Final Report

August 31, 2016

Safety Performance Enhancement Analysis of Rumble Stripes with Elements: A Case Study on Rural Highway US 285 in New Mexico

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Final Technical Report

Research Project Subagreement No. UNR-14-61 Task C

Safety Performance Enhancement Analysis of Rumble Stripes with Elements: A Case Study on Rural Highway US 285 in New Mexico

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A Report Prepared For

SOLARIS University Transportation Center
University of Nevada, Reno

In Cooperation With

U.S. Department of Transportation
Federal Highway Administration

August 2016

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EXCLUSIVE SUMMARY

Traffic crashes result in significant life and economic loss and also bring have emotional burden to the society. More than 50% of all fatal crashes and traffic crash fatalities occurred in rural areas. Lane departure crashes are a major type of crashes in terms of crash frequency and injury severity. Lane departure crashes include run-off-the-road (ROR), head-on, cross-median, and overturn crashes, and overturn crashes are a major crash type. In New Mexico, 65% of all fatalities and 44.5% of all serious injuries occurring on roadways from 2004 to 2009 involved lane departure. Alcohol, speed, fatigue, and distraction are frequent contributing factors to lane departure crashes. Drivers who are fatigued and/or inattentive at the wheel can understandably veer off the roadway onto the shoulder or even cross the centerline and veer into oncoming traffic, posing the horrific injury outcomes. Additionally, poor visibility of roadway lane shoulders has been identified as one of the leading causes of lane departure crashes during nighttime and inferior weather conditions.

Rumble strips have been an effective highway safety countermeasure for inattentive or distractive drivers against potential overturn crashes due to their audible rumbling sound and tactile vibration, especially on rural highways. However, due to infrastructure deterioration that can be attributed to aging, traffic loading, rainfall, and temperature variation, roadway shoulder striping becomes less visible to provide the motorist with adequate information of the edge of the outside driving and lead to an increase in overturn crash occurrence frequencies and severities.

U.S. 285 is a major highway that runs through Colorado, New Mexico, and Texas with a large portion acting as a crucial corridor for the eastern portion of New Mexico,

and also carries a significant portion of overturn crashes. Shoulder rumble strips are applied on both edges but these rumble strips are gradually deteriorated due to aging, traffic loading, and the change of weather. In order to reduce the potential and injury severities of overturn crashes, New Mexico Department of Transportation (NMDOT) District Two initiated a project and applied retroreflective rumble stripes with elements on existing rumble strips along U.S. 285 within NMDOT District Two jurisdiction to increase their visibility. In this project, retroreflective rumble stripes were applied by using high-durable acrylic traffic paint on existing rumble strips and then placing double drop dry elements to enhance the visual representation of edge line location as well as the angles associated with a rumble strip.

With this project, this research is conducted to evaluate the safety performance of the newly implemented retroreflective rumble stripes in overturn crash occurrence prevention. In this study, a field survey was conducted to collect road users' knowledge and opinion rumble strip and the implemented retroreflective rumble stripes regarding their safety effects, and 225 valid survey responses were collected for analysis. In brief, it is worth knowing that the majority of participants stated that the retroreflective rumble stripes were effective and welcomed in the area. In particular, over 71% of the participants had positive feelings toward retroreflective rumble stripes and over 95% of the participants believed that the NMDOT should implement shoulder and centerline retroreflective rumble stripes throughout rural roadways across New Mexico. Rumble strips are not expensive to install and the increase in quantity of retroreflective striping will not be a cost to drivers for future projects. An EB Before-after analysis was then conducted based on historical overturn crash data on U.S. 285 before and after the

retroreflective rumble stripes were implemented. A safety performance function was trained based on crash and Annual Average Daily Traffic (AADT) data of U.S. 285. It is shown in the results that, on average, there is a 28.5% reduction in crash occurrences after the implementation of the retroreflective rumble stripes, indicating the effectiveness of this countermeasure in rural traffic safety improvement. Therefore, it is recommended that the NMDOT and other transportation agencies should implement shoulder and centerline retroreflective rumble stripes for future measures of motorist safety and crash reductions.

CHAPTER 1.   INTRODUCTION

1.1. Research Background

Compared to urbanized areas, rural areas have a higher potential for more severe driver injuries in traffic crashes in spite of a lower crash frequency (Eiksund, 2009; Jones et al., 2008; Wu et al., 2015; Wu et al., 2016b). According to the National Highway Traffic Safety Administration (NHTSA) (NHTSA, 2013), 54% of total fatal crashes and 55% of total fatalities occurred in US rural areas, where only 19% of the total population are living. At the regional level in New Mexico, there were 350 fatalities due to traffic accidents in 2011, and 273 of them were on rural roadways (NMDOT, 2012). Rural highways are prone to induce traffic accidents with severe injuries and deaths due to the relative higher speed and low traffic volume. Overturn crashes due to lane departure are the major type of crash on rural roadways. According to Viner (1995), 46% of fatal and severe injuries on rural highways resulted from overturn crashes.

Lane departure crashes are a major type of crash that induces significant life and economic loss. Lane departure crashes include run-off-the-road (ROR), head-on, cross-median, and overturn crashes, and overturn crashes are a major crash type. ROR crashes involve vehicles that leave the travel lane and encroach onto the shoulder and beyond and hit one or more of any number of natural or artificial objects, such as bridge walls, poles, embankments, guardrails, parked vehicles, and trees. The Fatality Analysis Reporting System (FARS) reported in 2011 that there were 32,367 fatal crashes in the United States, of which 10,414 crashes were single-vehicle run-off-roadway crashes (NHTSA, 2013). In New Mexico, 65% of all fatalities and 44.5% of all serious injuries occurring on roadways from 2004 to 2009 involved lane departure (NMDOT, 2010).

Lane departure and overturn crashes are mainly attributed to inattentive driving and lack of alert countermeasures to avoid lane departure. Alcohol, speed, fatigue, and distraction are frequent contributing factors to lane departure crashes. Additionally, poor visibility of roadway lane shoulders has been identified as one of the leading causes of lane departure crashes during nighttime and inferior weather conditions.

Rumble strips, also known as "sleeper lines" or audible lines, have been an effective highway safety countermeasure for inattentive drivers against potential lane departure crashes due to their audible rumbling sound and tactile vibration, especially on rural highways. There are mainly three types of rumble strips that are applied on roadways based on their implementation locations with respect to the driving lane: shoulder rumble strips, centerline rumble strips, and transverse rumble strips (FHWA, 2011b). Rumble strips have been widely used in many states to prevent roadway departure crashes, and the preventive effects have been increasingly examined. For example, the Minnesota Department of Transportation (Miller, 2008) evaluated the safety effect of centerline rumble strips on rural highways in reducing crossover accidents for 2 and 3 wheeled vehicles. It was found that these rumble strips didn't pose negative effects to these vehicles and should be introduced in defensive driving education. Of these three types of rumble strips, shoulder rumbles strips are the most effective in reducing run-off-road and overturn crashes. Significant research has been conducted to evaluate the effectiveness and potential negative impacts of shoulder rumble strips in overturn crash prediction (Chen et al., 2016d; Chung, 1994; FHWA, 1997; Marvin and Clark, 2003; Park et al., 2014; Wu et al., 2016a).

1.2. Problem Statement

Rumble strips are an effective way to reduce run-off-road crashes by reminding road users about their lateral positions on roadways with rumbling sound and tactile vibrations. Rumble strips have been widely used on highways in New Mexico. However, in rural areas where supplemental roadway light doesn't usually exist, the outside lane shoulder retro-reflective pavement stripping is poorly visible during night time and wet weather conditions such as rain, fog, or snow. Due to deterioration that can be attributed to age, wear, and rain, the shoulder striping is difficult to see and does not provide the motorist with adequate information regarding the outside edge of the roadway, which may lead to the increase of off-road crash occurrences. In order to improve the visibility of rumble strips during nighttime and under adverse weather conditions, retroreflective rumble stripe paintings on existing rumble strips have been widely used in many states (Adikens, 2014; Agent, 2010; Ellis, 2015; Farkas, 2010a; Federal Highway Administration (FHWA), 2010; Hallmark et al., 2009; Lindly and Narci, 2006; Maryland State Highway Administration, 2011; Pike et al., 2010; U.S. Department of Transportation, 2012).

U.S. 285 is a major United States highway running south-north across Texas, New Mexico, and Colorado. This highway is a major corridor on the eastern plains of New Mexico carrying significant in-state and cross-state traffic volume and playing a significant role in improving local economic prosperity. Rumble strips were installed on both sides of U.S. 285 in New Mexico to prevent overturn crashes. However, these rumble strips deteriorated gradually and became less visible during nighttime or under adverse weather conditions with low visibility, such as rain, fog, snow, etc. Its southern segment from Vaughn to the state line experienced 490 crashes from 2007 to 2010, of which 121 (25%) were classified as overturn crashes. Of these overturn crashes, 7 were fatal crashes and 75 were injury crashes, inducing significant casualties

and property loss on roadways. To address this issue, New Mexico Department of Transportation (NMDOT) proposed to employ rumble stripes with elements to improve roadway edge visibility and retroreflectivness by painting retroreflective pavement striping over the existing rumble strips on highway U.S. 285 from Vaughn to State Line. The applied rumble stripes are 6-inch striping placed directly on rumble strip to reduce driver stress during nighttime and provide better information on the location of outside lane edges. The University of New Mexico, in coordination with NMDOT, conducted this research project to evaluate the safety performance of rumble stripes with elements using U.S. 285 as a case study, where a stated preference survey was conducted among road users for the designated section on U.S. 285 to gather travelers' opinions on the installed retroreflective rumble stripes and elements. The detailed information regarding the projected survey results is illustrated in Chapter 5.

1.3. Research Objectives

The goal of this research is to improve driving safety on rural highway US 285 by employing rumble stripes with elements on the shoulder rumble strips of US 285. To meet this goal, the following objectives need to be achieved:

- Identify the state-of-the-art and current use of paint striping of shoulder rumble strips in the United States.

- Evaluate the visibility improvements of the edge striping under dark and wet weather conditions based on onsite before-and-after observations and interviews.

- Collect drivers' opinions regarding the visibility of the rumble stripes and their effectiveness in overturn crash prevention.

- Develop Bayesian statistical models to investigate the heterogeneous impacts on drivers' opinions toward rumble stripping.

- Propose further recommendations based on the analysis results to enhance overturn crash prevention.

1.4. Report Organization

The remainder of this report is organized as follows: Chapter 2 reviews previous work regarding distracted driving and the applications and performance of rumble strips in peer regions. Chapter 3 introduces the detailed information of the US 285 retroreflective rumble stripe implementation project as well as previous supporting studies regarding US 285. The explicit research methodology design is illustrated in Chapter 4, including historical crash data analysis, roadway survey questionnaire design and collection, and binary logit regression model development. Historical data and survey response analyses were conducted and the results are comprehensively discussed in Chapter 5 to verify the necessity and effectiveness of retroreflective rumble stripe implementation in reducing overturn crash frequency and injury severity. Chapter 6 provides conclusions of this research effort and recommendations for future research.

CHAPTER 2.   STATE OF THE ART

2.1. Rural Highway Traffic Safety

Rural highways, including rural interstates and non-interstate highways, are major corridors carrying a significant portion of traffic with high speed, which are prone to induce traffic accidents with severe injuries. According to the Insurance Institute for Highway Safety (IIHS), there were about 10%-20% more motor vehicle crash deaths in rural areas than urban areas in the past several decades, as shown in Figure 2-1. Within the same period, the rate of vehicle crash deaths per 100 million vehicle miles traveled (VMT) was also significantly higher in rural areas than in urban areas, as shown in Figure 2-2.
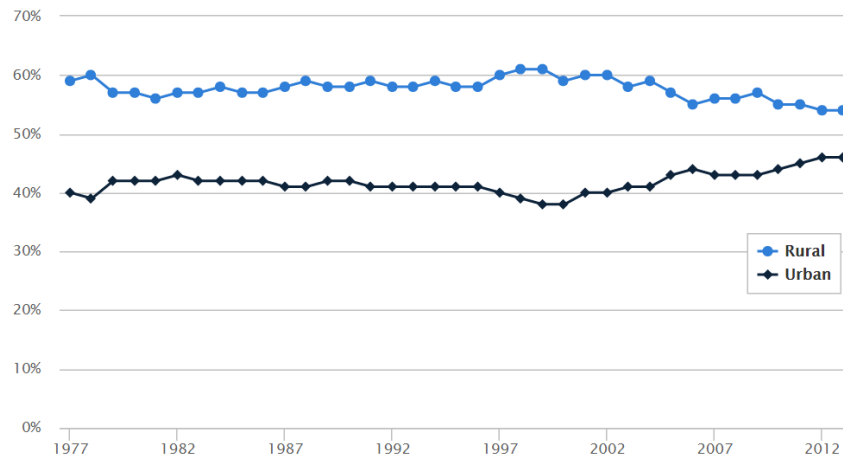
Figure 2-1 Motor Vehicle Crash Death Distribution by Land Use (1977-2013)

(Source: Institute for Highway Safety (IIHS))
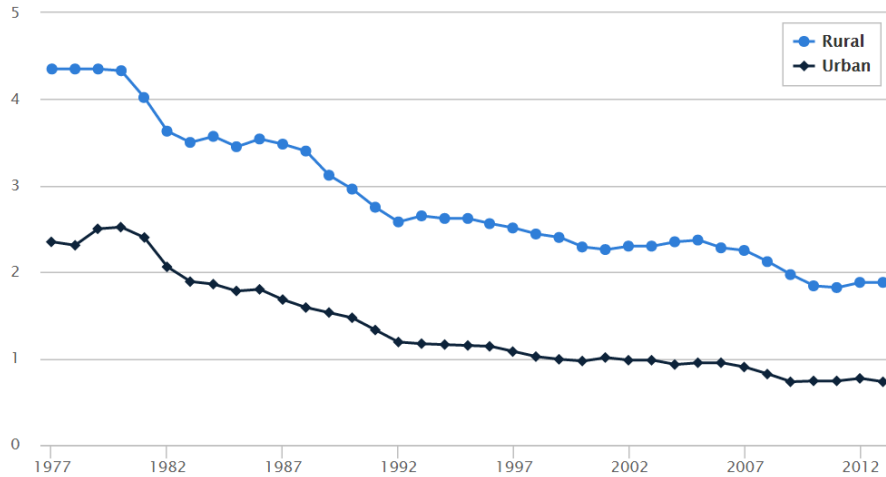
Figure 2-2 Motor Vehicle Crash Deaths per 100 Million VMT by Land Use (1977-2013)

(Source: Institute for Highway Safety (IIHS))

Due to the significant loss of life and properties, tremendous effort has been made to address traffic safety issues on rural highways. Governmental agencies and researchers have been investigating the impacts of rural interstate speed limits on traffic casualties at national and regional levels since the 1980s (Cannon et al., 2009; FHWA, 2004; McCarthy, 1993). With the development of mathematical models and computing techniques in recent years, significant research has been conducted to address rural highway safety issues by examining factors regarding infrastructure, vehicle, human behavior, and traffic environment, and their effects on crash frequency and injury severity. For example, using a multivariate analysis, Siskind et al. (2011) found that speeding, alcohol involvement, and traffic rule violations are major factors resulting in fatal crashes in rural areas. Lord et al. (2005) proposed predictive models to investigate the association between crash-flow-density and crash-flow-V/C ratio on rural freeway sections and assessed their influence on crash frequencies. Khorashadi et al. (2005) explored the difference in driver injuries between rural and urban highway crashes with

truck involvement through a multinomial logit (MNL) model. Farah et al. (2009) developed a Tobit model to examine the relationship between crash potential and drivers' passing behavior on rural two-lane highways and concluded that driver characteristics are among the significant attributes affecting crash potentials. Cafiso et al. (2010) developed synthetical analysis models to evaluate the safety performance of two-lane rural highways based on crash risk factors regarding exposure geometry, consistency, and context information. Using a mixed logit model, Chen and Chen (2011) evaluated the distinctiveness in the injury patterns of truck drivers in single-vehicle and multi-vehicle crashes on rural highways and assessed their risk factors. None-regression and non-parametric models were also utilized in traffic safety studies. Karlaftis and Golias (2002) employed a hierarchical tree-based regression model in rural highway accident analysis. Kashani and Mohaymany (2011) applied classification tree models to predict injury severity patterns of two-lane rural roadway traffic accidents. De Oña et al. (2013) examined the primary factors contributing to rural highway crash severity through latent class clustering (LCC) and Bayesian network (BN) techniques and concluded that the synthetic use of these techniques outperforms separate applications. Chen et al. (2016a, 2016b) developed hierarchical Bayesian regression models to investigate contributing factors on driver injury severities in rural interstate traffic crashes and rural non-interstate traffic crashes. Wu et al. (2014, 2016) utilized nested logit models and mixed logit models to evaluate the heterogeneous influence of contributing factors on driver injury severities in rural highway crashes.

2.2. Overturn Crashes and Inattentive Driving

Overturn crashes are a major crash type resulting in significant life and economic loss. According to the NHTSA, there were 2955 fatal overturn crashes on U.S roadways, accounting for 9.9% of all fatal crashes in 2011(NHTSA, 2013b). These rates were even worse in the State of New Mexico. According to NMDOT (2013), there were 306 fatal crashes in New Mexico in 2011. Overturn (34.6%) was the primary factor contributing to these fatal crashes, followed by collisions with other vehicles (29.1%). These fatal crashes resulted in 351 fatalities, of which 127 deaths (36.2%) resulted from overturned vehicles. Our research group has conducted several studies on overturn crashes based on New Mexico crash dataset using different regression models and machine learning techniques, focusing on the contributing factors and their influence on driver injury severity outcomes (Chen et al., 2016d; Wu et al., 2016a).

Table 2-1 New Mexico Fatal Crash Classification in 2011

Crash Classification	Fatal Crash	
	Count	Percent
Other Vehicle	89	29.10%
Fixed Object	50	16.3
Parked Vehicle	6	2.00%
Overturn	106	34.60%
Animal	3	1.00%
Other(Non-Collision)	7	2.30%
Other Object	3	1.00%
Pedestrian	34	11.10%
Pedalcyclist	4	1.30%
Vehicle on Other Road	3	1.00%
Railroad Train	1	0.30%
Total	306	100%

Inattentive driving is the primary cause of overturn crashes. Inattentive driving is the act of driving carelessly or being engaged in a secondary task, such as eating, phone

usage, talking with passengers, etc. Inattentive driving is one of the top contributing factors inducing traffic crashes and casualties, leading to 23.5% of total crashes and 12.5% of total fatalities (NMDOT, 2013). With the increasing prevalence of cell phone usage, driving while conversing on the phone or texting have been considered major types of inattentive driving behaviors that distract drivers' attention from roadways and increase traffic accident risk (Klauer et al., 2014). Hence, a significant number of states have approved corresponding laws or regulations to prohibit cell phone usage while driving. In the United States, 13 states and the District of Columbia (D.C.) have banned all drivers using hand-held phones while driving. 44 states and D.C. have banned texting for all drivers while driving. Additional regulations regarding cell phone usage are also enforced on novice drivers and school bus drivers (Governors Highway Safety Association, 2014).

Due to the significant loss of life and productivity resulting from distracted driving nationally, considerable studies have been conducted to address this issue from multiple perspectives, especially regarding cell phone usage. Donmez et al. (2008) discovered through driving experiments that retrospective and retrospective/concurrent joint feedback could degrade driver distraction and improve driving performance. Neyens and Boyle (2008) discovered that cell phone usage and passenger conversations introduce more severe injuries than those from other types of distracted driving behaviors. Hallett et al. (2011) examined the popularity and risk perception of cell phone use when driving and public attitude on legal prohibition of cell phone usage when driving through an internet survey. Specific attention has also been paid to particular driver groups or phone types. Neyens and Boyle (2007) examined the impact of different distractions on the

propensity of crash types popularly associated with teenage drivers and concluded that cell phone usage was a catalyst for rear-end crashes. Schlehofer et al. (2010) assessed college students' driving performance with the concurrent use of cell phones from a psychological perspective and verified the association between frequent cell phone use and inferior driving records. Nikolaev et al. (2010) assessed the impact of hand-held cell phone usage during driving on traffic accident risks based on historic crash data and examined the effectiveness of legislation on phone use prohibition during driving through a before-after analysis in terms of accident rates. Treffner and Barrett (2004) verified the adverse impact of hands-free mobile phone usage on driving control from biomechanical and perceptual perspectives through driving tracking techniques. Based on drivers' heart rate, Reimer et al. (2011) discovered that mid-age drivers are as capable as young drivers in managing hands-free phone calls while driving. The adverse effects of text messaging while driving have also been investigated from multiple perspectives. Klauer et al. (2014) found that dialing and reaching for cell phones during driving increase the risk of a crash or near-crash among novice drivers by 8.32 and 7.05 times, respectively, and texting increases risk by 3.87 times. Young et al. (2014) investigated the effects of text-messaging via touch screen and numeric keyboard phones on driving performance and eye glance behavior patterns and discovered similar intensity of driving performance decrement across two types of phone interfaces. Corresponding countermeasures were also proposed given these research discoveries. Shabeer and Wahidabanu (2012) developed an early detection system for phone calls to avoid cell phone usage during driving and reduce accident risks due to mobile communication. Defensive driving education is an effective precautionary procedure to mitigate inappropriate driving

behavior, including distracted driving, such as cell phone usage, resulting in an acceptable increase of travel delay. Steimetz (2008) evaluated the influence of defensive driving efforts in trade-offs between accident cost and travel-delay cost using a joint-evaluation model.

As is revealed in Table 2-2 (NMDOT, 2013), approximately 79.4% of all overturn crashes and 80.2% of all fatal overturn crashes occurred off-road, either on the left side or right side of the road. Rumble strips, especially shoulder rumble strips, are effective in reminding drivers to stay in lane and avoid overturn crashes, and therefore have been widely implemented in many states to prevent overturn crash occurrence and reduce crash severity.

Table 2-2 Classification of New Mexico Overturn Crashes by Crash Severity, 2011

Overturn Crash Location	Severity of Crashes							
	Fatal Crashes		Injury Crashes		Property Damage Only Crashes		Total Crashes	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Right Side of Road	56	52.80%	590	46.20%	456	52.10%	1,102	48.80%
Left Side of Road	29	27.40%	390	30.60%	273	31.20%	692	30.60%
On the Road	14	13.20%	241	18.90%	99	11.30%	354	15.70%
Not Stated	7	6.60%	55	4.30%	48	5.50%	110	4.90%
Total	106	100%	1,276	100%	876	100%	2,258	100%

2.3. Rumble Strip Type and Implementation

Rumble strips are a roadway safety measure to alert inattentive drivers to a potential crash or conflict situation due to lane departure by causing an audible rumbling sound and tactile vibration. Rumble strips are a series of raised or grooved patterns and are divided into three main categories depending on their functions and installation locations: shoulder rumble strips (Figure 2-3), centerline rumble strips (Figure 2-4), and

transverse rumble strips (Figure 2-5). Shoulder rumble strips are used primarily to reduce run-off-road collisions (Torbic et al.,2009). They alert distracted or drowsy drivers that they are leaving the roadway or crossing the centerline. Centerline rumble strips are used on undivided highways to reduce cross-over incidents and resultant head-on collisions. Transverse rumble strips are placed in the travel lanes where most if not all vehicles will cross them. They are used to alert the driver of an upcoming intersection, tollbooth or similar hazard. They may cross the entire road from shoulder to shoulder, or they may only be in the wheel paths (FHWA, 2012; Srinivasan et al., 2010). Rumble strips can also act as a roadway guide for drivers in areas where rain, fog, snow and dust obscure pavement edges.

Figure 2-3 Shoulder Rumble Strip

Figure 2-4 Centerline Rumble Strip

Figure 2-5 Transverse Rumble Strip

Federal Highway Administration (FHWA) (FHWA, 2011a) defined four types of rumble strips based on the difference in the way in which they are installed, shape and size, and the magnitude of noise and vibration generated: milled, rolled, formed, and raised. The design for each type of rumble strip is detailed below.

•   Milled-in: This design is made by cutting (or grinding) the pavement surface with carbide teeth affixed to a 24 inch (600 mm) diameter rotating drum. The indentations formed are approximately 0.5 inches (13 mm) deep, 7 inches (180 mm) wide parallel to the travel lane, and 16 inches (400 mm) long perpendicular to the travel lane. The indentations are approximately 12 inches (300 mm) on center and offset from the edge of the travel lane a distance of 4 inches (100 mm) to 12 inches (300 mm). Some research has been completed recently on the effectiveness of narrower and shallower cuts. Such variations from the original dimensions are discussed in detail later in the report.

•   Rolled-in: The rolled-in design is generally installed by using a steel wheel roller to which half sections of metal pipe or solid steel bars are welded. The compaction operation presses the shape of the pipe or bar into the hot asphalt shoulder surface. The resultant shape is generally 1 inch (25 mm) deep, 2 inches (50 mm) to 2.5 inches (64mm) wide parallel to the travel lane, and 18 inches (450 mm) to 35 inches (900 mm) long perpendicular to the travel lane. The indentations are usually set 8 inches (200 mm) on center and offset from the travel lane edge from 6 inches (150 mm) to 12 inches (300mm).

•   Formed: The formed rumble strip is added to a fresh concrete shoulder with a corrugated form, which is pressed onto the surface just after the concrete placement and finishing operations. The resultant indentations are approximately 1 inch (25 mm) deep, 2 inches (50 mm) to 2.5 inches (64 mm) wide parallel to the travel lane, and 16 inches (400 mm) to 35 inches (900 mm) long perpendicular to the travel lane.

•   Raised: Raised rumble strip designs can be made from a wide variety of products and installed using several methods. Products used may consist of raised

pavement markers, a marking tape affixed to the pavement surface, an extruded pavement marking material with raised portions throughout its length, or an asphalt material placed as raised bars on the shoulder surface. The height of the raised element may vary from 0.25 inches (6 mm) to 0.5 inches (13 mm). Spacing and width across the shoulder vary widely.

2.4. Rumble Strip Applications and Safety Performance in U.S.

Federal government agencies and state DOTs have also actively emphasized the safety impacts and applicability of rumble strips. NCHRP 641: *Guidance for Design and Application of Shoulder and Centerline Rumble Strips* and the *Highway Safety Manual* recorded the effectiveness of rumble strips in crash occurrence reduction. Centerline Rumble Strips (CLRS) on rural 2-lane roads result in a 44% reduction in head-on/fatal and injury crashes and a 14% reduction in all types of crashes. CLRS on urban 2-lane roads result in a 64% reduction of head-on/fatal and injury crashes. Shoulder Rumble Strips (SRS) on rural 2-lane roads result in a 33% reduction of run-off-road fatalities and injuries, as well as 15% of all run-off-road crashes. SRS on multilane divided roads result in a 16% reduction of all crash types and severities. FHWA conducted a safety evaluation analysis of roll-in shoulder rumble strips using data obtained from Illinois and California and found that the installation of CSRS on rural freeways in Illinois leads to an average of 7.3 percent average reduction in single vehicle run-off-road injury accidents. They also found that the installation of CSRS produces a deduction of 7.3 percent for single-vehicle run-off-road accidents on urban freeways in California (FHWA, 1997). The Montana Department of Transportation found in 2003 that shoulder rumble strips on interstates

reduced the rollover accident rates but the severity of roll-over accidents increased. This was thought to be because the rumble strips "scared" inattentive drivers to the extent that they overreacted (Marvin and Clark, 2003). NMDOT (2010) proposed rumble strips as an effective strategy to address inattentive driving crashes in their comprehensive transportation safety plan. The Minnesota Department of Transportation conducted a study on rumble strips and concluded that they offered a low cost and easy-to-install option (Corkle et al., 2002). A 2005 Maryland study suggests that transverse rumble strips are effective measures in drawing drivers' attention, and they therefore recommended them to be implemented at working zones (Maryland Highway Safety Administration, 2005). The Virginia Department of Transportation performed a series of tests for pavement roughness and sound levels on various typical rumble strips and found that the milled type was 12.6 times and 3.35 times greater in the pavement roughness index and sound levels, respectively, than the rolled type (Chung, 1994). The state of Colorado installed centerline rumble strips along a 17-mile section of a winding two-lane, undivided mountain highway and found that head-on crashes decreased by 22 percent and sideswipe crashes decreased by 25 percent (Outcalt, 2001). The Washington DOT comprehensively examined the combined implementation of centerline rumble strips and shoulder rumble strips in run-off-the-road crash prevention and also evaluated the influence of driving contributing factors, such as posted speed, lane width, shoulder recovery width, annual average daily traffic, and roadway geometry on run-off-the-road crash occurrence (Olson et al., 2013). The Utah Department of Transportation comprehensively evaluated the positive and negative effects of centerline rumble strips on rural undivided roadways in traffic safety improvement. Centerlines were

recommended due to their significant cross-over crash prevention effect, high benefit to cost ratio, flexible installation condition adaptability, and positive public opinions (Saito and Richards, 2005). Other example studies also include: Räsänen (2005) who discovered that rumble strips are able to keep vehicles' traveling lane at curvatures, which extended the service life of edge lines and improved traffic safety on curves. Khan et al. (2015) applied empirical Bayes (EB) in a before-after crash analysis to assess the effectiveness of shoulder rumble strips in reducing run-off-the-road crashes and discovered that a reduction of 14% in ROR crash frequency was achieved with the installation of rumble strips on rural two-lane highways. With more detailed analysis, Wu et al., (2014) discovered that shoulder rumble strips were effective in reducing the occurrence of total number of crashes, but the effectiveness in reducing the likelihood of severe injury outcomes was not statistically significant. Anund et al. (2008) conducted a driving simulation study to evaluate the alerting effect of rumble strips on fatigue driving and discovered that the alerting effect was obvious but short-lived. La Torre et al. (2012) summarized effective countermeasures to alleviate human errors leading to roadside crashes, including barrier terminals, shoulder rumble strips, forgiving support structures for road equipment, and shoulder width.

Rumble strips also perform as a driving guidance and provide drivers adequate edge information. For example, a Texas study (Carlson and Miles, 2003) mentioned that "Snowplow drivers have come to depend on shoulder rumble strips to help them find the edge of the travel lane during heavy snow and other low visibility situations. In mountainous areas, shoulder rumble strips are handy because they provide tread for vehicles traveling up long slopes."

Even though rumble strips are effective in crash avoidance, they may raise other safety concerns. Shoulder rumble strips might pose potential safety issues to bicyclists using roadway shoulders as travel paths. Elefteriadou et al. (2000) developed shoulder rumble strip configurations to decrease the negative vibration effects experienced by bicyclists but maintain effective alerting influence on fatigued drivers. The researchers recommended "bicycle-tolerable" rumble strip design based on different speed limits (45 mph and 55mph). A similar study was also conducted by the New Jersey Department of Transportation to evaluate the negative effects of shoulder rumble strips on bicyclists and the proposed state standards on installations of rumble strips regarding minimum shoulder width, minimum riding surface, and lateral location and dimensions of rumble strips (Daniel, 2007).

2.5. Potential Problems and Solutions

As discussed above, high visibility lane edge markings are key elements for guiding drivers under low visibility driving conditions. Rumble strips are not only able to remind inattentive drivers to drive within traveling lanes but are also capable of providing drivers with adequate lane edge information, especially during nighttime or adverse conditions with low visibility. However, due to infrastructure deterioration that can be attributed to aging, traffic loading, rainfall, and temperature variation, roadway shoulder striping becomes less visible to the motorist. Without visible stripling, the motorist may not have adequate information regarding the edge of the outside lane, which can lead to an increase in run-off-road crash occurrence frequencies and severities. Rumble stripes have been proposed and implemented as an effective solution to increase nighttime lane

edge visibility to prevent roadway departure and overturn occurrences. A rumble strip

becomes a rumble stripe when a retroreflective pavement marking is placed on it. Rumble

stripes integrate the benefits of rumble strips and retroreflective lane markings. The

contour of the rumble strip drains water, and the reflective rumble striping provides a

back wall allowing the retroreflective markings to highlight the lane edge during

nighttime and other low visibility weather conditions (Federal Highway Administration

(FHWA), 2011b). It was also found that retroreflective markings under rumble strips

have more reflectivity than the standard edgeline/centerline markings, and these rumble

stripes are more resilient and durable than standard markings, especially in heavy winter

climates (Torbic et al., 2009). Numerical studies and practices have been conducted to

highlight the implementation standard and performance of retroreflective rumble stripes

in peer regions, as summarized below in *Section 2.6 Marking Retroreflectivity and*

Rumble Stripe Applications.

2.6. Marking Retroreflectivity and Rumble Stripe Applications

Retroreflective materials have wide applications in transportation systems,

including traffic signs and pavement markings. They also provide road users necessary

information for safety and expedite trip activities. The Manual on Uniform Traffic

Control Device (U.S. Department of Transportation, 2012) defines transportation-related

retroreflective colors and the specific meaning for each color in traffic signs and

pavement markings and also addresses the use of markings in combinations with

longitudinal (shoulder, centerline) rumble strips and transverse rumble strips. Figure 6

shows the examples of longitudinal rumble strip markings. According to MUTCD, "if it

is desirable to use a color other than the color of the pavement for a longitudinal rumble strip, the color of the rumble strip shall be the same color as the longitudinal line the rumble strip supplements".
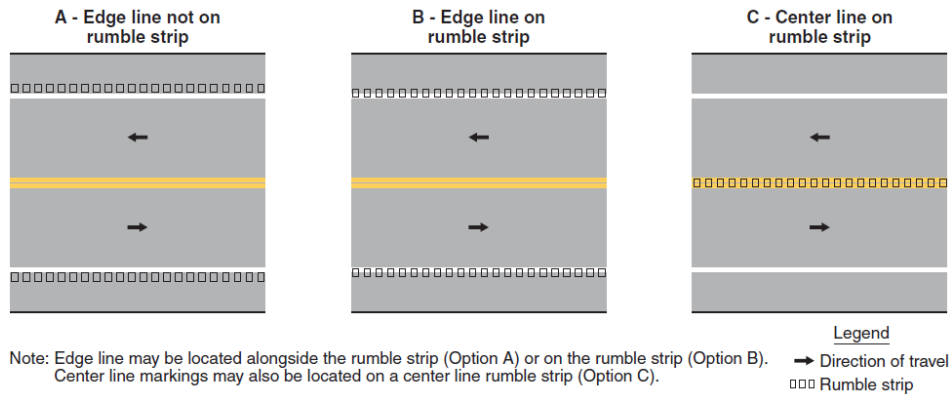
Figure 2-6 MUTCD Longitudinal Rumble Strip Markings

(Source: MUTCD 2009 Edition)

The minimum maintained retroreflectivity levels for longitudinal pavement markings were also proposed by the FHWA as follows:

"Public agencies or officials having jurisdiction shall use a method designed to maintain retroreflectivity of the following white and yellow longitudinal pavement markings, at or above the minimum levels in Table 3A-1:

1.   Center line markings on roads where they are required or recommended by Section 3B.01. This shall include any no-passing zone markings, longitudinal two-way left-turn lane markings, and yellow markings used to form flush medians on such roads.

2.   Lane line markings on roads where they are required or recommended by Section 3B.04. This shall include any dotted lane lines, lane drop markings, and longitudinal preferential lane markings on such roads.

3.   *Edge line markings on roads where they are required or recommended by Section 3B.07. This shall include any channelizing lines delineating gores, divergences, or obstructions on such roads.*

4.   *Any optional edge line markings that are used to qualify for the lower minimum retroreflectivity values in the "All other roads" row of Table 2-3.*

Table 2-3 Minimum Maintained Retroreflectivity Levels[1] for Longitudinal Pavement Markings (Source: MUTDC 2009 Edition)

	Posted Speed (mph)		
	≤30	35–50	≥55
Two-lane roads with centerline markings only[2]	n/a	100	250
All other roads[2]	n/a	50	100

1. Measured at standard 30-m geometry in units of mcd/m^2/lux
2. Exceptions:
   A. When RRPMs supplement or substitute for a longitudinal line (see Section 3B.13 and 3B.14), minimum pavement marking retroreflectivity levels are not applicable as long as the RRPMs are maintained so that at least 3 are visible from any position along that line during nighttime conditions.
   B. When continuous roadway lighting assures that the markings are visible, minimum pavement marking retroreflectivity levels are not applicable.

Rumble stripes have been utilized in peer regions to increase lane edge visibility during nighttime and under low visibility weather conditions such as rain, fog, and snow. As discussed above, the MUTCD specifies the minimum maintained retroreflectivity for pavement markings, which also applies to the retroreflecitve paintings on rumble strips (FHWA, 2010).

Maryland State Highway Administration (SHA) (2011) developed explicit guidance for the applications of rumble strips and rumble stripes, where the potential applications, bicycle permissions, design dimensions, gap spacing, specific design considerations regarding centerline, shoulder and transverse rumble strip/rumble stripes are defined in detail for state applications. For example, according to the SHA, "Installation of rumble stripes should be coordinated with permanent pavement marking and RPM placement. Permanent pavement markings and RPMs shall be installed after

installation of the rumble strips is complete. Typically thermoplastic or paint materials shall be used for rumble stripe markings."

