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16. Abstract Texas has the highest number of fatal crashes involving large trucks in the US since 1994, and this number in 2012 grew by 82% from 299 crashes in 2009. Due to the size and weight, crashes involving large trucks are usually more destructive, and therefore are a major health and safety concern for Texans. Studies are needed to better understand the risk factors related to large truck crash and identify effective countermeasures to reduce crash involving large truck. The goals of this research are to analyze the risk factors of large truck involved crash, recommend low-cost, high effective countermeasures, as well as determine about how many large truck crashes can be reduced by specific countermeasures implementation .To achieve the research goals, the research team (1) conducted crash data analysis to identify the crash hot spots and contributing factors to the large truck involved crashes; (2) conducted risk assessment in order to prioritize the risk factors; (3) surveyed truck drivers to validate the identified crash risk factors; (4) identified potential effective countermeasures for preventing large truck-involved crashes; (5) conducted cost benefits analysis and recommend the most cost-effective countermeasures. Finally, 14 crash risk factors related to roadway conditions, traffic control, drivers and vehicle characteristics were identified, and 24 cost-effective safety countermeasures related to traffic engineering, traffic law enforcement, road user education, emergency response, were identified, and their costs and benefits were analyzed.					
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Development of Systemic Large Truck Safety Analyses

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SUMMARY

Texas has the highest number of fatal crashes involving large trucks in the US since 1994, and this number in 2012 grew by 82% from 299 crashes in 2009. Due to the size and weight, crashes involving large trucks are usually more destructive, and therefore they are the major health and safety concern for Texans. Studies are needed to better understand the risk factors related to large truck crashes and identify cost effective countermeasures to prevent and mitigate crashes involving large trucks.

The goals of this research are to analyze the risk factors of large truck involved crash, recommend low-cost, high effective countermeasures, as well as determine about how many large truck crashes can be reduced by specific countermeasures implementation. To achieve the research goals, the research team (1) conducted crash data analysis to identify the crash hot spots and contributing factors to the large truck involved crashes; (2) conducted risk assessment in order to prioritize the risk factors; (3) surveyed truck drivers to validate the identified crash risk factors; (4) identified potential effective countermeasures for preventing large truck-involved crashes; (5) conducted cost benefits analysis and recommend the most cost-effective countermeasures.

First, the researchers have conducted a thoroughly literature review, and assessed the state-of-the-practice regarding the safety problems associated with large trucks. A large amount of literatures have been reviewed and the results have been summarized into three parts: 1) contributing factors related to large truck-involved crashes, 2) methodologies applied to large truck safety analysis and 3) safety countermeasures for preventing or mitigating large truck-involved crashes.

After that, truck crash data was collected from the Crash Records Information System (CRIS). A large and comprehensive database was then developed based on truck crash data from 2011 to 2015 for the entire state of Texas. This database contains records of 85,184 large truck crashes and more than 170 attributes for each crash record, including information about the drivers, vehicles, characteristics of the crashes, roadway conditions, and environmental conditions.

Then, to identify risk factors contributing to large truck-involved crashes and their severity, crash data based risk analysis was performed. Two approaches were adopted for

this effort: 1) collision diagram based hot spot analysis, and 2) comprehensive crash data analysis.

To investigate roadway related risk factors contributing to large truck involved crashes, collision diagram based in-depth crash risk analysis was conducted. To perform this analysis, 10 hot areas in Texas with high number of large truck involved crashes, especially fatal and incapacitating crashes, were identified by applying ArcGIS based techniques. Then, all crash reports collected from those 10 hot areas were reviewed and analyzed to develop collision diagrams. Depending on its size, the number of collision diagrams developed for each hot area varies from 1 to 10. Finally, a total of 47 collision diagrams were developed for the 10 hot areas. For each hot area, crashes were analyzed by type, location and environmental conditions. Based on the analysis results, 14 risk factors related to roadway conditions, traffic control, drivers and vehicle characteristics were identified.

For the comprehensive truck crash data analysis, two different methods, i.e. descriptive analysis and statistical model based analysis, have been used. By conducting descriptive analysis, crash risk factors related to driver, vehicle, roadway and environmental conditions have been analyzed. After that, a crash severity model was developed to identify the significant factors contributing to the large truck crash severity.

Next, a survey was conducted to collect large truck drivers' inputs about the safety issues that they are facing as well as their opinions on how to prevent large truck involved crashes. The information collected through the survey was used to validate and refine the research findings, such as the identified crash risk factors and to propose potential countermeasures for preventing or mitigating large truck involved crashes. The survey includes three parts: 1) crash risk factors, 2) countermeasures and 3) general questions. Survey questionnaires were sent to large truck drivers through their companies. In addition, graduate research assistants went to 10 truck stops and interviewed large truck drivers. In total, 129 surveys were collected.

Finally, cost benefit analysis was performed to analyze 23 cost-effective safety countermeasures related to traffic engineering, traffic law enforcement, road user

education, emergency response. It was found that the CRFs generated by all those countermeasures are from 10%-39%, and the B/C ratios are from (1.5:1) to (464.67:1).

The studies led to a number of findings and recommendations associated with truck crash prevention and mitigation. First, from the traffic engineering point of view, if an intersection or roadway segment has heavy truck volume, following are recommended:

- Increase the visibility of traffic signal heads and traffic signs,
- Provide clear turning guide lines on the pavement for the dual left-turn/right-turn lanes,
- Use channelized right turn design to provide more protections to trucks when they are turning on red,
- Avoid using two way left-turn lane design and, instead, install raised medians with full or directional openings to better control the location and amount of traffic conflicts, and
- Avoid using two-way frontage road because it will cause drivers' confusion on the right of way rules.

In addition, enhancing the traffic law enforcement for both truck drivers and general road users can effectively prevent the large truck involved crashes. New technologies, such as alcohol interlocks, red-light cameras, and speed cameras are highly recommended due to their high B/C ratios (great than 12%). Furthermore, to reduce truck crash risk, education is essential not only to large truck drivers, but also to other road users. According to the literature, providing road user education on safely driving around the trucks has great potential in improving truck safety. Finally, emergency response time is the key factor for survival rates after a crash occurred. To lower the fatalities of large truck crash, three new technologies based countermeasures, i.e. Install eCall, Advanced Life Support Quick Response Vehicle (ALS QRV), and Traffic Signal Preemption for Emergency Vehicle, are recommended. These countermeasures have shown great benefits in term of reducing emergency response time, crash fatality rate and the associated cost.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

A large truck, as defined by the US Department of Transportation, is any vehicle with a gross vehicle weight rating greater than 10,000 pounds. Large trucks take more time than any other vehicles when accelerating, slowing down and stopping. In addition, large trucks have large blind spots and make wide turns. Therefore, if an unexpected traffic situation comes upon, there may not be enough time and room for large trucks to avoid a collision.

Since 1994, Texas has had the highest number of fatal crashes involving large trucks in the US. Due to their size and weight, crashes involving large trucks often result in fatal injuries, property damages as well as a significant amount of economic loss. According to Texas Department of Transportation's Texas Motor Vehicle Crash Statistics, from 2009 to 2012, the number of large truck-involved fatal crashes statewide increased from 299 to 543, an 82% increase. Having such a high number of large trucks involved crashes is a major health and safety concern for Texans. To better understand the risk factors contributing to large truck crash and identify effective countermeasures for crash prevention will not only benefit truck drivers and their companies, but also bring safety and economic benefits to other road users and the whole state.

1.2 RESEARCH GOAL AND OBJECTIVES

The goals of this research are to analyze the risk factors of large truck involved crash, recommend low-cost, high effective countermeasures, as well as determine about how many large truck crashes can be reduced by specific countermeasures implementation. To achieve the research goals, research team has accomplished the following major tasks:

- Reviewed and summarized literatures related to large truck safety
- Conducted crash data analysis to identify the crash hot spots and contributing factors to the large truck involved crashes
- Conducted risk assessment in order to prioritize the risk factors
- Surveyed truck drivers to validate the identified crash risk factors
- Identified potential effective countermeasures for preventing large truck-involved

crashes

- Conducted cost benefits analysis and recommend the most cost-effective countermeasures.

1.3 OUTLINE OF THIS REPORT

This report covers all the tasks conducted during the span of the research project. In Chapter 2, numerous literatures related to large truck safety are reviewed and synthesized. Chapter 3 and Chapter 4 introduce the process for conducting crash risk analysis to identify risk factors. In Chapter 5, a survey of large truck drivers is presented and survey responses are analyzed. After that, cost benefit analysis of those identified countermeasures is explained in Chapter 6. Finally, conclusions and recommendations are provided in Chapter 7.

CHAPTER 2: CONDUCT LITERATURE REVIEW

To ensure successfully complete this project, a thoroughly literature review has been conducted, and the state-of-the-practice regarding safety problems associated with large trucks has been assessed. In this chapter, a large amount of literatures has been reviewed and the results have been summarized into three parts: 1) contributing factors related to large truck-involved crashes, 2) methodologies applied to large truck safety analysis and 3) safety countermeasures for preventing or mitigating large truck-involved crashes.

2.1 CONTRIBUTING FACTORS TO LARGE TRUCK- INVOLVED CRASHES

Usually, a large truck-involved crash cannot be attributed to one single cause and there may be many factors contributing to this crash. Identifying key causes is a necessary step in identifying the proper countermeasures for preventing such crashes.

According to the data from Federal Motor Carrier Safety Administration, the No. 1 factor in truck crashes is driver behavior. Other factors such as roadway conditions, vehicle related factors and environmental conditions might also contribute to large truck-involved crashes. This part summarized previous research findings include the following parts:

- Driver related contributing factors
- Roadway related contributing factors
- Vehicle related contributing factors
- Environmental related contributing factors
- Other contributing factors, such as carrier characteristics and rest area availability

2.1.1 Driver Related Contributing Factor

Driver related factors are one of the most important factors contributing to large truck-involved crashes. One study found that “Human Factors” was reported as the most common contributing factors in truck crashes when the truck was found to be at fault (Spainhour et al., 2005). Among all driver related factors, fatigue is viewed as the most important and was widely studies. Not only is fatigue present in almost 60% of crashes (AAA 1985), addressing fatigue can address a myriad of other issues such as working conditions, hours-of-service regulation and driving conditions.

Therefore, studies focused on driver fatigue will be introduced first, followed by the studies on other driver related factors.

2.1.1.1 Driver Fatigue

Driver fatigue is one of the leading causes contributing to large truck-involved crashes. In this study, driver fatigue is defined as, after prolonged periods of continuous driving, drivers experience mental and physical functional disorder that impairs their capabilities to be a safe and effective driver. According to Saccomanno (1995), there are three different types of fatigue that drivers of the industry susceptible to: 1) industrial fatigue, 2) cumulative fatigue, and 3) circadian fatigue. Industrial fatigue occurs when drivers are working constantly over an extended period of time without appropriate rest, the drivers' efficiency and productivity will decrease. Cumulative fatigue happens when, working too many days on any prolonged, repetitive task without an extended break. Circadian fatigue occurs by a deviation from the natural 24-hour rhythm of work that favors either daytime over nighttime schedules.

Fatigue increases the risk and severity of an accident if the driver doesn't pay attention to the signs of fatigue and stop driving. Table 2-1 summarized the key findings from literatures regarding driver fatigue. In addition, highlights from these literatures are listed below:

- Nighttime driving is associated with higher truck crash risk and the highest risk time period is between 4 AM and 6 AM,
- Fatigue is significantly affected by external factors such as shipper demands, travel speed, management and driver attitude, physical work involved, rates of pay and shift start times,
- Upon, hitting rumble strips, the alertness effect was short lived and signs of sleepiness returned in 5 minutes,
- Fatal fatigue-related crashes represented 71% of single-vehicle crashes, and roll-over and fixed object crashes were the common types of fatigue-related fatal crashes,
- When drivers drive longer than 9.5 hours without adequate rest (industrial fatigue), fatigue related crashes show a significant increase,

- Time-on-task can lead to increased mental deficiency, which is parallel to the after effects of sleep deprivation, and
- Drivers are more likely to experience drowsy driving when using sleeper berth.

