

## **Safety Cost Assessment of At-Grade intersection: A Case Study of X-junctions on Two way-Two lane highways in Thailand**

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**Abstract:** This paper investigates accident costs and accident cost rates of different types of traffic control of at-grade X-junctions on two way-two lane highways in Thailand. From a safety point of view, intersections are the most major element of the highway network. The author investigated 61 X-junctions in Thailand. It describes the review of international experience of the effectiveness of converting cross intersection to roundabout. It was found that accident cost rates of unsignalized X-junction is higher than that of signalized X-junctions (3 or more phases) on two way-two lane highways in Thailand. As the result of benefit-cost ratio, one-lane compact roundabout is preferable for substitution of compact-size unsignalized intersection, and big- size (flare) signalized (3 or more phases) intersection on two way-two lane highways in Thailand based on international reviews of safety costs.

*Keywords:* Accident cost rate, Benefit-cost ratio, X-junction, Roundabout

### **1. INTRODUCTION**

In most of countries in the world, intersection accidents on highways are one of the main challenges of road safety. The numbers and severities are increasing at intersections, day by day. It is not only one of the challenges in the transport sector but also economic losses are considerable throughout most of the countries. Enormous human potential is being destroyed with grave economic and also social consequences. Thailand is also facing this kind of crashes at intersections on the highways and road crashes have been a major cause of death and injury. Increasing severity rates of accidents of at-grade intersections on the highways are regarded as one of the most serious social problems. Millions of people spend their treasure times at hospital after severing crashes, and a lot of people lose their lives, work or hobby in every year as they face it. Hence, the highway safety is a major transport issue worldwide. Therefore, economic losses caused by traffic accidents must be emphasized. Among them, many accidents are occurring on at-grade intersections which are one of the black spots of the highway and they are in a key position for road users changing their routes.

For these reasons, this research finds out safety cost assessment of at-grade intersections on two-way two-lane highways in Thailand. Therefore, the author would like to suggest that one-lane compact roundabout is suitable to replace at X-junctions on two way-two lane highways in Thailand base on international reviews for safety cost.

In this study, the author analyzes the accident cost rates of at-grade X-junctions in Thailand and compares ACR of other countries roundabout data to Thailand compact one-lane roundabout on two-way two-lane highways for converting at-grade X-junction to roundabout. Moreover, the author estimates the cost of compact one lane roundabout for Thailand, and calculate the benefit-cost ratio for the converting each type of intersections to roundabout by using some international sources.

The paper is organized as follows. Section 2 describes objectives, scope and limitation

of the study. Section 3 discusses at-grade intersection safety and safety cost assessment based on comprehensive reviews of various international experience. Section 4 presents overview of traffic accidents in Thailand. Section 5 shows Accident Cost and Accident Cost Rate of at-grade X-junctions with different type of traffic control on two way- two lane highways in Thailand. Type of accident of at-grade X-junctions on two way-two lane highways is presented in section 6. Section 7 shows comparison of Accident Cost Rate of X-junctions between Thailand and German highways. Cost-benefit analysis for conversion of each intersection type to compact one lane roundabout is described in Section 8. Conclusion and recommendation are presented in the final section of this paper.

## **2. OBJECTIVES, SCOPE AND LIMITATION OF THE STUDY**

The main objective is the assessment of safety cost at Thailand two way- two lane highway at-grade intersections related to X-junction and roundabout, and different type of traffic controls. The specific objectives are;

- 1) to analyze accident cost rate of at-grade intersections related to type of X-junctions and type of traffic control,
- 2) to estimate accident cost rate of one-lane compact roundabout for Thailand two-way two-lane highways based on international experience,
- 3) to estimate and compare risk assessment based on economic factors , such as accident cost rate, construction cost, maintenance cost and operation cost , between different type of access controlled X-junctions (exist practice in Thailand) and one-lane compact roundabout (based on international experience), and
- 4) to review overall components of accident cost rate in Thailand.

This study is based mostly on literature review of at-grade intersection safety around the world. A basic fundamental concept on the safety cost assessment of X-junctions and roundabouts, having different types of traffic controls, is considered in this study. However, this study is focused on the at-grade intersections which connect only two way - two lane highways. The type of intersection is only X- junction (4-leg intersection) and the types of traffic controls are,

- (a) no control (unsignalized),
- (b) signal control without protected right turning vehicles (2-phases), and
- (c) signal control with protected right turning vehicles (3 or more phases).

Only highways under the responsibility of the Department of Highways (DOH) were studied. Special requirements on the selection of sites are that intersections should not be located on horizontal and vertical curve, and should not be a part of grade separated intersections.

The required statistical data, accident data and annual average daily traffic data of selected X-junctions were analyzed from DOH and police recorded data from 2008 to 2011. Furthermore, other required measurement data were collected by the self-surveying. These intersections can be found in Bangkok area, Southern area, Western area, Northern area and Eastern area.

However, most of signal control without protected right turning vehicles (two-phases) of X-junctions is already changed to three or more phases signal control. Therefore, the author investigated 23 numbers of unsignalized intersections and 38 numbers of three or more-phases signalized intersections.

In the first step, the author reviews international papers, TRB papers, and handbooks which are related to the research outcome. In the second step, she classifies the X-junctions. In the third steps, she checks available accident data from DOH and Police and AADT (2008-

2011) data for pre-selection of intersections, and then investigates at 61 intersections. In the fourth step, she goes to general field study to collect detail data of selected intersections. As the fifth step, she analyzes the accident cost rates (ACR) and accident costs (AC) of selected X-intersections. In the sixth step, she estimates the cost of compact one lane roundabout for Thailand and calculate benefit-cost ratio between one-lane compact roundabout and X-junctions on two way-two lane highways in Thailand. Finally, the author will conclude this research and give recommendations.

### 3. REVIEW OF AT-GRADE INTERSECTION SAFETY AND SAFETY COST ASSESSMENT

#### 3.1 Overview of general requirements for at-grade intersection safety

Intersections have a range of control strategies, ranging from being uncontrolled, having a priority control, or using roundabouts or traffic signals. Safety is one the important considerations in selection of control strategy. From a safety point of view, intersections are the most major element of the highway network. At-grade intersections are risky element because different road users (vehicles, cyclists and pedestrians) are required to use the same level space and a collision is only avoided if they are separated in time. The different type of road user requirements should be considered in the design process of intersection infrastructure. The various aspects requirements of intersection designs are shown in Table (1).

Table 1. General design requirements for intersections

Uniformity	The geometric design and the traffic control design located intersections in a road network should be uniform.
Recognisability	The intersection must be recognizable early enough from all access lanes, and clearly arranged, such that at least the road user who need to wait at the intersection and who have the priority in it.
Drivability	The intersection must be drivable, safe, walkable , and useable for user groups in appropriate way; especially for handicapped road users the barrier-free use should be offered.
Visibility	The intersection should be visible for road users, road users should be visible for other road users who is necessary sight.
Understandability	The road user need to understand the traffic control and the priority rules at the intersection and to identify the lanes, they can use at the intersection in an easy way.

