

Contents

Acknowledgments	i
Table of contents	ii
List of Tables	vii
List of Figures	x
Glossary of Terms	xi
1 Introduction	1
1.1 General Background	1
1.2 Function of U-turns on Thai Highways	3
1.3 Need for the Study - RoSCoE	3
1.3.1 Road Safety at U-turns	4
1.4 Road Safety Measurement and Analysis	8
1.4.1 Crashes Based Safety Analysis	8
1.4.2 Near-crash Events as an Alternative Approach	9
1.4.3 Traffic Conflict Technique (TCT)	10
1.5 Pilot Study: Thai Crash Data Management System	11
1.6 Research Objectives	11
1.7 Scope of Study	12
1.8 The State of Science	13
1.9 Outline of the Thesis	14
1.10 Research Approach and Design	15
2 Literature Review	16
2.1 General	16
2.2 Road Safety and Socio-economic Costs	16
2.3 Safety at Thai U-turns	17
2.4 Layout Designs of U-turn and Road Safety	18
2.4.1 Spacing of Median Openings	18
2.4.2 Classification of U-turns, their Advantages and Disadvantages	18
2.4.3 Median Acceleration Lanes	23
2.4.4 Loops or Outer-widening	24
2.5 Road Safety Measurement Using Historical Crash Data	24
2.5.1 Road Safety Analysis and Crash Costing	24
2.5.2 Limitation of Using Historical Crash Data	27
2.6 Traffic Crash Data: Availability, Quality and Reliability	28
2.7 Surrogate Safety Measures	31
2.7.1 Traffic Conflict Techniques (TCT) as an Alternative Approach	32
2.7.2 Traffic Event Hierarchy	35

2.7.3	Validity and Reliability of TCT	36
2.8	Traffic Conflict Indicators and Severity Measurement	38
2.8.1	Time to Accident / Speed (TA/Speed)	38
2.8.2	Time To Collision (TTC)	39
2.8.3	Post Encroachment Time (PET)	40
2.8.4	Strengths and Weaknesses of Conflict Indicators	41
2.9	Severity of Traffic Events	42
2.9.1	Crash Severity Grading (Category) and Severity Indexes	42
2.9.2	Conflict Severity Grading and Severity Indexes	43
3	Methodology	52
3.1	General	52
3.1.1	Classification of U-turns on Thai Highways	52
3.1.2	The Zones at U-turns	52
3.2	Pilot Study: Evaluation of Crash Data in Thailand	55
3.2.1	Results of Pilot Study	56
3.3	Conflict Based Investigation	57
3.3.1	Traffic Conflicts at U-turns	58
3.3.2	Conflict Type, Category and Situation at U-turns	60
3.3.3	Conflict Points at U-turn Zones	63
3.3.4	Exclusion of Turning Zone Conflicts	64
3.3.5	<i>Product of Through and Turning Volumes</i> (PTTV)	64
3.3.6	Selection of Conflict Indicators	68
3.3.7	Hourly Conflict Numbers	69
3.3.8	Operating Speed	71
3.4	Safety Assessment Using the <i>Severity Conflict Index</i> (SCI)	72
3.4.1	Severity Conflict Index	72
3.5	Safety Assessment Using the <i>Relative Conflict Index</i> (RCI)	73
3.5.1	Relative Speed and <i>Speed Adjustment Factor</i> (f_{spd})	74
3.5.2	<i>Conflict Orientation Factor</i> (COF)	75
3.5.3	<i>Level of Conflict</i> (LC)	76
3.5.4	<i>Relative Conflict Index</i> (RCI)	76
3.6	Comparison of the Conflict Indexes	79
4	Data Collection	80
4.1	Selection of Study Locations	81
4.2	Layout Geometry of a U-turn	82
4.3	Functional Length of Auxiliary Lanes	83
4.4	Time Duration for Field Data Recording	84
4.5	Traffic Volumes	84
4.6	Operating Speed	84
4.7	Traffic Conflict Data	86
4.7.1	Identification of Traffic Conflicts	86
4.7.2	Conflict Type	87
4.7.3	Conflict Severity	87
4.7.4	Conflict Category	87