Table 2-1: Summary of Studies for Fatigue Contributing to Large Truck Crashes

Research Topics	Key Finding
General	<ol style="list-style-type: none"> 1. The National Transportation Safety Board estimates that 31% of all truck driver fatalities and 58% of all single-truck crashes are fatigue-related (Schulz, 1998). 2. Analyzed over 600 long-haul truck drivers that were assigned fault in traffic incidents, found nearly 13 percent of the incidents occurred when the driver experienced moderate-to-high driver fatigue (Olson et al., 2005) 3. Drivers who drive more miles are more likely to violate Hour of Service (HOS) regulations, drive when drowsy, and be involved in crashes (McCartt, Wright, Rohrbaugh, & Hammer, 2000Williams & Monaco, 2001). 4. Long-haul combination unit trucks are 4.5 times more likely to be involved in a fatigue-related crash than a passenger vehicle, due to the increased exposure, vehicle operational life and frequency of night time driving (Perrin et al., 2007) 5. Nearly 66% of drivers reported episodes of drowsiness within the past month and nearly 5% on most, if not all days. Almost 50% admitted to fallen asleep at the wheel at least once ever, and 25% reported fallen asleep at the wheel at least once during the past year. (TranSafety, 1998) 6. Time-on-task can lead to increased cognitive impairment, this fatigue effect is more prominent after sleep deprivation (Geol et al., 2009)
Measure of Drowsiness	<ol style="list-style-type: none"> 1. 1/5 of the driving errors committed by drivers were linked with raised levels of PERCLOS, which is an eyelid droop measure of drowsiness (Hanowski et al., 2000)
Industrial Fatigue	<ol style="list-style-type: none"> 1. Longer driving distances attributed to the increase in fatigue-related large truck crashes, with a considerable surge in crash rates for driver that driver more than hours of driving without proper rest (Saccomanno et al., 1995) 2. Nearly 2/3 of the crashes that occurred in the second half of the trip, affirming that trip duration is a key factor (Harris and Mackie, 1972) 3. Rest breaks taken before the 6th or 7th hour of driving, appear to lower crash risk significantly for many times of day (Lin et al., 1994) 4. Trips of five or more hours were found to have more crashes than expected (Mackie and Miller, 1978) 5. Drivers that drive more than eight hours were two times more likely to have been involved in a crash than drivers who had driven less hours (Jones and Stein, 1990) 6. In the fourth hour of driving, the risk of having a crash was increased by approximately 65%, 80 % in the seventh hour and 150% in the eighth and ninth hours (Lin et al., 1993)
Cumulative Fatigue	<ol style="list-style-type: none"> 1. Patterns of driving that was exposed to a highest risk of a crashes were those that drove heavily in the previous three days, and constantly drove from 3 PM to 3 AM and from 10 PM to 10 AM. Patterns of driving that had a lower risk were drivers driving from 8 PM to 6 AM, but with limited driving in the previous three days (Lin et al., 1993) 2. Multi-day driving patterns have only a marginal effect on crash risk, but limiting driving to daytime driving before the trip of interest, resulted in the lowest crash risk (Jovanis et al., 1991) 3. Considering the amount of rest and recovery needed, drivers improved baseline performance and were able to resume driving duties within 24 and 36 hours of the end of a driving week, respectively (O'Neil et al., 1999) 4. Drivers that had sleep restricted to only 3 hour, their performance was not fully recovered even after three consecutive nights

Research Topics	Key Finding
	<p>with 8 hours of sleep (Balkin et al., 2000)</p> <ol style="list-style-type: none"> 5. Wylie et al. (1996) report that CMV driver's average 4.8 hours of sleep during their principal sleep periods, far less than is necessary as judged by formal clinical criteria. In addition, Williams and Monaco (2001) found an inverse relationship between the number of hours slept in the past 24 and the frequency of violating HOS regulations (i.e., driving when fatigued). 6. The scheduling requirements of CMV driving work often result in truck drivers getting inadequate and poor quality daily sleep. Such deficits, in turn, have been found to adversely affect driving performance (Balkin et al., 2000). 7. Chronic partial sleep restriction is more apt to occur than total sleep deprivation. This is vital because recovery from chronic partial sleep deficiency takes longer to recover from than sleep deprivation. Because of the working conditions of truck drivers, they are more likely to be exposed to chronic partial sleep deprivation (Raftery et al., 2011)
Circadian Fatigue	<ol style="list-style-type: none"> 1. Crashes where the driver was dozing off to sleep were seven times more likely to occur between 12AM and 8 AM, with the highest risk occurring between 4 AM and 6 AM (Mackie and Miller, 1978). 2. Daytime driving between 10 AM and noon, had a significantly lower crash risk compared a 40 percent increase in crash risk when driving during night or dawn. (Lin et al., 1994) 3. Seventy- one percent of fatal fatigue-related crashes were single-vehicle crashes, with fixed object crashes and roll-overs to be the most common types of fatigue-related crashes (Massie et al., 1997). 4. Driver fatigue was a factor for only 0.4% of truck crashes when the trip was 50 miles or less and 3.0% of truck crashes when the trip was greater than 50 miles (Massie et al., 1997). 5. An estimated that 58 percent of the large truck single-vehicle crashes that occur at night had circadian fatigue as a likely cause (NTSB, 1995) 6. Night shifts made drivers feel more tired than day shifts, but did not produce significantly lower performance, indicating that night shift drivers are able to adequately manage their fatigue (Williamson, 2004) 7. For the retail distribution segment of the truck industry (short haul), there are following different findings regarding the time of day for fatigue related crash risk. It is because the retail distribution drivers do not spend rest periods away from home and can get better rest during their off duty. <ol style="list-style-type: none"> a. One of the safest periods of the day for the retail distribution section of the trucking industry is from midnight to 5 AM (Drissel and Spiegel, 2003) b. Drowsiness for retail distribution was two times more likely to occur between 6:00 AM and 9:00 AM, with nearly 30 percent of all observed fatigue occurring within the first hour of the work shift (Barr et al., 2005)
Sleep Stimulants	<ol style="list-style-type: none"> 1. The trucking industry has a major concern with truck drivers using stimulants to fight the effects of fatigue because they may be at greater risk of a fatigue-related crash (Williamson, 2007) 2. Drivers who had the greatest problem managing fatigue were twice as likely to use stimulants (Williamson, 2007)
Influencing Variables on Driver Fatigue	<ol style="list-style-type: none"> 1. Internal variables that have the potential to influence fatigue are: genetic factors, gender, age, race, nutrition, body mass index, endurance (both mental and physical), circadian strength, chronotype, phase and desynchronize, personality, sleep requirement and debt, and health status (physical and psychological) (Milia et al., 2011) 2. External variables that have the potential to influence fatigue are: working arrangements, time and method of commuting,

Research Topics	Key Finding
	<p>physical and cognitive state at commencement of shift, the start time and duration of the shift, workload, motivation, time since last sleep, quality and duration of sleep, napping, recovery time between shifts, meal timing and content, work conditions, medication and drug use, job control, monotony (Milia et al., 2011)</p> <ol style="list-style-type: none"> 3. A multivariate logistic regression was conducted and identified six independent factors that were predictive of self-reported falling asleep at the wheel, which are; Greater daytime sleepiness, more hours of work and fewer hours off duty, older and more experienced drivers, shorter and poorer sleep on the road, symptoms of sleep disorder and greater tendency for nighttime drowsy driving (McCartt et al., 2000) 4. Fatigue is greatly affected by external factors including shipper demands, travel speed, management and driver attitude, physical work involved, rates of pay, shift start times, etc. (Dolyniuk, 1995)
Sleeper Berth effects on drowsy driving	<ol style="list-style-type: none"> 1. When drivers use sleeper berth (versus sleep in the bed), they are more likely to experience drowsy driving (FMCSA, 1999). 2. Research suggests that the drowsy driving risk from the use of sleeper berth is not due to the motion of the truck, but from the lack of consecutive sleep hours (Hertz, 1988)
Age impacts on Fatigue	<ol style="list-style-type: none"> 1. Researchers found that driver age was the strongest predictor of critical incident (Hanowski et al., 2000) 2. Age alone is not a reliable predictor of job performance (Trucking Research Institute and Inter Science America, 1998) 3. When investigating Hours-of-service violations in the U.S. nearly 50% of the drivers were in violation of work hour regulations, with drivers 30 and younger dominating the likelihood of engaging in such behavior in interstate carrier operations (Hertz, 1991) (Jones and Stein, 1990) 4. Age is not a good predictor of sensory-motor abilities. Traditionally, cognitive abilities decline with age, all driver are not susceptible to those deficiencies (Trucking Research Institute and Inter Science America, 1998) 5. Higher levels of fatigue were associated with younger and less experienced drivers (Barr et al., 2005). However, another research indicate that older, more experienced drivers showed a higher likelihood of falling asleep at the wheel (McCartt et al., 2000)
Vehicle configuration on driver fatigue	<ol style="list-style-type: none"> 1. Triple trailer combinations resulted in higher levels of workload and fatigue for the driver, with the A dolly configuration resulting in the highest workload and fatigue (FMCSA, 2000) 2. The ratio of double- to single-trailer fatal and non-fatal crash involvement rates would improve if doubles were equipped with standard A-frame dollies (Morris, 2003) 3. There was no substantial increase in fatal crash rate during overnight travel for tractor-trailer trucks on freeways, Interstates, and expressways (Hendrix, 2002)
Operating environment effects on driver fatigue	<ol style="list-style-type: none"> 1. Research has shown that starting the work week tired and longer loading and unloading time are significant factors that increase the measures of driver fatigue. 2. Hours of uninterrupted sleep, consistency of route and consistency of time, were each found to be significant statistical factors for at least one fatigue measure (Crum et al., 2001) 3. The lack of sleep situation is further aggravated by the lack of safe rest places for truck drivers (Federal Highway Administration, 1996a). Drivers may be forced to continue to drive when no rest options are readily available.

2.1.1.2 Other Driver Related Contributing Factors

Except for fatigue, there are other various driver related factors also contributing to large truck-involved crashes, especially when large truck drivers were at-fault. These factors include drivers' errors, such as misjudging a curve at a turn, drivers' health conditions, drivers' training, experience, and a variety of important issues as presented in Table 2-2.

Highlights from the literature regarding other driver related contributing factors are listed below:

- 1) When trucks were found to be at fault, the human factors and inattention was reported as the most common contributing factors in over 50% of crashes.
- 2) Truck drivers who did not meet or exceed the higher end of the reading text standard were nearly 1.58 more likely to have been involved in a safety incident than drivers who did meet the required standards.
- 3) Drivers with frequent job changes (i.e., three or more different carriers per year for 2 years or more) were two times more likely to be involved in a crash with fault being assigned to them than drivers with less frequent job changes.
- 4) Research shows that 73% of truck drivers were either overweight or obese. In addition, obese drivers offered a crash rate that is two times higher than non-obese drivers.

Table 2-2: Summary of Studies for Other Driver Factors Contributing to Large Truck Crashes

Research Topics	Key Finding
Speeding	<ol style="list-style-type: none"> 1. Roughly 22% of large truck fatal crashes involving more than one vehicle are speed-related. Approximately 7% of multi-vehicle large truck fatal crashes involve speeding on the part of the truck driver and approximately 15% involve speeding on the part of another driver. 2. The contributory most often cited in single-vehicle heavy truck fatal and injury crashes was “driving too fast for conditions” – 17% and 16%, respectively (Mayhew et al., 2004) 3. 10% of articulated and 3% of heavy rigid trucks were probably speeding at the time of the crash (Curnow, 2002). 4. Available data shows a high proportion of heavy vehicles exceed speed limits on both open and urban roads. It is estimated that if all heavy vehicles complied with speed limits, there would be a 29% reduction in crashes (Brooks 2002)
Single or Team Driver	<ol style="list-style-type: none"> 1. Single drivers are more likely (64.6%) to be distracted than team drivers (Hanowski et al., 2005) 2. Solo drivers exhibited significantly more drowsiness than the team drivers (FMCSA, 1999).
Impaired Physical abilities	<ol style="list-style-type: none"> 1. Drivers who are impaired due to a variety of physical and cognitive abilities, suffer from 2 to 5 times increase in the risk of causing a crash (Staplin et al., 2003) 2. Drivers with dementia are less likely to report driving problems, and their perception of their own driving ability is not reliable. Therefore, they are much less likely to self-limit their driving exposure than persons with, for example, declining vision, and reporting by physicians is more critical 3. During the early stages of dementia, the crash rate for AD patients is only slightly higher than that for the general driving population. But as the disease progresses, the AD-related crash rate more than doubles, and regular reassessments (every six months) are recommended. <p data-bbox="512 954 1262 987"><i><u>Drivers under the Federal Vision and Diabetes Waiver program</u></i></p> <ol style="list-style-type: none"> 1. Non-waivered drivers who did meet the current medical standards were determined to be 2.605 crashes per million vehicle-miles traveled (VMT). By comparison, crash rates for the vision and diabetes waiver groups were 1.706 and 2.309, respectively, suggesting that neither waiver group presents a threat to public safety (FHWA, 1999) 2. There was an observed an increased risk of crash for straight truck drivers with diabetes with complications and 46 to 55-year-old articulated and straight truck drivers with diabetes without complications. Drivers of single-unit trucks who are diabetic without complications and not using insulin had an increased crash risk of 1.68 to 1.76 when compared with healthy drivers of the same vehicle class (Laberge-Nadeau et al., 1998 and 2000)
Sleep Related disorders	<ol style="list-style-type: none"> 1. Researchers found that mild (17.6%), moderate (5.8%), and severe (4.7%) sleep apnea occurs in commercial drivers (Pack et al., 2002), (Young et al., 1993) 2. Truck drivers that identified with sleep-disordered breathing had a two times risk for crash rate per mile than drivers without sleep-disordered breathing (Stoohs et al., 1993, 1994 and 1995)