(Adopted from Guideline for the design of roundabouts for Thailand, Draft version,2010)

#### 3.2. Effectiveness of roundabouts

A roundabout is a road intersection with circulatory traffic. Furthermore, if road users enter into a roundabout, they are required to give way to road users already in the roundabout. The traffic passing through the intersection is regulated in one direction anti-clockwise (in countries driving on the right) around a circular traffic island placed in the center. Therefore, road users could not drive a straight path through the junction in roundabouts. However, they must drive round a traffic island located in the middle of the junction and thus speed is reduced in it. The traffic approaching a roundabout is usually required to give way to the traffic already in the roundabout (offside priority). The number of potential conflict points between the traffic streams passing through an intersection is reduced from 9 to 8 at T-

junctions and from 32 to 20 at crossroads (Elvik and Vaa , 2004).

Many researchers presented the contribution of traffic safety of roundabouts. As many decades, European countries have a long tradition of regarding roundabouts. Single - lane compact roundabouts were start interested in the mid 1980ies. In Germany, single-lane roundabouts have increasingly been employed outside built-up areas since the end of 1980s. In the review of roundabout in Germany by Brilon (May, 2005), he described that many investigations have been made regarding safety of the single - lane compact roundabouts. According to the German philosophy, the standard type of a roundabout has a diameter between 26 m and 45 m. It has only one single lane on each of the entries and exits as well as on the circle and it also has a central island which cannot be used by traffic. Due to the needs of larger vehicles (swept path for turning), the circular roadway must be wider than a usual lane. With 26 m diameter, thus, the circular lane must be widened up to 8 m. In such cases, a paved apron can be recommended for urban conditions.

Moreover, he analyzed accident rates and accident cost rates for compact single-lane roundabouts. The accident records of compact roundabouts are believed mainly due to the low speed level of all drivers within the intersection. Furthermore, the compact roundabout seems to be the safest type of intersections for pedestrians and cars. He recommended that the walkways crossing the entries and exits for pedestrians should be built in a distance of 4 to 5 m away from the margin of the circle. In addition, Scandinavian evaluations of roundabouts conclude that single-lane roundabouts with one-lane entries are very safe for pedestrians and bicyclists (Ulf and Jörgen, 1999). One review paper from Germany (Richter et.al) presented that roundabout with outer diameters of 35 to 45 m is lower accident characteristic figures than roundabouts with smaller outer diameters between 25 and 35 m. In addition, he showed that outside built-up area, a few amount of accidents occurred at single-lane roundabouts than at the other basic form of junction. The accident severity is significantly lower at roundabouts.

In a review paper from Norway and Sweden (Tran, 1999, and Bru'de and Larsson, 1999), it is described that injury crashes rates are higher in large roundabouts than in small roundabouts but this result is not controlled for other factors, so that it may affect accident rates in roundabouts. The use of roundabouts in Australia is quite popular, large numbers of previously priority controlled junctions have been replaced by roundabouts. In newly developed suburbs roundabouts are widely used as junction control device. The major benefits of roundabouts are their better safety records over that of traffic signals and their higher capacity relative to signalized intersections particularly those with 4-phase controlled (Brilon, 1993).

Generally, roundabout has more capacity than other give-way intersection and also intersection with signalized control. The fuel consumption is lower than at intersection with traffic light installation. In a review paper of Richer, the investment costs for conversion at-grade junctions to roundabouts were high. However, high maintenance costs are expected with projects for the operation of a traffic light installation. In addition, the benefit components show more significant advantages in roundabouts with regard to the accident costs and fuel costs.

Concerning emissions from the description of international review papers, a reduction may be expected when replacing signalized intersections by roundabouts and an increase when replacing yield-controlled intersections by roundabouts. The noise level also decreased at intersections that are substituted by roundabouts (Hydén, and Várhelyi, 2000).

In the past decades, some research investigated the safety effectiveness of roundabouts. They have proven that a considerable reduction in the number of injury accidents was caused by converting an intersection into a roundabout. The effects on accidents with slight injuries are lower than the effects on accidents with deaths and serious injuries. Elvik.R. et.al (2009)

described the effect on roundabout on the number of accidents (Table. 2).

Table 2. Effects on accidents of converting intersections to roundabouts

Type of intersections	Percentage change in the number of accidents		
	Accident severity	Best estimate	95% confidence interval
All roundabouts	All severities	-36	(-43, -29)
All roundabouts	Fatal accidents	-66	(-85, -24)
All roundabouts	Injury accident	-46	(-51, -40)
All roundabouts	Property damage only accidents	+10	(-10, +35)
Previous yield junctions	All severities	-40	(-47, -31)
Previous signalized junctions	All severities	-14	(-27, + 1)
X-junctions	All severities	-34	(-42, -25)
T-junctions	All severities	-8	(-28, +18)
Roundabouts in rural areas	All severities	-39	(-79, -54)
Roundabouts in urban areas	All severities	-25	(-34, -15)

Source; Elvik.R. et.al (The handbook of road Safety measures, Second edition, 2009)

The results showed that the total number of accidents is greatly reduced in roundabouts. These results referred to all types of roundabouts. Hence, Brabander and Vereeck 2005 said that the effectiveness of roundabouts is greater at higher speed limits. The review paper of Elvik et al. 2003 presented that there are no significant differences in the effects of roundabouts between different countries.

In addition, another review papers also presented that not only reduction of motor vehicle crashes and injuries but also other important societal benefits such as reductions in vehicle emissions, fuel consumption, traffic delays and noise are significant (Jacquemart, 1998 , and Hyden and Varhelyi, 1999).

### 3.2 Theoretical safety effects of roundabouts

Most areas that implement roundabouts experience an impressive impact on their accident record. Because of this remarkable reputation, some countries have converted many intersections into roundabouts. Large traffic circles of roundabout design were built in France at the beginning of the 19th Century (Brown, 1995; Thai & Balmeffrezol, 2000). France was building almost 1500 roundabouts a year (Guichet 1997). In the Netherlands, since the late 1980s, approximately 400 roundabouts have been built over a period of only six years (Schoon and van Minnen 1994). In United Kingdom (UK), give-way priority to the circulatory traffic on roundabouts operated since 1966. In the United States (U.S), the use of roundabouts is rather limited (Persaud et al., 2001), although they were increasing. Road safety and traffic flow both in rural and urban areas could be improved by roundabouts. FHWA, 2002 presented that a study of 11 modern roundabouts in the United States showed a 37 % reduction in the number of accidents and a 51 % reduction in the number of injuries. Thus, both State Farm Insurance and the Insurance Institute for Highway Safety encouraged the widespread use of roundabouts.

Taekratok. T (June, 1998) said that roundabout higher safety is due to the following:

- 1) The avoidance of left-turn accidents (for right-hand side driving countries), which are the causes of most fatal or serious accidents at cross intersections.

- 2) The smaller number of conflict points in some circumstances.
- 3) The slow relative speeds of all vehicles in the conflict area.
- 4) The simplicity of decision-making at the entry point.
- 5) The protection of pedestrians on splitter islands which permit crossing one direction of traffic at a time and provide a refuge.