4.7.5	Classification of Involved Vehicles	88
4.7.6	Marking of a Conflict Situation	88
5	Data Compilation and Results	90
5.1	Traffic Volumes	90
5.2	Product of the Through and Turning Volumes (<i>PTTV</i>)	94
5.3	Safety Assessment Using the <i>Severity Conflict Index (SCI)</i>	95
5.3.1	Classification of the <i>Observed Conflicts</i> Using the Severity-level of Situation	95
5.3.2	Calculation of the <i>Average Hourly Conflict Number</i> Using the Severity Level of Situation	95
5.3.3	Calculation of <i>Severity Conflict Indexes</i>	96
5.4	Safety Assessment Using <i>Relative Conflict Index (RCI)</i>	102
5.4.1	Operating Speed	102
5.4.2	<i>Hourly Traffic Conflicts</i> Classified using the Type of Conflict Situation	103
5.4.3	Calculation of LC	104
5.4.4	Calculation of <i>Relative Conflict Number (RCN)</i>	106
5.4.5	Calculation of <i>Relative Conflict Index (RCI)</i>	107
6	Analysis of Results: Safety Assessment	110
6.1	Traffic Volumes	110
6.1.1	Hourly Traffic Volume	110
6.1.2	Percentage Share of Turning Volume	110
6.1.3	Percentage Share of the HCV in Turning Volume	110
6.2	Operating Speed	111
6.3	Geometry and Dimensions of U-turns' Components	111
6.4	Conflict Points at U-turns	112
6.5	Safety Assessment Using the <i>Severity Conflict Index (SCI)</i>	112
6.5.1	<i>Severity Conflict Indexes</i> for Downstream Zones	112
6.5.2	<i>Severity Conflict Indexes</i> for Upstream Zones	113
6.5.3	<i>Severity Conflict Indexes</i> for U-turns	113
6.6	Safety Assessment Using <i>Relative Conflict Index (RCI)</i>	114
6.6.1	<i>Relative Conflict Indexes</i> for Downstream Zones	114
6.6.2	<i>Relative Conflict Indexes</i> for Upstream Zones	115
6.6.3	<i>Relative Conflict Indexes</i> the for U-turns	116
6.7	Secondary Finding: Inappropriate Driving Behaviour	117
6.7.1	Inappropriate Driving Behaviour of Thai Motorcyclists	117
6.7.2	Effect of the Application of Directional Island	117
6.7.3	Inappropriate Overtaking Maneuver Using the U-turn Infrastructures	120
7	The Challenge, Conclusions and Recommendations	122
7.1	The Challenge and Opportunity	122
7.2	Conclusions	122
7.3	Limitations and Recommendations	125

Bibliography	126
Publications Arising from the Thesis	131
Appendices	132
Appendix A Location and Geometric Data of U-turns	133
A.1 Location of U-turns	133
A.2 Geometric Data of U-turns	134
A.3 The <i>Standard Drawing</i> of U-turns of the DoH, Thailand	136
Appendix B Sample data-sheet for traffic count	137
Appendix C Traffic flow at U-turns	138
C.1 Recorded traffic volume data	138
C.2 Hourly Traffic Volume Data	141
C.3 Traffic Flow Charts	144
C.3.1 Traffic flow at UT-1 (A)	144
C.3.2 Traffic flow at UT-1 (B)	145
C.3.3 Traffic flow at UT-2 (A)	146
C.3.4 Traffic flow at UT-2 (B)	147
C.3.5 Traffic flow at UT-3 (A)	148
C.3.6 Traffic flow at UT-3 (B)	149
C.3.7 Traffic flow at UT-4 (A)	150
C.3.8 Traffic flow at UT-4 (B)	151
C.3.9 Traffic flow at UT-5 (A)	152
C.3.10 Traffic flow at UT-5 (B)	153
C.3.11 Traffic flow at UT-6 (A)	154
C.3.12 Traffic flow at UT-6 (B)	155
C.3.13 Traffic flow at UT-7 (A)	156
C.3.14 Traffic flow at UT-7 (B)	157
C.3.15 Traffic flow at UT-8 (A)	158
C.3.16 Traffic flow at UT-8 (B)	159
Appendix D An Observed Serious Conflict Situation	160
Appendix E Calculation of Relative Conflict Number	161
Appendix F Data Tables for Severity Conflict Indexes	164
F.1 Observed conflict numbers	164
Appendix G Photographs from Field Investigations	167
G.1 Photos of inappropriate driving behaviour, illegal parking and directional islands	167