Research Topics	Key Finding
	3. Researcher found that commercial drivers diagnosed with sleep apnea had no greater likelihood of having crashes of any kind, than drivers without sleep apnea, but mileage exposure was not taken into consideration (Barr et al., 2004)
Obesity	<ol style="list-style-type: none"> 1. Researchers observed 73% of truck drivers are either overweight or obese. Additionally, obese drivers had a two times higher crash rate than non-obese drivers. (Stoohs, 1993, 1994, and 1995) (Korelitz, 1993) 2. Obesity amongst commercial drivers are approximately twice that of the general population (Roberts and York, 2000)
Alcohol and Drug Use	<ol style="list-style-type: none"> 1. In 1999, 0.2 % of CDL holders tested positive for alcohol use and 1.3 percent tested positive for controlled substances (FMCSA, 2001b) 2. Prescription drug use was an “associated factor” in 28.7 percent of all crashes sampled, and over-the-counter drugs were an associated factor 19.4 percent of the time (FMCSA, 2006b) 3. In 2002 only 2 percent of large truck drivers in fatal crashes had tested Blood Alcohol Content (BAC) levels above 0.08 percent, versus about 25 percent of drivers of passenger vehicles (NHTSA, 2003) 4. Both passenger car and single-unit truck driver condition to be among the top three explanatory variables for crash occurrence, however, the proportion of truck drivers reported to be in an unsafe condition was small (1.4% compared to 10% of car drivers) (Shao, 1987) 5. Large truck crashes involving alcohol are most severe in relation to injuries and fatalities (Golob et al., 1987) 6. In crashes where alcohol or drug use was identified as being the main cause of the crash, the probability of it being severe or fatal increased roughly 250% in rural areas and nearly 800% in urban areas (Khorashadi et al., 2005)
Driver Trip by time of week	1. When comparing interstate truck crashes and total interstate crashes; there was a lower percentage of fatal truck crashes than all fatal crashes on the weekend (Agent, Pigman, 2002)
Loss of Control	1. Three critical maneuvers were identified as the most common causing loss of control: negotiating a curve, avoidance maneuvers, and road edge recovery (Kharrazi & Thomson, 2008)
Age impacts on Fatigue	<ol style="list-style-type: none"> 1. Researchers found that driver age was the strongest predictor of critical incident (Hanowski et al., 2000) 2. Age alone is not a reliable predictor of job performance (Trucking Research Institute and Inter Science America, 1998) 3. When investigating Hours-of-service violations in the U.S. nearly 50% of the drivers were in violation of work hour regulations, with drivers 30 and younger dominating the likelihood of engaging in such behavior in interstate carrier operations (Hertz, 1991) (Jones and Stein, 1990) 4. Higher levels of fatigue were associated with younger and less experienced drivers (Barr et al., 2005). However, another research indicate that older, more experienced drivers showed a higher likelihood of falling asleep at the wheel (McCartt et al., 2000)
Driver Experience	1. Drivers with less than one year of experience had higher crash involvement rates than drivers with two or more years

Research Topics	Key Finding
	<p>of experience. On the contrary, Researcher found that the most experienced drivers driving more than ten years had the lowest crash risk. (Chira-Chavala, 1986), (Lin et al., 1993)</p> <ol style="list-style-type: none"> 2. Driver experience was found to be a stronger indicator of crash rate than age. Crash rates drop significantly when experience is greater than four years, and when drivers are under the age of 21 they have a crash rate approximately 5 times greater than an average driver (Chira-Chavala, 1985), (Steiff, 1990) 3. 85 % of carrier safety managers consider driving experience (minimum of 4 years) with other carriers to be an important hiring criterion (Corsi and Barnard (2003) (Knipling et al., 2003)
Driver background	<ol style="list-style-type: none"> 1. Researchers found that nearly 50% of heavy vehicle drivers involved in crashes already had at least one demerit in their personal files (Gou et al., 1993) 2. There is a positive correlation between essential skills proficiency and the likelihood of having a safety incident (MacLeod & Kline, 2004) 3. Drivers who did not meet or exceed the upper end of the reading text standard or the document use standard were 1.58 and 1.69 times respectively more likely to have been involved in a safety incident than drivers who met these standards (MacLeod & Kline, 2004)
Driver Race and Gender	<ol style="list-style-type: none"> 1. For white drivers, the probability of being involved in a crash is 29.5% lower than the crash probability of drivers of other races. No gender differences were detected (Lourens et al. 1999)
Drivers Age	<ol style="list-style-type: none"> 1. Drivers under age 30 encompass less than 15 percent of all large-truck drivers but they account for roughly 30 percent of the drivers of large-trucks involved crashes (Eicher et al., 1982) 2. Drivers under the age of 26 are nearly 6 times as likely to be involved in a crash compared to driver over the age of 26 (Lyles et al., 1991) 3. Fatal accident involvement was found to increase with decreasing driver age. Drivers under the age of 21 were 6 times more likely to be involved in fatal crashes than other drivers. This association was not due to other factors related to crash involvement (Campbell,1991) 4. Older commercial drivers (>50) experienced performance deficiencies on traditional ability measures like reaction time, range of motion, but drove a truck simulator better than younger truck drivers (Llaneras et al., 1995) 5. Truck drivers over 51 years of age were at increased risk for a fatality, should a crash occur (Bunn et al., 2005) 6. Truck drivers, aged 18 to 21, had moving violation rates two times more than those of the middle-aged drivers (30 to 49 years old) and were about 50% more likely to be charged with a violation in a crash (Blower, 1996) 7. Drivers younger than 30 or older than 45 showed higher crash rates than drivers between the ages of 30 to 45 years old (Chira-Chavala, 1985) 8. Age Consideration in Hiring Process: Researcher found that nearly 60 % of high-safety fleets, 66 % of large fleets and 69 % for hiring owner-operators considered age 25 and older to be an important factor when selecting driver

Research Topics	Key Finding
	(Corsi and Barnard, 2003).
Driver Job Change Frequency	<ol style="list-style-type: none"> 1. Driver that change their jobs frequently were two times as likely to be involved in a crash with fault being assigned to them. It is uncertain whether job changes increase a driver’s risk, or whether poor driving results in dismissal or other management actions resulting in job changes. (Staplin and Lococo, 2003) 2. Employee turnover is an issue that may lead to poor safety performance associated with inexperienced drivers. (Howarth, 2007)
Seat Belt	<ol style="list-style-type: none"> 1. Three hundred eleven of 588 (53 percent) fatally injured large truck drivers in 2002 were not wearing safety belts, and 134 (23 percent) of these drivers were ejected from the vehicle. Of the nearly 4,000 commercial vehicle occupants observed, the safety belt usage rate was 48 percent. This compares unfavorably with a current passenger vehicle occupant usage rate of 79 percent (FMCSA 2003b) 2. It is estimated that the number of fatalities and serious injuries during heavy truck crashes could be reduced by roughly 25% had occupants been wearing seat belts (Horii, 1987) 3. Researcher reported that numerous obese, “large-bellied” commercial truck drivers do not wear their safety belts (Bergoffen et al., 2005) 4. The use of seat belts with 3 anchoring points in trucks that are also fitted with airbags would effectively prevent 37% of fatalities, 36% of serious injuries, and 22% of slightly injured truck occupants (Simon & Botto, 2001) 5. The major reasons reported for not wearing a seat belt included stopping frequently, inconvenience, and not being safety conscious (Kim & Yamashita, 2007)

2.1.2 Roadway Related Contributing Factors

Roadway design's impact on large truck crashes is very important. Large truck involved crashes take place on rural highways, as well as more congested settings in urban areas. According to a previous study conducted by University of Kentucky (Jerry & Agent, 1999), the following specific roadway areas were identified as the high-risk locations for large truck crashes.

- Interchange ramps
- Steep grades
- Sharp curvature on two lane roads
- Intersections with sight distance restrictions and/or high speed

In addition, the geometric design and traffic control on the road can influence the result of a truck involved crash, i.e. it is a minor rear end crash or a fatal multivehicle crash. Road alignment not only impacts the occurrence of a crash but its severity. One study revealed that 98% of driver error-related fatal crashes occur on curves (Garber and Joshua 1989) which is an alarming figure that indicate that further investigation is needed on the relationship between roadway condition and the occurrence of large truck-involved crashes.

In efforts to gain a better understanding of roadway related factors that influence high injury and fatality rates related to large truck crashes, the results of previous studies on roadway related contributing factors were summered in Table 2-3. In this table, the key findings were summarized and categorized by the factors from a variety of literature reviewed by the research team.

Highlights from the literature regarding roadway related factors are listed below:

- In the U.S., rural roads handled only about 40% of all vehicle miles traveled, however more than 60% of all fatalities occurred on rural roads.
- Crashes that occurred on roads that have street lighting at night were projected to be less severe due to improved roadway visibility.
- Downward sloping roads were more often associated with loss of control than upward sloping roads.

- Fatal brake failure crashes were more likely to be held on horizontal curves, however brake failure crashes on a combination of horizontal curve and vertical grade were more serious than those occurring on vertical grade alone.
- Considering the effects of roadway geometrics, researchers found crashes to be more severe on two-lane rural highways than on four-lane rural highways.

Table 2-3: Summary of Studies for Roadway Factors Contributing to Large Truck Crashes

Research Topics	Key Findings
General	<ol style="list-style-type: none"> 1. Roadway environment, is the second most prevalent factor cited as a contribution to a crash (GAO, 2003) 2. Roadway related factors was present for 14% of trucks and 16% of the other vehicles in two-vehicle crashes (Craft, 2005) 3. When assigning fault, driver-related factors can also involve roadway characteristics (Garber and Joshua, 1989) 4. Geometric characteristics such as the number of lanes, lane widths less than 11 feet, shoulder widths, and grades greater than 4 percent were also found to have relationships with the crash rate (Garber and Ehrhart, 2000)
Curves	<ol style="list-style-type: none"> 1. Truck crash rates on two-lane rural roadways depended on shoulder width and horizontal curvature (>6 degrees) (Mohamedshah et al., 1993) 2. Single-vehicle truck crashes are more likely than multi-vehicle truck crashes to occur on a curve or grade. In addition, Run-off-road (ROR) crashes were indicated as an event in 40% of truck crashes (Daniel and Chien, 2003) 3. There is an influx of crashes in large trucks and passenger vehicles due to horizontal curvature and passenger vehicle volumes (Schneider, 2009) 4. Fatal brake failure crashes were more likely to happen on horizontal curves, however brake failure crashes on a combination of horizontal curve and vertical grade were more serious than those occurring on vertical grade alone (Trevorrow & Eady, 2010) 5. Greatest rollover risk was posed by curves producing readings of five degrees or more. Furthermore, the recent increases in speed limits, if associated with higher actual speeds, can limit a driver's ability to slow down to reduce the force of impact. Therefore, more rollovers and severe injuries are expected on roadways that allow higher speeds, all else being equal (Cate & Richards, 2001) 6. Crashes that occurred on curves were significantly more likely to involve rollovers. Approximately 43% (503 of 1176) of curve-related crashes were rollovers, while 25% (999 of 3973) of straight roadway crashes were rollovers.
Road Grades	<ol style="list-style-type: none"> 1. A Downward sloping road was more often associated with loss of control than a road sloping up (Kharrazi & Thomson, 2008)

Research Topics	Key Findings
Different Types of Roadways	<p><u>Rural or Urban Roads</u></p> <ol style="list-style-type: none"> 1. Although, rural roads only handle only about 40% of all vehicle miles traveled, more than 60% of all fatalities occurred on rural roads (GAO, 2001) 2. 66% of the 5,567 fatalities in truck-involved crashes occurred in rural areas (Matteson and Blower, 2003) 3. Crashes are more severe on two-lane rural highways than on four-lane rural highways (Hedlund, 1977) 4. Almost half, 48%, of fatalities involving combination trucks occurred on non-divided 2-lane traffic ways, that is, conventional 2-lane roads with one lane in each direction. 5. On undivided highways, the crash risk is higher than it on rural interstates (Chirachivala and Kostyniuk, 1984) 6. There are 13 exclusive variables that significantly influenced driver-injury severity in rural but not urban areas, and 17 unique variables that significantly influenced driver-injury severity in urban but not rural areas (Khorashadi et al., 2005). <p><u>Toll Roads</u></p> <ol style="list-style-type: none"> 1. Large trucks were significantly under-involved in single-vehicle crashes on all state toll roads, with a 27-58% lower likelihood of being in single vehicle crashes than passenger vehicles (Solomon, 1999) (Braver et al., 2002) <p><u>Highways</u></p> <ol style="list-style-type: none"> 1. Seiff (1989) reported that limited-access highways are 4 times safer for trucks than other highways. 2. Lyles et al. (1991) found that crash rates for non-limited-access highways and local streets were typically 2 to 3 times higher and 7 to 10 times higher, respectively, than those for limited-access highways. 3. For undivided highways, researchers identified lane width, slope change rate, shoulder width, and horizontal curvature are all significance variables contribute to crashes, based on the results from the regression model (Garber and Joshua, 1991)
Roadway Posted Speed	<ol style="list-style-type: none"> 1. Garber et al. (2003) concluded that neither differential or uniform speed limits for trucks and other vehicles on rural highways is consistently associated with reduced truck speeds or superior crash reduction.
Roadway Lighting	<ol style="list-style-type: none"> 1. The researcher considered the effects of roadway lighting, among other factor, on crash severity. Crashes that occurred at night but on a roadway lit with street lighting were predicted to be less severe. A driver who has increased night vision due to lighting may have a heightened ability to avoid a crash or minimize its severity (Burke et al., 2002)
Roadway Pavement Conditions	<ol style="list-style-type: none"> 1. Concrete fatigue damage due to different axle configurations increases with an increasing number of axles within an axle group for a given stress ratio (Chatti et al. 2009) 2. Multiple axle groups were found to have less damage in fatigue per load carried for both pavement types, however they were found to cause more damage in rutting of flexible pavements and roughness for rigid pavements (Chatti et al.2009)

2.1.3 Vehicle Related Contributing Factors

Although, the human element may lead the way when assigning fault, the vehicle also plays an important role in the occurrence of a traffic crash. When considering the effects of the vehicles characteristics on large truck safety, the vehicle's configuration, cargo body type, vehicle weight, and other factors are the points of concern.

