ROAD TRAFFIC SAFETY EVALUATION AT THAI U-TURNS USING SEVERITY CONFLICT INDEXES

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Abstract. The purpose of this study is to evaluate the road traffic safety at the at-grade U-turns on 4-lane divided highways of Thailand with focusing their layout geometric. In Thailand, the U-turns are considered as one of the major segments of highways that contributing a higher number of crashes. The several layout geometric designs of the U-turns and variation in dimensions of their variables (acceleration lane, deceleration lane and loon/ widening) are influencing factors for the drivers’ expectancy; causing undesirable driving behavior and confusion among the road users. These characteristics led to a higher frequency of crashes at the U-turns.

For the study purposes a total eight types of at-grade U-turn layout geometric identified throughout Thailand. Due to the limitation of availability and reliability of road crash data in Thailand a surrogate approach, based on the traffic conflict was adopted for the study. Although the Traffic Conflict Technique (TCT) is widely accepted as an alternative and proactive approach but the subjective nature of its parameters is debatable since its origin. The U-turns’ geometric data, traffic conflicts and volume data were recorded in the field.

The Severity Conflict Indexes (SCI) assessed by applying the weighing factors (based on severity of the conflicting situation) to the observed conflicts exposed to the conflicting traffic volumes. A higher value of SCI represents a lower level of traffic safety at a U-turn and a significant relationship was obtained between dimension of the variables of U-turn and the level of road traffic safety.

Keywords: Road traffic safety, U-turn, Severity Conflict Index, Traffic Conflict Technique.
1 Introduction

1.1 Road traffic crash trend in Thailand

Road traffic crashes in developing and emerging countries tend to be one of the major causes of fatalities and disabilities. In 2010 the United Nations General Assembly unanimously adopted a resolution calling for a “Decade of Action for Road Safety 2011–2020”. The goal of the Decade (2011–2020) is to stabilize and reduce the increasing trend in road traffic fatalities, saving an estimated 5 million lives over the period [1]. Road traffic injuries take an enormous toll on individuals and communities as well as on national economies. Middle-income countries, which are motorizing rapidly, are the hardest hit. Economic growth in Thailand has brought about an expanding network of roads and an increasing number of the driving public. The growing number of vehicles on the roads, in turn, has contributed to significant increases of road crashes annually. In Thailand, the road traffic crash problem is now also regarded as one of the most serious social problems. The total economic losses due to road crashes in Thailand were estimated to be 140,000 million Baht or 2.56 Percent of the Gross Domestic Product (GDP) in 2002 [2]. The total traffic crash costs for Thailand for the year 2004 were estimated as 153,755 million Baht or approximately 2.37 Percent of the GDP [3]. The reported road traffic fatalities (in 2010) 13766 and estimated GDP lost due to road traffic crashes about 3% [1]. Although there is declining trend of traffic crash in Thailand [4], yet the number of crashes are high among Southeast Asian countries [1]. The figure 1 shows traffic crash trend in Thailand.

![Fig. 1. Road traffic crash trend in Thailand (Source: Prapongsena (2012))](image)

1.2 Function of the U-turns on the Thai highways

The median at-grade U-turns on the divided Thai highways are provided for the U-turning movements to facilitate road users to join the opposite direction traffic stream. The basic functions of the median at-grade U-turns on the Thai highways are shown in the Fig. 2
Fig. 2. The basic functions of the median U-turns

The U-turns are also constructed to reduce the number of at-grade X-junctions (to avoid direct right turn from a highway to a minor road and direct right turn from a minor road to a highway (for left hand traffic)). Other purposes are to reduce travel time for emergency services, efficient law enforcement and for highway maintenance purposes etc. The distance between the U-turn and minor road is varying (approximately 100 m to 2 km); also there are no specific guidelines available for the separation distance between the U-turns. The experts believe the separation distance between two adjacent U-turns is varying from approximately 1.5 to 3 km on Thai highways, depends upon field geography and local road design practice. The several type layout geometric design practice of the U-turn followed in Thailand, some are standard (as per design guidelines of the Department of Highways) and rests are non-standard (based on the local design practice). For the study purpose, the U-turns were classified based on the applications of the geometric variables.