Pike et al. (2010) measured the retroreflectivity of flat, profiled, and rumble stripe thermoplastic pavement markings using multiple handheld and mobile retroreflectometers to evaluate the influence of stepping distance on average dry retroreflectivity of these markings. It was found that stepping distance has no practical influence on average retroreflectivity, and the vertical structure of the rumble stripe markings doesn't increase the dry retroreflectivity. Additionally, the flat segment between the depressions of the rumble stripe pavement marking produces the best retroreflective effects.

The University Transportation Center of Alabama (Lindly and Narci, 2006) comprehensively evaluated flat thermoplastic edge markings and rumble stripes on highways to compare the service life, life-cycle cost, and wet-night visibility of these two markings. It was found that rumble stripes tend to have better retroreflectivity than flat thermoplastic edge markings since the retroreflectivity of rumble stripes tends to decay at a lower rate with respect to cumulative traffic volume. It was also discovered that rumble stripes have a longer service life but a higher five-year average annual maintenance cost.

The Iowa Department of Transportation implemented rumble stripes on the top 5% of low-volume rural roads for run-off-road crashes in order to avoid possible intrusion into the travel lanes. Horizontal curves generally had most frequent run-off-road crash occurrence and were ideal locations for rumble stripe implementations (Hallmark et al., 2009). The before-after crash analysis recommends installing narrow-width rumble stripes along rural roads experiencing a high frequency of run-off-road crashes.

With the occurrence of deadly crossover crashes, the Minnesota Department of Transportation installed six miles of rumble stripes on critical sections of U.S. 12 to reduce the occurrence and severity outcome (Adikens, 2014). The Ohio Department of Transportation implemented rumbles stripes on the shoulders of 1600 miles of rural state roads by cutting 6 inch wide and ⅜-inch deep rumble strips on white edge lines, but these rumbles stripes raised issues regarding bicyclists' rights and safety on these roads (Farkas, 2010).

The Kentucky Transportation Cabinet installed rumble stripes on rural two-lane roads to prevent lane departure crashes. The installed rumble strip had a width of 12 inches and a length of 7-7.5 inches, with depth ranging from ½-5/8 inch, and a 4 inch wide white edge line was applied onto the left most edge of rumble strips. Crash analysis results show that these rumble stripes should additionally be installed on rural two-lane roads to prevent lane departure and improve rural road traffic safety (Agent, 2010).

Vermont Agency of Transportation (VTrans) (Ellis, 2015) implemented centerline rumble stripes by grooving semi-circular depression steps on pavement and applying pavement markings adjacent to the rumble stripe to avoid head-on crashes on two-lane undivided highways. Evident reductions have been observed in the number of injury and fatal events in post-installation areas, verifying the effectiveness of this implementation. The applied rumble stripes are also more cost-effective in installing permanent pavement markings.

2.7. Empirical Bayes Before-After Analysis

Empirical Bayes (EB) before-after analysis is an important procedure to estimate the effectiveness of a roadway treatment in traffic safety improvement. Developed by Hauer (citation), it has been widely utilized in interactive highway safety design model and *Highway Safety Manual*. A lot of studies have applied the EB before-after method to assess the effectiveness of a certain transportation safety treatment (citation). Persaud et al. (2001) utilized the EB method to evaluate the safety effect of roundabout conversions in the U.S. Harwood et al. (2002) evaluated the effectiveness of different methods in safety before-after analysis of left turn and right turn lanes and concluded that the EB method was the most accurate and reliable. Montella (2009) applied the EB method in a before-after study to assess the safety effect of road curve delineation improvements in south Italy. Zhou et al evaluated the safety effect of roadway median treatment using the EB method. Azizi and Sheikholeslami (2013) used the EB method to study the safety effect of U-turn conversion in Iran. Wu et al. (2015) applied the EB method to evaluate the safety effects of roadway narrow pavement widening in Texas. Li et al. (2015) evaluated the safety effect of automated mobile speed enforcement on urban arterials in crash occurrence reduction through the EB method. Elvik (2013) assessed the safety influence of environmental speed limit in Oslo, Norway, via the EB before-after approach. Høye (2015a, 2015b) conducted before-after studies with the EB method to evaluate the safety effects of section control and speed cameras, respectively, on traffic crash reduction.

CHAPTER 3.   PROJECT INFORMATION

3.1. Studied Area and Previous Projects

U.S. 285 is a major United States highway running south-north across Texas, New Mexico, and Colorado. Its New Mexico section is a major rural corridor on the eastern plains of New Mexico. The studied area consists of the area between Milepost 0 (South state line) and Milepost 204 (Vaughn, NM) **(**Figure 3-1**)**. Within this study area, U.S. 285 is either 2-lane undivided roadway or 4-lane divided roadway with a median varying from 12 to 40 feet in width. The posted speed limit along U.S. 285 within the study area maintains 70 miles per hour in rural areas and gradually decreases to 30 miles per hour when approaching towns and villages. According to the Mid-Region Council of Governments, the average traffic volume on U.S. 285 is approximately 2400 vehicles per day. Within the study area, U.S. 285 majorly intersects with U.S. 62, U.S. 70, and U.S. 82 and merges with U.S. 60 and U.S. 64**.**

The NMDOT has completed the following construction and research projects that are within, overlap with, or are close to the study area in this research:

- **1997, U.S. 285 Reconstruction Project**: A roadway reconstruction project from Milepost 233 to Milepost 222.73. It also included drainage structure improvements.

- **1998, U.S. 285 Reconstruction Project**: A roadway reconstruction project from Milepost 194.19 to Milepost 204.47. It also included drainage improvements.

- **1999, U.S. 285 Reconstruction Project in Vaugh, NM**: A roadway reconstruction project in Vaughn, NM from Milepost 183.48 to Milepost 194.19. It also included drainage improvements and bridge replacement.

• **2014, U.S. 285 Corridor Speed Analysis Project:** A corridor speed analysis along U.S. 285 from Milepost 125 to Milepost 242. Corridor geometry and crash summaries were included.
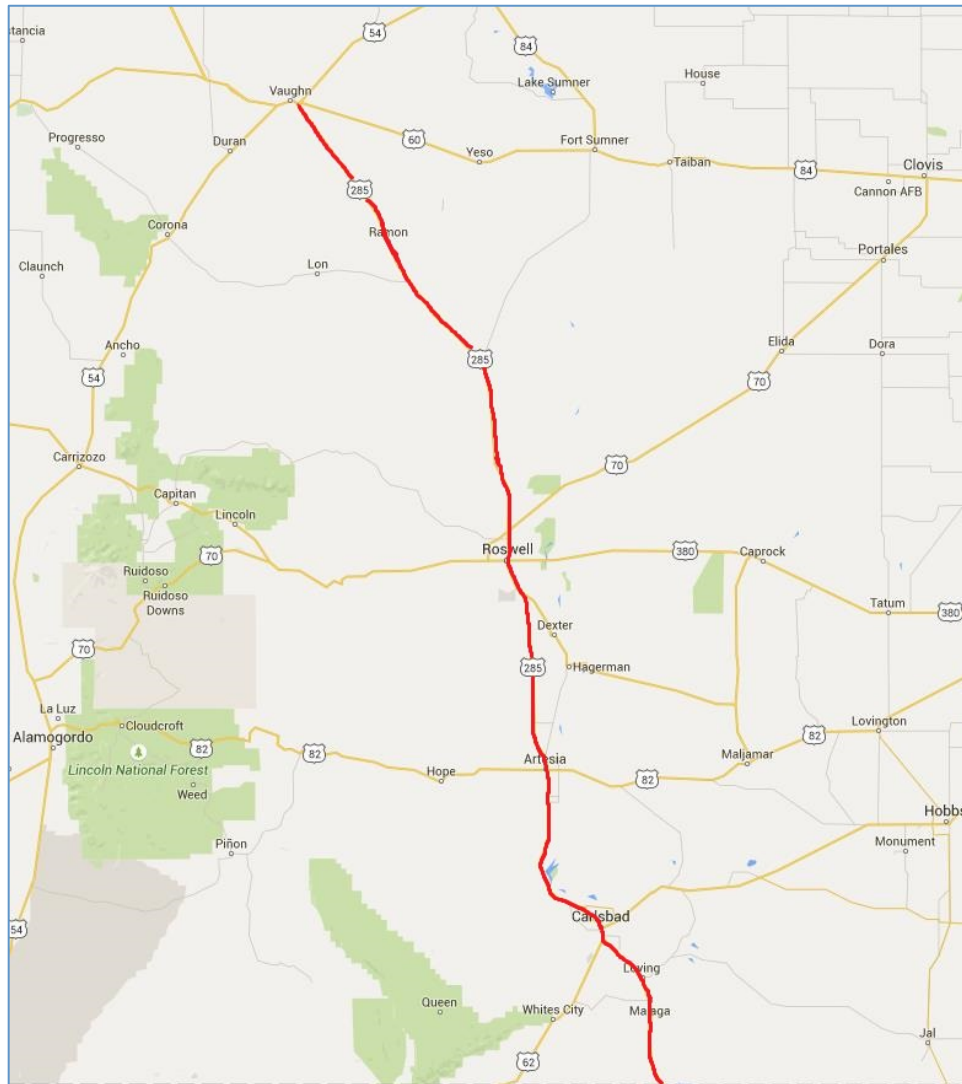
Figure 3-1 U.S. 285 Study Area

3.2. Rumble Strip Configuration and Rumble Stripe Installation

Within the study area, U.S. 285 is a major arterial with a significant portion of overturn crashes and shoulder rumble strips applied on both edges (Figure 3-2). The rumble strips are deteriorated due to aging, traffic loading, and weather change, and

become less visible during nighttime and adverse weather conditions. In order to reduce the potential for overturn crashes and injury severities, NMDOT initiated a project and applied retroreflective rumble striping with elements on existing rumble strips along U.S. 285 to increase their visibility. In this project, the rumble strip paintings were applied by using two applications of high-durable acrylic traffic paint installed at 22 to 25 mils wet film thickness per application as per Item Number 018 on existing rumble strips. Following the second application, Double Drop dry elements were placed as per Item Number 022. Both of these paintings and elements add to the visual representation of edge line location as well as the angles associated with a rumble strip magnifying the reflective capability of a painted stripe. These applications were implemented parallel to the existing shoulder stripe on the inside and outside rumble strips for multi-lane median divided sections and only on the outside rumble strips for two-lane sections. Their colors matched the adjacent should stripe color, as shown in Figures 3-3 and Figure 3-4. The rumble strips were fully within the width of the existing milled rumble strip and did not overlap onto the shoulder pavement. The detailed milepost information of these implementation sections is listed as follows in Table 3-1.

Table 3-1 Rumble Striping and Elements Implementation Description

Section No. (Milepost Information)	County	Retroreflecitve Striping	Double Drop dry element bead
1 (Milepost 0-Milepost 16)	Eddy County	6" wide high-durable striping, outside only, placed on existing rumble strip, 2 applications	6" wide (1.5 times length), outside only, single application
2 (Milepost 36.9-Milepost 54.9)	Eddy County	6" wide high-durable striping, outside and inside, placed on existing rumble	6" wide (1.5 times length), outside and inside, single application

		strip, 2 applications	
3 (Milepost 118-Milepost 154.5)	Chavez County	6" wide high-durable striping, outside and inside, placed on existing rumble strip, 2 applications	6" wide (1.5 times length), outside and inside, single application
4 (Milepost 154.5-Milepost 173.5)	DeBaca County	6" wide high-durable striping, outside and inside, placed on existing rumble strip, 2 applications	6" wide (1.5 times length), outside and inside, single application
5 (Milepost 173.5-Milepost 183.5)	Lincoln County	6" wide high-durable striping, outside and inside, placed on existing rumble strip, 2 applications	6" wide (1.5 times length), outside and inside, single application
6 (Milepost 183.5-Milepost 204.0)	Guadalupe County	6" wide high-durable striping, outside and inside, placed on existing rumble strip, 2 applications	6" wide (1.5 times length), outside and inside, single application

The retroreflectivity of the applied rumble stripes with elements were also tested by NMDOT with a retro pass value of 250 mcd/m^2·lux. The average values for the rumble stripes were 723 mcd/m^2·lux on the southbound and 594 mcd/m^2·lux on the northbound, both of which met the application standard.

Figure 3-2 Existing Shoulder Rumble Strips on U.S. 285 (within NMDOT D2 Administrative boundary)

Figure 3-3 Installed White Rumble Stripes (Near Outside Shoulder)

Figure 3-4 Installed Yellow Rumble Stripes (Near Insider Shoulder and Median)

CHAPTER 4. RESEARCH METHODOLOGY

4.1. Historical Crash Analysis

The research team examined historical traffic crash records on major U.S. highways within the NMDOT District 2 administrative boundary from 2007-2013, provided by NMDOT. These crash data were extracted from the New Mexico uniform crash report and illustrate comprehensive crash level information regarding crash types, time, locations, severity, weather condition, road geometry features, cause of crash, etc. (NMDOT, 2009). A standard crash report is attached in Appendix A. There are several major U.S. highway crossings in NMDOT District 2 carrying a significant amount of traffic and severe crashes. Therefore these crossing were selected in the crash analysis to examine crash distributions, including U.S. 54, U.S. 60, U.S. 62, U.S. 70, U.S. 82, U.S. 84, U.S. 285, and U.S. 380. To highlight the purpose of this research, overturn crashes and overall crashes on U.S. 285 were extracted from the entire dataset for more detailed analysis, and descriptive statistics with respect to different crash factors are provided and discussed. Thanks to the availability of the geographical information of the crashes in the most recent three years of the dataset (2010-2013), these crashes were mapped into Geographical Information Systems (GIS) to better visualize and present their spatial and temporal distributions.

4.2. Survey Design and Administration

A stated preference survey was designed to evaluate the safety effect on the installed retroreflective rumble stripes and elements along U.S. 285 from Vaughn, NM to the south State Line. Supervised by NMDOT, the survey was designed by the

Department of Civil Engineering at UNM, and was conducted at rest areas and gas stations along the designated road sections where the amount of stop-by road users was significant and stable. A wide range of data were collected to examine road users' demographic information, travel patterns, and their opinions on the effects of rumble strips and retroreflective rumble stripes in reducing overturn crashes. The designed survey was composed of four sections with a total of 34 questions. The first section collects road users' demographic information and physical conditions. The section part examined road users' commuting patterns regarding travel purpose, travel mode, and travel time. The third section revealed road users' knowledge background regarding inattentive driving, overturn crashes, and rumble strips. The final part investigated road users' opinions regarding the safety effect of the installed retroreflective rumble stripes and elements on U.S. 285 rumble strips. To relieve participants' burden, the questionnaire was relatively uncomplicated and on average took approximately 8-10 minutes to complete. Two undergraduate research assistants were employed to collect survey responses onsite (Figure 4-1) and input these responses into electronic Microsoft Excel files. The complete survey as well as the introduction is attached in **Appendix B: U.S. 285 Rumble Stripe Safety Performance Questionnaire.**

Figure 4-1 Field Survey Collection

4.3. Survey Data Examination and Statistical Analysis

Before statistical analysis and mathematical modeling on the collected survey data could take place, special care was taken to screen out outliers and incomplete data, such as records with participant gender missing or participant age entered as 0 or 5. A total of 225 valid surveys were collected and utilized for this analysis. To facilitate the statistical analysis and logit-BN modeling shown in 4.4, continuous variables were discretized with a limited number of exclusive categories. For instance, driver age is a demographic information variable with continuous integer values, and we classified it as the following groups: 20 years old or younger, 21-34 years old, 35-44 years old, 45-54 years old, 55-64

years old, and 65 or older. For variables with multiple exclusive values where some of these values are only present in a few data records, some values were combined for model simplification purposes. For example, the survey question: "In your opinion, would the applied retroreflective rumble stripes and elements help drivers to avoid road departure and improve roadway safety?" was selected and provided five options to evaluate travelers' opinions regarding the implemented rumble stripes with elements: "definitely no", "probably not", "not sure", "probably yes" and "definitely yes", rated as 1-5 accordingly. In order to facilitate the modeling procedure and ensure representative model results, these values were grouped into two categories: Positive (including "probably yes" and "definitely yes") and Non-positive (including "definitely no", "probably not", and "not sure"). Statistical analysis and pivot tables were utilized for distribution of driver demographic and travel behavior features and their cognitive responses on rumble strips/rumble stripes. The analyses results are discussed in Section 5.2.1.

4.4. Empirical Bayes Before-After Analysis for Safety Effect Evaluation

Bayesian analysis is gaining its popularity in traffic safety analysis, including Bayesian inference and Bayesian-based machine learning analysis (Chen et al., 2016b, 2016e, 2015a, 2015b). Empirical Bayes is an important model in Bayesian family and has been widely used in before-after analysis (Hauer, 1997; Persaud et al., 2010; Powers and Carson, 2004; H. Wu et al., 2015). The empirical Bayes before-after analysis procedure was employed to assess the safety performance of the implemented retroreflective rumble stripes with elements on U.S. 285 within NMDOT District 2 jurisdiction on overturn crash prevention. In the EB analysis procedure, the safety effect of a treatment at a site is

estimated as the reduction of the expected number of crashes in the after period δ_{site} resulting from the treatment:

$$\delta_{site} = \pi - \lambda \tag{4-1}$$

where π is the expected number of crashes that would have occurred without the treatment and λ is the total number of reported crashes observed in the after period.

In the analysis procedure, π is estimated as follows: first, a group of untreated sites with similar lane widths, traffic volume and other characteristics as treated sites are selected as the reference group. Regression models are used to develop safety performance functions (SPFs) by crash severity for the untreated sites. Additionally, annual SPF multipliers are usually calculated to account for temporal trends of crash occurrence. Then, the expected number of crashes E_b is calculated from the estimated SPFs, and is combined with the observed number of crashes O_b in the m_b year before the treatment to estimate the expected annual crash count N_b for the before period show as below:

$$N_b = w_1 \times O_b + w_2 \times E_b \tag{4-2}$$

where w_1 and w_2 are the corresponding weight parameters for O_b and P_b, and are estimated from the equations below:

$$w_1 = \frac{E_b}{\alpha + m_b \times E_b} \tag{4-3}$$

$$w_2 = \frac{\alpha}{\alpha + m_b \times E_b} \tag{4-4}$$

where α is equal to the inverse dispersion parameter estimated in the regression models.

Then π is estimated by multiplying N_b by a factor accounting for the length of the after period and the change of traffic volume between the before and after periods,

$$\pi = N_b \times \frac{E_a}{E_b} \times m_a \tag{4-5}$$

where E_a is the estimated number of crashes in the after period from the SPFs, and m_a is the length of the after period in number of years.

The variance of π is calculated as follows:

$$Var(\pi) = \frac{N_b \times \left(\frac{E_a}{E_b} \times m_a\right)^2}{\frac{\alpha}{E_b} + m_b} \tag{4-6}$$

The safety impact of the treatment for the treated group can be estimated by

$$\delta_{total} = \pi_{total} - \lambda_{total} \tag{4-7}$$

where π_{total} is the total sum of π for all sites with treatment and λ_{total} is the sum of λ for all the sites with treatment.

Accordingly, the variance of δ_{total} is estimated by

$$Var(\delta_{total}) = \sum Var(\pi) + \sum Var(\lambda) \tag{4-8}$$

The effectiveness could be evaluated by the index of effectiveness(H. Wu et al., 2015), which is defined as follows:

$$\theta = \frac{\frac{\lambda_{total}}{\pi_{total}}}{1 + \left[\frac{Var(\pi_{total})}{\pi_{total}^2}\right]} \tag{4-9}$$

and the corresponding variance of θ is

$$Var(\theta) = \frac{\theta^2 \left(\left[\frac{Var(\lambda_{total})}{\lambda_{total}^2}\right] + \left[\frac{Var(\pi_{total})}{\pi_{total}^2}\right]\right)}{\left[1 + \frac{Var(\pi_{total})}{\pi_{total}^2}\right]^2} \tag{4-10}$$

It shows in Eq.(4-9) that the index of effectiveness θ is defined as the ratio of the number of crashes that occurred after treatment is conducted to the expected number if the treatment is not conducted. The percentage of crash occurrence reduction is $100 \times (1 - \theta)$ %. In this study, we use the index of effectiveness θ to evaluate the performance of the implemented retroreflective rumble stripes in overturn crash reduction.

CHAPTER 5.   DATA DESCRIPTION AND ANALYSIS

5.1. Crash Data Analysis

NMDOT District 2 is a major administrative district located in the southeast plains in New Mexico and manages roadways in Roswell, NM and the surrounding area. In 2007-2013, there were 7272 crashes on the highway system in District 2, of which 5014 crashes occurred on U.S. highways, including U.S. 54, U.S. 60, U.S. 62, U.S. 70, U.S. 82, U.S. 84, U.S. 285 and U.S. 380. Of these crashes, 1111 (22.16%) were overturn crashes. Figure 5-1 summarizes the overturn crashes on these U.S. highways within NMDOT, District 2 administration.

Crash Distribution 2007-2013

	US 285	US 380	US 54	US 60	US 62	US 70	US 82	US 84
■ Number of Overturn Crashes	234	88	206	33	113	271	152	14
■ Number of Total Crashes	929	394	661	175	375	1489	934	57
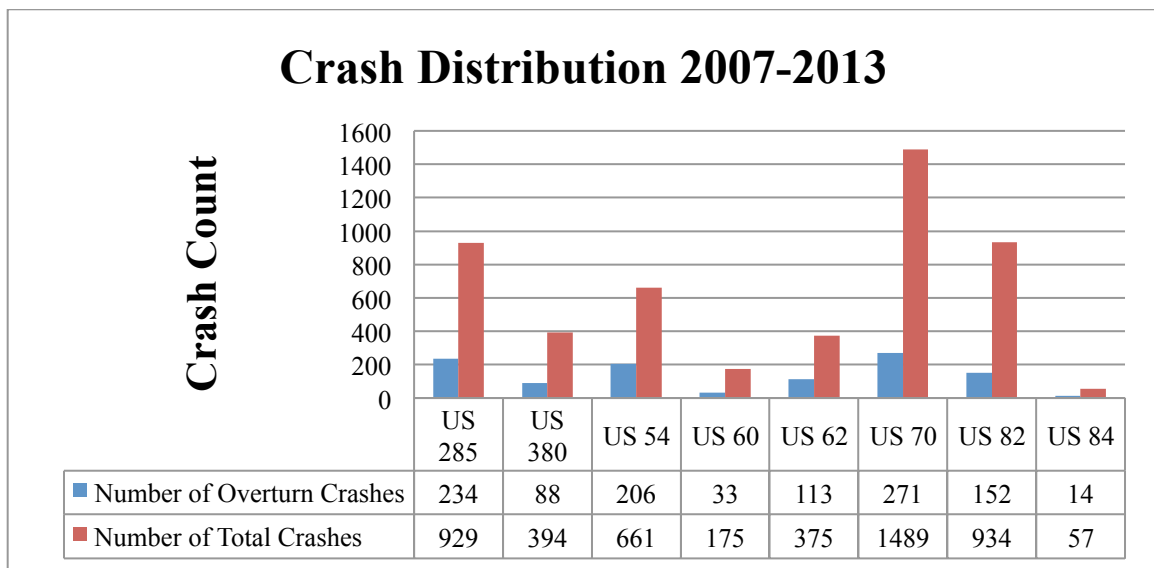
Figure 5-1 Overturn Crash Distributions on U.S. highways in District 2(2007-2013)

As is shown in Figure 5-1, U.S. 70 is the corridor experiencing the highest total number of crashes (1489 crashes in total), followed by U.S. 82 (934 crashes in total), and U.S. 285 (929 crashes). In terms of overturn crashes, U.S. 70 is still the corridor with the highest frequency with a total number of 271 overturn crashes from 2007-2013. This is followed by the most studied road in this research project, U.S. 285, which has a total of

234 crashes. This data reveals that overturn crash is a major type of crash on these highways, contributing up to one third of the total number of crashes.
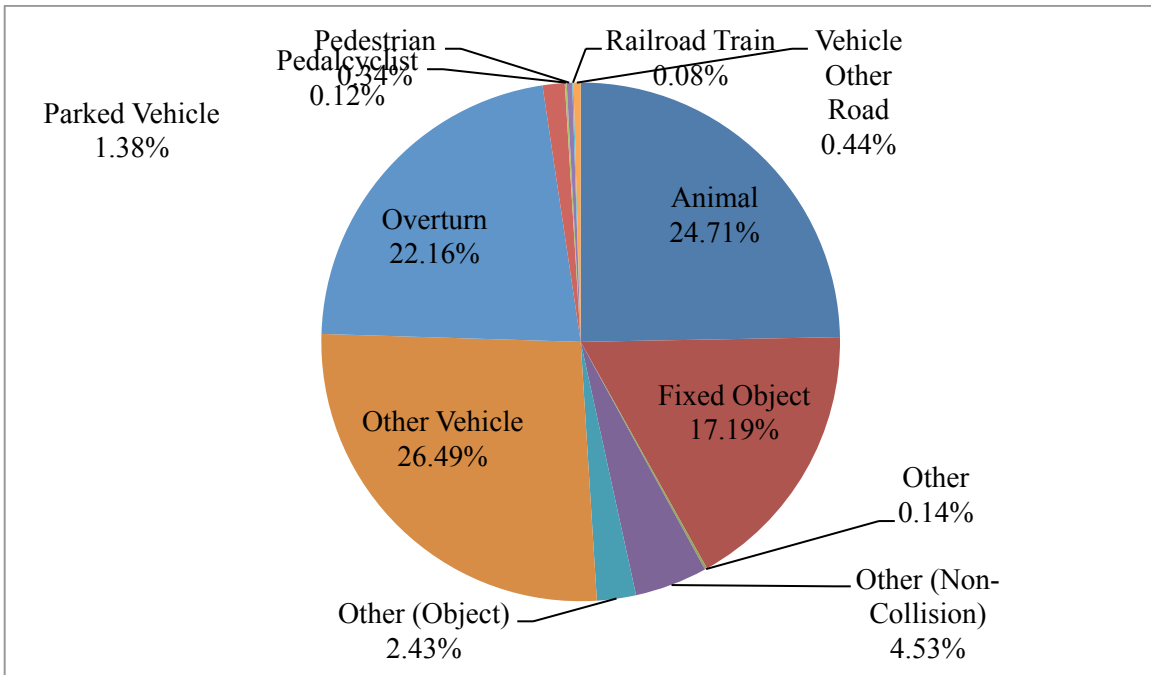
Figure 5-2 Crash Type Distribution on U.S. Highways in District 2 (2007-2013)

Figure 5-2 provides more details regarding crash type distributions on these U.S. highways within the NMDOT, District 2 administrative boundary from 2007 to 2013. It is shown in this Figure that collision with other vehicles is the most frequent crash type, accounting for 26.49% of all the reported crashes. Animal collision is the crash type with the second highest proportion, taking a major share of 24.71% of all the reported crashes. This is because most of these U.S. highways cross remote rural areas with a high frequency of animal road-crossing. Overturn crashes are another major crash type with the third highest crash frequency, accounting for 22.16% of all the crashes in the 7 year timespan. This signifies the necessity of conducting this research to reduce the occurrence of overturn crashes.
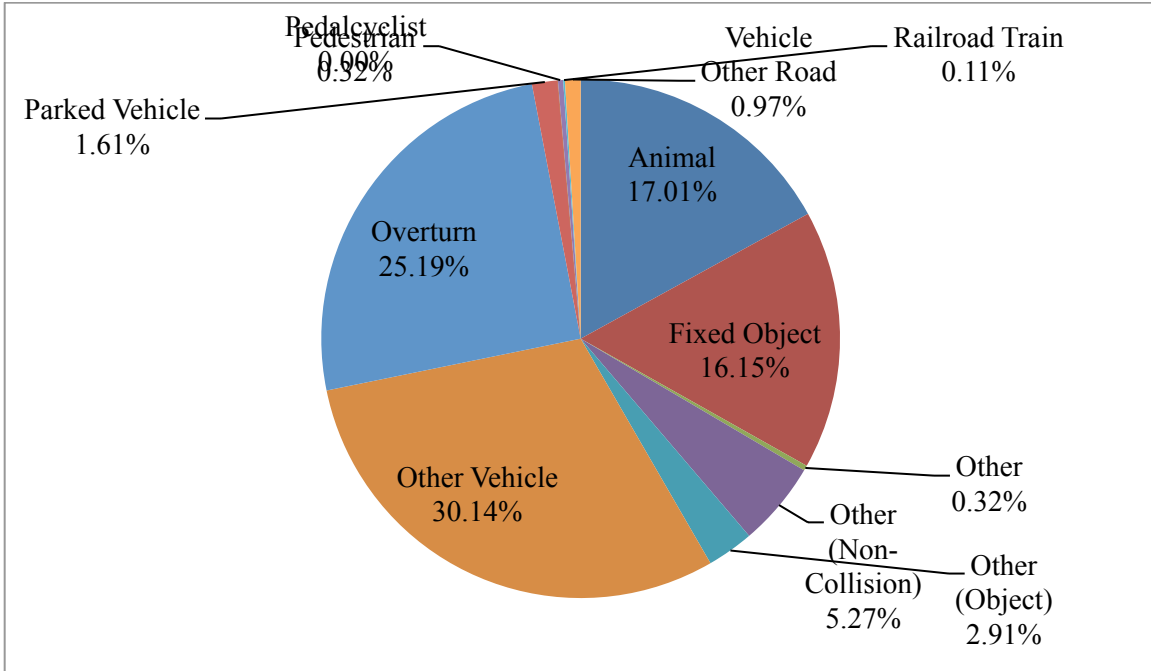
Figure 5-3 U.S. 285 Crash Type Distributions (2007-2013)

Figure 5-3 illustrates the crash type distributions on U.S. 285 from 2007 to 2013 within the NMDOT, District 2 administrative boundary from 2007 to 2013. It is shown in this Figure that collision with other vehicles is also the most frequent crash type, accounting for 30.14% of all the reported crashes. Overturn collision is the crash type with the second highest proportion, taking a major share of 25.19% of all the reported crashes in the 7-year timespan. This also signifies the necessity of conducting this research to reduce the occurrence of overturn crashes. Other major crash types include animal collisions (17.01%), collisions with fix objects (16.15%), and other non-collisions (5.27%).

Tables 5-1 to 5-6 demonstrate detailed severity distributions of overturn crashes on U.S. 285 regarding crash year, day of the week, lighting condition, county location, weather condition and contributing factors. It is found in that there is not significant increase or decrease in the annual amount of overturn crashes from 2007 to 2013, but

these crashes were more likely to occur on Thursday, Friday and Saturday, according to the statistics in Table 6. Besides, the majority (145 crashes) of these overturn crashes occurred daylight conditions, given the relative heavy traffic volume in the daytime. For the rest 89 overturn crashes, 75 occurred under dark condition without lighting, indicating that sufficient light condition during nighttime is necessary to reduce overturn crash occurrence. Besides, most of the overturn crashes between 2007 and 2013 occurred under clear weather conditions, with a total of 177 crashes. For the rest under adverse weather conditions, the majority occurred under snowy, snowy or windy weather conditions. As to crash spatial distribution, it is found that Chavez County, New Mexico has the highest number of overturn crashes from 2007 to 2013, with a total number of 161 crashes, followed by Eddy County and De Baca County and Lincoln County. There were only two overturn crashes in Lea County and Guadalupe County from 2007 to 2013. As is shown in Table 5-6, the major contributing factors include driver inattention, too fast for conditions, excessive speed, other non-error factors, alcohol/drug involvement, and left of center.