For large truck configuration, Federal Highway Administration (FHWA) uses a 13-Category Scheme to classify vehicles:

- Class 1: Motorcycles
- Class 2: Passenger Cars
- Class 3: Other Two-Axle, Four-Tire Single Unit Vehicles
- Class 4: Buses
- Class 5: Two-Axle, Six-Tire, Single-Unit Trucks
- Class 6: Three-Axle Single-Unit Trucks
- Class 7: Four or More Axle Single-Unit Trucks
- Class 8: Four or Fewer Axle Single-Trailer Trucks
- Class 9: Five-Axle Single-Trailer Trucks
- Class 10: Six or More Axle Single-Trailer Trucks
- Class 11: Five or fewer Axle Multi-Trailer Trucks
- Class 12: Six-Axle Multi-Trailer Trucks
- Class 13: Seven or More Axle Multi-trailer Trucks

Table 2-4 summarizes the key findings that are categorized by factors from a variety of literatures the team reviewed. Highlights of these findings regarding vehicle related factors are listed below:

- Upon all single trucks involved in crashes 77% had defective equipment that warranted citation, and nearly two fifths of trucks involved in crashes had defects warranting taking the vehicle out of service as compared,
- Researchers found that carriers transporting household goods experience a decreased level of crash severity,
- Researcher found that tankers, flatbeds and straight trucks had a higher crash rate

when the truck was loaded rather than empty

- The fatality rate was reduced by nearly 37% through prevention of front under-ride,
- It was found that 40% of trucks that were struck by other vehicles had one or more lighting violations, as opposed to only 13% of the trucks that struck other vehicles. These lighting violations include the malfunction of headlights, tail lights, brake lights, signal lights, and marker lights,
- With every increase in inspection violation, the proportion of trucks involved in crashes increases by about 0.04%.

Table 2-4: Summary of Studies for Vehicle Factors Contributing to Large Truck Crashes

Category	Research Topics	Key Findings
Vehicle Configuration	General findings	<ol style="list-style-type: none"> 1. A variety of historical studies that have attempted to link vehicle configuration to crash frequency were either inconclusive or deemed invalid because of methodological flaws, data insufficiencies, or obscuring effects of the operating environment (Carson, 2007) 2. Scopatz and DeLucia (2000) noted a lack of reliable data on the exact configuration of vehicles involved in crashes, as well as a lack of specific measures of exposure. Without quality data on configuration and good measures of exposure, questions regarding the comparative safety of various vehicle configurations cannot be answered empirically.
	Multiple Trailer Configuration	<ol style="list-style-type: none"> 1. Overall, researcher found no consistent difference between crash involvement rates for singles and doubles. Although, it is noted that a lack of control of potential confounding factors, such as driver age and work operation attributes, limits these conclusions (Lyles et al. 1991) (Braver et al., 1997) 2. Researchers found that doubles experienced lower crash rates than singles in 1983 and 1985 but experienced higher crash rates in 1984, which was a year of greatly expanding doubles operation (Jovanis et al., 1990) 3. Researcher reported a 6% and 12% higher overall crash rate for doubles than singles, respectively (Glennon, 1981), (Graf and Archuleta, 1985) 4. Researchers reported a 2% lower overall crash rate for doubles than singles, and double trailer combinations to be underrepresented in crashes, while bobtail tractors are overrepresented (Chirachavala and O'Day, 1981), (Seiff, 1989)
	Other Vehicle Configuration Characteristics	<ol style="list-style-type: none"> 1. Researcher observed higher crash rates for 2-axle straight trucks, singles with 3-axle tractors, single vans and tankers engaged in local service, single or double flatbeds engaged in over-the-road service, doubles with 2-axle tractors, and doubles for the majority of vans, tankers and flatbeds configurations. (Chirachavala and Cleveland, 1986) 2. The probability of drivers in tractor trailers, there was a 26% injuries of the crash resulting in being severe or fatal compared to crashes involving single-unit trucks (Khorashadi et al., 2005) 3. Researcher found that crashes involving cab-over-engine tractors were significantly more likely to result in a fatality or major injury (Campbell and Carsten, 1981) (Philipson et al., 1978) 4. The fatality rate was reduced by nearly thirty-seven percent through prevention of front under-ride. (Krishnaswami et al, 2002)

Category	Research Topics	Key Findings
Truck Lighting and Visibility		<ol style="list-style-type: none"> 1. It was found that 40% of trucks that were struck by other vehicles had one or more lighting violations, as opposed to only 13% of the trucks that struck other vehicles. These lighting violations included headlights, tail lights, brake lights, signal lights, and marker lights. (FMCSA, 2002). 2. The use of retro-reflective tape on trailers, as mandated by FMVSS 108, was beneficial in both daylight and dark conditions. Under all conditions, the tape reduced side and rear impacts by 29%. In dark-not-lighted conditions, the tape reduced impacts by 41% (Morgan, 2001) 3. Higher mounted headlights increased the distance of detection of retroreflective pavement marking for the large truck drivers (Rumar et al., 1999)
Mechanical Conditions	Brake Related Defects	<ol style="list-style-type: none"> 1. Brake-related defects were noted as the most common, reoccurring in 56% of crashes, while steering-related defects appeared in 21% of the crashes (Jones and Stein, 1989) 2. It is estimated that 13% of crashes involving heavy vehicles result from non-compliant mechanical components on those vehicles and that defects in the braking system is the most frequent cause of those crashes (Gou et al., 1993) 3. It was found that brake defects were quite common and were found in 56% of the tractor-trailers involved in crashes (Jones and Stein, 1989)
	Defective/Non-compliant Component	<ol style="list-style-type: none"> 1. 77% of single trucks involved in crashes had defective equipment warranting citation as compared to 66% of those randomly sampled and that 41% involved in crashes had defects warranting taking the vehicle out of service as compared to 31% of those not in crashes (Jones and Stein, 1989) 2. Researchers estimated that heavy vehicles with major non-compliant components have a propensity to be involved in a crash five times higher than that of compliant vehicles (Gou et al., 1993)
	Truck Inspection Violations	<ol style="list-style-type: none"> 1. About 2% of all inspected, zero-violation vehicles were subsequently involved in crashes. With every increase in violation, the proportion of vehicles involved in crashes increases by about 0.04%. A smaller percentage of zero-violation vehicles that undergo Level I inspections are subsequently involved in crashes (compared with zero-violation vehicles that undergo Level II and Level V inspections), but, with every increase in violation, the proportion of vehicles involved in crashes increases at a higher rate for vehicles that undergo Level I inspections (Thakuriah et al., 2001)
Cargo Characteristics	Improperly Secured Cargo	<ol style="list-style-type: none"> 1. Researcher estimated that improperly secured or unbalanced loads was a factor in 2% of large truck crashes (Gou et al., 1993) 2. A study conducted by Safety Management Service Company concluded, there are some cargo securement related factors that contribute to truck rollovers, which are: unusually top-heavy load, cargo distribution, and load shift. (2003)

Category	Research Topics	Key Findings
	Type of Cargo	1. Researchers found that carriers transporting household goods experience a decreased level of crash severity. It is because household goods are typically moved in enclosed containers, are relatively light in cargo weight, and may be moved for shorter than average distances (Burke et al., 2002)
	Cargo loaded or not	1. Researcher found that tankers, flatbeds (singles and doubles) and straight trucks had a higher crash rate when loaded rather than empty (Chirachavala and Cleveland, 1986)

2.1.4 Environmental Related Contributing Conditions

Generally, environmental factors, such as adverse weather, affect the performance of both large trucks and passenger vehicles. Basically, all studies reached to one similar conclusion that most of the large truck-involved crashes occurred during normal conditions, which is explainable because adverse weather conditions are quite less compared with normal condition. Of all adverse conditions, “Rain” and “Snow” are the top conditions when large trucks are more easily to get involved into crashes. In Table 2-5, the key findings about the impacts of environmental factors on the large truck crashes are summarized based on a variety of literatures that were reviewed by the research team.

Highlights from the literature regarding environmental conditions are listed below:

- Nearly 70% of truck crashes occur on days where the weather is clear, and nearly 90% of truck crashes occur on dry roads.
- With no adverse weather being reported over 85% of the time, rain was the next most common adverse weather condition reported.
- Passenger vehicle are more susceptible to environmental conditions than large trucks

Table 2- 5: Studies of Environmental Factors Contributing to Large Truck Crashes

Research Topics	Key Findings
General	<ol style="list-style-type: none"> 1. It was found that 67.8% of truck crashes occur in clear weather, and 87.3% of truck crashes occur on dry roads (Spainhour et al., 2005). 2. Adverse weather conditions were reported in 14% of fatal crashes and 12 % of the non-fatal crashes involving large trucks in 2005. (FMCSA 2007). 3. Large truck crashes are evenly distributed throughout all months of the year, which indicate that seasonal effects did not significantly affect large truck crashes (Garber and Joshua ,1989) 4. Weather station data have been found to be used as a predicted method in determining the likelihood of an overturning crash (Young & Liesman, 2007)
Adverse Weather	<ol style="list-style-type: none"> 1. Nearly 41% of single vehicle large truck crashes occurred with poor roads and windy conditions in Manitoba, Canada (Kosior and Summerfield, 2001) 2. Overall crash occurrence increases with hours of snowfall. It was also observed that automobile crashes to be much more sensitive to environmental conditions than truck crashes (Jovanis and Chang, 1986) 3. During a storm period, crash rate was of 5.86 crashes per million vehicle kilometers on rural Interstate highways. During non-storm periods, the crash rate was 0.41 crashes per million vehicle kilometers (Khattak et al., 2001) 4. The crash rate increased by 13 times during snowy weather (Khattak et al., 2001) 5. More than 60 % of all weather-related fatalities occur in rainy conditions (Rossetti

Research Topics	Key Findings
	<p>and Johnsen, 2011).</p> <p>6. Winds greater than 25 mi/h can inhibit the maneuverability and stability of trucks, particularly in exposed areas, such as interstate highways (Rossetti and Johnsen, 2011).</p> <p>7. From 1995 to 2005, of all weather-related fatal CMV crashes, about 12% occurred in fog conditions, including combinations of “rain and fog” and “sleet and fog” (Rossetti and Johnsen, 2011)</p>

2.1.5 Other Contributing Factors to Large Truck-Involved Crashes

Except for the four categories of factors discussed before, there are more factors causing or contributing to large truck crash, including carrier characteristics and rest area availability.

2.1.5.1 Carrier Characteristics

In recent years, the trucking industry has incurred many challenges that need immediate attention, such as location of carrier’s base state and driver’s compensation. Table 2-6 below summarized carrier characteristics related factors that contribute to large truck crashes. Highlights from the literature regarding are listed below:

- Firms that actively have fleets between 45 and 1,000 trucks have a 20% higher chance of a crash occurring than firms operating over 1,000 trucks.
- Trucking firms with higher gross revenues are typically inclined to have better driver safety performance, On the other hand, firms with higher average hauls (in miles) tended to have poorer driver safety performance due to exposure.
- Drivers that are paid in the amount of work they did reported more fatigue than drivers paid at an hourly rate
- Drivers paid on a payment-by-results or contingency payment basis were 2-3 times more likely to use stimulant to address fatigue, due to the environment of work.

Table 2- 6: Studies for Carrier Characteristics related Factors Contributing to Large Truck Crashes

Research Topics	Key Findings
Carrier Fleet Size	<ol style="list-style-type: none"> 1. Fleets with fewer than 50 trucks were more than twice as likely to have a fatal crash involvement as fleets with more than 50 trucks (Campbell and Carsten, 1981) 2. Firms operating between 45 and 1,000 trucks have a 20% higher crash rate than firms operating over 1,000 trucks. (BMCS 1983)
Intrastate Carriers	<ol style="list-style-type: none"> 1. Researchers found that Interstate Commerce Commission (ICC) authorized carriers fatal and injury crash involvement rates are greater than non-authorized carriers (Campbell and Carsten, 1981)
Carrier Financial Performance	<ol style="list-style-type: none"> 1. Carrier profitability is related to the crash rate for all carriers except the smallest (Bruning, 1989) 2. Firms with higher gross revenues are inclined to have better driver safety performance, based on lower driver inspection indicator and driver SEA scores. Conversely, firms with higher average hauls (in miles) tended to have poorer driver safety performance because of exposure (Corsi and Keane, 2002).
Drivers' Pay	<ol style="list-style-type: none"> 1. Driver who have higher wages tend to have better driver safety performances (Corsi and Keane, 2002) 2. Higher pay rates and pay increases are a result of lower expected crash counts and higher probability of no crashes (Rodriguez et al., 2003). 3. human capital such as pay, job tenure, and percentage of miles driven during winter months, have a better indicate of crash frequency than demographic factors (Rodriguez et al., 2003) 4. A driver's decisions to stay with a company was largely based on the compensation they received. Increased pay was also associated with a reduction in crashes (Howarth, 2007) 5. Drivers that are paid in the amount of work they did reported more fatigue than drivers paid at an hourly rate (Williamson et al., 2001) 6. Drivers paid on a payment-by-results or contingency payment basis were 2-3 times more likely to use stimulants (Williamson, 2007)

2.1.5.2 Rest Area Availability

A major trouble for truck drivers, especially over-the-road drivers, is finding a proper place to stop and take a rest. Rest area availability will affect the appearance of driver fatigue, and further causing safety problems. Some studies have been conducted to investigate the impacts of availability of rest area on truck safety.