1.3 Road traffic safety at the U-turns

The midblock U-turn junctions interrupt the through traffic movement. After arriving at the midblock median opening, the U-turning vehicle wait for the large enough gap and make U-turn maneuver. There are interactions between the through traffic and the U-turn traffic streams. As the traffic volume increases on the through streams, the U-turning traffic faces difficulty in finding a sufficient gap to enter the other side of the driveway. As a result these drivers will experience longer travel and delay time. The reduction of traffic volume in one stream could increase the movement capacity in the other stream. The U-turning vehicles affect the through traffic movement in the opposite direction when they merge. The U-turning vehicles also affect the through traffic movement in the same direction when they stop and create queue. Sometimes the storage length at Upstream Zone provided for the U-turning vehicles to make a U-turn may get occupied completely. This may lead to a dangerous situation where the vehicles will extend back onto the highway (spill back), obstructing the through movement traffic.

The U-turning vehicles often do not wait for the large enough acceptable gap of the through traffic. They gradually move onto the conflicting lane to show the intention to go. The through vehicles sometimes do not allow for U-turn, by increasing speed or changing lane or honking vehicle’s horn or opening headlight. Eventually, the through traffic stops and allows the U-turn traffic to move. According to the observation at the U-turn junction, when the U-turn traffic has long queue or waited for longer time, the U-turn traffic tends to be more aggressive to make U-turn. At the same time, the conflicting through traffic tends to be willing to stop and allow the U-turn traffic to go. In theory, the through traffic should get priority over the U-turn traffic all the time.
1.4 U-turn density and geometric design consistency

The at-grade U-turns on divided highways functions almost similar to un-signalised ‘at-grade intersections’ and ‘access points’ where merging, diverging and crossing maneuvers are performed by road users. At the U-turns, the merging and diverging movements are performed at the inner lanes which make these susceptible to traffic crashes. Frequent lane-changes on highways at merging, diverging, and weaving areas could disrupt traffic flow and, even worse, lead to crashes. Also lane-changes could have significant bottleneck effects on overall traffic flow. The practitioners believe that crash frequency augments rapidly when the density (number of U-turns per kilometer length) of at-grade U-turns rises. This indicates that the number of U-turns should be reduced or another solution is the construction of grade separated U-turns which means to space, to reduce or to eliminate the variety of events to which the driver has to respond. It is one of the most important factors in crash reduction.

Furthermore the several type of layout geometric of the U-turns produces inconsistent design characteristics of road infrastructure. This means that drivers cannot drive safely at high speeds all the time and everywhere, since changes in the road environment require constant adaption in speed and influence driver expectancy. The requirement of adapting speed to suit the environment can increase the opportunity for human error and lead to high risk of crash and injury. The posted speed limit at the Thai U-turns is same as mid block speed limit (80 Kilometers per hour). The higher speed increases the severity of the impact in a collision. The conjunction of the high speed and the varying geometric conditions are major factors in crash causation with a high fatal crash rate.

1.5 Effect of geometric variables of the U-turns

The U-turn geometric design varies with application and dimensions of its variables, such as auxiliary lanes (acceleration, deceleration and loons). The placement of auxiliary lanes makes it interesting and challenging to study road traffic safety at the Thai U-turns. In contrast to other highway access points and some intersections, the acceleration (merging) lane and deceleration (diverging) lane provided along inner lanes of highways at the U-turns. Practically the inner lanes are used for overtaking and for vehicles moving with a higher speed. So the merging and diverging maneuvers at the inner lanes make the U-turns susceptible towards traffic crash hazards. The lengths of these auxiliary lanes are not uniform at most of the U-turns. The shorter length of these does not have enough space to make comfortable lane change; this may result in a safety problem for the weaving and storage maneuvers. The maneuvers of motorcyclists for the U-turning movement make study more complex and challenging. The Thai motorcyclists mostly travel on the outer paved shoulder and rarely use inner auxiliary lanes for the U-turning movements, so these have to cross all through lanes of both the directions. Similarly heavy commercial vehicles having difficulty to use inner acceleration lanes due to requirement of larger turning radius, so these vehicles either merge into through lanes or use loons (outer paved area). The main reason for placing a loon is to provide additional space to facilitate the larger turning path of commercial vehicles along narrow medians to negotiate U-turns. With the use of loons, it may be possible to gain the safety and operational benefit of a divided roadway.

2 Literature review

2.1 NCHRP 524 report [5]
The NCHRP 524 report focused on the safety of the U-turns at unsignalized intersections. This report included an intensive safety evaluation of the U-turns for different types of median openings and the places of the median openings on major roads. Some of the findings related to the layout geometric of the U-turns are presented in following sections.