For pedestrians, roundabouts reduce a certain number of potential conflicts that occur on conventional intersections such as conflicts between high-speeding vehicles and pedestrians crossing the street, conflicts between right-turning vehicles and pedestrians crossing the street, and conflicts between left-turning vehicles and pedestrians crossing the street on signalized as well as other intersections. Pedestrians are as safe at roundabouts as at other intersections by consideration of two factors; provision of splitter islands on the approaches which allow pedestrians to cross the road in stages and slower vehicle speeds. In addition to safety benefits, traffic flow in roundabouts is more variable than for signalized intersections (Brilon and Vandehey, 1998), because there is more room for driver discretion (Vandehey, 1998; Myers, 1994).

### **3.3 Effective of converting intersections to roundabouts on road safety**

The review paper of Safety and Capacity of roundabout design (July 25, 2004) presented that several studies have examined the safety implications of replacing standard intersections with roundabouts in the United States, Europe, and Australia. Hyden and Varhelyi (2000) found that replacing intersections with roundabouts carried a “very significant risk reduction” for bicyclists and pedestrians, but not for cars.

Elvik, R. et al (2002) reviewed the evidence from non-US studies which concerned the effect on road safety of converting intersections to roundabouts in which entering traffic is required to yield to circulating traffic (TRB, 2003). The analysis showed that roundabouts as substitution of intersections could significantly reduce the number and severity of accidents. According to the paper, roundabouts were found to reduce both the number and severity of injury accidents. He presented that roundabouts are associated with a reduction of 30% to 50% in the number of injury accidents. Moreover, the largest reductions were found for fatal accidents which are reduced by 50% to 70%. Roundabouts appear to be more effective in reducing injury accidents in 4-leg junctions than in 3-leg intersections.

The accident cost rates of the conversion of crossroads to roundabouts decreased by 14.77 € per 1000 vehicles to 7.36 € per 1000 vehicles (Brilon and Stuwe 1991). A study from Germany (Richter) showed that the accident rate of roundabouts on roads outside built-up areas is slightly below the comparison values of single-level intersections with traffic light installations and single-level junctions without traffic light installations. The accident cost rate of the roundabouts was DM 13.00 per 1000 vehicles. The comparison value of other basics of intersection outside built-up areas showed higher accident cost rates. After the conversion of the crossroads to roundabouts, the accident cost rates fell by 78% (on average) from DM 98.00 per 1000 vehicles to DM 22.00 per 1000 vehicles. Therefore, the traffic safety of junctions can be improved by conversion of crossroads to roundabouts.

In general, the installation of roundabouts results in significant reductions to road accidents. This effect is systematically higher for fatal or serious injury crashes and lower for minor injury crashes. In some case studies, the negative safety effect of roundabouts on material damage only crashes was identified. In particular, statistically significant results are shown in Table 3.

Table 3. Review of significant results of converting intersections to roundabouts

Previous review papers	International	Description of results of converting intersections to roundabouts
Elvik, R., (2003)		Replacing intersections into roundabouts could also have more effective on accidents in four-leg intersections than in three-leg intersections
Elvik, R., Vaa, T. (2004)		Replacing stop-controlled and signalized controlled intersections to roundabouts may be found a 31% and 11% reduction in injury accidents for three-leg intersections and 41% and 17% reduction in injury crashes for crossroads.
Persaud, B. N., Retting, R. A., Garder, P. E., and Lord, D. (2001)		Replacing stop-controlled and signalized controlled single-lane urban and rural intersections to roundabouts may be resulted about in 75% and 35% reduction in injury accidents and about 85% and 75% reduction in all accidents.

### 3.4 Accident Cost Rates related to different type of intersections and various type of traffic controls

In Europe (2008), more than 5,000 of fatalities in road crashes at intersections were recorded, corresponding to more than 20% of total fatalities (ERSO, 2008). The choice of intersection type and type of traffic control has strongly influenced the expected accident occurrence. Results of accident cost rates related to various intersection types and types of traffic control at German highway intersections showed that it is possible to reduce accident cost rate (ACR) by the choice of intersection type and type of traffic control. Differences of up to ~80% of ACR are possible.

In figure (1), the safety level of different types of intersections and various types of traffic controls is shown. Some intersection types are poor safety level and some are better safety level. In at-grade intersection types, the accident cost rate of roundabouts is lower than that of the other three types of at-grade X-intersections. Especially, the ACR of roundabouts is about one fifth of the ACR of yield signed intersection and signalized intersection (2 phases). Its ACR is 12 €/ 1000 vehicles on German highways.

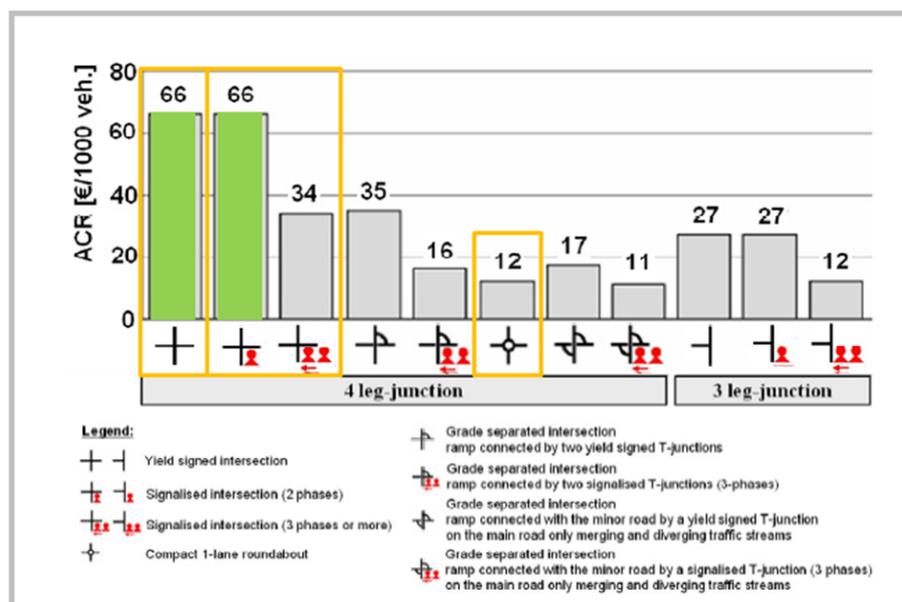


Figure 1. Accident Cost Rates related to various intersection types and types of traffic control at German highway intersections (according to Meewes, 2003)

#### **4. OVERVIEW OF TRAFFIC ACCIDENTS IN THAILAND**

It has been calculated that the economic losses due to road accidents in Thailand are approximately 115,932 million baht per year or about 2.13% of the GDP (Tanaboriboon, 2004a). Economic growth in Thailand has brought about an expanding network of roads and an increasing number of the driving public. The total costs of traffic accident in Thailand for the year 2004 are estimated at 153,755 million baht (approximately US\$ 3,460 million). The growing number of vehicles on the roads has contributed to significant increases of road accidents annually. Road accidents have been a major cause of death and injury in Thailand. World Health Organization (WHO) published that a road traffic death rate of 19.6 per 100,000 inhabitants was determined for Thailand, according to the “Global Status Report on Road Safety”. The influence of traffic accidents in Thailand has changed steadily over the gone 26 years. Current national Government policy for road safety about overall road safety target are (1) Reducing fatalities rate of road traffic accident of below 10 deaths per 100,000 population within the Decade of Action for Road safety (2011 – 2020), (2) Reducing the fatalities rate from road traffic accident of 14.15 deaths per 100,000 population within the year 2012 in the short term target (status paper on road safety 2010, Thailand).

