ANALYSIS OF RISK FACTORS AFFECTING DRIVER INJURY SEVERITY OF RUN OFF ROAD CRASH FOR THAILAND HIGHWAYS

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การวิเคราะห์ปัจจัยเสี่ยงต่อระดับความรุนแรงของการบาดเจ็บของผู้ขับขี่ประเภทไถลตกข้างทาง กรณีศึกษาทางหลวงในประเทศไทย

นายจำเริญ เส

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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จำเริญ เส : การวิเคราะห์ปัจจัยเสี่ยงต่อระดับความรุนแรงของการบาดเจ็บของผู้ขับขี่ประเภทไถลตกข้างทาง กรณีศึกษาทางหลวงในประเทศไทย (ANALYSIS OF RISK FACTORS AFFECTING DRIVER INJURY SEVERITY OF RUN OFF ROAD CRASH FOR THAILAND HIGHWAYS) อาจารย์ที่ปรึกษา : ศาสตราจารย์ ดร.วัฒนวงศ์ รัตนวราห, 104 หน้า.

การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาถึงปัจจัยที่มีอิทธิพลหรือส่งผลต่อความรุนแรงของการบาดเจ็บของผู้ขับขี่ในการชนลักษณะออกนอกเส้นทางของยานพาหนะคันเดียว (Single-vehicle run off road crash) ด้วยความตั้งใจที่จะพัฒนามาตรการและกลยุทธ์ที่เหมาะสมสำหรับหน่วยงานที่เกี่ยวข้องเพื่อยกระดับความปลอดภัยแก่ผู้ขับขี่หรือผู้ใช้ถนนต่อการเกิดการชนในลักษณะออกนอกเส้นทางของยานพาหนะคันเดียว เพื่อให้บรรลุวัตถุประสงค์ดังกล่าวจะแบ่งเป็นการศึกษาออกเป็น 3 การศึกษาย่อยดังนี้

การศึกษาที่ 1: การชนในลักษณะออกนอกเส้นทางของยานพาหนะคันเดียวในประเทศไทย พบว่าการชนลักษณะดังกล่าวมีความถี่ในการเกิดอุบัติเหตุ จำนวนการเสียชีวิต และบาดเจ็บสาหัสค่อนข้างสูง ซึ่งในการศึกษาครั้งนี้ได้มีการประยุกต์ใช้ Multinomial logit model ในการวิเคราะห์ข้อมูลเพื่อศึกษาถึงปัจจัยความเสี่ยงที่มีอิทธิพลหรือส่งผลต่อความรุนแรงของการบาดเจ็บในการชนลักษณะออกนอกเส้นทางของยานพาหนะคันเดียว โดยใช้ข้อมูลอุบัติเหตุย้อนหลังระหว่างปี พ.ศ. 2554 - 2560 จากฐานข้อมูลระบบสารสนเทศอุบัติเหตุบนทางหลวง (Highway Accident Information Management System, HAIMS) ผลการวิเคราะห์พบว่าผู้ขับขี่ที่มีอายุมากกว่า 55 ปี, ผู้ขับขี่ที่เป็นเพศชาย, ผู้ขับขี่ที่อยู่ภายใต้อิทธิพลของสุรา และอาการง่วง เป็นปัจจัยที่ส่งผลให้เพิ่มโอกาสการเสียชีวิตในการชนลักษณะออกนอกเส้นทางบนถนนทางตรง นอกจากนี้ยังพบว่ามีปัจจัยอื่น ๆ ที่ช่วยบรรเทาหรือลดความรุนแรงของการบาดเจ็บ ได้แก่ ผู้ขับขี่ที่มีอายุระหว่าง 25 - 35 ปี, การใช้เข็มขัดนิรภัย, การไถลออกนอกเส้นทาง และชนสิ่งกีดขวางทั้งบนถนนทางตรงและทางโค้ง, เกาะกลางถนน, ทางแยก และการเกิดอุบัติเหตุในช่วงเดือนเมษายน ทั้งนี้ จากการศึกษาพบว่าควรมุ่งเน้นให้มีการรณรงค์ที่เกี่ยวข้องกับความปลอกภัยทางถนน การบังคับใช้กฎหมายที่เคร่งครัด รวมถึงปรับปรุงอุปกรณ์ที่ติดตั้งข้างทางเพื่อลดระดับความรุนแรงของการบาดเจ็บในการชนลักษณะออกนอกเส้นทาง

การศึกษาที่ 2: ในการศึกษานี้มีวัตถุประสงค์เพื่อศึกษาและเปรียบเทียบผลกระทบของปัจจัยลักษณะของถนน, ลักษณะการชน, ประเภทของยาพาหนะ, ลักษณะของผู้ขับขี่ และช่วงเวลาของการเกิดอุบัติเหตุ ต่อความรุนแรงของการบาดเจ็บของผู้ขับขี่ ระหว่างการเกิดอุบัติเหตุบนถนน 2 ช่องจราจร และถนน 4 ช่องจราจร โดยการประยุกต์ใช้แบบจำลอง Multinomial Logit จากผลการ

วิเคราะห์พบว่า ผลของแบบจำลองทั้ง 2 แบบจำลองเป็นไปในทิศทางเดียวกัน โดยพบว่าผู้ขับขี่ที่มีอายุมากกว่า 55 ปี, ผู้ขับขี่ที่อยู่ภายใต้อิทธิพลของสุรา, ผู้ขับขี่ที่มีอาการง่วง, การไถลออกนอกเส้นทางบนถนนทางตรง และทางโค้ง และการเกิดอุบัติเหตุบนถนนพื้นผิวคอนกรีตที่แบ่งทิศทางการจราจรด้วยเกาะกลางแบบกดเป็นร่อง เป็นปัจจัยหรือตัวแปรที่ส่งผลให้มีโอกาสในการเสียชีวิตเพิ่มขึ้น ส่วนปัจจัยหรือตัวแปรที่ส่งผลให้ลดความรุนแรงของการบาดเจ็บ ได้แก่ ผู้ขับขี่ที่มีอายุ 25 – 35 ปี, การใช้เข็มขัดนิรภัย, การเกิดอุบัติเหตุบนถนนที่แบ่งทิศทางการจราจรด้วยเกาะกลางแบบยก และการชนสิ่งกีดขวาง

การศึกษาที่ 3: อายุของผู้ขับขี่มีความเกี่ยวข้องอย่างมากต่อลักษณะทางกายภาพของแต่ละบุคคล เวลาในการตอบสนอง และการรับรู้ถึงความเสี่ยงที่จะได้รับซึ่งมีอิทธิพลต่อความรุนแรงของการบาดเจ็บ มีการศึกษามากมายที่ศึกษาถึงอายุของผู้ขับขี่ต่อความรุนแรงของการบาดเจ็บในอุบัติเหตุการชนของยานพาหนะคันเดียว (Single vehicle crash) ซึ่งการศึกษาส่วนมากจำแนกตัวแปรอายุออกเป็นกลุ่ม แต่จะทำการวิเคราะห์ด้วยแบบจำลองเพียง 1 แบบจำลองเท่านั้น ในขณะที่มีการศึกษาจำนวนน้อยที่ทำการวิเคราะห์ข้อมูลกลุ่มช่วงอายุของผู้ขับขี่โดยการจำแนกการวิเคราะห์ออกเป็นหลายแบบจำลองตามช่วงอายุด้วยแบบจำลอง Discrete choice เพื่อเติมเต็มช่องว่าง (gap) ของงานวิจัยในลักษณะดังกล่าว ข้อมูลอุบัติเหตุในการชนลักษณะยานพาหนะคันเดียว (Single vehicle crash) ซึ่งรวบรวมระหว่างปี พ.ศ.2554 - 2560 จึงถูกนำมาวิเคราะห์ในการศึกษาครั้งนี้ โดยการประยุกต์ใช้แบบจำลอง Multilevel logistic เพื่อเปรียบเทียบความรุนแรงของการบาดเจ็บในการชนลักษณะยานพาหนะคันเดียวซึ่งจำแนกตามกลุ่มช่วงอายุ ผลการศึกษาพบว่าผู้ขับขี่ที่อยู่ภายใต้อิทธิพลของสุรา และความเหนื่อยล้ามีอิทธิพลต่อการเสียชีวิตจากอุบัติเหตุทั้งในกลุ่มผู้ขับขี่ที่เป็นวัยรุ่นและผู้สูงอายุ แต่พบว่าการใช้เข็มขัดนิรภัยในการขับขี่จะช่วยลดโอกาสเสี่ยงในการเสียชีวิตจากอุบัติเหตุในผู้ขับขี่ในวัยกลางคนและผู้สูงอายุ ในส่วนอุปกรณ์ด้านความปลอดภัยทางถนน อาทิเช่น ราวกั้นกันอันตราย (Guardrail) พบว่าส่งผลต่อการลดความเสี่ยงต่อการเสียชีวิตในผู้ขับขี่วัยรุ่นและวัยกลางคนได้อย่างมีนัยสำคัญ นอกจากนี้ยังพบว่าในการขับขี่ตอนกลางคืนที่ไม่มีแสงไฟส่องสว่างสามารถเพิ่มโอกาสในการเสียชีวิตของผู้ขับขี่ในวัยกลางคน

สาขาวิชา วิศวกรรมขนส่ง ลายมือชื่อนักศึกษา ______

ปีการศึกษา 2562 ลายมือชื่ออาจารย์ที่ปรึกษา ______

CHAMROEUN SE : ANALYSIS OF RISK FACTORS AFFECTING DRIVER INJURY SEVERITY OF RUN OFF ROAD CRASH FOR THAILAND HIGHWAYS. THESIS ADVISOR : PROF. VATANAVONGS RATANAVARAHA, Ph.D., 104 PP.

SINGLE-VEHICLE RUN OFF ROAD CRASH/THAILAND/DRIVER SEVERITY/MULTINOMIAL LOGIT/HIERARCHICAL LOGIT MODEL

This study set objectives to investigate factors affecting driver injury severity in single vehicle run off road crash with intention to generate appropriate countermeasure and strategy for related authorities to implement in order to improve road safety performance for all vulnerable road users against single-vehicle run off roadway crash. To achieve the objectives, this study is further subcategorized into 3 sub-studies as follows:

Study 1: This study utilized multinomial logit model as methodological approach to identify the risk factors potentially influencing driver injury severity of single-vehicle ROR crash using accident records between 2011 and 2017 which were extracted from Highway Accident Information Management System (HAIMS) database. The analysis results show that the age of driver older than 55 years old, male driver, driver under influence, drowsiness, ROR to left/right on straight roadway increase the probability of fatal crash, while other factors are found to mitigate severity such as the age of driver between 26-35 years old, using seatbelt, ROR and hit fixed object on straight and curve segment of roadway, mounted traffic island, intersection related and accident during April.

Study 2: Objective of this study is to identify and compare impact of risk factors on driver injury severity involving in single-vehicle ROR between accident occurred on 2-lanes highways and 4-lanes highway using Multinomial Logit model. According to result, significant variables of both models move along the same direction. Variables were found to increase chance of fatality are driver older than 55-year-old, driver under influence of alcohol, drowsiness driver, ROR on straight and curve, accident on highways with depressed median and accident on concrete pavement. The variables were found to mitigate severity are adult driver 25-35-year-old, using seat belt, accident on highway with raised median and hit fixed object accident.

Study 3: Most of these studies grouped age into several age-groups and investigate it in a single model analysis, while there were very few studies that separate data into several subset data base on number of created age group and analyze each subset separately utilized traditional discrete choice model without accounting for potential unobserved heterogeneity. To fill this research gap, multilevel logistic model is selected to compare driver injury severity in single-vehicle crash based on age-group with road-segment heterogeneity. Important findings show that DUI (driver under the influence) and fatigue influence fatal crash among young and old driver, seatbelt-usage reduce risk of being fatal among mid-age and old driver, roadside feature such as guardrail significantly reduce fatality risk among young and mid-age driver, and night time driving without light increase probability of fatality for mid-age driver.

School of Transportation Engineering Student's Signature ____________

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SYMBOLS AND ABBREVIATIONS

ROR	=	Run off roadway
OR	=	Odd Ratio
β	=	Structural coefficient
$\chi2$	=	Chi-square
LL	=	Log-Likelihood
CI	=	Confident interval
df	=	Degree of freedom
ε	=	Unobserved random error
ρ^2	=	McFadden-pseudo R-square
ICC	=	Intra-class correlation
Std.	=	Standard error

CHAPTER I

INTRODUCTION

1.1 Rationale of the research

1.1.1 General background

According to the World Health Organization (WHO) report (2018), the world problems associated with the accident on roadways is getting worse, number of fatalities due to the road accidents have increased from 1.25 million (in 2013) to 1.35 million people (2018) and up to 50 million injuries in just a single year which mean that almost 3700 victims dies on the world road's every day and fatalities rate by road accident has reached the rank of eighth leading cause of death globally and first among age group between 5 and 29 years old. Additionally, Figure 1.1 also indicate that low- and middle-income countries bear the greatest burden of injuries and fatalities on roadways accident. Southeast Asia have regional accident rates of road traffic deaths significantly higher than the global rate with 20.7 deaths per 100 000 population. Being one of the middle-income countries, Thailand is currently undergoing development on agricultural commercial and industrial expansion with the support from the government to make improvement on transportation sector to be faster, safer and more comfortable for all road user. But this expansion has led to increasing trend of capacity of personal vehicle operate on road that has led to increasing of accident on road claimed significant loss of lives as well as economic loss. In addition, Figure 1.2 show that the number of fatality rate in Thailand had no significant improvement in 5 years range between 2011-2016. In 2015 the rate of fatalities because of the accident was 36.2 per 100000 and ranked second in the world after Liberia, and this trend has decrease to 32.7 in 2018 which is considered to be still significantly high. In this sense, more research study and implication need to be taken in order to find effective solutions in order to reduce number of accident as well as number of fatalities from road accident.

Federal Highway Administration (FHWA) give definition of Run Off Road (ROR) crash as a non-intersection crash which occurs after a vehicle crosses an edge line or a center line, or otherwise leave the traveled way. According to 7 years accident record (2554 -2560) of Highway Accident Information Management System (HAIMS), Thailand's number of ROR crash was the leading type of crash among all type. This crash type posed high number of injuries and fatalities on roadway and in hospital. Figure 1.3 show that ROR alone accounted for 52% out of total accident (53485 cases) followed by rear end crash at only 26%. However, there is no previous research study about factor influencing severity of driver involve in ROR crash on Thailand highway yet, thus this research study aims to fulfill research gap.

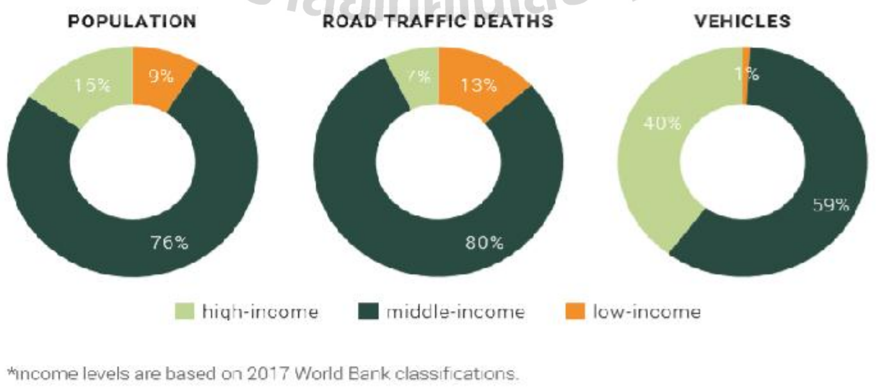

Figure 1.1 Proportion of population, road traffic deaths, and registered motor vehicles

Source: Global road safety status report (WHO 2018)

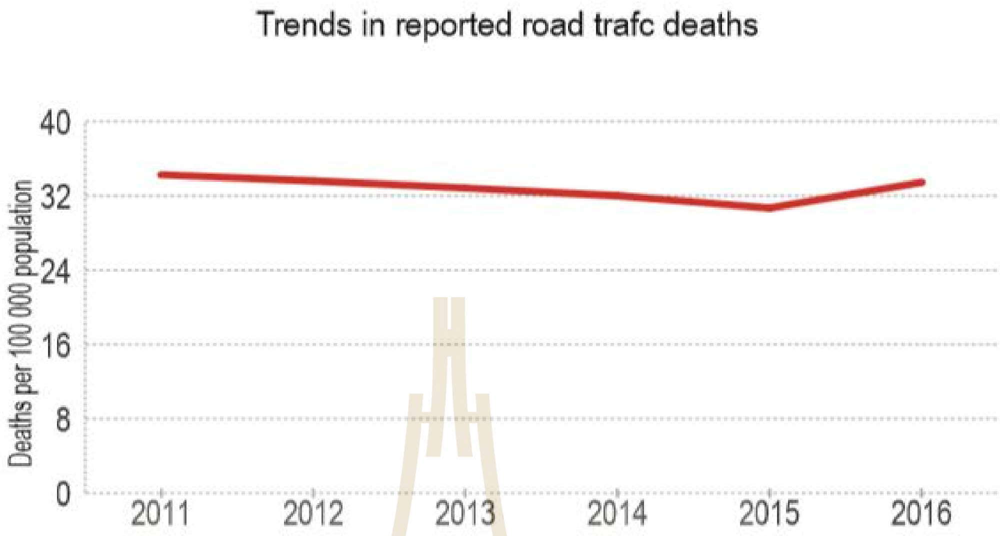

Figure 1.2 Trend of death rate due to traffic accident in Thailand from 2013 to 2016

Source: Global road safety status report (WHO 2018)

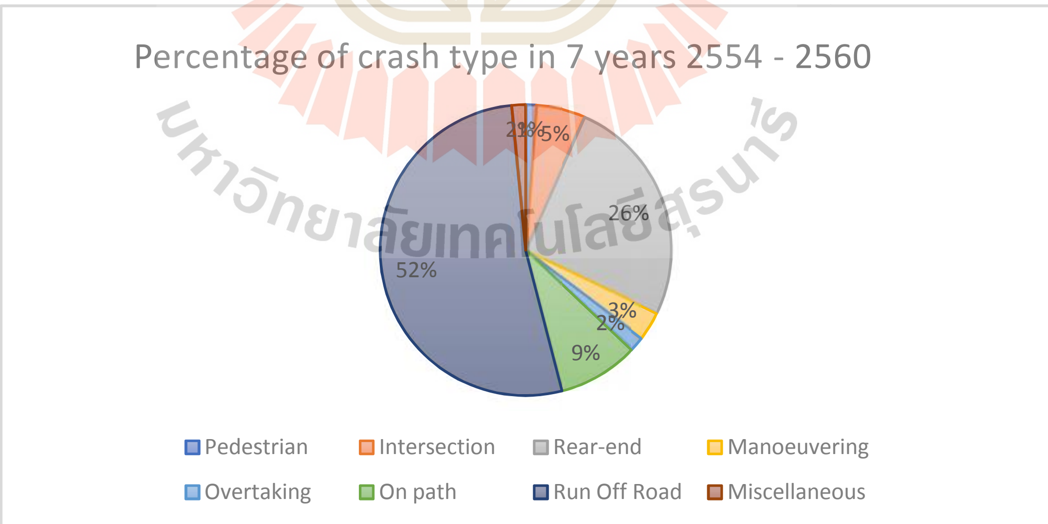

Figure 1.3 Crash type percentage of 7 years (2011-2017) accident records in Thailand

Source: Highway Accident Information Management System (HAIMS)

1.1.2 Factor influence driver severity

Traffic accident usually happen due to number of factors such as human, road environment, vehicle, etc. According to WHO report 2018, there are several reasons for this increasing trend of crash rate namely rapid urbanization, poor safety standards on road, lack of law enforcement, people driving distracted or fatigued, driver under influence of drug and alcohol, speeding, failure to wear seat belt of helmets, etc. Many previous research studies have grouped accidents related factors into five group that associate with each accident for their analysis investigation to identify risk factors affecting injury severity. Theses factor are driver factors, vehicle factors, roadways and operational design factors, environment factors and crashes characteristic factor (Awadzi, Classen, Hall, Duncan, & Garvan, 2008; Eluru & Bhat, 2007; Eluru, Paleti, Pendyala, & Bhat, 2010; Huang, Chin, & Haque, 2008; Islam & Mannering, 2006; Khorashadi, Niemeier, Shankar, & Mannering, 2005; Morgan & Mannering, 2011; Rana, Sikder, & Pinjari, 2010; Shaheed & Gkritza, 2014; Xie, Zhang, & Liang, 2009; Xie, Zhao, & Huynh, 2012; Yamamoto, Hashiji, & Shankar, 2008). Following section will provide more detail about each considered factor that were used in the previous research study.