List of Tables

2.1	Average unit cost per casualty or case by severity	26
2.2	Deceleration-to-Safety braking levels proposed by Hydén (1996)	44
2.3	Severity weights by conflict type	48
2.4	<i>Level of Conflict</i> calculations by Dixon (2011)	51
3.1	Classification of U-turns on Thai Highways	54
3.2	Speed-vector of vehicles in turning stream	74
3.3	<i>Conflict Orientation Factor</i> for various type of conflicts	76
3.4	Comparison of Conflict Indexes	79
4.1	Functional length of auxiliary lanes	83
4.2	Letters and numbers used for conflict symbols marking	89
5.1	Traffic volumes for 4 hours at UT-1	90
5.2	Hourly traffic volumes at UT-1	90
5.3	Hourly volumes and percentage of turning volume	91
5.4	Percentage share of heavy commercial vehicles into the turning volumes	93
5.5	Calculation of <i>PTTVs</i>	94
5.6	Observed conflict numbers at <i>UT-1</i> on the basis of the severity of situation	95
5.7	The observed <i>Number of Conflicts</i> and the calculated <i>Average Hourly Number of Conflicts</i> on the basis of the severity of conflict situation.	97
5.8	Calculated <i>Average Hourly Traffic Conflict Numbers</i> and <i>PTTVs</i>	98
5.9	Calculated <i>Severity Conflict Indexes</i> for the Zones and U-turns	99
5.10	Observed conflict numbers classified on the basis of type of conflict	103
5.11	A sample calculation of <i>LC</i>	104
5.12	The <i>Level of Conflict</i> for turning streams at U-turns	105
5.13	Calculation of <i>Relative Conflict Number</i> for <i>UT-1</i>	106
5.14	<i>Relative Conflict Indexes</i> for U-turns	107
6.1	Share of vehicle type in turning volumes at <i>UT-3</i>	118
6.2	Share of vehicle type in turning volumes at <i>UT-4</i>	118
A.1	Physical locations of selected U-turns	133
A.2	Dimensions of U-turns' variables	134
A.3	Average dimensions of U-turns' variables	135
B.1	Sample data-sheet for traffic composition and volume count	137
C.1	Traffic volumes for 4 hours for UT-1	138
C.2	Traffic volumes for 4 hours for UT-2	138
C.3	Traffic volumes for 4 hours for UT-3	139
C.4	Traffic volumes for 4 hours for UT-4	139

C.5	Traffic volumes for 4 hours for UT-5	139
C.6	Traffic volumes for 4 hours for UT-6	140
C.7	Traffic volumes for 4 hours for UT-7	140
C.8	Traffic volumes for 4 hours for UT-8	140
C.9	Hourly traffic volumes for UT-1	141
C.10	Hourly traffic volumes for UT-2	141
C.11	Hourly traffic volumes for UT-3	142
C.12	Hourly traffic volumes for UT-4	142
C.13	Hourly traffic volumes for UT-5	142
C.14	Hourly traffic volumes for UT-6	143
C.15	Hourly traffic volumes for UT-7	143
C.16	Hourly traffic volumes for UT-8	143
E.1	Calculation of <i>Relative Conflict Number</i> for UT-1	161
E.2	Calculation of <i>Relative Conflict Number</i> for UT-2	161
E.3	Calculation of <i>Relative Conflict Number</i> for UT-3	162
E.4	Calculation of <i>Relative Conflict Number</i> for UT-4	162
E.5	Calculation of <i>Relative Conflict Number</i> for UT-5	162
E.6	Calculation of <i>Relative Conflict Number</i> for UT-6	163
E.7	Calculation of <i>Relative Conflict Number</i> for UT-7	163
E.8	Calculation of <i>Relative Conflict Number</i> for UT-8	163
F.1	Observed conflict numbers based on severity of situation for UT-1 . . .	164
F.2	Observed conflict numbers based on severity of situation for UT-2 . . .	164
F.3	Observed conflict numbers based on severity of situation for UT-3 . . .	165
F.4	Observed conflict numbers based on severity of situation for UT-4 . . .	165
F.5	Observed conflict numbers based on severity of situation for UT-5 . . .	165
F.6	Observed conflict numbers based on severity of situation for UT-6 . . .	166
F.7	Observed conflict numbers based on severity of situation for UT-7 . . .	166
F.8	Observed conflict numbers based on severity of situation for UT-8 . . .	166