Table 5-1 U.S. 285 Overturn Crash Severities by Year

Year	Fatal Crash	Injury Crash	Property Damage Only Crash	Grand Total
2007	3	24	14	41
2008	1	16	9	26
2009	1	15	7	23
2010	2	20	9	31
2011	2	23	18	43
2012	1	21	9	31
2013	3	21	15	39
Grand Total	**13**	**140**	**81**	**234**

Table 5-2 U.S. 285 Overturn Crash Severities by Days of the Week

Day	Fatal Crash	Injury Crash	Property Damage Only Crash	Grand Total
Sunday	1	23	5	29
Monday	4	15	8	27
Tuesday	3	14	7	24
Wednesday	0	12	11	23
Thursday	2	25	16	43
Friday	2	22	18	42
Saturday	1	29	16	46
Grand Total	**13**	**140**	**81**	**234**

Table 5-3 U.S. 285 Overturn Crash Severities by Lighting Condition

Lighting Condition	Fatal Crash	Injury Crash	Property Damage Only Crash	Grand Total
Dark-Lighted	0	1	3	4
Dark-Not Lighted	4	46	25	75
Dawn	0	2	3	5
Dusk	0	3	2	5
Daylight	9	88	48	145
Grand Total	**13**	**140**	**81**	**234**

Table 5-4 U.S. 285 Overturn Crashes by Weather Condition

Weather	Fatal Crash	Injury Crash	Property Damage Only Crash	Grand Total
Clear	13	110	54	177
Snowing	0	8	16	24
Raining	0	10	4	14
Wind	0	9	4	13
Sleet or Hail	0	2	1	3
Fog	0	1	1	2
Other	0	0	1	1
Grand Total	**13**	**140**	**81**	**234**

Table 5-5 U.S. 285 Overturn Crash Severities by County

County	Fatal Crash	Injury Crash	Property Damage Only Crash	Grand Total
Chaves	8	72	36	116

|				
De Baca	3	15	15	33
Eddy	0	40	20	60
Guadalupe	0	0	1	1
Lea	0	0	1	1
Lincoln	2	13	8	23
Grand Total	**13**	**140**	**81**	**234**

Table 5-6 U.S. 285 Overturn Crashes by Top Contributing factors

| Row Labels	Fatal Crash	Injury Crash	Property Damage Only Crash	Grand Total
Driver Inattention	4	40	28	72
Too Fast For Conditions	0	16	20	36
Excessive Speed	3	20	5	28
Other-No Error	0	12	5	17
Alcohol/Drug Involved	3	9	1	13
Left of Center	0	8	5	13
Avoid Ped Etc.	1	4	3	8
Defect Tires	0	6	1	7
Poor Driving	0	3	3	6
None	0	2	3	5
Passed Stop Sign	1	3	1	5
Mech. Defect	0	3	1	4
Avoid Vehicle	0	2	1	3
Defective Tires	0	3	0	3
Drove Left Of Center	1	1	1	3
Failure To Yield	0	2	0	2
Improper Turn	0	1	1	2
Mechanical Defect	0	2	0	2
Avoid Pedestrian, Etc.	0	1	0	1
Imp. Lane Change	0	0	1	1
Improper Lane Change	0	1	0	1
No Indication	0	1	0	1
Other - No Driver Error	0	0	1	1
Grand Total	**13**	**140**	**81**	**234**

5.2. Survey Data Analysis

5.2.1. Participant Demographic and Travel feature Analysis

In Sections I and II of the designed survey, several questions were proposed to collect the demographic features, including driver age, gender and education level, and travel behavior characteristics, including annual travel mileage and primary vehicle type. The summaries of answers to these questions are presented below.
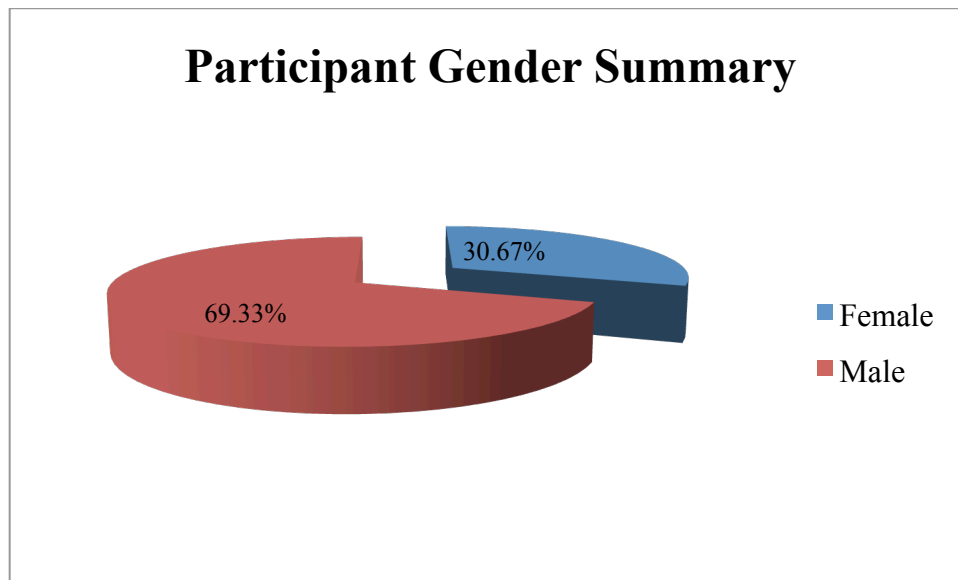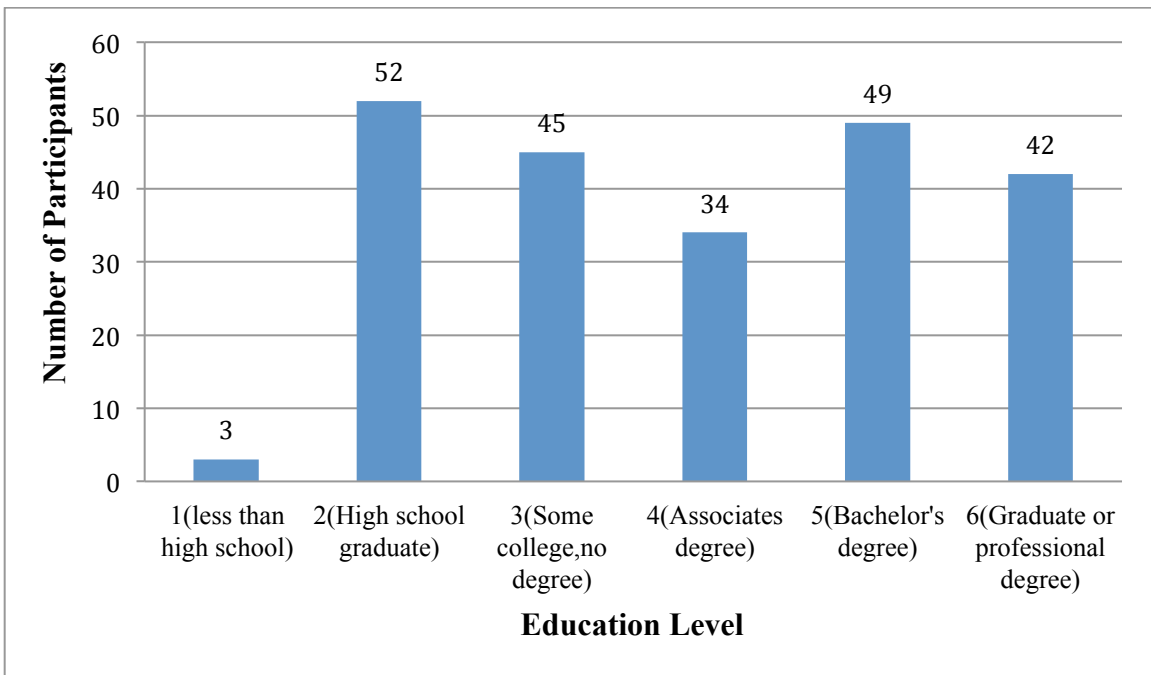

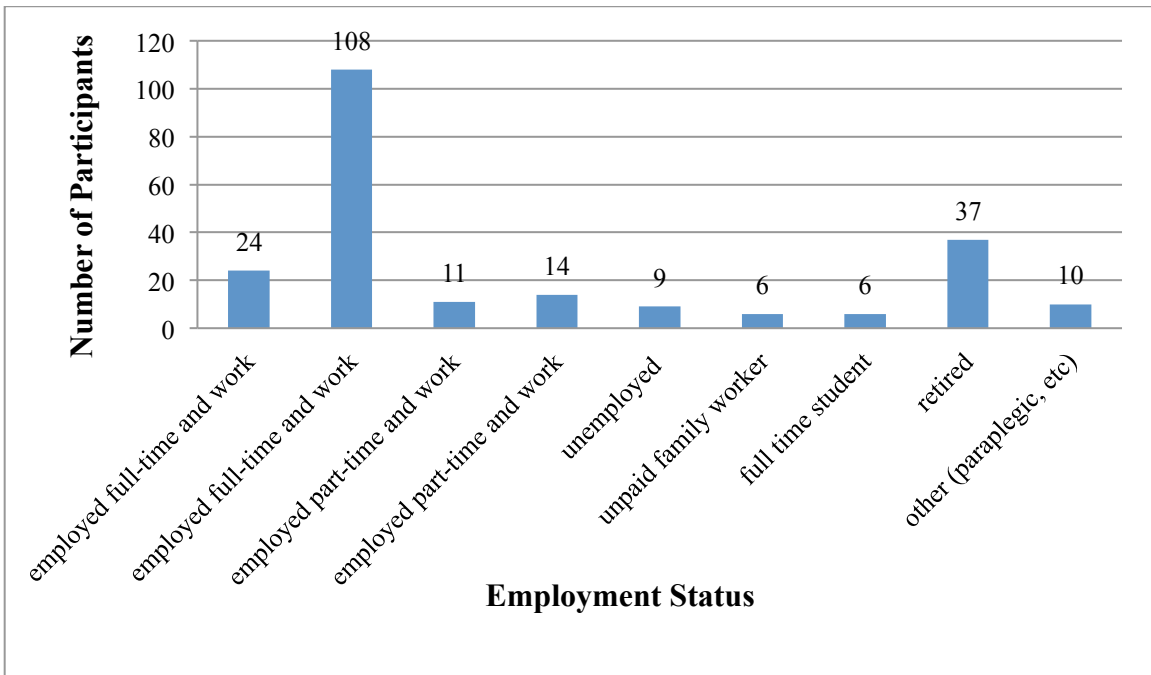**Figure 5-4 Survey Participant Distribution by Gender**
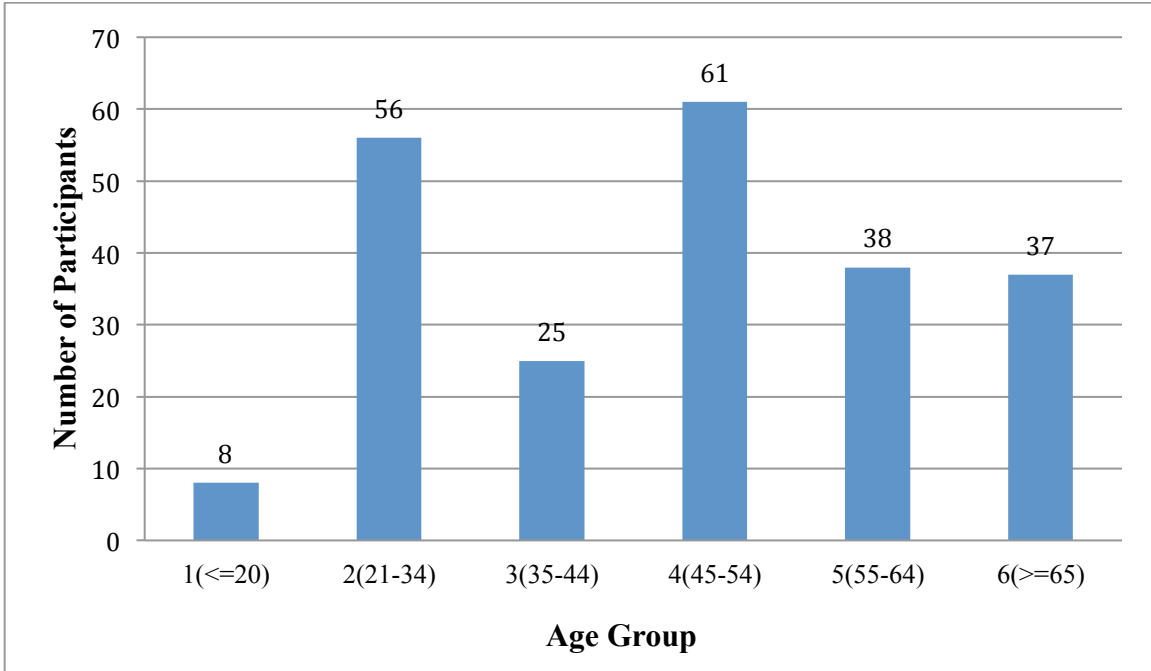
Figure 5-5 Survey Participant Distribution by Age
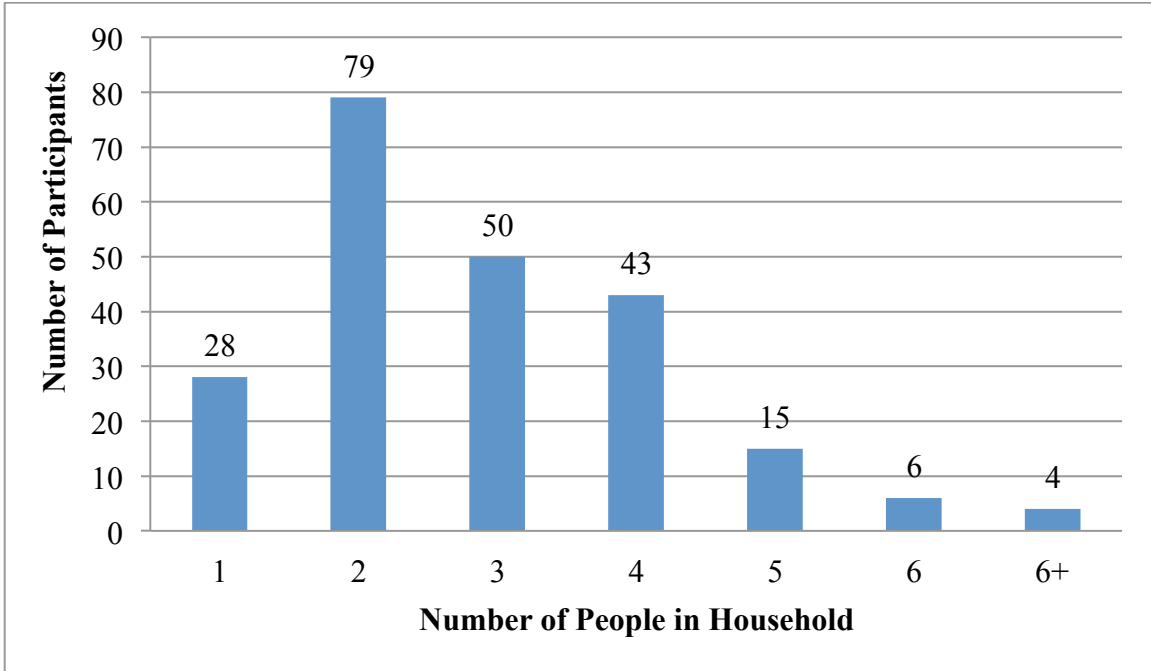

Figure 5-6 Survey Participant Distribution by Education Level

Of the 225 citizens who participated in the survey, 69.33% were male and 30.67% were female. More than 71.56% of the citizens surveyed were above the age of 35 with

the majority of the people falling in the age range 45 to 54. The second largest age group is between 25 and 34 years of age. When it came to the educational levels of the citizens who participated in the survey, the largest group is with high school degree level, and other major groups include those with college no degree, bachelor degree and graduate /professional degree. Overall, 40.44% of the citizens had obtained a Bachelor's Degree or higher in their educational career.
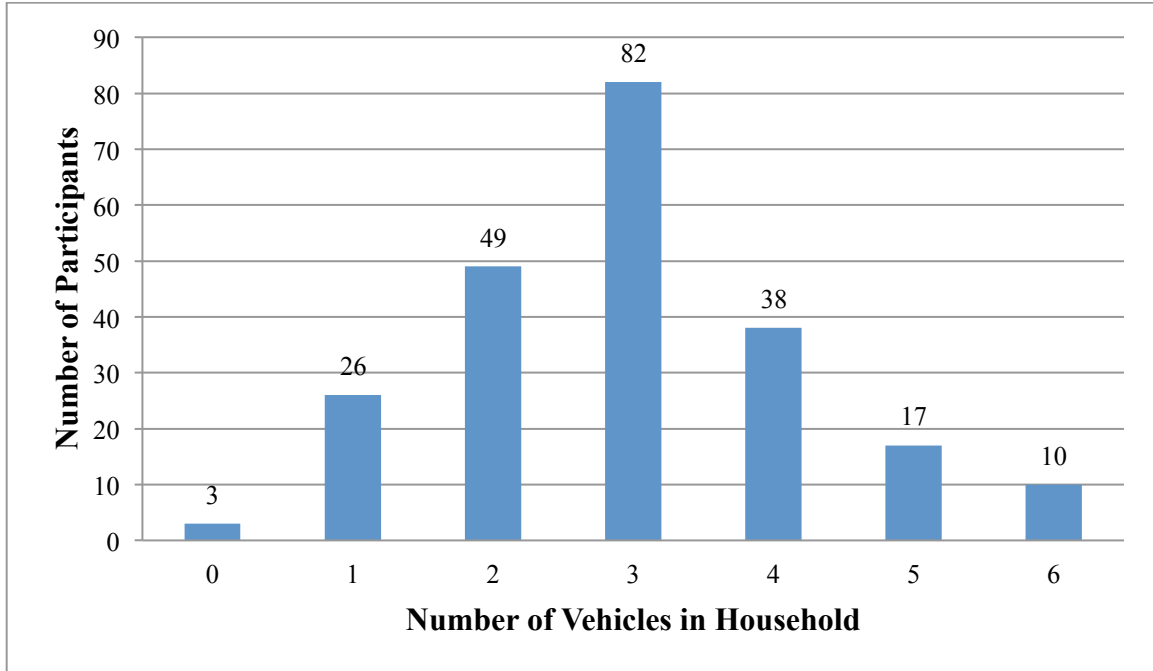

Figure 5-7 Survey Participant Distribution by Employment Status

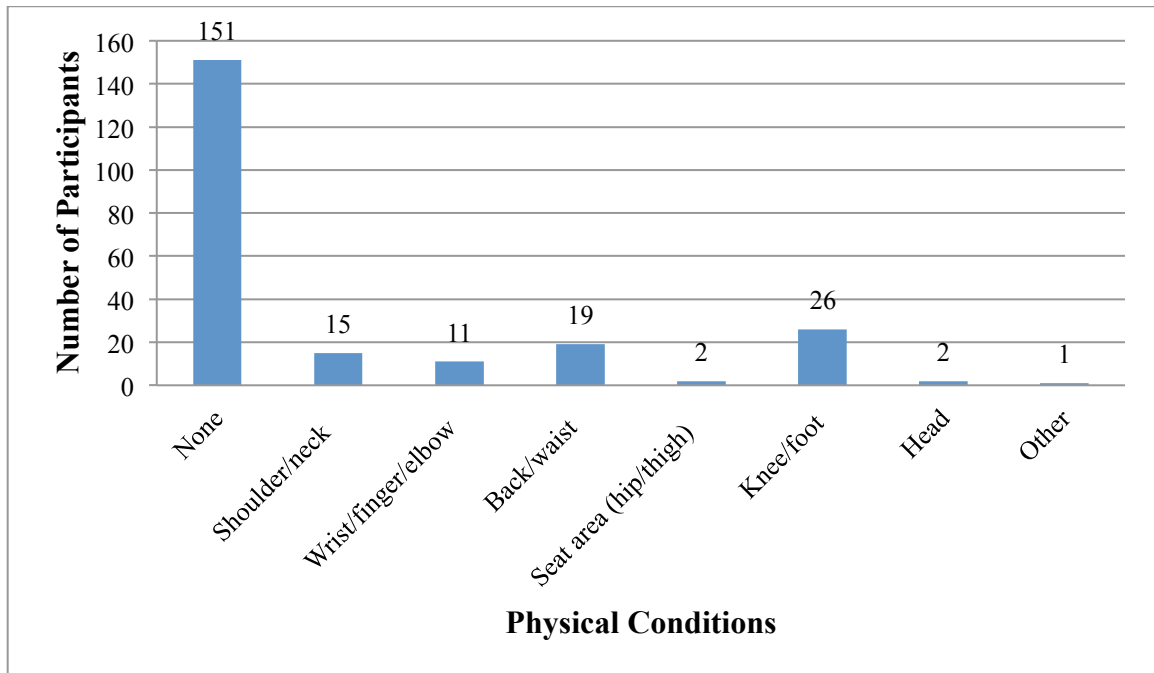**Figure 5-8 Survey Participant Distribution by Number of People in Household**
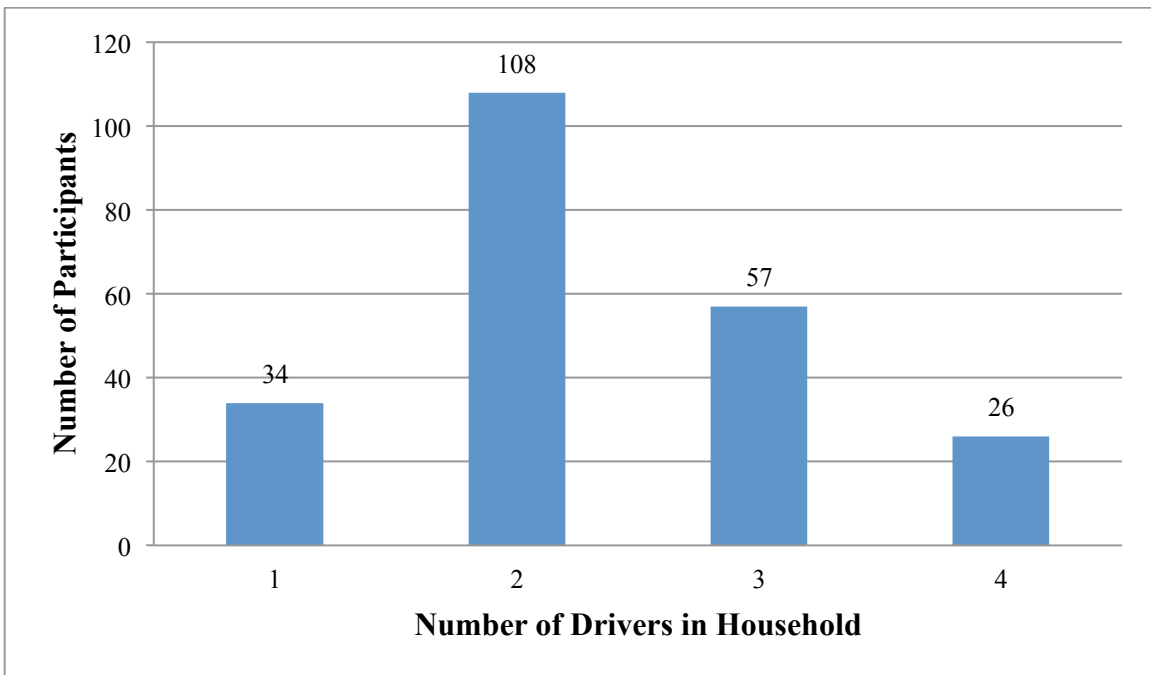
Figure 5-9 Survey Participant Distribution by Number of Drivers in Household

Figure 5-10 Survey Participant Distribution by Number of Vehicles in Household

Figures 5-7 to 5-10 reveal the distributions of survey participants regarding other demographic features, including employment status, household size, number of drivers in household, and number of vehicles in household. It is shown that, of all the survey participants, 108 participants work full-time and outside home, taking the largest share (48.00%) among all the categories. Following that there are 37 participants who are retired and 24 participants working full-time at home, accounting for 16.44% and 10.67% of all survey participants, respectively. For household size information, the largest group are 79 participants from household of two persons, accounting for 35.11% of all survey participants, followed by 50 participants from 3-person household, 43 participants four-person household, 28 participants from single-person household, 15 participants from 5-person household, and 10 participant from household of 6 persons or more. Regarding the number of drivers in household, the largest group is 108 participants who are from households with 2 drivers, followed by 57 participants from households with 3 drivers,

34 participants from households with single drivers and 26 participants from households with 4 drivers. As to number of vehicles in household, the largest group is 82 participants from households with 3 vehicles, followed by 49 participants from households with 2 vehicles, 38 participants from households with 4 vehicles, 26 participants from households with 1 vehicle, and 10 participants from households with 6 vehicles. There are also three participants from households with no vehicles.
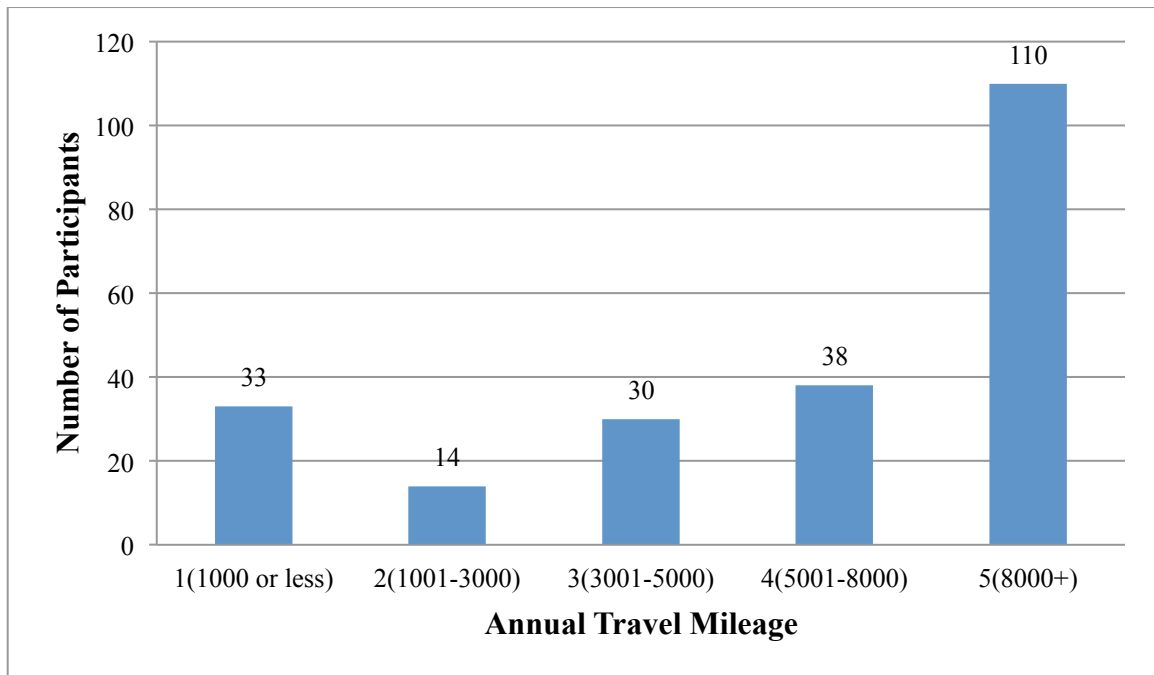

Figure 5-11 Survey Participant Distribution by Physical Conditions

Figure 5-11 reveals the physical condition information that may affect normal vehicle operations for all participants. It is shown that, of all the participants in this study, 151 participants don't have any adverse physical conditions affecting normal vehicle operations, accounting for 67.11% of all survey participants. Major adverse physical conditions include discomfort at knee/foot (26 participants), back/waist (19 participants), shoulder/neck (15 participants), and wrist/figure/elbow (11 participants).

5.2.2. Participant Commuting Patterns

The following questions collect information regarding the commuting patterns of all the survey participants.

Question 2-1 On Average, how many miles do you rider per year?

Figure 5-12 Participant Annual Travel Mileage Distribution

It is revealed in Figure 5-12 that there are 110 participants who travel 8000 miles or more annually, taking a significant share of 48.89% of all survey participants, followed by 38 participants travelling between 5001 and 8000 miles, 33 participants traveling less than or equal to 1000 mile annually, 30 participants traveling between 3001 and 5000 miles annually, and 14 participants traveling between 1001 and 3000 miles annually.

Question 2-2 On Average, how many days per week do you commute on U.S. 285 (between Vaughn and Roswell, NM)?
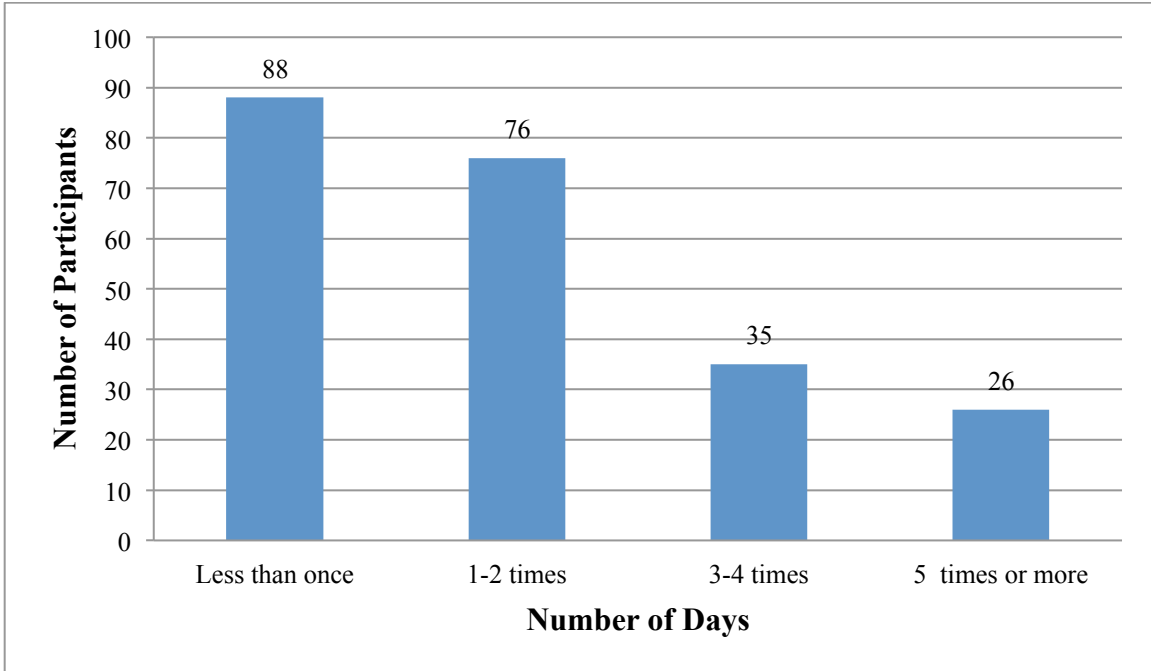
Figure 5-13 Participant U.S. 285 Travel Frequency Distribution

It is shown in Figure 5-13 above that the largest group regarding travel frequency on U.S. 285 is 88 participants traveling less than once per week, equal to 39.11% of all the participants. Following them are 75 participants traveling once or twice per week, 35 participants traveling 3-4 times per week, and 26 participants traveling 5 times or more per week on U.S. 285. Overall, there are 72.89% of the participants traveling twice or fewer per week on U.S. 285, and correspondingly 27.11% of all the participants travel 3 times or more per week on U.S. 285.

Question 2-3 What is your typical period of weekdays when you commute on U.S 285 (Select all that apply)?
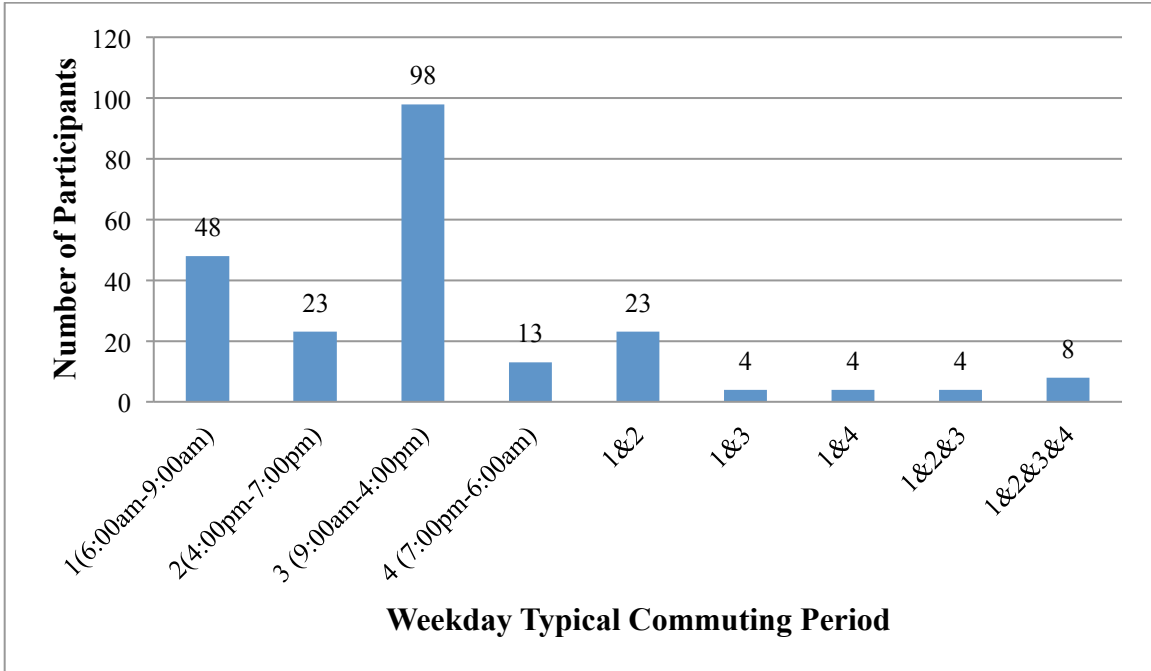
Figure 5-14 Weekday Typical Commuting Period Distribution

Question2-4 What is your typical period of weekend day when you commute on U.S 285 (select all that apply)?
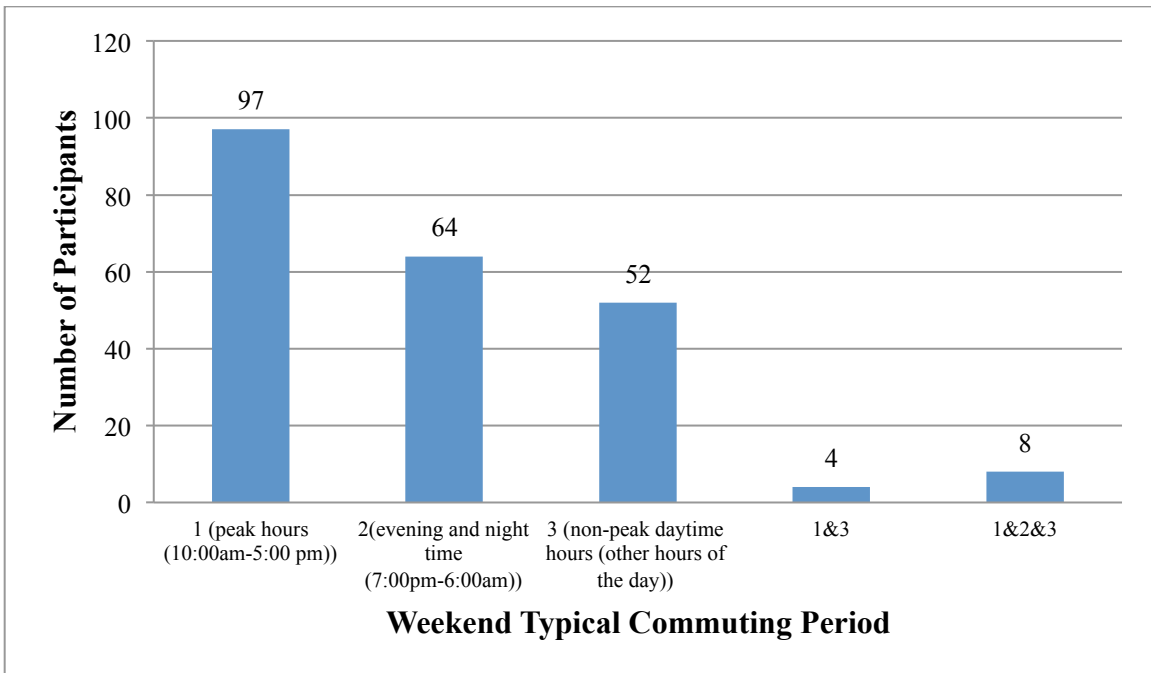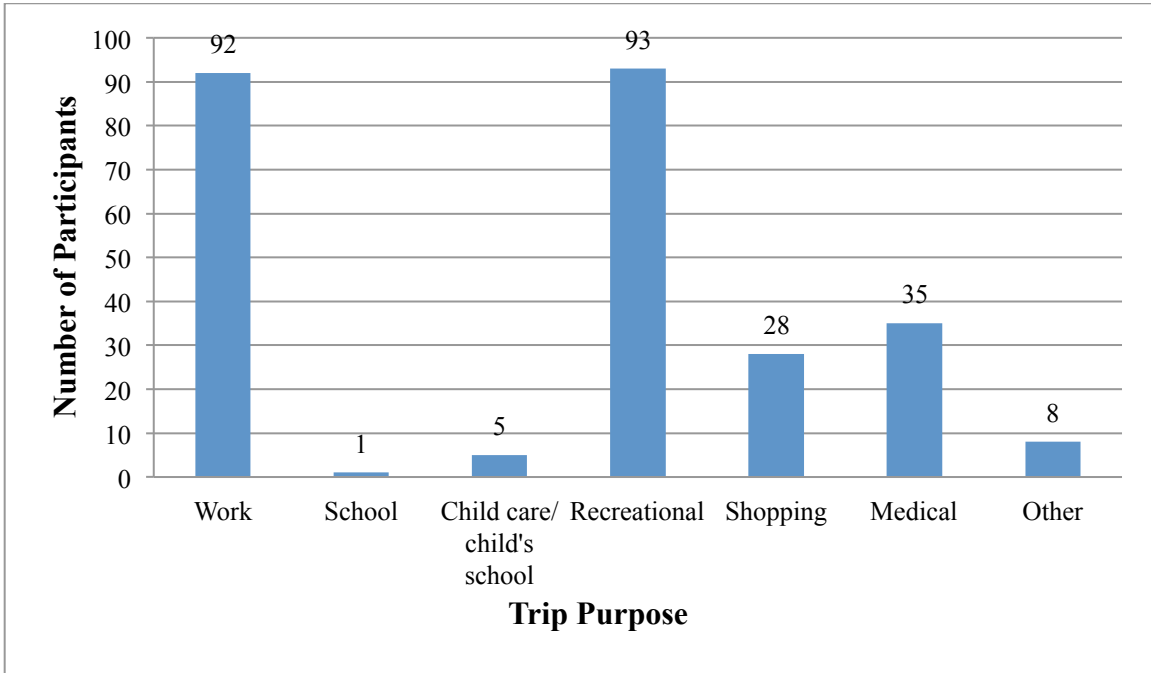

Figure 5-15 Weekend Typical Commuting Period Distribution

Question 2-5 What is your main trip purpose(s) when you travel on U.S. 285?
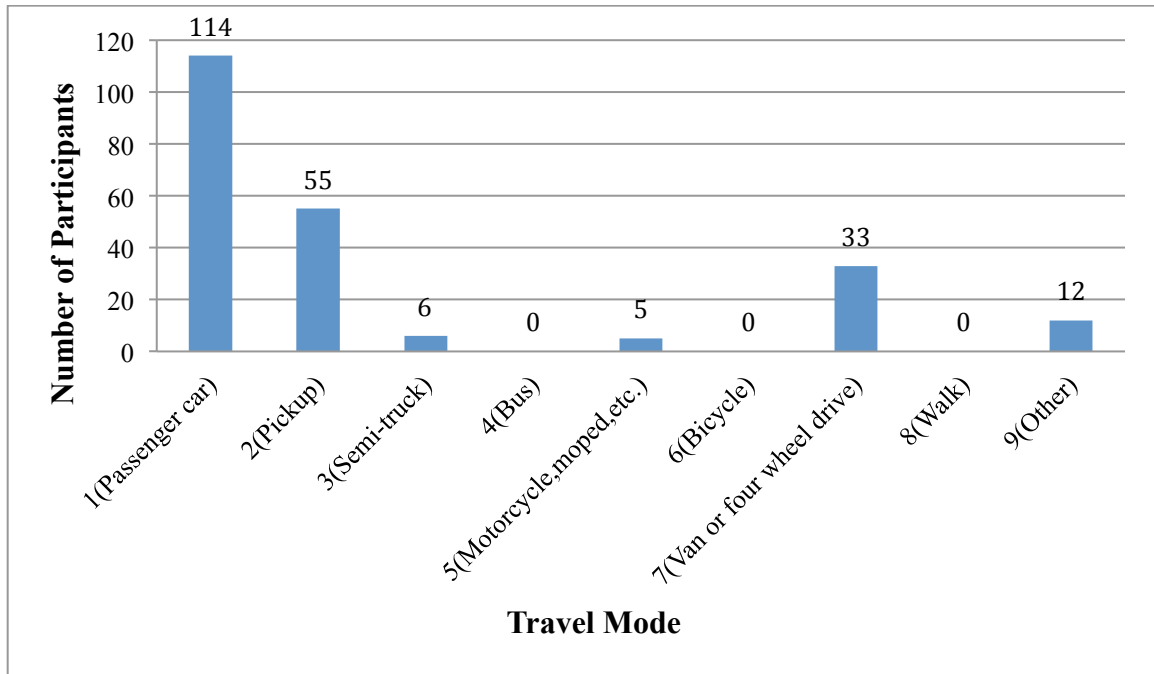

Figure 5-16 Participants' Trip Purpose Distribution

It is found in Figures 5-14 and 5-15 that during the weekday, the most typical time period for commuting on U.S. 285 is between 9:00 AM and 4:00 PM, followed by 6:00 AM-9:00AM. While during the weekend, the most typical time period for commuting on U.S. 285 is weekend peak hours (10:00 AM-5:00 PM), followed by evening and night time (7:00 PM-6:00 AM) and non-peak daytime hours. As for trip purposes for commuting on U.S. 285, the most frequent travels are recreational and work trips, with comparable amount of participants falling in each category. It is understandable that recreational travel purpose is the most popular since there are Carlsbad Caverns National Park, Bottomless Lakes State Park, and Roswell, NM famous for UFO investigations and reports, along U.S. 285, attracting significant tourist volume. Besides recreational and travel purposes, shopping and medical service are also two

major trip purposes for these survey participants, as is shown in Figure 5-16. Other trip

purposes include school, childcare, airport commute, family event commute, etc.