Driver characteristic is commonly considered the most influential in crash occurrence and injury severity that have been included in most of the research study on risk factors of the accident analysis. A study by Dissanayake and Roy (2014) found that driver characteristic has potential to increase probability of ROR crash severity such as driver ejection, old driver, driver under influence (alcohol), license state, being at fault, medical condition of driver. Additionally, Amarasingha and Dissanayake (2018) conducted the study on factor associated with urban and rural

ROR crash in The United States and result show that avoidance/evasive, driver being ill, falling asleep or fatigues leading to ROR accident. Between 5% and 35% of all road death are reported as under influence of alcohol (Organization, 2019; Vissers, 2017). Moreover, Elvik, Høye, Vaa, and Sørensen (2009) found that driving after drinking alcohol significantly increase the risk of a crash and the severity of that crash and wearing seat-belt decrease the risk of death among driver and front seat occupants by 45 to 50% and the risk of death and serious injuries among rear seat occupants by 25%. Stevenson et al. (2008) state that mandatory seat-belt legislation is highly effective in promoting seat-belt wearing and is a cost-effective means of reducing road traffic deaths and injuries, especially in rapidly motorizing low- and middle-income countries.

In term of vehicle characteristic, Mannering, Shankar, and Bhat (2016) suggested that vehicle types involve in the accident such as truck, bus, passenger car etc. can be considered as factor influence injury severity due to difference in mass, advance tech and other design element. Age of vehicle and goodness of safety equipment inside the cars may also play importance role in determine injury severity in case of an accident.

The study conducted by Ratanavaraha and Suangka (2014) have found that an increase in speed on the road section increase greater chance of accident severity into fatal accident. In addition, Dissanayake and Roy (2014) also found that road related factor such as speed, asphalt pavement, dry road condition that influence injury severity. The research result of Vadeby and Forsman (2018) indicate that an increase of speed at which vehicle operate directly affect the risk of the crash and severity, and more importantly the likelihood of falling into fatal crash. Beside speed related factor, some previous studies (Wang et al., 2011; Zhu, Dixon, Washington, & Jared, 2010) show that roadway grade and curve roads are significant factor in determination of injury and crash severity. Number of previous research study that include number of lanes, and found that increasing number of lanes cause an increase in number of vehicle changing lane as traffic jam increase which result in increased traffic crash and chance of severe injuries at freeways merging location (Kononov, Bailey, & Allery, 2008; Liu & Subramanian, 2009).

Weather conditions such as rainy, windy, foggy, or stormy could be considered prominent risks factor on severity and occurrence in traffic accident and have been considered in the previous studies (Tabl1 1.1). Because in Thailand the accident frequency increase rapidly during Thai tradition holiday such as Songkran or New Year's Eve when compare to other time of years; thus, specific time throughout the year maybe also considered to increase in accident frequency and severity. Beside, Dissanayake and Roy (2014)'s study show that accidents happen in environmental factor daylight, and time of day between 6 pm to midnight are likely to end up with more severe accident.

There are several crash characteristics of the ROR crash recorded by the police namely, off carriageway to the left/right on straight/curve, off carriageway to the left/right on straight/curve and hit fixed object, out of control on the carriageway, off and across the median, mount island etc. All these crash type may cause difference injury level due its specific crash characteristic. Dissanayake and Roy (2014) found that vehicle getting destroyed or disable, vehicle maneuver being straight or passing, hit fixed object type such as tree and ditches tend to cause more severe injury crash.

1.1.3 Multinomial logit

Multinomial logit is known as one of the most commonly used unordered respond framework in crash severity analysis. It was used to identify the risk factors affecting severity of motorcycle crash (Chimba & Sando, 2010), injury severity of the road accident in the Erzurum and Kars province of Turkey Celik and Oktay (2014), pedestrian-vehicle crash severity (Tay, Choi, Kattan, & Khan, 2011), driver injury severity in intersection-related crash (Wu et al., 2016). Benefit of this unordered response model over the ordered response model are providing more flexible control over the interior category probability as state in (Celik & Oktay, 2014) and no need to account for ordinal categorical outcome while the ordered response model occasionally urge unrealistic parameter that can cause bias in result interpretation. Therefore, Multinomial logit is one of the promising approaches in crash severity analysis.

1.1.4 Multilevel logistic model

Multilevel model analysis is rarely adopted in the injury severity analysis study. Multilevel model is well-known due to ability to allow correlation of the variable within hierarchical cluster and ability to address unobserved heterogeneity. The correlation within cluster (higher level) often violate the assumption of residual independence that was assumed in many methodological approach and if this correlation is left uncheck, the consequence is parameter estimate tend toward zero, bias parameters estimate, bias standard error or heterogeneity of the regression (D.-G. Kim, Lee, Washington, & Choi, 2007; Raudenbush & Bryk, 2002) therefore multilevel modeling was proposed to solve this issue. This methodological approach provides potential benefit when available crash data can be arranged into hierarchical structure, for instant, crash at lower level and spatial region at higher level.

1.1.5 Effect of number of lanes on highway accident

Number of lanes and lane width of highway might have effect on driver's speed, crash characteristic, performance of the vehicle and different roadway characteristic design that might also have effect on driver injury severity in case of accident. Cross section and geometric elements of the highway has also been found to significantly affect the driver behaviors (Bella, 2013), which consist of some of the most outstanding factors affecting crash severity such as age group, gender, and especially speed utility. The study of accident severity analysis had brought out the potential factor that have significantly relationship with injury severity. With these known safety issue, they can help the safety planner to draw out the countermeasures (redesign the road, monitor traffic safety device, black spot monitoring, and other traffic law for driver) potentially mitigate severity in the accident for specific region. Awadzi et al. (2008) studied about relationship among crash related factor and the younger and older adult injury in fatal motor vehicle accident. The result show that the number of lanes have the possibility to reduce driver injuries and fatalities. Specifically, the crashes on 2-lanes highway increase higher chance or more severe injury of accident up to 81%, but on 4-lanes highway severity of the accident increase only 23%. Another study by Kashani and Mohaymany (2011) conduct the research study on traffic injury severity on 2-lanes rural road and the result show that improper overtaking and unequip seatbelt are the most important factor affecting the severity of injuries.

1.1.6 Effect of age on injury severity

Driver with different age have different physical strength, health, reaction time, psychological thought and visual ability, etc. These characteristic affect driver behaviors which is also more likely to affect injury severity. For example, J.-K. Kim, Ulfarsson, Kim, and Shankar (2013) ‘s study show that old driver is strongly associated with fatal single vehicle crash than mid-age and young driver which was consensus with the finding of previous work (Xie et al., 2012). Another study by Weiss, Kaplan, and Prato (2014) specifically on only young driver show that seatbelt non-used, drunk driving, and inexperience are the most. Islam and Mannering (2006) studied the effect of age on gender in single vehicle crash and the result show that substantial and statically significant, different exist between driver age injury severity.

1.2 Purpose of the research

The objectives of this research are:

1.2.1 To identify the potential factors which influence driver injury severity involving in single-vehicle run off road crash.

1.2.2 To identify the differences between factors influencing driver injury severity involving in single-vehicle run off road crash between 2-lanes and 4-lane highways.

1.2.3 To investigate potential influence factor on driver injury severity involving in single-vehicle run off road crash between young, mid-age and old driver by using advance discrete choice model accounting random effect at road segment level.

1.3 Scope of the research

The scopes of this research are as follows:

1.3.1 A seven years (2011- 2017) accident record in Thailand (obtained from HAIMS) will be used for the analysis.

1.3.2 Study focus only on single-vehicle ROR crashes that occurred on Thailand highway nationwide.

1.3.3 Crash cases with incomplete information will be ignored from the study

1.3.4 Multinomial Logit model and Multilevel logistic model are utilized for this research study.

1.4 Research questions

This research has the following research questions:

1.4.1 What are the appropriate methodological approach for study crash injury severity?

1.4.2 What are potential factors that significantly influencing driver's level of injury severity for ROR crash?

1.4.3 Between 2-lanes and 4-lanes highway single-vehicle ROR accident, how are factors influencing driver injury severity different?

1.4.4 What are similarities and differences between potential factors affecting driver severity between young, mid-age and old driver involving in single-vehicle run off road crash? Are these age-groups drivers contributed to significant difference in injury severity in case of single-vehicle ROR?

1.5 Contributions of the research

The contributions of this research are as follows:

1.5.1 Result with regard to vehicle and driver characteristic will help to establish policies, strategies, and other regulation in order to prevent likelihood of more severe crash.

1.5.2 Result with regard to road characteristic and crash characteristic will help to provide insightful recommendation on roadways revision or additional traffic safety provision in order to mitigate crash severity.

1.5.3 Result with regard to environmental characteristic will help to identify how (in what way) effect of roadway environment affect injury severity which is resourceful information to generate countermeasure in order to extensively prevent more severe crash.

1.6 Organizations of the research

This research is divided into 5 chapters as follows:

Chapter I: Introduction section mentions the rationale and the importance of the problem objectives, purpose of the research, scope of the research, research questions, and expected contributions of the research.

Chapter II: The analysis of risk factors affecting driver injury severity of single-vehicle ROR for Thailand highway nationwide buy using Multinomial logit model. This chapter utilize all single-vehicle ROR crash dataset in order to overall picture.

Chapter III: Driver injury severity in single-vehicle ROR crash on 2-lanes and 4-lanes highway in Thailand. The multinomial logit model is adopted to identify the relationship between crash related factor (roadway characteristic, crash characteristic, driver characteristic, vehicle; and environmental and temporal characteristic) with driver injury severity involved in single-vehicle ROR accident on 2-lanes highway and 4-lanes highway. Discussion the different between result the two model was also taken place in this chapter.

Chapter IV: Comparing driver injury severity in single-vehicle crash based on age using multilevel logistic model with road-segment heterogeneity. Young, mid-age and older driver subset were analyzed separately by considering crash related factor as lower level and road-segment as higher level of hierarchical structure.

Chapter V: Conclusion and recommendations. This section concludes the results from chapter II–chapter IV and gives the suggestions from the findings.

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CHAPTER II

RISK FACTORS AFFECTING DRIVER SEVERITY OF SINGLE- VEHICLE RUN OFF ROAD CRASH FOR THAILAND HIGHWAY

2.1 Abstract

Single-Vehicle Run Off Road (ROR) crash has been the leading crash type in terms of frequency and severity in Thailand. In this study, multinomial logit analysis was applied to identify the risk factors potentially influencing driver injury severity of single-vehicle ROR crash using accident records between 2011 and 2017 which were extracted from Highway Accident Information Management System (HAIMS) database. The analysis results show that the age of driver older than 55 years old, male driver, driver under influence, drowsiness, ROR to left/right on straight roadway increase the probability of fatal crash, while other factors are found to mitigate severity such as the age of driver between 26-35 years old, using seatbelt, ROR and hit fixed object on straight and curve segment of roadway, mounted traffic island, intersection related and accident in April. This study recommends the need for improving road safety campaign, law enforcement and roadside safety features that potentially reduce level of severity of driver involving in single-vehicle ROR crash.

2.2 Introduction

According to the report on road safety of World Health Organization (WHO) (Organization, 2018), traffic accident on Highways is becoming worse problem from year to year, number of fatalities due to traffic accident have increased from 1.25 million (2013) to 1.35 million people (2016) and up to 50 million were injured in just a single year; numerically, almost 3700 victims die on the world road's every day. The greatest burden of injury and fatality from road accident has been occurring in most of the low- and middle-income countries. Being one of the middle-income countries in Southeast Asia, Thailand is currently under process of development on all sectors including improvement on transportation sector to be faster, safer and more comfortable for all road users. Whereas, this expansion has led to increasing trend of capacity of personal vehicle operate on road and accident on road that caused significant loss of lives and economic. In 2015, the rate of fatalities due to the accident was 36.2 per 100000 and ranked second in the world after Libya, and this trend has decreased to 32.7 in 2018 which is considered to be still significantly high.

Based on 7 years accident record (2011 -2017) obtained from Highway Accident Information Management System (HAIMS) of the Department Of Highway (DOH), Thailand's number of run off road (ROR) crash was the leading type of crash among all crash types and caused the highest number of injuries and fatalities on highway and in hospital. ROR crash alone accounted for 52% out of total accidents (53485 cases) followed by rear end crash at only 26%. Additionally, 9877 cases happened to be single-vehicle ROR crash which killed victim 1361 and caused serious injury 1406 out of 9877 drivers. However, there is no previous research study that specifically in-depth identify risk factors influencing severity of driver involving in single-vehicle

ROR crash for Thailand Highway yet. Therefore, this research paper aims to fulfil the gap to explore factors contributing on driver injury severity involving in single-vehicle ROR crash for Thailand highway using multinomial logit. The contribution of this study can provide insight future traffic safety policy that may potentially reduce injury driver severity involving in single-vehicle ROR crash in Thailand.

2.3 Literature review

The analysis of crash severity to identify the significant risk factors has been conducted by many researchers. Yasmin and Eluru (2013) reviewed many previous works on their methodological approach and factors that were considered for crash severity analysis and five main characteristics were used in almost on every existing research including driver, roadway and operational design, vehicle, temporal and environmental, and crash characteristic. In traffic safety research, Driver characteristics have been considered as significant influence on the crash injury severity (Yasmin & Eluru, 2013). Cejun Liu and Ye (2011) found that driver-related factors were the major causes of single-vehicle ROR crash including performance error, sleepiness, driver under influence, overcompensation, and distraction. The influence of age groups was also found as a potential risk factor that could affect the driver injury severity. Drivers younger than 25 years old were less likely to be severely injured in the single-vehicle crash (Lee & Mannering, 2002; P. Savolainen & Mannering, 2007; Shaheed & Gkritza, 2014) while older drivers were found to be more associated with fatal ROR crash (Das & Sun, 2016; Dissanayake & Roy, 2014). The uses of seatbelt while driving were also found as potential safety equipment that prevent the victim of ROR crash from severe injury (Al-Bdairi & Hernandez, 2017;

Islam & Hernandez, 2013; Yiyun Peng & Boyle, 2012; Schneider, Savolainen, & Zimmerman, 2009). In terms of gender, female drivers are likely to get more severely injured in single-vehicle ROR crash (Roque, Moura, & Cardoso, 2015; Schneider et al., 2009; Wu et al., 2014). Potential risk factors affecting the severity of ROR crash can also have relationship with the vehicle types. Schneider et al. (2009)'s study revealed that ROR involving with pickup truck are higher possibility to be severely injured followed by passenger car and semitrailer truck. The influence of roadway characteristics on the driver injury severity were also studied in the existing literature. Yichuan Peng, Geedipally, and Lord (2012)'s research study found some factors that positively affect injury of the single-vehicle ROR crashes such as wider shoulder width and wider lateral clearance which increase the opportunity to recovery back to the travel lane and decrease probability of hitting fixed object on the side of the road, respectively. Changqin Liu and Subramanian (2009) also highlighted that road alignment with curve, rural roadway and high-speed limit road were significantly associated with high risk of being in the fatal single-vehicle ROR crash. With regard to environmental characteristic, Lee and Mannering (2002) found that ROR crash during clear or cloudy and on wet road were likely to result in less severe crash than those that had ice or snow on roadway, foggy and raining or snowing condition. Russo, Di Pace, Dell'Acqua, and De Luca (2017) argued that the injury crash possibly caused by the failure of road Geometry that is firmly associated with road comfort, road familiarity, road section, environment, and ability to perceive the curve road ahead.

2.4 Methodology

2.4.1 Methodological approach

In accident analysis study, the injury severity outcomes can be treated as unordered category or natural ordering to analyse the unordered response model and ordered response model, respectively. Numbers of researcher also utilized ordered framework for their accident severity analysis, namely generalized ordered logit (Abegaz, Berhane, Worku, Assrat, & Assefa, 2014; Kaplan & Prato, 2012; Yasmin, Eluru, Bhat, & Tay, 2014), heteroscedastic ordered logit (Wang & Kockelman, 2005a, 2005b) and ordered probit (Abdel-Aty, 2003). However, one of the most commonly used unordered respond framework; multinomial logit, was used to identify the risk factors affecting severity of motorcycle crash (Chimba & Sando, 2010), injury severity of the road accident in the Erzurum and Kars province of Turkey (Celik & Oktay, 2014), pedestrian-vehicle crash severity (Tay, Choi, Kattan, & Khan, 2011), driver injury severity in intersection-related crash (Wu et al., 2016). The advantages of the unordered response model over the ordered response model are providing more flexible control over the interior category probability as state in (Celik & Oktay, 2014) and no need to account for ordinal categorical outcome while the ordered response model occasionally urge unrealistic parameter restriction (P. T. Savolainen, Mannering, Lord, & Quddus, 2011). Hence, in this study, Multinomial logit is adopted for single-vehicle ROR crash driver injury severity analysis for Thailand Highway. Following Washington, Karlaftis, and Mannering (2010), suppose that *Tij* is the linear function that determine the severity level *j* in the accident *i* and *Pij* is the probability of a driver *i* being of severity *j*:

$$Tij = \quad jXij + \pounds ij \tag{2.1}$$

$$Pij = \frac{EXP[\quad jXij]}{\sum_{j} EXP[\quad jXij]} \tag{2.2}$$

Where βj is a vector of the coefficients to be estimated for injury severity outcome j, Xij is the vector of explanatory variable and εij is the unobserved random error.