The number of accidents on highways is registered by the Department of Highways (DOH) of Thailand. For 2010, the national highways accident database contains 12,054 crashes with 1,370 persons lost their lives in 821 crashes.

Stefanie Blei in 2010 investigated 23 signalized intersections in the Kingdom of Thailand. She found that the oversized cycle times up to 224s are an important point of criticism and cycle times exceeding 120s have only a marginal impact on the capacity but the influence on road safety is significant. Hence, she suggested that cycle times above 120s should be avoided. Therefore, she pointed out, that there is also risk for serious or fatal crashes due to insufficient design principles in Thailand.

##### **4.1 Under-reporting of road casualty accidents in Thailand**

Piyapong Srirat (May 2008, AIT) analyzed the under-reporting of road casualty accidents in Thailand. He studied to apply the results from the integration between two accident databases collected by the Department of Highways (DOH) and the Royal Thai Police in accident under reporting. They included the characteristics of site of crash, location of accident occurrence, date, time, probable cause, property damage and also the number of persons killed and injured. Conversely, the hospital data collect the case of severity, disability and death, but not providing the property damage. The result shows that 59.3 percent of under-reporting accident data was found from DOH data when comparing to the police accident data.

##### **4.2 Thailand traffic accident cost**

One paper of Eastern Asia Society for Transportation Studies described Thailand traffic accident costs. That paper reported the result of the study of traffic accident costing (2004) in Thailand by using the HC approach in five pilot provinces in Thailand. The total traffic accident costs for Thailand for the year 2004 are estimated to be 153,755 million baht (about US\$ 3,460 million) or approximately 2.37 percent of the GDP of that year. Moreover, it has been estimated that the average cost per casualty and case by crash severity are 3,324,834 baht per fatality, 3,470,080 baht per disability, 128,433 baht per serious injury, 28,091 baht per slight injury, and 30,871 baht per PDO case, respectively (Table 4).

Presently, the Bureau of Highway Safety of the Department of Highways (DOH)

modified the accident cost rates of Thailand for 2011. Therefore, for the whole area of Thailand, the average cost per casualty and case by crash severity are 5.062 to 5.956 million baht per fatality, 5.114 to 6.910 million baht per disability, 0.158 to 0.164 million baht per serious injury, 0.0386 to 0.0389 million baht per slight injury, and 0.052 million baht per PDO case ( see in column-1,Table 5). The average cost per casualty and case by crash severity for the Bangkok area, and other provinces (except Bangkok area) are described in column (2) and (3), Table 5.

Table 4. The average unit cost per casualty or case by severity (2004)

Severity	Average Unit Cost(Baht)
Fatality	3,324,834
Disability	3,470,080
Serious Injury	128,433
Slight Injury	28,091
PDO case	30,871

Source: Traffic accident costing for Thailand (EASTS, 2007)

Table 5. The average unit cost per casualty or case by severity (2011)

Severity	(1) Thailand (Million Baht)	(2) Bangkok (Million Baht)	(3) Other Provinces (Million Baht)
Fatality	5.062 – 5.956	10.561 - 12.413	4.757 - 5.599
Disability	5.114 - 6.910	11.611 - 13.934	5.608 - 6.729
Serious Injury	0.158 - 0.164	0.328 - 0.337	0.148 - 0.155
Slight Injury	0.0386 - 0.0389	0.1731 - 0.1733	0.0297 - 0.0298
Property Damage Only	0.052	0.164	0.039

Source: DOH, Bureau of Highway Safety

## 5. ACCIDENT COSTS AND ACCIDENT COST RATES OF AT-GRADE X-JUNCTIONS IN THAILAND

In this paper, accident costs and accident cost rates of intersections are calculated by different sized and different traffic control type of intersections.

### 5.1 Data collection

In this paper, the author studied 61 X-junctions on two way-two lane in Thailand (figure. 2 and 3 ) which are under responsibility of DOH highways to collect DOH and police recorded accident data (2008-2011), investigate onsite geometric data and signal program. In onsite inspection, the author measured geometric data, speed, signal program, delay and counted traffic volume for percentage share of type of vehicle in each intersection.

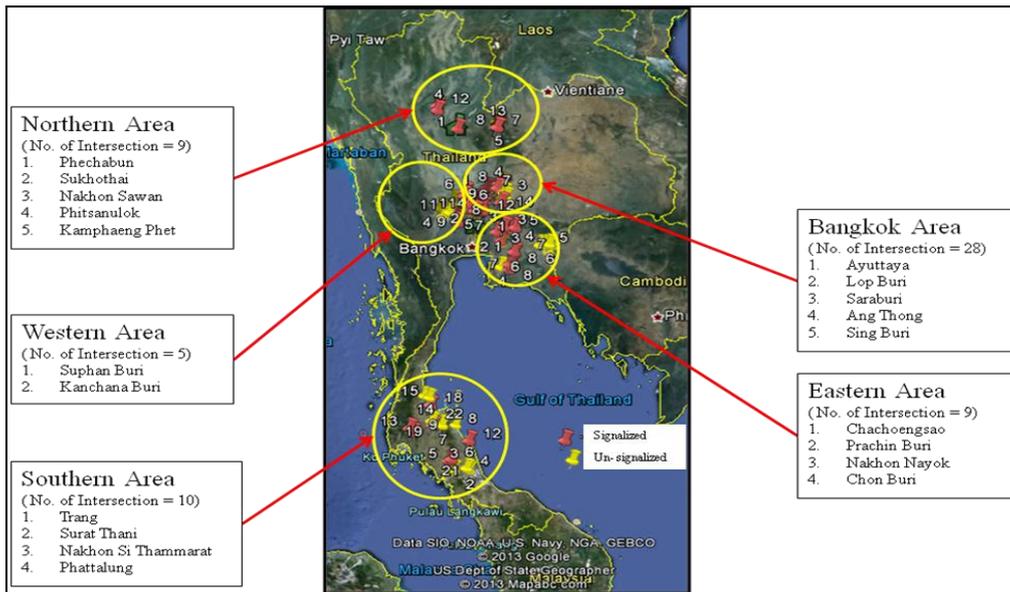
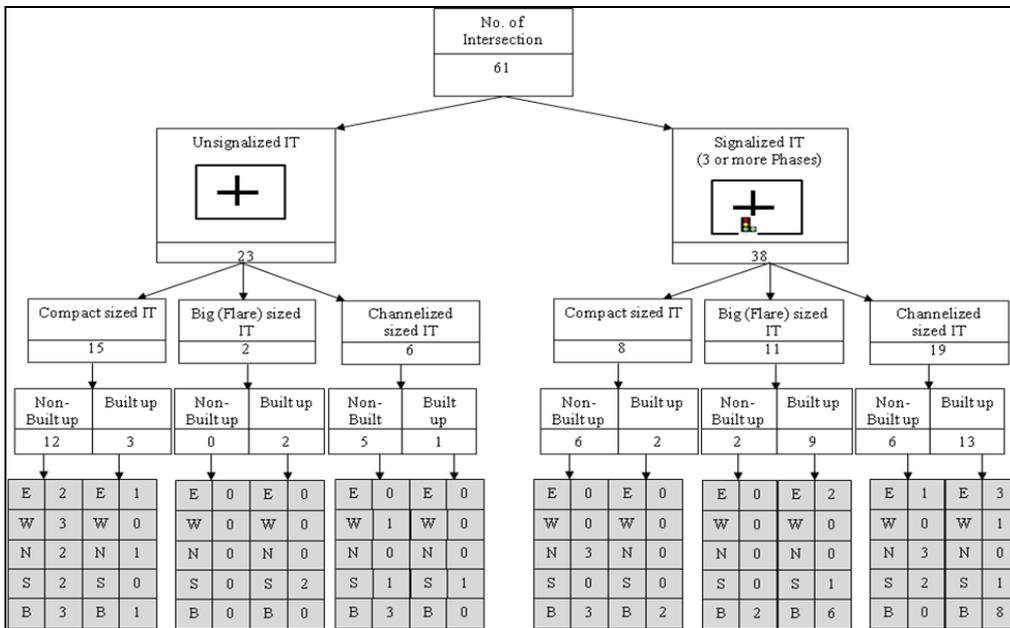