Question 2-6 What type of vehicles do you use most often when traveling? (Please select one answer)

Figure 5-17 Participants' Travel Mode Distribution

When it came to the participants' travel mode, more than half of the participants

drove passenger vehicles. 55 participants (24.44%) drove pick-up trucks and 33 (14.67%)

participants drove van or four-wheel drive. It is important to note that motorcyclists

accounted for just 2.22% of the motorists and not a single bicyclist or bus driver

participated in the survey.

5.2.3. Cognitive Responses on Rumble Strips

The following evaluates participants' driving history information and their cognitive levels and opinions of the participants regarding the rumble strips.

Question 3-1 How many driving years do you have?   _____ Years (Total)
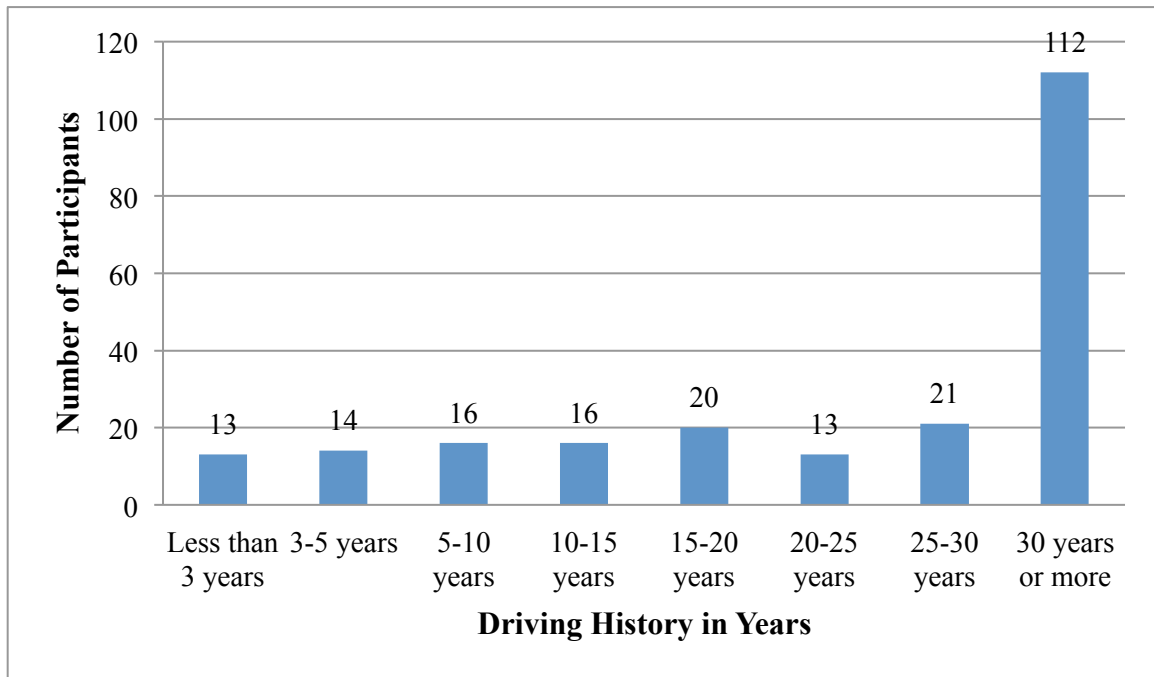
Figure 5-18 Driving Experience Distribution

As for driving history, approximately half (112 participants) of all the participants have 30 years or more of driving experience, as is shown in Figure 5-18, followed by 21 participants falling into the category "25-30 years" and 20 participants falling into "25-30 years". The rest participants almost evenly fall into the other five categories, with 13 to 16 participants in each category.

Question 3-2-1 Have you ever committed inattentive driving? (Yes / No)
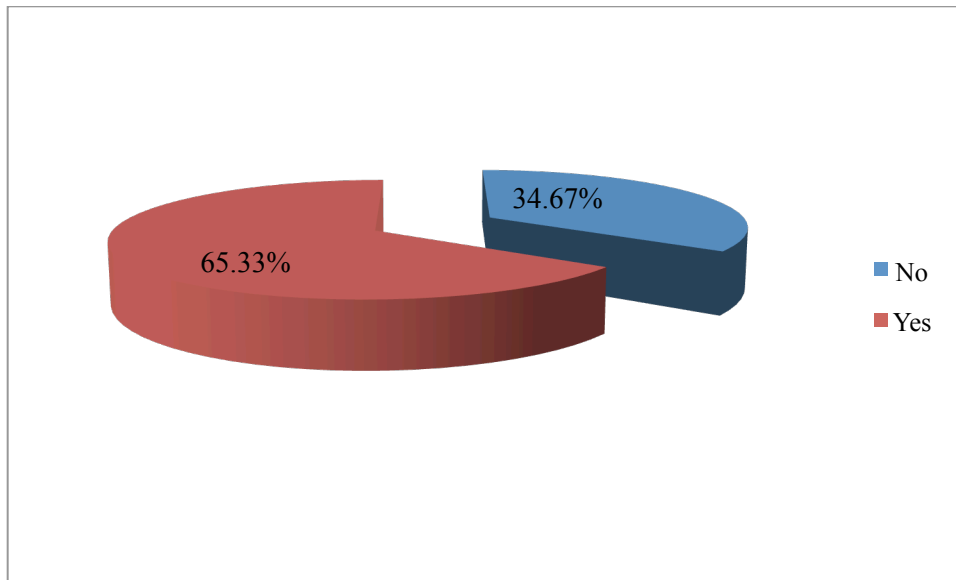
**Figure 5-19 Inattentive Driving Participant Proportion**

Question 3-4 What type(s) of distracted or inattentive driving did you involve? (Select all that apply)

Statistics in Figure 5-19 reveal that 147 participants committed inattentive driving, accounting for 65.33% among all the survey participants in this study. For these drivers that committed inattentive driving, the most common inattentive driving type is drowsy and fatigue driving, which was performed by 104 survey participants, equal to 70.74%, as is shown in Figure 5-20. The second most common inattentive driving type is speeding, which was performed by 56 participants and was comparable to "talking on hands-free/hand hold electronic device" and "other inside activity (eating, changing CD, attending children, etc.)". Other major inattentive driving types also include "manually operating electronic communication device (texting, typing, dialing)", "passenger distraction", and "external distraction".
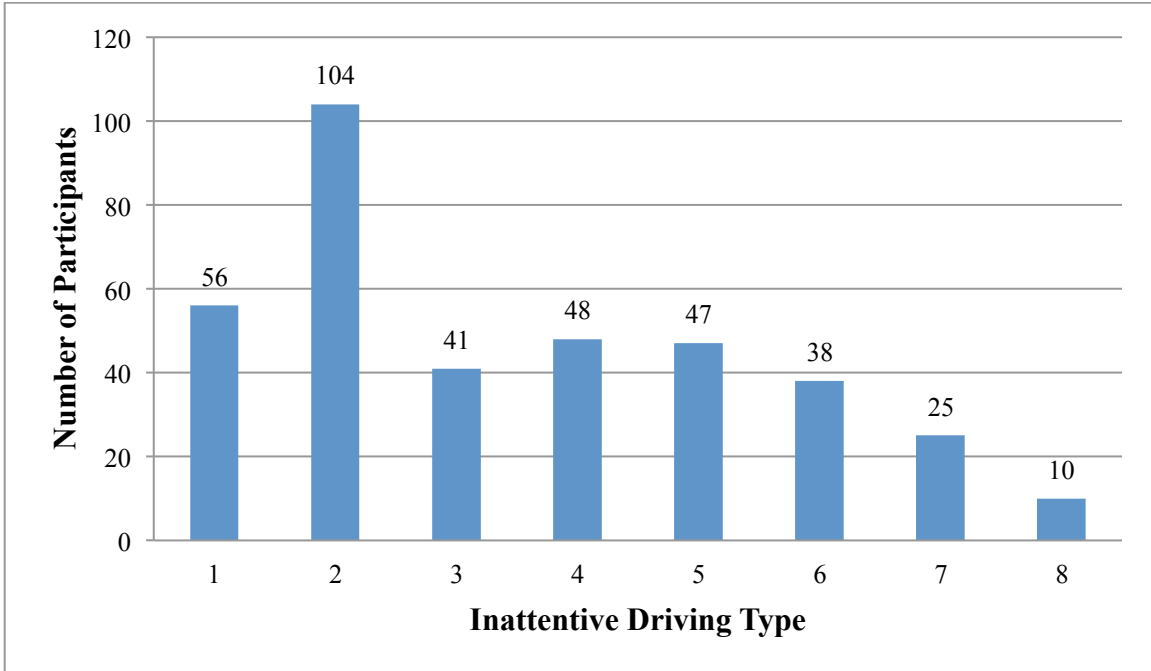
1=Speeding, 2=Drowsy and fatigue driving, 3=Manually operating electronic communication device (texting, typing, dialing), 4=Talking on hands-free/hand hold electronic device, 5=Other inside activity (eating, changing CD, attending children, etc.) 6=Passenger distraction, 7=External distraction, 8=other

Figure 5-20 Inattentive Driving Behavior Distribution

Question 3-5 Have you ever taken a defensive driving /driving safety course? (Yes/ No)
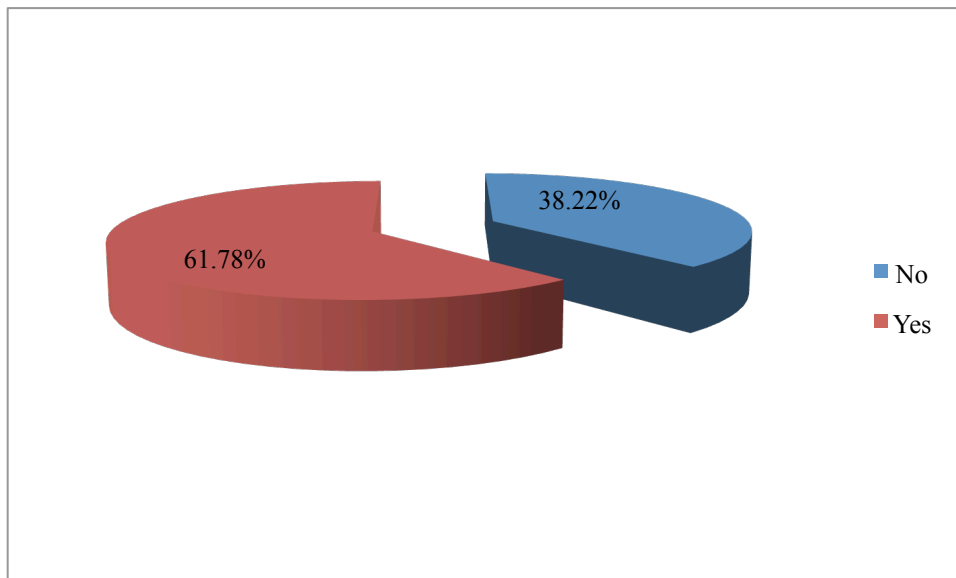
Figure 5-21 Proportion of Participants Taking Defensive Driving Courses

Question 3-6 Do you know well what a shoulder rumble strip is? (Yes / No)
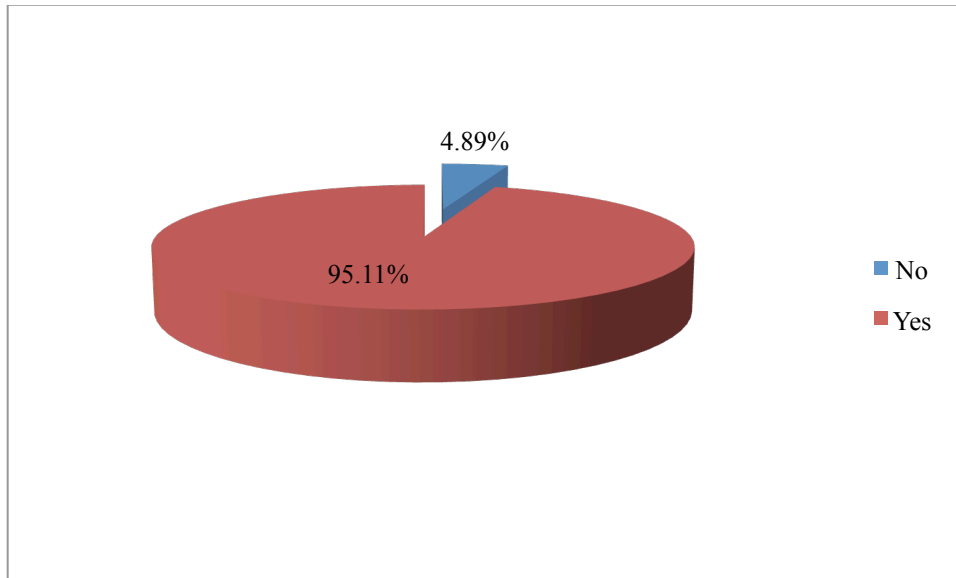
Figure 5-22 Proportion of Participants Knowing Rumble Strips

Question 3-7-1 Have you ever run over a shoulder rumble strip?

Figure 5-23 Proportion of Participants Running Over Should Rumble Strips

Question 3-7-2 If yes, how often does this happen?(Yes / No)

Figure 5-24 Should Rumble Strips Running Frequency Distribution

Question 3-8 What was the cause or causes for driving over the shoulder rumble strips?

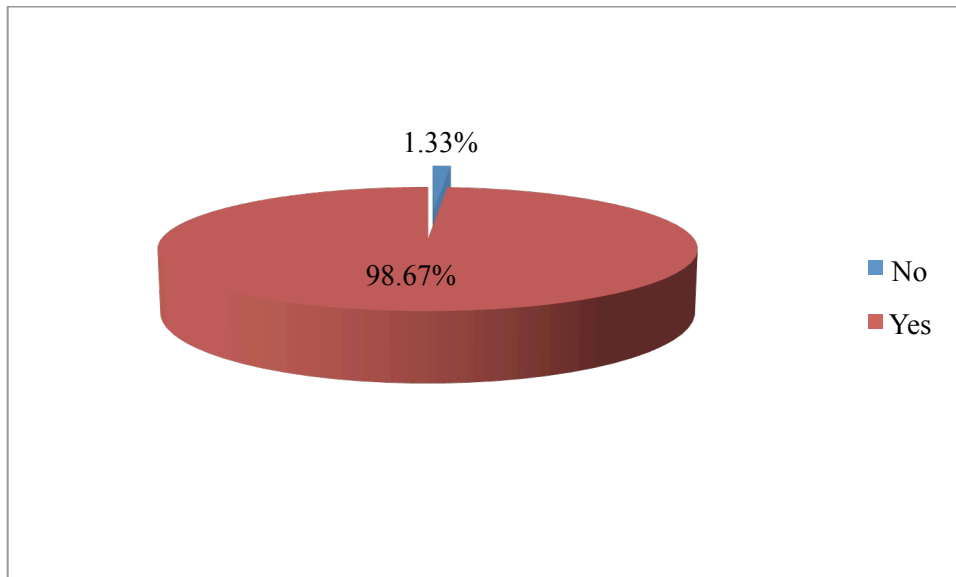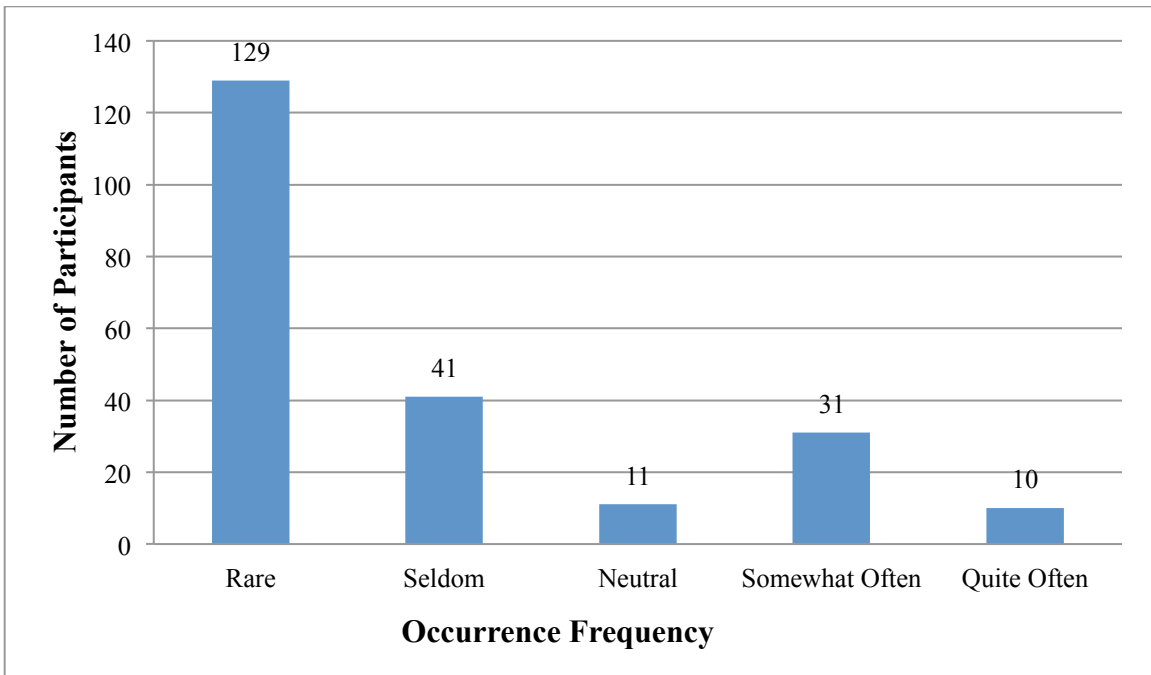Figures 5-21 to 5-25 demonstrate participants' driving history regarding defensive driving training and rumble strip running. It shows that 139 participants took defensive driving courses previously, accounting for 61.78% of all the participants in this study. 95.11% of all the survey participants have good understandings of rumble strips, and 98.67% of all the participants ran over a rumble strip in the past. It is also found that 129 participants ran over should rumble strip rarely, accounting for 58.11% of those participants who ran over a rumble strip previously. Detailed investigation on the causes of running over shoulder rumble strips reveals that drowsy and fatigue driving is the primary cause and has been conducted by 48.65% of the participants running over shoulder rumble strips. Other major causes include other inside activity, intentionally pull

off the road, external distraction, passenger distraction, manually operating electronic communication device, and talking on hands-free/hand hold electronic device, accounting for 26.58%, 25.67%, 22.22%, 20.27%, 15.32%, and 12.16%, respectively. It should be noted that survey participants select all the causes that apply, and therefore the sum of these statistics is larger than 100%.
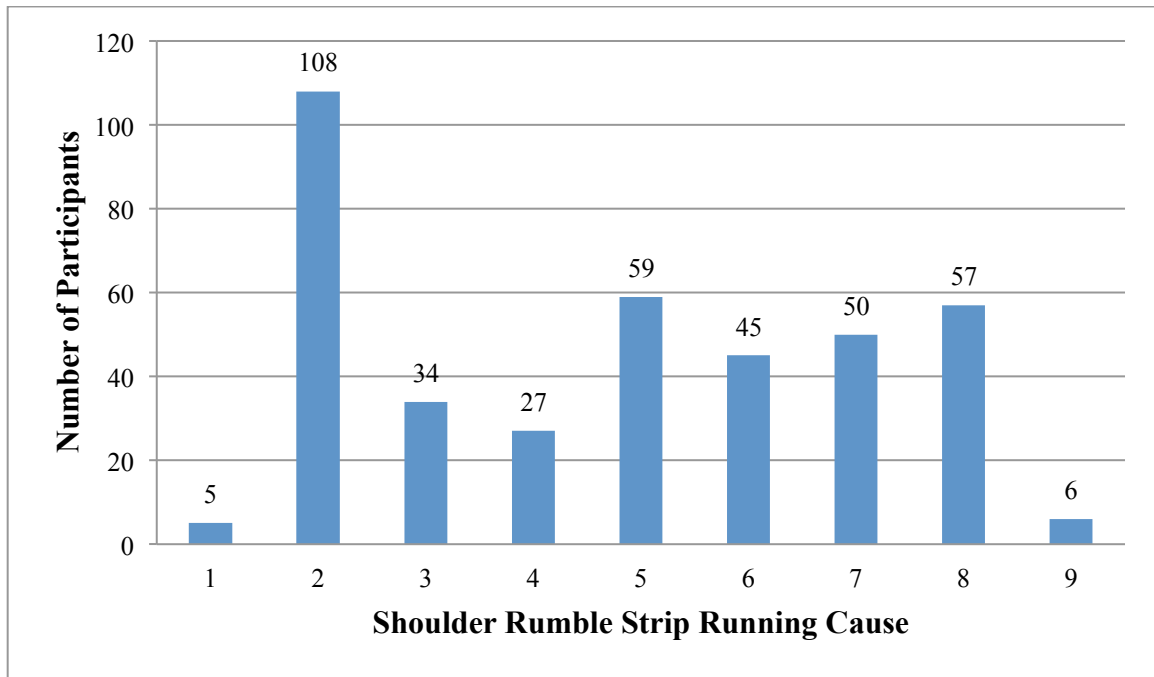
1=Speeding, 2=Drowsy and fatigue driving, 3=Manually operating electronic communication device (texting, typing, dialing), 4=Talking on hands-free/hand hold electronic device, 5=Other inside activity (eating, changing CD, attending children, etc.), 6=Passenger distraction, 7=External distraction, 8=Intentionally pull off the road, 9=Others (i.e. forced off road by other vehicles)

Figure 5-25 Shoulder Rumble Strip Running Cause Distribution

To better demonstrate participants' attitude on rumble strips regarding their safety effects, for the following questions, we plotted detailed distributions of participants' responses for Questions 8-12 by gender, age and education level information. Detailed discussions are presented below.

Question 3-9: When driving consciously and alertly, what would be your reaction when running onto a rumble strip?
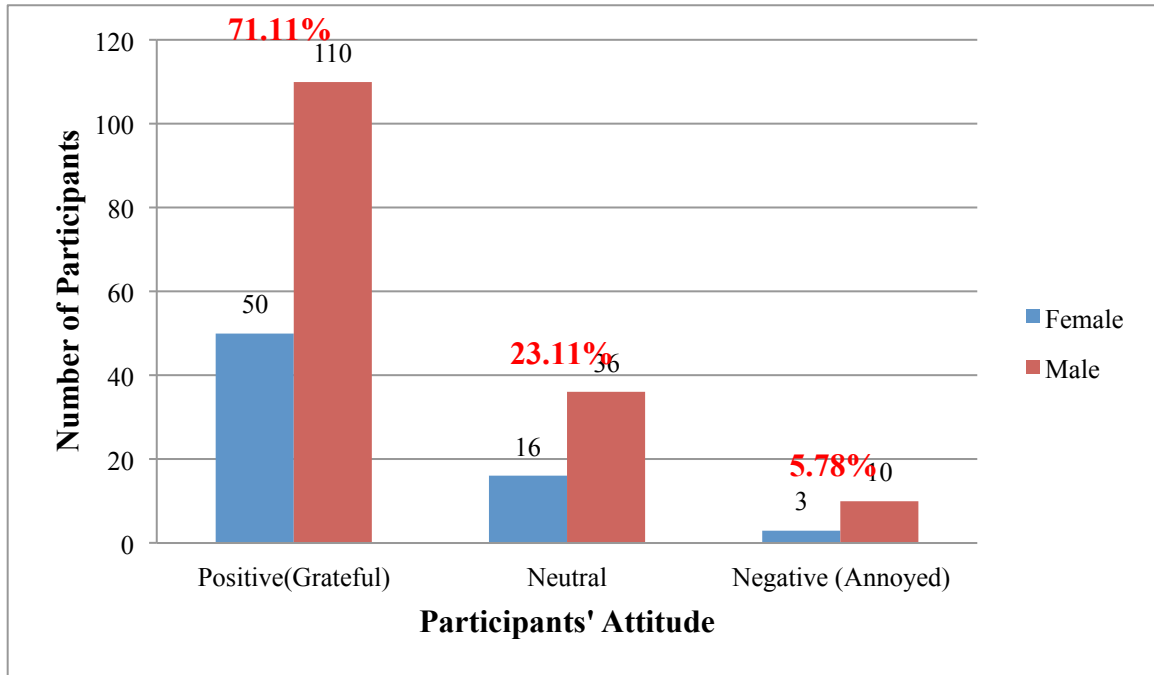
Figure 5-26 Question 3-8 Response Summary by Gender

Figure 5-27 Question 3-8 Response Summary by Age

Figure 5-28 Question 3-8 Response Summary by Education Level

It shows in Figures 5-26 to 5-28 that, overall, 71.11% of all the survey participants have a positive reaction when they drive consciously and run onto rumble
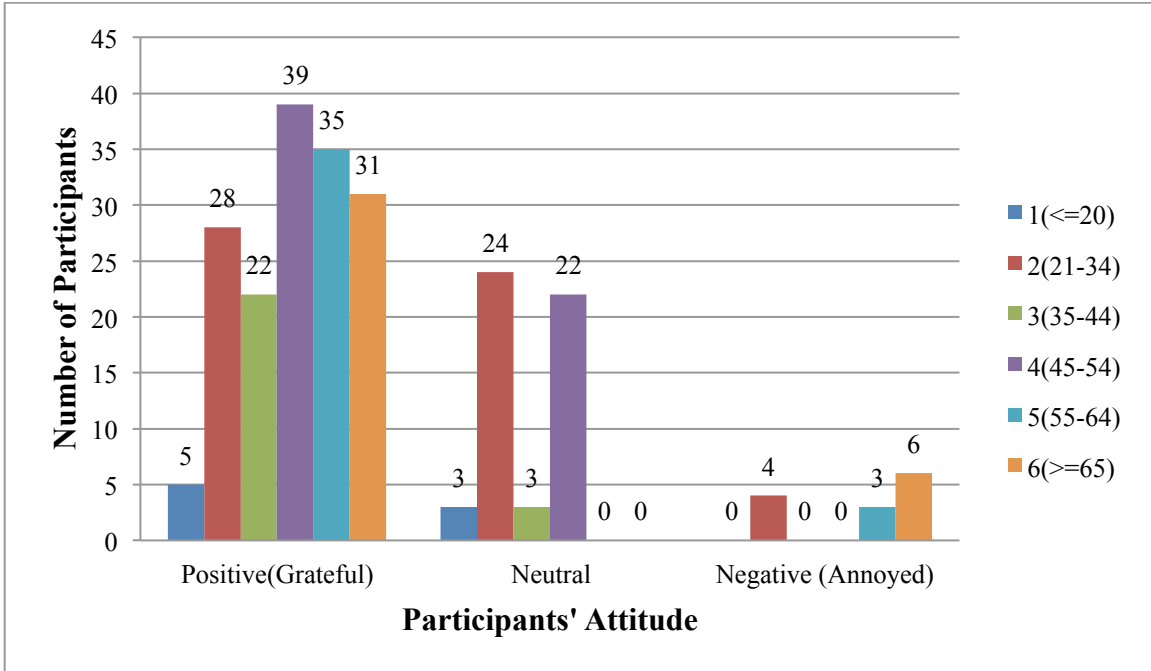
strips, and 23.11% of these participants have a neutral feeling about it. Only 5.78% of participants have negative feeling when driving consciously and running onto rumble strips. Moreover, it shows that among all the participants having positive feelings, the largest age group is those between 45 and 54 years of age, followed by those between 55 and 64, and 65 years old or more. A possible reason is that these participants have relative more driving experience and better understand the importance of rumble strips in crash occurrence prevention. Regarding education level, it shows that the largest participant groups having positive feelings are those with bachelor and advanced degrees.

Question 3-9: If you perform an inattentive driving, what would be your reaction when running onto a rumble strip?

Figure 5-29 Question 3-9 Response Summary by Gender
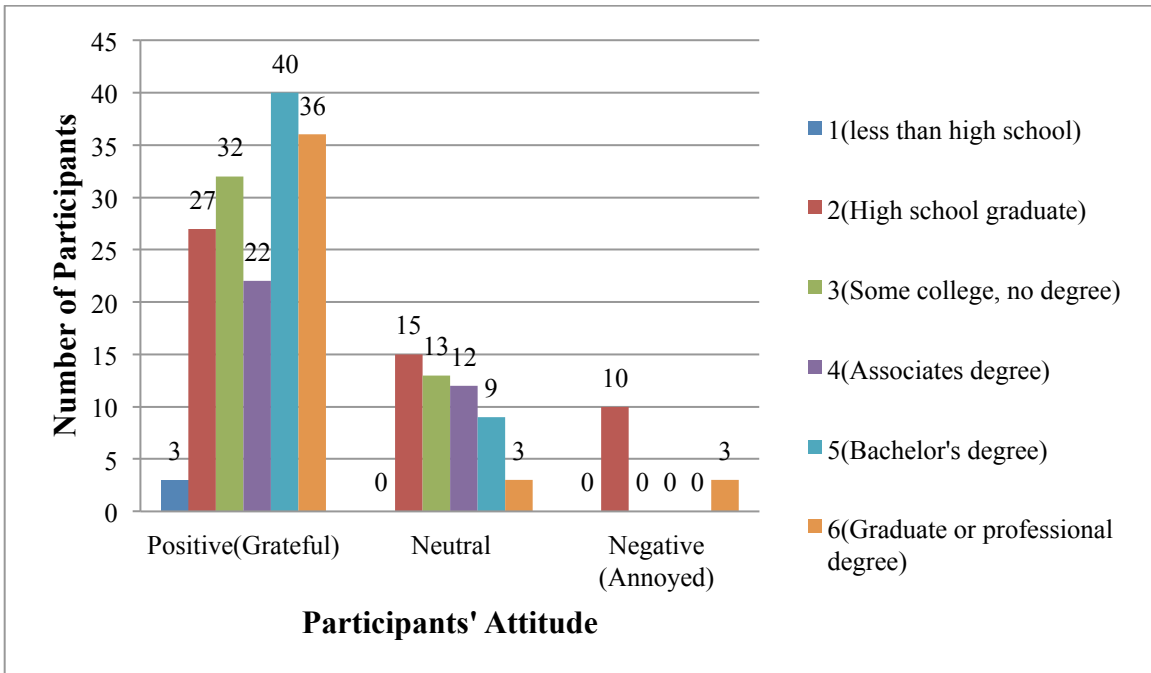
Figure 5-30 Question 3-9 Response Summary by Age
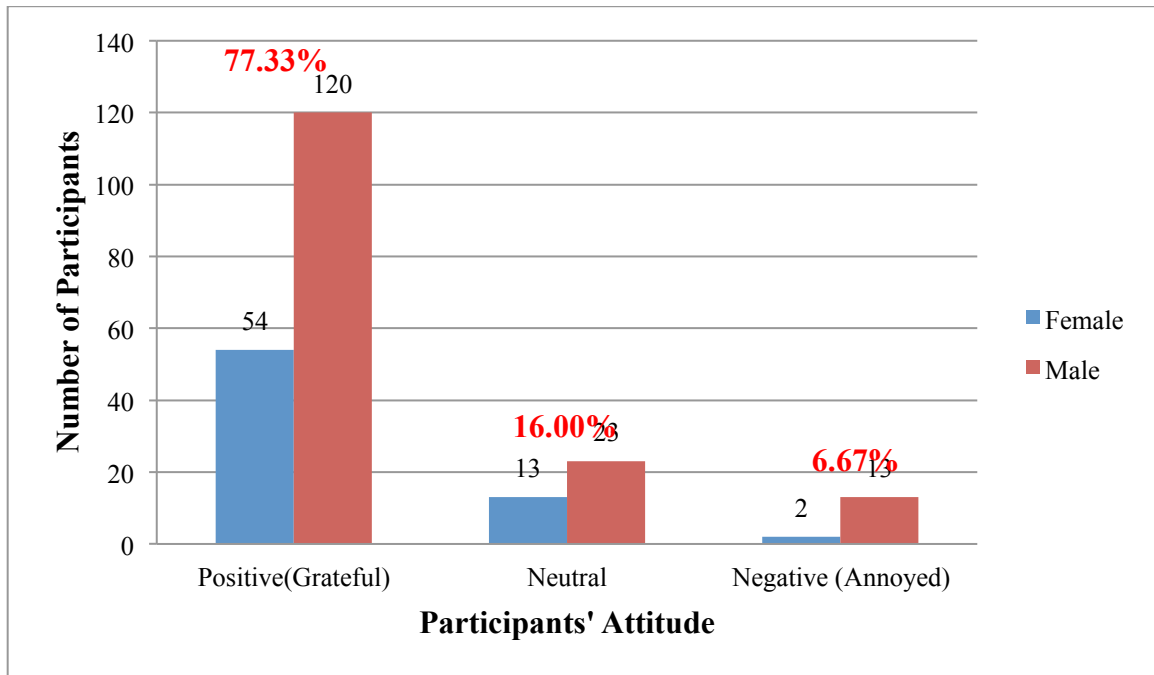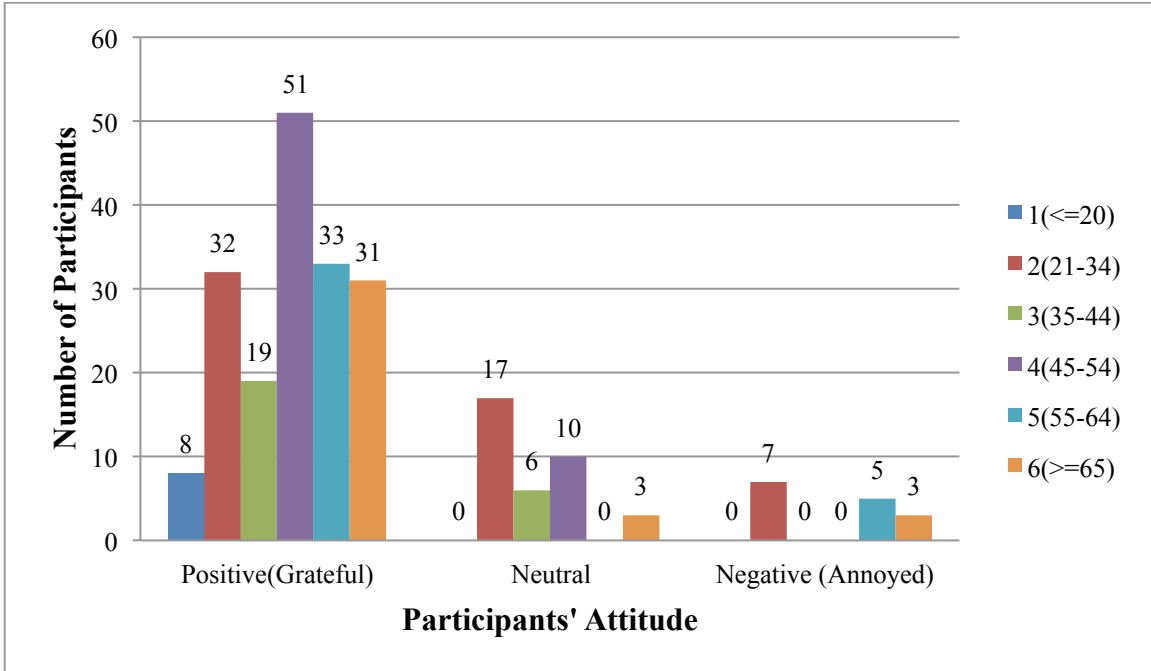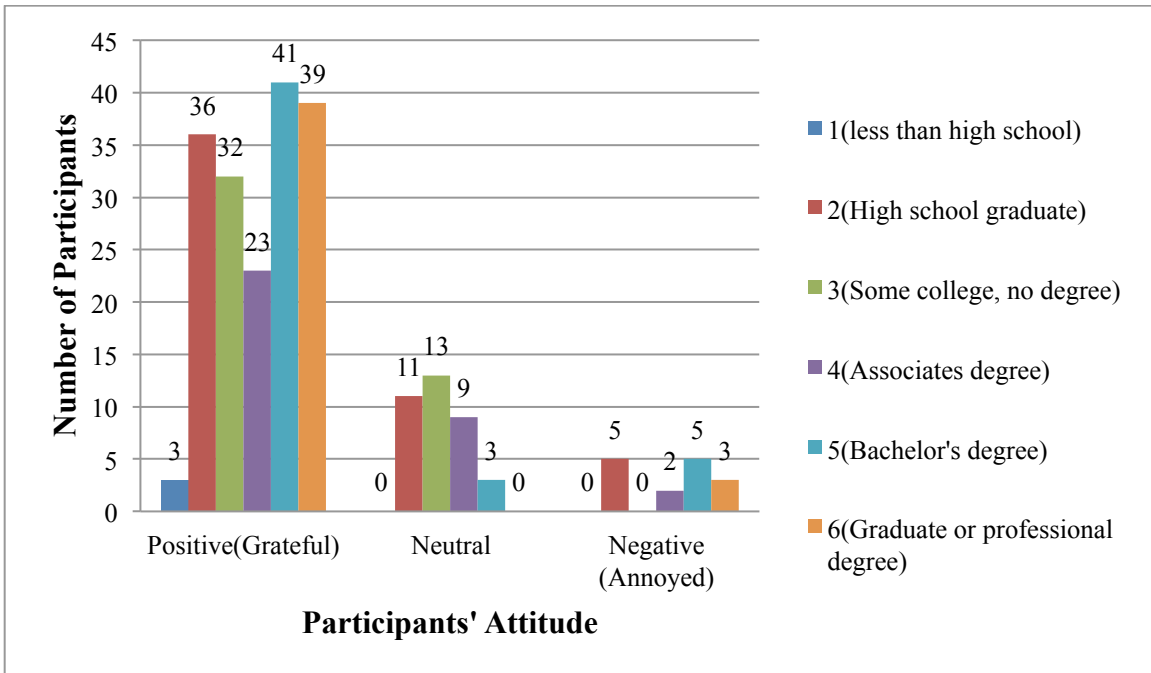

Figure 5-31 Question 3-9 Response Summary by Education Level

It shows in Figures 5-29 to 5-31 that, overall, 77.33% of all the survey

participants have a positive reaction when they drive inattentively and run onto rumble

strips, and 16.00% of these participants have a neutral feeling about it. Only 6.67% of

participants have negative feeling when driving inattentively and running onto rumble

strips. These statistics indicate that, comparing with these driving consciously; more

people express their gratitude to rumble strips for saving them from inattentive driving.