Since multinomial logit require firmly consideration of correlation between independent variable and dependent variable and possible multicollinearity among the independent variable; thus, the Pearson' chi-square test is estimated to evaluate the relationship between each risk factor and driver injury severity (Chen et al., 2016).

Odd ratio of each significant risk factors is used to interpret the estimated results. Odd ratio > 1 indicates an increase probability and odd ration < 1 indicates a decrease of probability of that injury severity with relative to base category injury severity. Formula of odd ratio is given as:

$$OR = EXP(\quad i) \tag{2.3}$$

2.4.2 Data collection

This research study used the single-vehicle ROR crash data between 2011-2017 that occurred on Thailand highways which originally obtained from HAIMS. All available variables that associated with each accident case and driver severity were extracted and categorised into factors namely, driver, vehicle, roadway, crash characteristic, and environment and temporal. Only single-vehicle ROR crashes were used; and crashes with incomplete information (due to insufficient details in the police report) were neglected from the study. During this seven-year periods, there were 9877 single-vehicles ROR crashes happened. The total extracted risk factors for each case were 40 variables. Each variable was coded 1 = "Yes", 0 = "Otherwise" except GENDER (1 = "Male", 0 = "Female"); R_SURF (1 = "Concrete pavement", 0 = "Asphalt pavement") and EN_SURF (1= "Road with dry surface", 0 = "Road with wet surface"). Table 2.1 summarizes all the possible risk factors descriptively with each level driver injury severity. The injury severity outcome of each driver was categorized into three levels of injury Fatal/Serious/Minor Injury. The recommended minimum sample size for multinomial logit model is 2000 observations (Ye & Lord, 2014), therefore the sample size in this study is acceptable.

2.5 Result and Discussion

Before fitting all risk factors into multinomial logit model, Chi-square and log-likelihood ratio test were conducted to test independence and association between each risk factors and driver injury severity. Table 2.2 presents the results of Chi-square and log-likelihood ratio test. The results show that some factors are not statistically significant at 0.05 level, namely AGE_36 _45, AGE_ 46_55, PASS_ INFRONT, DEFECT_CAR, DEF-ECT_CAR, PASSENGER_CAR, PICKUP_ INVOLVE R_COND, R_SURF, VERTICAL, COMMUNITY, DEPRESSED _MEDIAN, EN_STAT, EN_ LIGHT and TIMEGROUP. Consequently, all these independent variables (risk factors) were not included in the final multinomial logit model estimation.

Table 2.1 Data Description

Variable Name	Variable Description	Minor	Severe	Fatal	Total	
Driver factors						
AGE_26_35	Age 26-35 years old	2446	457	414	331	33.6%
AGE_36_45	Age 36-45 years old	1719	358	351	242	24.6%
AGE_46_55	Age 46-55 years old	1115	215	232	156	15.8%
AGE_56_UP	Age >55-year-old	581	106	137	824	8.3%
GENDER	Female driver	931	171	144	124	12.6%
	Male driver	6179	1235	1217	863	87.4%
SAF_EQ	Used Seatbelt	2919	544	459	392	39.7%
ALCOHOL	Under alcohol influence	94	32	46	172	1.7%
EXEED_SPEED	Exceed speed limit	5587	1111	981	767	77.7%
FALL_ASLEEP	Fall asleep	801	168	222	119	12.1%
PASS_INFRONT	Something passes in front	172	27	23	222	2.2%
Vehicle factors						
DEFECT_CAR	Defective car device	249	42	49	340	3.4%
PASSENGER_CAR	Passenger car	2474	519	455	344	34.9%
PICKUP_INVOLVE	Pickup truck	3170	601	571	434	44.0%
TRUCK_INVOLVE	Heavy truck/trailer	1044	164	195	140	14.2%
Crash characteristics						
OFF_LEFT_STRAIGH	ROR to left on straight	439	166	276	881	8.9%
OFF_RIGHT_STRAIG	ROR to right on straight	251	80	167	498	5.0%
LEFT_FIXED_STRAI	ROR to left/hit object	1328	221	143	169	17.1%
RIGHT_FIXED_STRA	ROR to right/hit object	1172	220	135	152	15.5%
ACROSS_MEDIAN	ROR and across median	131	36	44	211	2.1%

Table 2.1 Data Description (Continued)

Variable Name	Variable Description	Minor	Severe	Fatal	Total	
OFF_LEFT_CUVE	ROR on left bend	197	38	89	324	3.3%
OFF_RIGHT_CUVE	ROR on right bend	167	47	72	286	2.9%
LEFT_FIXED_CURV	ROR on left bend/hit object	690	113	107	910	9.2%
RIGHT_FIXED_CUR	ROR on right bend/hit object	786	120	118	102	10.4%
MOUNT_ISLAND	Mounted traffic island	1808	335	166	230	23.4%
R_COND	Occurred in construction area	155	41	37	233	2.4%
Road factors						
N_LANE	Happened on 2 lanes road	1873	371	449	2693	27.3%
R_SURF	Concrete pavement road	506	120	102	728	7.4%
	Asphalt pavement road	6604	1286	1259	9149	92.6%
VERTICAL	Road on grade area	716	150	152	1018	10.3%
INTERSECTION	Intersection area	524	88	58	670	6.8%
U_TURN	U-turn area	681	119	63	863	8.7%
COMMUNITY	Community area	63	17	11	91	0.9%
NO_MEDIAN	Without median	2005	401	485	2891	29.3%
RAISED_MEDIAN	Raised median	1937	367	261	2565	26.0%
DEPRES_MEDIAN	Depressed median	2470	517	502	3489	35.3%
Environmental and temporal factors						
EN_SURF	Dry surface road	5651	1149	1121	7921	80.2%
	Wet surface road	1459	257	240	1956	19.8%
EN_STAT	Dirt/dusty road	23	5	6	34	0.3%
EN_WEATHER	Raining, dust, foggy	1553	272	258	2083	21.1%
EN_LIGHT	Nighttime	3328	678	652	4658	47.2%
TIMEGROUP	6 pm-midnight	1236	261	244	1741	17.6%
APRIL_ACCIDENT	Happened in April	752	213	204	1169	11.8%

Table 2.3 presents the multinomial logit estimated results of single-vehicle ROR driver injury severity. The base dependent category is fatal injury (follow the previous research studies of (Celik & Oktay, 2014; Ye & Lord, 2014). There were totally 26 independent variables that have strong association with driver injury severity based on results of Table 2.2 with 9877 observations were used for analysis in the final model. The odd ratio (OR) of estimated model is used to interpret the predict probability of odds that the independent variables are likely to fall into specific injury category. The model fitting information is shown in Table 3 with Chi-square = 790.836 and significantly small P-vale = 0.000, thus the multinomial logit model was fit fairly well. McFadden R2: 0.0508 is relatively small, but has been used in the previous works (Khattak, Pawlovich, Souleyrette, & Hallmark, 2002; Ratanavaraha & Suangka, 2014).

The estimate results show that driver's age between 26-35 years old were more likely (OR = 1.18, 95% CI = 1.03-1.35) to have minor injury in the accident when compare with the fatal injury. The minor injury severity level for this age group is almost 1.2 times more likely to occur than fatal injury. In contrast, drivers who were older than 55 years old were found to be more likely (OR = 0.750, 95% CI = 0.57 – 0.98) to fall into fatal injury rather than severe injury. In this case, older drivers are 1.33 times more likely to die in the accident relative to severe injury. To our best understanding is because young drivers have better health, physically body condition and perception reaction to situation than older driver (age is strongly correlated with human physical characteristics (Mannering, Shankar, & Bhat, 2016)). In addition, this result is in line with previous research (Xie, Zhao, & Huynh, 2012). Similarly, the negative coefficient of variable GENDER indicates that male drivers are likely to have higher risk of falling into fatal accident than females with relative to minor injury (OR = 0.763, 95% CI = 0.62 – 092). This result is consistent with the finding of (Chang & Yeh, 2006; Eustace, Almutairi, & Hovey, 2016; Shawky, Hassan, Garib, & Al-Harthei, 2015). However, this finding contrasts with some of previous works as presented in the current literature review. A reasonable explanation is the differences in driving behavior (driving speed, decision making relative to possible risk, uses of alcohol/drug or ability to resist drowsiness) of males versus females in different regions.

Driver who used seatbelt while driving is found to be significantly reduce the rate of being in fatal crash relative to both minor and sever injury with (OR = 1.43, 95% CI = 1.27 – 1.65 and OR =1.308, 95%, CI = 1.11 – 1.53, respectively) in case of ROR crash happened, which is logical finding and consistence with result of (Neyens & Boyle, 2008; Schneider et al., 2009).

Table 2.2 Chi-square and log-likelihood test bewteen related factors and severity

Variable	χ2 (P-value)	Log Likelihood (P-value)	df
GE_26_35	8.9831(0.010)	9.0807(0.010)	2
AGE_36_45	-	-	-
AGE_46_55	-	-	-
AGE_56_UP	6.7462(0.034)	6.4841(0.039)	2
GENDER	6.8533(0.032)	7.097(0.028)	2
SAF_EQ	26.343(<0.001)	26.737(<0.001)	2
ALCOHOL	31.007(<0.001)	26.891(<0.001)	2
EXCEED_SPEED	29.48(<0.001)	28.134(<0.001)	2
FALL_ASLEEP	27.444(<0.001)	25.523(<0.001)	2
PASS_INFRONT	-	-	-
DEFECT_CAR	-	-	-
PASSENGER_CAR	-	-	-

Table 2.2 Chi-square and log-likelihood test bewteen related factors and severity (Continued)

Variable	χ2 (P-value)	Log Likelihood (P-value)	df
PICKUP_INVOLVE	-	-	-
TRUCK_INVOLVE	8.8001(0.012)	9.1965(0.01)	2
OFF_LEFT_STRAIGHT	296.55(<0.001)	250.75(<0.001)	2
OFF_RIGHT_STRAIGHT	183.69(<0.001)	146.91(<0.001)	2
LEFT_FIXED_STRAIGHT	56.027(<0.001)	61.249(<0.001)	2
RIGHT_FIXED_STRAIGHT	37.709(<0.001)	41.477(<0.001)	2
ACROSS_MEDIAN	11.975(0.003)	10.993(0.004)	2
OFF_LEFT_CUVE	52.858(<0.001)	43.308(<0.001)	2
OFF_RIGHT_CUVE	36.316(<0.001)	31.438(<0.001)	2
LEFT_FIXED_CURVE	7.350(0.025)	7.554(0.023)	2
RIGHT_FIXED_CURVE	12.916(0.002)	13.362(0.001)	2
MOUNT_ISLAND	111.84(<0.001)	126.07(<0.001)	2
R_COND	-	-	-
N_LANE	26.09(<0.001)	25.245(<0.001)	2
R_SURF	-	-	-
VERTICAL	-	-	-
INTERSECTION	18.168(<0.001)	20.039(<0.001)	2
U_TURN	35.243(<0.001)	40.527(<0.001)	2
COMMUNITY	-	-	-
NO_MEDIAN	30.954(<0.001)	29.995((<0.001)	2
RAISED_MEDIAN	38.675(<0.001)	40.801(<0.001)	2
DEPRESSED_MEDIAN	-	-	-
EN_SURF	8.392(0.01)	8.5309(0.01)	2
EN_STAT	-	-	-
EN_WEATHER	8.7118(0.01)	8.8428(0.01)	2
EN_LIGHT	-	-	-
TIMEGROUP	-	-	-
APRIL_ACCIDENT	38.565(<0.001)	36.987(<0.001)	2
(-) Not significant			

The results for drivers under influence of alcohol are almost 2.36 times higher possibility (OR = 0.424, 95% CI = 0.28 – 0.63) to die in the accident relative to the minor injury category which is reasonable finding and consensus with the study of (Li, Keyl, Smith, & Baker, 1997; Changqin Liu & Subramanian, 2009). This might be significantly important finding, since during long holiday season such as New Years and Songkran, numbers of accident increase dramatically and kill significant numbers of citizen due to drunk driving which Thailand authority has been trying to tackle every year.

Table 2.3 Multinomial logit model estimated result of driver injury severity

Variable	Minor		Severe	
	Coefficient	OR (95% CI)	Coefficient	OR (95%CI)
Constant	1.216(0.223) **		-0.495(0.296) *	
AGE_26_35	0.165(0.068) **	1.180(1.03-1.35)	-	-
AGE_56_UP	-	-	-0.288(0.141) **	0.750(0.57-
GENDER	-0.271(0.100) ***	0.763(0.62-0.92)	-	-
SAF_EQ	0.374(0.065) ***	1.453(1.27-1.65)	0.269(0.081) ***	1.308(1.11-
ALCOHOL	-0.858(0.202) ***	0.424(0.28-0.63)	-	-
FALL_ASLEEP	-0.323(0.126) ***	0.724(0.56-0.92)	-	-
OFF_LEFT_STRAIGHT	-0.609(0.192) ***	0.544(0.37-0.79)	-	-
OFF_RIGHT_STRAIGHT	-0.682(0.204) ***	0.506(0.33-0.75)	-	-
LEFT_FIXED_STRAIGHT	1.117(0.197) ***	3.056(2.09-4.49)	0.833(0.264) ***	2.301(1.37-
RIGHT_FIXED_STRAIGH	1.016(0.199) ***	2.761(1.87-4.07)	0.850(0.264) ***	2.304(1.39-
LEFT_FIXED_CURVE	0.693(0.204) ***	2.000(1.34-2.98)	-	-
RIGHT_FIXED_CURVE	0.719(0.202) ***	2.052(1.38-3.04)	-	-
MOUNT_ISLAND	1.148(0.196) ***	3.153(2.14-4.63)	0.998(0.260) ***	2.714(1.63-
INTERSECTION	0.316(0.147) **	1.372(1.02-1.83)	-	-
APRIL_ACCIDENT	-	-	0.245(0.110) **	1.278(1.03-

Fatal injury is the base category;
(-) not significant; (*) p < 0.1; (**) p < 0.05; (***) p < 0.000;
Number of observations = 9877;
Log-Likelihood: -7380.1;
McFadden R2: 0.050854;
Likelihood ratio test: χ2 = 790.84; df = 52 (p-value < 0.000)

Drowsiness also have potential to influence injury severity. Accidents caused by driver falling asleep have higher possibility (OR = 0.724 95% CI = 0.56-0.92) to die rather than get minor injury, probably because of drowsiness put crash in the position where strong impact is produced due to unpreparedness for the accident.

With regard to crash characteristics, the results show that the single-vehicle ROR crash on straight to both left or right are likely (OR = 0.544, 95% CI = 0.37 – 0.79 and OR = 0.506, 95% CI = 0.33 - 0.75, respectively) to fall into fatal injury than minor injury. However, the estimated result indicates that the minor injury is around 3 and 2.7 times (OR = 3.056, 95% CI = 2.09 – 4.49 and OR = 2.761 95% CI = 1.87 – 4.07) are more likely to occur than fatality for ROR to the left or right on straight and hit fixed object respectively; additionally, severe injury accident is also more likely (OR = 2.301 CI = 1.37 – 3.84 and OR = 2.304, CI = 1.39 – 3.92 respectively) to occur than fatal accident. For single-vehicle ROR on curve to left or right and hit fixed object are likely to have minor and severe injury 2 times higher (OR = 2.000 95% CI = 1.34 – 2.98 and OR = 2.052, 95% CI = 1.38 – 3.04 respectively) than fatality. This result is consensus with finding of (Eustace et al., 2016; Lee & Mannering, 2002). However, (Dissanayake & Roy, 2014)s' work argued that crash with fixed object are likely to increase the probability of more severe injury. Possible explanation was stated in (Lee & Mannering, 2002), the severity of ROR accident can be complicated considering association with roadside features such as, other fixed objects, guardrail, traffic sign poles and other purpose sign pole along the roadway in addition to difference of driver characteristic such as speed, driver condition, or awareness along the road way sections. additionally, driver behavior in Thailand tends to drive using higher speed (77.7% of total single-vehicle ROR crashes were caused by exceeding speed limit), thus in case of vehicle get into ROR crash, driver tends to overcorrect and transfer into rollover crash; in this manner, it increases chances of more severe crashes to the driver rather than ROR and hit the fixed object. Considering the accidents on curve sections, the current results make sense because the ROR on curve injury severity could reduce significantly by safety barrier on the side of curve road as object to prevent the vehicle from running out of the road and rollover crashes and functionally can absorb the energy from the crash to reduce crash impact as well as crash severity.

Driver who mounted traffic island are less likely (OR = 3.153, 95% CI = 2.14 – 4.63 minor injury, OR = 2.714, 95% CI = 1.63 – 4.52 severe injury) to die in the accident. This is because of traffic island's function is traffic calming device that force driver to reduce the speed that might lower the crash impact as well as crash severity. Similarly, within the intersection areas, ROR crash type drivers are less likely (OR = 1.372, 95% CI = 1.02 – 1.83) to die in the accident relative to minor injury level. Within intersection areas driver may be more careful when vehicle approach intersection and likely to drive at slower speed. Even though in case of ROR accident due to obstacle ahead, it may not increase driver's severity level.

April is the period that Thailand experiences the highest accident frequency, drivers are likely (OR = 1.278, 95% CI = 1.03-1.58 to fall into severe injury rather than fatal injury in the accident and not significant between fatal and minor injury. However, the fatality frequency during this period is 204 (17.45%) and severely injured is 213 (18.22%) out of 1169 victims were still considerably high when compare to numbers of victims throughout the year.

2.6 Conclusions

In Thailand, single-vehicle ROR accident accounted for 18% of the total crashes and claimed significant loss of life and disability. Therefore, the objective of this study is to identify potential risk factors affecting the driver injury severity of the single-vehicle ROR crash for Thailand highway. Multinomial logit model was used to estimate 9877 accident records and 40 risk factors were included under five factors namely, driver, vehicle, roadway, crash characteristic, and environmental and temporal factors.