### 2.1.1 Classification of the U-turns

The U-turns were classified on the basis of layout geometric and used following key variables to classify the design:
- Application of acceleration and/ or deceleration lanes,
- Application of directional island, and
- Application of loons.

### 2.1.2 Spacing of median openings

The report stated that by increasing the spacing between median openings improves arterial flow and safety by reducing the number of conflicts and conflict points per mile, providing greater distance to anticipate and recover from turning maneuvers. Spacing of openings should be consistent with access management classifications of criteria.

### 2.1.3 Median acceleration lanes

They provide vehicles a path to accelerate to an appropriate speed before entering into the through travel lanes on a divided highway. Median acceleration lanes provide both safety and operational benefits in that the entering vehicles do not cause vehicles on the through travel lanes to decelerate substantially. They have following advantage and disadvantages as shown in the Table 1

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>— reduce delays when traffic volumes are high</td>
<td>— It is difficult to merge from median acceleration lanes because of blind spots</td>
</tr>
<tr>
<td>— provide higher merging speeds</td>
<td>— are not used properly by drivers</td>
</tr>
<tr>
<td>— reduce the crashes</td>
<td>— create anxiety to through traffic</td>
</tr>
</tbody>
</table>

### 2.1.4 Loons or outer-widening

The loons are defined as expanded paved aprons opposite a median crossover. Their purpose is to provide additional space to facilitate the larger turning path of commercial vehicles along narrow medians. With the use of loons, it may be possible to gain the safety and operational benefit at a divided roadway. In spite of benefits of loons at the U-turns, following are the safety concerns at loons:
- Fixed-object crashes with delineator posts, sign posts, and guardrail,
- Sideswipe crashes involving vehicles merging into mainline traffic from the loon,
- Commercial vehicles backing up and parking within the crossover.

### 2.2 Near-crash events as an alternative approach

If there are shortcomings (limitations of the availability and reliability of crash and traffic data) of collision based safety measure, the road traffic safety analysis can benefit greatly from the
methods that use an observable and non-collision based interactions. In order to perform a alternative and comprehensive form of safety analysis, and to assess and predict levels of traffic safety at specific types of traffic facilities, there is a distinct need for faster, more informative, and more resource effective methods that yield valid and reliable safety measures in the short-term without the need for (or in addition to) crash data. Similarly, these alternative safety measures can provide a foundation to estimate safety impact with a desired level of accuracy and provide a substitute for crash data in places (e.g. less developed countries) where crash data is either non-existent or extremely unreliable.

2.2.1 Traffic conflict technique (TCT)

A many non-collision measures or surrogate measures of safety have been proposed and used over the past few decades, leading to the creation of technical observation approaches referred to as traffic conflict techniques (TCT). The approach is to study traffic conflicts or near miss events which occur more frequently, can be clearly observed and are related to probability of collisions. The TCT have been advocated as a proactive and supplementary approach to collision-based road safety analysis. However, there are issues of subjectivity, reliability and cost associated with the use of human observers. The main advantage of such measures is related to their resource-effectiveness given that they occur more frequently than crashes and require relatively short periods of observation in order to establish statistically reliable results.

The beginning traffic conflict study is usually considered to be that of Perkins and Harris (1967, [6]), in which conflicts were identified as readily observable evasive maneuvers taken by the drivers. Examples (indicators) of such are the abrupt changing of lanes or the observation of brake lights and rapid deceleration.

A formalized definition of a traffic conflict was later adopted as “an observable situation in which two or more road users approach each other in space and time for such an extent that there is a risk of collision if their movements remain unchanged” [7], and the observation method formalized in the term as Traffic Conflict Technique (TCT).

The conflict safety indicators are particularly useful where there is an emphasis on the assessment and comparison of safety enhancement measures at specific traffic facilities and, in some cases, the interactions of specific road-user categories. The methodologies used to collect conflict data also make the results sensitive to site-specific elements related to roadway design and the dynamic and complex relationships among different traffic variables such as traffic flows, speed and proportions of turning movements [8].

The use of traffic conflict technique accepted as measures of safety in their own right, has been limited in transportation planning and traffic engineering in many countries throughout the world due to its debatable nature of reliability and validity.