Figure 2. Study Area in Thailand



Note: N= Northern, B= Bangkok, S= Southern, E = Eastern, W= Western

Figure 3. Investigated X-junctions on two way- two lane highways in Thailand

The author found that under-reporting accident data in selected intersections from DOH database to Police accident data is 76.1 percent ((448/ (140+448)). It is shown the following figure 4.

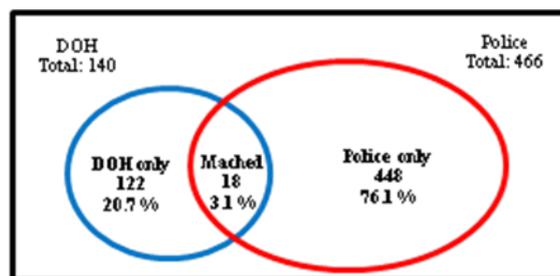


Figure 4 . Matching of DOH and Police accident data in selected intersections

## 5.2 Accident Cost (AC) of at-grade X-junctions in Thailand

Accident costs are economic losses caused by traffic accidents which consider the number and severity of accidents. For selected 61 X-junctions, the number of disabled person is not classified in the reported accident data. So, the author calculated the revision of average unit cost per casualty or case by severity which is based on column no (1) in table 5. Therefore, the average cost per casualty and case by crash severity for the whole area of Thailand are 5,509,000 baht per fatality, 365,715 baht per serious injury, 38,750 baht per slight injury, and 52,000 baht per PDO case, respectively.

In 61 intersections, the average AC of signalized intersection (3 or more phases) is 7.0 million Baht in which fatal accident cost (AC (Cat; Fal)) is 6.3 million Baht, serious injury accident cost (AC (Cat; SI)) is 0.6 million Baht and slight injury cost (AC (Cat; SL)) is 0.1 million Baht. AC of unsignalized intersection is 8.9 million Baht in which fatal accident cost is 8.2 million Baht, serious injury accident cost is 0.6 million Baht and slight injury cost is 0.1 million Baht (see in lower right side corner of figure 5). Accident cost of each intersection size is shown in figure (5).

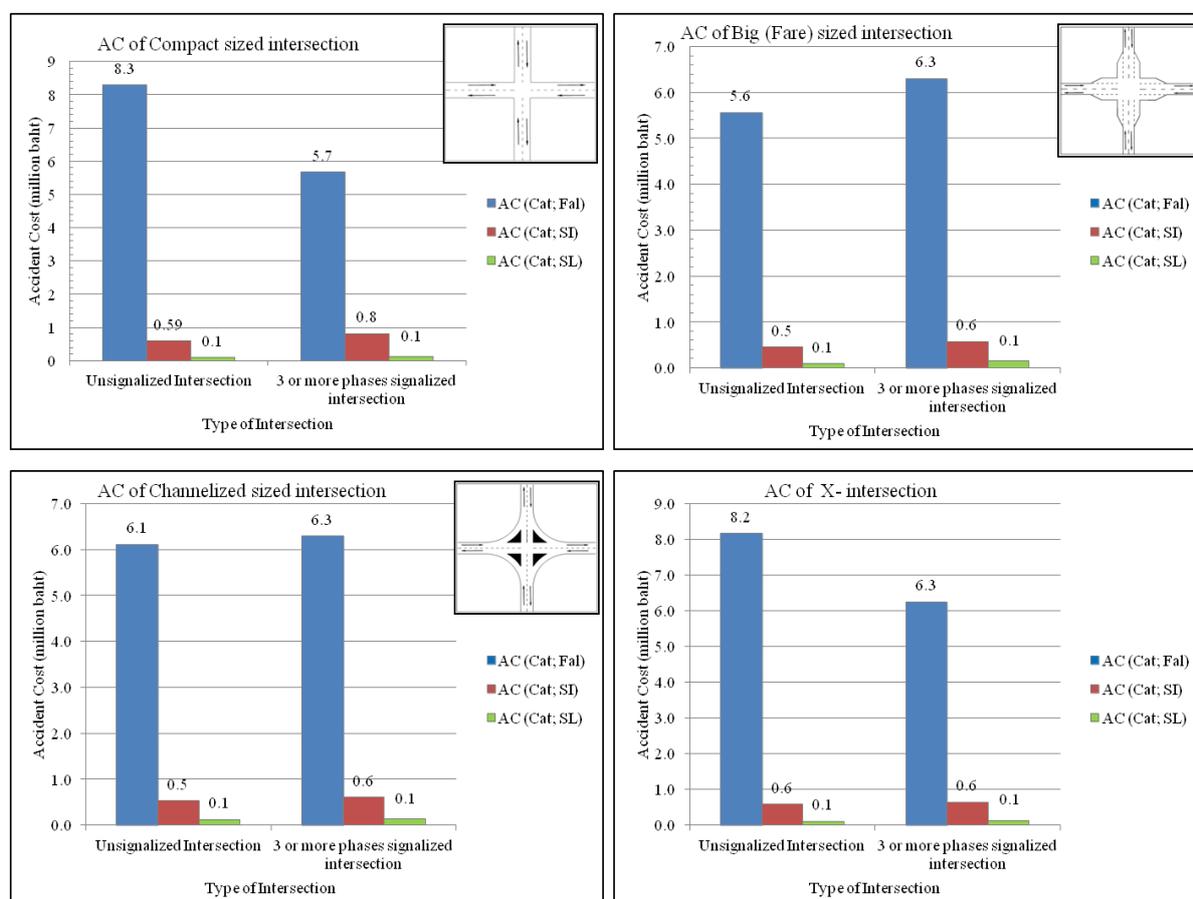


Figure 5. Accident Cost of X-junctions on two way-two lane highways in Thailand

There has under reporting accident data between DOH and Police. Therefore, the average accident cost of investigated intersection is calculated by 6 scenarios. They are 0%, 15%, 30%, 45%, 60% and 76.1% of under reported accident data. The average accident cost of fatal accidents (ACFal) in compact-size unsignalized intersection is the highest on two way- two lane highways in Thailand (see in Table 6).