The estimated results show that old drivers, male drivers, drivers under influence, drowsiness, ROR to left/right on straight roadway increase the probability of fatal crash, while other factors are found to mitigate severity such as age of driver between 26-35 years old, use of seatbelt, ROR and hit fixed object on straight and curve segment of roadway, mounted traffic island, intersection related and April accident. With regard to the results of the current study, Thailand road safety related authorities are commended to emphasize their future effort on improving education campaigns on road safety for all road users, especially older drivers and male drivers, law enforcement on drunk driving and overspeed driving, and roadside safety features, particularly ROR black spot and curve roads.

The contributions of this study are limited in terms of prediction accuracy due to possible under-reporting data of the police recorded accident reports that may lead to biased estimated results. Secondly, other insufficient information of driver behaviors (such as overcorrection, health condition, driver skill, and ejection), vehicles (vehicle age, size, weigh), road properties (shoulder type, roadside treatment, sides lope, curve radius), and crash characteristics (detail of fixed object, sequences of crash). In spite of these shortcoming, this study is the first attempt that provides an inside statistical method to reveal the risk factors that influencing driver injury severity of single-vehicle ROR crash for Thailand highway. Future research should focus more on validity and reliability of the police crash reports and investigate more contributed risk factors in order to increase prediction accuracy of the model.

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CHAPTER III

DRIVER INJURY SEVERITY IN SINGLE-VEHICLE RUN OFF ROAD CRASH ON 2-LANES AND 4-LANES HIGHWAY IN THAILAND

3.1 Abstract

The aim of this study was to identify factors such as: roadway operational characteristic, crash characteristic, surrounded environment, vehicle type, driver information, severity level of driver, and temporal information, affecting driver injury severity involving in single-vehicle run off road accident occurred on 2-lanes highways and 4-lanes highway using Multinomial Logit model. The analyses used secondary data obtained from police accident record (extracted from Highway Accident Information Management System (HAIMS)). According to result, significant variables of both models move along the same direction. The variables were found to increase chance of fatality are driver older than 55-year-old, driver under influence of alcohol, drowsiness driver, run off road on straight and curve, accident on highways with depressed median and accident on concrete pavement. The variables were found to mitigate severity are adult driver 25-35-year-old, using seat belt, accident on highway with raised median and hit fixed object accident. The contributions of this study were drawn: Thailand related authorities such as Department of Highway or Royal Thai Police should emphasize their effort on education campaigns on road safety for all road users, especially old drivers, enforce the law on drunk driving and

seatbelt; and for road design perspective: monitor and build roadside safety features such as safety barrier alongside the highway particularly run off road black spot and curve roads. The study also mentions the safety benefit of asphalt pavement over concrete pavement for 4-lane highways and safety planner should consider implementing raised median for 2-lane highways in urban area for safety purpose.

3.2 Introduction

According to the global status report on road safety 2018 of World Health Organization (WHO) (Organization, 2018), cause of death due to traffic accident is still in increasing trend from 1.25 million (2013) to 1.35 million (2016) and has been occurring in most of low and middle-income countries across the world. Being one of the middle-income countries, Thailand is reported to be top 10 countries with most accident death rate every year by WHO. Last 5 years, in 2015 fatalities rate due to traffic accident in Thailand was 36.2 (rank second in the world after Libya) and has dropped to only 32.7 in 2018 (rank ninth in the world) per 100, 000 population.

Considering the accidents type in Thailand, run off roadway accident represented the highest in term of occurrences rate (Champahom et al., 2020). From the police report between 2011-2017, according to Figure 1 run off roadway crash in Thailand accounted for 52% out of the total number of crashes (accident data extracted from Highway Accident Information Management System (HAIMS)). This crash type accident was evidently considered as the highest frequency rate and lead to a significant number of injuries and fatalities (Kim, Ulfarsson, Kim, & Shankar, 2013; Wu, Zhang, Zhu, Liu, & Tarefder, 2016). While these accident statistics continue be over-presented, every corner of safety research is definitely worth contributing to seek various safety-countermeasure policies and engineering standpoint in order to radically lower these number.

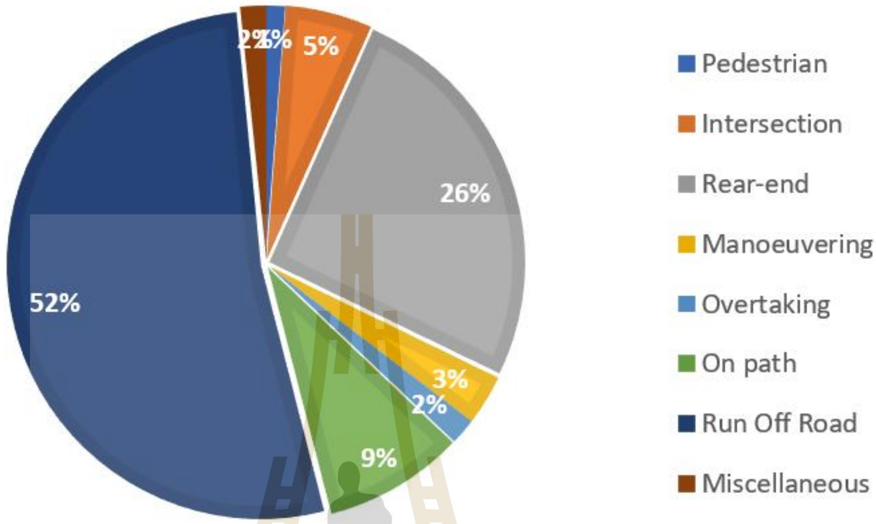

Figure 3.1 Percentage of crash type occurred between 2011 – 2017 (HAIMS)

In single-vehicle run off road crash research, many studies have developed the model to identify the relationship between driver injury severity versus accident related factors such as roadway characteristic, crash characteristic, driver information, vehicle factor and environmental and temporal factor (Kim et al., 2013; Xie, Zhao, & Huynh, 2012; Zhou & Chin, 2019). While these researches provide great contribution, they had limitation due to accounting all crash on all highway that have different number of lanes in a single analysis. The number of lanes of highway might have effect on driver's speed, crash characteristic, performance of the vehicle and different roadway characteristic design that might also have effect on driver injury severity in case of accident. Cross section and geometric elements of the highway has also been found to significantly affect the driver behaviors (Bella, 2013), which consist of some of the most outstanding factors affecting crash severity such as age group, gender, and especially speed utility. The study of accident severity analysis had brought out the potential factor that have significantly relationship with injury severity. With these known safety issue, it can help the safety planner to draw out the countermeasures (redesign the road, monitor traffic safety device, black spot monitoring, and other traffic law for driver) that potentially mitigate severity in the accident for specific region.

The Awadzi, Classen, Hall, Duncan, and Garvan (2008) studied about relationship among crash related factor and the younger and older adult injury in fatal motor vehicle accident. The result show that the number of lanes have the possibility to reduce driver injuries and fatalities. Specifically, the crashes on 2-lanes highway increase higher chance or more severe injury of accident up to 81%, but on 4-lanes highway severity of the accident increase only 23%. Another study by Kashani and Mohaymany (2011) conduct the research study on traffic injury severity on 2-lanes rural road and the result show that improper overtaking and unequip seatbelt are the most important factor affecting the severity of injuries. However, there are no previous study that identify the factors predicting driver injury severity on 4-lanes highways yet. Therefore, this research was the first attempt to differentiate driver injury severity analysis between the single-vehicle run off road on 2-lanes highway and 4-lanes highway.

In term of methodological approach in accident analysis, severity outcomes can be treated as unordered category or natural ordering to analyze the unordered response model and ordered response model, respectively. Numbers of researcher also utilized ordered framework for their accident severity analysis, namely generalized ordered logit (Abegaz, Berhane, Worku, Assrat, & Assefa, 2014; Kaplan & Prato, 2012; Yasmin, Eluru, Bhat, & Tay, 2014), heteroscedastic ordered logit (Wang & Kockelman, 2005a, 2005b) and ordered probit (Abdel-Aty, 2003). However, one of the most commonly used unordered respond framework; multinomial logit, was used to identify the risk factors affecting severity of motorcycle crash (Chimba & Sando, 2010), injury severity of the road accident in the Erzurum and Kars province of Turkey (Celik & Oktay, 2014), and pedestrian-vehicle crash severity (Tay, Choi, Kattan, & Khan, 2011). The advantages of the unordered response model over the ordered response model are providing more flexible control over the interior category probability as state in (Celik & Oktay, 2014) and no need to account for ordinal categorical outcome while the ordered response model occasionally urge unrealistic parameter restriction (Savolainen, Mannering, Lord, & Quddus, 2011). Therefore, in this study, Multinomial logit is adopted for single-vehicle run off road crash driver injury severity analysis for Thailand Highway. The mains objectives of this study are to use multinomial logit model to identify the relationship between crash related factor (roadway characteristic, crash characteristic, driver characteristic, vehicle; and environmental and temporal characteristic) with driver injury severity involved in single vehicle run off road accident on 2-lanes highway and 4-lanes highway; and provide potential safety countermeasure for related authorities and safety planner base on the finding of the current study

3.3 Methodology

3.3.1 Methodological approach

In In econometric study, the injury severity study is commonly well suited with discrete outcome model (Schneider, Savolainen, & Zimmerman, 2009), since level of injury sustained is classified as one of three dichotomous injury severity categories: Minor injury, severe injury, and fatality. When classification of injury severity is more than two level, multinomial logit is well applicable and has been widely used by many previous research study (Geedipally, Turner, & Patil, 2011; Schneider et al., 2009; Shankar & Mannering, 1996; Wu, Zhang, Ci, et al., 2016). Therefore, this study developed the multinomial logit model for analysis to identify the potential factors affecting the driver severity of single-vehicle run off road crash on 4-lanes highway and on 2-lanes highway. Severity of the driver is specified into three level: Minor Injury (include properties damage only), Severe injury (seriously injured), Fatal (died at hospital/at accident point). As well discussed by (Chen & Fan, 2019; Shankar & Mannering, 1996): suppose that T_{ij} is the linear function that determine the severity level j and P_{ij} is the probability of a driver i have severity j, thus T_{ij} and P_{ij} and can be derived as:

$$Tij = \quad jXij + £ij \tag{3.1}$$

$$Pij = \frac{EXP[\quad jXij]}{\sum_j EXP[\quad jXij]} \tag{3.2}$$

Where β_j is a vector of the coefficients to be estimated for injury severity outcome j, X_{ij} is the vector of explanatory variable and ε_{ij} is the unobserved random error. Odd ratio is the exponential of value βj ($exp(\beta j)$) of each significant risk factors and was used to interprets the estimated results. Odd ratio > 1 indicates an increase probability and odd ration < 1 indicates a decrease of probability of that injury severity with relative to base category injury severity.

3.3.2 Data collection

This study proposes to investigate the driver injury severity of single-vehicle run off road accident occurred on 2-lanes highway and 4-lanes highway by using the secondary data obtained from police accident record (Highway Accident Information Management System (HAIMS)) that contained the detail information about each accident case such as crash type (rear-end, run off road, pedestrian, intersection, overtaking, on path, etc.), surrounded environment (raining, wet road, dusty road, etc.), vehicle type, driver information (sex, age, driver condition, etc.), level of severity of the driver (minor injury, severe injury, die at hospital and die at accident point), highway information (road condition, median type, U-turn, pavement type, horizontal and vertical alignment etc.), and temporal information (time of accident, day/night, and date of accident). Same as many previous researches, this study use three level of driver injury severity: fatal (driver who either die at accident point or at hospital), severe injury (driver who severely injured in the accident and need hospitalization), minor injury (driver who result in minor injury due to accident and don't need hospitalization, or properties damage only (PDO)). Then data is further extracted only single-vehicle run off road crash from the whole data set. This study gather data from past 7 years from 2011 to 2017. After that, data is divided into two data subset bases on number of lanes which were single-vehicle accident on 2-lanes highway and single-vehicle accident on 4-lanes highway. According to Table 3.1, there were 2693 single-vehicle accident case on 2-lane highway and killed 449 drivers; and, 5887 single-vehicle accident case on 4-lane highway and killed 761 drivers. Table 3.2 and Table 3.3 present description of all variables that were considered in the analysis.

Table 3.1 Accident frequency on 2-lanes road and 4-lanes road

Number of Lane	Minor injury	Severe injury	Fatal	Total
2-Lanes Road	1873	371	449	2693
4-Lanes Road	4275	851	761	5887
Total	6148	1222	1210	8580

Table 3.2 Explanatory variables description

Variable	Description
Driver Characteristic	
AGE_26_35	1 = Driver age was between 26-35, 0 = Otherwise
AGE_36_45	1 = Driver age was between 36-45, 0 = Otherwise
AGE_46_55	1 = Driver age was between 46-55, 0 = Otherwise
AGE_56_UP	1 = Driver age was older than 55, 0 = Otherwise
Gender	1 = Male driver, 0 = Female driver
SAF_EQ	1 = Driver use seatbelt, 0 = Otherwise
ALCOHOL	1 = Driver under effect of alcohols, 0 = Otherwise
EXEED_SPEED	1 = Driver drive with exceed speed limit, 0 = Otherwise
FALL_ASLEEP	1 = Driver fall asleep while driving, 0 = Otherwise
Road Characteristic	
R_COND	1 = Accident occur at area of road maintenance, 0 = Otherwise
R_SURF	1 = Pavement type is asphalt, 0 = Pavement type is concrete
HORIZONTAL	1 = Accident occur on the curve road section, 0 = Otherwise
VERTICAL	1 = Accident occur on the graded road section, 0 = Otherwise
INTERSECTION	1 = Accident occur within Intersection, 0 = Otherwise
U_TURN	1 = Accident occur within U-turn, 0 = Otherwise
COMMUNITY	1 = Accident occur within community area, 0 = Otherwise
NO_MEDIAN	1 = Accident occur on road without median, 0 = Otherwise
RAISED_MEDIAN	1 = Accident occur on road with raised median, 0 = Otherwise
DEPRES_MEDIAN	1 = Accident occur on road with depressed median, 0 = Otherwise
Vehicle Characteristic	
PASSENGER_CAR	1 = Vehicle in accident is passenger car, 0 = Otherwise
PICKUP_INVOLVE	1 = Vehicle in accident is pickup truck with 4 wheels, 0 = Otherwise

Table 3.2 Explanatory variables description (Continued)

Variable	**Description**
TRUCK_INVOLVE	1 = Vehicle in accident is heavy truck and trailer, 0 = Otherwise
Crash Characteristic	
MOUNT_ISLAND	1 = If the vehicle mounted the traffic island, 0 = Otherwise
PASS_INFRONT	1 = Accident occur due to something pass in front, 0 = Otherwise
DEFECT_CAR	1 = Accident occur due to defective car device, 0 = Otherwise
OFF_LEFT_STRAIGHT	1 = Vehicle run off road to the left on straight, 0 = Otherwise
OFF_RIGHT_STRAIGHT	1 = Vehicle run off road to the right on straight, 0 = Otherwise
LEFT_FIXED_STRAIGHT	1 = Vehicle run off road to the left and hit fixed object, 0 = Otherwise
RIGHT_FIXED_STRAIGHT	1 = Vehicle run off to road the right and hit fixed object, 0 = Otherwise
ACROSS_MEDIAN	1 = Vehicle run off road and across median, 0 = Otherwise
OFF_LEFT_CUVE	1 = Vehicle run off road during on left bend, 0 = Otherwise
OFF_RIGHT_CUVE	1 = Vehicle run off road during on right bend, 0 = Otherwise
LEFT_FIXED_CURVE	1 = Vehicle run off during left bend and hit fixed object, 0 = Otherwise
RIGHT_FIXED_CURVE	1 = Vehicle run off during right bend and hit fixed object, 0 = Otherwise
Environmental and Temporal Characteristic	
EN_SURF	1 = Accident occur on wet road, 0 = Accident occur on dry road
EN_STAT	1 = Accident occur on wavy or dirty road, 0 = Otherwise
EN_WEATHER	1 = Accident occur during raining, dust, foggy, 0 = Otherwise
EN_LIGHT	1= Accident occur during nighttime, 0 = Otherwise
TIMEGROUP	1 = Accident happened between 6 pm and midnight, 0 = Otherwise
APRIL_ACCIDENT	1 = Accident happened in April, 0 = Otherwise

Table 3.3 Driver injury frequency and percentage distribution for 2-lane highway

Variable	**2-lane highway accident**					
	Fatal		**Severe**		**Minor**	
AGE_26_36	118	4.38%	112	4.16%	639	23.73%
AGE_36_46	115	4.27%	101	3.75%	461	17.12%
AGE_46_56	82	3.04%	56	2.08%	317	11.77%
AGE_56_UP	50	1.86%	32	1.19%	162	6.02%
GENDER (female)	43	1.60%	38	1.41%	221	8.21%
GENDER (male)	406	15.08%	333	12.37%	1652	61.34%
SAF_EQ	146	5.42%	124	4.60%	813	30.19%
ALCOHOL	26	0.97%	14	0.52%	47	1.75%
EXEED_SPEED	297	11.03%	273	10.14%	1358	50.43%
FALL_ASLEEP	78	2.90%	46	1.71%	229	8.50%
R_COND	18	0.67%	18	0.67%	42	1.56%
R_SURF (concrete)	9	0.33%	4	0.15%	32	1.19%

Table 3.3 Driver injury frequency and percentage distribution for 2-lane highway (Continued)