List of Figures

1.1	Road death rates in 2010	2
1.2	The road traffic crashes trend in Thailand	2
1.3	Basic functions of median at-grade U-turns	3
1.4	Crash frequency by the location on Thai highways	4
1.5	Spillback effect by a queue of U-turning vehicles	5
1.6	Typical driving maneuvers by Thai motorcyclists at a U-turn	7
1.7	Illicit driving maneuver by a heavy commercial vehicle while diverging at a U-turn	7
1.8	Crossing maneuver by heavy commercial vehicles	8
1.9	A schematic representation of research approach and design	15
2.1	Illicit driving at Thai Highways	17
2.2	Type 1a—Conventional Midblock Median Opening Without Deceleration Lanes	19
2.3	Type 1b—Conventional Midblock Median Opening With Deceleration Lanes	19
2.4	Type 1c—Conventional Midblock Median Opening With Deceleration Lanes and Loons	20
2.5	Type 2a—Directional Midblock Median Opening Without Deceleration Lanes	21
2.6	Type 2b—Directional Midblock Median Opening With Deceleration Lanes	21
2.7	Type 2c—Directional Midblock Median Opening With Deceleration Lanes and Loons	22
2.8	The process of crash data collection and reporting system showing the sources of under-reporting	29
2.9	The road traffic crash under-reporting between the DoH and the Royal Thai Police	30
2.10	The safety pyramid (Hyden, 1987)	34
2.11	Traffic safety and the relationship between errors, standard behaviour, traffic conflicts and crashes	35
2.12	Uniform severity level and severity zones according to Hyden	39
3.1	Types of U-turns on Thai highways	53
3.2	Zones at a U-turn	55
3.3	Road Traffic events with respect to the time duration	58
3.4	The 32 conflict points at a conventional median opening at a four-legged intersection	59
3.5	The 12 conflict points at a typical combination of U-turns and T-junctions (equivalent to a four-leg intersection)	59
3.6	Conflict situations at Upstream-zones	61
3.7	Conflict situations at Turning-zones	62