A survey conducted by A NCHRP sponsored project, found that more than 90% of commercial drivers felt there was a shortage of parking facilities, especially for long-term or overnight parking. Drivers also expressed a preference for private facilities (truck

stops) rather than public rest areas, citing both security concerns and the availability of amenities such as food and shower facilities. (NCTPA Report 500, 2004)

Smith et al. (2005) concluded that for drivers trying to maximize productivity and maintain the hours of service regulations, they have problems with the lack of legal parking spaces and facilities. These drivers often are forced to stop on the side of the road creating potential safety hazards for themselves and other road users.

A research conducted by Taylor and Sung (1999) discovered that the probability of a nighttime single-vehicle crash occurring on a rural freeway segment increases when the distance to the last rest area exceeded 30 miles.

2.2 METHODOLOGIES

In the literature, historic large truck crash data as well as police reports of large truck-involved crashes were reviewed and analyzed to identify contributing factors related to the crash, and analyze the relationship between the identified factors and crash occurrence or severity. The safety analysis is very important and depending on the completeness, accuracy, and timeliness of available data. There are three common approaches to conduct safety data analysis:

1. Clinical Method
2. Crash Data Based Method
 - a. Descriptive Method
 - b. Odds Ratio
 - c. Statistical Modeling
3. Simulator or Simulation Based Analysis

The first approach is called clinical method, in which experts determine the causes of particular crashes by examining each crash. The second one is referred to as the crash data based method, which relies on data analysis to identify various crash factors and relative countermeasures. The third approach is referred to as simulator and simulation based method, which relies on driving simulator and computer programs to monitor driver behavior and imitating the operation of real world traffic condition.

This section introduced each method, as well as some studies applied such method.

2.2.1 Clinical Method

In the clinical method, typically, multidisciplinary teams of experts study individual crashes in great detail, drawing on team members' expertise in crash reconstruction, vehicle dynamics, psychology, and other relevant disciplines. For each crash, the experts determine primary and contributing causes according to some hierarchy of causation. The resulting data will then be analyzed by statistical means to examine the association between particular causal factors and crash types, and so on. But a determination of cause and relative contribution of various factors is made for each crash by the clinical judgment of the experts.

The merit of the expert judgement method lies in the fact that it does not require data, elaborate statistical tools or expertise. The forecast can be made easily and speedily. This is a practical forecasting method when time series data over several years are not available. The disadvantage, however, is that it relies on judgement, hunch and intuition.

The Large Truck Crash Causation Study (LTCCS, 2006) conducted by the National Highway Traffic Safety Administration (NHTSA) examined the 2001-2003 large truck crash data at 24 locations around the country. Crash data were reviewed by national truck crash experts. The coding of the events surrounding the crash begins with the "critical event," "critical reason" for the critical event, and "associated factors" present.

In the Indiana Tri-level study of the traffic crashes (Treat, et.al., 1979), information about the crashes were gathered and then clinical judgments were made by a panel of experts, assigning the cause or causes of each crash. The major human direct causes include improper lookout, excessive speed, inattention, improper evasive action, and internal distraction. Leading environmental accident causes include view obstructions and slick roads. The major vehicular causes of accidents include brake failure, inadequate tread depth, side-to-side brake imbalance, under-inflation, and vehicle related vision obstructions.

2.2.2 Crash Data Based Method

2.2.2.1 Descriptive Method

Descriptive method is used to describe the main features of a collection of crash data.

Distribution figures are usually used to show the characteristics of crashes such as time of day, weather condition, manner of collision, accident location, road surface condition, etc.

A detailed analysis (Blower, 2007) was conducted with Michigan crash data from 2001 to 2005. Using descriptive method, it was evident that angle, rear-end, and head-on crashes appeared to be the most predominant crash patterns among commercial motor vehicles.

Two-vehicle crashes were analyzed in the 1995–1998 Fatality Analysis Reporting System (FARS) database (Kostyniuk, 2002) to compare car-car crashes with car-truck crashes. The research identified driving maneuvers or actions of cars and large trucks that have a higher chance of resulting in fatal car-truck collisions than fatal collisions with a similar vehicle.

To compare characteristics of fatal rural and urban crashes, data from the FARS for the period 1994–2003 was studied (Burgess, 2005). The study found that there are approximately 42% more fatal crashes in rural areas compared to urban areas.

2.2.2.2 Odds Ratio

The odds ratio reflects the impact of a contributing factor on two different crash events. It is defined as:

$$\text{Odds Ratio (OR)} = \text{oddsA}/\text{oddsB}$$

Where oddsA and oddsB are the probability of event A and event B occur under a given contributing factor.

- A contributing factor is considered to have more impact on event A, if $OR > 1$;
- A contributing factor is considered to have more impact on event B, if $OR < 1$;
- A contributing factor is considered to have equal impact on event A and B, if $OR = 1$.

Vap and Sun (2007) analyzed truck and passenger car interactions for the state of Missouri on its urban and rural freeways. In their study, odds ratios of trucks-at-fault

crash rates versus passenger vehicles-at-fault crash rates under different conditions were estimated. Results showed that on urban freeways, the percentage of trucks-at-fault ratio was considerably high.

2.2.2.3 Statistical Modeling of Crash Frequency and Severity

For statistical model method, contributing factors to crash frequency and severity can be identified by numerous statistical models. In the following section, different models for crash frequency and crash severity analysis were introduced individually.

(1) Crash Frequency Models

Crash frequency means the number of crashes on roadway segments or at intersections over a period of time. Various models have been developed in previous studies. Because the accident counts are discrete and nonnegative integer, count-data models such as the Poisson model have been applied to model crash counts.

Poisson regression and negative binomial model

In statistics, count data and contingency tables can be modeled by Poisson regression. A Poisson distribution is assumed to the response variable Y in Poisson regression and the logarithm of the expected value is modeled by a linear combination of unknown parameters. Negative binomial regression is a type of generalized linear model in which the dependent variable is the number of occurrence of an event.

Daniel et al. (2002) built an accident prediction model for analyzing factors affecting truck crashes on roadways with intersections. LIMPID software was used to obtain the analysis results of Poisson regression and negative binomial models.

Daniel et al. (2004), investigated an urban arterial with heavy truck volumes and a large number of signalized intersections by using Poisson regression and negative binomial models for truck accident frequency prediction.

Miaou and Lum (2004), illustrated the effects of highway geometric design on truck accident involvement rates using the Poisson regression model. Base on the modeling result, the reduction in truck-involved crashes due to improved geometric design was estimated.

Logistic regression model

Logistic regression model is to model the relationship between the dependent variable and different independent variables based on cumulative logistic distribution assumption.

A study was conducted (Murray et al., 2006) in collaboration with the American Transportation Research Institute focusing on driver behavior and their relationship to future truck involved crashes. Driver related data was tested using a logistic regression model.

An analysis of the effect of the geometric incompatibility of light truck vehicles (LTV) on driver's visibility of other passenger cars involved in rear-end crashes was presented (Aty and Abdelwahab, 2003). Nested logit models were calibrated to estimate the probabilities of the four crash configurations. It was concluded that the largest contributing factor to a rear-end collision is the driver's visibility and inattention in following a vehicle. Also, the lead vehicle stopped suddenly would increase possibilities of a car-truck rear-end crash.

Bayes approach

Bayesian analysis is a method of statistical inference that allows one to combine prior information about a population parameter with evidence from information contained in a sample to guide the statistical inference process.

Garber et al. (2006), compared the safety effects of a uniform speed limit for all vehicles to a differential speed limit for cars and heavy trucks. A modified empirical Bayes framework was used to evaluate crash frequency variations with changes in speed limit. The results of modified Bayes approach showed that differential or uniform speed limit policies for rural interstate have no consistent safety impacts. In most cases, the predicted number of after-period crashes was less than the actual number of crashes.

(2) Crash Severity Models

Crash severity models are commonly used for classifying crash data according to severity or collision types. In previous studies, a series of crash severity models were developed to predict the number of accidents at different severity levels.

Ordered probit model

In statistics, ordered probit model is a generalization of the popular probit model when there are more than two outcomes of an ordinal dependent variable. Similarly, the popular logit model also has a counterpart called ordered logit model.

Khattak and Targa (2004), investigated the levels of injury severity and the number of total injuries in truck-involved work zone crashes. Ordered probit models were developed to estimate the number of severe injuries in the crash. It was found that the most predominant case for truck crashes was in the area that the road was completely closed with a detour in the opposite direction.

Duncan et al. (2004), investigated injury severity in truck-passenger car rear-end collisions. This study used the ordered probit model to identify particular contributing factors on crash injury severity levels. The independent variables used in the developed ordered probit model include speed limit, light conditions, weather conditions, etc. The conclusion was that environmental and roadway conditions were the major contributing factors to the injury severity of these types of crashes.

Multinomial logistic regression

Multinomial logistic regression is a classification method that generalizes logistic regression to multiclass problems, which have more than two possible outcomes. The model predicts the probabilities of the outcomes, given a set of independent variables.

Yan et al. (2009) conducted a study on rear-end collisions in trucks using two national crash databases: The Fatality Analysis Reporting System (FARS) and the General Estimates System (GES). Multinomial logistic regression results showed that factors such as driver age, alcohol use, speed, day of week, interstate, weather condition, divided/undivided highway, and lighting condition have a significant correlation to truck-involved rear-end crashes.

Another study was conducted by Yan et al. (2009) used data from FARS during the years 2000-2004. In this study, only two-vehicle angular crashes were investigated by using multi-logistic regression modeling. Based on the modeling result, the severity of truck-involved angle crashes can be reduced by improving either the conspicuity of truck trailers or lighting design of the highway.

2.2.3 Simulator or Simulation Based Analysis

Driving simulators are widely used for research purposes in the area of human factors, to monitor driver behavior, performance, and attention to design and evaluate new vehicles or new advanced driver assistance systems. Traffic simulation is the imitation of the operation of a real-world transportation system over time. Traffic simulation approach has been widely used for transportation system performs analysis.

Brown et al. (2009) conducted a research to assess the effectiveness of tractor electronic stability control (ESC) systems on heavy trucks in terms of reducing the incidences of rollovers and jackknives by using the National Advanced Driving Simulator (NADS) at the University of Iowa. The specific types of ESC simulated in this study were Roll Stability Control (RSC) and Yaw Stability Control (YSC) in the following combinations: no ESC, RSC, and RSC +YSC. The results of driving simulator experiment showed that RSC can reduce rollovers in geometry-based situations such as tight curves and exit ramps. Additionally, drivers with the RSC+YSC system were six times more likely to avoid a jackknife than were drivers without a system when encountering similar conditions at event onset.

An evaluation of truck lane restrictions was conducted using the VISSIM microscopic traffic simulation software package as an analysis tool (Cate et al., 2004). The results showed that by reducing the maximum speed differential and the minimum distance between vehicles, the aggressiveness of lane changes would increase. Also, less lane changes will reduce the opportunity for collision by limiting the interaction between the vehicles.

2.3 COUNTERMEASURES FOR PREVENTING LARGE TRUCK CRASH

To prevent or mitigate large truck-involved crashes, various countermeasures have been developed and studied by researchers. This part described the countermeasures targeting to reduce general large truck-involved crashes, specific type of lager truck-involved crash, as well as some countermeasures for all crashes but especially important for large truck crash prevention. From previous studies, these countermeasures include traditional and emerging countermeasures, engineering based countermeasures, types related to road user education, traffic law enforcement, and Intelligent Transportation Systems (ITS).

In this section, following five types of existing countermeasures will be summarized and discussed in order:

- Engineering; i.e. speed limit, lane restriction, pavement markings, etc.
- Vehicle; i.e. strengthen vehicle maintenance, in-vehicle new technologies, etc.
- Roadway user education; i.e. safety awareness, defensive driving, etc.
- ITS related countermeasures; i.e. warning systems for long downgrades, Dynamic Curve Warning Systems, and electronic screening near weigh station, etc.
- Traffic law enforcement

Please note, one safety countermeasure normally cannot address truck safety issue. To achieve the best result, multiple countermeasures should be applied simultaneously. For example, to implement an engineering countermeasure, training to truck drivers, as well as increase law enforcement are both needed. Therefore, in this part, we will introduce not only some isolated countermeasures, but also integrated strategies, which combines more than one treatment together to reduce large truck-involved crashes. At the end of this section, systematic strategies to reduce large truck-involved crashes will be presented.

2.3.1 Engineering Countermeasures

Besides common safety treatments address all crash, there are some engineering countermeasures focus on large truck-involved crash prevention and mitigation. Trucks need to be given important consideration during roadway geometric design. Revision of existing design guides needs to take into account current dimensions of trucks and vertical curvature considerations.

Harwood et al. (2003) concluded that traffic control devices and traffic regulations play a significant role in the safe movement of heavy vehicles. In particular, the research mentioned that safety benefits are capable through the use of differential speed limits, lane use restrictions, exclusive lanes, and modified signal timing.

2.3.1.1 Different Speed Limits for Trucks and Passenger Vehicles

The Surface Transportation and Uniform Relocation Assistance Act (STURAA), enacted on April 2, 1987, permitted individual States to raise speed limits from the previously

mandated national speed limit of 55 MPH to 65 MPH on rural interstate highways. After this date, some States uniformly raised their speed limits for passenger cars and trucks. Other States raised the speed limit for passenger cars only while leaving the truck limit at 55 MPH, creating a Differential Speed Limit (DSL) - different speed limits for cars and heavy trucks traveling on the same roadway. On November 28, 1995, the national maximum speed limit was repealed, giving States further flexibility in setting their limits. By 2002 several States had experimented with both DSLs and USLs.