Variable	2-lane highway accident					
	Fatal		Severe		Minor	
R_SURF (asphalt)	440	16.34%	367	13.63%	1841	68.36%
HORIZONTAL	220	8.17%	152	5.64%	882	32.75%
VERTICAL	93	3.45%	74	2.75%	365	13.55%
INTERSECTION	19	0.71%	18	0.67%	144	5.35%
U_TURN	3	0.11%	2	0.07%	29	1.08%
COMMUNITY	4	0.15%	3	0.11%	17	0.63%
NO_MEDIAN	422	15.67%	335	12.44%	1705	63.31%
RAISED_MEDIAN	5	0.19%	17	0.63%	65	2.41%
DEPRES_MEDIAN	9	0.33%	7	0.26%	34	1.26%
PASSENGER_CAR	138	5.12%	112	4.16%	611	22.69%
PICKUP_INVOLVE	198	7.35%	175	6.50%	851	31.60%
TRUCK_INVOLVE	85	3.16%	55	2.04%	319	11.85%
MOUNT_ISLAND	11	0.41%	24	0.89%	96	3.56%
PASS_INFRONT	7	0.26%	7	0.26%	46	1.71%
DEFECT_CAR	21	0.78%	22	0.82%	82	3.04%
OFF_LEFT_STRAIGHT	103	3.82%	69	2.56%	173	6.42%
OFF_RIGHT_STRAIGHT	53	1.97%	19	0.71%	56	2.08%
LEFT_FIXED_STRAIGHT	46	1.71%	69	2.56%	446	16.56%
RIGHT_FIXED_STRAIGHT	20	0.74%	43	1.60%	226	8.39%
ACROSS_MEDIAN	2	0.07%	0	0.00%	8	0.30%
OFF_LEFT_CUVE	51	1.89%	21	0.78%	92	3.42%
OFF_RIGHT_CUVE	37	1.37%	29	1.08%	70	2.60%
LEFT_FIXED_CURVE	47	1.75%	44	1.63%	298	11.07%
RIGHT_FIXED_CURVE	60	2.23%	41	1.52%	357	13.26%
EN_SURF (dry)	388	14.41%	310	11.51%	1529	56.78%
EN_SURF (wet)	61	2.27%	61	2.27%	344	12.77%
EN_STAT	4	0.15%	1	0.04%	7	0.26%
EN_WEATHER	72	2.67%	72	2.67%	383	14.22%
EN_LIGHT	223	8.28%	174	6.46%	859	31.90%
TIMEGROUP	94	3.49%	74	2.75%	364	13.52%
APRIL_ACCIDENT	75	2.78%	76	2.82%	256	9.51%

Table 3.4 Driver injury frequency and percentage distribution for 4-lane highway

Variable	4-lane highway accident					
	Fatal		Severe		Minor	
AGE_26_36	248	4.21%	285	4.84%	1470	26.31%
AGE_36_46	192	3.26%	210	3.57%	1040	18.61%
AGE_46_56	129	2.19%	136	2.31%	648	11.60%
AGE_56_UP	71	1.21%	58	0.99%	343	6.14%
GENDER (female)	83	1.41%	102	1.73%	598	10.70%
GENDER (male)	678	11.52%	749	12.72%	3677	65.81%
SAF_EQ	279	4.74%	360	6.12%	1832	32.79%
ALCOHOL	15	0.25%	14	0.24%	40	0.72%
EXEED_SPEED	559	9.50%	683	11.60%	3450	61.75%
FALL_ASLEEP	139	2.36%	106	1.80%	482	8.63%
R_COND	14	0.24%	11	0.19%	82	1.47%
R_SURF (concrete)	59	1.00%	77	1.31%	226	4.05%
R_SURF (asphalt)	702	11.92%	774	13.15%	4009	71.76%
HORIZONTAL	190	3.23%	196	3.33%	1071	19.17%
VERTICAL	47	0.80%	64	1.09%	284	5.08%
INTERSECTION	31	0.53%	53	0.90%	296	5.30%
U_TURN	44	0.75%	99	1.68%	526	9.41%
COMMUNITY	6	0.10%	12	0.20%	40	0.72%
NO_MEDIAN	53	0.90%	53	0.90%	245	4.39%
RAISED_MEDIAN	190	3.23%	276	4.69%	1457	26.08%
DEPRES_MEDIAN	453	7.69%	449	7.63%	2126	38.05%
PASSENGER_CAR	256	4.35%	333	5.66%	1526	27.31%
PICKUP_INVOLVE	326	5.54%	360	6.12%	1936	34.65%
TRUCK_INVOLVE	90	1.53%	88	1.49%	566	10.13%
MOUNT_ISLAND	119	2.02%	251	4.26%	1366	24.45%
PASS_INFRONT	14	0.24%	14	0.24%	94	1.68%
DEFECT_CAR	20	0.34%	16	0.27%	134	2.40%
OFF_LEFT_STRAIGHT	146	2.48%	81	1.38%	234	4.19%
OFF_RIGHT_STRAIGHT	107	1.82%	55	0.93%	179	3.20%
LEFT_FIXED_STRAIGHT	81	1.38%	123	2.09%	685	12.26%
RIGHT_FIXED_STRAIGHT	89	1.51%	135	2.29%	728	13.03%
ACROSS_MEDIAN	30	0.51%	29	0.49%	93	1.66%
OFF_LEFT_CUVE	36	0.61%	17	0.29%	100	1.79%
OFF_RIGHT_CUVE	33	0.56%	18	0.31%	92	1.65%
LEFT_FIXED_CURVE	50	0.85%	62	1.05%	342	6.12%
RIGHT_FIXED_CURVE	49	0.83%	70	1.19%	381	6.82%

Table 3.4 Driver injury frequency and percentage distribution for 4-lane highway (Continued)

Variable	4-lane highway accident					
	Fatal		Severe		Minor	
EN_SURF (dry)	49	0.83%	70	1.19%	281	5.03%
EN_SURF (wet)	157	2.67%	168	2.85%	943	16.88%
EN_STAT	2	0.03%	4	0.07%	15	0.27%
EN_WEATHER	162	2.75%	171	2.90%	1000	17.90%
EN_LIGHT	335	5.69%	408	6.93%	1952	34.94%
TIMEGROUP	113	1.92%	150	2.55%	684	12.24%
APRIL_ACCIDENT	105	1.78%	110	1.87%	416	7.45%

3.4 Result and Discussion

In this study, the program R version 3.6.1 was used to analyses two separate model: the single-vehicle run off road on 2-lanes highway model and on 4-lanes highway accident model. Minimum recommend sample size of multinomial logit is 2000 observations (Ye & Lord, 2014), which help confident interval get smaller and stays stable around true value and eliminate biases in estimating mean value of variables for all coefficients, thus this study sample size was warranted. First, all the explanatory variables were included in the analysis; and then, final models were conducted by excluding the explanatory variable that were not statistically significant at 0.10 from the fist analysis. The model fit information show that: accident on the 2-lanes highway model has Log-Likelihood (convergence): -2072, Likelihood ratio test: χ^2 = 409.36 (sig < 0.000); McFadden ρ^2: 0.066 and the 4-lane model has Log-Likelihood(convergence): -4366, Likelihood ratio test: χ^2 = 295.65 (sig < 0.000); Both McFadden R^2 in the model are small because the value of likelihood at convergence (LL(C)) is close to likelihood null model (LL(0)) that explain the weak relationship between dependent and independent variable (ρ^2 = 1-LL(C)/LL(0)) but acceptable as in the past study (Ratanavaraha & Suangka, 2014; Rifaat & Chin, 2007). The variables that significantly affect driver severity at 0.1 significant level (90% confidence level) are obtained for result interpretation, which was also used in previous studies (Champahom et al., 2020; Weiss, Kaplan, & Prato, 2014). The model results are presented in Table 3.5 and Table 3.6.

Table 3.5 Estimated result of multinomial logit for 4-lanes highway Accident model

Variable	Estimate (Std. Error)	Odd Ratio
Minor:(intercept)	1.545 (0.238) ***	-
Severe:(intercept)	0.305 (0.290)	-
Severe: AGE_56_UP	-0.352 (0.188) *	0.70
Minor: GENDER	-0.304 (0.132) **	0.74
Minor: SAF_EQ	0.342 (0.086) ***	1.41
Severe: SAF_EQ	0.310 (0.106) ***	1.36
Minor: ALCOHOL	-0.770 (0.324) **	0.46
Minor: FALL_ASLEEP	-0.376 (0.112) ***	0.69
Severe: FALL_ASLEEP	-0.308 (0.144) **	0.74
Minor: R_SURF	0.281 (0.156) *	1.32
Minor: U_TURN	0.473 (0.166) ***	1.60
Severe: U_TURN	0.473 (0.192) **	1.60
Minor: DEPRES_MEDIAN	-0.213 (0.086) **	0.81
Minor: PASSENGER_CAR	0.592 (0.148) ***	1.81
Severe: PASSENGER_CAR	0.384 (0.185) **	1.47
Minor: PICKUP_INVOLVE	0.612 (0.144) ***	1.84
Minor: TRUCK_INVOLVE	0.748 (0.175) ***	2.11
Minor: OFF_LEFT_CUVE	-1.077 (0.203) ***	0.34
Severe: OFF_LEFT_CUVE	-1.164 (0.302) ***	0.31
Minor: OFF_RIGHT_CUVE	-1.094 (0.212) ***	0.34
Severe: OFF_RIGHT_CUVE	-1.025 (0.301) ***	0.36
Minor: OFF_LEFT_STRAIGHT	-1.545 (0.120) ***	0.21
Severe: OFF_LEFT_STRAIGHT	-0.934 (0.154) ***	0.39
Minor: OFF_RIGHT_STRAIGHT	-1.461 (0.137) ***	0.23
Severe: OFF_RIGHT_STRAIGHT	-0.986 (0.182) ***	0.38

Base category: Fatal

Significant codes: ‘***’ 0.01; ‘**’ 0.05; ‘*’ 0.1

LL(convergence): -4366

LL(null): -4571

McFadden ρ^2: 0.045

Likelihood ratio test: χ^2 = 409.36 (sig = < 0.000)

Table 3.6 Estimated result of multinomial logit for 2 lanes highway Accident

Variable	**Estimate (Std. Error)**	**Odd Ratio**
Minor:(intercept)	1.465 (0.111) ***	-
Severe:(intercept)	-0.276 (0.149) *	-
Minor: AGE_26_35	0.426 (0.124) ***	1.53
Minor: SAF_EQ	0.477 (0.116) ***	1.61
Minor: ALCOHOL	-0.877 (0.271) ***	0.42
Minor: FALL_ASLEEP	-0.370 (0.155) **	0.69
Severe: FALL_ASLEEP	-0.419 (0.207) **	0.66
Minor: RAISED_MEDIAN	0.912 (0.475) *	2.49
Severe: RAISED_MEDIAN	1.417 (0.520) ***	4.12
Minor: OFF_LEFT_CUVE	-1.124 (0.200) ***	0.33
Severe: OFF_LEFT_CUVE	-0.729 (0.290) **	0.49
Minor: OFF_RIGHT_CUVE	-1.129 (0.226) ***	0.33
Minor: OFF_LEFT_STRAIGHT	-1.136 (0.158) ***	0.32
Minor: OFF_RIGHT_STRAIGHT	-1.633 (0.217) ***	0.20
Severe: OFF_RIGHT_STRAIGHT	-0.843 (0.299) ***	0.43
Minor: LEFT_FIXED_STRAIGHT	0.585 (0.182) ***	1.79
Severe: LEFT_FIXED_STRAIGHT	0.618 (0.229) ***	1.86
Minor: RIGHT_FIXED_STRAIGHT	0.735 (0.252) ***	2.09
Severe: RIGHT_FIXED_STRAIGHT	0.979 (0.299) ***	2.66
Severe: APRIL_ACCIDENT	0.439 (0.188) **	1.55

Base category: Fatal

Significant. codes: ‘***’ 0.01; ‘**’ 0.05; ‘*’ 0.1

LL(convergence): -2072

LL(null): -2220

McFadden ρ^2: 0.066

Likelihood ratio test: χ^2 = 295.65 (sig = < 0.000)

3.4.1 Driver factors

Driver characteristic were found to significantly affect injury severity in any type of crashes (Abdel-Aty, 2003; Islam & Mannering, 2006; Yau, 2004). In this study analysis, young driver (age less than 26 years old is coded as “otherwise” in each age group) was chosen to be reference level to interpret result of all other age group result. According to the result, in single-vehicle accident on 4-lanes highway, the variable AGE_56_UP have the negative coefficient. This show that the driver whose age older than 55 years old have higher possibility (Odd ratio Sever: AGE_56_UP = 0.7) of fatal in the accident. In contrast, the variable AGE_26_35 was found to have positive coefficient meaning that young driver age between 26-35 years old tend to mitigate severity (Odd ratio Minor: AGE_26_35 = 1.53) in single-vehicle accident on 2-lane Highways. In both analysis model, the result of the variable ALCOHOL and FALL_ASLEEP show that driver involved in the accident due to effect of alcohol and drowsiness have higher chance (4-lanes accident Odd ratio Minor: ALCOHOL = 0.46, Odd ratio Minor: FALL_ASLEEP = 0.69, Odd ratio Severe: FALL_ASLEEP = 0.74 and 2-lanes accident Odd ratio Minor: ALCOHOL = 0.42, Odd ratio Minor: FALL_ASLEEP = 069, Odd ratio Severe: FALL_ASLEEP = 0.66) in get into fatal crash rather than injury crash. The result of variable SAF_EQ show that drivers who uses seatbelt are more likely to escape fatal chance (4-lanes accident Odd ratio Minor: SAF_EQ = 1.41, Severe: SAF_EQ = 1.36; and 2-lanes accident Minor: SAF_ EQ = 1.61) than driver who did not use seatbelt. These results confirm the finding of Xie et al. (2012) which suggest that young driver tend to receive less severe injury, old driver are likely to involve in more severe crash, driver under influence tend to involve in severe or fatal crash, and seatbelt could mitigate driver injury severity. The effect of fatigue increase the chance of fatal crash that is in line with the finding of (Spainhour & Mishra, 2008; Srinivasan, 2002).

3.4.2 Road factors

Road characteristic were also found to be correlated with driver injury severity for both models. In single-vehicle accident on 4-lane highway, the result show that: the positive coefficient of variable R_SURF suggest that accident on concrete pavement tend to be more severe (Odd ratio Minor: R_SURF = 1.32) than those that happened on asphalt pavement. Pavement is generally known as the factor relate to the quality of the ride, but there is limited understanding its relationship to the traffic crash. This result is consensus with the finding of the study of Li, Liu, and Ding (2013) that found that accident happened on Jointed Concrete Pavement (JCP) had significant higher severity outcome and the reason is probably because JCP pavement failures are frequently located at pavement joints and such failures sometimes result in major impact to the driving condition. Vehicles maneuvering to avoid failure areas while driving at a relatively high speed on JCP pavements could lead to severe crashes, especially 2 lane highway. However, this result is doubtful and further research investigation between extra detail information of pavement and accident outcome is recommended. Accident within U-turn area, drivers tend to sustain injury (Odd ration Minor: U_TURN = 1.6, Severe: U_TURN = 1.6) with respect to fatal crash. In Thailand, most of the U-turns are opened on road with low traffic volume, residential area and urban street. This could be because driver tend to drive at slow speed when approaching U-turn area due to their awareness of the vehicle queued to make U-turn. The Variable DEPRES_MEDIAN (Odd ration Minor: DEPRES_MEDIAN = 0.81) coefficient shows that driver have higher possibility of getting in fatal crash with respect to minor injury. While the 2-lane accident model result show that positive coefficient of variable RAISED_MEDIAN (Odd ration

Minor: RAISED_MEDIAN = 2.49, Severe: RAISED_MEDIAN = 4.12) suggest that there are higher chance of driver being in minor or sever injury rather than die in the accident (2.49 and 4.12 times higher respectively). The possible explanation of the accident on 4 lane highway with depressed median increasing chance of fatality is that when the vehicle drive at high speed and run of roadway into depressed median, vehicle tend to rollover in the crash due to inclination of the slope. The rollover crash was more likely to be more severe type of crash due to its extreme crash characteristic. However, raised median are frequently used in the urban arterial streets (Garber & Hoel, 2009). The reason raised median help driver mitigate severity is that it acts as traffic-calming device that is installed to reduce the vehicle speed. This finding is consensus with result of previous studies (Al-Bdairi & Hernandez, 2017; Schultz, Thurgood, Olsen, & Reese, 2011).

3.4.3 Vehicle factors

From the police reports, the only vehicle factor known was vehicle type. Only on the 4-lane highway accident model were found that vehicle type has statistical relationship with driver injury severity. The positive coefficient show that passenger car, pickup truck, and truck driver sustain injury severity (Odd ratio Minor: PASSENGER_CAR = 1.81, Minor: PICKUP_INVOLVE) =1.84 and Minor: TRUCK_INVOLVE = 2.11). This result is in line with the finding of (Kockelman & Kweon, 2002) that found that light-duty truck (minivans, SUVs, and pickups truck) appear to protect the driver from more severe injury.

3.4.4 Crash factors

4-lane and 2-lane accident crash model: Run off road on horizontal curve increase the chance of fatal crash (with the share of odd ratio approximately 0.31). This result indicates that single-vehicle accident on horizontal curve is 1/0.31 = 3.22 times higher chance to die in the crash relative to both minor and severe injury. This finding is consensus with the study of (Liu & Subramanian, 2009) that also found that roadway alignment with curve were significantly associated with high risk of fatal crash. In the result of 4-lanes highway accident model: Run off road to left/right on straight increase the chance of fatal crash (Odd Ration approximately 0.23). 2-lane accident crash model: the variable Minor: OFF_RIGHT_STRAIGHT have odd ratio of 0.2 (5 times higher chance) Minor: OFF_LEFT_STRAIGHT have odd ratio of 0.33 (3 times higher chance). Both results indicate that single-vehicle to both directions increase the chance of fatality. However, when the run off road to the right side, it creates higher chance of fatality to the driver. Noticeably, the odd ratio of variable minor and sever of LEFT_FIXED_STRAIGHT is 1.79 and 1.86 respectively; and odd ratio of variable minor and sever of RIGHT_FIXED_STRAIGHT is 2.09 and 2.66 respectively on only 2-lanes accident model.

3.4.5 Temporal factor

In Thailand, Songkran is the nation holiday last for 3 days every year between 13th April till 15th April. During this time period, the road accident reaches its peek frequency due to an increasing number of car travel on the highway. Thai authorities, every year, launch road safety campaign prior to the holiday in order to reduce accidents. The police also strictly enforce the traffic law and put firmly attention on the focus on driver under influence of alcohol. Drunk driving and speeding were the foremost causes of accident. On the other hand, in the 4-lanes highway accident model there were no significant factor; but, in 2-lane highway accident model's result show that accident during April, driver increase chance of get into severe injury (Odd ratio = 1.55) relative to fatality in the accident. However, there was no significant between minor injury relative to fatality.

3.5 Conclusions

This paper used the statistical model to find potential crash related factor such as: driver, road geometry, crash characteristic, vehicle, and environment and temporal factor that significantly influence on driver injury in single vehicle run off road crash on 2-lane highway and 4-lane highway. Accident data was extracted from the police report of Highway Accident Information Management System (HAIMS). Arrangement of data was structured to fit the one of the most commonly used discrete outcome model, multinomial logit model. Time frame of data to be used in the analysis was between 2011 – 2017). There were 2693 single-vehicle accident case on 2-lane highway and 5887 single-vehicle accident case on 4-lane highway.