2.2.2 Validity and Reliability of TCT

Despite the many advantages related to the use of TCT, a number of fundamental problems have been identified. The reliability and validity are two issues strongly connected to the usability of TCT. These concern the lack of a consistent definition, their validity as a measure of traffic safety, and the reliability of their associated measurement technique. According to Chin and Quek (1997, [9]) these problems are largely responsible for a general lack of understanding and support for this type of method. Arguably, this has hindered the general development and acceptability of conflict safety indicators by traffic safety analysts.
The reliability and validity of the traffic conflict have been a major concern, and there are a number of studies that have tried to address this issues ([10], [11], [12], [13]). Some empirical studies found that there were clear relationships between traffic conflicts and crashes [14]. Despite the concerns about those issues, traffic conflict techniques have been used in various studies to evaluate safety.

The relationship between traffic volumes and conflicts has been another subject for researchers to investigate. Salman and Al-Maita (1995, [15]) had a research on three leg intersections. The summation of all volumes entering the intersection and the square root of the product of the volumes that generated the conflicts were used to correlate conflicts and volumes. It was found that the correlation between the conflicts and the square root of the product of volumes was higher than that of the summation of volumes.

For the subjective TCT, the field observers are a source of error when collecting conflict data, due to the subjective nature of deciding if a given driving event is a conflict or not. Each observer is required to judge whether or not a situation is a conflict, resulting in variability in the grading of traffic conflicts by different people. As a result, the human-collected data was not necessarily accurate, especially if multiple observers were used. Nonetheless, traffic conflicts have been shown to have some correlation with crash frequency, and the consensus is that higher rates of conflicts correlate to lower levels of safety [16].

2.2.3 Traffic conflict indicators and conflict severity measurement

The conflict indicators are defined as measures of crash proximity, based on the temporal and/or spatial measures that reflect the ‘closeness’ of road-users (or their vehicles), in relation to projected point of collision. The objective evidence of a traffic conflict by the (NCHRP) definition is the evasive action which is indicated by a brake-light or a lane change affected by the offended driver. First definition of a conflict was mainly based on brake light indications. Since then a number of different indicators for conflict techniques have been developed in different countries. A variety of observation methods have been developed to measure traffic conflicts including the observation of driver behaviour and recording the number of near misses or avoidance manoeuvres. Broadly these can be classified into subjective and objective methods. Subjective methods include considerable judgment by the conflict observer and conflict severity taking into account the level of deceleration (weighted deceleration, which included longitudinal-braking and lateral-swerving-deceleration). To eliminate the subjectivity from traffic conflict analysis, objective measures are used. As objective measures for traffic conflicts having higher validity and include a cardinal or ordinal time-proximity dimension in the severity scale.

There are mainly three indicators are widely recognised and discussed to assess the severity of conflicting situation, Time to Accident / Speed (TA/Speed), Time To Collision (TTC) and Post Encroachment Time (PET).

2.2.3.1 Time to Accident / Speed (TA/Speed)

The conflict measure is determined at a point in time and space when evasive action is first taken by one of the conflicting road-users [6]. The TA/Speed value is based on the necessity of a collision course and evasive action. An event with a low TA and a high Speed value indicates an event with high severity.
The **Conflicting Speed** is the speed of the road user taking evasive action, for whom the TA value is estimated, at the moment just before the start of the evasive action.

The **Time to Accident (TA value)** is the time that remains to an accident from the moment that one of the road users starts an evasive action if they had continued with unchanged speeds and directions.

2.2.3.2 Time to Collision (TTC)

Time-To-Collision is usually regarded as a more objectively determined measure of crash proximity in comparison to Time-to-Accident, and generally involves the use of image-processing (video analysis) determined measures.

The TTC value is also based on the necessity of a collision course. The proximity is estimated during the approach. TTC is a continuous function of time as long as there is a collision course; the time required for two road users to collide if no evasive action is taken. The $TTC_{min}$ is a specific estimate of the TTC during the entire interactive process of the conflict event, rather than the value recorded at the time evasive action is first taken as in the TA-Speed. So, $TTC_{min}$ is the lowest value of TTC in the approaching process of two road-users on a collision course. A lower value of the TTC or $TTC_{min}$ indicates an event with high severity [17].

