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ASIAN TRANSPORTATION RESEARCH SOCIETY

ATRANS Safety Map Promotion and Implementation: Academic-Public-Private Partnership

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List of Abbreviations and Acronyms

AADT	Annual average daily traffic
ADT	Average daily traffic
APP	Academic-public-private collaboration partnership
ATRANS	Asian Transportation Research Society
DLT	Department of Land Transport
DOH	Department of Highways
DPM	Department of Disaster Prevention and Mitigation
DRR	Department of Rural Roads
PDCA	Plan Do Check Act
POLA	Provincial Office for Local Administration
PSU	Prince of Songkla University
SEM	Structural equation modeling
TDRI	Thailand Development Research Institute
UBU	Ubon Ratchathani University

CHAPTER I INTRODUCTION

1.1 Statement of problems

In Thailand, road crashes have been a pressing problem causing fatalities and injuries to Thai citizens for many decades. During the seven days of the New Year festive holiday, there were 373 deaths and 3,499 injuries from 3,421 crashes across the country (Road Safety Directing Center, 2020). These figures present a declining trend in road safety in Thailand compared to the previous years. However, to tackle road traffic problems, cooperation among all agencies concerned is essential. A big challenge is how to create intensive cooperation from all related sectors (public, private, and academic) to step forward to the goal of zero death and serious injury.

In the past six years, ATRANS continuously supported the common research project on developing ATRANS Safety Map Applica, Figure 1. The application has been used to collect the data of crash locations and risk locations in several areas across Thailand. The collected data can be used to analyze hazardous locations. Safe road treatments of several locations have been proposed to road safety-related agencies to correct those locations. The goal of this application, on one hand, would be a startup toolkit (Figure 2) to collect some missing data of crash and risk locations, for example, latitude and longitude, risk factors, for government offices (public side). On the other hand, the application and/or the data collected would help encouraging road safety culture in communities (private side). However, the studies in previous research years have been encountered with weak attention and involvement from the public and communities.

Figure 1 Milestone of ATRANS Safety Map Applica

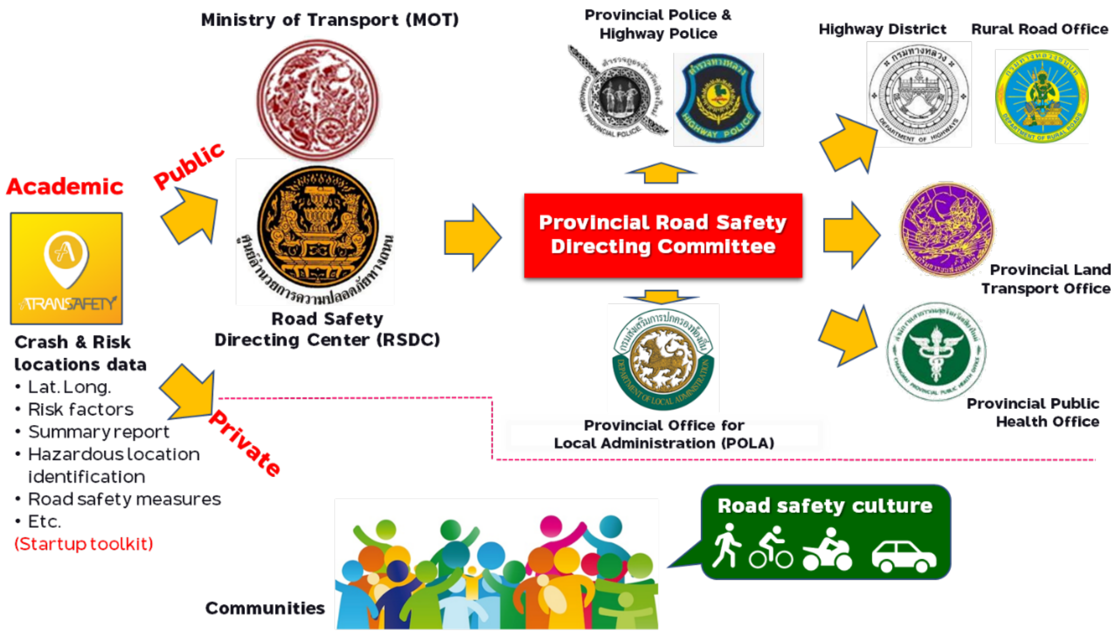


Figure 2 Goal of ATRANS Safety Map Applica

From several works of literature, some studies addressed the issues of community participation in road safety (see, for example, Howat, Cross, & Stevenson, 2001; Iamtrakul, Simcharean, & Jantaworn, 2012; Masuria et al., 2015). Barriers to community participation can be classified into two groups: personnel and planning issues (Howat, Cross, & Stevenson, 2001). The former includes (1) reasons why people are often reluctant to become involved in projects in their communities, (2) a lack of leadership, and (3) a lack of skills. The latter includes (1) inappropriate program foci, (2) inappropriate program evaluation, (3) lack of resources, and (4) a lack of sustainability. Enhancing road safety through awareness and understanding of the local community (Private partner) is one component of the key success. Cooperation of various local road safety agencies (Public partner) and local (or national) academy/research institute (Academic partner) searching for a sustainable solution to improve road safety in the community is another key success. Therefore, strengthening road safety in the local community requires mutually intensive cooperation among the three key partners which include academic, public, and private partners.

This research aims at promoting and implementing the ATRANS Safety Map application through the concept of collaboration partnership as shown in Figure 3. The figure shows that the collaboration partnership consists of three partners. The first partner is the academy which includes, for example, ATRANS, Prince of Songkla University (PSU), Ubon Ratchathani University (UBU), Thailand Development Research Institute (TDRI). The ATRANS research team will improve the ATRANS Safety Map, especially the risk location (Hiyari) function, to be more user-friendly. The improved application will be implemented in a couple of study areas through the process of public participation with the private partner in the study areas, for example, senior communities, school communities. Road safety-related knowledge, based on a safe system approach, from academic partners will also be transferred to the private partners to understand road safety situations in their community. The private partners will then identify and propose safety treatment to correct the risk areas in their community with the supports from the academic partners and public partner, for example, DOH, DRR, DLT, Police, municipality, technical colleges, and other public sectors, through the process of workshops. This approach could ensure that appropriate steps are taken to maximize the likelihood of community participation in a sustainable way.

One of several outcomes of the development of the ATRANS Safety Map is the crash data stored in the ATRANS Safety Map database. These data could be used to identify factors affecting crashes and severity. This is another gap to fulfill in this research.

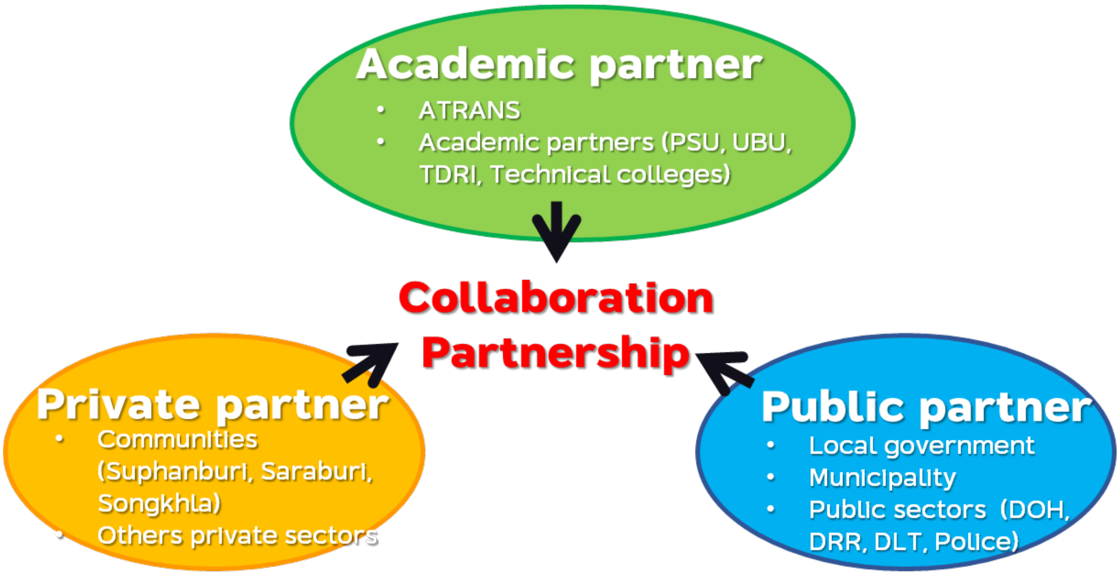


Figure 3 Concept of academic-public-private (APP) collaboration partnership
Source: Adapted from Kashiwa-no-ha Smart City (Kashiwa-No-Ha Internation Campus Town Initiative Committee, 2014)

1.2 Research objectives

This research aims at promoting the ATRANS Safety Map through the concept of collaboration partnership. Three objectives include:

1) to improve the risk location function in the application to be more user friendly,
2) to apply the application improved from the first objective to identify and propose safety countermeasures for risk locations in study areas through the process of APP collaboration partnership, and
3) to analyze the factors contributing to crash severity in Thailand.

CHAPTER 2 LITERATURE REVIEW

2.1 Safety data

Laureshyn & Várhelyi (2018) explained the basic concept of traffic conflicts which is based on the traffic process that is several elementary events. These events differ in their degree of severity (unsafety) and there exist some relationships between the severity and frequency of events of that severity. Hydén (1987) illustrated the concept with a 'safety pyramid' (see Figure 4). The lower part of the pyramid represents the normal interactions (encounters) between road users that are safe and occur most of the time. At the other extreme, the top of the pyramid consists of the most severe events such as fatal or injury accidents and that is very infrequent compared to the total number of the events. If the form of the relation between the severity and frequency of the events is known, it is theoretically possible to calculate the frequency of the very severe but infrequent events (accidents) based on the known frequency of the less severe, but more easily observable events (conflicts).

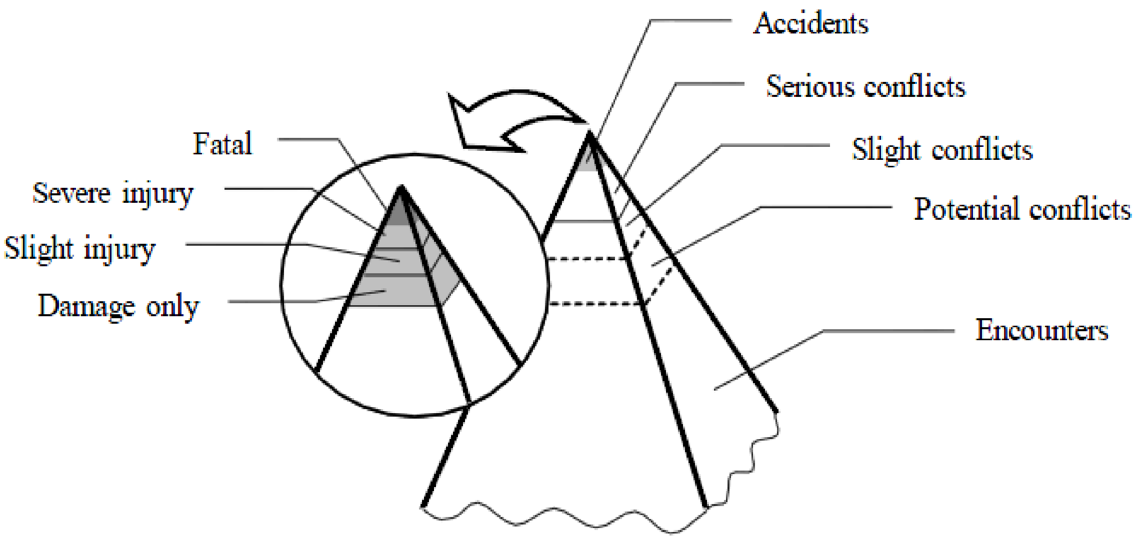


Figure 4 Safety pyramid
Source: Hydén (1987) cited in Laureshyn & Várhelyi (2018)

2.2 How to develop a user-friendly mobile app

User-friendly means that for customer app is intuitive, easy to use, simple, and that the customer can rely on the product. It is easy to start with the app and understand how to use it, high complexity is not valuable for the user. Reliability is a crucial element as an app cannot help the user while having bugs and not working properly (Pawet, 2019).

In general, User experience (UX) and User interface (UI) are directly related to user friendly. The UX means that the app was made for the customer to fulfill his needs and expectations. When the UI means that the interface of the app is well customized and easy to understand for the targeted group (Pawet, 2019).

A UX designer's primary concern is to address the feel of a product for a set of users. So, the UX designer will explore different options to solve user-specific pain points and provide them with a valuable solution. Ultimately, products with good UX are user-friendly and straightforward (Pawet, 2019).

Contrary to popular belief, a user interface design is not just about buttons and navigation menus, but about the interaction between the user and the app. The UI design is not just how a product looks, but how it works. Where will the buttons be placed and called-to-action for users to quickly understand the flow of the app? Does a particular interface even need buttons? If so, what is the purpose of those buttons? For an excellent user interface, the app should provide users with the actions required to figure out how the app will help them accomplish a goal. Thus, the goal of user interface design is to make the user's interaction as simple and efficient as possible, in terms of accomplishing user goals, known as user-centered design (Pawet, 2019).

Figure 5 summaries ten awesome tips for developing user-friendly apps (Pawet, 2019), which include:

1) Make the app useful. An app must, first and foremost, be helpful to the user in a real way, such as saving their time, money and generally make their life easier.
2) Understand users. this might be an obvious one, but it is too often being skipped out by app developers due to lack of time and impatience: need to get people to test an app before going live. These cannot be folks who had been in any way involved in the process of designing or developing of product. Testing by users how they are navigating the app, whether it is intuitive enough and does not cause them frustration.
3) Make sure onboarding is (super) easy. Apps that require users to register in the first step are a thing of the past. Forcing people through this stage creates very high bounce rates. Get rid of any barriers that might stop people by asking them about their details even before they start using the app. If the application requires any of these things, make sure users already like the app before asking them to commit and trust.
4) Use best practices of app development. With so many applications around and so few truly successful ones, it is smart to follow in the footsteps of those who succeeded. This does not have to mean copying anyone, it just means not repeating the mistakes of so many who came before.
5) Avoid redirects. A good app should consist of everything that a user needs to navigate it and solve his problem. Hence, linking or redirecting to external pages from the app is a very bad practice.
6) Design user touchpoints. Consider specific situations when the user might want to use the app and prepare accordingly. People have mixed feelings about them, but that is only because many apps overuse this mechanism or use it the wrong way. But when applied correctly, push notifications will attract people back into the product exactly at the time when they most need it.
7) Integrate when possible. This could just be summed up by 'don't reinvent the wheel'. If the application has a payment system, a chat bot, or a file-sharing option, use the tools people are already familiar with that can integrate into the product at a low cost.

8) Make pretty things people want. As much as the main function of design is good user experience, making a product look good should not be underestimated either. Slick-looking apps tend to get more downloads.
9) Create a safe environment. If requiring users' details, make sure that use trustworthy encrypted services.
10) Grow friendly apps by listening to users. Technology advancement is exponential. New operating systems create new possibilities for mobile apps to avoid previously notorious errors. User behavior also changes, meaning that what worked amazingly yesterday may be annoying for next month. Keep reading and replying to users' comments, encourage them to share feedback, and implement their suggestions in the next version of the app.

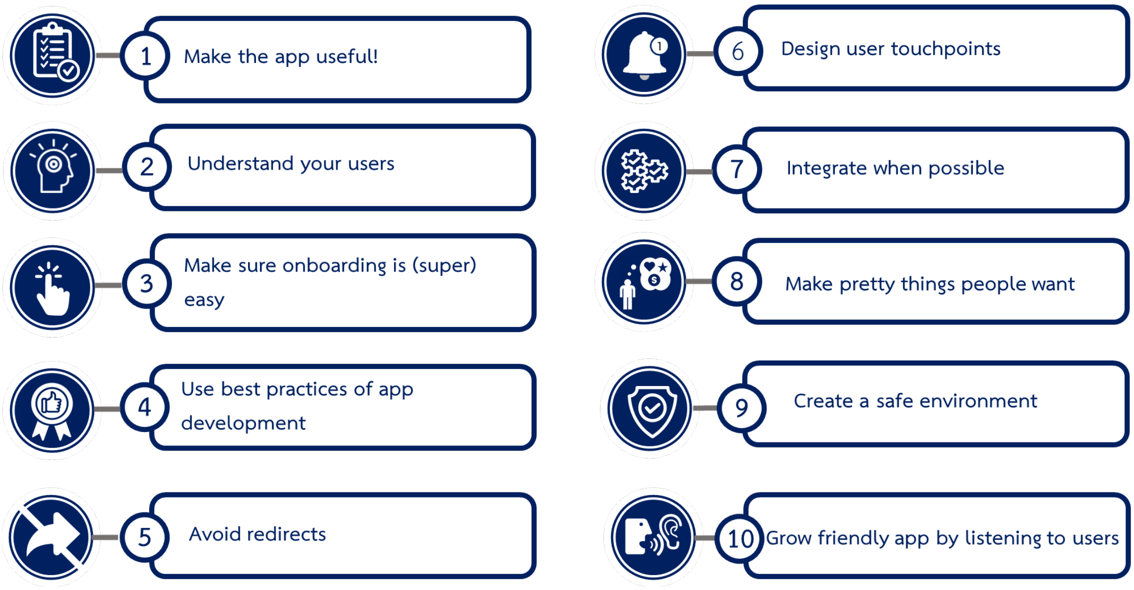


Figure 5 Ten awesome tips for developing user-friendly apps.
Source: Pawet (2019)

2.3 Safety Data Analysis

In general, safety data is used for identifying the size of the road safety problem, analysis of problems, development of strategy, identification of solutions, for advocacy, and monitoring, analysis, and evaluation (PIARC, 2019).

The data are very useful to several agencies and individuals, including (PIARC, 2019):

- Traffic engineers - in the identification, analysis, and treatment of existing risks and the prevention of future risk problems.
- Policy-makers - at national, regional, and local levels in setting crash reduction targets, developing road safety action plans, and monitoring performance.
- Police - in the identification of problem locations and times for enforcement.
- Health sector - for resource planning, injury surveillance, health promotion, and injury prevention interventions.
- Research community - in preventative studies and in testing and improving the effectiveness of road safety treatments.
- Insurance companies - in setting insurance rates and premiums.

- Vehicle manufacturers - in the development of safer vehicles.
- Prosecutors - in the use of data as evidence.

As mentioned in Section 2.1, safety data can be classified as crash data and non-crash data (i.e., potential conflict data). Thus, analyzing each type of safety data is important for further applications.

2.3.1 Crash Data Analysis

Crash data can be used to analyze significant factors contributing to a crash and unsafe driving behaviors. Several studies have been conducted to investigate these factors. Table 1 shows some research works determining significant factors contributing to a crash. Most of them found that road characteristics (geometry, junction, traveling lane, safety equipment, pavement condition) and traffic conditions (volume and speed) are major causes influencing a crash (Salifu, 2004; Hong *et al*., 2005; Reurings & Janssen, 2007; Littidej, 2007; Ngamchan, 2010; Mustakim & Fujita, 2011; Rahman, 2012; Thipwet, Kumphun, & Pueboobpaphun, 2012; Tipakornkiat, Boonrasi, Koonpoon, & Anusiri, 2014; Choocharukul, Wikijpaisarn, & Subsompon, 2014; Eboli & Mazzulla, 2015). Moreover, recent research works focused on road user, vehicle, and the environment and found that these factors are also the main causes affecting a crash (Eboli & Mazzulla, 2007; Jadaan, Al-Fayyad, & Gammoh, 2014; Useche, Montoro, Alonso, & Tortosa, 2018; Satiennam, Satiennam, Triyabutra, & Rujopakarn, 2018; Wong, Smith, & Sullivan, 2018; Ding, Jiao, Zhu, & Liu, 2019).

