56	45	42	68	55	41	4.23	5.22	4.97	81	71	45	85	80	50	719	693	700
		Outbound	62	53	40	66	57	42	4.25	4.69	5.02	82	74	49	86	77	52	727	602	724
		Both directions	60	54	40	67	56	42	5.62	5.52	4.85	82	73	47	83	76	53	1,446	1,295	1,424
	PC	Inbound	80	62	44	82	65	48	4.42	3.56	3.03	90	79	59	95	82	67	768	601	621
		Outbound	75	60	45	80	63	52	4.09	3.12	3.35	90	82	58	97	85	69	770	600	607
		Both directions	78	59	47	81	64	50	4.28	3.62	3.77	90	81	58	98	85	70	1,538	1,201	1,228
Weekend	MC	Inbound	67	52	39	70	60	45	3.36	3.53	4.11	83	77	52	86	83	55	605	607	625
		Outbound	62	54	42	68	56	44	3.15	3.29	4.26	81	75	55	84	86	60	610	631	609
		Both directions	66	57	40	69	59	45	3.44	4.06	4.49	82	76	54	85	87	59	1,215	1,238	1,234
	PC	Inbound	76	49	45	81	60	46	3.69	4.57	4.20	91	82	59	96	90	64	650	605	715
		Outbound	74	59	44	78	67	48	3.26	3.67	3.87	89	83	59	99	98	68	673	712	685
		Both directions	77	60	40	80	64	47	3.49	4.01	4.31	90	83	59	94	95	63	1,323	1,317	1,400

Regarding PC, on weekdays the range of the speeds in both directions were found from 78 kph to 98 kph in the case of C1, 59 kph to 85 kph in the case of C2, and 47 kph to 70 kph in the case of C3, respectively. The average speeds were moderately reduced, from 81 kph to 64 kph, after the C2 improvement and decreased to 50 kph after the C3 improvement. The standard deviations were relatively reduced from 4.28 kph to 3.62 kph after the C2 improvement, and slightly increased to 3.77 kph after the C3 improvement. The 85th percentile speeds were slightly reduced, from 90 kph to 81 kph after the C2 improvement, and considerably decreased to 58 kph after the C3 improvement.

Identically, on weekends, the range of the speeds in both directions were found from 77 kph to 94 kph in the case of C1, 60 kph to 95 kph in the case of C2, and 40 kph to 63 kph in the case of C3, respectively. The average speeds declined from 80 kph to 64 kph after the C2 improvement, and significantly reduced to 47 kph after the C3 improvement. The standard deviations relatively changed from 3.49 kph to 4.01 kph after the C2 improvement, and slightly increased to 4.31 kph after the C3 improvement. The 85th percentile speeds were slightly reduced, from 90 kph to 83 kph after the C2 improvement, and significantly decreased to 59 kph after the C3 improvement.

3.1.2 Speed changes

The differences between two sets of speed data were analyzed by utilizing the t-test. The results of t values are presented in Table 3 clearly indicating that during weekdays and weekends, the average speeds of MC and PC in both directions decreased significantly at a 99% confidence level after the C2 and C3 improvements. In addition, the difference was distinctly found from the t values after the C3 improvement.

Table 3 also shows the changes of 85th percentile speeds. It was found that after the C2 installation, the 85th percentile speeds of MC in both directions were slightly reduced by 6-9 kph (or 7-11%). A larger difference was found, 22-26 kph (or 29-36%), after the C3 improvements were installed. Similarly, in the case of PC, the 85th percentile speeds were marginally reduced by 7-9 kph (or 8-10%) after the C2 improvements and a greater difference of 23-24 kph (or 28-29%) was seen after the C3 improvements.

The above results could be implied when comparing C1 to a zebra crossing with advanced traffic markings and warning signs (i.e., C2) that increases the visibility of drivers and, consequently, resulting in vehicle speeds being relatively reduced before approaching the pedestrian crossing area. In addition, in the case of C3, overhead traffic lights could further improve greater visibility. Also, speed cameras additionally installed could warn drivers to slow their vehicles.

Table 3 Results of speed changes.