Several studies have been conducted to investigate the safety impacts of differential speed limits for cars and trucks. A study conducted by Harwood et al. (2003) found that differentially reducing large truck speed limits by 5 MPH is likely to reduce their prevailing speeds by 1 to 3 MPH but that the safety effects of this are mixed or questionable. However, the relationship between DSLs and crash is remain uncertain.

2.3.1.2 Lane Restriction

Exclusive truck lanes are one countermeasure to mitigate effects of increasing truck traffic. Introduction of barrier-separated lanes, express lanes, and managed lanes such as dual-dual lanes and toll roadways are effective strategies to offset the increase of conflict associated with an increase in the number of lanes. (Sundanda Dissanayake & Niranga Amarasingha, 2012).

Prohibiting trucks from using left lane (US) with a speed limit of 55 mph in conjunction with a 60-mph limit for passenger vehicles on a four-lane rural freeway has road safety benefits (Korkut, Ishak, & Wolshon, 2010). While most evaluations of safety strategies that restrict trucks to only the right lane (US) show no positive or negative safety effects for such restrictions (Alvarez, 2007).

Where steep upgrades reduce truck speed by 16km/h, truck-climbing lanes should be considered (Alvarez, 2007)

Although some research showed lane restriction has safety benefits, other research reached different conclusion. Based on his research, Lindsey (2009) indicated that lane access restrictions were observed to have limited effectiveness.

2.3.1.3 Traffic Signs

Traffic signs and signals are also very important to guide truck drivers' safety operation. Many studies have been conducted to investigate on the signs placement and specific warning/ signage.

Study revealed that warning signs on approaching curves and widening and improving clear zones are effective countermeasures for decreasing truck crash involvement. (Sundanda Dissanayake & Niranga Amarasingha, 2012). In his research, Charlton mentioned advance warning signs are more effective when used in combination sight board and repeated arrow signs (Charlton, 2007).

One countermeasure suggested by McMurty et al. (2007) was to apply truck specific warnings/advisory speeds (both before and during the curve) that incorporate dynamic signing. Vehicles at risk are identified by sensors and dynamic signage is then used to notify the drivers of the impending danger with enough time for corrective measures to be taken.

In addition to curves, work zones also present an increased safety risk for heavy vehicles. Some possible work zone countermeasures to consider include rumble stripes, highway advisory radio, and queue detection and warning systems. As with many new technologies there is little work to draw conclusions on effectiveness of any of the improvements mentioned, but nonetheless there are a multitude of countermeasures available for consideration.

2.3.1.4 Rumble Strips

Rumble strips are one of FHWA's nine proven safety countermeasures. Install centerline rumble strips at hot spots (curves and two-lane rural highway) could help truck drivers stay in lane, therefore reduce the crash risk. At a cost of \$700-\$900 per mile, they are a low cost, effective countermeasure.

A report by McMurty et al. (2007) suggested that using rumble strips for work zones to reduce an increase rollover risk happened at curve.

2.3.2 Vehicle Related Countermeasures

This countermeasure group includes the measures for avoiding vehicle technical failures therefore reduce crash potential. Then, new in-vehicle technologies which could benefit

large truck safety are also be introduced.

2.3.2.1 Strengthen Truck Maintenance

Vehicle maintenance is one of the most fundamental activities of commercial vehicle fleet safety management. The FMCSA and the states have various regulations and enforcement programs to ensure that vehicles have properly functioning equipment. However, Blower, (2002), discovered that roadside inspection vehicle out-of-service rates for mechanical problems are quite high (20-30%). Various studies of truck crash characteristics and causation have addressed that truck mechanical problems, such as break problem, tie defects, is one of the contributing factors to large truck crashes.

NCHRP Report 500 (2004) recommended two strategies should be taken into consideration to strengthen truck maintenance, which are: 1) increase and strengthen truck maintenance programs and inspection performance, and 2) conduct postcrash inspections to identify major problems and problem conditions.

2.3.2.2 Properly Secure Cargo

The Federal Motor Carrier Safety Administration (FMCSA) published cargo securement rules on Sep. 27, 2002. The rules require motor carriers to change the way they use cargo securement devices to prevent articles from shifting on or within, or falling from commercial motor vehicles. The intent of the requirements is to reduce the number of accidents caused by cargo shifting on or within, or falling from, commercial motor vehicles operating in interstate commerce.

A guideline published by Purdue university introduced the common methods of cargo securement, working load limit, how to make connection, as well as other load securement regulations.

2.3.2.3 In-Vehicle Technologies

Technological improvements to vehicles have the ability to influence heavy-vehicle safety in two ways, which are improve the performance of the vehicle (avoid or survive crashes better), and improve the performance of the driver.

Kingsley (2009) conducted a research to evaluate crash avoidance countermeasures using data from LLCCS. In this study, the following advanced in-vehicle technologies were

introduced:

- Lane Departure Warning (LDW)/Lane Keeping Assist (LKA)
- Forward Collision Warning (FCW)
- Blind Spot Detection (BSD)/Lane Change Warning
- Drowsy Driver Detection
- Backover Crash Prevention
- Night Vision
- Tire Pressure Monitoring System (TPMS)
- Roll Stability Control (RSC)
- Electronic Stability Control (ESC)

Table 2-7 summarized the risk factors could be addressed by applying these in-vehicle technologies. Kingsley also analyzed their potential to prevent large truck-involved crash (Table 2-8)

Table 2-7: Risks Addressed by In-Vehicle New Technologies

	Fatigue	Speeding	Breaking	Slick Spots	In cab distraction	Vehicle defect	Poor directional control	False assumption of other road users actions	Aggressive driving behavior	HOS regulations	Blind spots	Maintenance Violation	Over Steering	Object avoidance
Lane Departure Warning (LDW)	√	√		√	√	√	√	√	√		√			
Forward Collision Warning (FCW)		√	√	√	√	√		√	√		√			
Blind Spot Detection (BSD)/ Lane Change Warning		√			√			√	√		√			
Drowsy Driver Detection	√						√			√				
Backover Crash prevention														√
Night Vision							√	√			√			
Tire Pressure Monitoring System (TPMS)							√					√		
Roll Stability Control (RSC)	√	√	√		√			√	√					
Electronic Stability Control (ESC)		√							√				√	
Electronically controlled braking system (ECBS)	√	√	√		√			√	√					√

Table 2- 8: Advanced Technologies and Their Potential to Prevent Crashes from the LTCCS

Advanced Crash Avoidance Technologies	Percentage of LTCCS Crashes Applicable
Forward Collision Warning (FCW)	23.8%
Electronic Stability Control (ESC)	19.3%
Roll Stability Control (RSC)	10.2%
Lane Departure Warning (LDW)	6.1%
Blind Spot Detection (BSD)	5.9%
Drowsy Driver Warning	4.1%
Tire Pressure Monitoring System (TPMS)	1.7%
Backover Crash Prevention	0.3%
Night Vision	0.5%
Total*	49.9%
Source: LTCCS Analysis, Kingsley, 2009.	

*The total value in the chart takes into account overlap among the systems. It is not the sum of the percentage of crashes applicable for each technology. Most of the crashes may be included in target populations of more than one advanced technology.

2.3.3 Roadway User Education

When large trucks collided with passenger vehicles, passenger vehicle drivers were at fault for most of the cases. Also, about 85% of vehicle occupant fatalities resulting from large-truck crashes occur in other vehicles involved in the crash (FMCSA, 2003a). Therefore, to reduce large truck-involved crash, education is essential not only to large truck drivers, but all other roadway users. There is a need for a broad-based public understanding of the hazards associated with driving too close to large trucks.

NCHRP Report 500 (Knipling, 2004) recommends two strategies and possible ways to increase road user knowledge, which are:

- Incorporate share the road information into driver materials
 1. Incorporate information into state driver handbooks and knowledge tests for both passenger vehicle operators and CDL licensure
 2. Refer the ADTSEA web site to get elaborate instruction on “sharing the road” with trucks
 3. Reach renewal applicants by two approaches: 1) Alert drivers on how to maneuver safety around large trucks when sending mail renewal notice by the licensing authority; 2) Include the information in driver safety schools operated in conjunction with courts.
 4. Disseminate educational brochures through rental car agencies.
- Promulgate share the road information through print and electronic media
 1. Provide printed material such as brochures, information sheets, wallet-sized plastic cards, and posters in both English and Spanish for general public information on this safety topic.
 2. Invite one or more champions in key leadership positions to contact media to report the topic related to safety belt use, drinking and driving and share the road information to spread the safety message to citizens.

2.3.4 ITS Related Countermeasures

This part introduces the ITS related countermeasures which have potential to improve the

safety of large trucks. Three types of warning systems which have been applied in U.S. are introduced here, which are *warning systems for long downgrades*, *Dynamic Curve Warning Systems*, and *electronic screening near weigh station*.

2.3.4.1 Warning Systems for Long Downgrades

Warning systems for long downgrades is to warn specific truck drivers that their speed is above a recommended safe descent speed for the geometric conditions and that they should reduce their speed in order to lower their potential for losing control of the vehicle on the downgrade. Several warning systems have now been installed across the country to provide real-time information to heavy vehicle drivers about to descend a grade. Table 2-9 summarized downgrade warning systems which have been implemented in U.S.

2.3.4.2 Dynamic Curve Warning Systems

Truck rollover crashes occur frequently along the U.S. highway system and often result in serious injuries. Truck rollover crashes typically occur at freeway exit ramps with tight curves that require a reduced speed compared to the normal travel speed on the freeway and on sharp curves following steep downgrades.

To help mitigate the occurrence of rollover crashes, intelligent rollover warning systems have been installed at several problem locations. Intelligent rollover warning systems are designed to calculate the rollover potential of vehicles and direct warning messages to specific drivers if necessary. Directed messages are conveyed to drivers via VMSs or flashing lights only when potential rollovers are detected. In this manner, dynamic curve warning systems alert only those drivers with a high probability of entering into a rollover situation. The most basic systems typically incorporate one vehicle parameter such as speed or vehicle height, while the more sophisticated systems can incorporate several vehicle parameters such as speed, weight, live load, nonlive load, vehicle height, and vehicle configuration for calculating the rollover potential of a vehicle.

2.3.4.3 Electronic Screening at Weigh Stations

Inspections of commercial vehicles at weigh stations are conducted to verify motor carrier compliance with safety, size and weight, and credential regulations. These regulations are in place to protect public investment in roadway infrastructure and to

improve traffic safety (Benekohal, et.al., 1999). However, the diverging and merging of trucks as they enter and exit weigh stations can interrupt the flow of traffic on mainline facilities, particularly when weigh stations become congested and queues of trucks overflow from the inspection facilities onto the freeways. Electronic screening of vehicles approaching a weigh station is increasingly being used to focus inspection activities on those vehicles most likely to be in violation of applicable regulations.

Table 2-9: Summarized Roadside ITS Countermeasures

ITS Countermeasures	Location	System Name	Components
Warning System for Long Downgrades	Colorado: inside the Eisenhower Tunnel in the westbound lanes of I-70	DTSWS: Downhill Truck Speed Warning System	<ul style="list-style-type: none"> • Loop detectors • WIM: weigh in-motion devices • VMS: a variable message sign.
	Oregon: Interstate 84 at Emigrant Pass	DSIS: Downhill Speed Information System	<ul style="list-style-type: none"> • WIM: weigh in-motion devices, • AVI: automatic vehicle identification devices • VMS: a variable message sign
	West Virginia: at the top of a long, steep downgrade on Interstate 64 at Sandstone Mountain	Sandstone Mountain Downhill Truck Warning System	<ul style="list-style-type: none"> • Two VMSs: two variable message signs, • Two flashers, • Loops and piezo sensors in each lane.
Warning System for Curve	California: 5 sites along I-5 near the Sacramento River Canyon in Shasta County	Speed Based Curve Warning System	<ul style="list-style-type: none"> • VMS: a variable message sign, • Radar Speed-Measuring Device, • Control/Communication Equipment.
	California: On a freeway-to-freeway connector ramp located at postmile 14.74 (SB) on I-5 in San Joaquin County	TARWS: Truck-Activated Rollover Warning System	<ul style="list-style-type: none"> • Inductive loop, piezoelectric sensor, and • Inductive loop combination (detector system), • Control/communication equipment, • Static warning sign with two flashing yellow beacons.
	Texas: on a freeway-to-freeway loop ramp located in Houston, Texas	TM&W: Truck Monitoring and Warning System-rp62	<ul style="list-style-type: none"> • Three infrared light-beam sensors, • TDA3: Traffic Data Acquisition, a special microcontroller-based signal processor, • Static warning sign with flashing yellow beacons.
	Missouri: at a location with a sharp curve	Sandstone Mountain Downhill Truck Warning System	<ul style="list-style-type: none"> • Two signs, • Two flashers, • One narrow band microwave height detector.
	Virginia and Maryland: at three ramps on the Capital Beltway (I-495) in Virginia and Maryland	ATRS: Automatic Truck Rollover Warning Systems	<ul style="list-style-type: none"> • WIM: Weigh-in-motion detectors, • Loop magnetic detectors (speed detectors), • Radar sensing height detectors, • Warning signs, • Controller/communication equipment
Warning System for Weigh Stations	Illinois: at the Williamsville, Ill., weigh station.	VRC: Vehicle Roadside Communication System	<ul style="list-style-type: none"> • AVI: vehicle identification system • WIM: weigh in motion system

2.3.5 Traffic Law Enforcement

Another alternative counter measure involves modifying enforcement practices. Several studies provided suggestions on how to improve traffic law enforcement, and reduce large truck crash risk.