From the literature, there are several models used in analyzing crash contributing factors. As shown in Table 2, since about the early 2000s, Generalized Linear (GL) and Multiple Linear Regression (MLR) have been used for crash analysis, e.g., Salifu (2004), Hong (2005), and Mustakim & Fujita (2011). These traditional models are simple. However, road crashes are random events. Afterthought, Poisson Regression (PR) and Negative Binomial Regression (NBR), which were considered more appropriate techniques for investigating crash contributing factors, have been applied extensively, e.g., Reurings & Janssen (2007), Littidej (2007), Ngamchan (2010), Rahman (2012), Thipwet *et al*. (2012), Tipakornkiat *et al*. (2014), and Choocharukul (2014).

Recently, more advanced models have been applied to fulfill some limitations of the previous models, such as Empirical Bayes (EB) (Rahman, 2012; Zou, Henrickson, Wu, Wang, & Zhang, 2015), Artificial Neural Network (ANN) (Jadaan, Al-Fayyad, & Gammoh, 2014), and Structural Equation Model (SEM) (Eboli & Mazzulla, 2007; Useche *et al*., 2018; Satiennam, *et al*., 2018; Wong, *et al*., 2018; Ding, *et al*., 2019).

The EB method combine can outperform other methods for identifying blackspots because the EB method combines historical crash records of the site and the expected number of crashes obtained from a safety performance function (SPF) for similar sites. However, the SPFs are difficult to develop based on a large number of sites. Also, the EB method can be affected by SPFs (Zou, Henrickson, Wu, Wang, & Zhang, 2015).

Table 1 Some studies determining significant factors contributing to a crash.

Factors		Salifu (2004)	Hong *et al.* (2005)	Reurings & Janssen (2007)	Littidej (2007)	Eboli & Mazzulla (2007)	Ngamchan (2010)	Mustakim & Fujita (2011)	Rahman (2012)	Thipwet *et al.* (2012)	Tipakornkiet *et al.* (2014)	Choocharukul *et al.* (2014)	Jadaan (2014)	Useche *et al.* (2018)	Satiennam *et al.* (2018)	Wong *et al.* (2018)	Ding *et al.* (2019)
Road characteristics	Geometry	✓	✓	✓	✓	✓		✓		✓		✓	✓				✓
	Junction		✓	✓	✓	✓	✓	✓	✓			✓					
	Traveling/ shoulder lane	✓	✓			✓		✓	✓	✓	✓	✓					
	Safety equipment	✓	✓	✓	✓												
	Pavement			✓	✓												
Traffic conditions (volume/speed)			✓		✓		✓	✓		✓	✓	✓					
Road user characteristics						✓							✓	✓	✓	✓	✓
Vehicle characteristics						✓											✓
Environment						✓											

Table 2 Models used in analyzing crash contributing factors.

Factors	Salifu (2004)	Hong *et al.* (2005)	Reurings & Janssen (2007)	Littidej (2007)	Eboli & Mazzulla (2007)	Ngamchan (2010)	Mustakim & Fujita (2011)	Rahman (2012)	Thipwet *et al.* (2012)	Tipakornkiet *et al.* (2014)	Choocharukul *et al.* (2014)	Jadaan (2014)	Useche *et al.* (2018)	Satiennam *et al.* (2018)	Wong *et al.* (2018)	Ding *et al.* (2019)
Generalized Linear (GL)	✓															
Multiple Linear Regression (MLR)		✓					✓					✓				
Poisson Regression (PR)			✓	✓					✓	✓	✓					
Negative Binomial Regression (NBR)			✓			✓		✓	✓	✓	✓					
Empirical Bayes (EB)								✓								
Artificial Neural Network (ANN)												✓				
Structural Equation Model (SEM)					✓								✓	✓	✓	✓

The ANN, which is a sub-domain of an artificially intelligent system, represents complex relationships like the human brain. This approach has been widely used to analyze the relationship between crashes and parameters affecting them for which data were available (Jadaan, Al-Fayyad, & Gammoh, 2014). ANN can model complex, nonlinear relationships without previous assumptions of the nature of the relationship (Karayiannis & Venetsanopoulos, 1993). However, for realistic and fast ways in developing models, it requires enough data (Riviere, Lauret, Ramsamy, & Page, 2006; Ogwueleka, Misra, Ogwueleka, & Fernandez-Sanz, 2014).

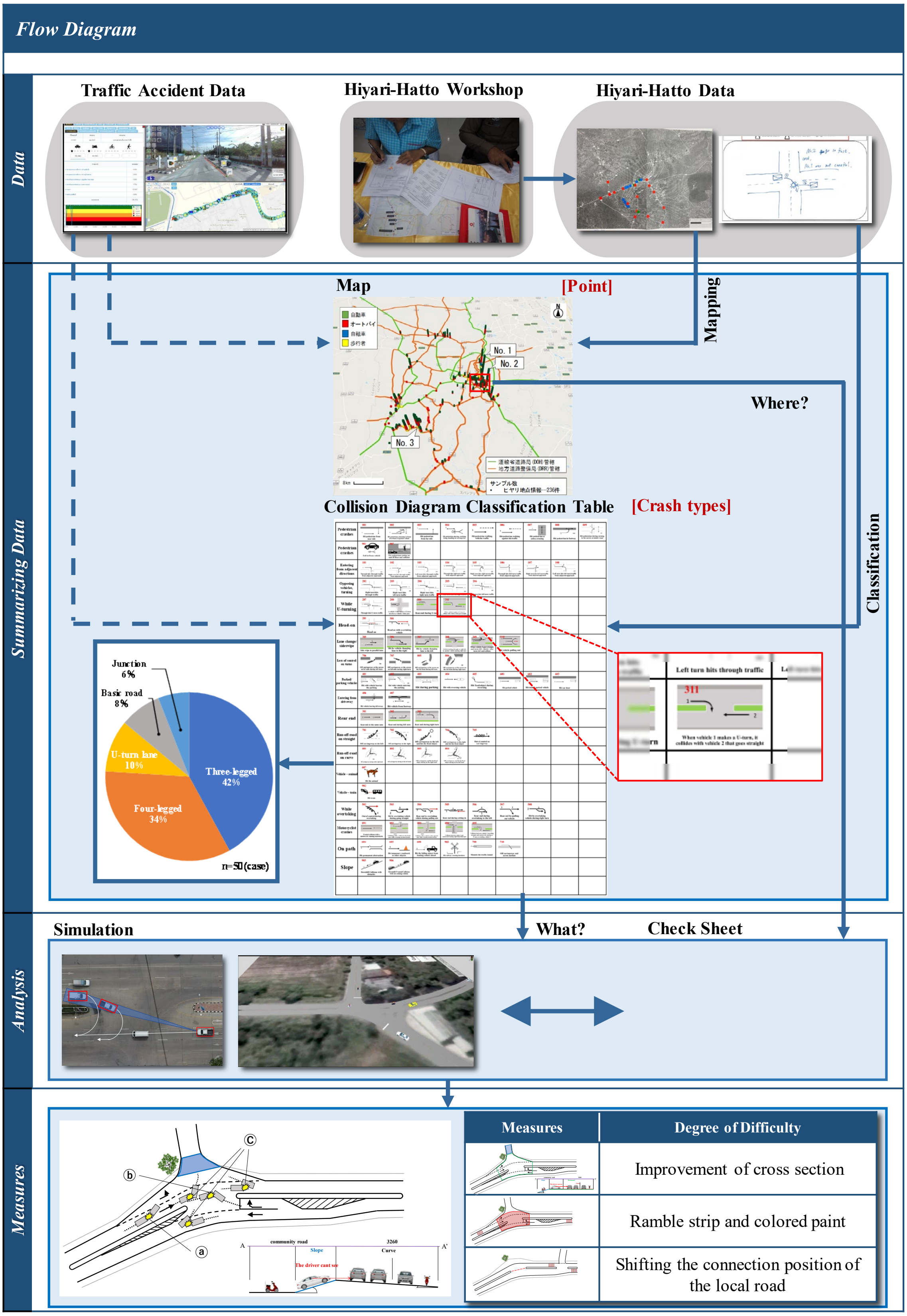
On the contrary, the SEM is a multivariate technique combining regression, factor analysis, and analysis of variance to estimate interrelated dependence relationships simultaneously. This method allows the modeling of a phenomenon by considering both the unobserved “latent” constructs and the observed indicators that describe the phenomenon. Thus, the SEM permits the investigation of the impact of some crash characteristics (such as environmental context, road characteristics, and driver characteristics) on crash severity (number of injured and vehicles involved in the accident) (Eboli & Mazzulla, 2007).

2.3.2 Conflict Data Analysis

A traffic conflict is an observable potential-crash situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged (Perkins & Harris, 1968 and Amundsen, forskningsråd, & Lund, 1977 cited in Tiwari, Mohan, & Fazio, 1998).

In many cases, traffic conflicts of certain types are good surrogates of crashes in that they produce estimates of average crash rates nearly as accurate, and just as precise, as those produced from historical crash data. Therefore, if there are insufficient crash data to produce and estimate, conflict data should be very helpful (FHWA, 1985).

Recently, Fukuda (2020) established a system that could analyze traffic conflict (Hayari-Hatto) data and crash data and applied it to propose appropriate countermeasures at blackspots in Suphanburi, resulting in a significant reduction in road crashes. In his study, the analysis was carried as shown in Figure 6. In the first step, Hayari-Hatto data were obtained from the Hiyari-Hatto workshop. The Hayari-Hatto data and traffic accident data were then applied to analyze collision types and identify blackspots. Proper countermeasure was finally proposed based on the collision types and the results of traffic simulation.



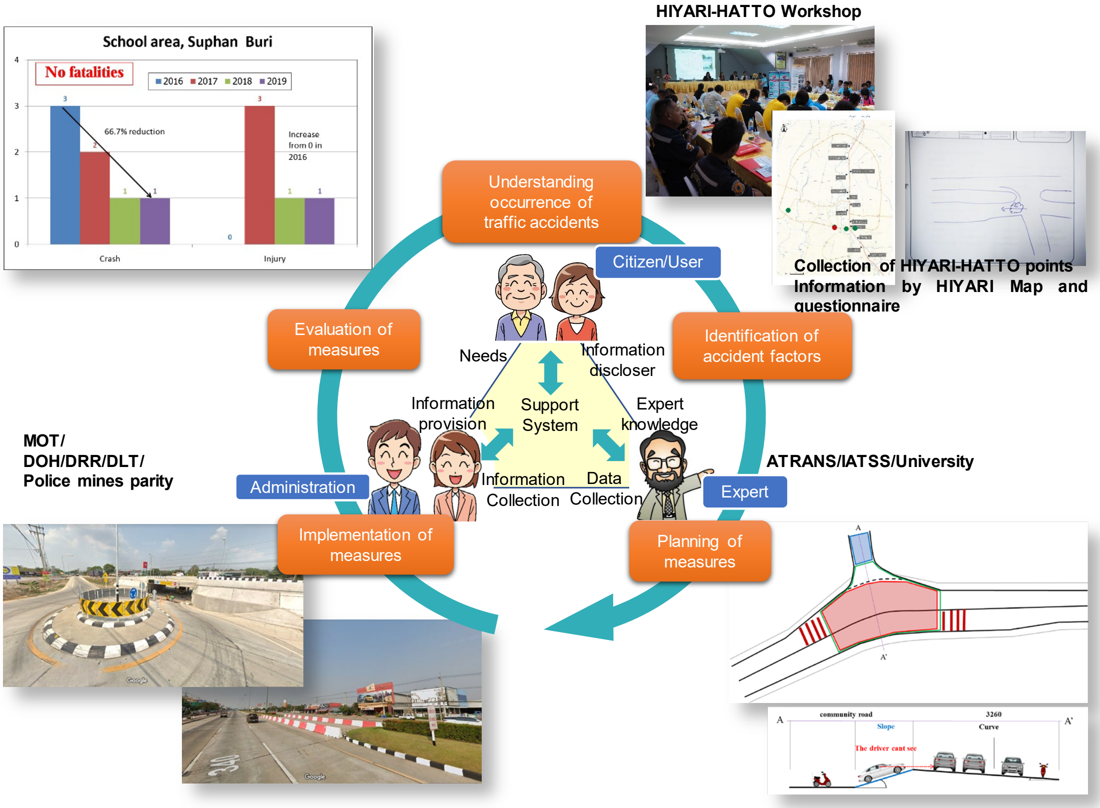
Source: Fukuda (2020)

Figure 6 Process to analyze Hiyari-Hatto data

2.4 Public Participation and Mobilisation on Road Safety

Community participation can make a positive contribution to the enhancement of road safety (Hingson, et al., 1996). However, impediments to the large scale and sustained involvement of community members exist. These barriers are numerous and are often inter-related. They tend to relate to either personnel issues or planning issues. The establishment of a local committee is one of the most effective ways to get community involvement in road safety-related interventions (Howat, Cross, & Stevenson, 2001).

Fukuda (2020) mentioned the key success points on road safety that it is important to be aware of problems daily, as in the PDCA (Plan, Do, Check, and Action) cycle. The process from data collection to evaluation of countermeasures can express like the PDCA cycle as shown in Figure 7. This cycle has 5 steps which include "Understanding occurrence of traffic accidents", "Identification of accident factors", "Planning of measures", "Implementation of measures", and "Evaluation of measures". The details of each step are comprehensively explained in Fukuda (2020). In his study, he applied a successful case of the Kamagaya Model in Japan to the case of Suphanburi (Thailand) in which residents, municipalities, and experts are jointly implementing traffic safety countermeasures based on the PDCA cycle.



Source: Fukuda (2020)

Figure 7 PDCA cycle for traffic safety

CHAPTER 3 METHODOLOGY

3.1 Research framework

The research framework consists of six tasks as shown in Figure 8, which include:

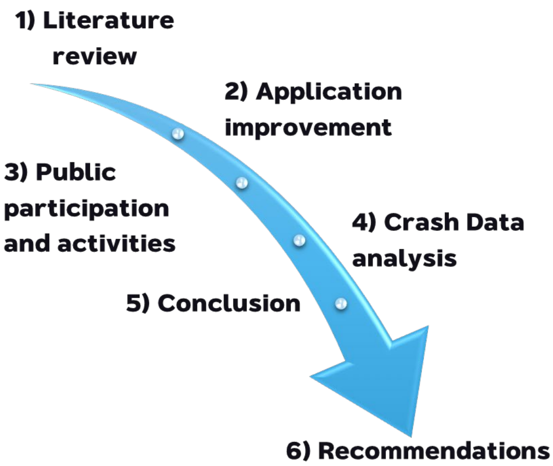


Figure 8 Research framework

3.2 Literature review

The literature related to how to create a user-friendly mobile application was reviewed. Also, some works of literature related to the process and good practices of community participation and mobilization on road safety were reviewed. Moreover, approaches and good practices on the analysis of factors influencing crash severity were investigated.

3.3 Application improvement

The risk location function of the current version of ATRANS Safety Map was improved to simplify the application and allow any users in local communities to use it easily, as shown in Figure 9, with the following functions:

- identifying the causes of any risk location; and
- proposing safety treatments for the identified risk location(s).

Moreover, a local admin management function was developed to allow the users (authorized by ATRANS) to screen and manage risk location and crash data reported in their area.

A few pilot tests were conducted to evaluate whether the application functioning properly.

Figure 9 Example interface of application improved

3.4 Public participation and activities

There were two types of workshops for public participation and road safety-related activities in Thailand, as shown in Figure 10, which include 1) risk location improvement workshop and 2) hazardous location improvement workshop.

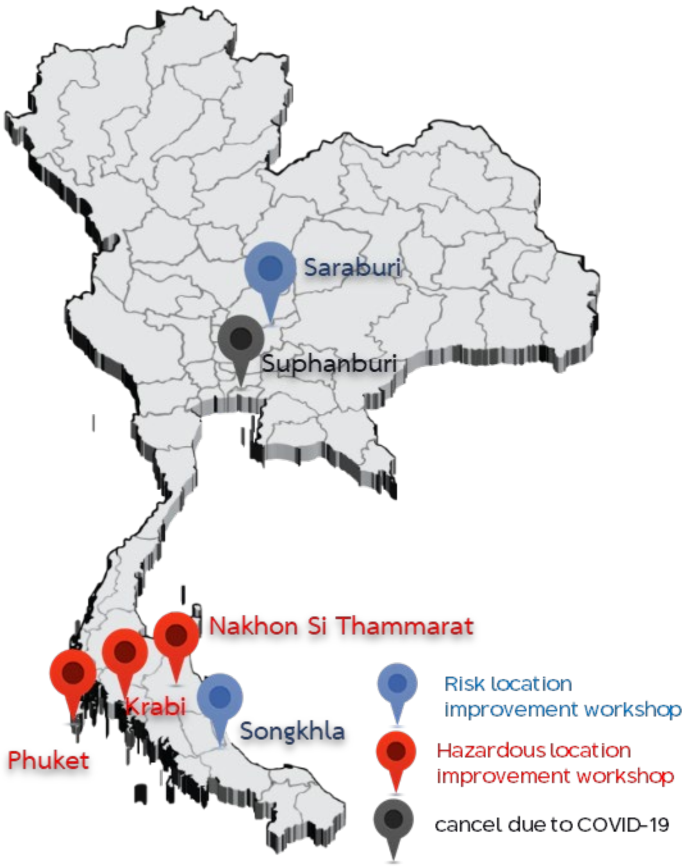


Figure 10 Study areas of public participation and road safety-related activities

Risk (or Hiyari) location improvement workshop was conducted to promote ATRANS safety map application and to extend the network for reporting risk location data using the ATRANS safety map. As shown in Figure 11, two workshops were conducted at Prince of Songkla University (Songkhla province) and Thaluang Cementhaianusorn Technical College (Saraburi Province). The first workshop (Figure 11a) was conducted on 24th August 2020. There were approximately 300 first-year bachelor students who attended and there were asked to use the application to report risk locations in the university. The second workshop (Figure 11b) was conducted on 26th November 2020. 48 students attended and used the application to report risk locations nearby the college.

a) Prince of Songkla University, Songkhla province

b) Thaluang Cementhaianusorn Technical College, Saraburi province

Figure 11 Risk (Hiyari) location improvement workshops

From the second workshop, road sections in front of the Thaluang Cementhaianusorn Technical College were investigated. Traffic volume and speed were analyzed. As shown in Figure 12, countermeasures were finally proposed to the college for further actions.