Table 6. Scenario of Average Accident Cost of X-junction by under reporting

scenario	Under reporting	Average Accident Cost (Million Baht)	Unsignalized IT			Signalized IT (3 or more phases)		
			Compact	Big	Channelized	Compact	Big	Channelized
1	0%	ACFal	8.3	5.6	6.1	5.7	6.3	6.3
		ACSI	0.6	0.5	0.5	0.8	0.6	0.6
		ACSL	0.1	0.1	0.1	0.1	0.1	0.1
2	15%	ACFal	9.5	6.4	7.0	6.5	7.3	7.2
		ACSI	0.7	0.5	0.6	0.9	0.7	0.7
		ACSL	0.1	0.1	0.1	0.1	0.2	0.1
3	30%	ACFal	10.8	7.3	7.9	7.4	8.2	8.2
		ACSI	0.8	0.6	0.7	1.1	0.7	0.8
		ACSL	0.1	0.1	0.2	0.2	0.2	0.2
4	45%	ACFal	12.0	8.1	8.9	8.2	9.1	9.1
		ACSI	0.9	0.7	0.8	1.2	0.8	0.9
		ACSL	0.1	0.1	0.2	0.2	0.2	0.2
5	60%	ACFal	13.3	9.0	9.8	9.1	10.1	10.1
		ACSI	0.9	0.7	0.8	1.3	0.9	1.0
		ACSL	0.2	0.1	0.2	0.2	0.2	0.2
6	76.1%	ACFal	14.6	9.9	10.8	10.0	11.1	11.1
		ACSI	1.0	0.8	0.9	1.4	1.0	1.1
		ACSL	0.2	0.2	0.2	0.2	0.3	0.2

(Note: ACFal= Accident Cost for Fatality, ACSI = Accident Cost for Serious Injury, ACSL= Accident Cost for Slightly Injury, IT= Intersection Type)

### 5.3 Accident Cost Rate (ACR) of at-grade X-junction in Thailand

Accident cost rates denote the accumulated economic loss caused by accidents in relation to the number of vehicles which have used the intersection. In the analysis of accident cost rate, the formula of ACR is shown in the equation (1).

$$ACR (cat;) = n ( cat;) * AC(cat; ) / TV \text{----- (equation .1)}$$

Note: ACR (cat;) = Accident Cost Rate of category in accident  
 n ( cat;) = number of category in accident  
 AC ( cat;) = accident cost of category in accident  
 TV = traffic volume (AADT)

The average accident cost rate of at-grade X-junctions on two way-two-lane highways in Thailand is 0.466 Baht per 1000 vehicles at unsignalized intersection, and 0.158 Baht per 1000 vehicles at signalized (3 or more phases) intersection (see in figure 6). In the compact-sized and channelized intersection, the average accident cost rate (ACR) of unsignalized intersections is higher than ACR of signalized type (3 or more phases). However, in Big-sized intersection type, the average ACR of unsignalized intersection is 2.62 times (0.152/0.058) lower than ACR of signalized (3 or more phases) intersection.

The six scenarios of the average accident cost rate of intersection are presented by 0%, 15%, 30%, 45%, 60% and 76.1% of under reported accident data. (see in Table 6).

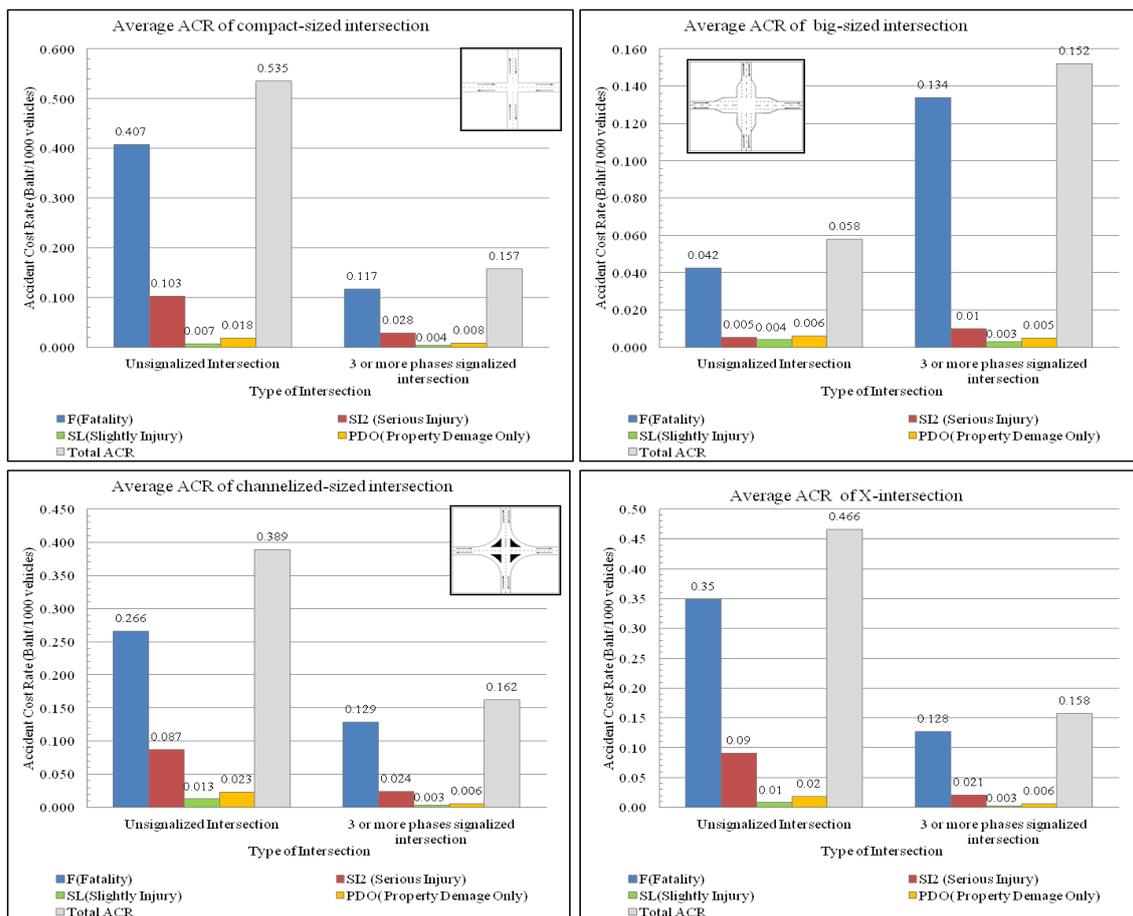


Figure 6. Accident Cost Rate of X-junctions on two way-two lane highways in Thailand

Table 7. Scenario of Average Accident Cost rate of X-junction by under reporting

scenario	Under reporting	ACR (Baht/1000 vehicles)	Unsignalized IT			Signalized IT (3 or more phases)		
			Compact	Big	Channelized	Compact	Big	Channelized
1	0%	Fal	0.41	0.04	0.27	0.12	0.13	0.13
		SI	0.10	0.01	0.09	0.03	0.01	0.02
		SL	0.01	0.00	0.01	0.00	0.00	0.00
		PDO	0.02	0.01	0.02	0.01	0.01	0.01
		Total	0.53	0.06	0.39	0.16	0.15	0.16
2	15%	Fal	0.47	0.05	0.31	0.13	0.15	0.15
		SI	0.12	0.01	0.10	0.03	0.01	0.03
		SL	0.01	0.00	0.02	0.00	0.00	0.00
		PDO	0.02	0.01	0.03	0.01	0.01	0.01
		Total	0.61	0.07	0.45	0.18	0.17	0.18
3	30%	Fal	0.53	0.06	0.35	0.15	0.17	0.17
		SI	0.13	0.01	0.11	0.04	0.01	0.03
		SL	0.01	0.01	0.02	0.01	0.00	0.00
		PDO	0.02	0.01	0.03	0.01	0.01	0.01
		Total	0.70	0.08	0.51	0.20	0.20	0.21