Day of week	Vehicle types	Directions	Difference between two speed datasets (t values)		Change of 85th percentile speeds (kph)	
			C1 vs C2	C2 vs C3	C1 vs C2	C2 vs C3
Weekday	MC	Inbound	3.316*	4.234*	- 10 (-12%)	- 26 (-37%)
		Outbound	3.393*	4.087*	- 8 (-10%)	- 25 (-34%)
		Both directions	3.355*	4.161*	- 9 (-11%)	- 26 (-36%)
	PC	Inbound	4.482*	4.758*	- 11 (-12%)	- 20 (-25%)
		Outbound	3.217*	3.431*	- 8 (-9%)	- 24 (-29%)
		Both directions	3.852*	4.095*	- 9 (-10%)	- 23 (-28%)
Weekend	MC	Inbound	3.334*	5.489*	- 6 (-7%)	- 25 (-32%)
		Outbound	3.053*	3.066*	- 6 (-7%)	- 20 (-27%)
		Both directions	3.194*	4.278*	- 6 (-7%)	- 22 (-29%)
	PC	Inbound	3.539*	3.484*	- 9 (-10%)	- 23 (-28%)
		Outbound	3.886*	6.320*	- 6 (-7%)	- 24 (-29%)
		Both directions	3.713*	4.920*	- 7 (-8%)	- 24 (-29%)

The differences between C3 and C1 were disregarded in this study because the improvements of the pedestrian crossing were made from C1 to C2 and from C2 to C3, consecutively. *Significant at a 99 percent confidence level ($t_{critical}$ = 2.576).

The changes in average speed and 85th percentile speed of PC after the implementation of the zebra crossing with a pedestrian signal studied in this paper were compared to those after the installation of a raised zebra crossing with a pedestrian signal studied in previous research [18-22]. The comparison is presented in Table 4. It was found that the maximum reduction of average speed in this study (17 kph) was almost two times lower than that in the case of raised crossing platform (36 kph), while the highest change of the 85th percentile speed (24 kph) was approximately 1.5 times lower than in the case of the raised crossing platform (38 kph). This may certainly be because vehicles have to reduce speed more when they enter a raised pedestrian crossing. The raised pedestrian crossing is more effective in terms of speed reduction compared to the at-grade zebra crossing implemented in this study. However, the practicality of installing raised pedestrian crossings on urban arterial roads is another issue for further study.

Table 4 Comparison of the speeds of passenger cars from this study to previous studies.

Speed change (kph)	Zebra crossing with pedestrian signal (This study)	Raised zebra crossing with pedestrian signal
Average speed	14-17 (22-27%)	8-36 (15-62%) *
85th percentile speed	23-24 (28-29%)	5-38 (11-58%) **

*From the studies [27-30] ** from the studies [27] and [31].

3.2 Results of estimated maximum speeds

The average speeds and the 85th percentile speeds at C1, C2, and C3 presented in the previous subsection may be affected by different traffic flows at the time of each data collection. For the sake of a fair comparison, the relations between mixed traffic flow rates (i.e., a combination of MC and PC flows) and the speeds of MC and PC in both directions under uncongested condition were analyzed by applying the Greenshield's model [16]. The relationships between mixed traffic flow rates and vehicle speeds are depicted in Figure 7.

As shown in Figure 6, all relationships between speed (x-axis) and traffic flow rate (y-axis) of MC and PC on weekdays and weekends were in parabolic form with zero intercept following the Greenshield's model. The results of R^2 were greater than 0.56. These relationships are acceptable and can be used to estimate the maximum speeds which were summarized in Table 5.