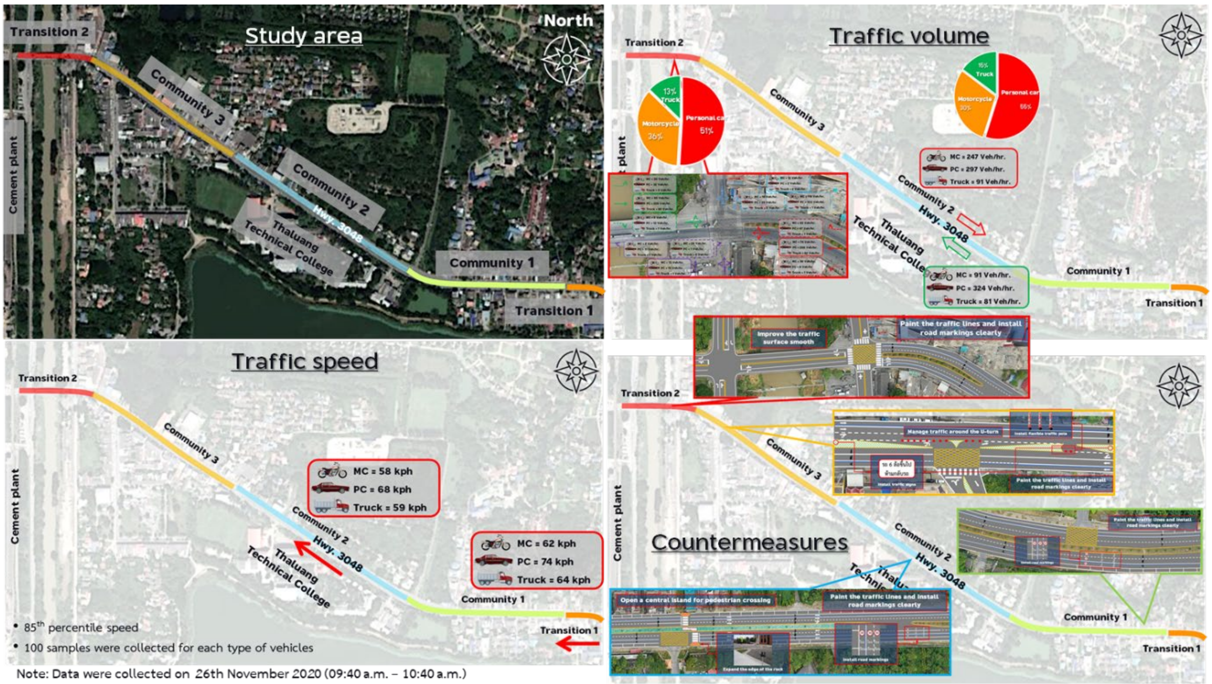


Figure 12 Results from the risk location improvement workshop in Saraburi

For the hazardous location improvement workshop, there were three workshops conducted in Phuket, Krabi, and Nakhon Si Thammarat, as shown in Figure 13. During each workshop, some basic knowledge on road safety and safe system approach was initially given to the participants. Several road safety professionals were attended, which include traffic police officers, DOH and DRR officers, rescue staff, public health professionals, Disaster prevention and mitigation provincial officers, Rotary 3330 members, and insurance staff.

Then, a brainstorming activity was generated to develop some ideas on how to improve the safety of hazardous locations in their response area. ATRANS safety map was also introduced as a tool for data collection before and after safety improvements. Finally, the conclusion and recommendations of hazardous locations were concluded for the implementation.

After the workshops, traffic volume and speed studies and road safety audits were conducted at each hazardous location. These studies were investigated again after the improvement. The results before and after the improvement are presented in Chapter 4.

a) Phuket

b) Krabi

c) Nakhon Si Thammarat

Figure 13 Hazardous location improvement workshops

3.5 Crash data analysis

In this research, crash data collected in the database of the ATRANS Safety map were analyzed by using descriptive analysis and multivariate statistical analysis approaches, for example, structural equation modeling (SEM). The details are presented in Chapter 5.

3.6 Conclusions and recommendations

Some significant findings from the study were concluded and highlighted. Especially, keys of success and barriers and lessons learned from the APP collaboration partnership were noted. Recommendations for safety improvement and future research were also mentioned in Chapter 6.

CHAPTER 4 RESULTS OF LOCATION INVESTIGATION

4.1 Overview of hazardous locations

There are nine hazardous locations investigated in this research, as shown in Figure 14. From the ATRANS project 002-2019, the three hazardous locations in Phuket were proposed to the Phuket road safety committee. The other six locations were proposed by Krabi and Nakhonsithamarat road safety committees. All nine locations have been granted from Safer Road Foundation (SRF) for safety improvement.

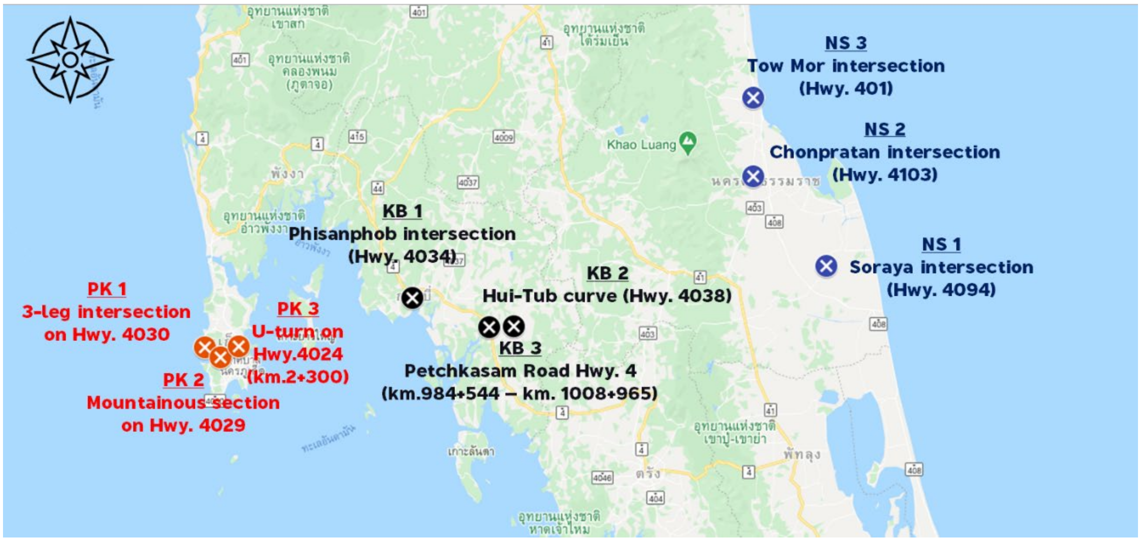
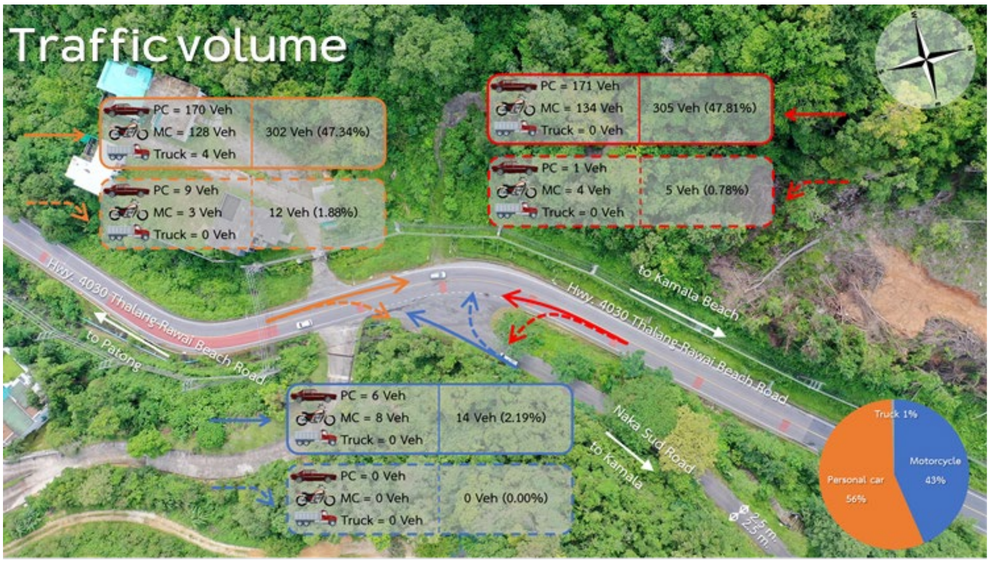


Figure 14 Hazardous locations investigated in this research

The details of before and after improvement for each hazardous location are presented in the following sections.

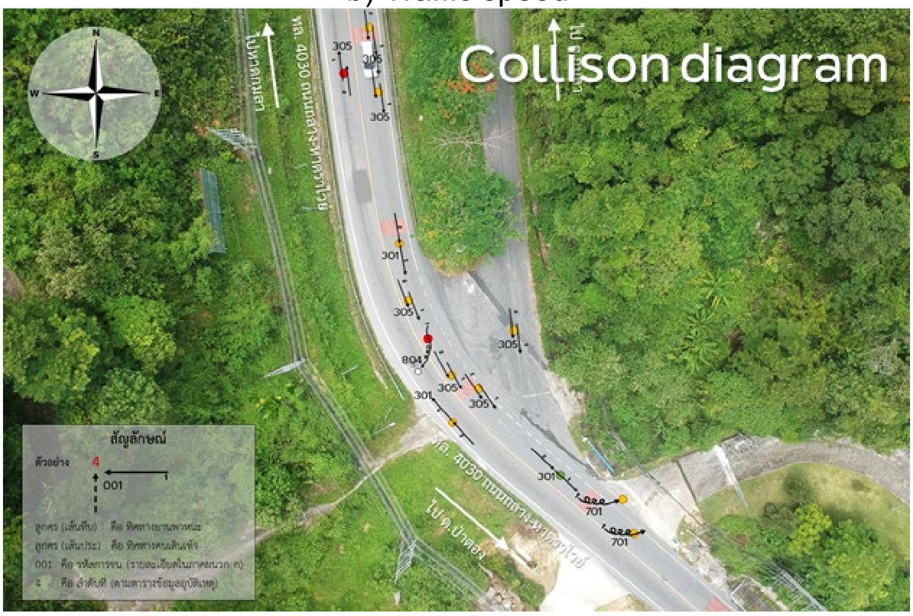
4.2 PK 1: 3-leg intersection on Hwy. 4030

The first site in Phuket (PK 1) is the three-leg junction located on Highway No. 4030. The results of traffic volume and speed data and collision diagram before an improvement are presented in Figure 15. During the workshop conducted in Phuket, countermeasures were discussed and finally proposed as shown in Figure 16. Unfortunately, this site has not been improved yet due to waiting for the road authority for implementation. However, the improvement of this site is engaged in this fiscal year. Note that for long-term improvement the concern authority should consider adjusting the road alignments both horizontal and vertical to be safer.



a) Traffic volume

b) Traffic speed



c) Collision diagram

Figure 15 Results of data collection of the site PK1

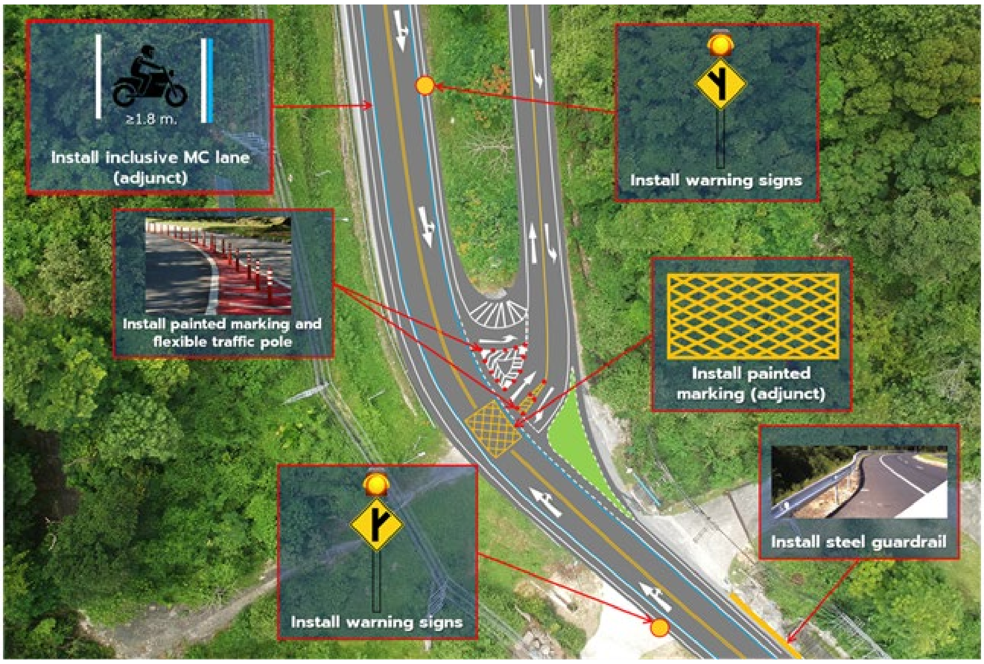


Figure 16 Countermeasures proposed for the improvement at site PK 1

4.3 PK 2: Mountainous section on Hwy. 4029

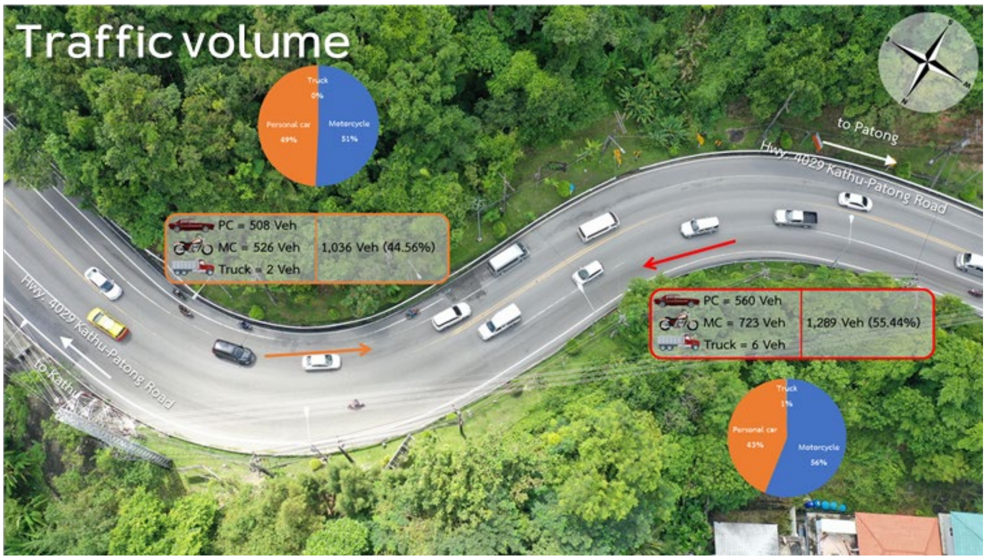
The second site in Phuket (PK 2) is the mountainous road section on Highway No. 4030, which connects Kathu district and Patong beach, one of the most attractive tourist areas in Phuket. The results of traffic volume and speed data and collision diagram before an improvement are presented in Figure 17. The countermeasures proposed for the improvement and those finally implemented are illustrated in Figure 18.

After the improvement, traffic volume and speed were again collected. The results are shown in Figure 19. The flow rate and the 85th percentile speed collected every 5-minute intervals were collected before and after the implementation. The data are plotted in the graph, which represents the relationship between flow rate and speed. The results are presented in Figure 20.

In each graph, free-flow speed for each type of vehicle was estimated using a linear regression model. Note that the values of R^2 are quite low due to the limited sample size. Future research should consider this issue.

The free-flow speed of passenger cars (PC) and motorcycles (MC) before and after improvements can be forecasted at a zero flow rate. The estimated free-flow speeds were used to predict the change in fatality probability of the PC and MC before and after the improvement. The relationship between impact speed and fatality probability was obtained from the study of Wramborg (2005). The results are presented in Table 3. It was found that the installation of a flexible guidepost along the median could reduce the free flow speed and the change in fatality probability of the PC in both directions, especially on the steep downgrade to the Patong direction.

Regarding the MC, the installation could improve some changes in speed and fatality probability, especially to Kathu's direction. A few changes were found in the direction of Patong. Thus, further, improvement is required, especially to reduce the speed of MC.



a) Traffic volume

b) Traffic speed

c) Collision diagram

Figure 17 Results of data collection before the improvement at site PK 2

a) Countermeasures proposed during the workshop

b) Countermeasures finally implemented
Figure 18 Countermeasures at site PK 2

a) Traffic volume
Figure 19 Results of data collection after the improvement at site PK 2

b) Traffic speed

Figure 19 Results of data collection after the improvement at site PK 2 (Cont.)

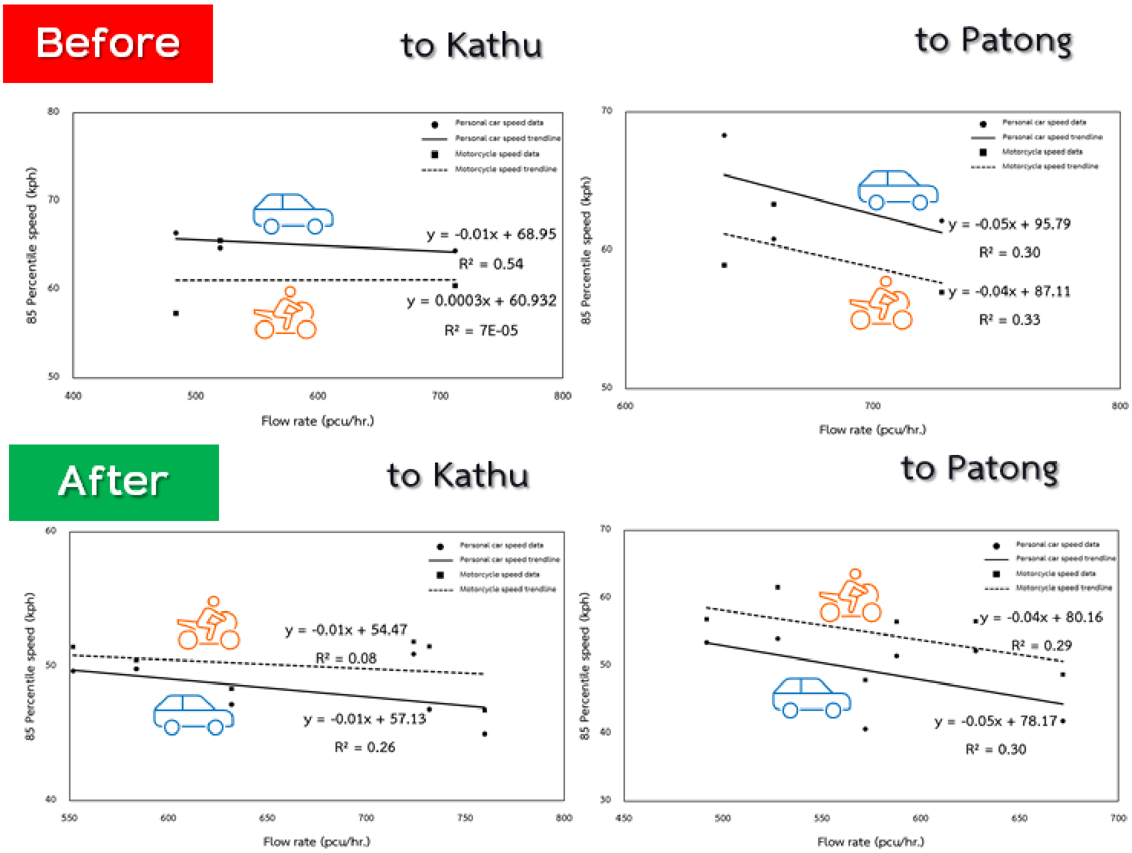


Figure 20 Relationship between flow rate and speed before and after the improvement at site PK 2

Table 3 Forecasted free-flow speed and fatality probabilities at site PK 2

Direction	Estimated free flow speed	Before (kph)	After (kph)	Speed change (kph)	Change in fatality probability* (%)
To Kathu	MC	61	54	7 (-11%)	-6%
	PC	69	57	12 (-17%)	-4%
To Patong	MC	87	80	7 (-8%)	0%
	PC	96	78	18 (-18%)	-58%

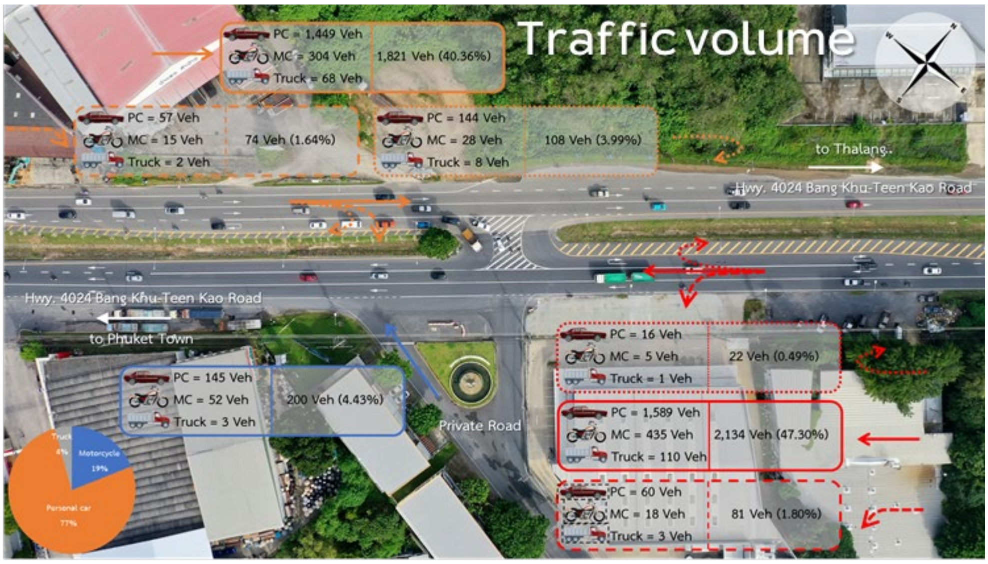
Note: *estimated from Wramborg's model for fatality probability (2005) by assuming that the MC could take a risk as the pedestrian.