The important findings of this study showed that driver older than 55 years tend to involve in more severe crash in the single vehicle run off road crash on 4 lanes highway and young driver between 25-35 years old were likely to mitigate severity on 2-lane highway. Accident on both type of highway, using seatbelt was also found to help the driver sustain their injury in the crash and drowsiness and drunk driver were found to have strongly associated with the fatal single-vehicle crash. The 4-lane highway accident with depressed median increase chance of fatality, but 2-lanes highway accident with raised median reduce chance of fatality. The accident on concrete pavement was found to increase chance that driver dies in the accident. In term of crash characteristic, single-vehicle accident on both highways were found to increase the chance of fatality on both curve road and on straight road section. However, if the vehicle run off road to hit the fixed objection on the side of the road, this manner was found to help driver sustain the injury severity.

Base on the finding, this study gives the recommendation as follow: Thailand authorities such as DOH (Department of Highway) and Royal Thai Police should emphasize their effort on improving education campaigns on road safety for all road users, especially older drivers and enforce the law on drunk driving and seatbelt. Additionally, roadside safety features such as safety barrier alongside the highway particularly run off road black spot and curve roads. This study also recommend that asphalt pavement is safer than the concrete pavement or additional benefit of the concrete pavement could be obtained by providing additional layer of asphalt on top the concrete slab. however, further research investigation should be carried out by using addition detail information about pavement at accident location in order to obtain more accurate result. Lastly, within all urban area, safety planner should consider implementing raised median to improve safety for driver in case of accident.

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CHAPTER IV

COMPARING DRIVER INJURY SEVERITY IN SINGLE-VEHICLE CRASH BASED ON AGE: APPLICATION OF MULTILEVEL LOGISTIC MODEL WITH ROAD-SEGMENT HETEROGENEITY

4.1 Abstract

There have been many studies that identify effect of age on driver injury severity in single vehicle crash. Most of these studies grouped age into several age-groups and investigate it in a single model analysis, while there were very few studies that separate data into several subset data base on number of created age group and analyze each subset separately utilized traditional discrete choice model without accounting for unobserved heterogeneity. To fulfill this research gap, a seven-year single-vehicle crash data set including all available crash related factor from 2011-2017 in Thailand, is adopted in this study. Multilevel logistic model is selected to compare driver injury severity in single-vehicle crash based on age-group with road-segment heterogeneity. Important findings show that influence of alcohol and fatigue increase risk of fatal crash among young and old driver, seatbelt-usage reduce risk of being fatal among mid-age and old driver, roadside feature such as guardrail significantly reduce fatality risk among young and mid-age driver, and night time driving without light increase probability of fatality for mid-age driver. This study

also provides insightful understand -ing of the impacts of all significant variables on severity outcome, and appropriate countermeasures and strategies in order to improve safety for driver involve in single-vehicle accident.

4.2 Introduction

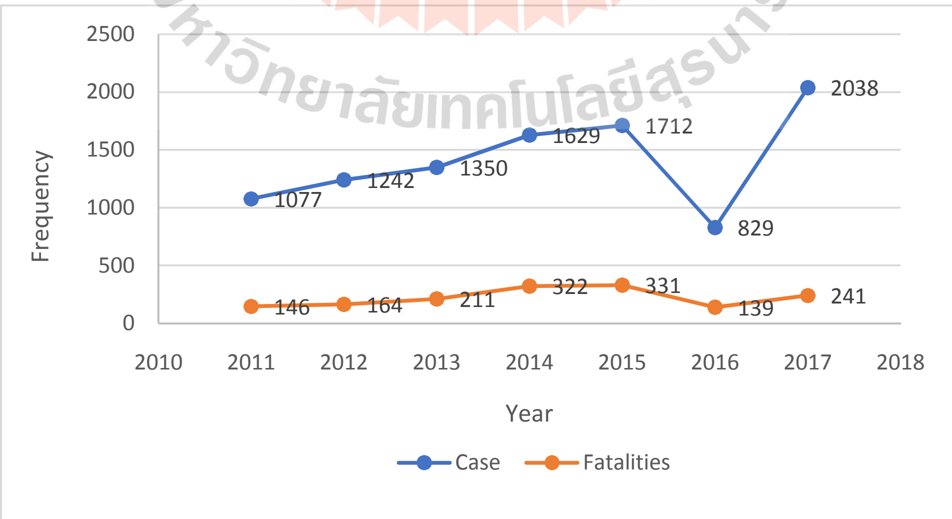
Single vehicle crash has been reported to be the most frequently occurred accident classifying by crash type and posed number of serious and fatal crashes in recent years. Between 2011-2017, there were a continuous increasing trend of single-vehicle accident rate (DOH, 2012, 2013, 2014, 2015, 2016, 2017, 2018) (see Figure 1). Within this period, there were 9877 case with 1361 driver fatalities (13.78%) of all single-vehicle crash cases. According to the police accident report examined in this study, fatalities rate was varied among three age groups. As shown in table 1, while old driver accounted the highest fatality rate at 16.21 %, young and mid-age driver has fatality rate of 13% and 13.35% respectively. Reasonable explanation could be because of age is correlated with each an individual's physical characteristic, reaction time, perceive risk taking which likely to influence injury severity (Mannering, Shankar, & Bhat, 2016).

There were numerous studies about effect of age on driver injury severity in single-vehicle crash. For example, J.-K. Kim, Ulfarsson, Kim, and Shankar (2013) 's study show that old driver is strongly associated with fatal single vehicle crash than mid-age and young driver which was consensus with the finding of (Xie, Zhao, & Huynh, 2012). Another study by Weiss, Kaplan, and Prato (2014) specifically on only young driver show that seatbelt non-used, drunk driving, and inexperience are highly influence fatal crash. Islam and Mannering (2006) studied the effect of age on gender in single-vehicle crash and the result show that substantial and statically significant, different exist between driver age injury severity. Regarding age in safety analysis, most of the studies (J.-K. Kim et al., 2013; Shaheed & Gkritza, 2014; Wu, Zhang, Zhu, Liu, & Tarefder, 2016; Xie et al., 2012; Zhou & Chin, 2019) grouped age into several age-groups to make one explanatory variable (with indicator 0,1,2,3..etc.) or several explanatory (each indicated by 1 = age, 0 = otherwise); and investigate in only one model analysis, while there was fewer study (Dissanayake, 2004; Islam & Mannering, 2006) that separate data into several subset data base on number of created age group and analyze each subset separately. The obvious advantage of separating data in subset is that it could provide more accurate and detail result about factor influencing crash severity in each age group to see how difference human characteristic, crash characteristic, vehicle characteristic, road characteristic, and environmental characteristic impact on driver injury severity between each age group. Therefore, separate test model based on aging is essential since age of driver highly influence driver behavior, perception and perceive risk level. This action was largely ignored in the previous literature of single-vehicle crash study.

To account unobserved heterogeneity in severity analysis has become critically important issues for researcher because, although the collected data are adequate to offer all detail information with multiple variables and descriptions, there are always some unobserved factor cannot be fully addressed (Li et al., 2018). For instant, road characteristic between road section are different such as shoulder width, lane width or median type that will considerably have different effect on severity depending on the speed of impact, angle of impact, and it resulting injury severity could possibly vary widely from one road-segment to the next (additional detail about possible unobserved heterogeneity see (Mannering et al., 2016)). To resolve this issue, accident analysis studies have adopted and applied advance discrete choice model in order to obtained the most accurate and reliable result from their statistical analysis. Two popular approaches, random parameters model (Behnood & Mannering, 2015; Haleem & Gan, 2013; J.-K. Kim et al., 2013; Li et al., 2019; Wu et al., 2014; Wu, Zhang, Chen, et al., 2016; Wu, Zhang, Zhu, et al., 2016) and finite-mixture model (latent class) (Adanu, Hainen, & Jones, 2018; Behnood, Roshandeh, & Mannering, 2014; Cerwick, Gkritza, Shaheed, & Hans, 2014; Shaheed & Gkritza, 2014; Xie et al., 2012; Yu, Li, Zhang, & Liu, 2019) are recommended as cutting-edge method to address the unobserved factor (Mannering et al., 2016). In spite of their strength, disadvantages of theses model was were presented in previous study (C. Chen, Zhang, Tian, Bogus, & Yang, 2015) where Random parameters are not able to capture the heterogeneity across different data groups which result in biased estimation, and latent class logit neglect the observation heterogeneity within each data group due to the assumption of observation homogeneity in each group. Accident data can be arranged into multiple level hierarchically, which mean that: driver, vehicle, or weather characteristic stand in the first level; while, road section or specific area (e.g. road-segment) at higher level (Dupont, Papadimitriou, Martensen, & Yannis, 2013). Therefore, appropriate methodological approach was proposed and widely used, hierarchical logistic model (Champahom et al., 2020; C. Chen et al., 2016; C. Chen et al., 2015; Huang, Chin, & Haque, 2008) Multilevel model is well-known due to ability to allow correlation of explanatory variable within hierarchical cluster and ability to account unobserved heterogeneity at the same time. The correlation within cluster (higher level) often violate the assumption of residual independence that was assumed in many methodological approach and if this correlation is left uncheck, the consequence is parameter estimate tend toward zero, bias parameters estimate, bias standard error or heterogeneity of the regression (D.-G. Kim, Lee, Washington, & Choi, 2007; Raudenbush & Bryk, 2002); therefore, multilevel modeling was proposed to solve this issue.

As discussed above factors such as driver age, gender, weather factor, etc. might have interaction effect with roadway geometry which also vary according to road-segment that may contribute to driver injury severity. So, to account both correlation between unobserved and observed factor, and the unobserved heterogeneity, multilevel logistic model is adopted for this study. Moving in the same direction, as shown in Table 2, the study that address unobserved heterogeneity to compare injury severity model between young, mid-age and older driver in single vehicle crash is still inadequate. To this end, the existing literature has provided insightful knowledge regarding unobserved heterogeneity solution and contributed to the analysis of crash injury severity. However, none of the existing research has addressed this issue in their crash injury severity analysis based on age-group comparison model yet; so, it is desirable to compare driver injury severity based on age through advance discrete choice model. Therefore, the present study proposed to use multilevel logistic model to compare driver injury severity in single-vehicle crash based on age with road-segment heterogeneity as impact factor at second level.

Research	Single-vehicle crash	Age group			Separately test for comparison	Road segment heterogeneity	Raised issue	Method
		Young	Mid-age	Old				
Current study	√	√	√	√	√	√	Comparing driver injury severity in single-vehicle crash based on age: Application of multilevel logistic model with road-segment heterogeneity	Multilevel binary logit model
(J.-K. Kim et al., 2013)	√	√	√	√	-	-	Driver-injury severity in single-vehicle crashes in California: A mixed logit analysis of heterogeneity due to age and gender	Mixed logit model
(Weiss et al., 2014)	√	√	-	-	-	-	Analysis of factors associated with injury severity in crashes involving young New Zealand drivers	Mixed logit model
(Islam & Mannering, 2006)	√	√	√	√	√	-	Driver aging and its effect on male and female single-vehicle accident injuries: Some additional evidence	Multinomial logit model
(Dissanayake, 2004)	√	√	-	√	√	-	Comparison of severity affecting factors between young and older drivers involved in single vehicle crashes	Binary logit
(Xie et al., 2012)	√	√	-	√	-	-	Analysis of driver injury severity in rural single-vehicle crashes	Latent class multinomial logit



4.3 Data

This study used the accident database from the Department of Highway of Thailand. Data collection have 2 step process: 1) obtaining the highway accident report occurred nationwide throughout Thailand between 2011-2017. Each crash case was survey and recorded by the official polices into Highway Accident Information Management System (HAIMS). Detail information about accident such as: causes of accident, severity, human characteristic, crash type, crash characteristic, vehicle characteristic, roadway characteristic, environmental characteristic, and spatial and temporal characteristic were recorded in the system. Then, data were screened for only single-vehicle run off road crash using crash code (provided by the Bureau of Highway safety, Department of Highway). Next, data were further divided into three group based on age of driver: group 1: less than 26-year-old, group 2: between 26 – 50-year-old and group 3: older than 50-year-old (this age-group range was also implemented in the past study (F. Chen & Chen, 2011)) 2): Using kilometer, route number, department code and control section number of each crash location to match with road segment number (provided by the department of highway (DOH)). Thus, road segment number were obtained for each accident case.

Number of crash case that each age group involved in were: 1746 cases for young driver, 6434 cases for mid-age driver, and 1697 for old driver. The total number of road segment are 2252 segments. Crashes at each road segment were categorized into two level of crash severity: fatal and injury. Table 4.2 describe the variable used for this study, and Table 4.3 provide the frequency and percentage of accident for each age group.

Table 4.2 Description of variables used in the analysis

Variable	**Description**
Driver Characteristic	
Gender	1 = Male driver, 0 = Female driver
SAF_EQ	1 = Driver use seatbelt, 0 = Otherwise
ALCOHOL	1 = Driver under effect of alcohols, 0 = Otherwise
EXEED_SPEED	1 = Driver drive with exceed speed limit, 0 = Otherwise
FALL_ASLEEP	1 = Driver fall asleep while driving, 0 = Otherwise
Road Characteristic	
R_COND	1 = Accident occur at area of road maintenance, 0 = Otherwise
N_LANE	1 = Accident on 2 lane highway, 0 = Otherwise
R_SURF	1 = Pavement type is asphalt, 0 = Pavement type is concrete
HORIZONTAL	1 = Accident occur on the curve road section, 0 = Otherwise
VERTICAL	1 = Accident occur on the graded road section, 0 = Otherwise
INTERSECTION	1 = Accident occur within Intersection, 0 = Otherwise
U_TURN	1 = Accident occur within U-turn, 0 = Otherwise
COMMUNITY	1 = Accident occur within community area, 0 = Otherwise
NO_MEDIAN	1 = Accident occur on road without median, 0 = Otherwise
RAISED_MEDIAN	1 = Accident occur on road with raised median, 0 = Otherwise
DEPRES_MEDIAN	1 = Accident occur on road with depressed median, 0 = Otherwise
Vehicle Characteristic	
PASSENGER_CAR	1 = Vehicle in accident is passenger car, 0 = Otherwise
PICKUP_INVOLVE	1 = Vehicle in accident is pickup truck with 4 wheels, 0 = Otherwise
TRUCK_INVOLVE	1 = Vehicle in accident is heavy truck and trailer, 0 = Otherwise
Crash Characteristic	
MOUNT_ISLAND	1 = If the vehicle mounted the traffic island, 0 = Otherwise
PASS_INFRONT	1 = Accident occur due to something pass in front, 0 = Otherwise
DEFECT_CAR	1 = Accident occur due to defective car device, 0 = Otherwise
OFF_LEFT_STR	1 = Vehicle run off road to the left on straight, 0 = Otherwise
OFF_RIGHT_STR	1 = Vehicle run off road to the right on straight, 0 = Otherwise
LEFT_FIXED_STR	1 = Vehicle run off road to the left and hit fixed object, 0 = Otherwise
RIGHT_FIXED_STR	1 = Vehicle run off to road the right and hit fixed object, 0 = Otherwise
ACROSS_MEDIAN	1 = Vehicle run off road and across median, 0 = Otherwise
OFF_LEFT_CUR	1 = Vehicle run off road during on left bend, 0 = Otherwise
OFF_RIGHT_CUR	1 = Vehicle run off road during on right bend, 0 = Otherwise
LEFT_FIXED_CUR	1 = Vehicle run off during left bend and hit fixed object, 0 = Otherwise
RIGHT_FIXED_CUR	1 = Vehicle run off during right bend and hit fixed object, 0 = Otherwise
Environmental and Temporal Characteristic	
EN_SURF	1 = Accident occur on wet road, 0 = Accident occur on dry road
EN_STAT	1 = Accident occur on wavy or dirty road, 0 = Otherwise
EN_WEATHER	1 = Accident occur during raining, dust, foggy, 0 = Otherwise
EN_LIGHT	1= Accident occur during nighttime, 0 = Otherwise
TIMEGROUP	1 = Accident happened between 6 pm and midnight, 0 = Otherwise
APRIL_ACCIDENT	1 = Accident happened in April, 0 = Otherwise

Table 4.3 Summary statistic of crash data of each age-group

Variable		Young				Mid-age				Old			
		Fatal		Injury		Fatal		Injury		Fatal		Injury	
		Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
GENDER	0	28	0.28	230	2.33	99	1.00	735	7.44	17	0.17	137	1.39
	1	199	2.01	1289	13.05	760	7.69	4840	49.00	258	2.61	1285	13.01
SAF_EQ	0	155	1.57	934	9.46	565	5.72	3281	33.22	182	1.84	838	8.48
	1	72	0.73	585	5.92	294	2.98	2294	23.23	93	0.94	584	5.91
ALCOHOL	0	213	2.16	1504	15.23	835	8.45	5484	55.52	267	2.70	1402	14.19
	1	14	0.14	15	0.15	24	0.24	91	0.92	8	0.08	20	0.20
EXEED_SPEED	0	53	0.54	292	2.96	244	2.47	1218	12.33	83	0.84	308	3.12
	1	174	1.76	1227	12.42	615	6.23	4357	44.11	192	1.94	1114	11.28
FALL_ASLEEP	0	190	1.92	1347	13.64	725	7.34	4946	50.08	224	2.27	1254	12.70
	1	37	0.37	172	1.74	134	1.36	629	6.37	51	0.52	168	1.70
R_COND	0	223	2.26	1475	14.93	836	8.46	5444	55.12	265	2.68	1401	14.18
	1	4	0.04	44	0.45	23	0.23	131	1.33	10	0.10	21	0.21
N_LANE	0	143	1.45	1155	11.69	589	5.96	4099	41.50	180	1.82	1018	10.31
	1	84	0.85	364	3.69	270	2.73	1476	14.94	95	0.96	404	4.09
R_SURF	0	18	0.18	137	1.39	61	0.62	381	3.86	23	0.23	108	1.09
	1	209	2.12	1382	13.99	798	8.08	5194	52.59	252	2.55	1314	13.30
HORIZONTAL	0	163	1.65	1121	11.35	580	5.87	3917	39.66	183	1.85	1026	10.39
	1	64	0.65	398	4.03	279	2.82	1658	16.79	92	0.93	396	4.01
VERTICAL	0	208	2.11	1397	14.14	767	7.77	4955	50.17	234	2.37	1298	13.14
	1	19	0.19	122	1.24	92	0.93	620	6.28	41	0.42	124	1.26
INTERSECTION	0	218	2.21	1415	14.33	822	8.32	5178	52.42	263	2.66	1311	13.27
	1	9	0.09	104	1.05	37	0.37	397	4.02	12	0.12	111	1.12
U_TURN	0	220	2.23	1396	14.13	825	8.35	5039	51.02	253	2.56	1281	12.97
	1	7	0.07	123	1.25	34	0.34	536	5.43	22	0.22	141	1.43
COMMUNITY	0	227	2.30	1505	15.24	853	8.64	5523	55.92	270	2.73	1408	14.26
	1	0	0.00	14	0.14	6	0.06	52	0.53	5	0.05	14	0.14
NO_MEDIAN	0	146	1.48	1109	11.23	558	5.65	4010	40.60	172	1.74	991	10.03
	1	81	0.82	410	4.15	301	3.05	1565	15.84	103	1.04	431	4.36
RAISED_MEDIAN	0	181	1.83	1084	10.97	699	7.08	4082	41.33	220	2.23	1046	10.59
	1	46	0.47	435	4.40	160	1.62	1493	15.12	55	0.56	376	3.81
DEPRES_MEDIAN	0	149	1.51	991	10.03	530	5.37	3605	36.50	180	1.82	933	9.45
	1	78	0.79	528	5.35	329	3.33	1970	19.95	95	0.96	489	4.95
PASSENGER_CAR	0	145	1.47	896	9.07	576	5.83	3658	37.04	185	1.87	969	9.81
	1	82	0.83	623	6.31	283	2.87	1917	19.41	90	0.91	453	4.59
PICKUP_INVOLVE	0	109	1.10	826	8.36	515	5.21	3171	32.10	166	1.68	748	7.57
	1	118	1.19	693	7.02	344	3.48	2404	24.34	109	1.10	674	6.82
TRUCK_INVOLVE	0	210	2.13	1388	14.05	721	7.30	4671	47.29	235	2.38	1249	12.65
	1	17	0.17	131	1.33	138	1.40	904	9.15	40	0.40	173	1.75
MOUNT_ISLAND	0	196	1.98	1120	11.34	755	7.64	4196	42.48	244	2.47	1057	10.70
	1	31	0.31	399	4.04	104	1.05	1379	13.96	31	0.31	365	3.70
PASS_INFRONT	0	227	2.30	1481	14.99	841	8.51	5451	55.19	270	2.73	1385	14.02
	1	0	0.00	38	0.38	18	0.18	124	1.26	5	0.05	37	0.37
DEFECT_CAR	0	224	2.27	1482	15.00	825	8.35	5368	54.35	263	2.66	1375	13.92
	1	3	0.03	37	0.37	34	0.34	207	2.10	12	0.12	47	0.48