Similarly, it shows among all the participants having positive feelings, the largest age

group is those between 45 and 54 years of age, followed three comparable age groups:

21-34 years of age, 55-64 years of age and 65 years old or more. Regarding education

level, it shows that the largest participant group having positive feelings is those with

bachelor and advanced degrees, followed by high school graduates and those with college

non-degree education experience. As to gender information, it shows a similar pattern

with the overall gender distribution that males are the larger group for the participants

with positive feelings.

Question 3-11

Do you think that they will have the following negative impacts while driving, please rate
from 1-5 for each item, where (1-strongly disagree, 2-somewhat disagree, 3-neutral, 4-
somwhat agree, 5-strongly agree
1) Discomfort _____
2) Nuisance to make legal passing maneuvers _____
3) Driver overreaction _____
4) Driver leftward correction of vehicle under certain situations _____
5) Poor vehicle handling _____
6) Vehicles crowding bicyclists under certain situations _____
7) Increased noise to the various residences along the highway _____
8) other _____(please specify)

This survey question comprehensively examined participants' attitude toward

seven negative impacts of rumble strips on normal driving, and the survey responses and

discussions are presented below.
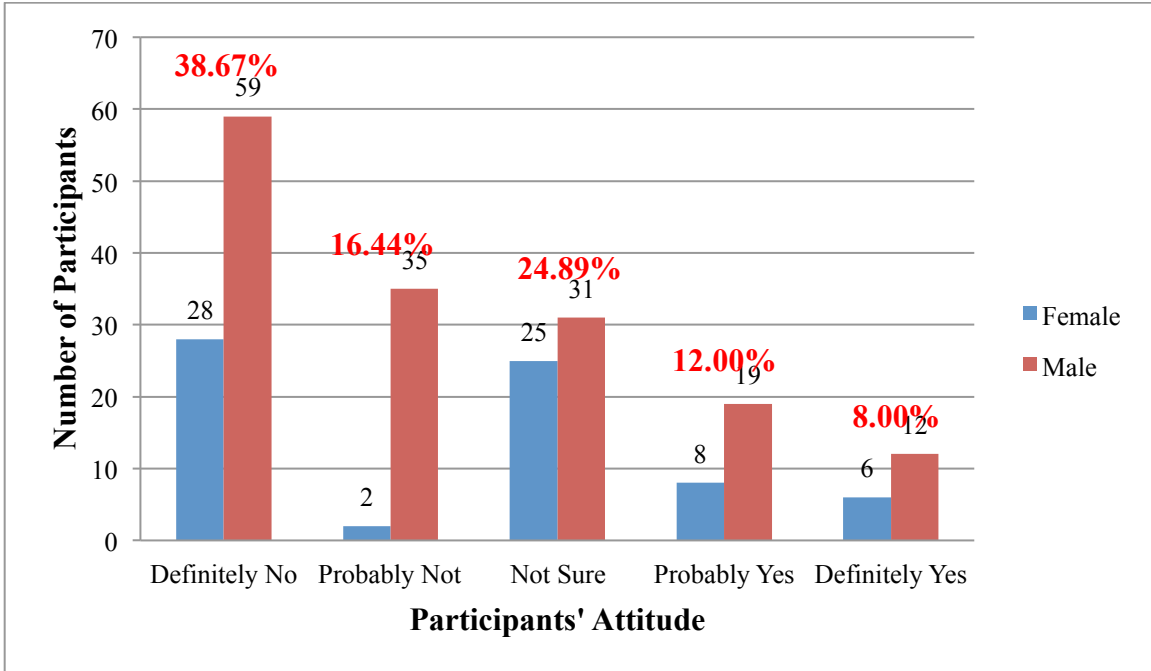
Figure 5-32 Participant's Attitude to Potential Discomfort by Gender
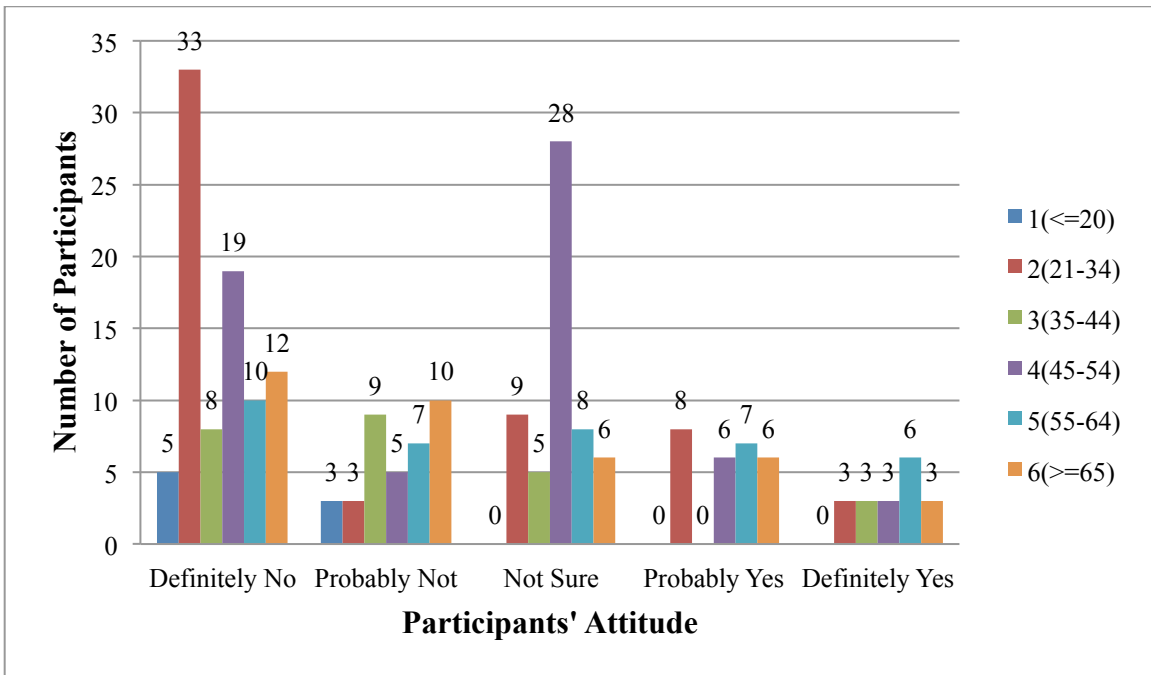
Figure 5-33 Participant's Attitude to Potential Discomfort by Age
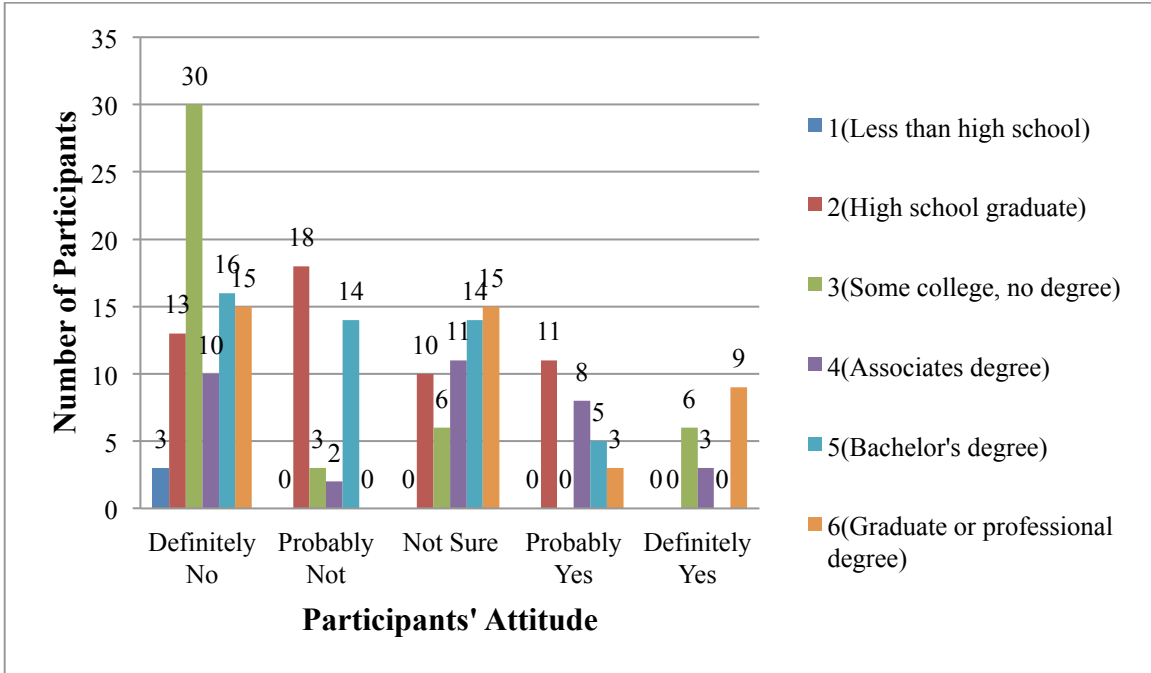
Figure 5-34 Participant's Attitude to Potential Discomfort by Education Level

Figures 5-32 to 5-34 show participants' responses regarding the discomfort rumble strips bring about. It is indicated that 38.67% of all the participants strongly believe that rumbles strips don't bring any discomfort to them during driving, followed by 24.89% of all participants having neutral attitude regarding the potential discomfort rumbles trips bring about, and 16.44% slightly disagree with the statement that rumbles strips bring discomfort to them in normal driving. Overall, there are 20.00% of all the participants having an opinion that rumble strips bring discomfort to road users in normal driving. Detailed response distributions regarding gender, age and education level information is illustrated in these figures.

Figure 5-35 Participant's Attitude to Passing Nuisance by Gender

Figure 5-36 Participant's Attitude to Passing Nuisance by Age

Figure 5-37 Participant's Attitude to Passing Nuisance by Education Level

It is indicated in these figures that 33.78% of all the participants strongly disagree that rumbles strips are nuisances for drivers to make legal passing maneuvers, followed by 27.56% of all participants having neutral attitude, and 15.56% of the participants slightly disagree with the statement that rumble strips bring discomfort to them in normal driving. Overall, there are 23.11% of all the participants believing that rumble strips are nuisances for road users to make legal passing maneuvers in normal driving. Detailed response distributions regarding gender, age and education level information are also illustrated in these figures.

Figure 5-38 Participants' Attitude to Driver Overreaction by Gender

Figure 5-39 Participants' Attitude to Driver Overreaction by Age

Figure 5-40 Participants' Attitude to Driver Overreaction by Education Level

Figures 5-38 to 5-40 show participants' responses regarding drivers' overreactions rumble strips may bring about. It is indicated that there are equal amount of participants strongly disagree with or have a neutral attitude toward that rumbles strips cause drivers' overreactions, both accounting for 26.22% of all participants in this survey. Following that there are 23.11% of all participants slightly agree with this potential issue and 19.11% of them slightly disagree with this issue, showing a significant divergence in their opinions. Overall, there are 28.44% of all the participants having an opinion that rumble strips cause driver overreactions in normal driving. Detailed response distributions regarding gender, age and education level information are illustrated in these figures.

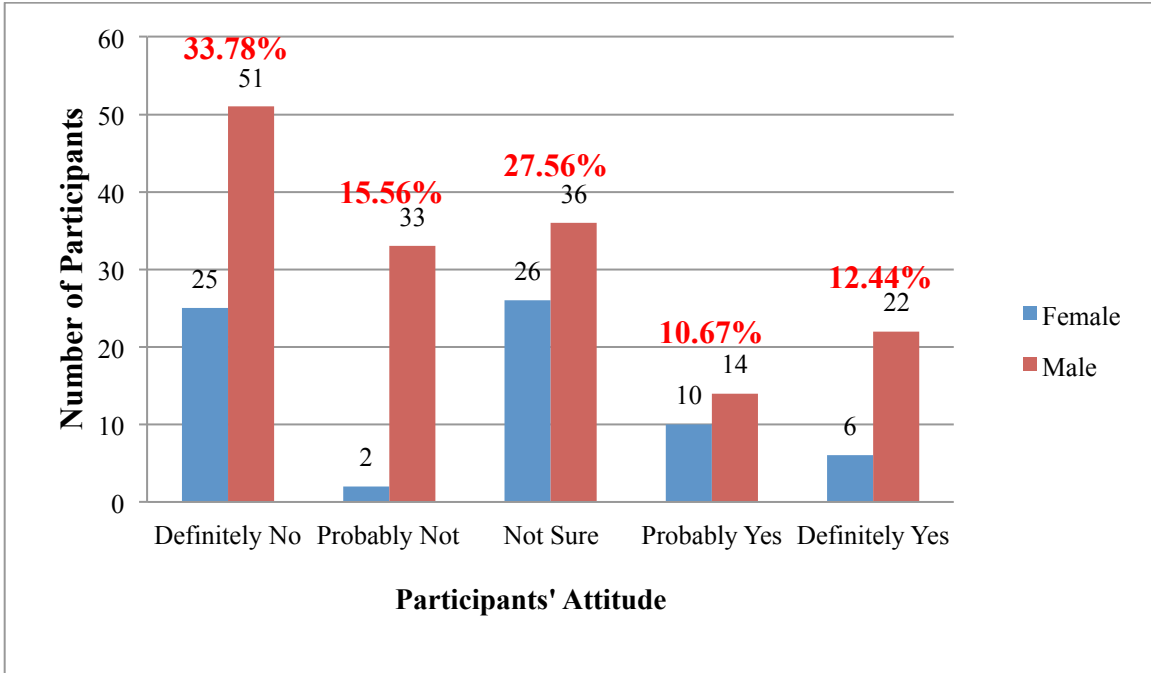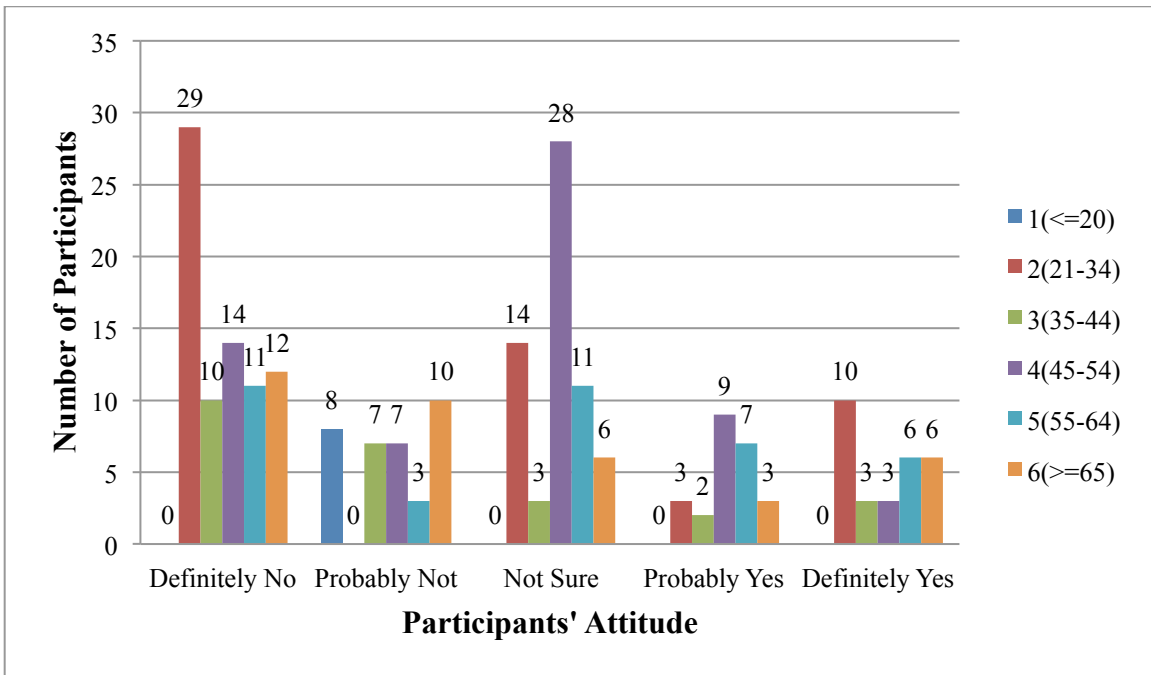**Figure 5-41 Participants' Attitude to Driver Leftward Correction by Gender**
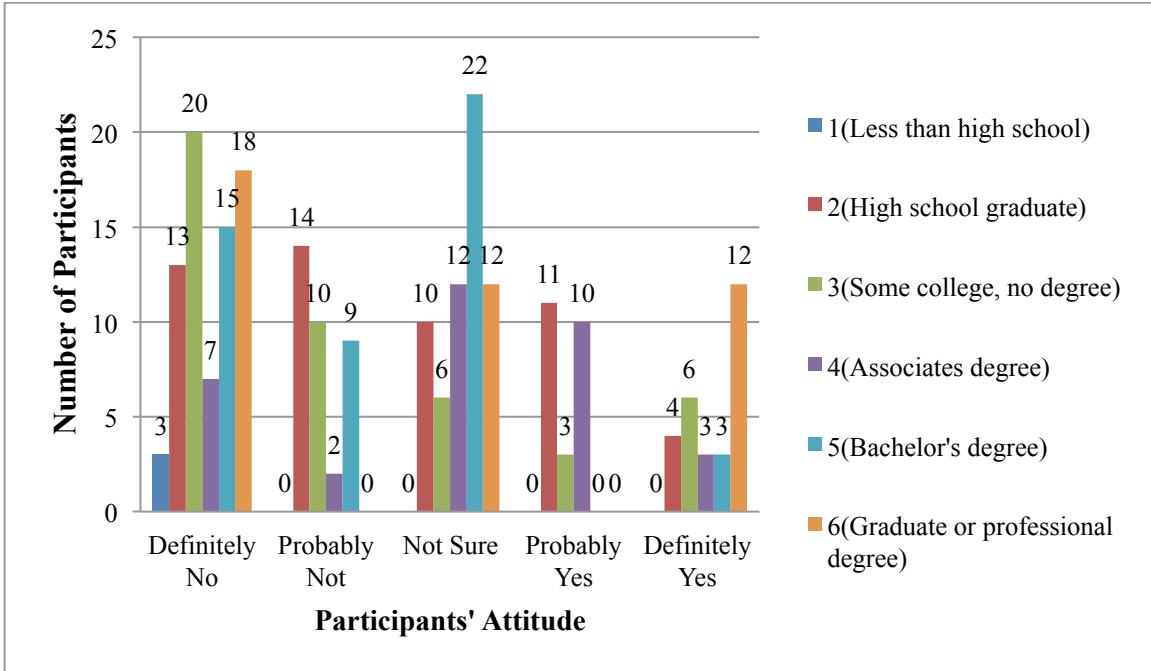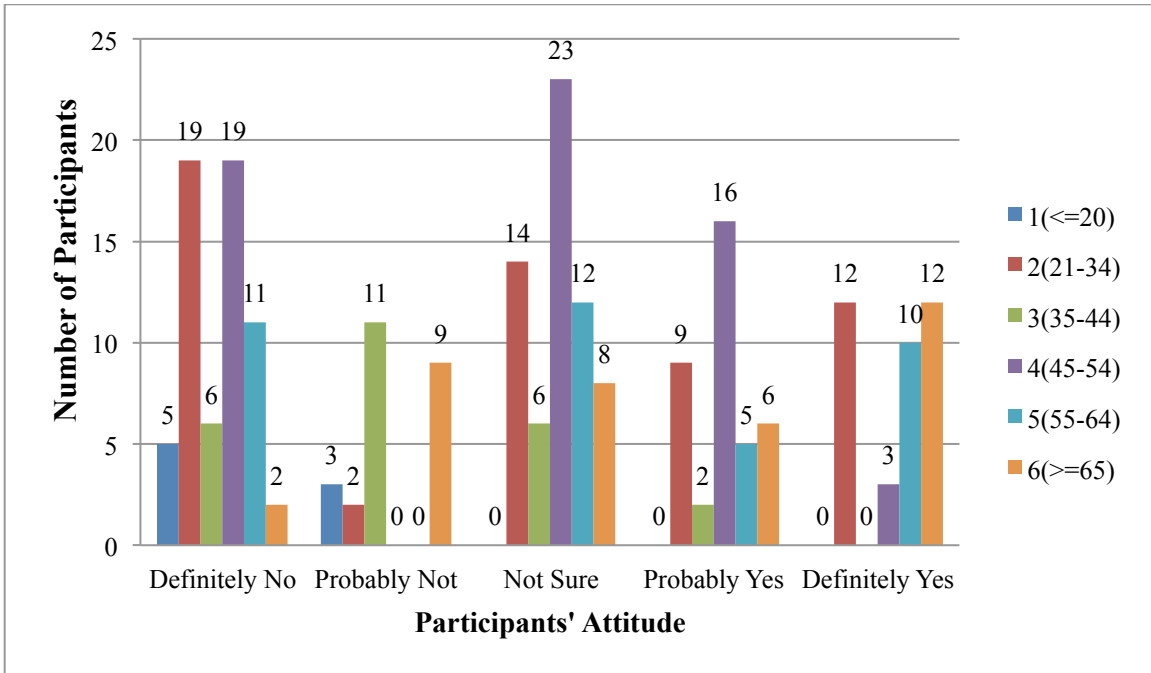

Figure 5-42 Participants' Attitude to Driver Leftward Correction by Age
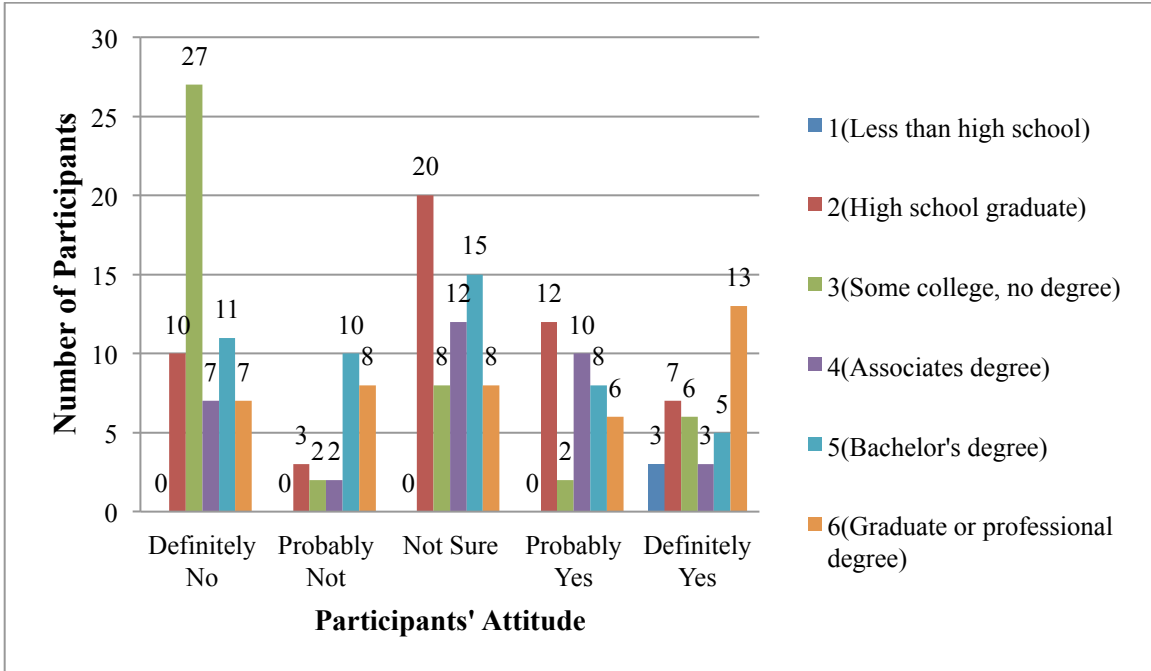
Figure 5-43 Participants' Attitude to Driver Leftward Correction by Education Level

Figures 5-41 to 5-43 show participants' responses regarding drivers' leftward correction of vehicle under certain situations. It is indicated that there are comparable amounts of participants strongly disagree with or have a neutral attitude toward that rumbles strips cause drivers' leftward correction of vehicles under certain situation, accounting for 27.56% and 28.00% of all participants in this survey, respectively. Following that there are also almost equal amount of participants slightly and strongly agree with this potential issue, which account for 16.89% and 16.44% of all the survey participants. Besides, there are also 11.11% of all the participants slightly disagree with this issue. Detailed response distributions regarding gender, age and education level information are also illustrated in these figures.
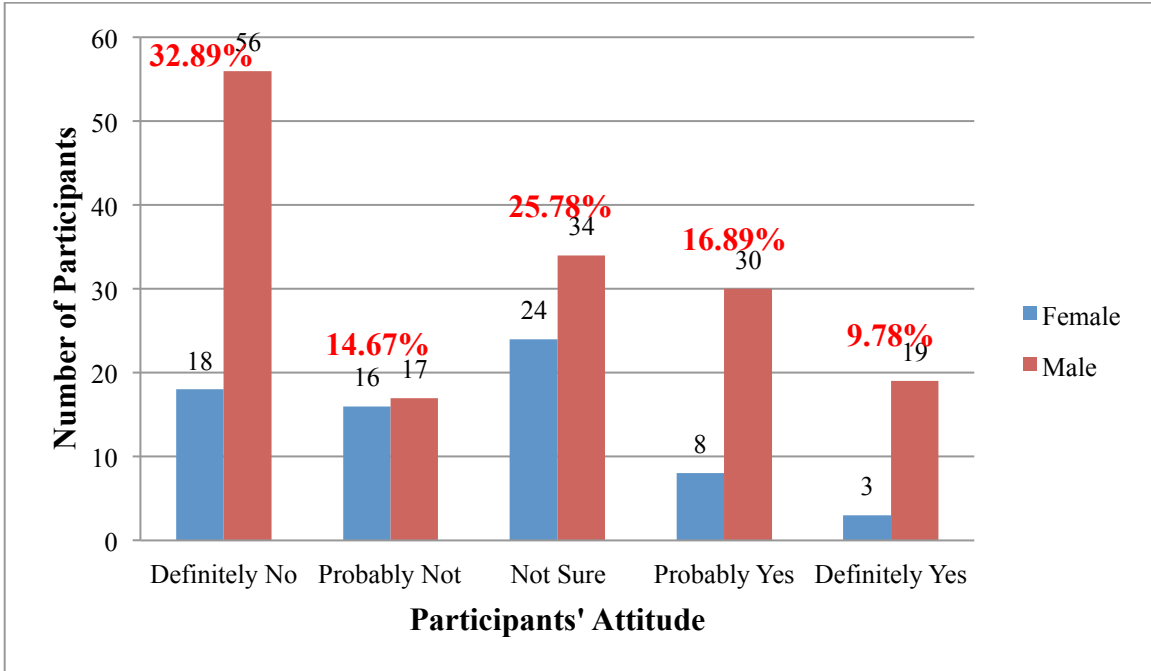
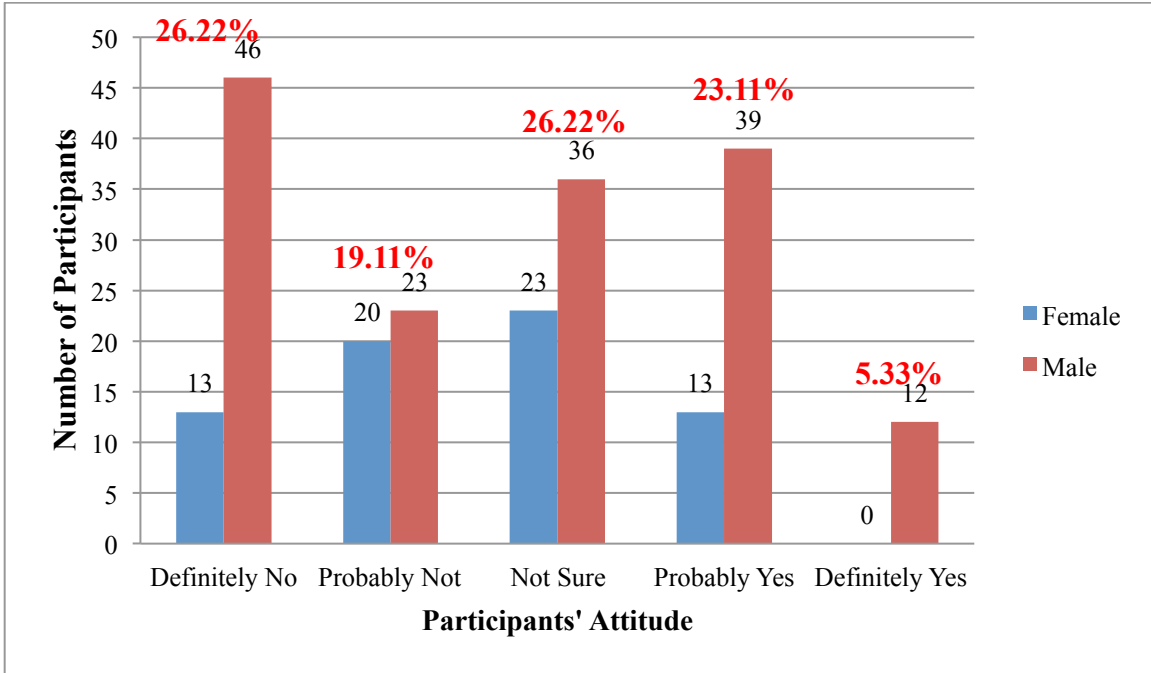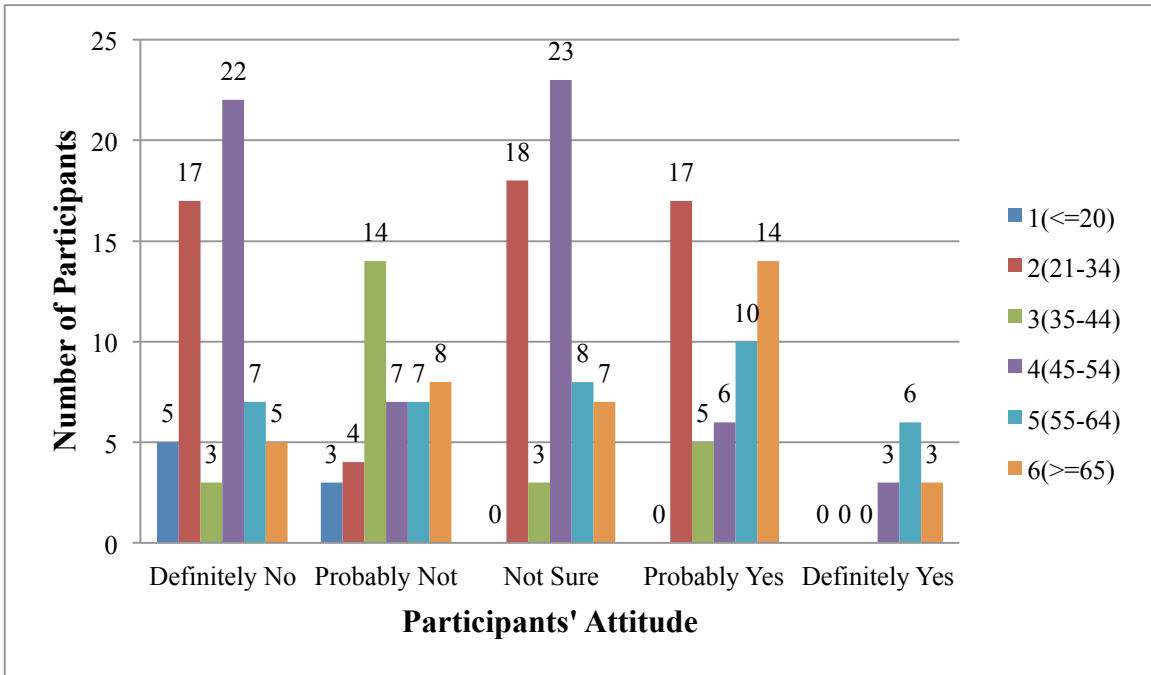**Figure 5-44 Participants' Attitude to Vehicle Handling/instrument Problems by Gender**
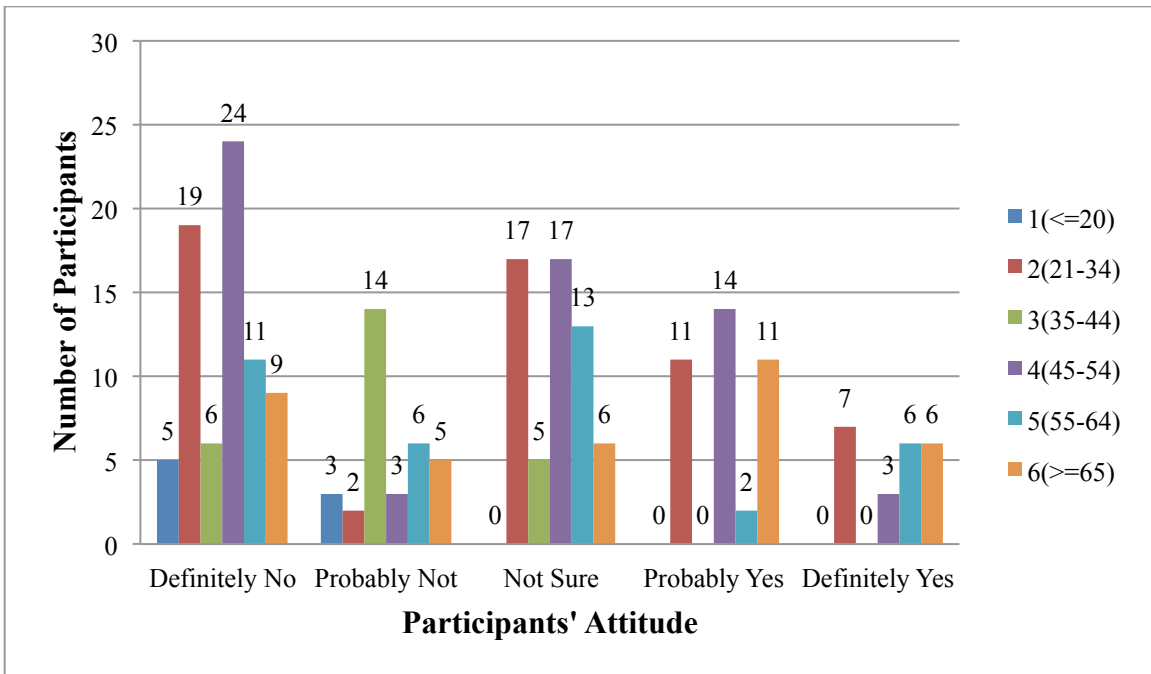
Figure 5-45 Participants' Attitude to Vehicle Handling/instrument Problems by Age
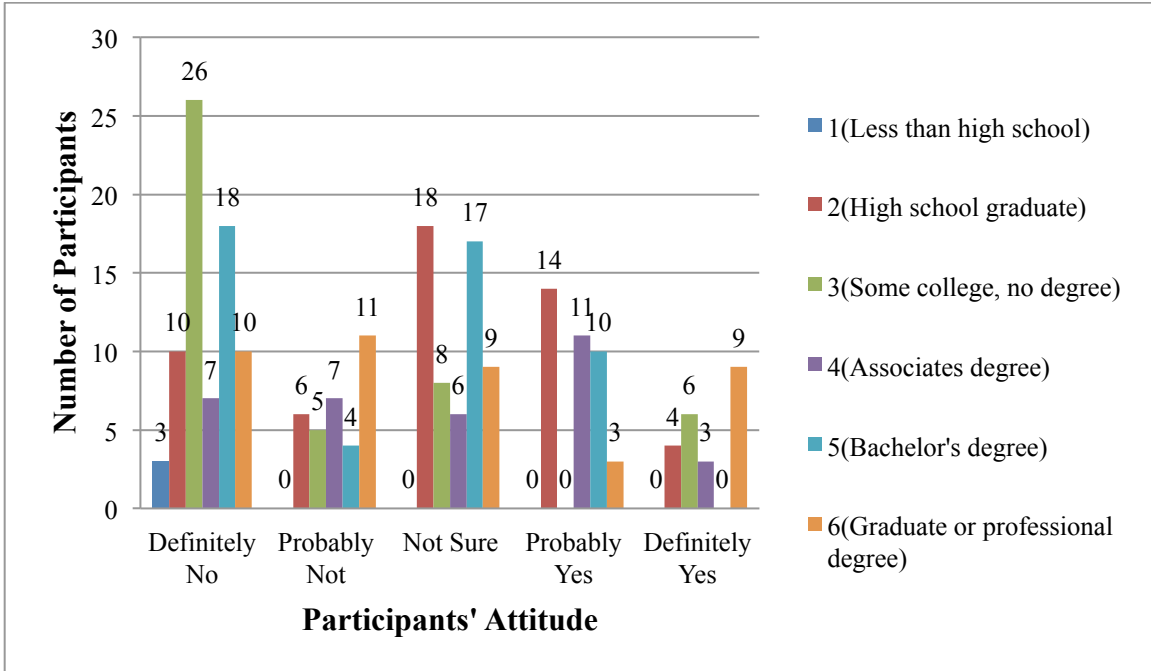
Figure 5-46 Participants' Attitude to Vehicle Handling/instrument Problems by Education Level