2.2.3.3 Post Encroachment Time (PET)

Post-encroachment time (PET) is the time between two vehicles on a near-collision course passing at a common point [18], [19]. To measure PET a collision course or an evasive action of road user(s) is not necessary. As with TTC, a lower PET indicates higher severity, and the minimum value is also the critical value.

2.2.4 Conflict severity grading and severity index

A conflict severity scale based on braking rates was proposed by Zimolong (1983, [20]), the four different conflict severity levels were specified: the first of these suggests a controlled use of brakes or controlled change of lanes to avoid collision; the second a severe use of brakes and/or an abrupt change of lanes; the third level involves emergency braking and fast driver reaction; and the fourth level involves collision.

Krivda (2013, [21]) mentioned a relative conflict rate and a weighted conflict rate for single lane roundabouts. Relative conflict rate is defined as hourly number of conflict situations per 100 vehicles. The relative conflict rate does not take into consideration the seriousness of the conflict situations. Thus, it is more practical to use the so-called weighted coefficient of the relative conflict rate ($C_{RW}$). The equation for all type of the conflict situation has the form as follows:

$$C_{RW} = \frac{\sum_{i=1}^{N} N_{CSI} \times C_{Si} \times 100}{V}$$

$$= \frac{N_{CS1} \times C_{S1} + N_{CS2} \times C_{S2} + N_{CS3} \times C_{S3}}{V} 	imes 100$$

(1)

where:

- $C_{RW}$ – weighted conflict rate [CS/100 veh],
- $N_{CSI}$ – number of conflict situations (CS) per hour [CS/h],
- $C_{Si}$ – coefficient of seriousness of conflict situations [-]
- $i$ – number of conflict situations of the same type ($i = 1, 2, 3$)
The seriousness of the conflict situation defined as follows:

1st level — potential conflict situations (mere breaking of road traffic rules by a single participant),

2nd level — conflict situations when one or more participants are restricted by another participant,

3rd level — conflict situations when one or more participants are endangered by another participant.

2.2.5 Traffic exposure

Yi and Thompson (2011, [22]) used a relationship between the traffic conflicts and the conflicting volumes at intersections as ”the total number of traffic conflicts is proportional to the square root of the product of the conflicting volumes”. This referred to by Sayed and Zein (1999, [23]) as the ”product of entering vehicles” (PEV):

\[ PEV = \sqrt{V_1 \times V_2} \]

where:

- \( V_1 \) and \( V_2 \) represent the traffic volumes (vehicles/hour) of the two conflicting traffic streams.

3 Methodology

3.1 Classification of the U-turns on the Thai highways

The U-turns were classified based on several combinations of its four layout geometric variables, viz. deceleration lane, acceleration lane, directional-island and outer widening or loon. Based on these combinations, for this study purpose the eight types of layout geometry of the U-turns were identified as shown in the Fig. 3 and the Table 2.

![Fig. 3. U-turn types on Thai highway](image)

Table 2. Classification of U-turn types on Thai highways

<table>
<thead>
<tr>
<th>U-turn type</th>
<th>Application of Deceleration lane</th>
<th>Application of acceleration lane</th>
<th>Application of directional island</th>
<th>Application of outer-widening</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT-1</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
### 3.2 Zones at a U-turn

For the study purpose the functional area of a U-turn was considered to be composed of three zones, as shown in the Fig. 4. The Upstream Zone consists of through lanes, deceleration lane and sometimes outer widening is also provided. It is used by the U-turning vehicles for substantial speed reduction and storage before merging to the opposite direction traffic streams. The Turning Zone is an open area between the medians and its width is equal to width of the median. For a directional U-turn, an island is installed at this zone to separate both directions turning streams. The Downstream Zone consists of through lanes, acceleration lane and either of outer widening or a loon. This zone is used by the U-turning road users for the acceleration before merging into through traffic streams with an adequate speed.

![Fig. 4(a). Downstream Zones](image1)

![Fig. 4(b). Turning Zone](image2)

![Fig. 4(c). Upstream Zones](image3)

**Fig. 4.** The three zones at a U-turn

### 3.3 Layout geometry of the U-turns

The figure 5 demonstrates a typical example of U-turn diagram containing layout geometry of its variables.