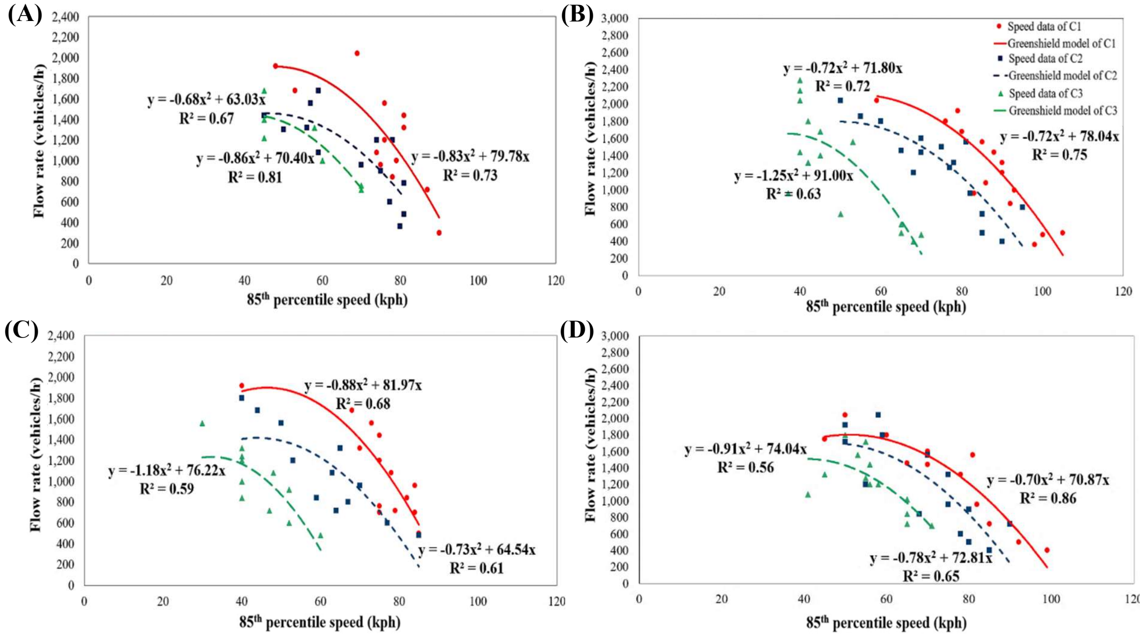

Figure 7 The relationships between traffic flow rate and speed under uncongested conditions of (A) motorcycles, (B) passenger cars on weekday, and (C) motorcycles, (D) passenger cars on weekend.

From Table 5, the results indicate that in the case of MC, the estimated maximum speeds were found to range between 93-96 kph at C1, 88-92 kph at C2, and 65-82 kph at C3, consecutively. In the case of PC, higher values for the estimated maximum speeds were found with the ranges being between 101-108 kph at C1, 93-99 kph at C2, and 73-81 kph at C3, consecutively.

According to the change in the maximum speeds, the results revealed that the estimated maximum speeds of MC decreased by 4-5 kph (or 4-5%) after the C2 improvements. Further reduction of 10-23 kph (or 11-26%) was found after the C3 improvements. Similarly, the estimated maximum speeds of PC were reduced by 8-9 kph (or 8%) after the C2 improvements and 12-26 kph (or 13-26%) after the C3 improvements, respectively.

It is noteworthy that the results of maximum speeds were in the same manner as those of the 85th percentile speeds presented in the previous section (i.e., slight reduction in the case of C2 improvements; larger decrease in the case of C3 improvements). On the other hand, smaller gaps of speed changes were found from the results of maximum speeds, compared to the 85th percentile speeds. The finding results implied that instead of the 85th percentile speeds based on different flow rates, the maximum speeds should be used to predict the probability of pedestrian fatality because these speeds not only indicate the maximum risk of a pedestrian being killed but also are based on the same traffic flow rate (i.e., flow rate is zero).

Table 5 Results of estimated maximum speeds and their differences.

Vehicle types	Day of week	Estimated maximum speed (kph)			Change of estimated maximum speeds (kph)	
		C1	C2	C3	C1 vs C2	C2 vs C3
MC	Weekday	96	92	82	- 4 (- 4 %)	- 10 (- 11 %)
	Weekend	93	88	65	- 5 (- 5 %)	- 23 (- 26 %)
PC	Weekday	108	99	73	- 9 (- 8 %)	- 26 (- 26 %)
	Weekend	101	93	81	- 8 (- 8 %)	- 12 (- 13 %)

3.3 Results of probabilities of pedestrian fatality

The estimated maximum speeds were then used to predict the change in fatality probability of a vehicle MC or PC-pedestrian collision by applying the Scott and Mackie model [17]. The results are presented in Figure 7. It was found that the fatality probability of a pedestrian hit by a MC or PC (both weekdays and weekends) in the cases of C1 were extremely high (i.e., 95-98% in the case MC and 100% in the case of PC), while C2 could significantly reduce pedestrian fatality probability by 4% in the case of MC, and slightly decrease them by 5% in the case of PC. However, the pedestrian fatality probabilities were still high (i.e., 91-94% in the case of MC and 95-100% in the case of PC) due to the speeds still being higher than the safe speed for pedestrians to cross (30 kph).

On the other hand, C3 could significantly reduce pedestrian fatality probabilities by 15-53% in the case of MC and moderately decrease them by 17-38% in the case of PC. However, the pedestrian fatality probabilities were moderately high, i.e., 42-83% in the case of MC and 62-83% in the case of PC. This was due to the estimated maximum speeds presented in the previous section still being far above the safe speed for pedestrians.