Figures 5-44 to 5-46 show participants' attitude regarding poor vehicle handling or instrument problems rumble strips may bring about. It is indicated that 32.89% of all the participants strongly disagree with that rumbles strips bring poor vehicle handling or instrument problems, followed by 25.78% of all participants having neutral attitude regarding this issue. There are also 60 participants slightly or strongly agree with that rumble strips cause vehicle poor vehicle handling or instrument problems, accounting for 26.67% of all participants in this survey. Detailed response distributions regarding gender, age and education level information are also illustrated in these figures.
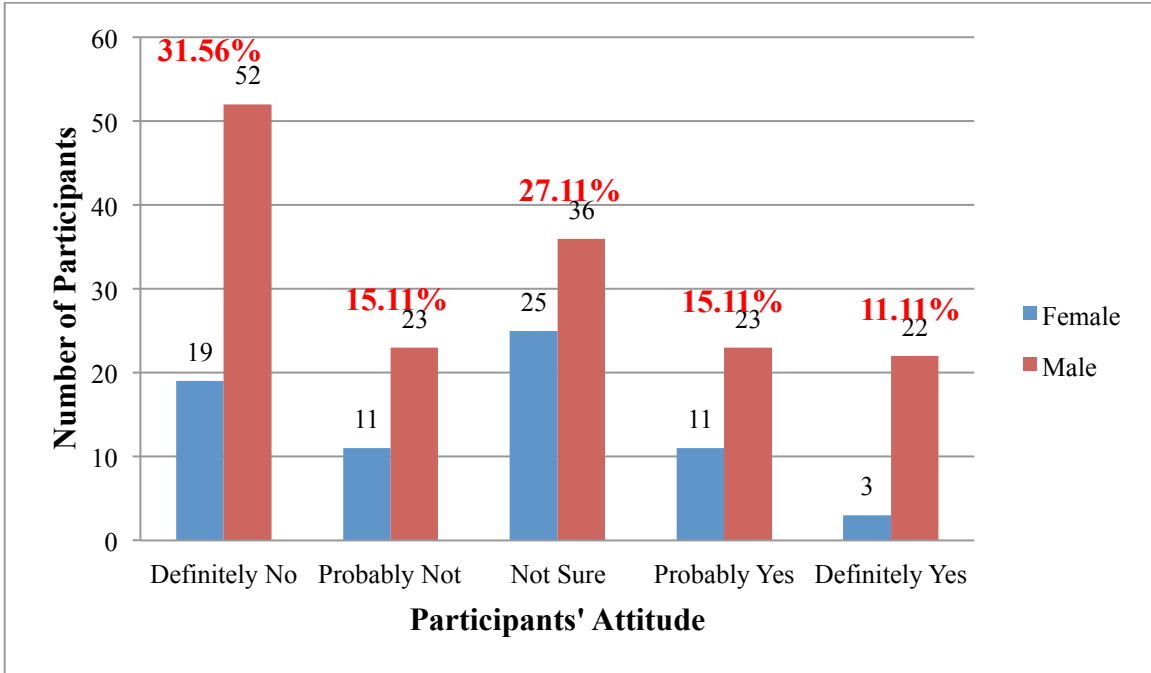
Figure 5-47 Participants' Attitude to Vehicle Crowding Bicyclist by Gender
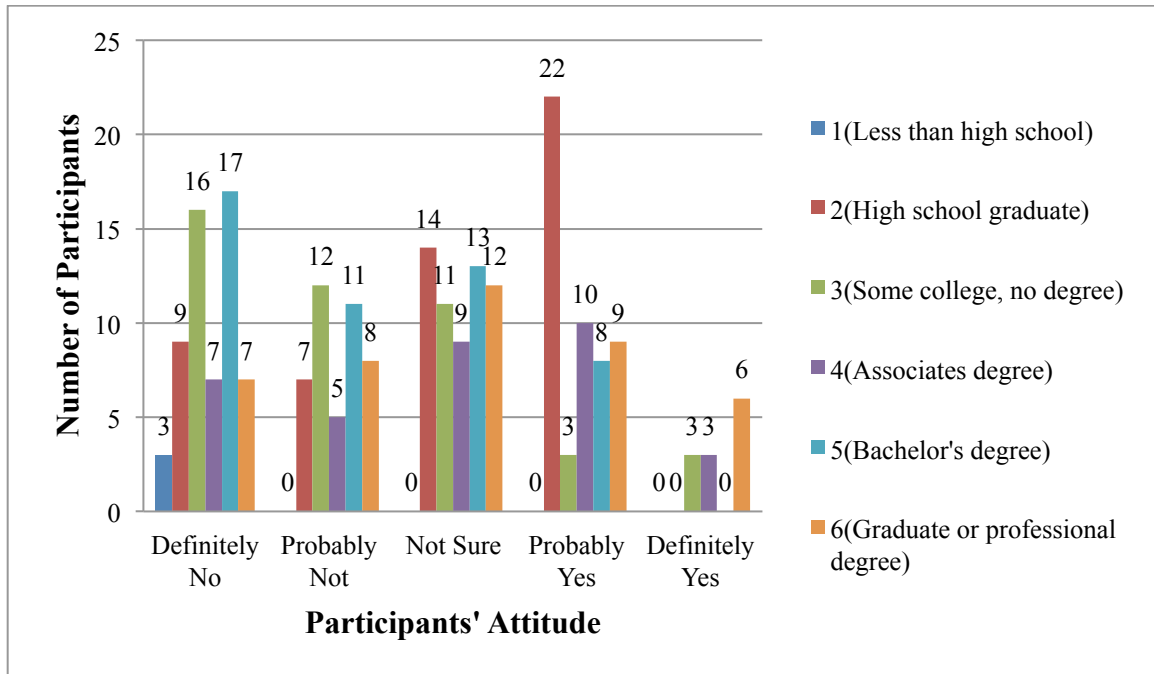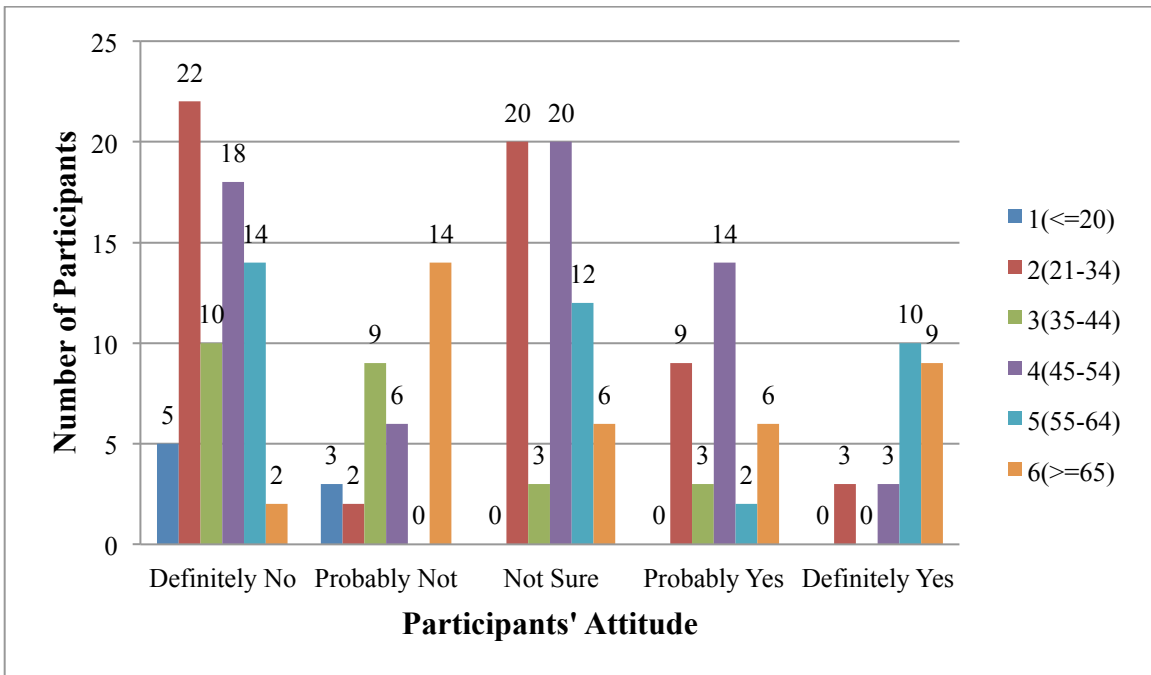

Figure 5-48 Participants' Attitude to Vehicle Crowding Bicyclist by Age
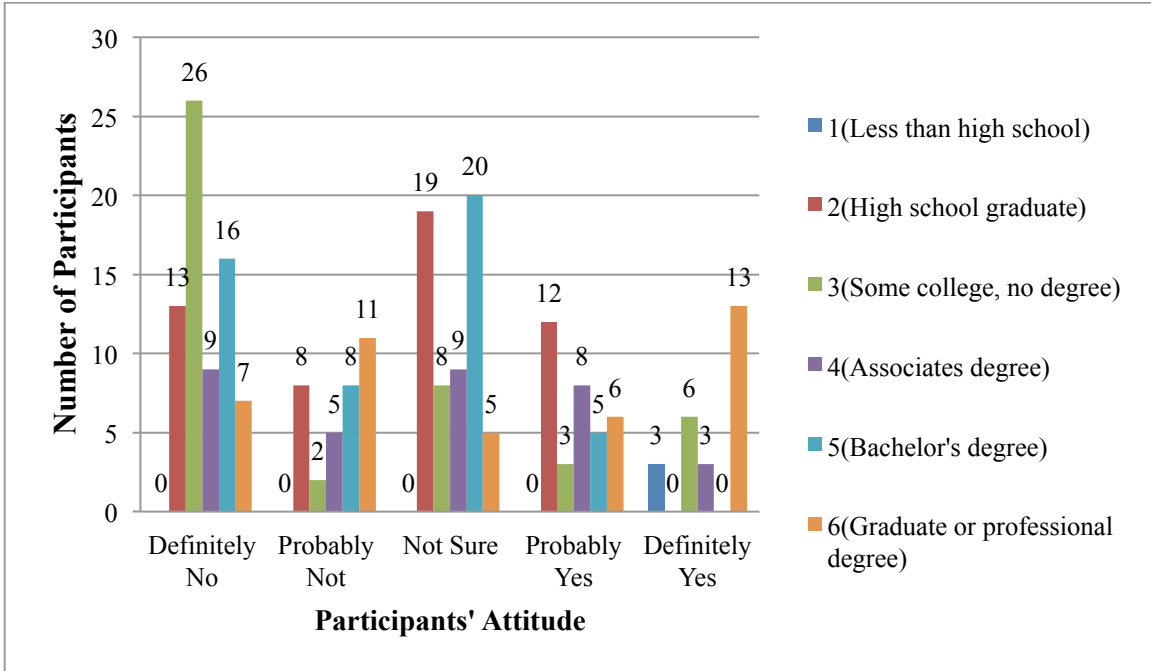
Figure 5-49 Participants' Attitude to Vehicle Crowding Bicyclist by Education Level

Figures 5-47 to 5-49 show participants' opinions on the potential that rumble strips cause vehicles to crowd bicyclist under certain situations. It shows that 31.56% of all the participants strongly disagree with that this issue, followed by 27.11% of all participants having neutral attitude. There are equal amounts of participants slightly agree and slightly disagree with this issue, each accounting for 15.11% of all participants in this survey. Detailed response distributions regarding gender, age and education level information are also illustrated in these figures.
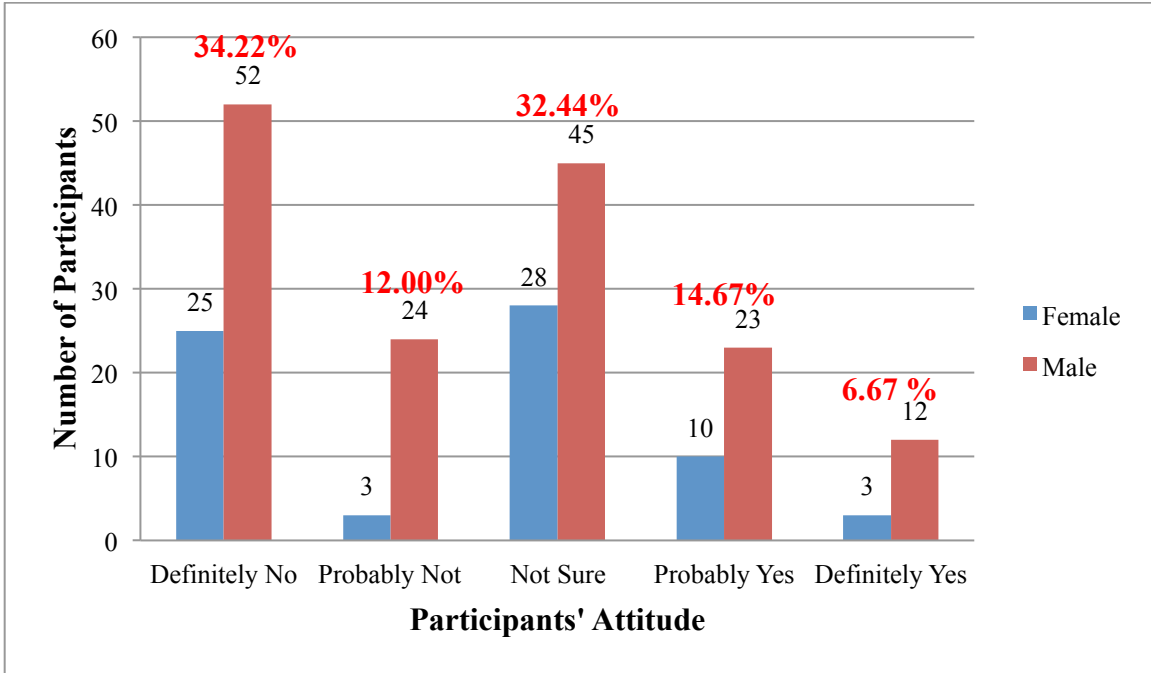
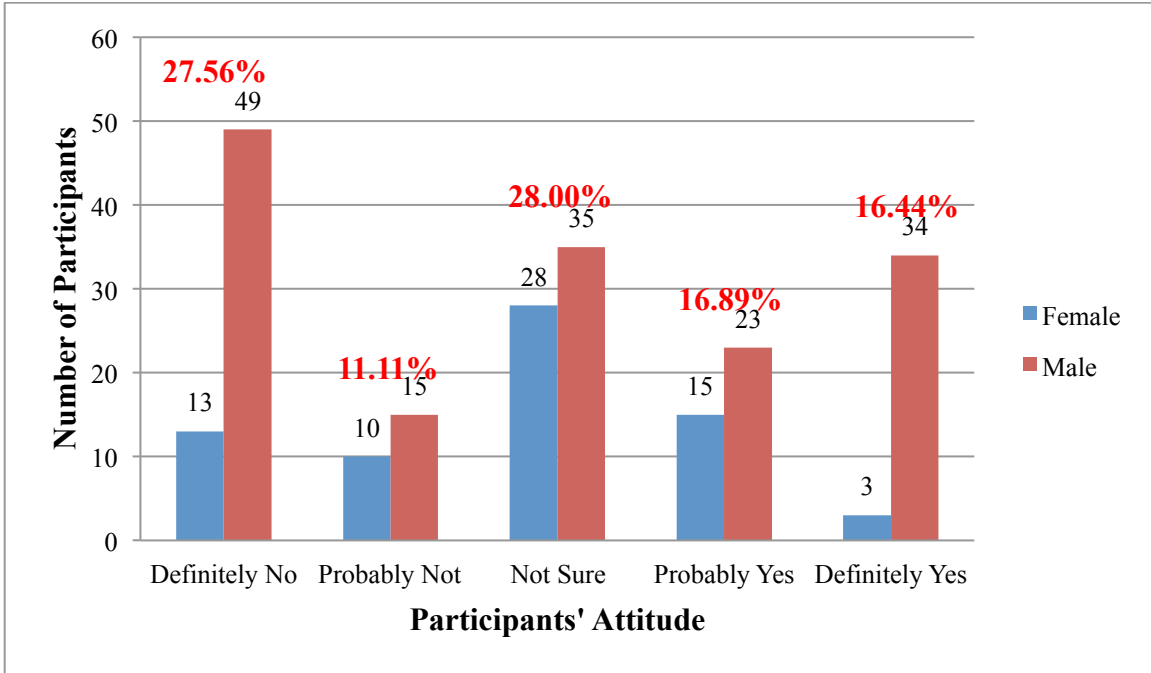**Figure 5-50 Participants' Attitude to Increased Noise from Rumble Strip by Gender**
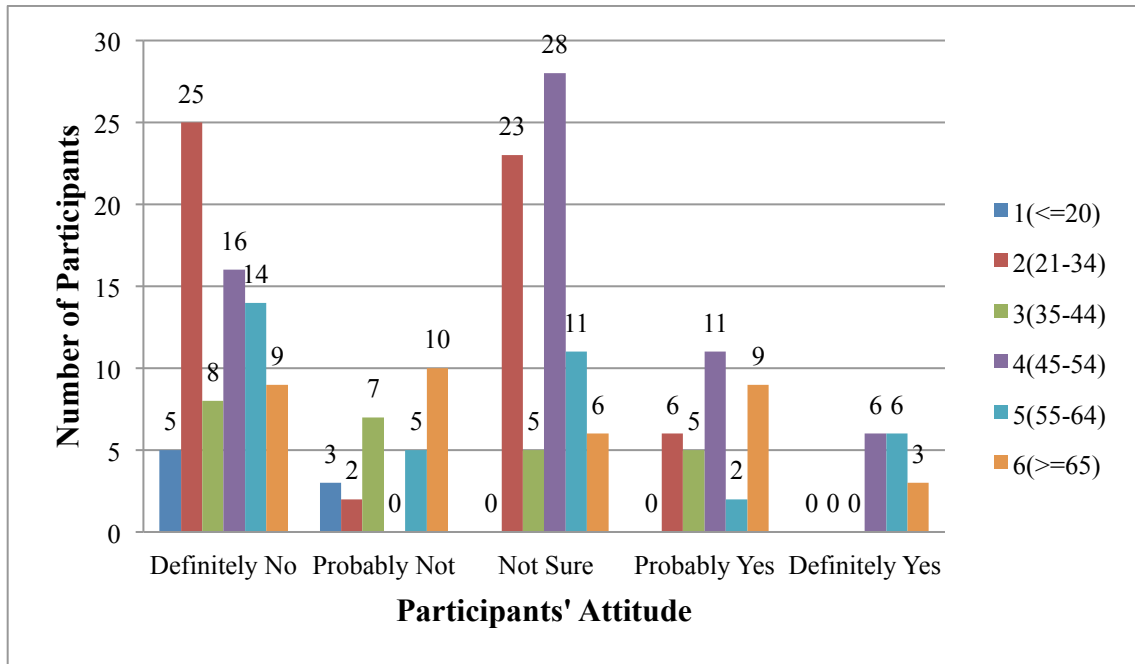
Figure 5-51 Participants' Attitude to Increased Noise from Rumble Strip by Age
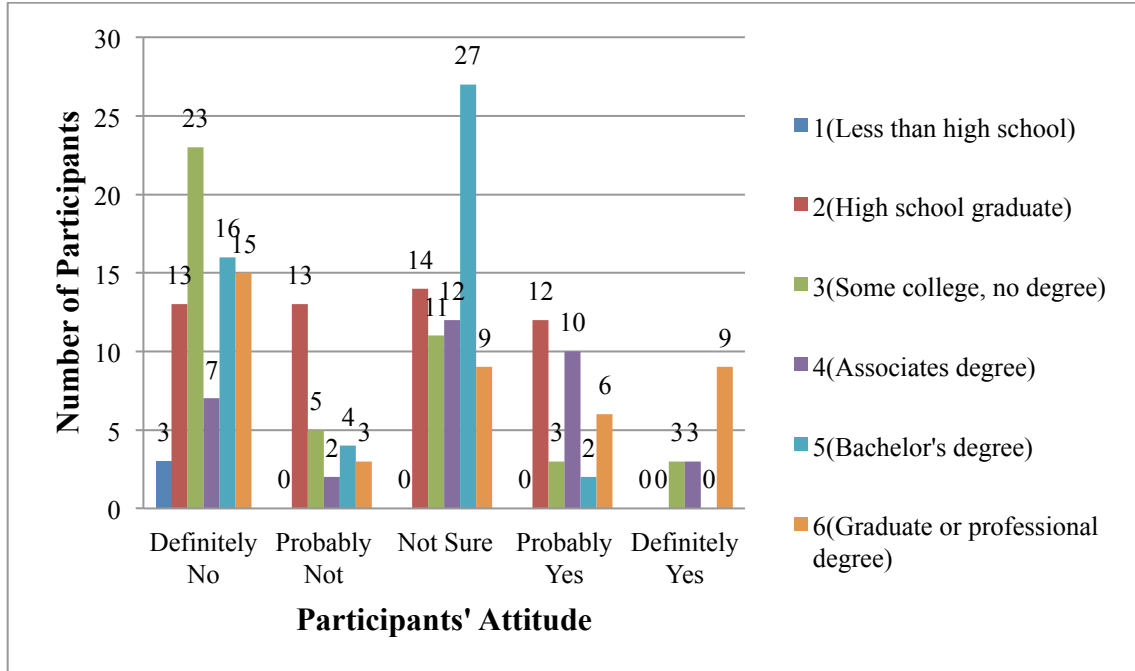
Figure 5-52 Participants' Attitude to Increased Noise from Rumble Strip by Education Level

Figures 5-50 to 5-52 show participants' opinions on the potential that rumble strips cause increased noises to the residence along the highway. It shows that 34.22% of all the participants strongly disagree with that this issue, followed by 32.44% of all participants having neutral attitude. There are also 14.67% of all the participants slightly agreeing with this issue and 6.67% strongly agreeing with this issue, and 12.00% slightly disagrees with this issue in this survey. Detailed response distributions regarding gender, age and education level information are also illustrated in these figures.

In this survey, no other potential negative impacts were received from the participants.

Question 3-12: If you perform an inattentive driving, would you have enough time to react properly to avoid crashes?
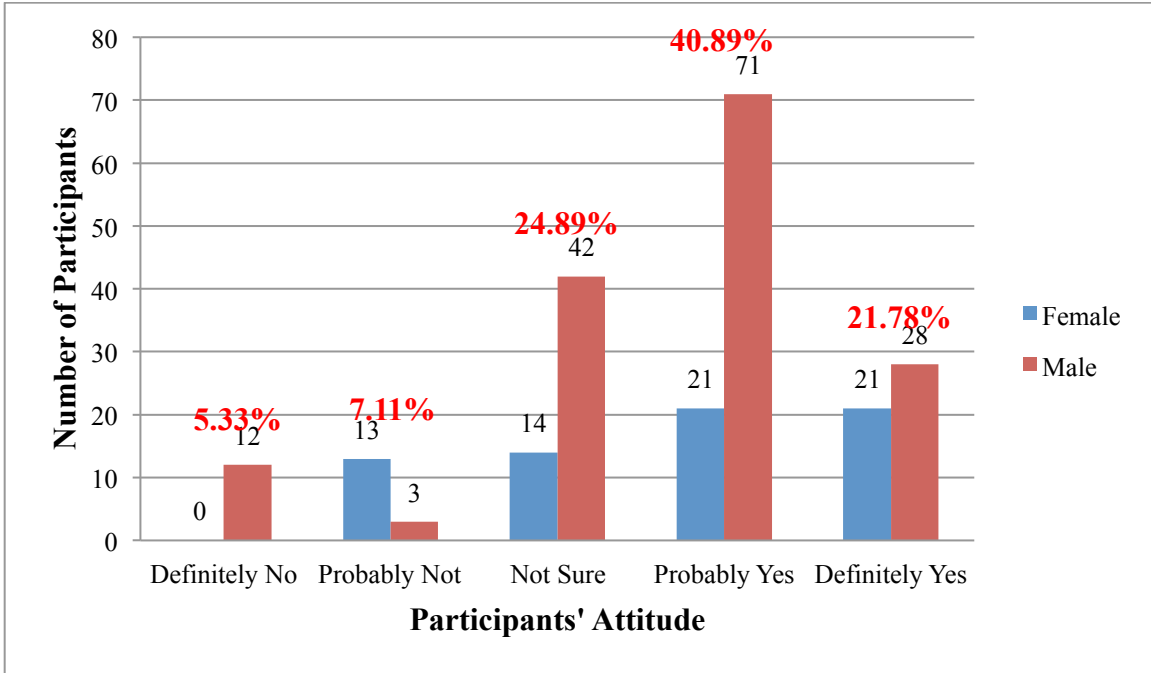
Figure 5-53 Participants' Opinion on Reaction Time Sufficiency by Gender
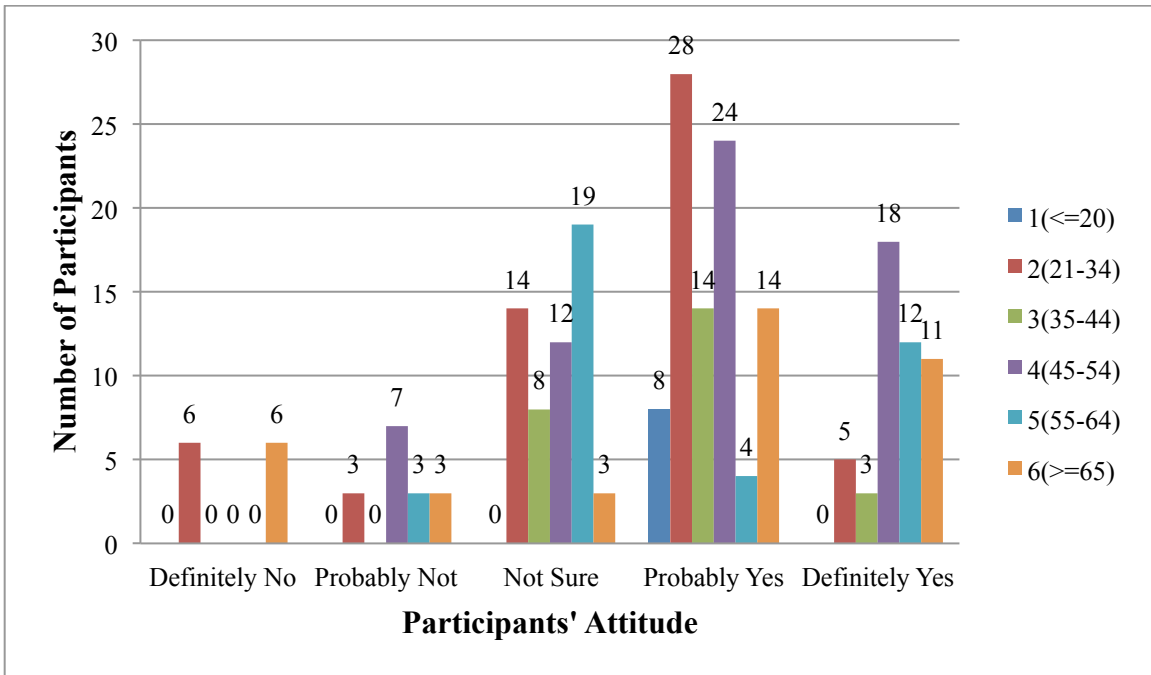
Figure 5-54 Participants' Opinion on Reaction Time Sufficiency by Age
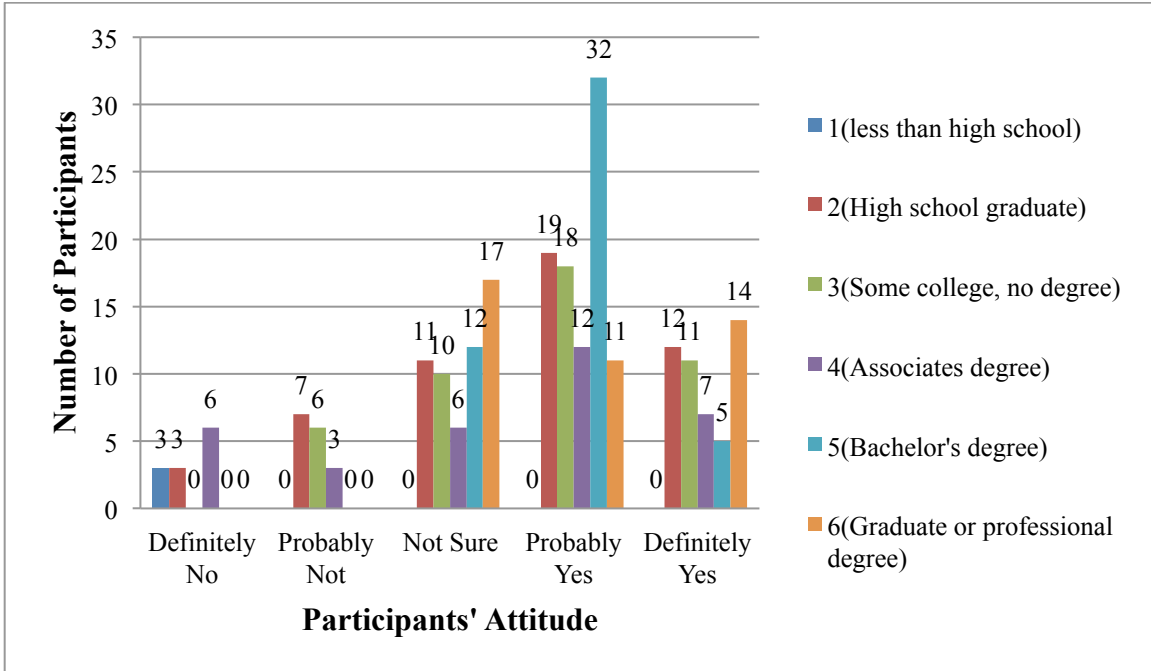
Figure 5-55 Participants' Opinion on Reaction Time Sufficiency by Education Level

It shows from Figures 5-53 to 5-55 that, overall, 40.89% of all the survey participants believe that they are likely to have enough time to make proper reactions to avoid crashes, followed by 24.89% of the participants not sure about the time sufficiency, and 21.78% of them strongly believe they will have enough time react properly. Overall, there are only 12.44% of the participants tend to having negative attitude regarding their time sufficiency for crash avoidance in inattentive driving. These statistics indicate that, most of the participants are optimistic about their reactions and driving skills for crash avoidance. Among the participants with "Probably Yes" answers, it also shows that male participants are the larger group, and the participants between 21 and 34 years old and those with a bachelor degree are the largest groups correspondingly. More detailed information regarding other groups is illustrated in these figures.

Question 3-13: Which type of sensation do you think is more effective in correcting drivers' run-off road behavior?
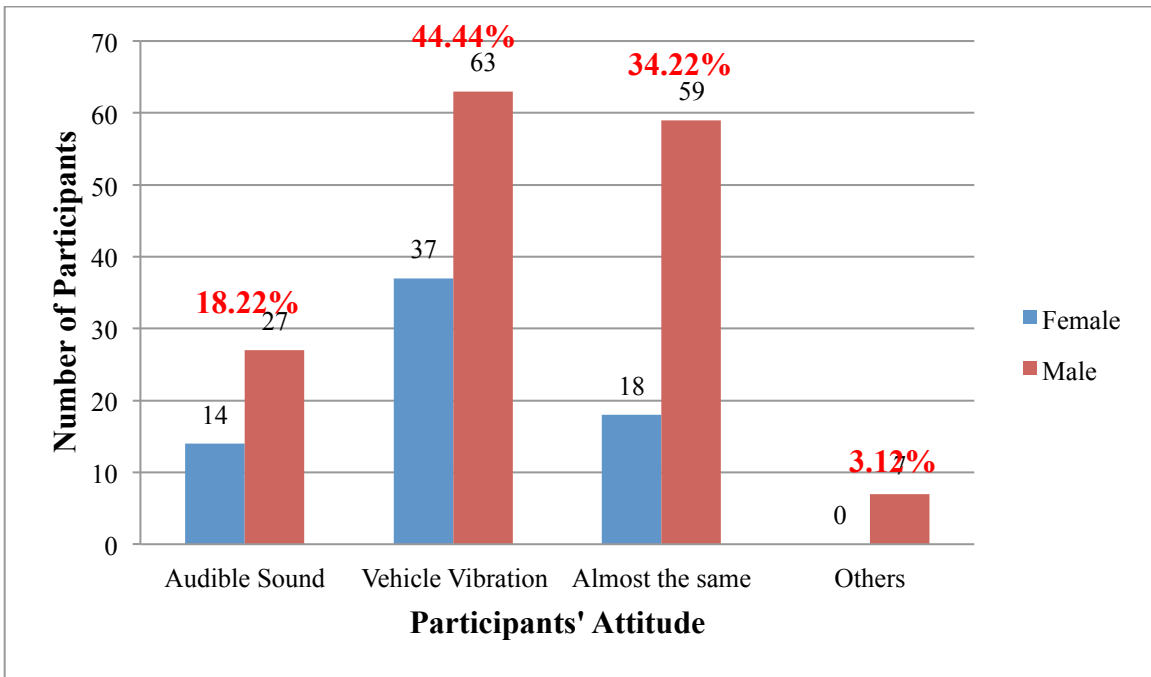
Figure 5-56 Participants' Opinion on Rumble Strip Safety Efficiency by Gender
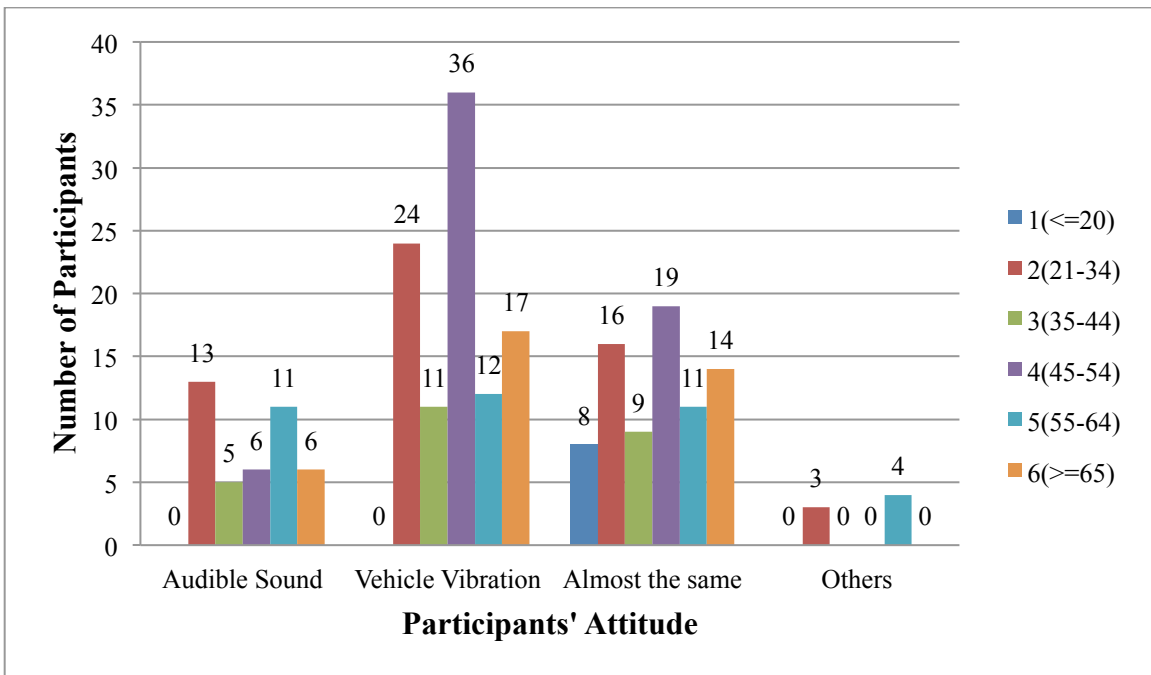
Figure 5-57 Participants' Opinion on Rumble Strip Safety Efficiency by Age
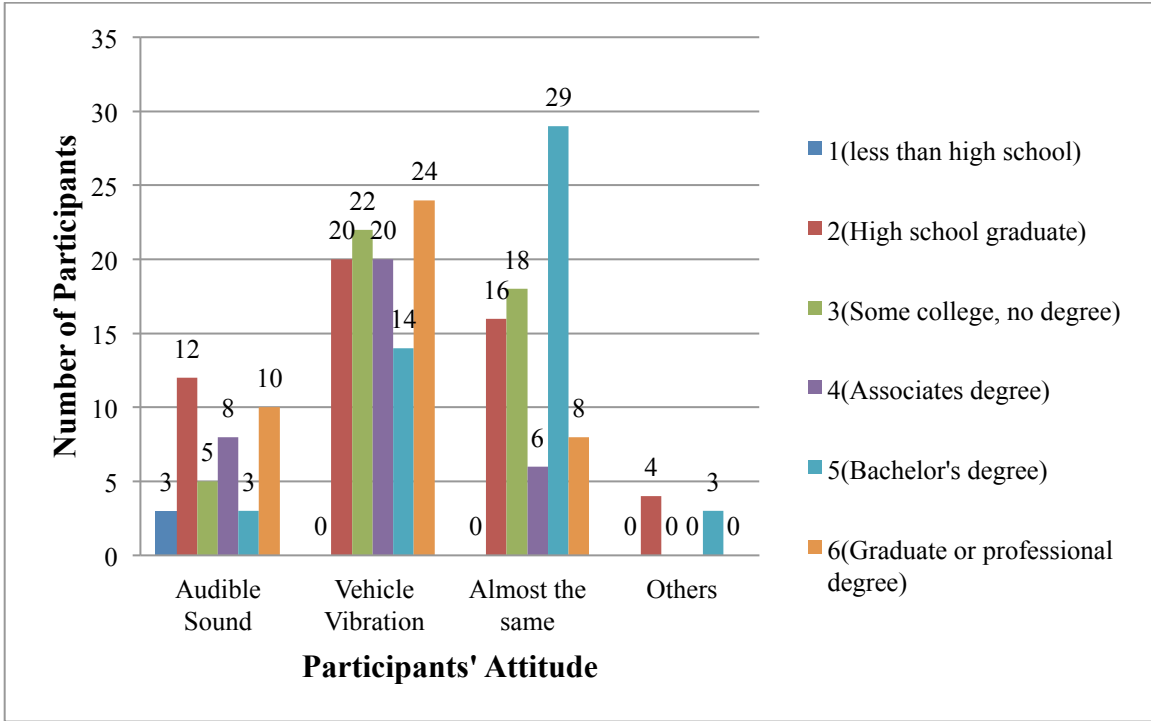
Figure 5-58 Participants' Opinion on Rumble Strip Safety Efficiency by Education Level

It shows in the results that 44.44% of the participants believe vehicle vibration is more effective, and 18.22% of them believe audible sound is more effective. There are also 34.22% of all participants believing that both effects are almost the same. These statistics demonstrate that there is significant cognitive difference among these participants regarding rumble strip effects. Detailed information regarding gender, age and education level information is also revealed in these figures. For example, among the participants preferring vehicle vibrations, it is found that male participants are the larger group, and the participants between 45 and 54 years old and those with a graduate or professional degree are the largest groups correspondingly.