![Fig. 5.](image4)

**Fig. 5.** The dimensions of the layout geometric variable at a U-turn

Where:

- \( W_m \) — Width of median
- \( W_{m_{aux}} \) — Width of median along aux. lane
- \( W_t \) — Width of through lane
- \( L_{dc} \) — Length of deceleration lane
- \( L_{dt} \) — Taper section length of deceleration lane
- \( L_{ac} \) — Length of acceleration lane
The functional length of a deceleration lane ($L_{dt}$) is defined as the summation of the length of the section of the deceleration lane with full width ($L_{dc}$) and half of the length of the taper section ($L_{dt}$) of the deceleration lane. Similarly, the functional length of an acceleration lane ($L_{af}$) is defined as the summation of the length of the section of the acceleration lane with full width ($L_{ac}$) and half of the length of the taper section of the acceleration lane ($L_{at}$). The typical example of the functional length of auxiliary lanes are shown in the Fig. 6.

Fig. 6. The functional lengths of the auxiliary lanes

### 3.4 Functional length of the auxiliary lane

The functional length of a deceleration lane ($L_{dt}$) is defined as the summation of the length of the section of the deceleration lane with full width ($L_{dc}$) and half of the length of the taper section ($L_{dt}$) of the deceleration lane. Similarly, the functional length of an acceleration lane ($L_{af}$) is defined as the summation of the length of the section of the acceleration lane with full width ($L_{ac}$) and half of the length of the taper section of the acceleration lane ($L_{at}$). The typical example of the functional length of auxiliary lanes are shown in the Fig. 6

### 3.5 Conflict severity indicators and Coefficient of Conflict Severity (CCS)

In contrast to intersection, the U-turns have a distinct geometry, longer conflict area in longitudinal direction and a higher operating speed. Therefore it is difficult to judge the speed & space between conflicting vehicles and measure the severity of a conflict using the Time to Accident (TA) indicator, here upon use of the TA/CS is practically not viable for this conflict based study at the U-turns.

For the measurement of the Time to Collision (TTC) indicator, it is mostly requires a photometric video-analysis that is both resource-demanding and laborious. Also for the video recording it is essential to have elevated positioning of cameras to capture an aerial view of the conflict areas. As this study focus on the U-turns at non built-up areas therefore the elevated spots were unavailable to install a camera in a position to get the aerial view. Due to these constraints the use of the Time to Collision conflict indicator was discarded.

At the U-turns the majority of conflicting events are produced due to the merging and diverging maneuvers. The literature survey allude that the Post Encroachment Time (PET) is suitable to measure the crossing conflict events and requires a fixed projected point of collision. The projected point easy to locate for the crossing conflicts, but it is very difficult for the merging and diverging conflicts; therefore the indictor Post Encroachment Time was not used in this study.

Due to the above mentioned constraints, a subjective approach was considered to measure the severity of traffic conflicts and the complexity of evasive action of the road users was considered as indicator of conflict. The three level of severity (seriousness) of traffic conflicts were adopted as illustrate in the Table 3.
For a comparative safety assessment, without giving weightiness (relative importance) to the conflict events with a higher level of seriousness is not considered an appropriate approach. The purpose of using the weights is to put more emphasize on the severe conflicts than slight ones. The values of *Coefficient of Conflict Severity* (CCS) are adopted from Krivda (2013, [21]) and which are used to calculate the *Severity Conflict Index* for the U-turns.

Table 3. Conflict severity indicators and severity coefficients

<table>
<thead>
<tr>
<th>Severity</th>
<th>Indicators</th>
<th>Coefficient of Conflict Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slight</td>
<td>Sudden lane change or mere braking</td>
<td>1</td>
</tr>
<tr>
<td>Moderate</td>
<td>Intense decelerate vehicle and almost stop</td>
<td>3</td>
</tr>
<tr>
<td>Severe</td>
<td>Hard braking or skid marks or braking sound</td>
<td>6</td>
</tr>
</tbody>
</table>

3.6 Product of the conflicting volumes for the U-turns

The *Product of Through and Turning (merging & diverging)* Volumes (*PTTV*) were computed for the U-turns as the traffic exposure to the observed conflicts for calculating the conflict indexes. It is defined as “the square root of the product of (average hourly) traffic volumes of conflicting streams (through and turning)“.

3.7 Exclusion of the Turning Zone conflicts

During the field investigation it was observed that the conflicts at the Turning Zone were very much infrequent and measurement of the conflict indicators based on a subjective traffic-conflict-technique was practically cumbersome and inappropriate. Therefore it was decided not to consider the Turning Zone conflicts for the safety investigation.