4	45%	Fal	0.59	0.06	0.39	0.17	0.19	0.19
		SI	0.15	0.01	0.13	0.04	0.01	0.03
		SL	0.01	0.01	0.02	0.01	0.00	0.00
		PDO	0.03	0.01	0.03	0.01	0.01	0.01
		Total	0.78	0.08	0.56	0.23	0.22	0.23
5	60%	Fal	0.65	0.07	0.43	0.19	0.21	0.21
		SI	0.16	0.01	0.14	0.04	0.02	0.04
		SL	0.01	0.01	0.02	0.01	0.00	0.00
		PDO	0.03	0.01	0.04	0.01	0.01	0.01
		Total	0.86	0.09	0.62	0.25	0.24	0.26
6	76.1%	Fal	0.72	0.07	0.47	0.21	0.24	0.23
		SI	0.18	0.01	0.15	0.05	0.02	0.04
		SL	0.01	0.01	0.02	0.01	0.01	0.00
		PDO	0.03	0.01	0.04	0.01	0.01	0.01
		Total	0.94	0.10	0.69	0.28	0.27	0.28

(Note: Fal= Fatality, SI= Serious Injury, SI= Slightly Injury, PDO= Property Damage Only)

## 6. TYPE OF ACCIDENT OF AT-GRADE X-JUNCTIONS ON TWO WAY-TWO LANE HIGHWAYS IN THAILAND

The author found that accident types depend on intersection size and type of traffic control of intersections. In the result of all 61 intersections (in figure 7), driving accident type is the most frequent one at unsignalized intersections and at signalized (3 or more phases) intersections. The accident types are classified by Table 8.

Table 8. Classification of type of accident

Color	Type of accident
●	<b>Driving accident:</b> A driving accident occurred when driver loses control over his vehicle because he chose the wrong speed according to the run of road, the road profile, the road gradient and drunk alcohol.
●	<b>Turn off accident:</b> A turning accident occurred when there was a conflict between a turning user and a road user coming from the same / opposite direction.
●	<b>Turning in/ crossing accident :</b> A turning in/ crossing accident occurred due to a conflict between a turning in or crossing road user without priority and a vehicle with priority. This applies at crossing, junctions of roads and farm tracks as well as access to properties or parking lots.
○	<b>Crossing over accident:</b> The accident was caused by a conflict between a vehicle and a pedestrian on the carriageway, unless the pedestrian walked along the carriageway, and unless the vehicle turned off the road. This applies also where the pedestrian was not hit by the vehicle.
●	<b>Accident in Longitudinal accident:</b> The accident occurred due to a conflict between road users moving in the same or the opposite direction. This applies unless the conflict is the result of a conflict corresponding to another accident type.

●	<p><b>Other accident:</b> Other accidents are accidents that include all accidents (eg. Turning around, backing up, accident between two parking vehicles, objects or animals on the road, sudden vehicle defects).</p>
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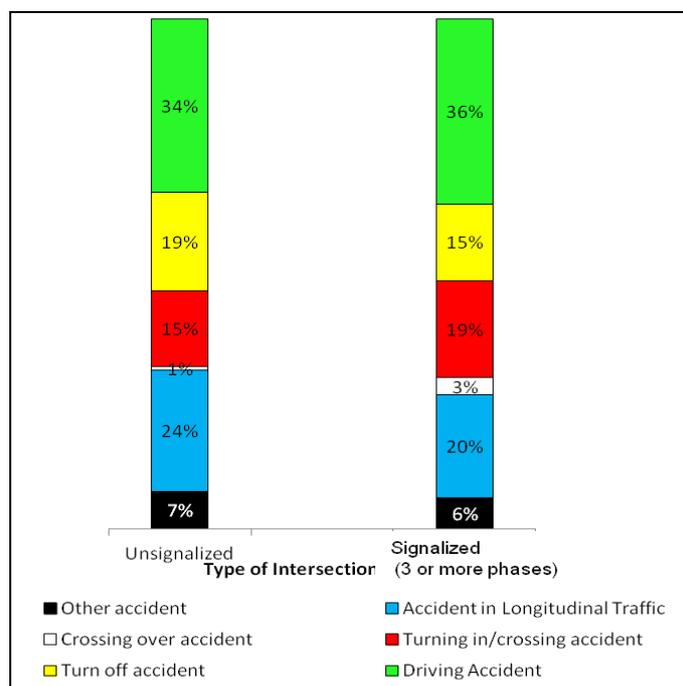


Figure 7. summarized type of accident of X-junctions on two way-two lane highways in Thailand (2008-2011)

## 7. COMPARISON OF ACCIDENT COST RATE OF X-JUNCTIONS BETWEEN THAILAND AND GERMAN HIGHWAYS

In Thailand , according to scenario (1), Accident Cost Rate of unsignalized X-junction is 0.466 baht/ 1000 vehicles and 0.158 baht/ 1000 vehicles in signalized intersection ( 3 or more-phases). According to GDP data from World Bank (2011), GDP per capita of Germany (39,211\$) is 4.17 times higher than Thailand GDP per capita (9,396 \$). In table 9, it shows comparison of ACR of X-junction between Thailand and German highways.

On German highway, ACR of yield signed intersection (66 euro per 1000 vehicles) is two times higher than ACR of signalized (3 or more phases) intersection (34 euro per 1000 vehicles). For Thailand, ACR of unsignalized intersection is three times higher than ACR of signalized (3 or more phases) intersection on highways.

Table 9. Comparison of ACR of X-junction between Thailand and German highways

Accident Cost Rate (Euro/1000 vehicles)		
Country	Unsignalized intersection	Signalized intersection (3 or more-phases)
Thailand	1.9432	0.6589
Germany	66.0	34.0

## 8. COST-BENEFIT ANALYSIS FOR CONVERSION OF EACH INTERSECTION TYPE TO COMPACT ONE LANE ROUNDABOUT

Cost-benefit analysis examines whether the benefits of an investment in road infrastructure exceeds the costs and can help decision makers to make their choice for a (road infrastructure) measure or a combination of measures. In this paper, the author only takes into account the road safety element and calculated the implementation cost and maintenance cost of each intersection type with existing conditions for Thailand by using DOH unit cost (Table 10).

Table 10. Implementation cost and Maintenance cost of existing intersection in Thailand

Cost of intersection (million baht)	Unsignalized			Signalized (included installation cost of signal control = 1.1 million baht)		
	compact-sized	big-sized	channelized-sized	compact-sized	big-sized	channelized-sized
Implementation cost (million baht/ intersection)	8.853	11.560	16.013	10.346	17.888	27.192
Maintenance cost (million baht/ yr)	0.046	0.061	0.082	0.063	0.088	0.135

The economic life of the intersection is considered to be 30 years and the discount rate is 7%. In this analysis, the measure of compact one-lane roundabout has 35 m outer diameter and 7 m circle width. The truck apron of roundabout is 2.33 m which is constructed by cobble stone. Therefore, the quantifying the estimated implementation cost and maintenance/operation cost of measure (compact one lane roundabout) is 9.575 million baht and 0.020 million baht, and thus total discounted costs for life cycle 30 years is 9.8231 million baht.