Question 3-13 Should NMDOT implement shoulder rumble strips at other locations across the state? (Yes / No)
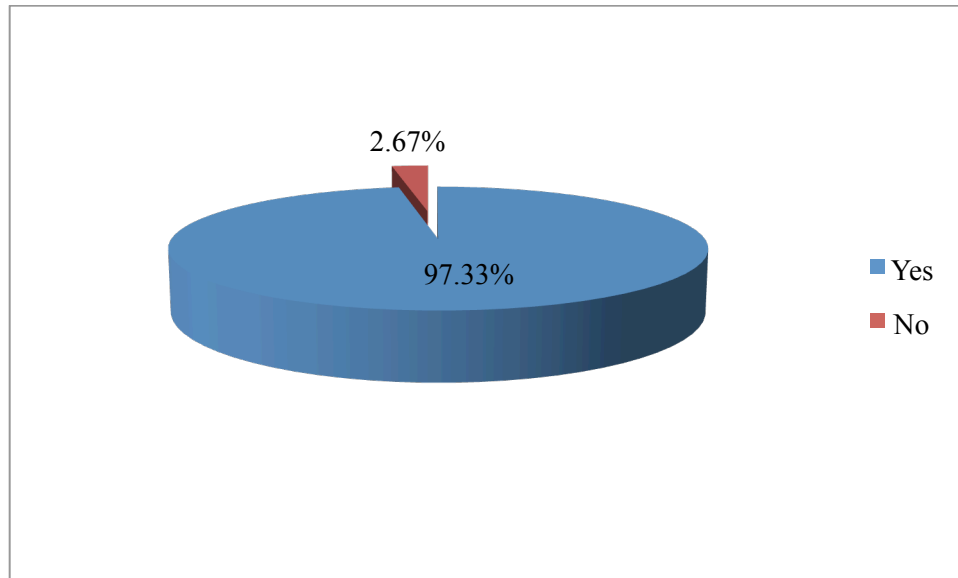
Figure 5-59 Participants' Opinion on Shoulder Rumble Strip Increasing Installation

As is shown in Figure 5-59, 97.33% of all the participants believe that NMDOT should implement shoulder rumbles strips at other location across the state.

5.2.4.   Cognitive Response on Retroreflective Rumble Stripes

The following five questions were selected to evaluate the cognitive levels and opinions of the participants regarding the rumble strips.

Question 4-1 Have you ever driven on the U.S. 285 section between Vaughn, NM and Roswell, NM in last year?
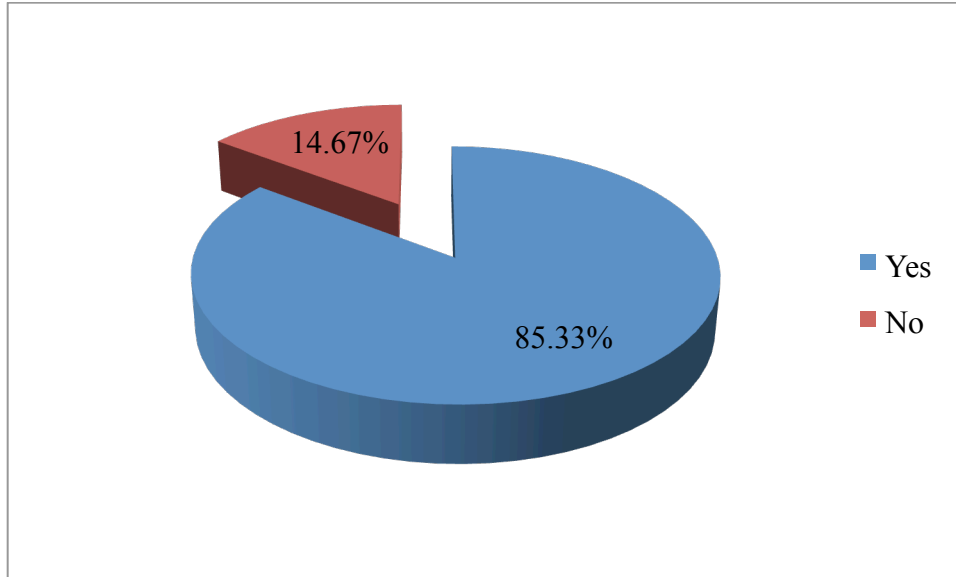
Figure 5-60 Distribution of Driving Experience on U.S. 285

Question 4-2 If yes in Question 1, have you noticed the newly painted stripes on these shoulder rumble strips? (Yes / No)
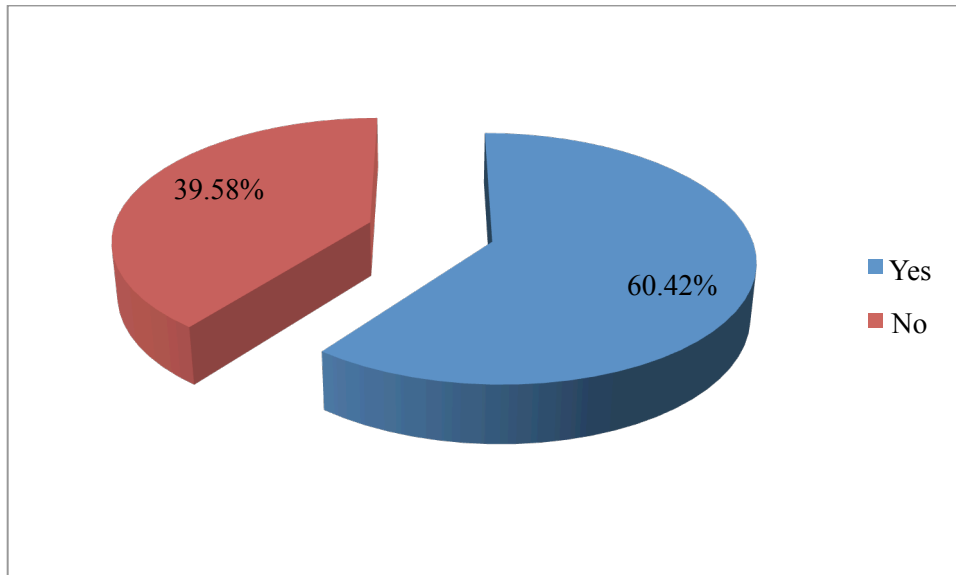
Figure 5-61 Proportion of Participants Noticing New Rumble Stripes

It shown in Figures 5-60 and 5-61 that 85.33% (192 participants) of the participants traveled on U.S. 285 last year. Among these 192 participants, 60% (116

participants) have noticed the newly painted stripes on the shoulder rumble strips along the studied section of U.S. 285.

To better demonstrate participants' attitude on the implemented retroreflective rumble strips regarding their safety effects, for the following questions, we plotted detailed distributions of participants' responses by gender, age and education level information. Detailed discussions are presented below.

Question 4-3: Are the white lines (near side slope) more visible when painted over the shoulder rumble strips than on flat pavement?
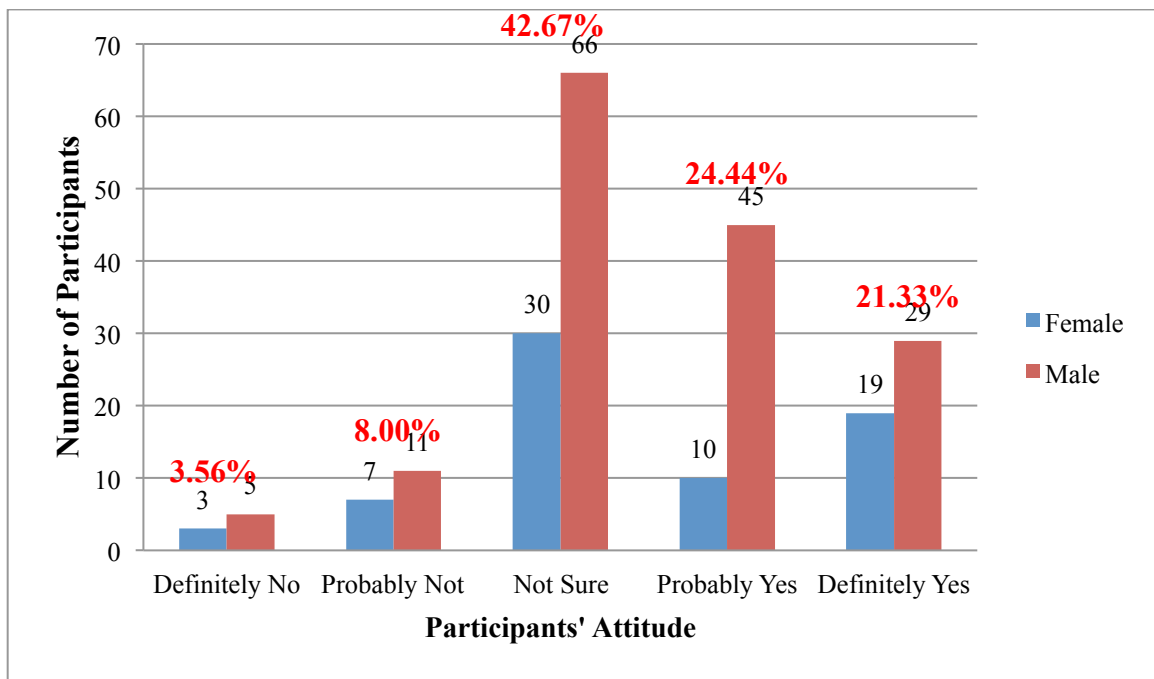
Figure 5-62 Participant's Attitude on White Stripe Visibility by Gender
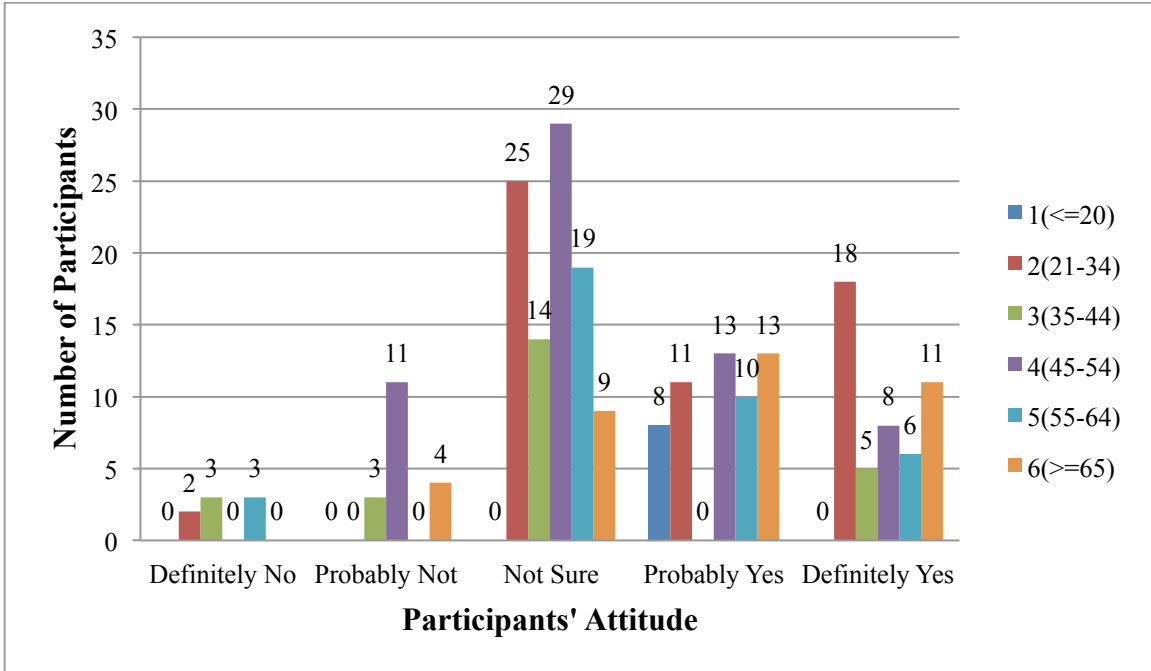
Figure 5-63 Participant's Attitude on White Stripe Visibility by Age
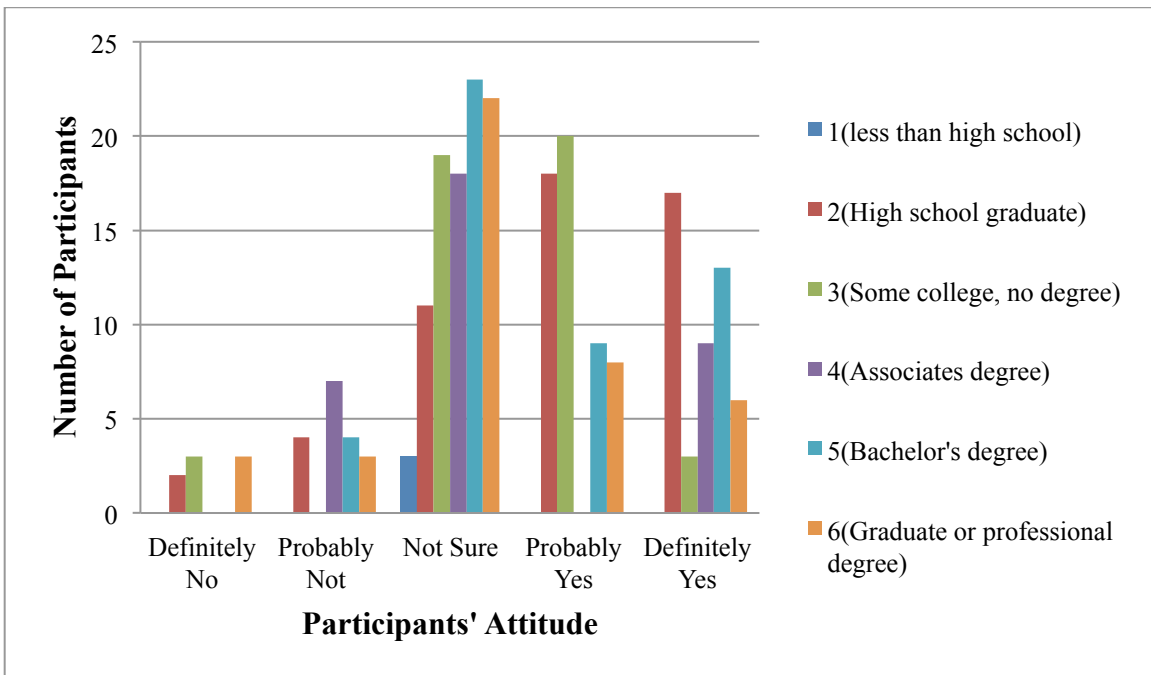
Figure 5-64 Participant's Attitude on White Stripe Visibility by Education Level

Figures 5-62 to 5-64 illustrate participants' opinions regarding the visibility of the

white stripes on shoulder rumble stripes; there are five choices from "Definitely No" to

"Definitely Yes". It is shown that 21.33% of people with "Definitely Yes", 24.44% with "Probably Yes", and 42.67 % have a neutral feeling. Overall, 88.44% of the participants have non-negative feeling. Detailed response distributions regarding gender, age and education level information are illustrated in these figures. For example, among the participants with "Definitely Yes" answer, it also shows that male participants are the larger group, and the participants between 21 and 34 years old and those with a high school degree are the largest groups correspondingly.

Question 4-4: Are the yellow lines (near median) more visible when painted over the shoulder rumble strips than on flat pavement?
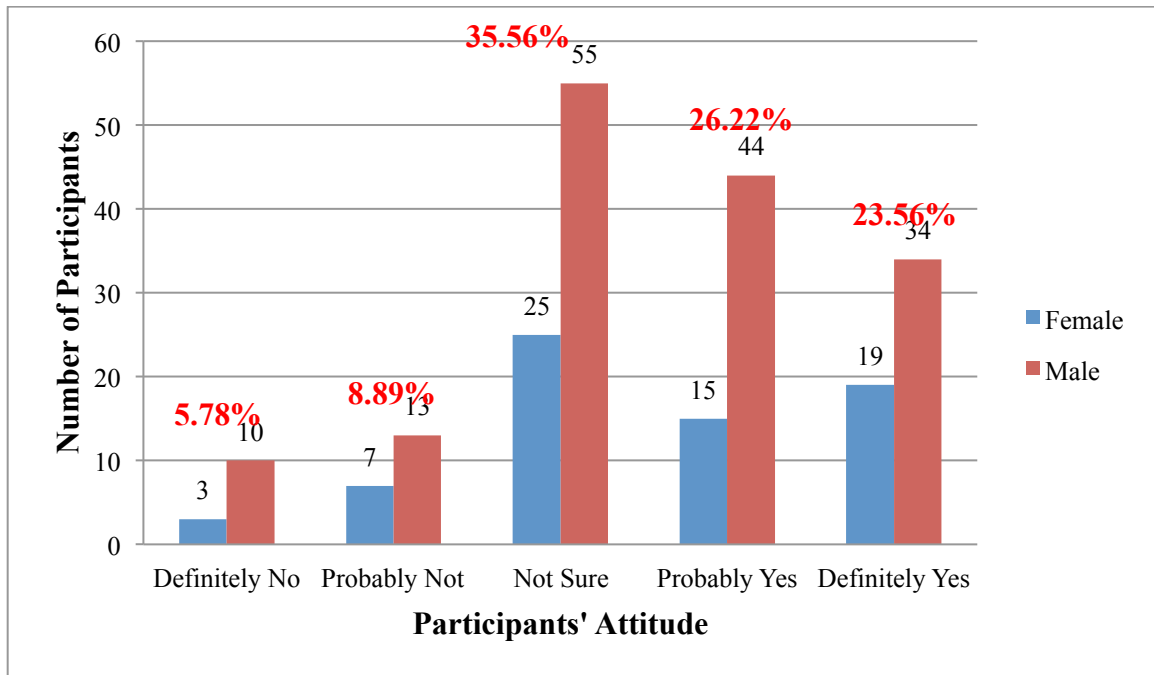
Figure 5-65 Participant's Attitude on Yellow Stripe Visibility by Gender
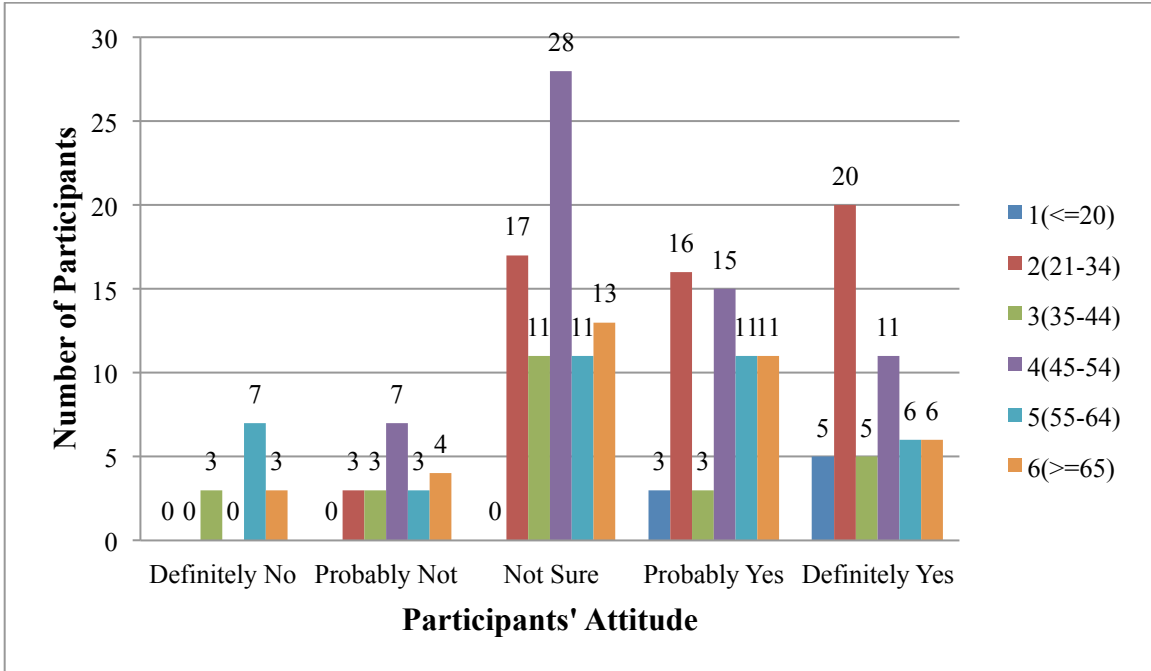
Figure 5-66 Participant's Attitude on Yellow Stripe Visibility by Age
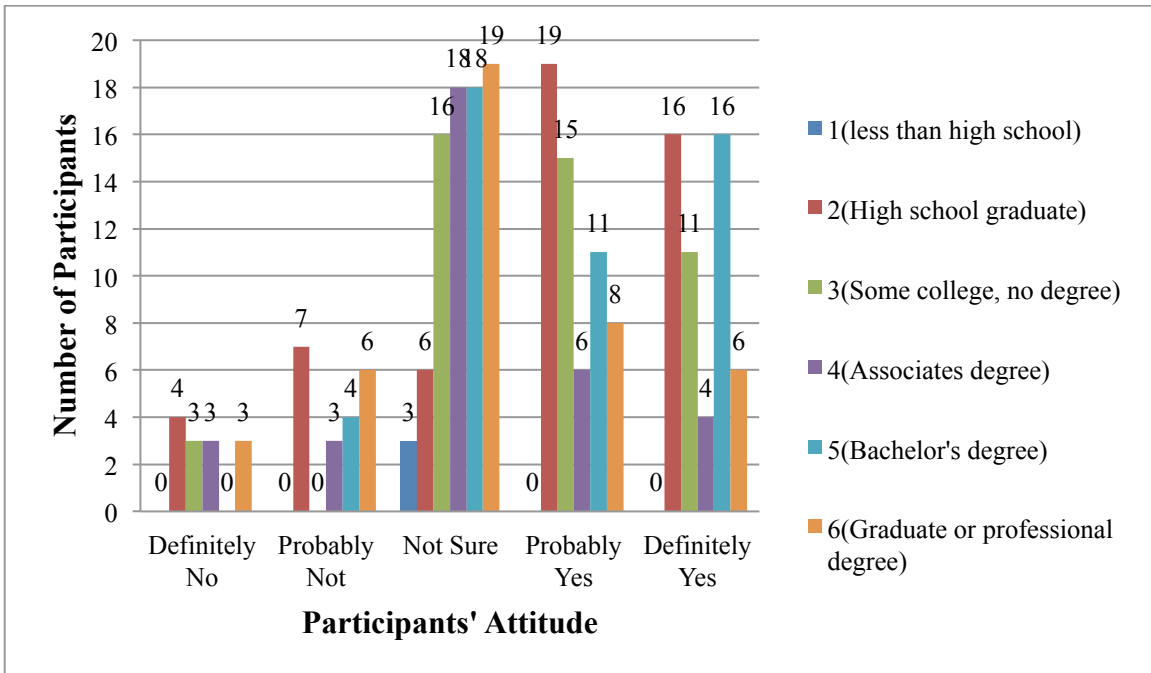
Figure 5-67 Participant's Attitude on Yellow Stripe Visibility by Education Level

Figures 5-65 to 5-67 illustrate the participants' opinions regarding the visibility of the yellow stripes on median rumbles strips, there are five choices from "Definitely no" to "Definitely yes". It is shown that 23.56% of people with "Definitely yes", 26.22% with

"Probably yes", and 35.56% have a neutral feeling. Overall, about 85.33% of the participants have non-negative feeling. Detailed response distributions regarding gender, age and education level information are illustrated in these figures. For example, similar to the results of the previous question, among the participants with "Definitely Yes" answer, it also shows that male participants are the larger group, and the participants between 21 and 34 years old is the largest group among all age groups. Besides, the participant groups with a high school degree and with a bachelor degree are both the largest groups with respect to education levels.

Question 4-5: Which type of retroreflective rumble stripping and elements is more visible and effective?
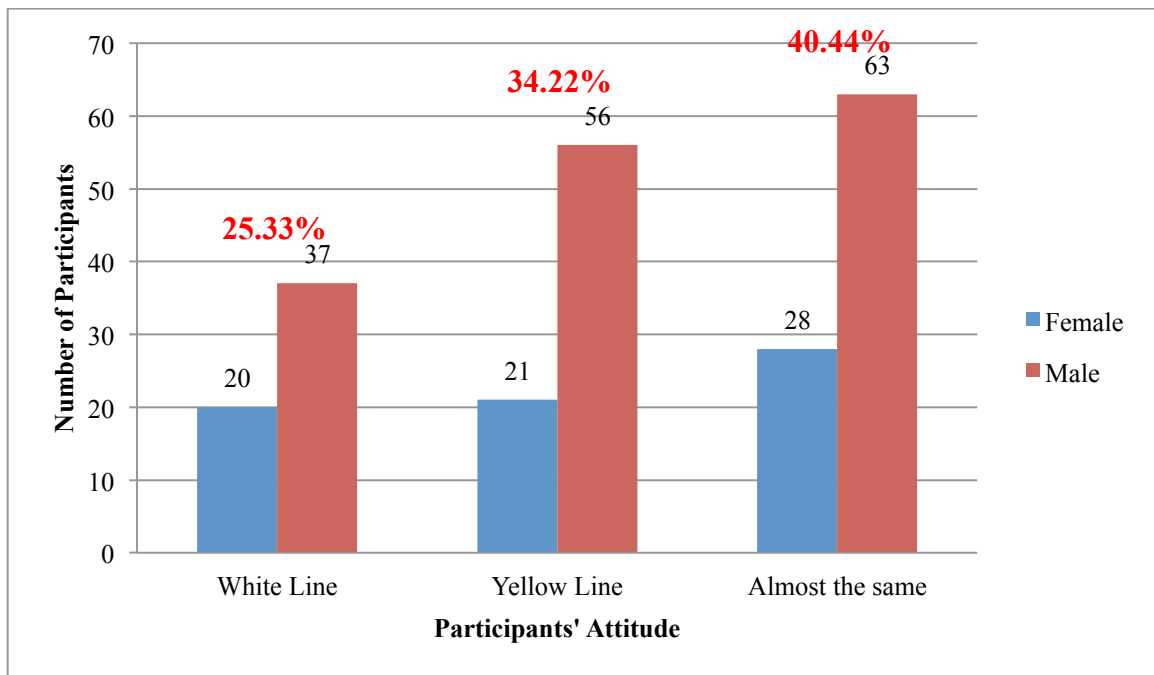
Figure 5-68 Comparison Results of White and Yellow Rumble Stripes by Gender
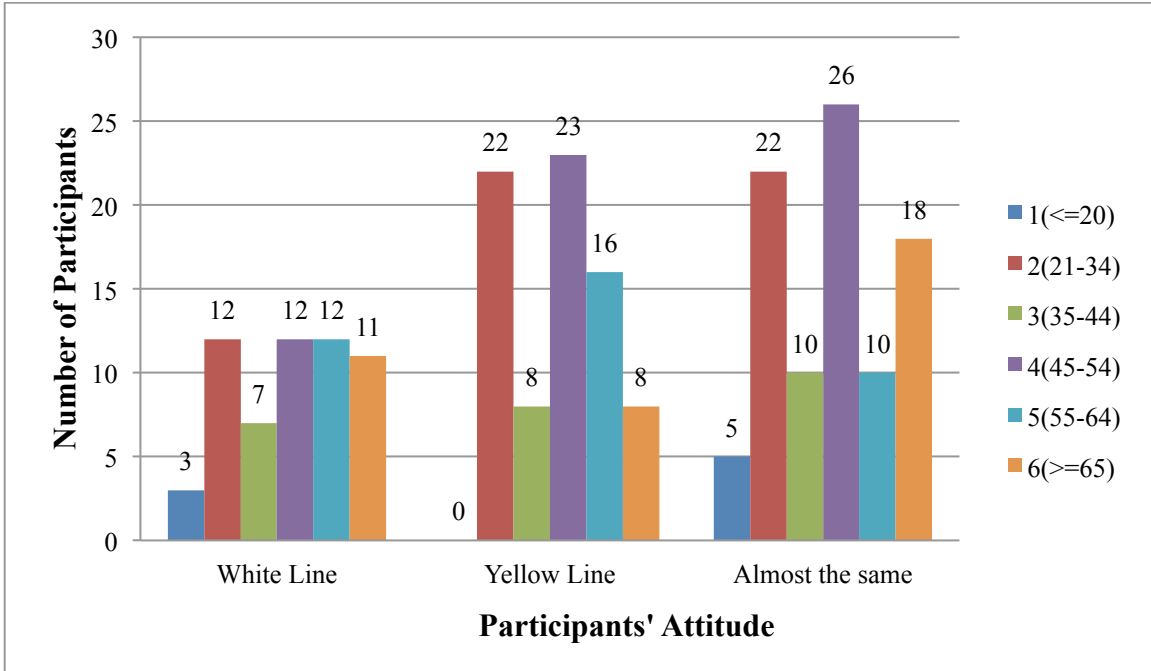
Figure 5-69 Comparison Results of White and Yellow Rumble Stripes by Age
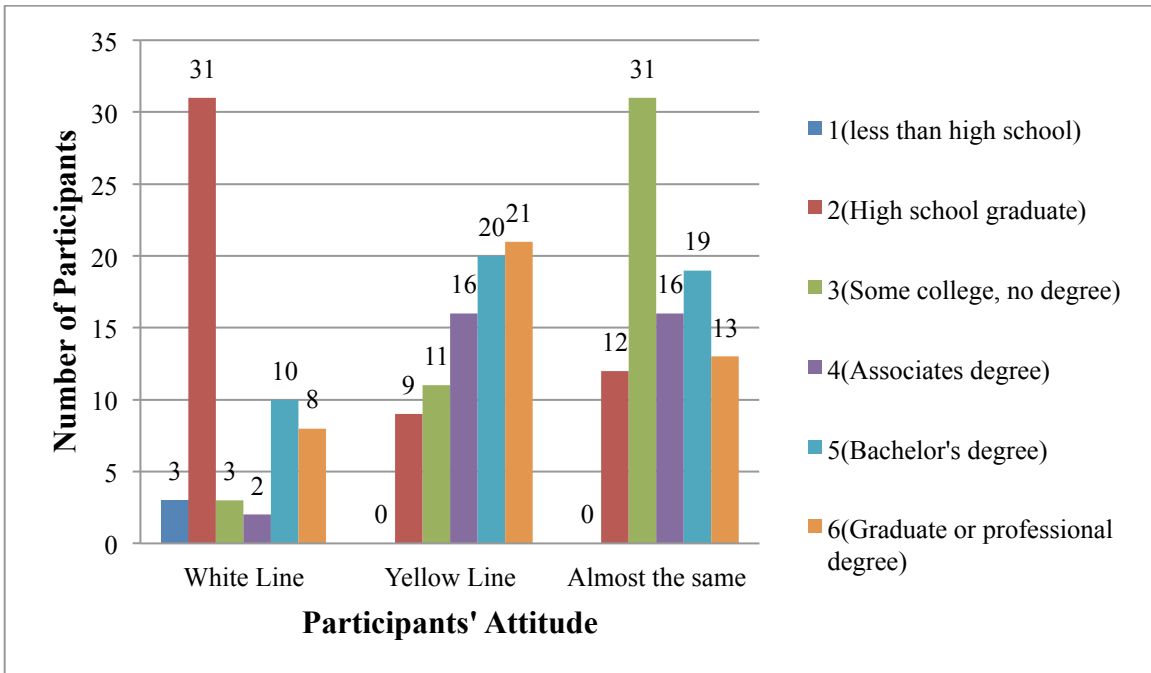
Figure 5-70 Comparison Results of White and Yellow Rumble Stripes by Education Level

Figures 5-68 to 5-70 illustrate the comparison results of white rumble stripes and yellow rumble stripes regarding their visibility and safety effectiveness. It is found that

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25.33% of the participants believe that the white rumble stripes are more visible and effective, and 34.22% of them believe that the yellow rumble stripes are more visible and effective. The rest 40.44% of all the participants hold a neutral opinion. More detailed distributions with respect gender, age and education levels could be revealed in these figures. For instance, it is shown in Figure 5-70 that the participants with a high school degree are the dominant group among all the participants preferring white rumble stripes.