3.8 Conflict Number

3.8.1 Hourly Traffic Conflict Number (HCN)

The *Hourly Traffic Conflict Number* (HCN) is defined as the number of observed conflicts at a zone divided by the number of observation hours for that zone. The several *Hourly Traffic Conflict Numbers* can be computed based on the classification of the severity of conflicting situation as slight, moderate and severe and location of conflict (Upstream and Downstream Zone).

3.8.2 Average Hourly Traffic Conflict Number (AHN)

The each U-turn has two Downstream Zones and two Upstream Zones, and for the each U-turn type the two locations were investigated. Therefore, for a particular type of zone, of a group of particular U-turn type, the *Average Hourly traffic conflict Number* (AHN) is defined as the summation of *Hourly Traffic Conflict Numbers* (HCN) at that particular zones divided by the number of that type of zones in that group. Further the *Average Hourly traffic conflict Numbers* were classified based on the severity of the conflicting situations.
3.9 Severity Conflict Index for the U-turns (SCI)

The Severity Conflict Index is defined as a ratio of the summation of the product of the Average Hourly Slight, Moderate & Sever Traffic Conflict Numbers and their respective value of Coefficient of Conflict Severity (CCS) to the Product of Through and Turning Volumes (PTTV) for U-turns. A higher value of Severity Conflict Index at a traffic facility represent comparative a lower level of traffic-safety. The Severity Conflict Indexes for the U-turns were computed by the following equation:

\[ SCI = \frac{AHN_{sl} \times CSS_{sl} + AHN_{mo} \times CSS_{mo} + AHN_{se} \times CSS_{se}}{PTTV} \]  

where:

- \( SCI \) – Severity Conflict Index for a group of U-turn type,
- \( CSS_{sl} \) – Coefficient of seriousness of slight conflict = 1,
- \( CSS_{mo} \) – Coefficient of seriousness of moderate conflict = 3,
- \( CSS_{se} \) – Coefficient of seriousness of severe conflict = 6,
- \( AHN_{sl} \) – Average Hourly Slight Traffic Conflict Numbers,
- \( AHN_{mo} \) – Average Hourly Moderate Traffic Conflict Numbers,
- \( AHN_{se} \) – Average Hourly Severe Traffic Conflict Numbers,
- \( PTTV \) – Product of through and turning (merging & diverging) volumes

4 Data type and data collection

The data which were collected depended on the form of the U-turn being studied and included traffic volumes, U-turning movement counts, using auxiliary lane counts, vehicle compositions, operating speed, geometric data and traffic conflicts. For the classified eight types of U-turn, two locations of each U-turn type were selected. Therefore a total 16 sites were selected and investigated throughout Thailand considering following basic requirements

- Located on 4-lane divided highways,
- Outside of built-up area,
- Physically divided highways having median width between 0.5m to 15m,
- Not to be located on horizontal curve,
- Not to be located on crest,
- Not to be part of T or X-junction,
- Not to be grade separated design, and
- No special design solution

The traffic conflicts were recorded by the video cameras in the fields. A total of 128 hours video of traffic operations data were recorded in the field (16 hours at each U-turn types). The recorded data were later reviewed in the laboratory for obtaining the traffic operations data. The video-analysis was used to generate the following data:

- Traffic volume,
- Vehicle composition (motorcycle, passenger car etc.) in traffic streams,
- Turning volume counts,
- Severity of the conflicts,
- Involved vehicles in a conflict

For the traffic volumes and conflict data collection, following criteria was considered:

- Only on weekdays (Monday to Friday) and during day-light hours,
- Morning/ Evening peak hours (2 hours for each side of each location) and afternoon non-peak hours (2 hours for each side of each location), and

13
Avoided during extreme (inclement) weather conditions.

5 Results

5.1 Traffic volumes

At a U-turn there are three types of traffic streams viz. through, diverging and merging.

5.1.1 Hourly traffic volumes

The recorded hourly through and turning (merging + diverging) traffic volumes are presented in the Fig. 7. The traffic volumes at the U-turn location UT-8 (A) were very low comparing to the rest of selected locations; therefore this location was excluded for this safety assessment study.