3.8	Conflict situations at Downstream-zones	63
3.9	Conflict Points at U-turns	65
3.10	Various Hourly Volumes	66
4.1	The symbol for the identification of U-turn type and location	81
4.2	U-turn geometric variables	82
4.3	Functional lengths of auxiliary lanes	83
4.4	Traffic flow streams at a U-turn	85
4.5	Symbol for the conflict situation marking	88
5.1	Traffic volume at U-turns	91
5.2	Percentage share of turning vehicles	92
5.3	Percentage share of <i>heavy commercial vehicles</i> into the turning volumes	93
5.4	Relationships between the <i>Severity Conflict Indexes</i> and the functional length of auxiliary lanes	101
5.5	Operating speed (85 th percentile) at the investigated U-turns	102
5.6	The relationship between the <i>Relative Conflict Indexes</i> and the functional length of auxiliary lanes	109
6.1	Inappropriate driving behaviour by Thai motorcyclist	117
6.2	A comparison of uses of the auxiliary lanes at <i>UT-3</i> and <i>UT-4</i>	119
6.3	Inappropriate Driving: Parallel U-turning maneuver by multiple vehicles	120
6.4	Inappropriate Driving: Using auxiliary lanes for overtaking maneuver	120
6.5	Inappropriate Driving: Using outer widening for overtaking maneuver	121
A.1	<i>Standard Drawing of Special U-turn details</i> of the 'Department of Highways' of Thailand	136
C.1	Traffic flow at UT-1 (A)	144
C.2	Traffic flow at UT-1 (B)	145
C.3	Traffic flow at UT-2 (A)	146
C.4	Traffic flow at UT-2 (B)	147
C.5	Traffic flow at UT-3 (A)	148
C.6	Traffic flow at UT-3 (B)	149
C.7	Traffic flow at UT-4 (A)	150
C.8	Traffic flow at UT-4 (B)	151
C.9	Traffic flow at UT-5 (A)	152
C.10	Traffic flow at UT-5 (B)	153
C.11	Traffic flow at UT-6 (A)	154
C.12	Traffic flow at UT-6 (B)	155
C.13	Traffic flow at UT-7 (A)	156
C.14	Traffic flow at UT-7 (B)	157
C.15	Traffic flow at UT-8 (A)	158
C.16	Traffic flow at UT-8 (B)	159
D.1	A recorded serious conflicting situation at a U-turn	160

G.1	Inappropriate driving behaviour: Illegal driving by motorcyclist	167
G.2	Inappropriate driving behaviour: Parallel U-turning (side-by-side queuing) by multiple vehicles	167
G.3	A photo of directional island	168
G.4	A temporary arrangement as alternative of directional island	168
G.5	A queue of vehicles for U-turning due to directional barriers	168
G.6	A vehicle using acceleration lane at U-turn type <i>UT-4</i>	169
G.7	Heavy Commercial Vehicles illegally parked at outer widening of U-turn type <i>UT-7</i>	169
G.8	Parked vehicles at loon of U-turn type <i>UT-8</i>	169

Glossary of Terms – Quick Reference Guide

Accident (traffic)	An interaction where two road users have collided that results in injury, fatality or property damage
Accident outcome	Consequences of an accident in terms of injury severity, fatality and material damage
Accident rate	Number of accidents in accordance with a measure of exposure
Accident risk	Risk for accident involvement (for different road-user classes). Objective risk reflects accident frequency in relation to a measure of exposure or population
Accident severity	Level of injury sustained in a traffic accident: usually categorized as slight, serious or fatal
Adaptive situation	An interaction between road users with lower severity than an accident or a serious conflict
Auxiliary Lanes	The portion of the roadway adjoining the traveled way for speed change, turning, storage for turning, weaving, truck climbing, and other purposes supplementary to through-traffic movement
Average Conflicts	Hourly Refers here to the total number of observed conflicts at a U-turn divided by the number of observation hours
Collision	Impact event between two or more road-users/vehicles, or a road-user (vehicle) and stationary object
Collision course	Unless the speed and/or the direction of the road users changes, they will collide
Conflict	A potentially unsafe interactive event that requires evasive action (braking, swerving or accelerating) to avoid collision
Conflict observation	Method that is used by trained observers to determine objective parameters (Time-to-Accident values etc.) in accordance with the Traffic Conflict Technique or subjective estimation of speed and distance or evasive maneuver of road-users/vehicles that are in a conflict situation
Conflict point	Common spatial location of projected trajectories for two or more road-users/vehicles
Conflict zone	Common area used by road-users/vehicles approaching from different trajectories
Conflict severity	Seriousness of a potential collision or near-accident measured by temporal or spatial proximity