Strathman et al. (2010)

This study aimed to identify strategies and practices that could potentially be implemented by the Oregon Department of Transportation Motor Carrier Transportation Division in an effort to reduce commercial motor vehicle crashes. To conduct their study, a cluster analysis was implemented to establish peer states with geographic, development, travel, and safety enforcement conditions similar to those found in Oregon. Once peer states were established, structured interviews of each state's Motor Carrier Safety Assistance Program representative were conducted. The states included in the study were Oregon, Colorado, Michigan, Minnesota, Nevada, Washington, Kentucky, and Florida. From the peer interviews a multitude of suggestions were compiled and reported. Though protocols for conducting driver and vehicle inspections are fixed, the interviews did offer some tactics that benefit the effectiveness of inspection activities:

- Having troopers prepare their own regional safety plans
- Placing special enforcement in places where there are no inspection/weigh stations
- Increasing the number of inspectors by using the private sector (e.g., truck repair businesses)
- Using aircraft to spot trucks attempting to bypass stops

The interviews also supplied additional useful tactics with respect to traffic enforcement practices; some of the findings are listed below:

- Joining top performing troopers with inspectors
- Targeting high-risk highway segments
- Using data tools to identify at risk drivers
- Patrolling in unmarked vehicles to identify unsafe automobile drivers around commercial vehicles

Additionally, the interviews also revealed various tactics to improve the overall effectiveness of compliance reviews:

- Extending compliance reviews to intrastate carriers
- Maintaining the training of inspectors
- Focusing on “at risk” carriers identified by the Federal Motor Carrier Safety Administration

Huges (2000)

A study was conducted in to evaluate a change in enforcement practices and a reallocation of efforts in North Carolina. Between the years of 1998 and 1999, the North Carolina Department of Transportation identified 21 counties as having the most truck involved crashes and as such reallocated and increased CMV enforcement in those 21-targeted counties. The increased CMV enforcement consisted of an increase in roadside inspections, an increase in driver and vehicle out of service violations, an increase in CDL citations, and an increase in public education efforts. The product of these combined efforts produced a 17.7% reduction in fatal truck involved crashes for the 21 county areas and a 5% decrease in truck-involved crashes statewide between the years of 1998 and 1999. Counties outside the 21 target counties actually saw a 7.6% increase in heavy-vehicle-involved fatal crashes which highlights the resource dependent nature of CMV enforcement practices and underscores a need for improvements geared toward offsetting manpower and personnel limitations.

The study suggests that improvements through a systematic reallocation of enforcement efforts is possible; however, other methods of improvement should also be considered in the future to ensure available resources are optimally utilized.

McCartt et al. (2007)

This study offered some suggestions for advancing enforcement techniques. For the most part, the suggestions presented focused on compliance programs and a select list of those suggestions is presented below.

- Identifying and focusing on problematic carriers and drivers with relatively poor safety records

- Building databases to support problem identification
- Increasing oversight of new drivers and carriers
- Electronic screening bypass systems that allow qualifying carriers, vehicles, and drivers to bypass weigh stations, port-of-entry facilities, and roadside inspections
- Automated vehicle performance monitoring (i.e., brakes, tires)

Lucke (1999)

In this study, the effectiveness and uniformity of roadside vehicle inspections was assessed by used a team of federal, state and industry representatives to survey at sites in 7 state, which included Illinois, Arizona, California, Tennessee, Connecticut, Minnesota, and West Virginia.

Based on these site visits, best practices were identified by the project team. Overall, the team found that a majority of the inspections observed to be uniformly conducted from state-to-state and some of the best practices the team found were:

- Use of an inspector evaluation process that focuses on the quality rather than quantity of inspections.
- Working with seasonal carriers during their off season to inspect their vehicles thoroughly.
- More outreach programs to make both the commercial vehicle industry and the general public more aware of commercial vehicle safety.
- Further utilization of technology to permit both the entry and access to real-time commercial vehicle information.
- Requiring drivers placed out of service to sign a form that explains the penalties of an out-of-service order and that they are aware of these penalties.

2.3.6 Systematic Strategies to Reduce Large Truck Crashes

Many federal and state agencies have conducted research on reducing large truck-involved crashes. Some of them have come up with guidelines, strategies or recommendations which may have been implemented in certain state. Following introduces ITS initiatives for improving truck safety, and a guide for reducing collision involving heavy trucks.

ITS Initiatives for Improving Safety in Highway/Heavy Vehicle Interactions

Commercial Vehicle Operations (CVO) is the largest ITS program directly related to commercial trucks. The purpose of the ITS/CVO program is to define, pilot test, and deploy technologies, information systems, and networks to enhance roadway safety, credentialing, and operations (Harwood et al., 2003). ITS/CVO applications fall into four areas:

- **Safety Information Exchange:** Improve targeting of high-risk operators by providing inspectors better access to current safety information; automate safety inspection activities; and support deployment of in-vehicle technologies designed to improve safety.
- **Electronic Credentialing:** Automate administration functions and enhance data communications capabilities of state and administrative agencies to enable paperless transactions between motor carriers and regulatory agencies.
- **Electronic Screening:** Screen commercial vehicles at fixed weigh stations, ports of entry, and mobile inspection sites for safety, size/weight, and credential compliance at mainline speeds.
- **Motor Carrier Operations:** Improve motor carrier safety and efficiency by providing timely, accurate information to fleet managers and accelerate development and deployment of emerging technologies.

The ITS/CVO services focus on enabling seamless information exchange between motor carriers, regulators, and safety enforcement agencies. Thus, the ITS/CVO program allows enforcement agencies to focus their resources on unsafe motor carriers and provides motor carriers access to current information that can be used to improve fleet operations and safety.

The ITS/CVO services focus on enabling seamless information exchange between motor carriers, regulators, and safety enforcement agencies. Thus, the ITS/CVO program allows enforcement agencies to focus their resources on unsafe motor carriers and provides motor carriers access to current information that can be used to improve fleet operations and safety.

In addition, the study concluded that the characteristics of individual motor carriers (size

of fleet, type of haul, routing variability, etc.) and their primary operational objectives (on-time performance, safety assurance, cost avoidance, etc.) directly impact a carrier's choice of technologies and perceived value of ITS/CVO services.

NCHRP Report 500 Volume 13: A Guide for Reducing Collision Involving Heavy Trucks (2004)

This guide provides a comprehensive approach to large truck safety problems. It recommends a list of strategies with covers various aspects of road user, the highway, the vehicle, the environment, and the management system. An effective solution to large truck safety problem requires cooperation and participation of each relevant agency, as well as public entities.

The emphasis area and strategies are:

1. Reduce fatigue-related crashes
 - Increase efficiency of use of existing parking spaces
 - Create additional parking spaces
 - Incorporate rumble strips into new and existing roadways
2. Strengthen CDL program
 - Improve test administration for the CDL
 - Increase fraud detection of state and third-party testers
3. Increase knowledge re: sharing the road
 - Incorporate Share the Road information into driver materials
 - Promulgate Share the Road information through print and electronic
4. Improve maintenance of heavy trucks
 - Increase and strengthen truck maintenance programs and inspection performance
 - Conduct post-crash inspections to identify major problems and problem conditions
5. Identify and correct unsafe roadway infrastructure and operational characteristics
 - Identify and treat truck crash roadway segments—signing
 - Install interactive truck rollover signing

- Modify speed limits and increase enforcement to reduce truck and other vehicle speeds
6. Improve and enhance truck safety data
 - Increase the timeliness, accuracy, and completeness of truck safety data
 7. Promote industry safety initiatives
 - Perform safety consultations with carrier safety management
 - Promote development and deployment of truck safety technologies

Table 2-10 to 16 summarized objectives and related strategies for reducing heavy-truck crashes, the implementation timeframe, and cost for some of the strategies.

Table 2-10: Reduce Fatigue-Related Crashes

Strategies	Possible Actions	Timeframe for Implementation	Relative Cost	Detailed Cost
Increase efficiency of use of existing parking spaces	<ul style="list-style-type: none"> • Expand and improve public rest areas, commercial truck stops, travel plazas • Provide real-time information on available space • Use alternative parking sites • Improve parking layout to make parking easier and safer 	Short	Low	<ul style="list-style-type: none"> • Changeable message systems: \$25,000-\$30,000 • Cell phone usage: \$20 monthly • Computer cost: \$1200
Create additional parking spaces	<ul style="list-style-type: none"> • Improve amenities, lighting, and rest area design • Change enforcement practices • Conduct additional studies to continually assess demand and operational issues. • Get supporting from public-private partnerships to support joint solutions 	Medium	Moderate	<ul style="list-style-type: none"> • \$51,000 per building for a new rest area solely for trucks (Virginia) • \$10,000 per parking space (Rest havens, Kentucky) • \$150,000 per 1000-square-foot rest room /vending building with utilities (Rest havens, Kentucky)
Incorporate rumble strips into new and existing roadways		Medium	Moderate	

Table 2-11: Strengthen CDL Program

Strategies	Possible Actions	Timeframe for Implementation	Relative Cost	Detailed Cost	Other Attributes
Improve test administration for the CDL	<ul style="list-style-type: none"> • Offer computerized testing • Offer randomized copies of the test to be used in those stations who are not equipped to provide computerized testing 	Short	Low	Hardware, software, computer support personnel and training	
Increase fraud detection of state and third-party testers	<ul style="list-style-type: none"> • Build a system for regular review and auditing of both third-party testers and state examiners • Establish a statistical reporting system to provide test scores or failure rates by individual examiners and third-party organizations. • Evaluate candidate examiners thoroughly, including a criminal history check and a driver history check. • Improve on-site auditing procedures • Perform covert surveillance by a private firm contracted by the state • Given solicitation to third-party new testers by a statewide bulletin akin to the Federal Register. • Make the state legislative leadership brief to ensure their understanding of the new program and why it was being implemented. 	Short	Low	Private-sector, third-party testers must provide a performance bond: ranges from \$100,000 to \$250,000. (In Pennsylvania)	Legislative Needed. All examiners all examiners should be re-certified, (state third-party testers) All examiners and third-party testers should be assembled annually

Table 2- 12: Increase Knowledge on Sharing the Road

Strategies	Possible Actions	Timeframe for Implementation	Relative Cost	Detailed Cost	Other Attributes
Incorporate Share the Road information into driver materials	<ul style="list-style-type: none"> • Incorporate information into state driver handbooks and knowledge tests for both passenger vehicle operators and CDL licensure • Refer the ADTSEA web site to get elaborate instruction on “sharing the road” with trucks • Reach renewal applicants by 2 approaches: <ol style="list-style-type: none"> a. Alert drivers on how to maneuver safety around large trucks when sending mail renewal notice by the licensing authority. b. Include the information in driver safety schools operated in conjunction with courts. • Disseminate educational brochures through rental car agencies. 	Short (Effectiveness will be over time)	Low	Minimal cost	
Promulgate Share the Road information through print and electronic media	<ul style="list-style-type: none"> • Provide printed material such as brochures, information sheets, wallet-sized plastic cards, and posters in both English and Spanish for general public information on this safety topic. • Invite one or more champions in key leadership positions to contact media to report the topic related to safety belt use, drinking and driving and share the road information to spread the safety message to citizens. 	Short	Medium	No significant costs. A need for someone to work with the media to inform them and encourage them to address this topic.	Officers in the Governor’s Highway Safety office should be familiar with the Share the road concept.

Table 2-13: Improve Maintenance of Heavy Trucks

Strategies	Possible Actions	Timeframe for Implementation	Relative Cost	Detailed Cost	Other Attributes
<p>Increase and strengthen truck maintenance programs and inspection performance</p>	<ul style="list-style-type: none"> • Detect and correct driver deficiencies and unsafe motor carrier practices before they result in crash to help State truck inspection programs ensure safety. • Adopt, enforce and strengthen the state laws that are compatible with the Federal Motor Carrier Safety Regulations and the completion of a Commercial Vehicle Safety Plan • Strengthen Motor carrier preventive maintenance (PM) programs to their vehicles 	<p>Medium</p>	<p>Moderate to high</p>		<ul style="list-style-type: none"> • The program is limited by its budget and staff allocations • Enforcement officers must be thoroughly trained on the details of the inspection and PM program procedures.
<p>Conduct postcrash inspections to identify major problems and problem conditions</p>	<ul style="list-style-type: none"> • Collect data on truck and other vehicles involved in crashes (detailed information on the tractor, the trailer, and the cargo) • Collect data on truck driver involved in crashes (include physical condition, training and experience, recent sleep history, use of drugs and medications, hours of service, company policies, trip origin and destination, restraint use, and motor carrier characteristics) • Collect data on the crash itself (including detailed information on truck condition and damage) • Give data feedback to the state to modified the particular problem 	<p>Medium</p>	<p>Moderate to high</p>		

Table 2-14: Identify and Correct Unsafe Roadway Infrastructure and Operational Characteristics