For further improvement, Figure 21 shows that installing a traffic pole continuously, installing a guardrail to close the gap at the curve section, providing safer access between the main road and roadside communities, and providing a safe MC lane are needed. In addition, for long-term improvement the concern authority should consider adjusting the road alignments both horizontal and vertical to be safer.

Figure 21 Further improvement required for site PK 2

4.4 PK 3: U-turn on Hwy.4024 (km.2+300)

The third site in Phuket (PK 3) is the U-turn on Highway No. 4024, which is the bypass road between Phuket town and Thalang district. The results of traffic volume and speed data and collision diagram before an improvement are presented in Figure 22. The countermeasures proposed for the improvement and those finally implemented are illustrated in Figure 23.

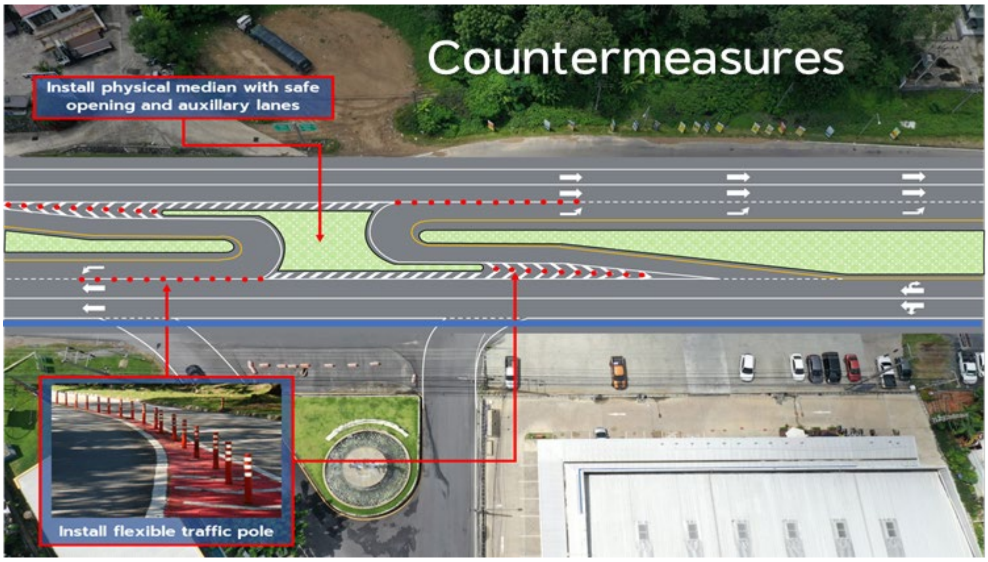


a) Traffic volume

b) Traffic speed

c) Collision diagram

Figure 22 Results of data collection before the improvement at site PK 3



a) Countermeasures proposed during the workshop

b) Countermeasures finally implemented

Figure 23 Countermeasures at site PK 3

After the improvement, traffic volume and speed were again collected. The results are shown in Figure 24.

The flow rate and the 85th percentile speed were collected every 5-minute intervals before and after the implementation. were plotted in the graph, following the same process as the previous case study. The relationships between flow rate and speed are presented in Figure 25 when the relationship between impact speed and fatality probability were estimated and presented in Table 4. It was found that the installation of a flexible guidepost at the painted median eliminated conflict areas (and some conflict movements) and could improve the safety of U-turn vehicles.

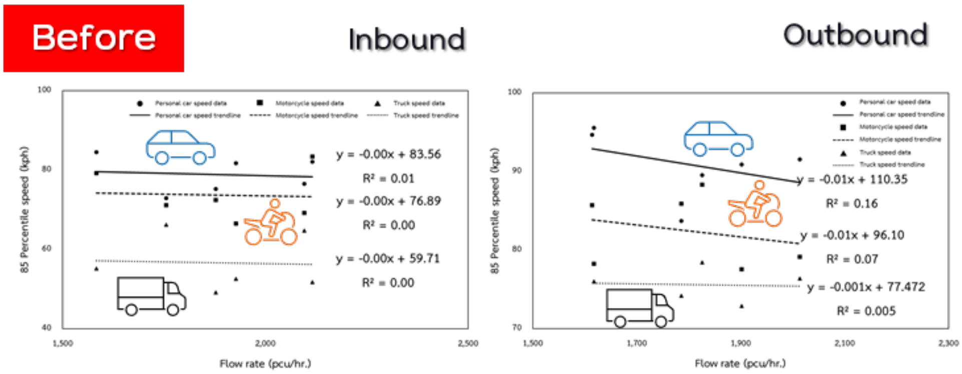
Regarding the inbound direction, the speeds of MC, PC, and, especially T (truck), increase. This maybe because illegal u-tun conflicts removed, the through traffic easily passes this location and consequently increases their speed.

On the other hand, for the outbound direction, the speeds of MC and PC decrease (except T increases). However, the speeds of PC and T are too high (> 100 kph). Thus, further, improvement is needed to reduce the vehicle speed in both directions.

a) Traffic volume

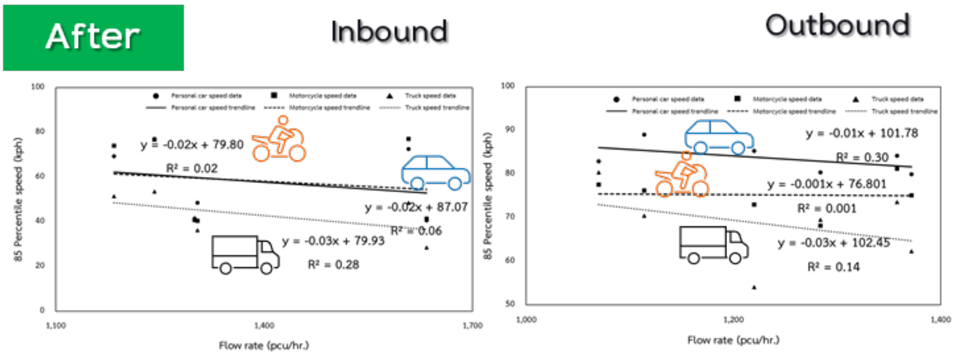
b) Traffic speed

Figure 24 Results of data collection after the improvement at site PK 3



a) Before improvement

Figure 25 Relationships between flow rate and speed before and after the improvement at site PK 3



b) After improvement

Figure 25 Relationships between flow rate and speed before and after the improvement at site PK 3 (Cont.)

Table 4 Forecasted free-flow speed and fatality probabilities at site PK 3

Direction	Estimated free flow speed	Before (kph)	After (kph)	Speed change (kph)	Change in fatality probability* (%)
Inbound	MC	77	80	3 (+4%)	0%
	PC	84	87	3 (+4%)	+1%
	Truck	60	80	20 (+33)	+67%
Outbound	MC	96	77	19 (-20%)	0%
	PC	110	102	8 (-8%)	0%
	Truck	77	102	25 (+33)	+6%

Note: *estimated from Wramborg's model for fatality probability (2005) by assuming that the MC could take a risk as the pedestrian.

Figure 26 shows some examples of further improvement, which include:

- installing traffic pole continuously,
- checking the turning radius of heavy vehicle and relocating the position of traffic poles at U-turn area so that heavy vehicle can make a single turn safely,
- extending safe acceleration lanes in both directions, and
- installing plastic barriers at the roadside island in front of the service road to reduce conflict areas and prevent illegal crossing to the U-turn.

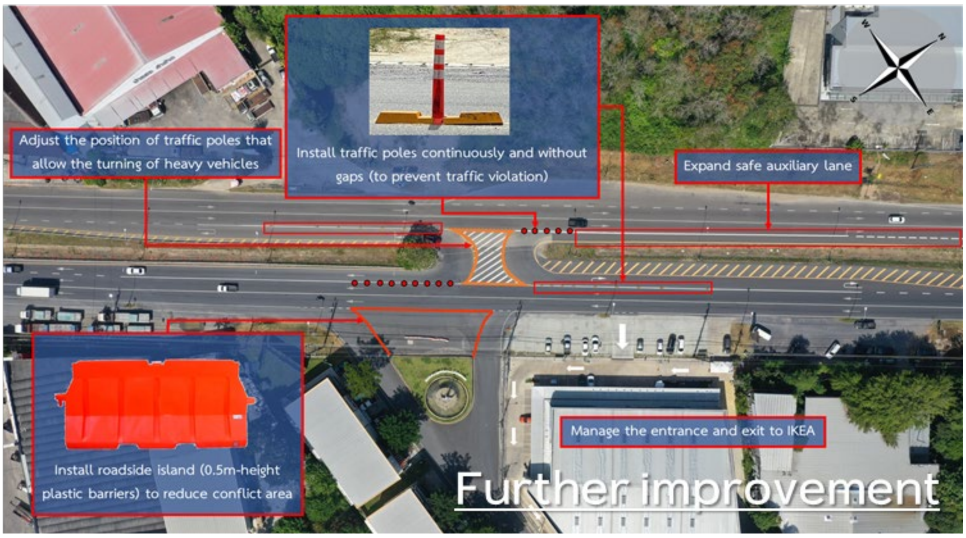


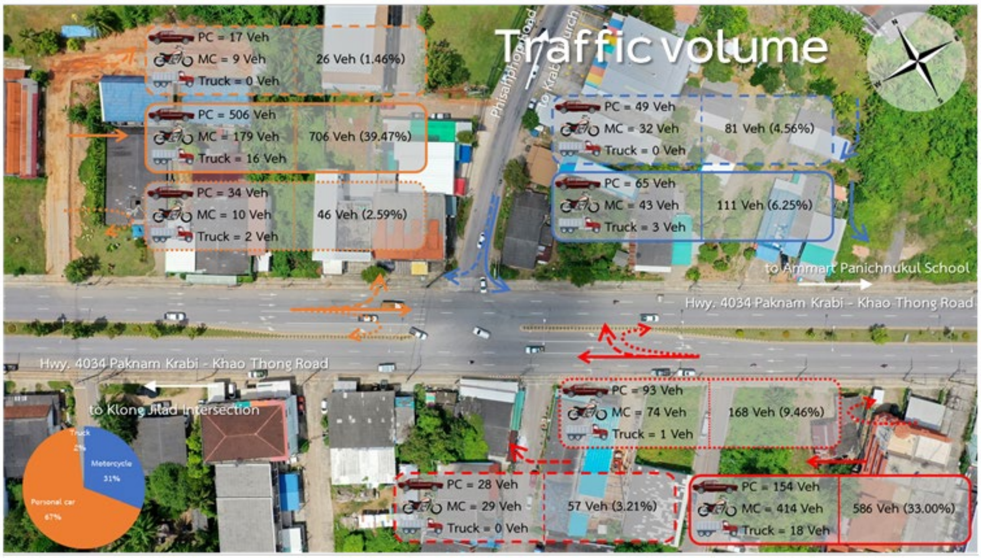
Figure 26 Further improvement required for site PK 3

4.5 KB 1: Phisanphob intersection (Hwy. 4034)

The first site in Krabi (KB 1) is the Phisanphob intersection which is a three-leg junction between Phisanphob road (local traffic) and Highway No. 4034 (intercity traffic). The results of traffic volume and speed data and collision diagram before an improvement are presented in Figure 27. The countermeasures proposed for the improvement and those finally implemented are illustrated in Figure 28.

After the improvement, traffic volume and speed were again collected. The results are shown in Figure 29. The flow rate and the 85th percentile speed collected every 5-minute intervals were collected before and after the implementation. The data are plotted to represents the relationship between flow rate and speed as shown in Figure 30. In each graph, free-flow speed for each type of vehicle was estimated using a linear regression model. Note that the values of R^2 are quite low due to the limited sample size. Future research should consider this issue.

Free-flow speed of passenger cars (PC) and motorcycle (MC) before and after improvements were estimated at zero flow rate. The estimated free-flow speeds were used to predict the change in fatality probability of the PC and MC before and after the improvement by applying the study of Wramborg (2005). The results are presented in Table 5. It was found that traffic signal installation reduced the speed and the change in fatality probability of the PC in both directions significantly. Regarding the MC, the speed in both directions was too high and risky (i.e., more than 80 kph). Therefore, traffic calming measure is needed to reduce the speed of MC.



a) Traffic volume

b) Traffic speed

c) Collision diagram

Figure 27 Results of data collection before the improvement at site KB 1

a) Countermeasures proposed during the workshop

b) Countermeasures finally implemented

Figure 28 Countermeasures at site KB 1

a) Traffic volume

Figure 29 Results of data collection after the improvement at site KB 1

b) Traffic speed

Figure 29 Results of data collection after the improvement at site KB 1 (Cont.)

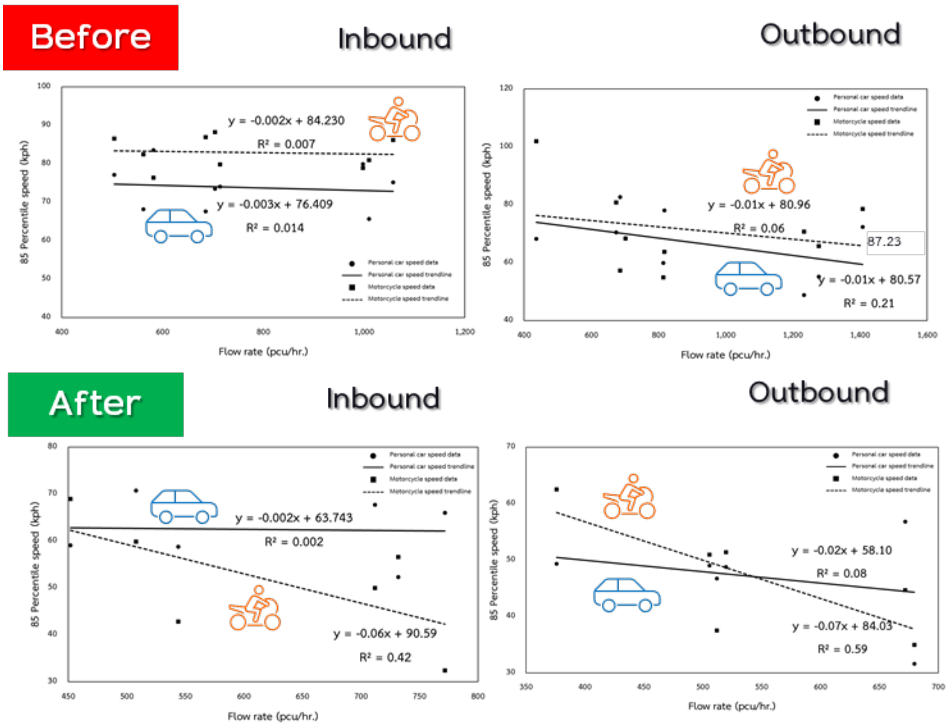


Figure 30 Relationship between flow rate and speed before and after the improvement at site KB 1

For further improvement, Figure 31 shows that installing traffic signal markings and installing additional traffic signal ahead sign on both approaches, and changing the arrow on the traffic signal from right turn to U-turn are needed. Also, strict enforcement of illegal crossing from Soi Krabi 49 should be considered.

Table 5 Forecasted free-flow speed and fatality probabilities at site KB 1

Direction	Estimated free flow speed	Before (kph)	After (kph)	Speed change (kph)	Change in fatality probability* (%)
Inbound	MC	84	91	7 (+8%)	0%
	PC	76	64	12 (-17%)	-42%
Outbound	MC	81	84	3 (+4%)	0%
	PC	81	58	23 (-28%)	-74%

Note: *estimated from Wramborg's model for fatality probability (2005) by assuming that the MC could take a risk as the pedestrian.

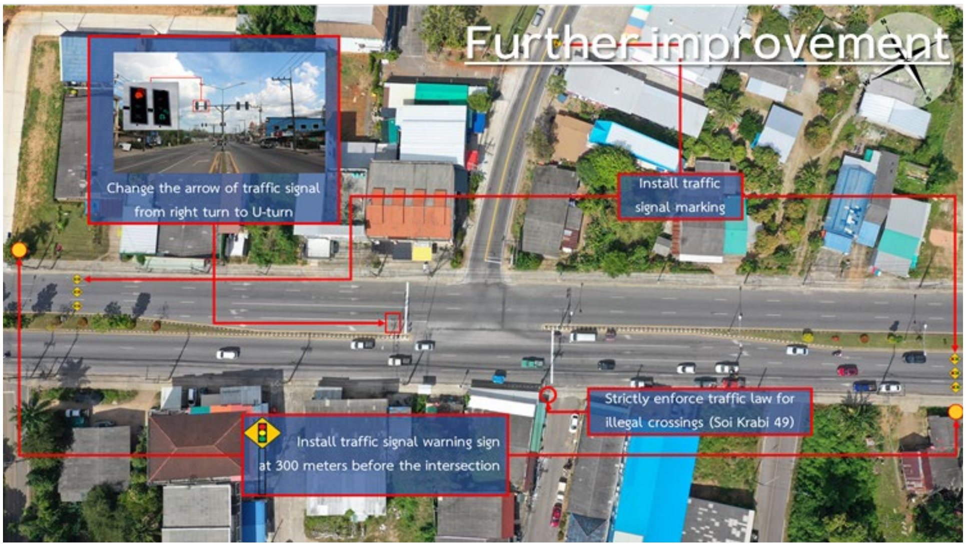


Figure 31 Further improvement required for site KB 1

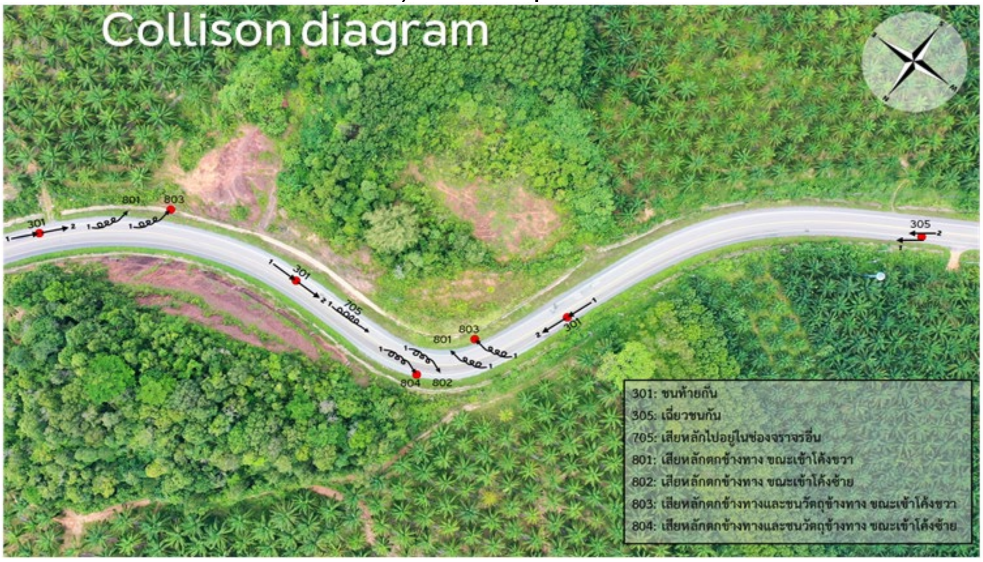
4.6 KB 2: Hui-Tub curve (Hwy. 4038)

The second site in Krabi (KB 2) is the sharp curve up the hill. This site is located on Highway No. 4038. The results of traffic volume and speed data and collision diagram before an improvement are presented in Figure 32. The countermeasures proposed for the improvement and those finally implemented are illustrated in Figure 33.