![Hourly Traffic Volumes](image)

Fig. 7. The hourly traffic volumes at the U-turn locations

5.1.2 Percent of the Hourly Turning Volumes

The volume of turning vehicles is a major variable that influencing the numbers of conflict out-turn. The Percent of Hourly Turning Volume is defined as a ratio of the summation of the Hourly Merging Volume and the Hourly Diverging Volume to summation of the Hourly Through Volume, the Hourly Merging Volume and the Hourly Diverging Volume. The Percent shares of the turning volumes are shown in the Fig. 8
Fig. 8. The turning volumes percent share

5.2 Severity Conflict Indexes

The assessed Severity Conflict Indexes and, the applications and functional length of the auxiliary lanes of the U-turns are illustrated in the Table 4 and Figure the 9

Table 4. The Severity Conflict Indexes and the length of the auxiliary lanes

<table>
<thead>
<tr>
<th>U-turn type</th>
<th>SCI (× 100)</th>
<th>Functional length of acceleration lane ($L_{af}$)</th>
<th>Functional length of deceleration lane ($L_{df}$)</th>
<th>Application of acceleration lane</th>
<th>Application of deceleration lane</th>
<th>Application of outer-widening or loon</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT-1</td>
<td>17.62</td>
<td>0 m</td>
<td>0 m</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>UT-2</td>
<td>13.56</td>
<td>0 m</td>
<td>56 m</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>UT-3</td>
<td>7.50</td>
<td>177 m</td>
<td>139 m</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>UT-4</td>
<td>7.09</td>
<td>124 m</td>
<td>124 m</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>UT-5</td>
<td>7.23</td>
<td>0 m</td>
<td>97 m</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>UT-6</td>
<td>10.00</td>
<td>108 m</td>
<td>106 m</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>UT-7</td>
<td>9.02</td>
<td>0 m</td>
<td>127 m</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>UT-8</td>
<td>7.46</td>
<td>0 m</td>
<td>129 m</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Fig. 9. The relationship between SCI and functional length of auxiliary lanes

6 Conclusions
A comparative higher value of the Severity Conflict Index represents a lower level of safety at a traffic facility.

6.1 Severity Conflict Indexes for the U-turns (SCI)

The U-turn type UT-1 has a highest value of SCI because non of the acceleration lane, deceleration lane and outer-widening/loons are applied on it, therefore this layout geometric design could be judge with lowest level of traffic safety followed by the UT-2, which has only the deceleration lanes with a shorter length.

The U-turn types UT-3, UT-4, UT-5 and UT-8 have almost equal and lowest values of SCIs; therefore these could have a comparative higher level of traffic safety. These U-turn types have only the two layout geometric variables. The data for the U-turn type UT-8 could produce unreliable results, because one location of the UT-8 was excluded due to the lower traffic volumes.

The U-turn types UT-6 and UT-7 have the medium values of SCIs and the moderate level of traffic safety. The one of the possible reason of these values could be the over-dimensioning of these U-turns which could provide the higher opportunities for undesirable driving behavior. The U-turn type UT-6 has three geometric variables the deceleration lanes at the Upstream Zones and, the acceleration lanes and the outer-widening at Downstream Zones. Similarly the UT-7 also has three geometric variables the deceleration lanes and the outer-widening at the Upstream Zones, and the outer-widening at Downstream Zones. These combinations of the three variables is not only provide a larger area of interaction for the conflicting through and merging streams, and also causing confusion among the drivers of conflicting vehicles to judge each-other maneuvers. The outer-widening at Upstream Zones of the U-turn type UT-7 are unnecessary and these were only used by the commercial vehicles for illegal parking.

7 Recommendations

The very first recommendation could be a very serious need of establishment of a well structured traffic crash data system in the Thailand for improving the road safety strategies to ensure timely & quality results. As this study has undergone to use a surrogate and subjective to human judgment approach, which is frequently debated by the experts and practitioners for its reliability and subjectivity.

Furthermore, there are some areas of this research, which are needed to be improved in future studies. The several conflict severity levels measuring objective methods such as Time-to-Collision, Post-Encroachment-Time should be considered as an important factor predicting the crash severity and reducing dependency of human judgments.

The U-turn types UT-1 and UT-2 having the lowest level of traffic safety therefore these should be modified as earliest possible and should not applied to the future projects. The U-turn types UT-6 and UT-7 also having a comparative lower safety level therefore these are also needed to modify and should not adopted for the future projects.

8 References

[2] Paramet Luatheap and Yordphol Tanaboriboon, "Determination of economic losses due to