Table 4.3 Summary statistic of crash data of each age-group (Continued)

OFF_LEFT_STR	0	174	1.76	1410	14.28	680	6.88	5186	52.51	231	2.34	1315	13.31
	1	53	0.54	109	1.10	179	1.81	389	3.94	44	0.45	107	1.08
OFF_RIGHT_STR	0	200	2.02	1442	14.60	758	7.67	5366	54.33	236	2.39	1377	13.94
	1	27	0.27	77	0.78	101	1.02	209	2.12	39	0.39	45	0.46
LEFT_FIXED_STR	0	191	1.93	1245	12.61	783	7.93	4576	46.33	244	2.47	1146	11.60
	1	36	0.36	274	2.77	76	0.77	999	10.11	31	0.31	276	2.79
RIGHT_FIXED_ STR	0	207	2.10	1261	12.77	771	7.81	4653	47.11	248	2.51	1210	12.25
	1	20	0.20	258	2.61	88	0.89	922	9.33	27	0.27	212	2.15
ACROSS_MEDIAN		224	2.27	1497	15.16	831	8.41	5462	55.30	262	2.65	1390	14.07
	1	3	0.03	22	0.22	28	0.28	113	1.14	13	0.13	32	0.32
OFF_LEFT_CUR	0	216	2.19	1483	15.01	802	8.12	5417	54.84	254	2.57	1381	13.98
	1	11	0.11	36	0.36	57	0.58	158	1.60	21	0.21	41	0.42
OFF_RIGHT_CUR	0	220	2.23	1486	15.05	809	8.19	5431	54.99	260	2.63	1385	14.02
	1	7	0.07	33	0.33	50	0.51	144	1.46	15	0.15	37	0.37
LEFT_FIXED_CUR	0	215	2.18	1384	14.01	792	8.02	5043	51.06	247	2.50	1286	13.02
	1	12	0.12	135	1.37	67	0.68	532	5.39	28	0.28	136	1.38
RIGHT_FIXED_ CUR	0	210	2.13	1373	13.90	779	7.89	4961	50.23	254	2.57	1276	12.92
	1	17	0.17	146	1.48	80	0.81	614	6.22	21	0.21	146	1.48
EN_SURF	0	182	1.84	1265	12.81	723	7.32	4392	44.47	216	2.19	1143	11.57
	1	45	0.46	254	2.57	136	1.38	1183	11.98	59	0.60	279	2.82
EN_STAT	0	225	2.28	1515	15.34	856	8.67	5557	56.26	274	2.77	1416	14.34
	1	2	0.02	4	0.04	3	0.03	18	0.18	1	0.01	6	0.06
EN_WEATHER	0	177	1.79	1251	12.67	714	7.23	4319	43.73	212	2.15	1121	11.35

4.4 Methodology

4.4.1 Model development

Only two previous studies (Dissanayake, 2004; Islam & Mannering, 2006) did the comparison of severity of affecting factor between age-group in single-vehicle crash by using traditional binary logit and multinomial logit which cannot address unobserved heterogeneity across observation. Therefore, in the present study, Multilevel logistic model is adopted in order to fill this gap. As detail describe by a recent study (Champahom et al., 2020) the multilevel analysis for road safety is categorized in to three type based on the characteristic of data analysis management: 1) multilevel modeling of aggregate accident data: consider data into hierarchical structure based on accident area (spatial data), 2) Multilevel modeling of disaggregate accident data: analyses for injury level pattern and can be organized data in hierarchical structure base on road characteristic or regional characteristic; and 3) Multilevel modeling of behavioral and attitudinal data: investigate the attitude of drivers through aspect such as speeding, drunk driving and other by question drivers according to road site. Accident data can be arranged into multiple level hierarchically, which mean that: driver, vehicle, or weather characteristic stand in the first level; while, road section or specific area is in the second level (Dupont et al., 2013).

In this study, road-segment (divided by the control number) is considered to be at second level as factor affecting driver injury severity following the recent research work (Champahom et al., 2020). Starting with the standard logistic regression applying multilevel concept, for each single-vehicle crash involve driver *j*th on road-segment *k*th, the two severity levels can be calculated as follows:

$$Yjk = \begin{cases} 1; \text{ in case of fatal crash} \\ 0; \text{ in case of injury crash} \end{cases}$$

Where $Yjk \mid pjk \sim Bernouilli(pjk)$, $pjk = Pr(Yjk = 1)$ is the probability of driver *j* from road *k* to be fatally injured in crash emanating from the relationship of the estimated parameters of explanatory variable that can be derived as follows:

$$\text{logit}(p_{jk}) = ¦_{jk} = {}_{0k} + \sum_{i=1}^{i} {}_{ik} X_{ijk} \tag{4.1}$$

Where $¦_{jk}$ is the log odds if driver *j* on road-segment *k*, which involve in single-vehicle fatal crash. X_{ijk} is the *i*th driver-level (lower level) explanatory variable for the *j*th driver unit for predicting the likelihood add of fatality in the *k*th road-segment crash. ${}_{0k}$ denote the intercept to be estimated in regression model which has fatal single-vehicle crash on road-segment *k*th only. ${}_{ik}$ is parameter estimate corresponding to X_{ijk}. As discussed the previous works (Champahom et al., 2020; C. Chen et al., 2016), ${}_{0k}$ and ${}_{ik}$ can be defined by the following equation:

$${}_{0k} = ¥_{00} + \sum_{n=1}^{N} ¥_{0n} W_{nk} + «_{0k} \tag{4.2}$$

$${}_{ik} = ¥_{i0} + \sum_{n=1}^{N} ¥_{in} W_{nk} + «_{ik} \tag{4.3}$$

Where W_{nk} is the nth explanatory variable for the *k*th road-segment and *N* is the number of road-segment level variable. $¥_{0n}$ are $¥_{in}$ the coefficient for W_{nk} corresponding to ${}_{0k}$ and ${}_{ik}$ respectively. $¥_{00}$ and $¥_{i0}$ are intercept for ${}_{0k}$ and ${}_{ik}$ respectively. $«_{0k}$ and $«_{ik}$ are random effect representing between road-segment variance or prediction error in information at the road level. Next, the multilevel model can be obtained by substituting equation (4.2) and (4.3) in (4.1)

$$¦_{ij} = ¥_{00} + \sum_{n=1}^{N} ¥_{0n} W_{nk} + «_{ok} + \sum_{i=1}^{I} (¥_{ik} + «_{ik}) X_{kij} + \sum_{n=1}^{N} \sum_{i=1}^{I} ¥_{0n} W_{nk} X_{ijk} \tag{4.4}$$

The whole model is called random slope model, when study drops $\sum_{n=1}^{N} ¥_{0n} W_{qj} + «_{kj}$, therefore the whole model become random intercept only (C. Chen et al., 2015; D.-G. Kim et al., 2007). And to avoid high model complexity, this study assumes $«_{kj}$ = 0 and is disregarded from the model. Thus, the final random intercept model become:

$$¦_{ij} = ¥_{00} + \sum_{n=1}^{N} ¥_{0n} W_{nk} + «_{ok} + \sum_{i=1}^{I} ¥_{ik} X_{kij} + \sum_{n=1}^{N} \sum_{i=1}^{I} ¥_{0n} W_{nk} X_{ijk} \tag{4.5}$$

Where $\sum_{n=1}^{N} \sum_{i}^{I} ¥_{0n} W_{nk} X_{ijk}$ is interaction level effect that assume driver level influence road level and Eq. (5) asserts that the effect of a variable at the driver level is predicted by the fixed effect of the road type (Champahom et al., 2020). For models that only exhibit a random intercept, reference to the driver odds log j from road k will yield fatality risk. represents the calculation of the log odds of fatality of common drivers on general roads. In other words, different road characteristics affect the likelihood of death in a diverse manner. and represent the effect values of driver level and road type.

4.4.2 Model validation with Intra-Class Correlation test (ICC)

Firstly, the test to assure the necessary of hierarchical model for the analysis was conducted. Fully, unconditionally model (model that are not conditional on model parameter vector) estimated for all three age-groups. Then, the proportion of the variance in outcome driver severity between level-2 unit (road segment) is examine by the intra-class correlation coefficient (ICC). τ^2_{00} is the variance of the dependent variable

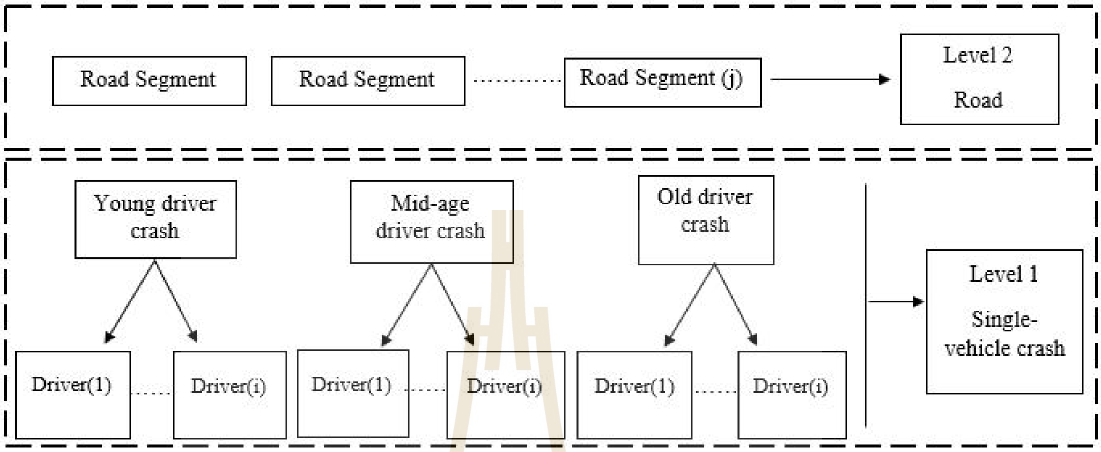


Figure 4.2 Hierarchical structure of single-vehicle crash

between each road segment on level 2. However, variance of binary logit at driver level (level 1) is not available, it is determined to be $\pi^2/3$ (Dupont et al., 2013). Thus, ICC (ρ) can be computed using the following equation.

$$\rho = \frac{\tau^2_{00}}{\tau^2_{00} + \pi^2/3} \tag{4.6}$$

4.4.3 Model validation with transferability test

The transferability test is the test to identify whether it is necessary to separate the model between each age group or unnecessary. The models were estimated separately for the difference age group: young, mid - age and old. The likelihood ratio test for parameter transferability, was computed to investigate the transferability of results over all three age-groups model, is given as (Washington, Karlaftis, Mannering, & Anastasopoulos, 2020):

$$X^2 = -2[LL(\beta_T) - LL(\beta_Y) - LL(\beta_M) - LL(\beta_O)] \tag{4.7}$$

Where *LL(βT)* is the log likelihood at convergence of the model estimated for all data, $LL(\beta_Y)$, $LL(\beta_M)$ and $LL(\beta_O)$ is the log likelihood at convergence of the model estimated for young, mid-age and old age group. It is used to compare with $X^2_{critical}$ critical with degree of freedom (*dfcritical*) of summation of *df* of each age group minus *df* of total model (*dfcritical = df(young) + df(mid-age) + df(old) - df(total)*). If $X^2 > X^2_{critical}$, each age-group should be estimated separately.

4.4.4 Model goodness-of-fit test

McFadden Pseudo R-square can be estimated using the value of log-likelihood for intercept only model and model with parameters estimate. And to account for estimation of potentially insignificant parameters, the number of parameters take part in the calculation. Computation of the measure of overall model fit which is McFadden adjusted-ρ^2 is defined by the formula below (Washington et al., 2020).

$$\text{Adjusted } \rho^2 = 1 - \frac{LL(\beta) - K}{LL(0)} \tag{4.8}$$

Where *LL(β)* is the log likelihood at convergence with parameter estimate, *LL(0)* is the initial log-likelihood with all parameter set to zero and *K* is the number of parameter estimate.

4.4.5 Marginal effect

The marginal effect reflects the impact of a one-unit change in an independent variable on the dependent variable (in this case, the expected frequency of non-fatal or fatal crashes). For crash severity level *k*, the marginal effect of the *m*th independent variable is calculated as:

$$ME^{a_{mj}}_{X_{mj}} = \frac{\partial a_j}{\partial X_j} = {}_{mj}EXP({}_{j}X'_{j}) \tag{4.9}$$

Where a_z is the estimated model for crash severity level z; X_{yz} is the independent variable; ${}_{yz}$ is the corresponding estimated coefficient; X'_z and ${}_z$ are the vectors of independent variables and the corresponding estimated coefficients, respectively.

The current study used R program package that include marginal effect (*margin*) (Leeper, Arnold, Arel-Bundock, & Leeper, 2017), fitting generalized linear model (*glm2*) (Marschner, Donoghoe, & Donoghoe, 2018) for analyzing coefficient without multilevel and fitting generalized linear mixed-effects models (*glmer*) for analyzing multilevel logistic model (Bates et al., 2015).

4.5 Result and Discussion

The model construct consists of three steps process: 1) test ICC to define necessity to use road segment at upper level in hierarchical model. 2) test goodness of fit and transferability parameter to define necessity to separate model between young, mid-age and old driver age group. 3) estimate the multilevel logit model for each age group model. The estimated result of all model is shown in table 4.

To obtain the ICC value, six random effect and fixed effect unconditional models were estimated. Using equation (6), ICC value of young, mid-age and old is 0.101, 0.122, and 0.128, respectively. These results indicate that 10.1%, 12.2% and 12.8% of unexplained variation in individual severity were resulted from between road-segments variance; or, of the total variation were accounted by random effect from road-segment heterogeneity for young, mid-age and old driver model, respectively. Therefore, it strongly suggests the usefulness of model specification of hierarchical structure, and without taking it into consideration, the standard logistic regression will produce biased and inaccurate estimated result (Huang et al., 2008). All model ICC value met acceptant criteria for the creation for multilevel model (Champahom et al., 2020; D.-G. Kim et al., 2007). Transferability test, test the necessity to separate the model between age group, was also obtained using equation (7). the value of X2 was found to be 188 with 142 degree of freedom and X2C,0.05,142 = 170 which is less than X2. This result indicates that young, mid-age, old model should be estimated and analyzed separately.

In term of model goodness-of-fit, if the model was estimated using the total model, McFadden ρ2 = 0.093; however, the model was estimated separately based on age-group, McFadden Pseudo ρ2 for young, mid-age and old driver model are 0.21, 0.111 and 0.159; respectively which are in acceptable criteria (Champahom et al., 2020; Forbes & Habib, 2015; Ratanavaraha & Suangka, 2014). This indicate that the prediction capability of separated models significantly outperforms the total model. The study examined the marginal effects of the statistically significant coefficients that will be used for result interpretation. The following section provide the discussion of the result.

with regard to driver characteristic, this variable group have noticeable effect on old driver rather than young and old driver group injury severity in single vehicle.