After the improvement, traffic volume and speed were again collected. The results are shown in Figure 34. The flow rate and the 85th percentile speed collected every 5-minute intervals were collected before and after the implementation. The data are plotted to represents the relationship between flow rate and speed as shown in Figure 35. In each graph, free-flow speed for each type of vehicle was estimated using a linear regression model. Note that the values of R^2 are quite low due to the limited sample size. Future research should consider this issue.

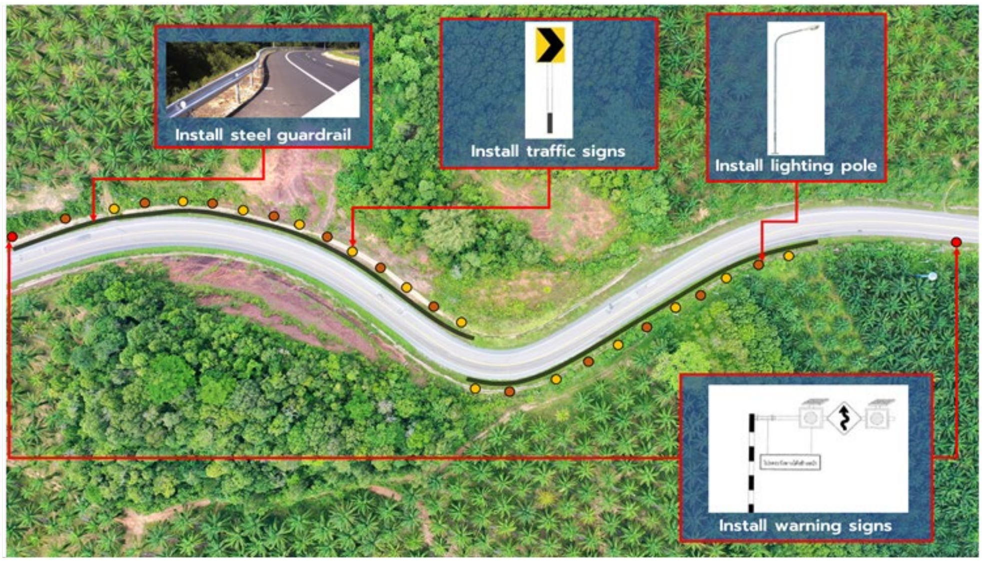
a) Traffic volume

b) Traffic speed

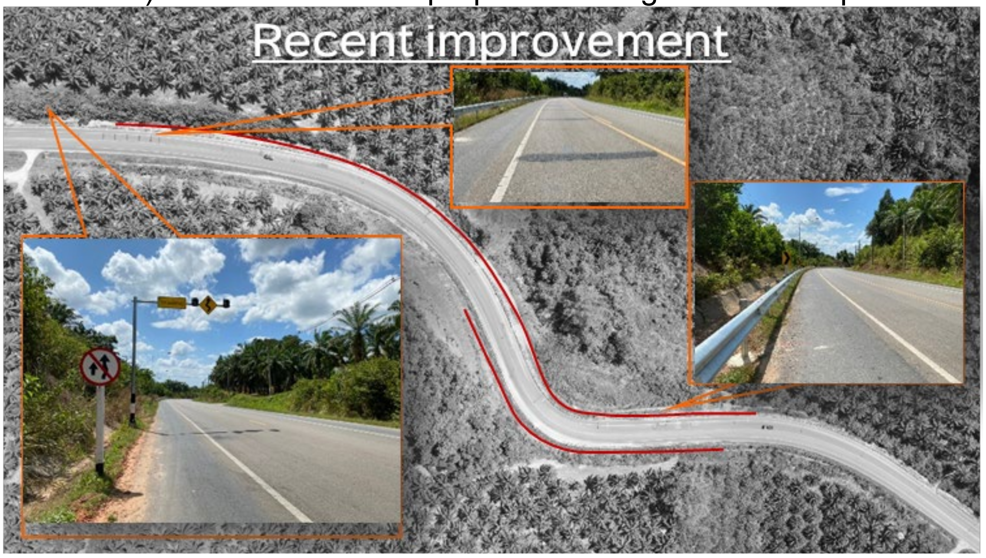


c) Collision diagram

Figure 32 Results of data collection before the improvement at site KB 2



a) Countermeasures proposed during the workshop

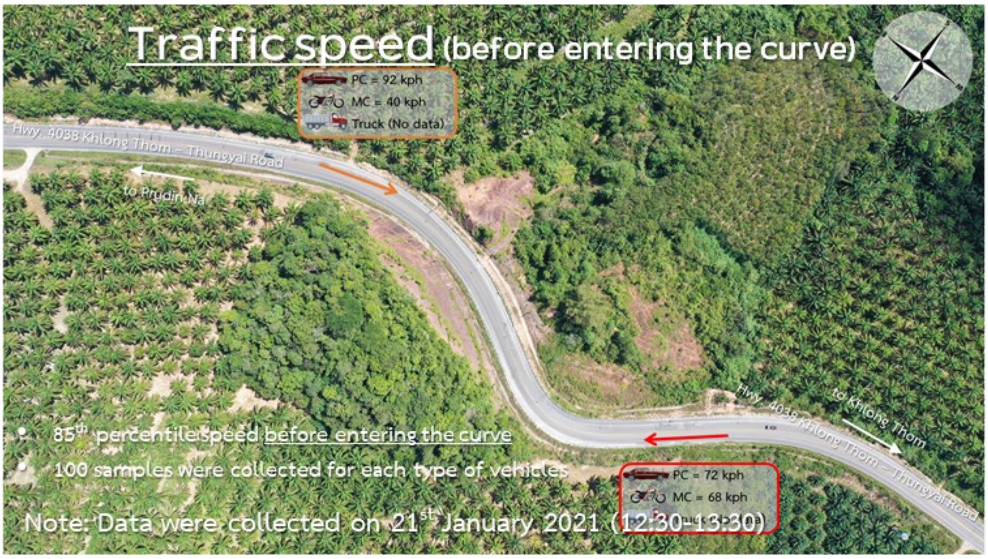


b) Countermeasures finally implemented

Figure 33 Countermeasures at site KB 2

a) Traffic volume

Figure 34 Results of data collection after the improvement at site KB 2



b) Traffic speed

Figure 34 Results of data collection after the improvement at site KB 2 (Cont.)

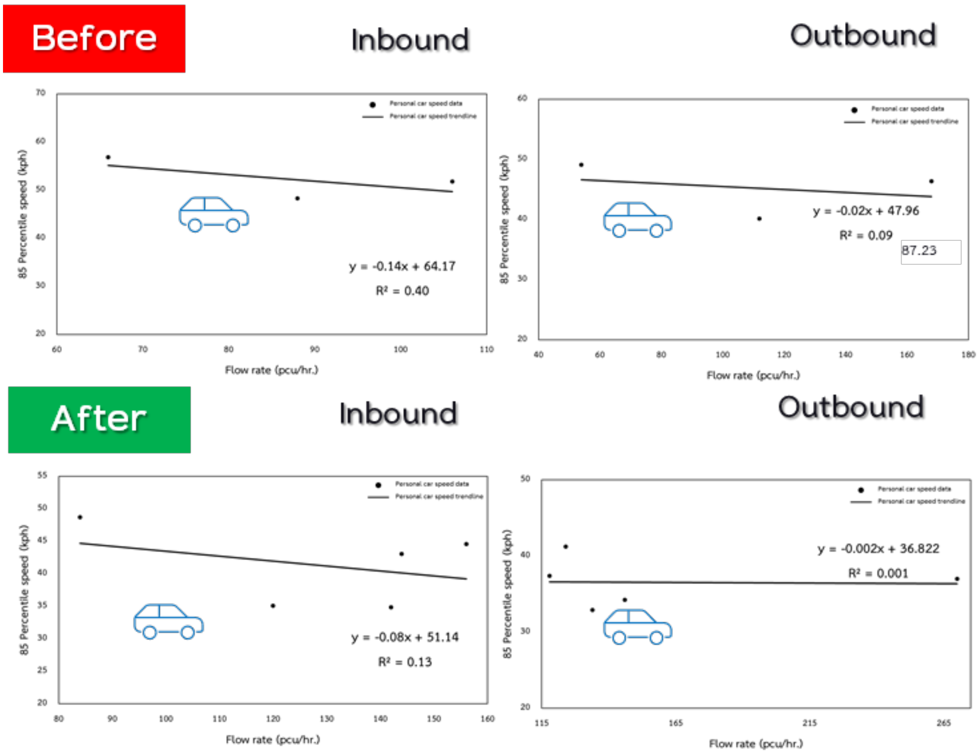


Figure 35 Relationship between flow rate and speed before and after the improvement at site KB 2

The free-flow speed of passenger cars (PC) before and after improvements were estimated at a zero flow rate. The estimated free-flow speeds were used to predict the change in fatality probability of the PC before and after the improvement by applying the study of Wramborg (2005). The results are presented in Table 6. It was found that installation of a no-overtaking sign, curve warning sign, roadside guardrail, and speed bump reduced the speed of the PC in both directions significantly. As a result, the fatality probability could be reduced moderately for the inbound direction which is a steep downgrade (i.e., -7%). However, traffic calming measure for, particularly, the inbound direction is needed because the speed limit sign along this curve shows at 40 kph.

Table 6 Forecasted free-flow speed and fatality probabilities at site KB 2

Direction	Estimated free flow speed	Before (kph)	After (kph)	Speed change (kph)	Change in fatality probability* (%)
Inbound	PC	64	51	13 (-20%)	-6%
Outbound	PC	48	37	11 (-23%)	0%

Note: *estimated from Wramborg's model for fatality probability (2005) by assuming that the MC could take a risk as the pedestrian.

For further improvement, Figure 36 shows that resurfacing of the driveway, improving the visibility of speed bump, and installing audio-tactile pavement with an optical speed bar are needed. In addition, for long-term improvement the concern authority should consider adjusting the road alignments both horizontal and vertical to be safer.

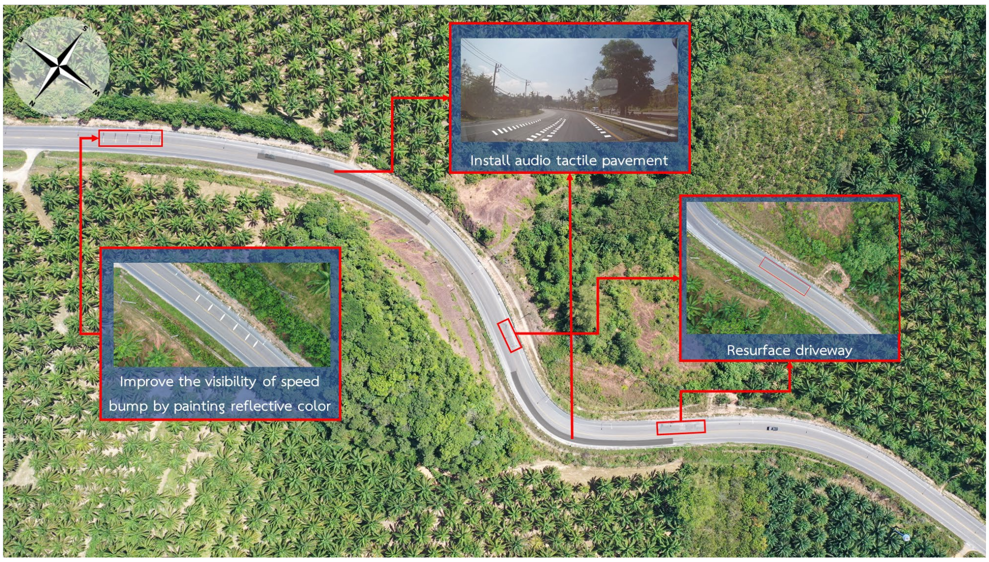


Figure 36 Further improvement required for site KB 2

4.7 KB 3: Petchkasem Road Hwy. 4 (km.984+544 – km. 1008+965)

The third site in Krabi (KB 3) is Highway No. 4, which is the arterial road. The results of traffic volume and speed data and collision diagram before an improvement are presented in Figure 37. The countermeasures proposed for the improvement and those finally implemented are illustrated in Figure 38.

After the improvement, only speed data were collected because it was found from the before improvement that speed was a major risk. The results of the two test sections are shown in Figure 39. Note that flow rate and speed data using Drone were not collected because the two test sections are located at the no-fly zone.

a) Traffic volume

b) Traffic speed

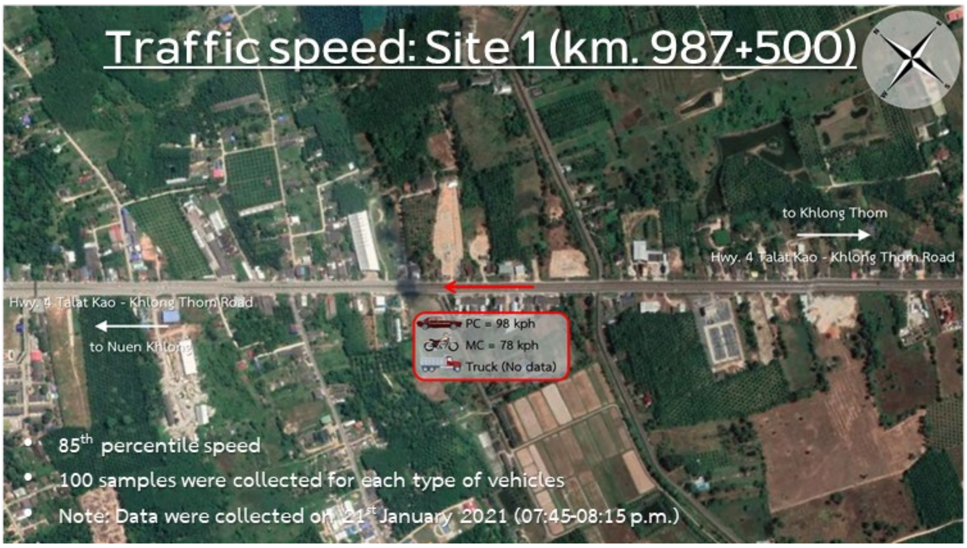
Figure 37 Results of data collection before the improvement at site KB 3

a) Countermeasures proposed during the workshop

Figure 38 Countermeasures at site KB 3

b) Countermeasures finally implemented

Figure 38 Countermeasures at site KB 3 (Cont.)



a) Traffic speed at Km. 987+500

b) Traffic speed at Km. 1006+000

Figure 39 Results of data collection after the improvement at site KB 3

The speeds before and after the improvement were used to predict the change in fatality probability of the PC and MC by applying the study of Wramborg (2005). The results are presented in Table 7.

It was found that installation of the reflective guide along the median island could improve visibility, especially during nighttime. However, the speed of vehicles and the change in fatality probability of the PC and MC at both locations were not reduced significantly. Moreover, the speed of MC on both locations was found at unsafe speed (i.e., more than 60 kph). Considering the speed of PC at km. 1006+000, it was too high (i.e., 112 kph). Therefore, traffic calming is needed for further action.

For further improvement, Figure 40 shows that trimming the grass at the central island, reinstalling road traffic marking on some sections, implementing a traffic calming scheme before the community, and installing a guard rail along the curve are needed.

Table 7 Fatality probabilities forecasted at site KB 3

Direction	85th percentile speed	Before (kph)	After (kph)	Speed change (kph)	Change in fatality probability* (%)
Km. 987+500 (Inbound)	MC	70	78	8 (+11%)	0%
	PC	99	98	1 (-1%)	0%
Km. 1006+000 (Outbound)	MC	72	77	5 (+7%)	0%
	PC	100	112	12 (+12%)	0%

Note: *estimated from Wramborg's model for fatality probability (2005) by assuming that the MC could take a risk as the pedestrian.

Figure 40 Further improvement required for site KB 3

4.8 NS 1: Soraya intersection (Hwy. 4094)

The first site in Nakhonsithamarat (NS 1) is called Soraya intersection, which is the intersection between Highway No. 4094 (major road) and Rural Road No. NS3005 (local road). The results of traffic volume and speed data 150 meters before entering the intersection and collision diagram before an improvement are presented in Figure 41. The countermeasures proposed for the improvement and those finally implemented are illustrated in Figure 42.

After the improvement, traffic volume and speed were again collected. The results are shown in Figure 43. The flow rate and the 85th percentile speed 50 meters before entering the intersection collected every 5-minute intervals were collected before and after the implementation. The data are plotted to represents the relationship between flow rate and speed as shown in Figure 44. In each graph, free-flow speed for each type of vehicle was estimated using a linear regression model. Note that the values of R^2 are quite low due to the limited sample size. Future research should consider this issue.

Free-flow speed of passenger cars (PC) and motorcycle (MC) before and after improvements were estimated at zero flow rate. The estimated free-flow speeds were used to predict the change in fatality probability of the PC and MC before and after the improvement by applying the study of Wramborg (2005). The results are presented in Table 8. It was found that installation of temporary (plastic) divisional island and channelizing island could reduce the speed and change in fatality probability of MC and PC in both directions, significantly (i.e., the estimated free-flow speed approaching the junction reduced to be less than 40 kph and the fatality probability decreased more than 77%).

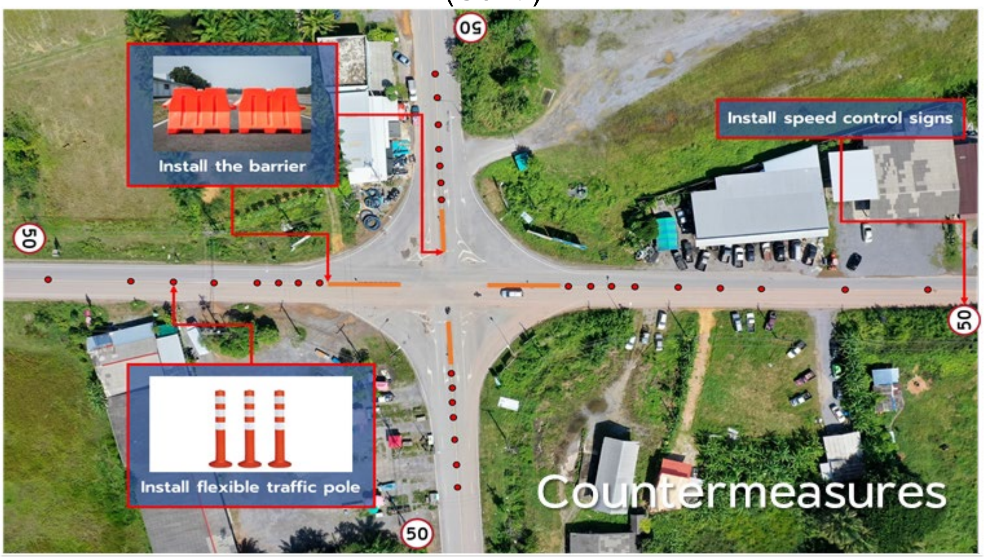
a) Traffic volume

Figure 41 Results of data collection before the improvement at site NS 1

b) Traffic speed

c) Collision diagram

Figure 41 Results of data collection before the improvement at site NS 1 (Cont.)