Crash	Term that is sometimes preferred to (traffic) accident due to the fact that it implies an element of causality rather than an unforeseen random occurrence
Downstream	The direction of traffic flow
Evasive action/ maneuver	Action taken to diverge from a collision course by changing speed or direction involves braking, accelerating, and/or swerving
Event	Any kind of incident or occurrence in traffic
Event severity continuum or safety hierarchy	Conceptions of unsafeness and severity of an event whereby all interactions are placed on the same scale with safe passages at one extreme and accidents involving fatalities at the other
Fatality	Death resulting from a traffic accident (usually within a 30 day period after the accident occurrence)
Hard traffic conflict	Refers here to a traffic conflict situation where one or more road user(s) use "hard brake" resulting braking sound or skid marks on road to avoid collision
Hourly Conflict Rate	Refers here to the "Average Hourly Conflicts" divided by "Hourly Volume"
Hourly Volume	Refers here to the total number of vehicle entering at a U-turn divided by the number of observation hours
Injury accidents	Traffic accidents that result in minor or serious injury to one or more parties. Some statistical measures and accident risk quotients include accidents that involve both injury and fatality
Interaction	A traffic event with a collision course where interactive behavior is a precondition to avoid an accident
Light traffic conflict	Refers here to a traffic conflict situation where one or more road user(s) force to reduce speed (without applying brake) and change lane to avoid collision
Loon	Expanded paved aprons opposite a U-turn/ median crossover used to facilitate the larger turning path of commercial vehicles along roadways with narrow medians
Median	The portion of a divided highway separating the traveled ways for traffic in opposing directions
Moderate traffic conflict	Refers here to a traffic conflict situation where one or more road user(s) apply brake (braking light glow) and almost stop to avoid collision

Near-accident	Any circumstance that requires a rapid, evasive maneuver by the participant vehicle, or any other vehicle, pedestrian, cyclist, or animal, to avoid a crash. A rapid, evasive maneuver is defined as steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities
Non-serious conflict	Conflict event in accordance with the Traffic Conflict Technique that is not of sufficient severity to be classed as serious according to a specified severity threshold function
Police reported accidents	Accidents that are reported to the police and are recorded in the accident database of accident statistics
Post-Encroachment Time (PET)	A safety indicator that represents a measure of the time measured from the moment the first road-user leaves the potential collision point to the moment the other road-user enters this conflicting point
Required braking rate (RBR)	Measure of conflict severity based on a momentary measure speed and distance to a conflict point, that represents the average (linear) braking required to avoid a collision from the point the measure is taken
Safety	Freedom from accident or loss
Safety hierarchy	Conceptions of unsafety and severity of an event. The serious injury accident is at the top
Serious conflict	An interaction where without an evasive action the impression is such that the situation easily could have ended up in an accident instead or event that cross severity threshold value of measuring parameters such as Time-to-Accident or Post-Encroachment Time etc
Severity hierarchy	The safety hierarchy transferred into measurable parameters based on certain presumptions
Shoulder	The portion of the roadway contiguous with the traveled way that accommodates stopped vehicles, emergency use, and lateral support for subbase, base, and surface courses
TCT	Traffic Conflicts Technique(s). TCT is a tool for estimating accident potential at road infrastructure, indirect measurement of safety and indicating methods of reducing hazardous conditions
Time-to-Accident (TA)	Conflict safety indicator measure determined in accordance with the Traffic Conflict Technique. Based on subjective estimation of speed and distance by trained observers for conflicting road-users in relation to a conflict point. The Time-to-Accident measure is recorded only once at the time when evasive action is first taken by a conflicting road-user

Time-to-Collision (TTC)	A continuous function of time as long as there is a collision course; Safety indicator measure based on an objective measure of speed and distance (usually involves photometric video-analysis) for conflicting road users in relation to their conflict course. The Time-to-Collision measure is recorded continually throughout a conflict course and is not dependent on evasive action by the conflicting road-users
Traffic conflict	An accepted definition is stated 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" (Amundsen and Hydén, 1977)
Traffic safety	Traffic safety refers to methods and measures for reducing the risk of a person/ vehicle using the road network being injured, death or harm and/or damage to material
Underreporting	Term used to describe the fact that many accidents are not reported to the police or concerning agencies and therefore are not represented in accident statistics
Upstream	The direction from which traffic is flowing
Validity	Validity concerns the accuracy with which a measure represents a theoretical construct (assessed often through consensus)
Weaving	The crossing of traffic streams moving in the same general direction accomplished by merging and diverging