Table 4.4 Model fit information of all age-group model

	Young model		Mid-age model		Old model	
Random effect		Std.		Std.		Std.
Between road-segment variance ($^{2}{}_{00}$)	0.368	0.606	0.456	0.675	0.483	0.694
Within road-segment variance (π/3)	3.29		3.29		3.29	
ICC	0.101		0.122		0.123	
Model fit information						
Log-likelihood at constants	673		2507		748	
Log-likelihood at convergence	568		2265		666	
Adjusted McFadden Pseudo ρ^2	0.210		0.111		0.159	
Number of observations	1746		6434		1697	
Number of road-segment	838		1795		814	
Log-likelihood at constants (total): 3921						
Log-likelihood at convergence (total): 3594						

crash. This is probably because old is weak in physical strength, reaction time, health condition. Old and young driver under alcohol influence increase the risk of fatal in the accident with the marginal effect 0.259 and 0.158, respectively; but this variable is not significant in the mid-age driver model. This finding is similar with result of previous studies (Roy & Dissanayake, 2011; Weiss et al., 2014). For young driver, probably level of alcohol is highly associated their perceive risk taking (aggressively behavior) which also highly influence crash impact and their injury severity. In addition, alcohol could have significant effect on old driver physical movement and their health condition could be dramatically affect by alcohol. Lead into the same direction, drowsiness old and young driver's fatality risk increases with marginal affect 0.073 and 0.075, respectively; but it doesn't significantly affect mid-age driver's severity. This is because fatigue can slow the reaction time, decrease alertness, reduce ability to control the vehicle that possibly generate strong impact due to unawareness of the accident. For old driver is statically associated with fatigue related crash probably due her health condition, lack of sleep, irregular sleeping time, and medication (drug may cause drowsiness and impair alertness), while, young driver is also proven to be strongly involved in fatigue

Table 4.5 Estimated result of multilevel logistic model of young driver severity

Variable	Young driver		
	Estimate	**Std.**	**Marginal effect**
(Intercept)	-3.233***	1.148	-
GENDER	-	-	-
SAF_EQ	-	-	-
ALCOHOL	2.430***	0.612	0.259
EXEED_SPEED	-	-	-
FALL_ASLEEP	0.993*	0.588	0.075
R_COND	-	-	-
N_LANE	0.857*	0.437	0.062
R_SURF	-	-	-
HORIZ	-2.503**	1.044	-0.014
VERT	-	-	-
INTER	-	-	-
U_TURN	-2.071**	1.030	-0.067
COMMUNITY	-	-	-
NO_MED	-	-	-
RAISED_MED	-	-	-
DEPRES_MED	-	-	-
PASSEN_CAR	-	-	-
PICKUP	-	-	-
TRUCK	-	-	-
DEFECT_CAR	-	-	-
MOUNT_ISL	-1.655***	0.613	-0.087
OFF_LEFT_STR	-	-	-
OFF_RIGHT_STR	-	-	-
LEFT_FIXED_STR	-	-	-
RIGHT_FIXED_STR	-1.461**	0.622	-0.076
OFF_LEFT_CUR	-	-	-
OFF_RIGHT_CUR	-	-	-
LEFT_FIXED_CUR	-3.267***	1.258	-0.098
RIGHT_FIXED_CUR	-2.339**	1.140	-0.086
ACROSS_MED	-	-	-
EN_SURF	-	-	-
EN_STAT	-	-	-
EN_WEATHER	-	-	-
EN_LIGHT	-	-	-
TIMEGROUP	-	-	-
APRIL_ACCIDENT	-	-	-
Significant codes: ‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1 Reference category: Injury			

Table 4.6 Estimated result of multilevel logistic model of mid-age driver severity

Variable	Mid-age driver		
	Estimate	**Std.**	**Marginal effect**
(Intercept)	-0.652	0.409	-
GENDER	-	-	-
SAF_EQ	-0.407 ***	0.098	-0.036
ALCOHOL	-	-	-
EXEED_SPEED	-	-	-
FALL_ASLEEP	-	-	-
R_COND	-1.003**	0.463	-0.059
N_LANE	-0.375**	0.184	-0.030
R_SURF	-	-	-
HORIZ	-	-	-
VERT	-0.456***	0.176	-0.034
INTER	-0.554**	0.245	-0.041
U_TURN	-2.321***	0.450	-0.091
COMMUNITY	-	-	-
NO_MED	0.434**	0.434	0.043
RAISED_MED	-	-	-
DEPRES_MED	0.395**	0.178	0.036
PASSEN_CAR	-0.511***	0.159	-0.045
PICKUP	-0.545***	0.155	-0.049
TRUCK	-0.518***	0.177	-0.043
DEFECT_CAR	-	-	-
MOUNT_ISL	-1.394***	0.281	-0.101
OFF_LEFT_STR	0.510*	0.268	0.052
OFF_RIGHT_STR	-	-	-
LEFT_FIXED_STR	-1.482***	0.283	-0.102
RIGHT_FIXED_STR	-1.231***	0.280	-0.089
OFF_LEFT_CUR	-	-	-
OFF_RIGHT_CUR	-	-	-
LEFT_FIXED_CUR	-0.742**	0.326	-0.057
RIGHT_FIXED_CUR	-0.662**	0.321	-0.052
ACROSS_MED	-	-	-
EN_SURF	-	-	-
EN_STAT	-	-	-
EN_WEATHER	-	-	-
EN_LIGHT	0.171*	0.101	0.016
TIMEGROUP	-	-	-
APRIL_ACCIDENT	-	-	-

Significant codes: ‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1
Reference category: Injury

Table 4.7 Estimated result of multilevel logistic model of old driver severity

Variable	Old driver		
	Estimate	**Std.**	**Marginal effect**
(Intercept)	-2.226***	0.812	-
GENDER	0.728**	0.309	0.066
SAF_EQ	-0.404**	0.167	-0.042
ALCOHOL	1.110**	0.529	0.158
EXEED_SPEED	-	-	-
FALL_ASLEEP	0.596*	0.351	0.073
R_COND	0.993**	0.476	0.137
N_LANE	-	-	-
R_SURF	-	-	-
HORIZ	-	-	-
VERT	-	-	-
INTER	-	-	-
U_TURN	-	-	-
COMMUNITY	-	-	-
NO_MED	-	-	-
RAISED_MED	-	-	-
DEPRES_MED	-	-	-
PASSEN_CAR	-	-	-
PICKUP	-0.431*	0.255	-0.046
TRUCK	-	-	-
DEFECT_CAR	-	-	-
MOUNT_ISL	-	-	-
OFF_LEFT_STR	0.981*	0.577	0.130
OFF_RIGHT_STR	1.880***	0.597	0.307
LEFT_FIXED_STR	-	-	-
RIGHT_FIXED_STR	-	-	-
OFF_LEFT_CUR	-	-	-
OFF_RIGHT_CUR	-	-	-
LEFT_FIXED_CUR	-	-	-
RIGHT_FIXED_CUR	-	-	-
ACROSS_MED	1.132*	0.666	0.160
EN_SURF	-	-	-
EN_STAT	-	-	-
EN_WEATHER	-	-	-
EN_LIGHT	-	-	-
TIMEGROUP	-	-	-
APRIL_ACCIDENT	-	-	-
Significant codes: ‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1 Reference category: Injury			

related crash due to insomnia, late-night driving, inexperience to cope with fatigue and low visibility roadway environment (ERSO, 2018). Old driver and mid-age driver who applied seatbelt while driving is found to be more likely to reduce fatal injury with marginal effect 0.042 and 0.036, respectively which is logical finding. This result is logical and consistent with previous work (Peng & Boyle, 2012; Schneider, Savolainen, & Zimmerman, 2009; Xie et al., 2012). When driver equip seatbelt while driving, it helps prevent impact of crash between the driver and vehicle part (dashboard, steering wheel, other component) by holding drivers' body in seat and ensure driver inside vehicle during crash. However, in young driver model, this variable is not significantly different probably due to aggressive driving behavior of young driver that could reduce effectiveness of seatbelt. But there were previous studies that found seatbelt non-used driver are likely to be more severely injured in the crash (Paleti, Eluru, & Bhat, 2010; Weiss et al., 2014). In term of gender, only older driver model that found male drivers increase fatality risk in the crash than woman with marginal effect of 0.066. This result is consistently similar to work of (Islam & Mannering, 2006) that found that old male driver impose more significant risk factor than old female driver.

With regard to roadway factor, the majority of significant variables of this group contribute to mid-age driver model more than young and old driver models. In young driver model, driver who involved in the accident within curve road section and U-turn area are likely to sustain injury severity with marginal effect 0.014 and 0.067, respectively; and, accident on 2 lane highway increase fatal risk with marginal effect 0.062. However, 7 variables were found to significantly affecting mid-age driver severity, namely accident within road under construction, 2-lane road, road on grade, intersection area and U-turn area, was found to reduce probability of fatality with marginal effect 0.059, 0.03, 0.034, 0.041 and 0.091, respectively; and, crashes that occurred on roadway without median and with depressed median were found to increase risk of fatality in the crash with marginal effect 0.043 and 0.0395, respectively. From the old driver model, old driver who involve in accident within road construction area increase the probability of fatality with marginal effect 0.137. Noticeable, young and mid-age drive model result are in the same direction. Roadway location like U-turn and intersection area general create numbers of conflicts to traffic (DOT, 2011; Potts, 2004) therefore become cautious area where driver drive with greater caution and slow their vehicle down while driving within these areas, therefore, even encounter crash it probably don't cause serious severity to driver. Ma, Shao, Yue, and Ma (2009)'s study found that intersection area accident is less severe than other common location which is in same direction of our result. Old driver, on the other hand, increase fatality risk by 13.7%, if accident happen within road construction area. The reason maybe older drivers have slower reaction time and find it difficult to adapt to complex roadway condition under construction such as dust, lane changing, lane merging and other unexpected obstacle ahead of their driving, etc.; and this unpreparedness could lead to more severe injury.

As regard to vehicle type, mid-age driver who drive passenger car, pickup truck and truck are more likely to sustain injury severity with marginal effect 0.045, 0.049 and 0.043, respectively. And, old pickup-truck driver was found to more likely to sustain injury severity with marginal effect 0.046.

Crash characteristic variable group has significant effect varying among all age group. Estimated result show that young driver whose vehicle run off roadway and hit fixed-object on curve to left, curve to right, on straight to right, and mounted traffic island are likely to sustain injury severity with marginal effect 0.098, 0.086, 0.076 and 0.087 respectively. Mid-age driver who involve in crash type such as mounted traffic island, off roadway on straight to left/right hitting fixed object, off roadway on curve to left/right hitting fixed object were found reduce chance of fatality in crash with marginal effect 0.101, 0.102, 0.089, 0.057 and 0.052 respectively. However, run off roadway on straight to the left increase probability of fatal crash by 5.2%. In old driver model, run off roadway on straight to left, to right, and across median increase the risk of fatal crash with marginal effect 0.13, 0.307 and 0.16%, respectively. The finding show that accident hit roadside feature such as safety barrier and guardrail significantly reduce fatality risk among young and mid-age driver, this result is logical and meet the purpose of the implementation. These finding is in line with previous studies (Roque, Moura, & Cardoso, 2015). However only old driver that were found to increase fatal risk in case of run off road on straight without roadside safety feature, and run across median accident (one of the most severe type of crash due to high risk of collision and high speed (Chitturi, Ooms, Bill, & Noyce, 2011)). This result can be explained by the (Martin, Mintsa-Eya, & Goubel, 2013) that found that roadway without guardrail in the shoulder contributes to significantly higher injury severity

Lastly, only one variable in the environmental factor was found to significantly affect mid-age driver model which is the accident that occurred during night time without light increase probability of fatality with marginal effect 0.016. This is because driver could find it difficult to clearly recognize the roadway condition, and therefore are more likely to get involve in a more severe crash (Li et al., 2018).

4.6 Conclusion

A seven-years single vehicle crash data from 2011-2017 is utilized to investigate age-group related crashes and their significant contributing factors to driver injury severities in nationwide Thailand. Multilevel logistic model is developed for analyzing this data set. The hierarchical structure of this study used road-segment as second level and crash related factor at lower level. The developed model is able to allow correlation of the variable within and between road-segment and ability to address unobserved heterogeneity. The model performance and goodness of fit measurement such as ICC, transferability test, adjusted McFadden pseudo R-square are computed. The result of ICC values show that the model can be analyzed and applied multilevel logistic model that determine estimate parameter to vary according road segment. The transferability value also indicates the necessity to investigate the model between age group separately. Adjusted McFadden Pseudo ρ^2 of each subset model are found to be in acceptable criteria and superior prediction accuracy to total model.

Based on the empirical result and previous experience, there are some appropriate countermeasures and strategies could be drawn in order to improve safety for driver involve in single vehicle accident. First, law reinforcement and training of driver and educational campaign should be strictly implemented in order to reduce drunk-driving and non-seatbelt usage (Anarkooli, Hosseinpour, & Kardar, 2017; Organization, 2018). In addition, increase light intensity, implementing stronger sanctions for driver with higher Blood Alcohol Content (BAC), and an in-vehicle warning system directed toward recognizing certain adverse driving behavior such (run off roadways, fatigue driving, etc.) that could be helpful to drive under low visibility condition (Li et al., 2018; Ohn-Bar, Tawari, Martin, & Trivedi, 2015), could also reduce the risk of driver being involved in more severe crash. Besides, improve provision of rumble strip of road shoulder, roadside safety feature (safety barrier, guardrail, etc.) and lighting condition maybe beneficial to reduce crash impact as well as driver severity (Anarkooli et al., 2017).

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CHAPTER V

CONCLUSION AND RECOMMENDATIONS

Traffic accident is undeniably one of the most challenging problem Thailand has encountered over the last decade. Cooperating with World Health Organization, Thailand related authorities have taken rapid action trying to lower number of accidents nationwide. However, evidently there has been no significant improvement, since in past eight years (2011-2018) death rate per 100 000 population due to traffic accident was always above 30 and ranked in the top tenth country in the world with highest death rate. According to statistic study in this research work, single-vehicle run off roadway crash occurred most frequently (highest in term of accident rate) and significantly high number of cases happened to be severe and fatal crash. These issues motivate the current research study to investigate impact of crash related factor (human, vehicle, roadway, crash mechanism, and environmental/temporal characteristic) on driver injury severity. These objectives were achieved by utilizing police accident record (obtained from HIAMS) and advance discrete choice models namely Multinomial Logit and Multilevel Logistic Model.

This research study is set to achieve three main objectives: (1) Identify the risk factors potentially influencing driver injury severity of single-vehicle ROR (2) Single-vehicle crash ROR severity on 2-lanes versus 4-lanes highways (3) Comparison of Single-vehicle ROR crash driver severity between young, mid-age and old driver.

5.1 Risk factors affecting driver severity of single-vehicle ROR

The estimated results show that old drivers, male drivers, drivers under influence, drowsiness, ROR to left/right on straight roadway increase the probability of fatal crash, while other factors are found to mitigate severity such as age of driver between 26-35 years old, use of seatbelt, ROR and hit fixed object on straight and curve segment of roadway, mounted traffic island, intersection related and April accident. With regard to the results of the current study, Thailand road safety related authorities are commended to emphasize their future effort on improving education campaigns on road safety for all road users, especially older drivers and male drivers, law enforcement on drunk driving and overspeed driving, and roadside safety features, particularly ROR black spot and curve roads.

5.2 Single-vehicle crash ROR severity on 2-lanes versus 4-lanes highways

The important findings of this study showed that driver older than 55 years tend to involve in more severe crash in the single vehicle run off road crash on 4 lanes highway and young driver between 25-35 years old were likely to mitigate severity on 2-lane highway. Accident on both type of highway, using seatbelt was also found to help the driver sustain their injury in the crash and drowsiness and drunk driver were found to have strongly associated with the fatal single-vehicle crash. The 4-lane highway accident with depressed median increase chance of fatality, but 2-lanes highway accident with raised median reduce chance of fatality. The accident on concrete pavement was found to increase chance that driver dies in the accident. In term of crash characteristic, single-vehicle accident on both highways were found to increase the chance of fatality on both curve road and on straight road section. However, if the vehicle run off road to hit the fixed objection on the side of the road, this manner was found to help driver sustain the injury severity.

5.3 Comparison of Single-vehicle ROR crash driver severity between young, mid-age and old driver

A seven-years single vehicle crash data from 2011-2017 is utilized to investigate age-group related crashes and their significant contributing factors to driver injury severities in nationwide Thailand. Multilevel logistic model is developed for analysing this data set. The hierarchical structure of this study used road-segment as second level and crash related factor at lower level. Multilevel logistic model is selected to compare driver injury severity in single-vehicle crash based on age-group with road-segment heterogeneity. Important findings show that alcohol and fatigue influence fatal crash among young and old driver, seatbelt-usage reduce risk of being fatal among mid-age and old driver, roadside feature such as safety barrier and guardrail significantly reduce fatality risk among young and mid-age driver, and night time driving without light increase probability of fatality for mid-age driver. This study also provides insightful understanding of the impacts of all significant variables on severity outcome, and appropriate countermeasures and strategies in order to improve safety for driver involve in single-vehicle accident.

5.4 Recommendations

The essential outcomes of this research work are primarily concluded. This insightful resource motivates recommendation to improve safety of driver who encounter single vehicle ROR crash as follow:

1) Emphasize effort on training of driver and educational campaign should be firmly implemented in order to reduce drunk-driving and non-seatbelt usage (especially young inexperience driver and male driver older than 50 years old (Anarkooli, Hosseinpour, & Kardar, 2017; Organization, 2018).

2) Implementing stronger sanctions for driver with higher Blood Alcohol Content (BAC) (especially driver younger than 26 years old and older 50 years old).

3) Provision of rumble strip on road shoulder and in-vehicle warning system directed toward recognizing certain adverse driving behavior such (run off roadways, fatigue driving, etc.) that could be helpful to drive under low visibility condition (Li et al., 2018; Ohn-Bar, Tawari, Martin, & Trivedi, 2015), could also reduce the risk of driver being involved in more severe crash.

4) Improve provision of roadside safety feature (safety barrier, guardrail, etc.), maybe potentially beneficial to reduce crash impact as well as driver severity (Anarkooli et al., 2017).

5) Increase light intensity along highways would assist driver to recognize the roadways condition. This action could help to reduce likelihood of crash and crash severity.

5.5 References

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APPENDIX I

LIST OF PUBLICATIONS

List of Publications

Se, C., Champahom, T., Jomnonkwao, S., & Ratanavaraha, V. (2020). Analysis of Young Thai Driver Severity Involving in Single-Vehicle Run Off Road Crash. **The 3rd Conference on Innovation Engineering and Technology for Economy and Society**, 4, 194-198.

Se, C., Champahom, T., Jomnonkwao, S., & Ratanavaraha, V. (2020). Driver injury severity in single-vehicle run off road crash on 2-lanes and 4-lanes highway in Thailand. **Engineering and Applied Science Research**. (In press)

BIOGRAPHY

Mr. Chamroeun Se was born on the 17th of January, 1994 at Battambang Province, Cambodia. He started his primary education at O-Nho Primary School, secondary education at Sovann Kiri Secondary School, and completed high school at Phnom Thom High School. Then, he further obtained Bachelor's Degree in Civil Engineering from Paragon International University (former Zaman University). After his graduation, he started his career as site engineer of bridges and highway construction HANSHIN Engineering & Construction Co. After two year of working experience, he was rewarded a scholarship to pursue his Master Degree in Transportation Engineering at Suranaree University of Technology (SUT).

His field of interest is road safety research and crash model. During his postgraduate study, he achieved one conference proceeding entitled "*Analysis of Young Thai Driver Severity Involving in Single-Vehicle Run Off Road Crash*" at the 3rd Conference on Innovation Engineering and Technology for Economy and Society. In addition, he published one research paper entitled "*Driver injury severity in single-vehicle run off road crash on 2-lanes and 4-lanes highway in Thailand*" Engineering and Applied Science Research (EASR).