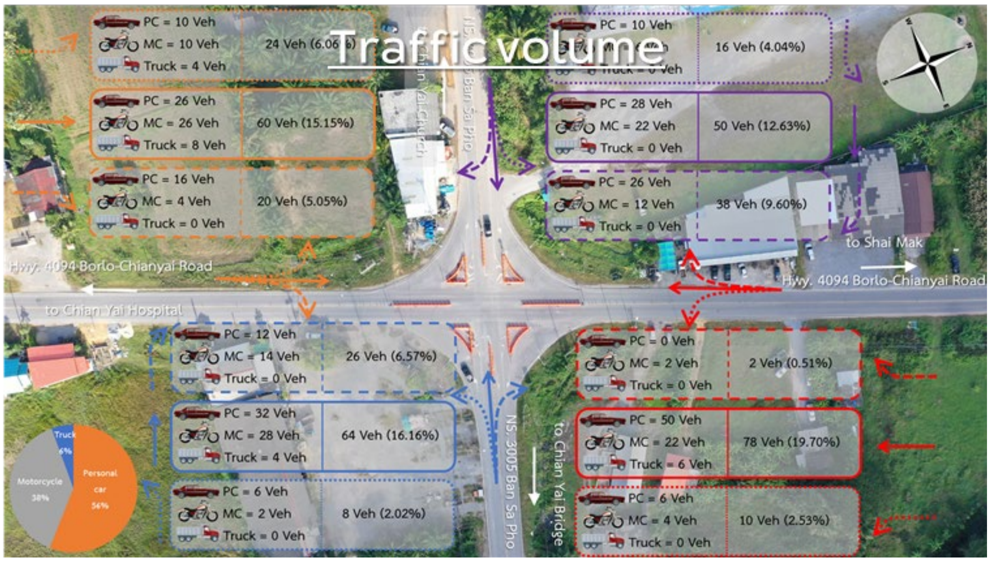


a) Countermeasures proposed during the workshop

Figure 42 Countermeasures at site NS 1

b) Countermeasures finally implemented

Figure 42 Countermeasures at site NS 1 (Cont.)



a) Traffic volume

b) Traffic speed

Figure 43 Results of data collection after the improvement at site NS 1

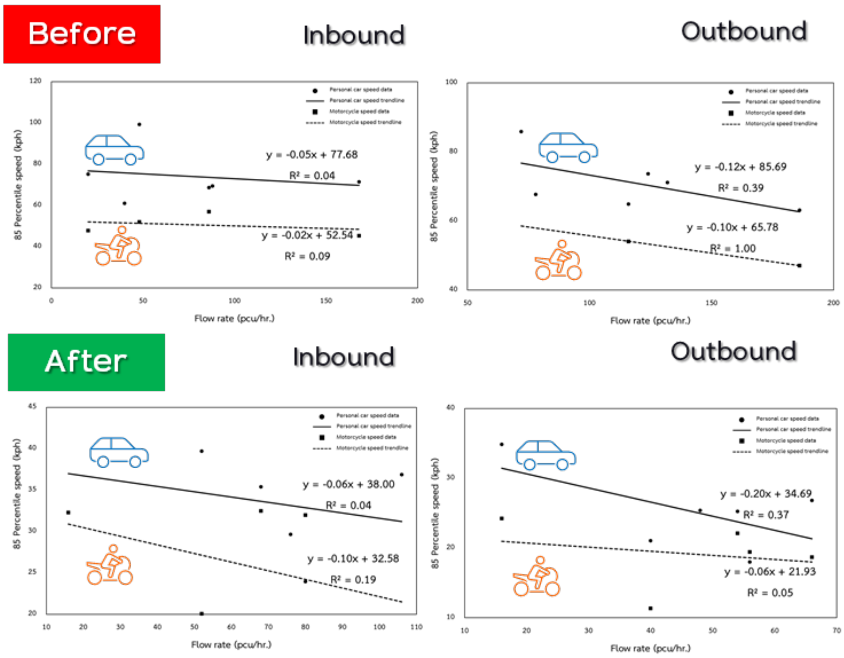


Figure 44 Relationship between flow rate and speed before and after the improvement at site NS 1

Table 8 Forecasted free-flow speed and fatality probabilities at site NS 1

Direction	Estimated free flow speed	Before (kph)	After (kph)	Speed change (kph)	Change in fatality probability* (%)
To Chian Yai (Inbound)	MC	53	33	20 (-38%)	-77%
	PC	78	38	40 (-51%)	-87%
To Shai Mak (Outbound)	MC	66	22	44 (-67%)	-94%
	PC	86	35	51 (-60%)	-97%

Note: *estimated from Wramborg's model for fatality probability (2005) by assuming that the MC could take a risk as the pedestrian.

For further improvement, Figure 45 shows that 50 kph speed limit sign markings should be pained on the two approaches of the main road. Also, the weight body at the bottom of the flashing light pole should be changed from stone (hazardous material) to be a forgiving material, e.g., plastic water container.

Figure 45 Further improvement required for site NS 1

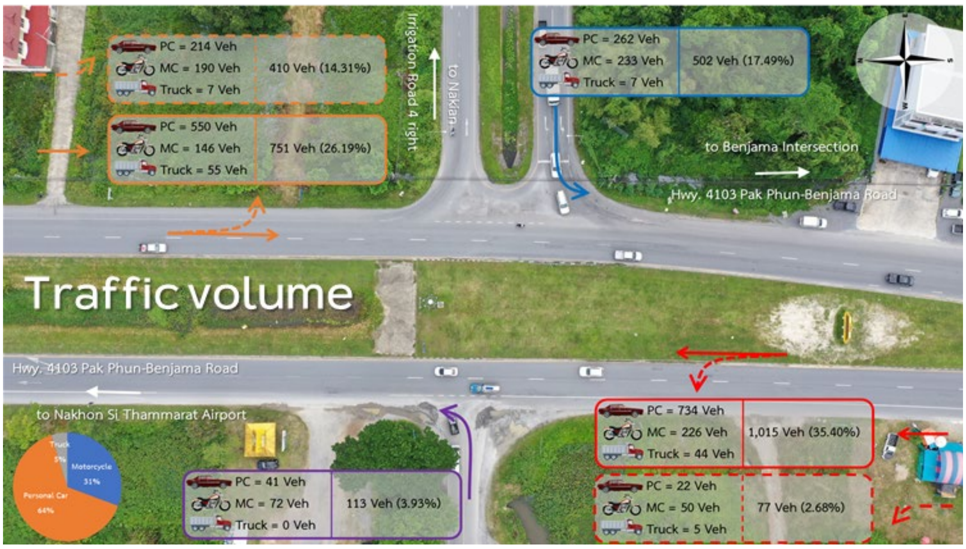
4.9 NS 2: Chonpratan intersection (Hwy. 4103)

The second site in Nakhonsithamarat (NS 1) is called the Chonpratan intersection, which is the 3-leg junction connecting Chonpratan road (local road along irrigation canal) and Highway No. 4103 (major road). The results of traffic volume and speed data and collision diagram before an improvement are presented in Figure 46. The countermeasures proposed for the improvement and those finally implemented are illustrated in Figure 47.

After the improvement, traffic volume and speed were again collected. However, both volume and speed data were mainly considered the approach going to the Benjamin intersection. It is because the vehicle on this approach has a high chance to crash with the vehicle from the local road. The results are shown in Figure 48. The flow rate and the 85th percentile speed collected every 5-minute intervals were collected before and after the implementation. The data are plotted to represents the relationship between flow rate and speed as shown in Figure 49. In each graph, free-flow speed for each type of vehicle was estimated using a linear regression model. Note that the values of R^2 are quite low due to the limited sample size. Future research should consider this issue.

Free-flow speed of passenger cars (PC), motorcycle (MC), and truck (T) before and after improvements were estimated at zero flow rate. The estimated free-flow speeds were used to predict the change in fatality probability of the PC, MC, and T before and after the improvement by applying the study of Wramborg (2005). The results are presented in Table 9.

It was found that the installation of LED lights improved the visibility of through traffic vehicles to see the merging vehicles. This visibility improvement could reduce the speed of the through traffic (i.e., MC, PC, and T). However, the fatality probability decreased slightly because the estimated free-flow speeds after the improvement are still too high (i.e., MC = 59 kph, PC = 89 kph, and T = 79 kph). Therefore, traffic calming is needed to reduce the speeds to be less than 50 kph (the safe speed at the junction).



a) Traffic volume

Figure 46 Results of data collection before the improvement at site NS 2

b) Traffic speed

c) Collision diagram

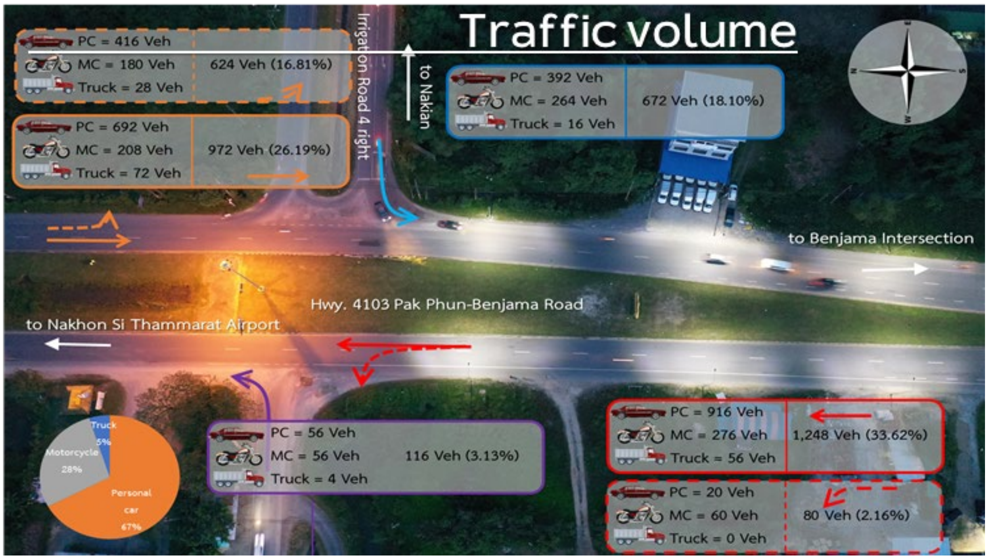
Figure 46 Results of data collection before the improvement at site NS 2 (Cont.)

a) Countermeasures proposed during the workshop

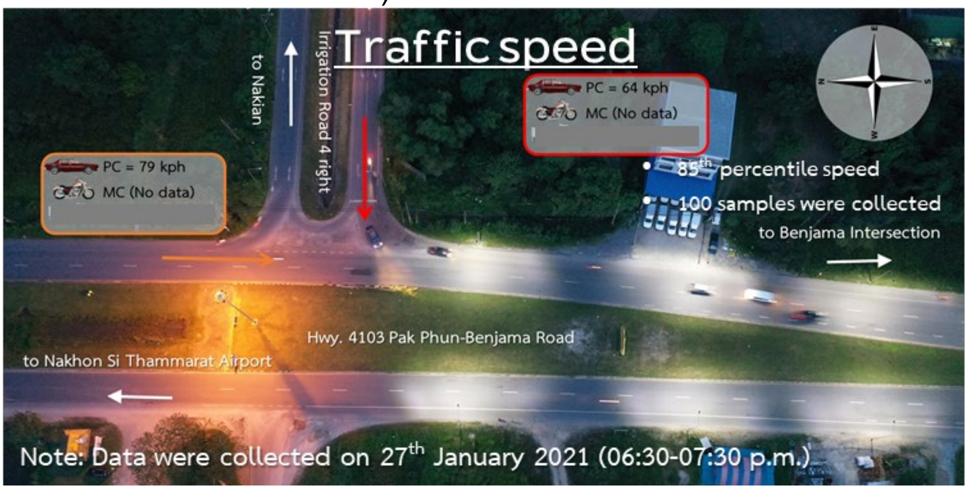
Figure 47 Countermeasures at site NS 2

b) Countermeasures finally implemented

Figure 47 Countermeasures at site NS 2 (Cont.)



a) Traffic volume



b) Traffic speed

Figure 48 Results of data collection after the improvement at site NS 2

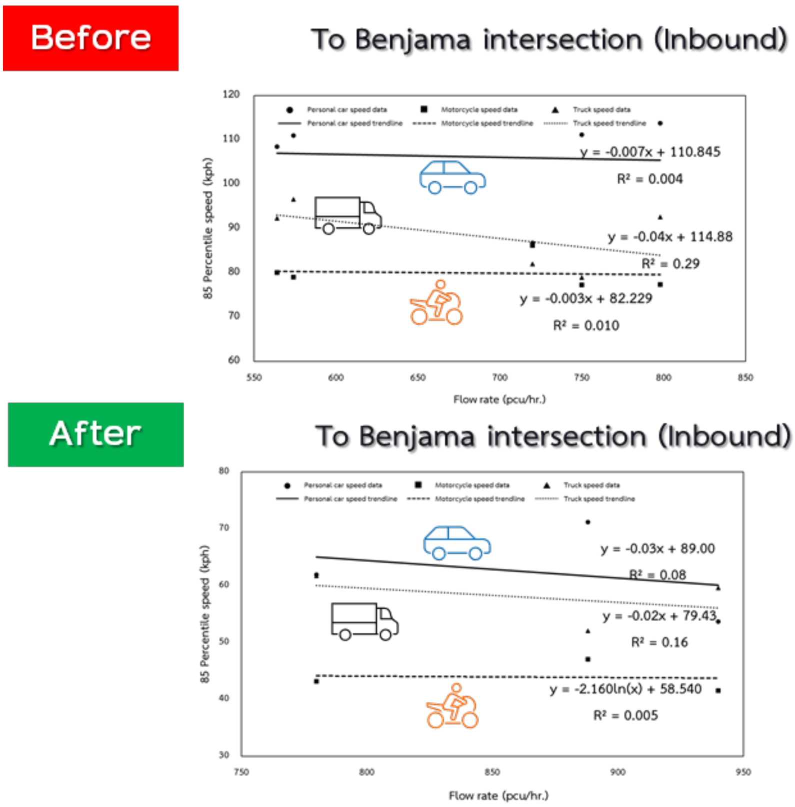


Figure 49 Relationship between flow rate and speed before and after the improvement at site NS 2

Table 9 Forecasted free-flow speed and fatality probabilities at site NS 2

Direction	Estimated free flow speed	Before (kph)	After (kph)	Speed change (kph)	Change in fatality probability* (%)
To Benjama Intersection (Inbound)	MC	82	59	23 (-28%)	-3%
	PC	111	89	22 (-20%)	0%
	Truck	115	79	36 (-31%)	-2%

Note: *estimated from Wramborg's model for fatality probability (2005) by assuming that the MC could take a risk as the pedestrian.

For further improvement, Figure 50 shows that, on the local road, installing exclusive U-turn lane, installing steel-beam guardrail protection at the U-turn, painting U-turn marking and installing traffic poles to separate U-turn vehicles and left-turning vehicles are needed. For the main road, improving the coverage area of traffic lights should be considered.

Figure 50 Further improvement required for site NS 2

4.10 NS 3: Tow Mor intersection (Hwy. 401)

The last site in Nakhonsithamarat (NS 3) is called Tow Mor intersection, which is the intersection between Highway No. 4094 (major road) and Rural Road No. NS3005 (local road). The results of traffic volume and speed data 150 meters before entering the intersection and collision diagram before an improvement are presented in Figure 51. The countermeasures proposed for the improvement and those finally implemented are illustrated in Figure 52.

After the improvement, traffic volume and speed were again collected. The results are shown in Figure 53. The flow rate and the 85th percentile speed collected every 5-minute intervals were collected before and after the implementation. The data are plotted to represents the relationship between flow rate and speed as shown in Figure 54. In each graph, free-flow speed for each type of vehicle was estimated using a linear regression model. Note that the values of R^2 are quite low due to the limited sample size. Future research should consider this issue.

Free-flow speed of passenger cars (PC), motorcycle (MC), and truck (T) before and after improvements were estimated at zero flow rate. The estimated free-flow speeds were used to predict the change in fatality probability of the PC, MC, and T before and after the improvement by applying the study of Wramborg (2005). The results are presented in Table 10.

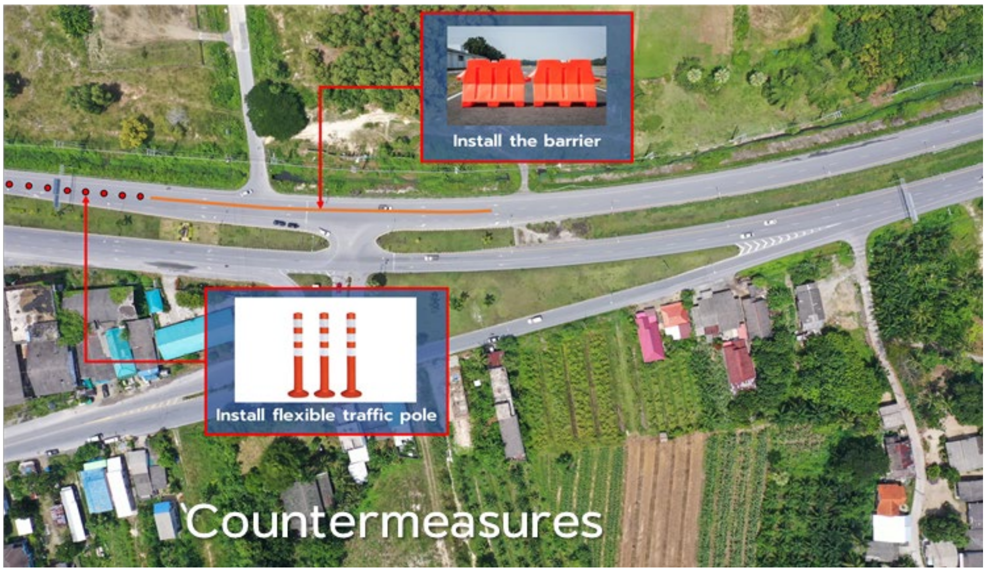
It was found that implementation of separated lanes reduced the speed of through traffic (T, MC, and PC, respectively) in the outbound direction significantly. However, the approaching speeds after the improvement were still high (i.e., MC = 56 kph, PC = 85 kph, and T = 65 kph). Therefore, traffic calming is needed to reduce the speed to be less than 50 kph (the safe speed at the junction).

a) Traffic volume

b) Traffic speed

c) Collision diagram

Figure 51 Results of data collection before the improvement at site NS 3



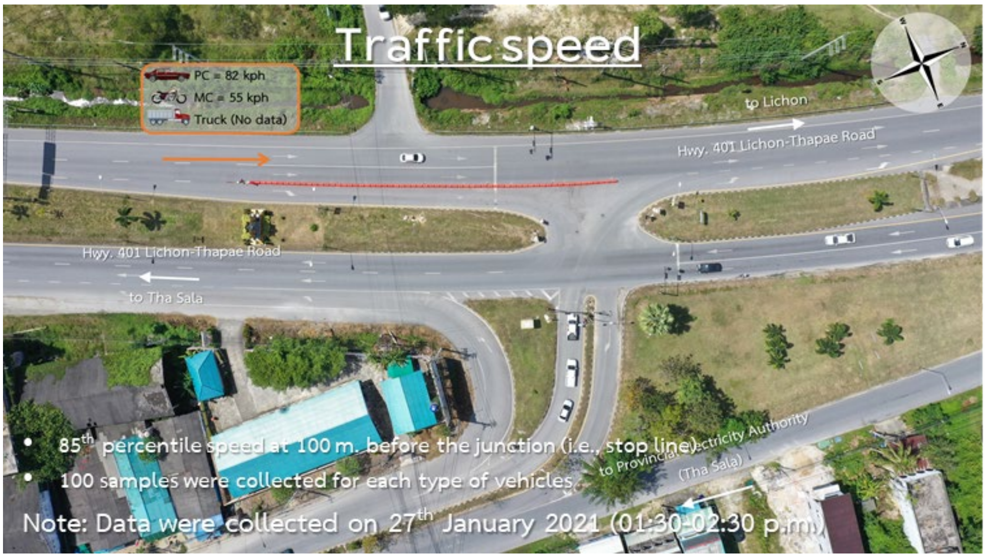
a) Countermeasures proposed during the workshop

b) Countermeasures finally implemented

Figure 52 Countermeasures at site NS 3

a) Traffic volume

Figure 53 Results of data collection after the improvement at site NS 3



b) Traffic speed

Figure 53 Results of data collection after the improvement at site NS 3 (Cont.)