Question 4-6: Would the applied retroreflective rumble stripes and elements help drivers to avoid road departure and improve roadway safety?
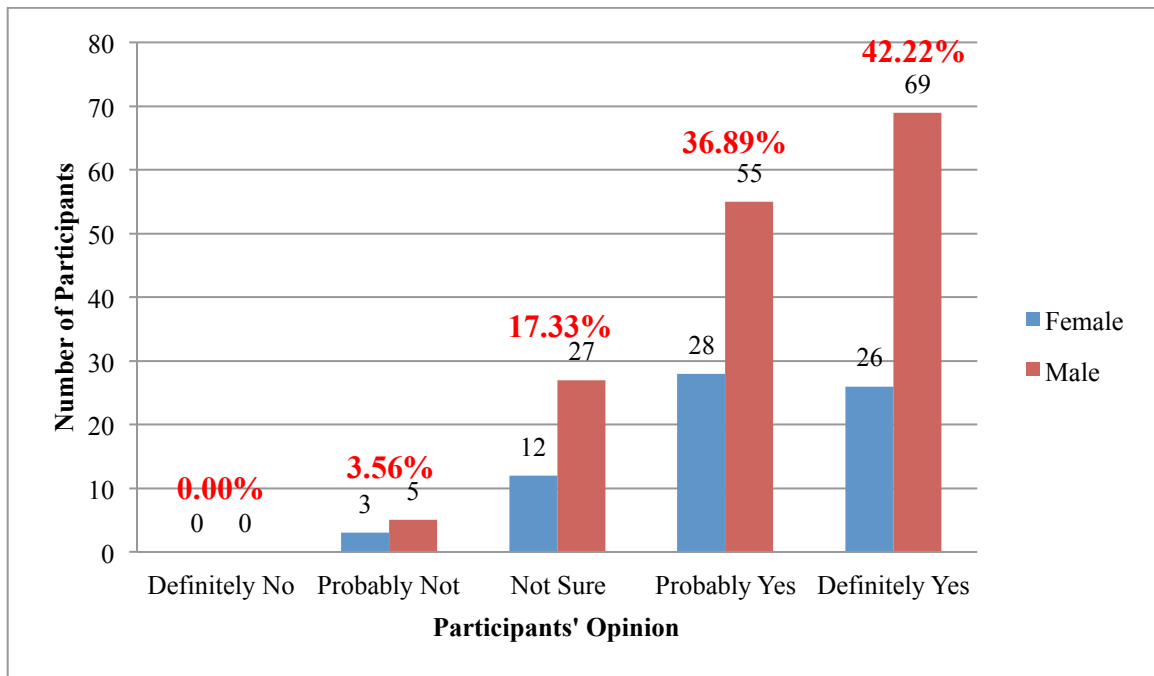
Figure 5-71 Opinion on Retroreflective Rumble Stripe Safety Effect by Gender
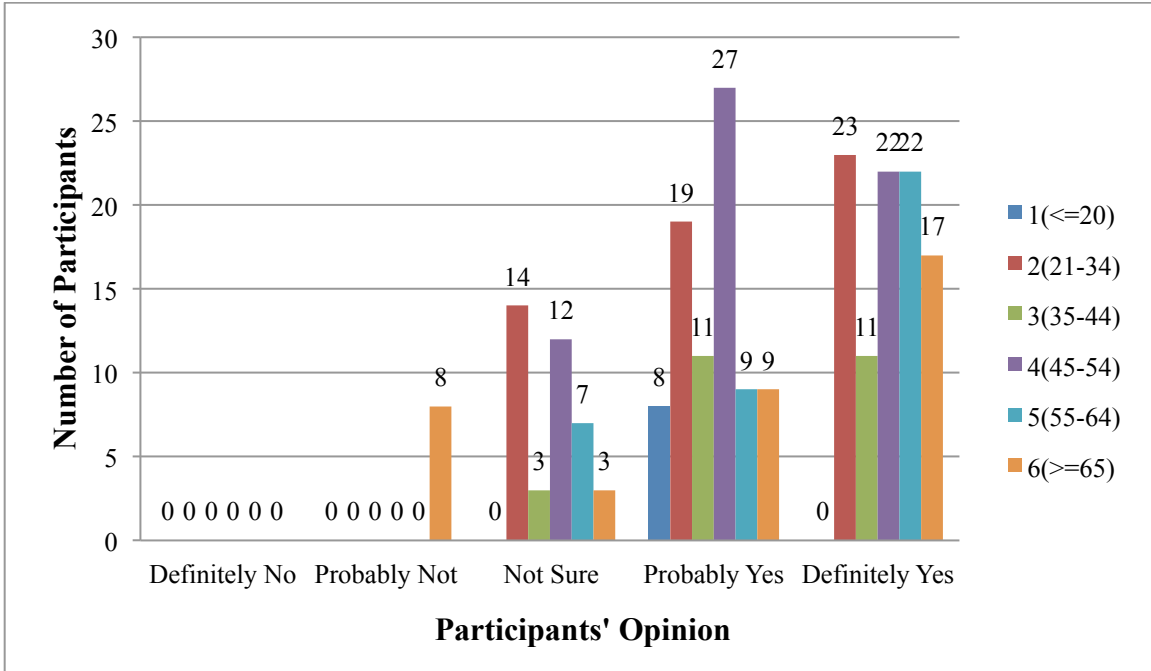
Figure 5-72 Opinion on Retroreflective Rumble Stripe Safety Effect by Age
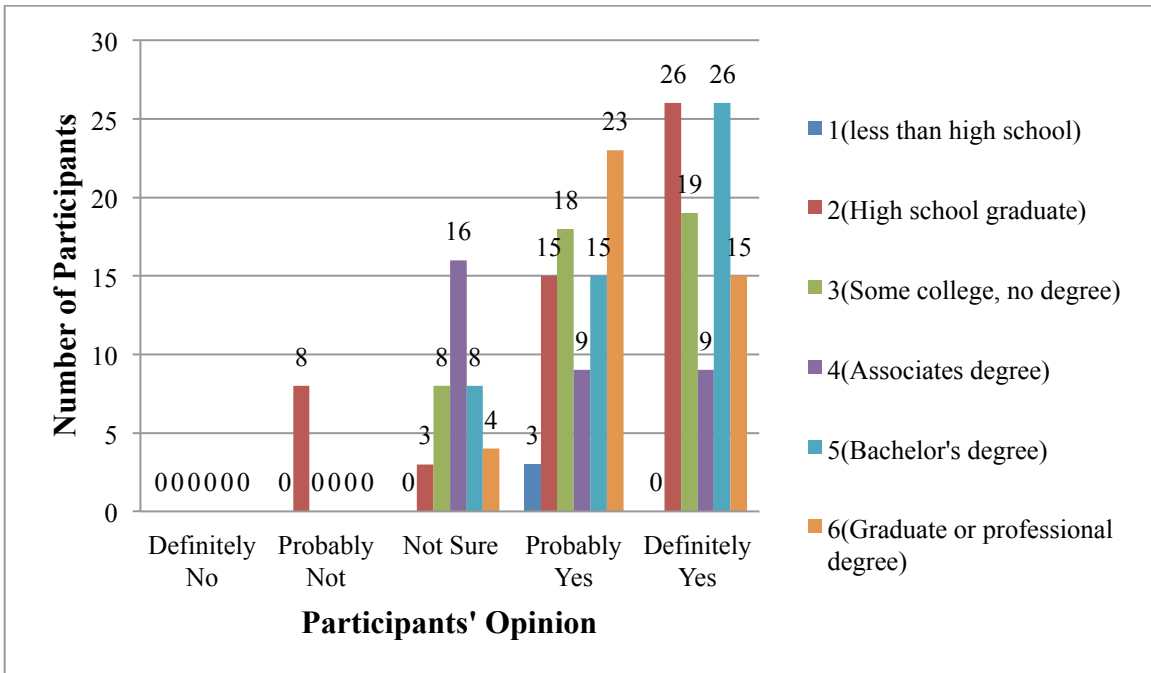
Figure 5-73 Opinion on Retroreflective Rumble Stripe Safety Effect by Education Level

This survey question asks about participants' opinion about if the applied retroreflective rumble strip will help avoid road departure and improve road safety. It is

shown in the results that 42.22% of them have a "Definitely Yes" answer, and 36.89% with "Probably Yes". There are also 17.33% of the participants having a neutral attitude. Overall, 79.11% of all participants have a positive answer and believe the retroreflective rumble stripping will enhance road safety. More detailed distribution patterns with respect to gender, age and education level is also revealed in Figures 5-71 to 5-73.

Question 4-7: Should NMDOT implement retroreflective stripping and elements at other rumble strip locations across the state?
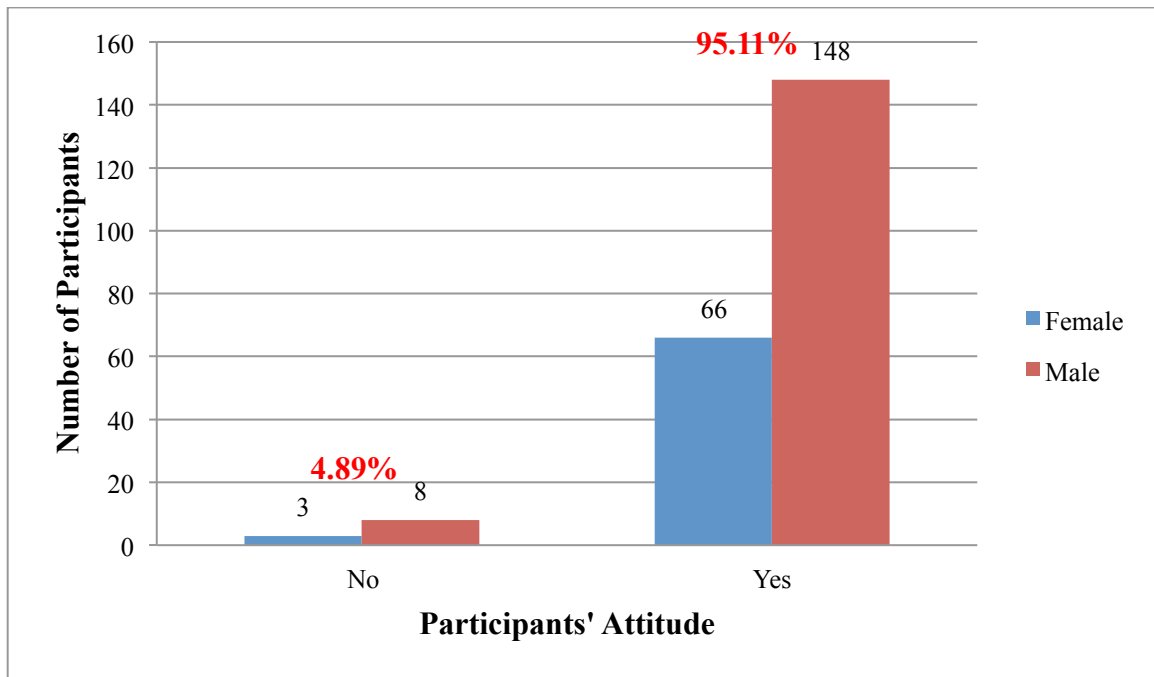
Figure 5-74 Opinion on Retroreflective Rumble Stripe Increasing Implementation by Age
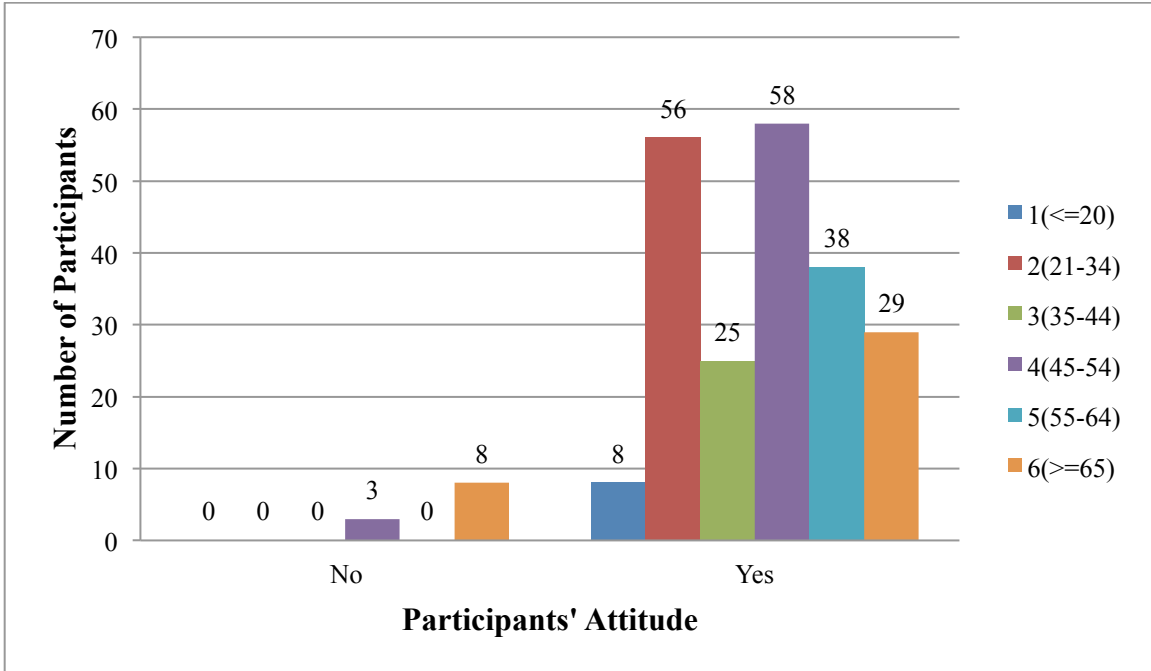
Figure 5-75 Opinion on Retroreflective Rumble Stripe Increasing Implementation by Age
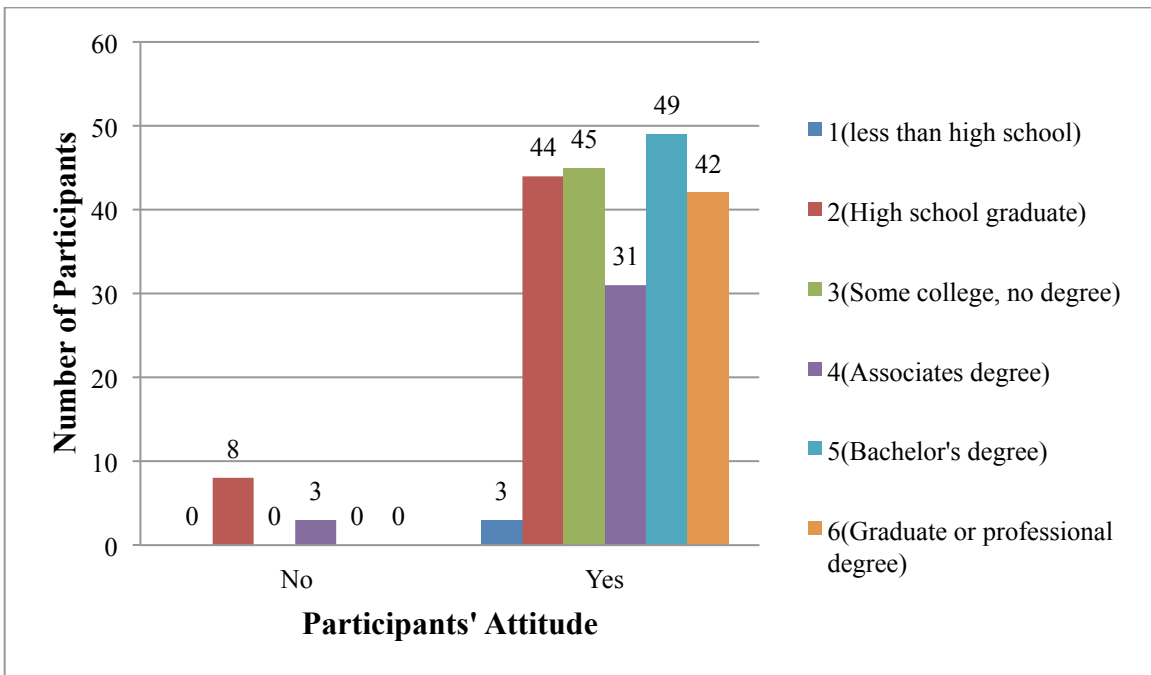
Figure 5-76 Opinion on Retroreflective Rumble Stripe Increasing Implementation by Education Level

As are shown in Figures 5-74 to 5-76, 95.11% of all the participants believe that NMDOT should implement these retroreflective rumble strips along other rural roads. Also, it is found that there are comparable amount of participants in favor of these retroreflective rumble stripes in the age group 21-34 and 45-54 years of age, and also comparable amount of participants in four education levels: high school graduate, college no degree, bachelor degree and graduate or professional degree.

Overall, these survey results illustrate the demographic features and traveling patterns of all survey participants and also their opinions on rumble strip and the newly implemented retroreflective rumble stripes regarding their safety effects. It is found in the survey results that 79.11% of all participants have a positive answer and believe the retroreflective rumble stripping will enhance road safety, and 95.11% of all the participants believe that NMDOT should implement retroreflective stripping and elements at other rumble strip locations in New Mexico.

5.3 Empirical Bayesian Before-After Analysis

5.3.1. Crash Data Information

Six roadway sections (shown in Table 3-1) in U.S. 285 where retroreflective rumble strips were implemented were analyzed in this study. The AADT information for U.S. 285 was extracted from NMDOT. Crash data from 2010 to 2015 were obtained from the NMDOT, the Traffic Safety Division (TSD), and Geospatial and Population Studies (GPS) at the University of New Mexico. Table 5-7 summarized the basic statistic of the 6 roadway sections with implementation of rumble strip.

Table 5-7 Data Description for Treated Sections

Variable	Mean		Minimum		Maximum	
	Before	After	Before	After	Before	After
Time Period	5 year	1 year	5 year	1 year	5 year	1 year
Average crash per year	3.9	2.5	2.4	0	6.2	4
Mean AADT	2214	2311	1785	1756	2789	2985
Segment Length (unit: mile)	19.85	19.85	10	10	35.6	35.6

In order to evaluate the impacts of rumble stripes on safety, the Empirical Bayes
(EB) Before-After analysis was conducted. A total of 22 segments with characteristics
similar to the 6 roadway segments with rumble strips were selected and used as the
reference group for the EB procedure. The full descriptive statistics of variables and the
covariates for the regression analysis are presented in Table 5-8.

Table 5-8 Data Description for Reference Group

Variable	Mean	Standard Deviation	Minimum	Maximum
Average crashes per year	1.76	1.74	0.20	6.20
Segment Length	12.45	11.63	0.17	36.50
Mean AADT	9788.2	9943.5	583	29547

5.3.2. Safety Performance Function Estimation

The Safety Performance Function (SPF), which is an equation giving an
estimation of the average crash per unit length per year for roadway segment (Hauer et
al., 2002), was conducted using the data of reference group. In previous studies, counts
were assumed to follow Poisson distribution. However, if the crash count data is widely
dispersed, the negative binominal regression will be employed for SPF development (H.

Wu et al., 2015). The over-dispersion parameter is estimated in the negative binomial regression, which represents the dispersion of crash count data. If this parameter is not significantly different from zero, it degrades to the Poisson regression. In this study, the over-dispersion parameter is not significantly different from zero, and therefore Poisson regression was conducted for SPF development using the data of the reference group, and the results are presented in Table 5-9. All parameters shown in Table 5-9 are significantly different from zero at 95% level. Then the average crash per km-year can be explained by a function of the variable, AADT, in this study. The positive value of the parameter of AADT shows that the average crash per unit length per year will increase as the AADT increases.

Table 5-9 Estimation Results for Safety Performance Function

Parameter	Mean	Standard Deviation	Z-value	P-value
Constant	-2.26	0.83	-2.75	0.01
AADT	8.07×10^{-5}	4.09×10^{-5}	1.973	0.05

5.3.3. EB Before-After Analysis

The SPF has been obtained through estimation using data of reference group. Then the EB method before-after analysis can be conducted based on the results of SPF. The results of EB are presented in Table 5-10.

Table 5-10 Estimation of Retroreflective Rumble Stripes on U.S. 285

Section ID	Count of Crash (2015 Data)	Expected Crashes	Standard Deviation
1	4	2.88	1.71
2	0	3.83	1.98
3	3	5.74	2.37
4	3	3.22	1.80
5	1	1.91	1.39
6	4	3.29	1.82
All	15	20.87	4.57

The index of effectiveness is calculated using the Eq (4-9), which is equal to 0.715. This result shows that there is a 28.5% reduction in crashes after implementing the rumble strips. Therefore it verifies the effectiveness of the implemented retroreflective rumble stripes in reducing overturn crash occurrence and improving the safety performance on rural highways.

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CHAPTER 6.   CONCLUSIONS AND RECOMMENDATIONS

Many engineering disciplines aim to improve society's infrastructure with the goal of improving human life and keeping people safe. Transportation engineering is no different. Compared to urbanized areas, rural areas have a higher potential for more severe driver injuries in traffic crashes in spite of a lower crash frequency (Eiksund, 2009; Jones et al., 2008). As was mentioned in Chapter 1, more than 50% of all fatal crashes and traffic crash fatalities occurred in rural areas. Lane departure crashes are a major type of crash that induces significant life and economic loss. Lane departure crashes include run-off-the-road (ROR), head-on, cross-median, and overturn crashes, and overturn crashes are a major crash type. In New Mexico, 65% of all fatalities and 44.5% of all serious injuries occurring on roadways from 2004 to 2009 involved lane departure (NMDOT, 2010). Lane departure and overturn crashes are mainly attributed to inattentive driving and lack of alert countermeasures to avoid lane departure. Alcohol, speed, fatigue, and distraction are frequent contributing factors to lane departure crashes. Drivers who are fatigued and/or inattentive at the wheel can understandably veer off the roadway onto the shoulder or even cross the centerline and veer into oncoming traffic, posing the horrific injury outcomes. Additionally, poor visibility of roadway lane shoulders has been identified as one of the leading causes of lane departure crashes during nighttime and inferior weather conditions.

Rumble strips have been an effective highway safety countermeasure for inattentive or distractive drivers against potential lane departure crashes due to their audible rumbling sound and tactile vibration, especially on rural highways. However, due to infrastructure deterioration that can be attributed to aging, traffic loading, rainfall, and

temperature variation, roadway shoulder striping becomes less visible to provide the motorist with adequate information of the edge of the outside driving and lead to an increase in run-off-road crash occurrence frequencies and severities.

U.S. 285 is a major highway that runs through Colorado, New Mexico, and Texas with a large portion acting as a crucial corridor for the eastern portion of New Mexico, and also carries a significant portion of overturn crashes. Shoulder rumble strips are applied on both edges (Figures 2-3 and 2-4) but these rumble strips are deteriorated due to aging, traffic loading, and the change of weather. In order to reduce the potential and injury severities of overturn crashes, NMDOT initiated a project and applied retroreflective rumble stripes with elements on existing rumble strips along U.S. 285 to increase their visibility. In this project, retroreflective rumble stripes were applied by using high-durable acrylic traffic paint installed at 22 to 25 mils wet film thickness to paint 6-inch wide striping on existing rumble strips, and then place double drop dry elements, both of which add to the visual representation of edge line location as well as the angles associated with a rumble strip magnifying the reflective capability of a painted stripe.

With this project, this research is conducted to evaluate the safety performance of the newly implemented retroreflective rumble stripes in overturn crash occurrence prevention. In this study, a field survey was conducted to collect road users' knowledge and opinion rumble strip and the implemented retroreflective rumble stripes regarding their safety effects, and 225 valid survey responses were collected for analysis. In brief, it is worth knowing that the majority of participants stated that the retroreflective rumble stripes were effective and welcomed in the area. In particular, over 71% of the

participants had positive feelings toward retroreflective rumble stripes and over 95% of the participants believed that the NMDOT should implement shoulder and centerline retroreflective rumble stripes throughout rural roadways across New Mexico. Rumble strips are not expensive to install and the increase in quantity of retroreflective striping will not be a cost to drivers for future projects.

An EB Before-after analysis was conducted based on historical overturn crash data on U.S. 285 before and after the retroreflective rumble stripes were implemented. A safety performance function was trained based on crash and average annual daily traffic (AADT) data of U.S. 285. It is shown in the results that, on average, there is a 28.5% reduction in crash occurrences after the implementation of the retroreflective rumble stripes, indicating the effectiveness of this countermeasure in rural traffic safety improvement. New Mexico Department of Transportation and other transportation agencies should implement shoulder and centerline retroreflective rumble stripes for future measures of motorist safety and crash reductions.

ACKNOWLEDGEMENTS

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Safety Performance Enhancement Analysis of Rumble Stripes with Elements: A Case Study on Rural Highway US 285 in New Mexico

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Appendix A State of New Mexico Uniform Traffic Crash Report

CRASH INVESTIGATION SH 10074 REVISED April, 2009 NMDOTUCR E April 2009

STATE OF NEW MEXICO
UNIFORM CRASH REPORT

REPORTING DEPARTMENT

☐ ON PRIVATE PROPERTY ☐ FATAL INJURY PROPERTY DAMAGE ONLY ☐ UNDER $500 ☐ $500 OR MORE ☐ HIT AND RUN

Case Number:
NMDOT:
CAD Num:

CRASH DATE (MM/DD/YY) MILITARY TIME CITY OCCURRED IN COUNTY

Sun ☐ M ☐ Tu ☐ W ☐ Th ☐ F ☐ S ☐ OCCURRED ON: (Route No. or Name) AT INTERSECTION WITH: TRIBAL LAND? ☐ Yes ☐ No

OTHER LOCATION ☐ FEET ☐ MILES N NE NW S SE SW E W PERMANENT LANDMARK - COUNTY LINE – INTERSECTION - MILEPOST LAT: LONG:

CRASH OCCURRED ☐ On Roadway ☐ Off Roadway CRASH CLASSIFICATION ☐ Overturned ☐ Rollover ☐ Other N-Col ☐ R. R. Train ☐ Pedestrian ☐ Pedalcyclist ☐ Other Vehicle ☐ Animal ☐ Vehicle on Other Rdwy ☐ Fixed Object ☐ Parked Vehicle ☐ Other Object ANALYSIS CODE:

VEHICLE NO. HEADED **1** N NE NW S SE SW E W On: Left Scene of Crash ☐ Yes ☐ No Posted Speed Safe Speed

Drivers Full Name (Last, First, Middle) Address

Driver's License Number State Type Status Restrictions Endorsements Expires City/State Zip Code Phone

Date of Birth - M/D/YR Occupation Seat Age Sex (M/F) Race Injury Code OP Code OP Used Properly Airbag Deploy Ejected EMS# Med Trans

Seat Pos. Occupant's Name (Last, First, Middle) Occupant's Address (City, State, Zip)

Vehicle Yr. Vehicle Make Color Body Style Cargo Body Type Vehicle Use (1) Vehicle Use (2) Towed? ☐ Yes ☐ No Towed due to disabling damage? ☐ Yes ☐ No Damage Severity ☐ Heavy ☐ Moderate ☐ Slight ☐ None ☐ Unknown ☐ All Areas Extent ☐ Disabled ☐ Functional ☐ Appearance ☐ Property ☐ Fire ☐ None ☐ Top ☐ Undercarriage

License Yr. State License Plate Number VIN

DOT # Interstate Carrier Code Towed By Towed To

Number of Axles Vehicle Weight Rating/Gross Combination Weight Rating ☐ 10,000 lbs. or less ☐ 10,001 lbs. to 26,000 lbs. ☐ Greater than 26,000 lbs. HazMat Placard ☐ Hazmat Placard 4 digit # OR Hazmat Name AND 1 digit # Hazmat Released? ☐ Yes ☐ No

Carrier's Name Carrier's Address Carrier's Zip

Owner's Name Owner's Company Name Owner's Address Owner's Zip Owner's Telephone

Insured By: (Name of Company) Policy Number Trailer or Towed Vehicles (1) Type Year Make License Yr. License State License Number

Trailer or Towed vehicles (2) Type Year Make License Yr. License State License Number Trailer or Towed Vehicles (3) Type Year Make License Yr. License State License Number

VEHICLE NO. HEADED **2** N NE NW S SE SW E W On: Left Scene of Crash ☐ Yes ☐ No Posted Speed Safe Speed

Drivers Full Name (Last, First, Middle) Address

Driver's License Number State Type Status Restrictions Endorsements Expires City/State Zip Code Phone

Date of Birth - M/D/YR Occupation Seat Pos. Age Sex (M/F) Race Injury Code OP Code OP Used Properly Airbag Deploy Ejected EMS # Med Trans

Seat Pos. Occupant's Name (Last, First, Middle) Occupant's Address (City, State, Zip)

Vehicle Yr. Vehicle Make Color Body Style Cargo Body Type Vehicle Use (1) Vehicle Use (2) Towed? ☐ Yes ☐ No Towed due to disabling damage? ☐ Yes ☐ No Damage Severity ☐ Heavy ☐ Moderate ☐ Slight ☐ None ☐ Unknown ☐ All Areas Extent ☐ Disabled ☐ Functional ☐ Appearance ☐ Property ☐ Fire ☐ None ☐ Top ☐ Undercarriage

License Yr. State License Plate Number VIN

DOT Interstate Carrier Code Towed By Towed To

Number of Axles Vehicle Weight Ratings/Gross Combination Weight Rating ☐ 10,000 lbs. or less ☐ 10,001 lbs. to 26,000 lbs. ☐ Greater than 26,000 lbs. HazMat Placard Hazmat Placard 4 digit # OR Hazmat Name AND 1 digit # Hazmat Released? ☐ Yes ☐ No

Carrier's Name Carrier's Address Carrier's Zip

Owner's Name Owner's Company Name Owner's Address Owner's Zip Owner's Telephone

Insured By: (Name of Company) Policy Number Trailer or Towed Vehicles (1) Type Year Make License Yr. License State License Number

Trailer or Towed Vehicles (2) Type Year Make License Yr. License State License Number Trailer or Towed Vehicles (3) Type Year Make License Yr. License State License Number

Crash Report Number Case Number

STATE OF NEW MEXICO UNIFORM CRASH REPORT
NM Statute 66-7-209
NMDOT COPY

SHEET OF SHEETS

Vehicle No. 1

Vehicle No. 2 or PEDESTRIAN - OTHER

Appendix B U.S. 285 Rumble Stripe Safety Performance Questionnaire

U.S. 285 Rumble Stripe Safety Effect Survey

The New Mexico Department of Transportation (NMDOT) recently renovated the rumble strips along U.S. 285 (between Vaughn and Roswell, NM) by applying retroreflective stripes with elements on rumble strips to enhance their visibility during night time and under adverse weather conditions. The Department of Civil Engineering at the University of New Mexico (UNM), assisted by NMDOT, is conducting a survey regarding U.S. 285 Rumble Stripe Safety Effect among U.S. 285 road users. With your feedback we will evaluate visibility and safety effects of the newly applied rumble stripes with elements. The questionnaire requires approximately 10 to 12 minutes to complete, and your answers will be kept **confidential**. We sincerely thank you for taking the time to let us know your opinion regarding the designated renovation. If you have any questions, please contact me at the following email address:

Guohui Zhang, Assistant Professor

Department of Civil & Environmental Engineering,

University of Hawaii at Manoa

(guohui@hawaii.edu)

Shoulder Rumble Strip Example

White Rumble Stripes (Near Side Slope)   **Yellow Rumble Stripes (Near Median)**

U.S. 285 Rumble Stripe Safety Effect Survey

Name_____ Date_____ Time_____

Location: (Southbound/Northbound, Mile Marker_____) Weather_____

Section I. Your Demographic Data

1. What is your gender?   1) Male   2) Female

2. What is your age?

3. What is the highest level of education you have completed?

1) Less than high school graduate
2) High school graduate (or equivalency)
3) Some college, no degree
4) Associates degree
5) Bachelor's degree
6) Graduate or professional degree

4. What is your current employment status?

1) employed **full-time** and work **from my home**
2) employed **full-time** and work **outside my home**
3) employed **part-time** and work **from my home**
4) employed **part-time** and work **outside my home**
5) unemployed
6) unpaid family worker
7) full time student
8) retired
9) other _____ (please specify)

5. _____ number of people in household including yourself?

6. _____ number of drivers in the household?

7. _____ number of vehicles in your household?

8. Do you have any physical conditions in any of the following parts that may affect your operation of vehicles? (Check "yes" or "no" for each one)

1) Shoulder/neck (Yes / No)
2) Wrist/finger/elbow (Yes / No)
3) Back/waist (Yes / No)
4) Seat area (hip/thigh) (Yes / No)
5) Knee/foot (Yes / No)
6) Head (Yes / No)
7) Other_____(please specify)

Section II. Your Commuting Patterns

1. On average, how many miles do you ride per year?

1) 1000 or less
2) 1001 - 3000
3) 3001 - 5000
4) 5001- 8000
5) 8000 +

2. On average, how many days per week do you commute on U.S. 285 (between Vaughn and Roswell, NM)?

1) Less than once
2) 1-2 times
3) 3-4 times
4) 5 times or more

3. What is your typical period of weekdays when you commute on U.S 285 (select all that apply)?
1) 6:00am-9:00 am   3) 9:00am-4:00pm
2) 4:00pm-7:00pm   4) 7:00pm-6:00am

4. What is your typical period of weekend day when you commute on U.S 285 (select all that apply)?
1) peak hours (10:00am-5:00 pm)
2) evening and night time (7:00pm-6:00am)
3) non-peak daytime hours (other hours of the day)

5. What is your main trip purpose(s) when you travel on U.S. 285 during?
1) Work   5) Shopping
2) School   6) Medical
3) Child care/ child's school   7) other _____ (please specify)
4) Recreational/Social
   Primary Trip Purpose:
   Secondary Trip Purpose:

6. What type of vehicles do you use **most often** when traveling? (Please **select one answer**)

1) Passenger car   6) Bicycle
2) Pickup   7) Van or four wheel drive (SUV)
3) Semi-truck   8) Walk
4) Bus   9) other _____ (please specify)
5) Motorcycle, moped, etc.

Section III. Rumble Strips

1. How many driving years do you have?   _____ Years (Total)

2. Do you know well about inattentive or distracted driving? (Yes/no)

3. Have you ever committed inattentive driving? (Yes / No)

4. If it is "Yes" in Questions 2, what type(s) of distracted or inattentive driving did you involve? If more than one applied, please indicate **the primary one**.
1) Speeding
2) Drowsy and Fatigue Driving
3) Manually operating electronic communication device (texting, typing, dialing)
4) Talking on hands-free/hand hold electronic device
5) Other inside activity (eating, changing CD, attending children, etc)
6) Passenger distraction
7) External distraction
8) Other_____(please specify)

5. Have you ever taken a defensive driving /driving safety course? Yes (When: _____) / No

6. Do you know well what a shoulder rumble strip is? (Yes / No)

7. Have you ever run over a shoulder rumble strip? If yes, how often does this happen? (Yes / No)
   1) Rare   3) Neutral   5) Quite Often
   2) Seldom   4) Somewhat often

8. What was the cause or causes for driving over the shoulder rumble strips?
1) Speeding
2) Drowsy and Fatigue Driving
3) Manually operating electronic communication device (texting, typing, dialing)
4) Talking on hands-free/hand hold electronic device
5) Other inside activity (eating, changing CD, attending children, etc.)
6) Passenger distraction
7) External distraction
8) Intentionally pull off the road
9) Other_____(please specify)
   Primary cause:
   Secondary cause (if have):

9. When driving consciously and alertly, what would be your reaction when running onto a rumble strip?
   1) Positive (Grateful, Relieved)   2) Neutral   3) Negative (Annoyed, Irritated, etc.)

10. If you perform an inattentive driving, what would be your reaction when running onto a rumble strip?
    1) Positive (Grateful, Relieved)   2) Neutral   3) Negative (Annoyed, Irritated, etc.)

11. Do you think that they will have the following negative impacts while driving, please rate from 1-5 for each item, where (1-strongly disagree, 2-somewhat disagree, 3-neutral, 4-somwhat agree, 5-strongly agree
9) Discomfort _____
10) Nuisance to make legal passing maneuvers _____
11) Driver overreaction _____
12) Driver leftward correction of vehicle under certain situations _____
13) Poor vehicle handling _____
14) Vehicles crowding bicyclists under certain situations _____
15) Increased noise to the various residences along the highway _____
16) other _____(please specify)

12. If you perform an inattentive driving, would you have enough time to react properly to avoid crashes?
    1) Definitely no   3) Not sure   5) Definitely yes
    2) Probably not   4) Probably yes
13. Which type of sensation do you think is more effective in correcting drivers' run-off road behavior?
    1) Audible sound   2) Vehicle vibration   3) Almost the same 4)Other_____(please specify)

14. Should NMDOT implement shoulder rumble strips at other locations across the state? (Yes / No)

Section IV. Retroreflective Rumble Stripes and Elements

1. Have you ever driven on the U.S. 285 section between Vaughn, NM and Roswell, NM in last year? (Yes / No)

2. If yes in Question 1, have you noticed the newly painted stripes on these shoulder rumble strips? (Yes / No)

3. Are the white lines (near side slope) more visible when painted over the shoulder rumble strips than on flat pavement?
   1) Definitely no   4) Probably yes
   2) Probably not   5) Definitely yes
   3) Not sure

4. Are the yellow lines (near median) more visible when painted over the shoulder rumble strips than on flat pavement?
   1) Definitely no   4) Probably yes
   2) Probably not   5) Definitely yes
   3) Not sure

5. Which type of retroreflective rumble stripping and elements is more visible and effective in highlighting lane edges and prevent road departures?
   1) White lines   2) Yellow lines   3) Almost the same

6. In your opinion, would the applied retroreflective rumble stripes and elements help drivers to avoid road departure and improve roadway safety?
   1) Definitely no   4) Probably yes
   2) Probably not   5) Definitely yes
   3) Not sure

7. Should NMDOT implement retroreflective stripping and elements at other rumble strip locations across the state? (Yes / No)

Thank you very much for your participation! Have a Safe and Joyful Trip!