The total registered (observed) number of accidents and the number of AADT (2008 to 2011) for each intersection type is shown in table 11.

Table 11. Total registered number of accidents and AADT data from 2008 to 2011

Total Accident Registered (2008-2011)								
Type of intersection	Unsignalized intersection (23 Nos.)				Signalized intersection (3 or more phases) (38 Nos.)			
	compact-sized	big-sized	channelized-sized	Total	compact-sized	big-sized	channelized-sized	Total
Fatality	24	1	4	29	17	30	53	100
Serious Injury	70	1	16	87	52	49	134	235
Slightly Injury	53	10	23	86	74	73	167	314
No. of Accident	92	11	24	127	101	120	240	461
No. of intersection	15	2	6	23	8	11	19	23
AADT range	1796 ~ 29540	6300~ 11800	1581~ 6400	1581~ 29540	4720~ 15850	1030~ 55273	2200~ 33000	1030~ 55273

For estimating the potential saving, the effect of the countermeasure is used by Rune Elvik's Handbook of road safety measures (second edition). The effect on accidents of converting intersections to roundabouts is 66 % reduction in fatal accident, 46 % reduction in injury accident, and 10 % increased in property damage only accident. The estimated effect on accident of converting unsignalized intersection to roundabout, and signalized (3 or more phases) to roundabout for Thailand is shown in table 12, and 13.

The estimated saving in accidents in 1<sup>st</sup> year for conversion of X-junction to compact roundabout is calculated with each severity criteria. Then, the author computed total discounted benefits in 30 years. They are shown in table 14 and 15. The simplified results of social return calculation for conversion of each intersection type to compact one-lane roundabout are presented in Table 16. Compact-size of Unsignalized intersection and big-sized of Signalized (3or more phases) intersection are preferable to convert compact one-lane roundabout in the results of net present value and benefit-cost ratio (see in Table 16).

Table 12. Estimated effect on accident of converting Unsignalized intersection to roundabout for Thailand

Severity	Accident Registered (observed)			Estimated effect measures( reduction) (roundabout, a)		
	A compact-sized	B big-sized	C channelized-sized	Aa	Ba	Ca
Fatality	1.60	0.50	0.67	1.60* 0.66= 1.06	0.33	0.44
Serious Injury	4.67	0.50	2.67	4.67* 0.46= 2.15	0.23	1.23
Slightly Injury	3.53	5.00	3.83	3.53* 0.46 = 1.63	2.30	1.76
PDO	6.13	5.50	4.00	6.13* 1.1 = 6.75	6.05	4.40

(Note: Aa= conversion of compact-size intersection to roundabout, Ba= conversion of big-size intersection to roundabout, Ca= conversion of channelized-size intersection to roundabout)

Table 13. Estimated effect on accident for conversion Signalized (3 or more phases) intersection to roundabout inThailand

Severity	Accident Registered (observed)			Estimated effect measures( reduction) (roundabout, a)		
	A compact-sized	B big-sized	C channelized-sized	Aa	Ba	Ca
Fatality	2.13	2.73	2.79	1.40	1.80	1.84
Serious Injury	6.50	4.45	7.05	2.99	2.05	3.24
Slightly Injury	9.25	6.64	8.79	4.26	3.05	4.04
PDO	12.63	10.91	12.63	13.89	12.00	13.89

Table 14. Estimated saving in accidents in 1<sup>st</sup> year for conversion of X-junction to roundabout

saving in accidents in 1 <sup>st</sup> year (m baht)	Conversion of Unsignalized intersection to Roundabout			Conversion of Signalized (3 or more phases) intersection to Roundabout		
	Aa	Ba	Ca	Aa	Ba	Ca
Fatality *5.509	5.8175	1.81797	2.42396	7.7264	9.9162	10.1424
Serious Injury *0.3657	0.78507	0.08411	0.44861	1.0935	0.7494	1.1865
Slight Injury * 0.03875	0.06298	0.08913	0.06833	0.1649	0.1183	0.1567
Damage only *0.052	0.35083	0.3146	0.2288	0.7222	0.624	0.7225
Total benefit in1 <sup>st</sup> year (m baht)	7.01638	2.30581	3.1697	9.7069	11.4079	12.208

(Note: Aa= conversion of compact-size intersection to roundabout, Ba= conversion of big-size intersection to roundabout, Ca= conversion of channelized-size intersection to roundabout)

Table 15. Estimated total discounted benefits in 30 years for conversion of X-junction to compact roundabout

Total discounted benefits in 30 years	Conversion of Unsignalized intersection to Roundabout			Conversion of Signalized (3 or more phases) intersection to Roundabout		
	Aa	Ba	Ca	Aa	Ba	Ca
saving in accidents (m Baht)	94.083	30.919	42.503	130.160	152.969	163.698
saving in Fuel (m Baht)	0.000	0.000	0.000	101.059	229.931	175.949
Travel time benefit(m Baht)	0.000	0.000	0.000	86.099	195.893	149.902
Operating saving (m Baht)	0.000	0.000	0.000	0.328	0.328	0.328
Total benefits(m Baht)	94.083	30.919	42.503	317.645	579.120	489.877

Table 16. Estimated social return calculation of conversion of X-junction to compact roundabout

Social return calculation	Conversion of Unsignalized intersection to Roundabout			Conversion of Signalized (3 or more phases) intersection to Roundabout		
	Aa	Ba	Ca	Aa	Ba	Ca
Total Cost (m Baht)	9.823	9.823	9.823	9.823	9.823	9.823
Total Benefits (m Baht)	94.083	30.919	42.503	317.645	579.120	489.877
Net Present Value (NPV) = Benefit -Cost	<b>84.260</b>	21.096	32.680	307.822	<b>569.297</b>	480.053
Benefit- Cost ratio (BCR) = Benefit/ Cost	<b>9.58</b>	3.15	4.33	32.34	<b>58.95</b>	49.87

(Note: Aa= conversion of compact-size intersection to roundabout, Ba= conversion of big-size intersection to roundabout, Ca= conversion of channelized-size intersection to roundabout)

## 9. CONCLUSION AND RECOMMENDATION

In conclusion, the result of this research found that the accident cost rate of unsignalized intersections is higher than the accident cost rate of signalized (3 or more phases) intersections on two way-two lane highways in Thailand. Furthermore, driving accident, and Accident in longitudinal accident type are the first and second highest accident type in both intersections. According to cost-benefit analysis, compact-size unsignalized intersection and Big-size (flare) signalized (3 or more phases) intersection are more preferable than other types of intersection for conversion of at-grade X junction to compact one lane roundabout on two way- two lane highways in Thailand.

Therefore, the author would like to suggest that the one-lane compact roundabout is suitable for substitution of X-junctions on two way-two lane highways in Thailand based on international reviews of safety costs.

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