Note that in this study it was assumed that the probability of a pedestrian being killed by MC and PC at the same maximum speeds are the same. Differences in severity of these two different types of vehicles should be investigated in further research.

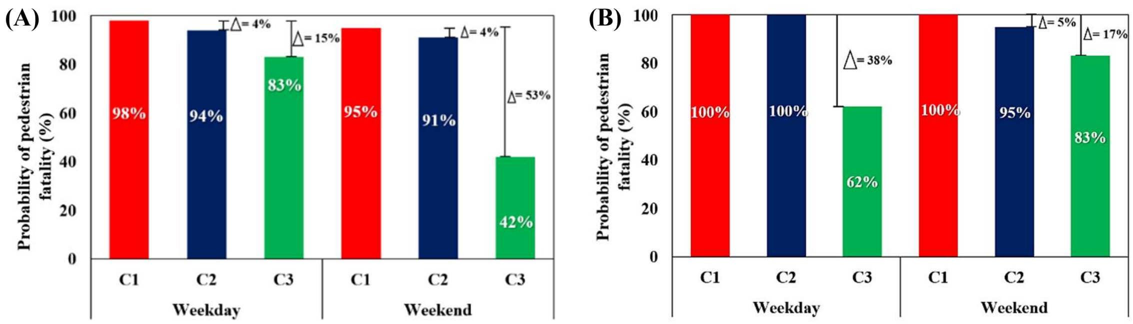

Figure 7 Predicted fatality probabilities of pedestrian-vehicle crashes (A) Motorcycle and (B) Passenger car.

4. Conclusion

This study provides valuable information concerning the evaluation of the effectiveness of pedestrian crossing improvements on arterial urban streets under mixed-traffic conditions. The two steps of the improvements were from C1 to a zebra crossing with traffic markings and C2, and from C2 to a zebra crossing with traffic markings, warning signs, and C3. The results of the vehicle speeds analysis revealed that C3 yielded greater safety enhancement for pedestrians crossing compared to C2. C2 slightly reduced the average speeds of MC by 10-11 kph (14-16%), and PC by 16-17 kph (20 - 21%), while C3 significantly reduced the average speeds of MC by 14 kph (24-25%), and PC by 14-17 kph (22-27%). Similarly, the 85th percentile speeds were slightly decreased: MC by 6-9 kph (7-11%), and PC by 7-9 kph (8-10%) after C2 installation. Meanwhile, greater differences were found after C3 implementation, i.e. a reduction in the 85th percentile speeds for MC of 22-26 kph (29-36%) and for PC of 23-24 kph (28-29%), respectively. In the same manner, the estimated maximum speeds were relatively reduced: MC by 4-5 kph (4-5%) and PC by 8-9 kph (8%) after C2 installation. Larger reductions were found after C3 improvement: MC by 10-23 kph (11-26%), and PC, by 12-26 kph (13-26%). The insights obtained from this study are based on the estimated maximum speeds of both vehicle types. These speeds were assumed to be the highest risk to a pedestrian if s/he were hit by a vehicle. Afterwards, the probabilities of pedestrian fatality were predicted. The finding results indicated that after C2 installation, the fatality probabilities of MC collisions reduced by 4%, while a slight decrease of 5% was found in relation to PC collisions. Conversely, C3 installation did reduce the fatality probabilities for MC collisions by 15-53%, while a slight decrease of 17-38% was found in relation to PC collisions. This demonstrated that a zebra crossing with traffic markings, warning signs, and pedestrian signals could significantly reduce probabilities of pedestrian fatality. The results from this study can be used to promote safer conditions for pedestrians in mixed-traffic in transition zones between suburban and urban arterial roads in Thailand where there is a large proportion of motorcycles.

Nevertheless, the improvement of pedestrian crossings by installing warning devices is not enough. Speeds of MC and PC are still far from safe for pedestrians (higher than 30 kph). Other effective traffic calming measures, such as physical improvements (e.g., curb extension), enforcement (e.g., radar speed signs), and land-use management (e.g., restriction of the number of driveways per lot) should be implemented to slow vehicles down and enhance the safety of pedestrians, especially on arterial roads with a great number of through traffic.

Furthermore, some limitations with the same fatality probability from MC and PC were assumed. This issue should be examined in future research. The lack of crash data could be overcome by investigating the conflict between vehicles and pedestrians as one of surrogate safety measures. The delay of pedestrians and drivers (or riders) could be included in the evaluation. Long-term evaluation in the change in driving and crossing behaviors is another challenge. Cost-benefit analysis should also be conducted.

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