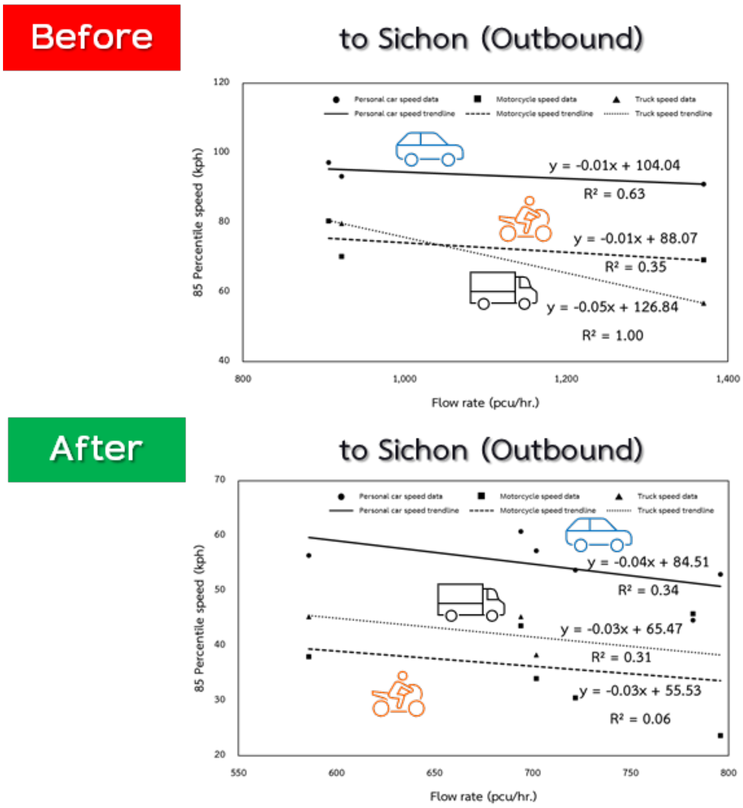


Figure 54 Relationship between flow rate and speed before and after the improvement at site NS 3

For further improvement, Figure 55 shows that it is required to install an exclusive though traffic lane on the left lane (instead of the existing right lane) with through traffic keep left sign at regular intervals and flexible guideposts before the plastic barrier.

Table 10 Forecasted free-flow speed and fatality probabilities at site NS 3

Direction	Estimated free flow speed	Before (kph)	After (kph)	Speed change (kph)	Change in fatality probability* (%)
To Sichon (Outbound)	MC	88	56	32 (-37%)	-6%
	PC	104	85	19 (-19%)	0%
	Truck	126	65	61 (-48%)	-60%

Note: *estimated from Wramborg's model for fatality probability (2005) by assuming that the MC could take a risk as the pedestrian.

Figure 55 Further improvement required for site NS 3

4.12 Results of risk location investigation

Similar to the hazardous locations, road geometry, traffic volume, and speed data on the road sections in front of the Thaluang Cementhaianusorn Technical College, Saraburi, as shown in Figure 56, were investigated. The traffic volume and speed data were analyzed and summarized in Figure 56.

Traffic and speed data together with road geometry and the risk reported by the community were gathered and used to propose the countermeasures to the community as shown in Figure 58. However, this proposal is just a starting point that needs further action.

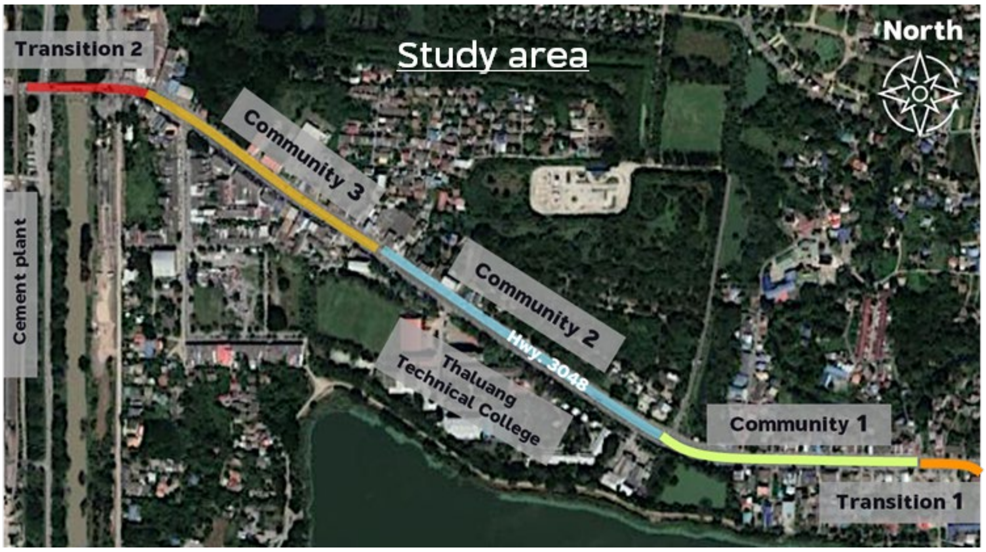
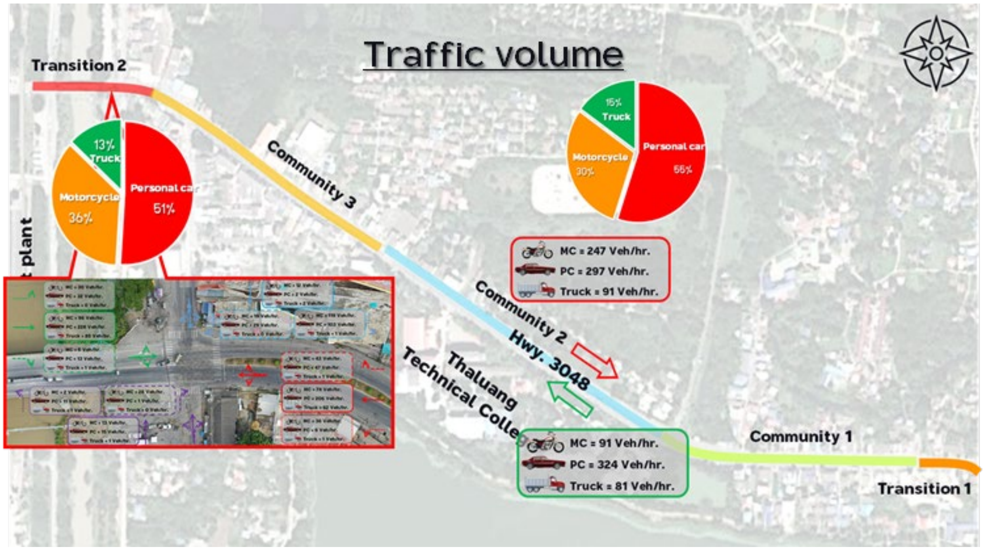
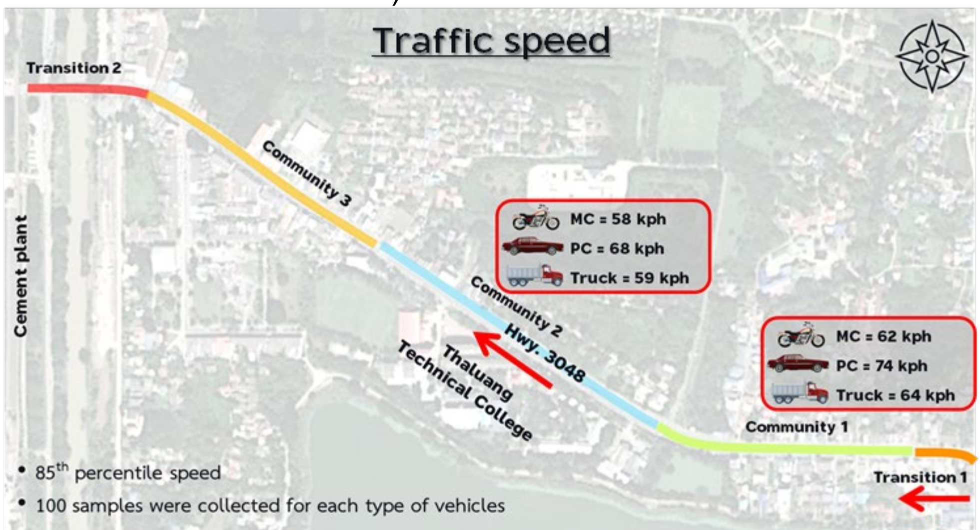


Figure 56 Five road sections considered for the case of Thaluang Cementhaiaanusorn Technical College



a) Traffic volume



Note: Data were collected on 26th November 2020 (09:40 a.m. – 10:40 a.m.)

b) Traffic speed

Figure 57 Traffic volume and speed in front of Thaluang Cementhaiaanusorn Technical College

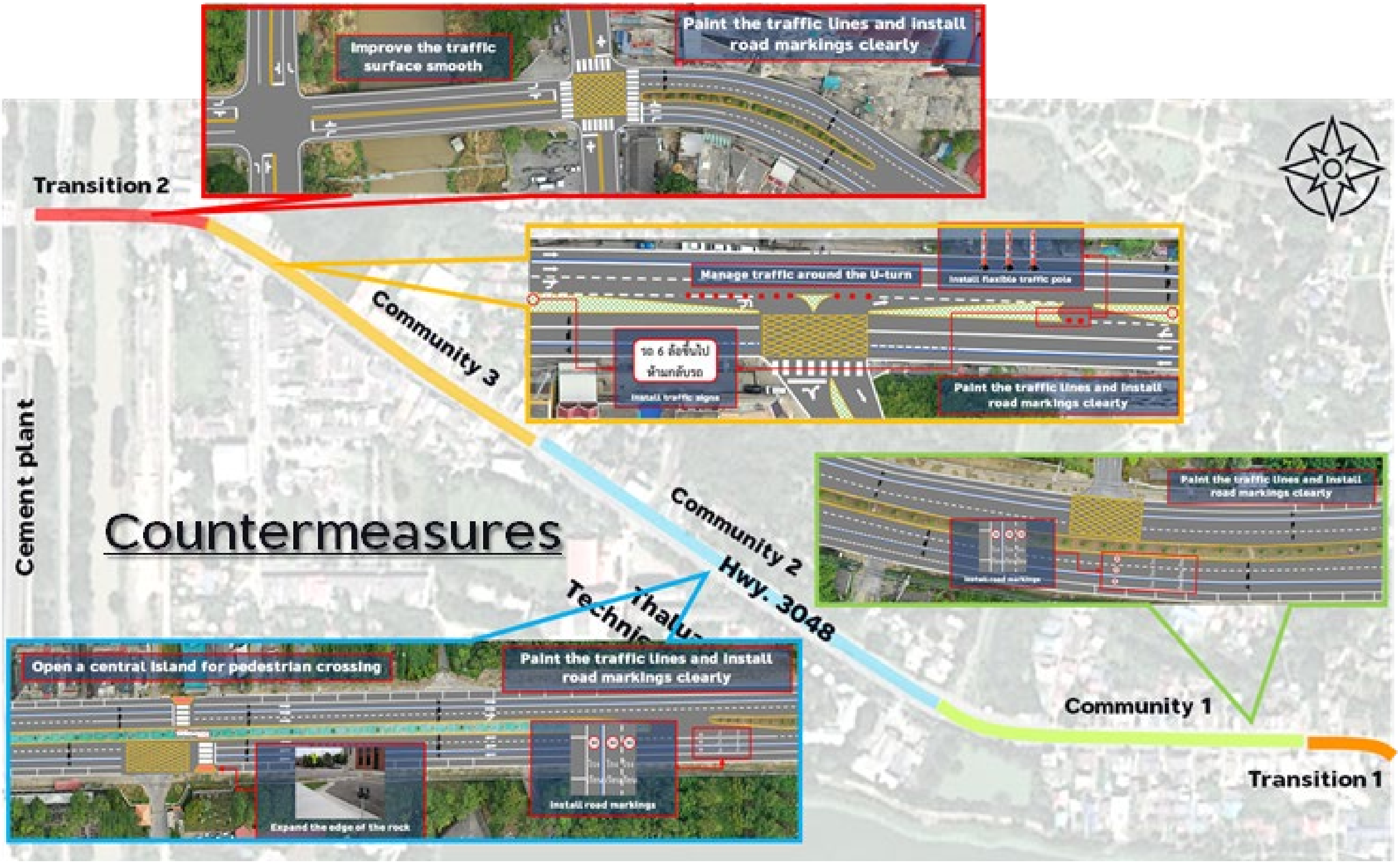
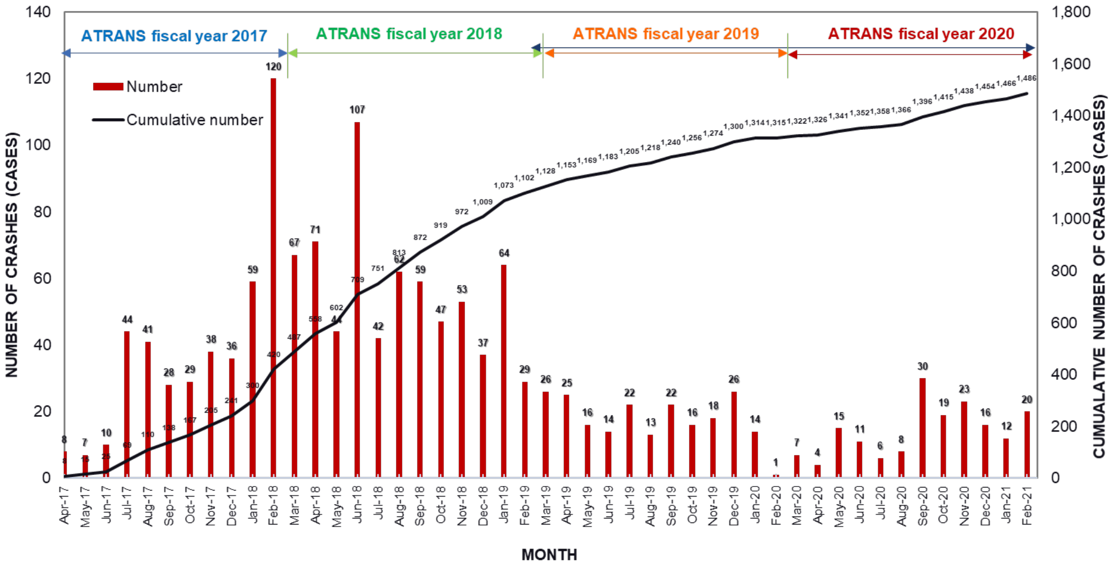


Figure 58 Countermeasures proposed to community for further actions

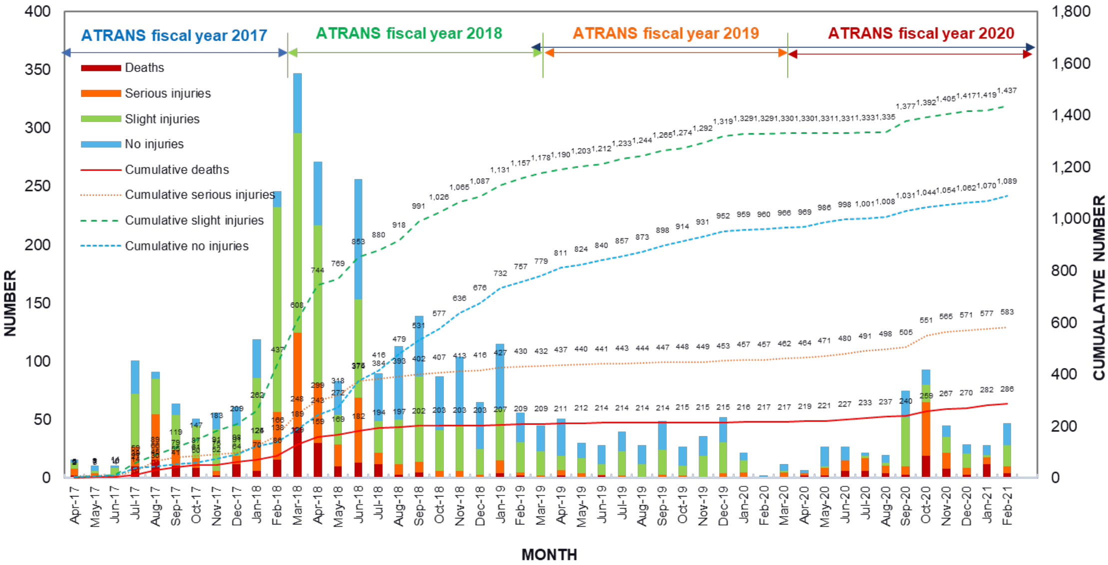
5.1 Overview of crash data collection

Crash data have been collected in the ATRANS Safety Map since 2017. The data can be summarized in terms of the number of crashes and the number of casualties as shown in Figure 59.

It was found that there was a total of 1,486 crashes and 3,350 casualties reported, which include 286 deaths, 583 serious injuries, 1,437 slight injuries, and 1,089 no injuries.



a) Number of crashes



b) Number of casualties

Figure 59 Crash data collected in the ATRANS Safety Map since 2017

5.2 Results of descriptive analysis

From all crash data collected, the recent three-year crash data (2018-2020) were cleaned and used for descriptive analysis. The details are as follows.

5.2.1 Crash, casualty, and vehicle involved

From the recent three-year crash data, there was a total of 1,171 crashes, resulting in 2,340 casualties and 2,044 vehicles. Figure 60 shows that More than half of the casualties are vulnerable road users, i.e., motorcyclists 52%.

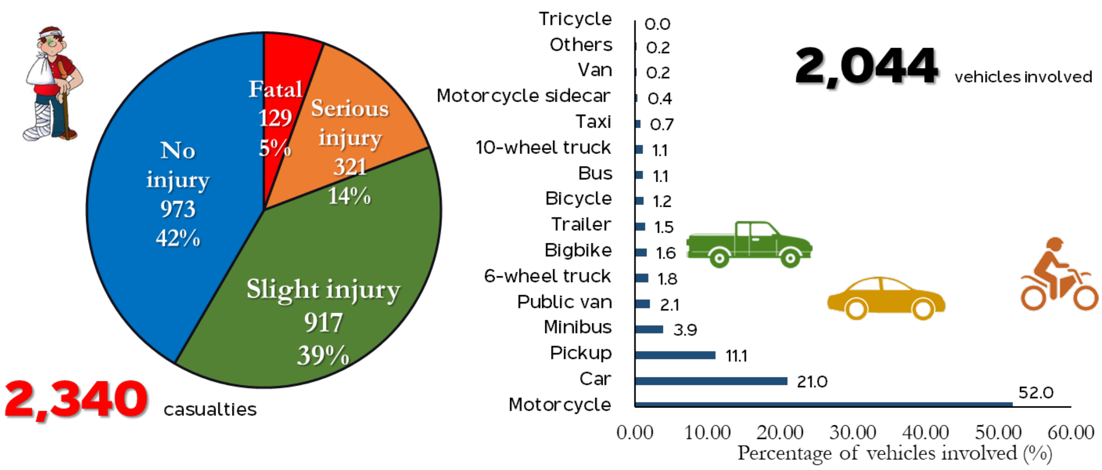


Figure 60 Percentage of casualties and vehicles involved

5.2.2 Crash pattern

Figure 61 shows the top ten crash patterns that commonly occurred. However, the top three crash patterns are two parallel cars crash, rear-end crash, and hit pedestrian, respectively.

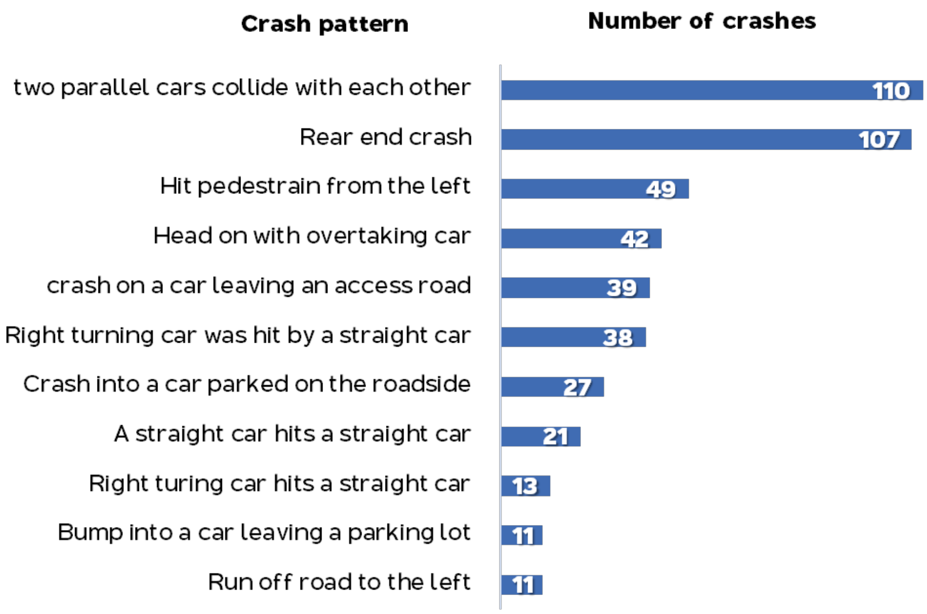


Figure 61 Top ten crash patterns

5.2.3 Motorcycle related crash

As shown in Section 5.2.1, the motorcycle (MC) is the major group involved in road crashes. The crashes related to motorcycles were analyzed and summarized in Figure 62. It shows that most crashes are MC with others (462 crashes or 39.5%), resulting in 55 riders died (42.6%). Regarding a single MC crash (24 cases or 22.6%), 24 riders died (18.6%). However, for the multiple MC crashes (14.5%), only 2 riders (1.6%) died.

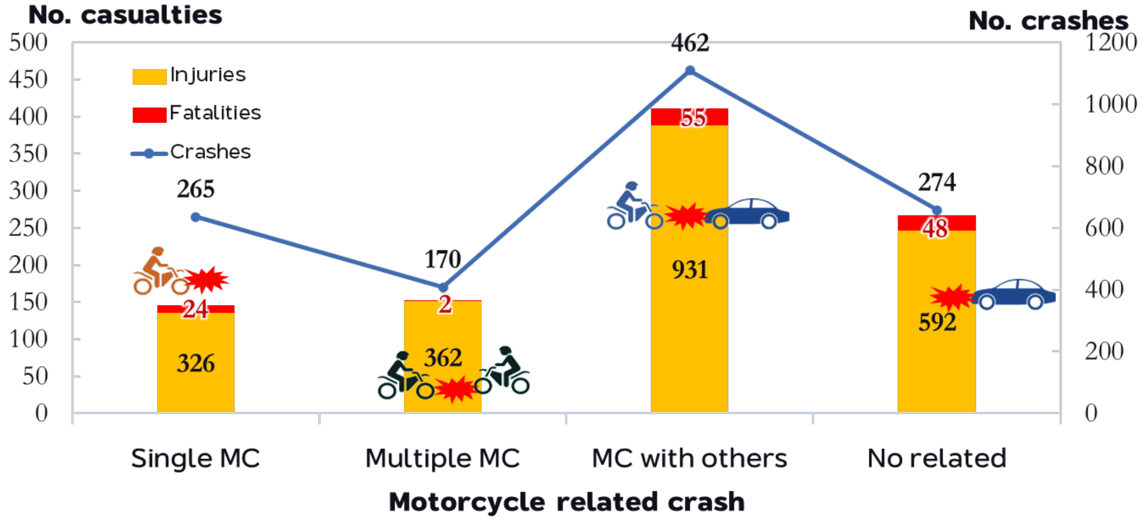


Figure 62 Number of motorcycle-related crashes and casualties

5.3 Results of crash modeling

The three-year crash data were used to identify the factors contributing to road crashes. The details are as follows.

5.3.1 Crash characteristics and selected variables

A statistical-descriptive analysis of the crash characteristics was carried out. The results show in Table 11.

From the crash characteristics (Table 11), due to a limitation of sample size, the data were grouped and selected to be exogenous observed variables as shown in Table 12.

Following the study of Eboli and Mazzulla (2007), in the proposed structural equation model the observed variables were the crash characteristics defined in Table 12 and two indicators of the crash severity, i.e., the number of injuries and vehicles involved in the crash. The latent variables are the unobserved crash aspects that can be explained by the observed variables.

A normality test was carried out. Table 13 shows that all variables passed normality tests, i.e., |Skewness| < 3 and |Kurtosis| < 10. However, when the Pearson correlation coefficient of the observed variables was evaluated. “JUNCTION”, “NOSIGN”, and “NOMARKING” are excluded from modeling due to relatively high correlation.

Table 11 Crash characteristics

	Crash characteristics	Description	Number of crashes	Percentage of crashes (%)
Road characteristics	Road classification	Local road Rural road Arterial road	338 316 517	44.2 26.9 28.9
	Road geometry	Straight section Curve Junction U-Turn	475 240 423 33	40.6 20.5 36.1 2.8
	Profile grade	Level Up/down	909 262	77.6 22.4
	Pavement type	Asphaltic concrete Concrete Gravel/earth	454 716 1	38.2 61.7 0.1
	Traffic sign condition	Clear Unclear	781 390	66.7 33.3
	Traffic marking condition	Clear Unclear	888 283	75.8 24.2
	Safety devices	Warning sign Barrier Delineator	26 287 4	8.2 90.5 1.3
Environment	Surface condition	Dry Wet	1046 125	89.3 10.7
	Crash time	Day Night	709 462	60.5 39.5
	Weather condition	Normal Sunny Rainy	892 210 69	76.2 17.9 5.9
Driving behavior	Speeding (* only this data was reported in the database)	Yes No	281 890	24.0 76.0

Table 12 Selected variables

	Variable	Description, Variable type
Exogenous observed variables	ARTERIAL	Road classification, binary Arterial road = 1, local road/rural road = 0
	JUNCTION	Road geometry, binary Junction = 1, straight section/curve/U-turn = 0
	GRADE	Profile grade, binary Up/down = 1, level = 0
	ASPHALTIC	Pavement type, binary Asphaltic concrete = 1, concrete = 0
	NOSIGN	Traffic sign condition, binary Unclear = 1, clear = 0
	NOMARKING	Traffic marking condition, binary Unclear = 1, clear = 0
	NODEVICE	Installation of safety devices, binary No = 1, yes = 0
	WETSURFACE	Surface condition, binary Wet = 1, dry = 0
	TIME_NIGHT	Crash time, binary Night = 1, day = 0
	UNCLEAR	Weather condition, binary Sunny/rainy = 1, Normal = 0
	SPEEDING	Speeding, binary Yes = 1, no = 0
Endogenous observed variables	NUM_VEHICLE	Number of vehicles involved
	NUM_CASUALTY	Number of casualties involved

Table 13 Normality test

Observed variable	Skewness*	Kurtosis**
ARTERIAL	-0.801	-1.360
JUNCTION	0.439	-1.810
GRADE	1.333	-0.222
ASPHALTIC	0.582	-1.664
NOSIGN	0.981	-1.040
NOMARKING	1.835	1.368
NODEVICE	-1.024	-0.954
WETSURFACE	2.550	4.512
UNCLEAR	0.473	-1.780
TIME_NIGHT	1.760	1.099
SPEEDING	1.198	-0.567
NUM_VEHICLE	-0.131	-0.151
NUM_CASUALTY	0.203	-0.711

Note * if |Skewness| < 3, then it is acceptable.
** if |Kurtosis| < 10, then it is acceptable.

Table 14 Correlation coefficient of observed variables

	ARTERIAL	JUNCTION	GRADE	ASPHALTIC	NOSIGN	NOMARKING	NODEVICE	WETSURFACE	UNCLEAR	TIME_NIGHT	SPEEDING	NUM_VEHICLE	NUM_CASUALTY
ARTERIAL	1												
JUNCTION	0.013	1											
GRADE	0.186**	-0.204**	1										
ASPHALTIC	0.102**	0.085**	-0.017	1									
NOSIGN	-0.024	0.156**	-0.106**	0.427**	1								
NOMARKING	-0.106**	0.172**	-0.080**	0.152**	0.577**	1							
NODEVICE	-0.257**	0.103**	-0.483**	-0.036	0.164**	0.170**	1						
WETSURFACE	0.079**	-0.097**	0.101**	0.017	-0.092**	-0.092**	-0.087**	1					
UNCLEAR	0.010	-0.108**	-0.002	-0.243**	-0.236**	-0.158**	-0.028	0.363**	1				
TIME_NIGHT	0.003	0.004	-0.013	0.214**	0.082**	0.017	0.022	0.042	-0.036	1			
SPEEDING	-0.015	-0.228**	0.007	-0.210**	-0.274**	-0.185**	-0.046	-0.016	0.197**	0.051	1		
NUM_VEHICLE	0.010	0.150**	-0.030	-0.034	0.034	-0.013	0.044	0.015	-0.056	-0.001	-0.136**	1	
NUM_CASUALTY	0.014	0.085**	-0.017	-0.031	-0.115**	-0.136**	-0.015	0.058*	-0.003	0.046	-0.104**	0.624**	1

Note: * and ** are statistically significant at a level of 95% and 99%, respectively.

In this research, the general structure of the SEM model was proposed in Figure 63, which includes two latent variables. The first variable called “Road characteristics” is linked to “ARTERIAL”, “GRADE”, and “NODEVICE”. The second variable called “ENVIRONMENT” is linked to “WETSURFACE”, “TIME_NIGHT”, and “SPEEDING”. Note that the variable “SPEEDING”, which is a driver characteristic, is grouped in the ENVIRONMENT because the data representing other driver characteristics, e.g., drunk driving, are not enough for the analysis. This is an issue for future research.

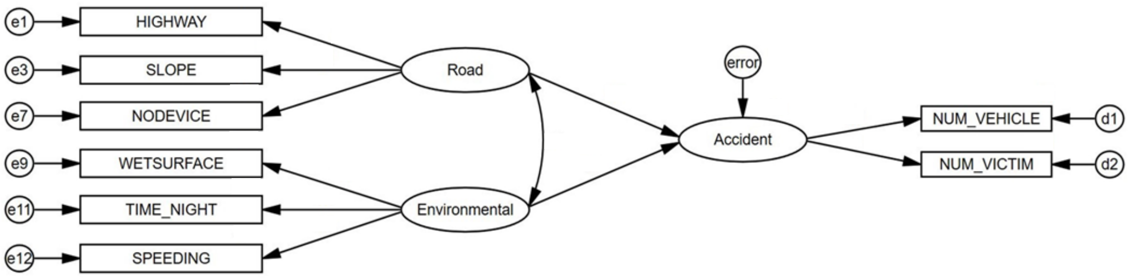


Figure 63 General structure of SEM model

5.3.3 Results of SEM model

The general model (Figure 63) was calibrated. The final SEM model is shown in Figure 64 when some tests on the goodness of fit are reported in Table 15. Also, the results of parameter estimation in the form of standardized regression weight are reported in Table 16. Note that the values of good level and acceptable level in Table 16 can be found from Bentler and Bonett (1980); Hooper, Coughlan, and Mullen (2007); O'Rourke and Hatcher (2013).

The model offers empirical findings and practical implementations. “Environmental” context (include driving behavior, i.e., speeding) is the latent variable with a major effect on crash severity (weight = 0.16). “WETSURFACE” observed variable has a major impact on the “Environmental” exogenous latent variable (0.19) when no safety device (NODEVICE) has a major impact on the “Road characteristics” latent variable (0.81).

Regarding endogenous latent variable, crash severity is best explained by the number of vehicles involved (weight = 0.87), when the number of casualties has a slightly lower effect (0.72).

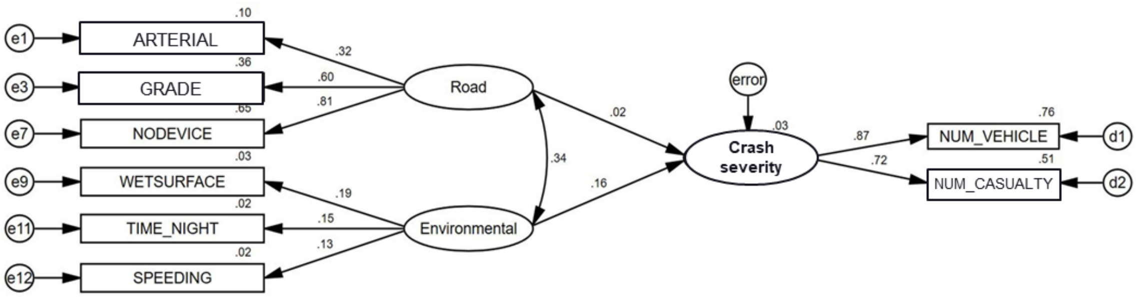


Figure 64 Final SEM model

Table 15 Goodness of fit indices

Indices	Values: From model	Good	Acceptable
CMIN/DF	2.718*	<2.00	2.00-3.00
RMSEA	0.038**	<0.05	0.05-0.08
GFI	0.989**	>0.95	0.90-0.95
AGFI	0.979**	>0.95	0.90-0.95
RMR	0.008**	<0.05	0.05-0.10
IFI	0.966**	>0.95	0.90-0.95
NFI	0.948*	>0.95	0.90-0.95
CFI	0.966**	>0.95	0.90-0.95
TLI	0.953**	>0.95	0.90-0.95
HOELTER	677**	>200	-

Note: CMIN/DF is Relative Chi-Square
RMSEA is Root Mean Square Error of Approximation
GFI is Goodness of Fit Index
AGFI is Adjusted Goodness of Fit Index
RMR is Root Mean Residual
IFI is Incremental Fit Index
NFI is Normed Fit Index
CFI is Comparative Fit Index
TLI is Tucker-Lewis Index
* is at a good level, when ** is at an acceptable level.

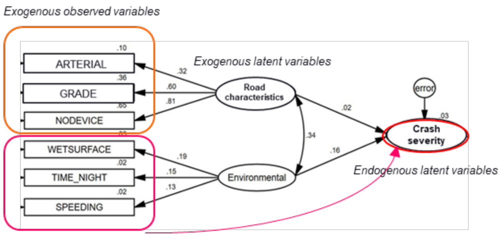
Table 16 Parameter estimation

			Standardized regression weight
SEVERITY	←	Road characteristics	0.02
SEVERITY	←	Environmental	0.16
HIGHWAY	←	Road characteristics	0.32
GRADE	←	Road characteristics	0.60
NODEVICE	←	Road characteristics	0.81
WETSURFACE	←	Environmental	0.19
TIME_NIGHT	←	Environmental	0.15
SPEEDING	←	Environmental	0.13
NUM_VEHICLE	←	Crash severity	0.87
NUM_CASUALTY	←	Crash severity	0.72

Figure 65 shows the indirect effects of observed variables on the endogenous latent variable. Each exogenous observed variable, linked to the endogenous latent variable through an exogenous latent variable, has an indirect impact on the endogenous latent variable (i.e., crash severity).

Considering the observed variables linked to the “Road characteristics”, “NO DEVICE” has a major impact, and this finding suggests that crashes are more severe on the road without safety devices (e.g., warning sign, barrier, delineator). “GRADE” has a slightly lower positive effect, and this means a larger up (or down) profile grade could cause higher crash severity. “HIGHWAY” has the lowest positive impact, and this means that crashes are more severe when they occurred on an arterial road.

Regarding the observed variables linked to the “Environmental” context, “WETSURFACE” has a major impact, and this finding suggests wet pavement surface could cause high severity. “TIME_NIGHT” has a slightly lower positive effect, and this means crashes during the night are more severe than daytime crashes. “SPEEDING” has the lowest positive impact, and this means higher speed causes more crash severity.



	Indirect effect (though Road characteristics)	Indirect effect (though Environmental)
ARTERIAL	0.32x0.02 = 0.006	
GRADE	0.60x0.02 = 0.012	
NODEVICE	0.81x0.02 = 0.016	
WETSURFACE		0.19x0.16 = 0.030
TIME_NIGHT		0.15x0.16 = 0.024
SPEEDING		0.13x0.16 = 0.021

Figure 65 Indirect effects of observed variables on endogenous latent variable

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In this research, the ATRANS Safety Map application was improved to be simpler and more user-friendly.

A core framework for a PDCA cycle of road traffic safety based on scientific analysis of crash and traffic data and on public involvement by the ATRANS Safety Map application was developed.

Hazardous location and risk location improvement workshops were conducted in five provinces to improve road safety by using the process of Academic-Public-Private partnership.

From the investigation of nine hazardous locations in three provinces, the proposed countermeasures could moderately improve the safety of the hazardous locations. However, some further actions regarding road geometry improvement, safe driving campaign, and traffic law enforcement are needed, especially the issue of speeding.

From the investigation of risk location in Saraburi, mixed traffic between truck, passenger car, and motorcycle and unsafe speed (>58 kph) around school zone and community area were two major concerns. Countermeasures (e.g., painted motorcycle lane, speed limit marking) was finally proposed to the college for further actions.

From the analysis of 3-year crash data (2018-2020) collected in the database of ATRANS Safety Map, there were 1,171 crashes, resulting in 2,340 casualties and 2,044 vehicles. More than half of the casualties are motorcyclists (52%) Regarding motorcycle-related crashes, the motorcycle crashed with other cars resulting in 42.6% of deaths when the single motorcycle crash caused 18.6% of deaths.

From the crash model developed by applying SEM, environmental context and driving behavior (i.e., speeding) is the major effect on crash severity (no. casualties and no. vehicles involved). Regarding the major effect, wet surface, nighttime, and speeding, respectively, are three main factors influencing crash severity. For recommendation, the wet surface should be prevented by improving either skid resistance or drainage system. Riding/driving at night should pay extra attention. Street lighting can also be considered. Safe speed should be encouraged to all road users. Speed enforcement should also be concerned.

For the road characteristics, three main factors are no safety device, up (or down) profile grade, and arterial road in that order. For recommendation, installation of safety-related devices is needed, especially up/down hill sections and arterial roads.

The core framework of this research would be worth expanding nationwide. Even some ineffective countermeasures in crash causes as failure cases found in this research would be worth accumulating and sharing nationwide. In addition, the evaluations of before and after observations of speeds of vehicles as one of the outputs of the road safety countermeasures would be useful for establishing EBPM (Evidence Based Policy Making) in road traffic safety.

6.2 Recommendations

For sustainable use of the ATRANS Safety Map application, a key powerful organization with good cooperation is needed.

For the site investigation, speed data in different periods should be collected.

From the public participation and activities, road safety authorities should consider more in the following issues: Safe road, especially self-explaining road, and forgiving road and roadside. Safe speed, especially in the community, or through the junction. Safe road users, especially pedestrians and motorcyclists. Safe vehicles, e.g., encouraging the use of safe motorcycles and helmets.

Long-term cooperation for data collection and road safety improvement.

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