Strategies	Possible Actions	Timeframe for Implementation	Relative Cost	Detailed Cost	Other Attributes
Identify and treat truck crash roadway segments—signing	<ul style="list-style-type: none"> Improve signage for trucks: <ol style="list-style-type: none"> directional signage relating to geographic locations such as major shippers and receivers; signage concerning specific hazardous roadway locations; signage for truck routes and hazardous materials corridors. Use vehicle-based technologies to complement infrastructure signage and other countermeasures. Provide intensified enforcement in areas considered especially hazardous for trucks. (Enforcement personnel need to be available for dedicated efforts at signage locations) 	Medium	Low	Costs include the original crash data analyses, the signing on selected corridors, and the enforcement required to maintain effectiveness	<ul style="list-style-type: none"> The strategy is considered experimental Training on the special dynamics and needs for truck safety should be included in training for this type of personnel.
Install interactive truck rollover signing	<ul style="list-style-type: none"> Apply infrastructure-based warning system: <ol style="list-style-type: none"> interactive signs that include highway detectors at curves. downhill speed advisories for trucks. Act targeted speed enforcement at each of these locations. Apply a vehicle-based system to prevent rollovers: <ol style="list-style-type: none"> Equip heavy vehicles with embedded roadway maps indicating highway curve locations and a positioning system to provide a warning to drivers. 	Medium	Moderate	\$210,000 per location for installing sensors to detect truck speed and provide feedback to truck drivers (In Pennsylvania)	Highway engineers may require training or consultation on various aspects of high-risk location identification, system design, installation, maintenance, and evaluation.
Modify speed limits and increase enforcement to reduce truck and other vehicle speeds	<ul style="list-style-type: none"> Permit differential speed limits at critical locations such as curves and steep downgrades. Take careful consideration when establishing the speed limits: <ol style="list-style-type: none"> Reevaluate no statutory speed limits on segments of their roadways at least once every 5 years by states and local agencies Two types of Speed Limit signs can be applied (to designate passenger car speeds, to show any special speed limits for trucks and other vehicles) 	Short	Moderate		

Table 2-15: Improve and Enhance Truck Safety Data

Strategies	Possible Actions	Timeframe for Implementation	Relative Cost	Detailed Cost	Other Attributes
Increase the timeliness, accuracy, and completeness of truck safety data	<ul style="list-style-type: none">• Improve the data system (such as TraCS system in Iowa)• Require inter-agency coordination and cooperation to ensure successful implementation.	Medium	Moderate to High	Varies hard ware, software, and training	

Table 2-16: Promote Industry Safety Initiatives

Strategies	Possible Actions	Timeframe for Implementation	Relative Cost	Detailed Cost	Other Attributes
Perform safety consultations with carrier safety management	<ul style="list-style-type: none"> • Provide safety education and consultation to the motor carrier industry by different levels of government in partnership with them. (educate in an advisory way) • Consult with the fleet owner or safety manager about their carrier operation, fleet's approach to compliance with key regulations, advice on building a stronger safety program, provide information to support carrier's safety management effort. • Consult with safety workshops for motor carrier managers, drivers, and dispatchers about regulation compliance, drug and alcohol testing requirements and procedures, driver selection and hiring, driver performance evaluation, carrier safety management, and vehicle maintenance. 	Medium	Moderate to High	<ul style="list-style-type: none"> • Personnel to manage and operate the program • Materials, equipment, and facilities • Experienced by fleets as they institute new programs and procedures 	Individuals providing consultation to fleets must be highly qualified
Promote development and deployment of truck safety technologies	<ul style="list-style-type: none"> • Improve basic safety-related components designs and technologies to ensure heavy-truck safety <ol style="list-style-type: none"> (1) Manufacturers play a principal role in determining vehicle safety design by the standard and optional safety equipment installed on their vehicles (2) The motor carrier industry also plays a principal role by selecting specific equipment for new vehicles develop and make marketed of the advanced technology collision avoidance systems • Apply advanced technologies to monitor and modify commercial driver safety behavior. (e.g. Adaptive cruise control, lane trackers and lane departure warnings, side sensing devices, vehicle and cargo tracking systems, driver alertness monitoring.) 	Long	Moderate to High	<ul style="list-style-type: none"> • Capital, operating and maintenance, training of the drivers and those who handle maintenance and repair • Costs depend upon the technology involved 	Depending upon the technology, driver acceptance and proper use of the equipment may be an issue.

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CHAPTER 3: COLLISION DIAGRAM BASED IN DEPTH CRASH RISK ANALYSIS

To investigate roadway related risk factors related to large truck involved crashes, collision diagram based in-depth crash risk analysis was conducted. To perform this analysis, 10 hot areas in Texas with high number of large truck involved crashes, especially fatal and incapacitating crashes, were identified by applying ArcGIS based techniques. Then, all crash reports collected from those 10 hot areas were reviewed and analyzed to develop collision diagrams. Depending on the size of the area, 1 to 10 collision diagrams were developed for each hot area. Finally, a total of 47 collision diagrams were developed for the 10 hot areas. For each hot area, crashes were analyzed by type, location and environmental and conditions. According to the analysis results, potential crash risk factors were identified and prioritized.

The data used for this research was obtained from TxDOT's Crash Records Information System (CRIS). Large truck-involved crash records in the past 5 years (2011-2015) were extracted and analyzed. This chapter introduces the data process procedure and GIS based hot area analysis techniques, as well as detailed analysis for each identified crash hot areas.

3.1 DATA PROCESS

The first step in identifying large truck crash hot areas was to gather crash data. For this project, all crash records in Texas from 2011 to 2015 was requested and downloaded through TxDOT's Crash Records Information System (CRIS). The raw data includes the following files:

- Crash extraction file
- Unit extraction file
- Damages extraction file
- Charges extraction file
- Person extraction file
- Primaryperson extraction file
- DL Restrictions extraction file

- CDL Endorsements extraction file
- Lookup extraction file

In this study, a large truck, as defined by the US Department of Transportation, is any truck with a gross weight rating greater than 10,000 pounds. Passenger car and light truck which has gross weight rating less than 10,000 were excluded. Also, buses are different with other large trucks, therefore were eliminated for this study. To extract large truck-involved crashes from all crashes, the information contained in the “unit extraction file” and “crash extraction file” was utilized. Table 3-1 listed the attributes in these two files used to identify the large truck-involved crashes, and Table 3-2 is the detailed explanation of each Commercial Vehicle (CMV) type ID.

Table 3- 1: Attributes Used to Extract Large Truck-involved Crashes

File Name	Attributes	Explanations	Values
Unit	Cmv_Fiveton_Fl	10,001 + LBS	‘yes’ or ‘no’
	Veh_cmv_Fl	CMV Unit Flag	‘yes’ or ‘no’
	Cmv_Veh_Type_ID	Vehicle Type	0,1,2,3,4,5,6,7,8,9,10,11, 94,95,98
Crash	Cmv_Involv_Fl	CMV Crash Identifier	‘yes’ or ‘no’

Table 3- 2: Commercial Vehicle (CMV) Type ID Explanations

CMV_VEH_TYPE_ID	DESCRIPTION
0	UNKNOWN HEAVY TRUCK
1	PASSENGER CAR
2	LIGHT TRUCK
3	BUS (9-15)
4	BUS (>15)
5	SINGLE UNIT TRUCK 2 AXLES 6 TIRES
6	SINGLE UNIT TRUCK 3 OR MORE AXLES
7	TRUCK TRAILER
8	TRUCK TRACTOR (BOBTAIL)
9	TRACTOR/SEMI TRAILER
10	TRACTOR/DOUBLE TRAILER
11	TRACTOR/TRIPLE TRAILER
94	REPORTED INVALID
95	NOT REPORTED
98	OTHER (EXPLAIN IN NARRATIVE)

The procedure of extracting large truck-involved crashes included following steps:

1. From ‘unit’ file, selected crashes with value ‘yes’ for ‘Cmv_Fiveton_Fl’;
2. From ‘unit’ file, excluded value “1-4’ for ‘Cmv_Veh_Type_ID’;

3. From 'unit' file, selected value 'Yes' for 'Veh_cmv_F1';
4. Collected crash IDs meet step 1, 2 and 3;
5. From 'crash' file, obtained Latitude, Longitude information of collected crash IDs.

Based on these five steps, large truck-involved crash records were extracted and then inputted into ArcGIS for hot spot analysis.

3.2 METHODOLOGY

The GIS approach to identify large truck-involved crash hot areas includes the following key steps:

1. *Input data into ArcGIS*: convert the extracted large truck-involved crash data into an ArcGIS layer, input GIS layer of Texas roadway network, and convert the coordinate systems of all the data layers to a projected coordinate system;
2. *Apply GIS Techniques to Identify Hot Spots*: apply ArcGIS techniques to identify hot spots of large-truck involved crashes
3. *Identify hot areas*: based on the results of identified hot spots, the hot areas with a cluster of hot spots were identified.

3.2.1 Input Data into ArcGIS

Large truck-involved crash data in each year was compiled into a single database, which was input to GIS first. Roadway Routes layer was downloaded from 2014 Texas Roadway Inventory Data in GIS format, which was published by TxDOT annually.

The large truck-involved crash data extracted from CRIS contains 121,633 crashes from 2011 to 2015. Table 3-3 shows the identified large truck crashes occurred by each year.

Year	Crashes
2011	20,058
2012	22,005
2013	23,635
2014	26,853
2015	29,082
Total	121,633

After crash data and roadway routes layer were imported to ArcGIS, coordinate system was defined for all data layers (crash data layer and roadway routes layer). In this study, the non-projected Geographic coordinate system NAD1983 was used at first. After that, all the layers were projected using the projected Geographic coordinate system, NAD1983 Texas Statewide Mapping System. Figure 3-1 shows the GIS map with inputting crash data layers.

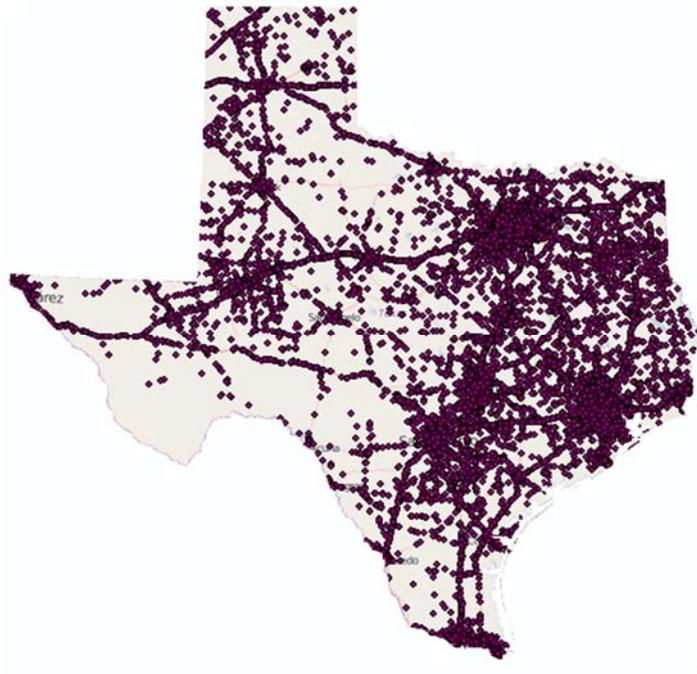


Figure 3-1: GIS Map after Inputting Crash Data Layers

3.2.2 Apply GIS Techniques to Identify Hot Spots

In order to identify the crashes hot spots, two GIS techniques were applied following in two steps:

Step 1: Apply the “Integrate” tool to integrate the closely located crashes to one hot spot

Integrate is a tool of ArcGIS which could be used to maintain the integrity of shared feature boundaries by making features coincident if they fall within the specified x,y tolerance. Features that fall within the specified tolerance distance are considered identical or coincident. Integrate accepts only simple feature classes as input (point,

multipoint, line, or polygon). In ArcGIS, the “Integrate” tool performs the following two tasks:

- 1) Finds features that are within the given tolerance distance.
- 2) Inserts common coordinate vertices for features that fall within the given x,y tolerance.

Figure 3-2 shows an example of integrating crash data. In Figure 3-2, there are 5 crashes located at points A, B, C, D, E and the distances between nearby points were marked. If a tolerance distance of 0.5 mile is assumed, by running the “Integrate” tool, point A and point B would be integrated because they were within the tolerance distance of 0.5 mile. Same as A and B’s integration, C, D and E also would be integrated.

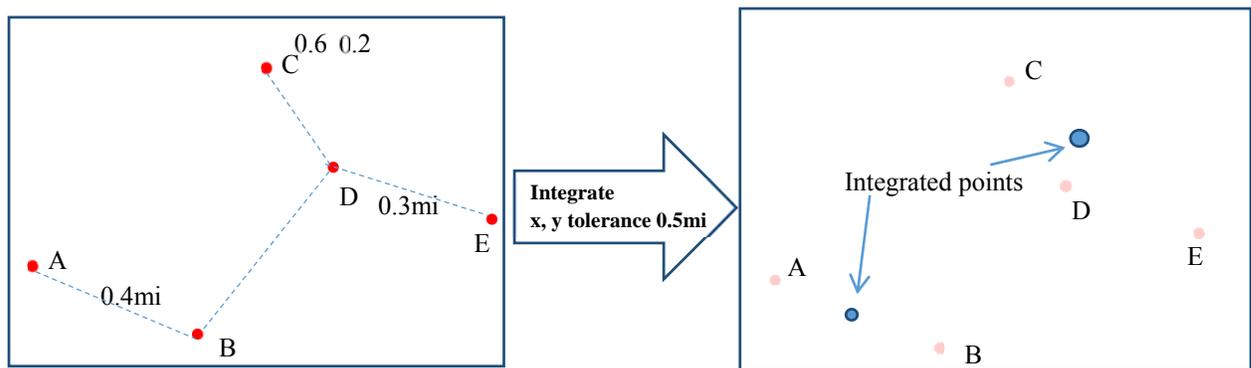


Figure 3- 2: Example of Integrating Crashes

In this step, the value for tolerance distance is critical—a tolerance that is too large may collect all the accidents spread in a large area and moved the actual hot spots to a new location which is not risky at all, while a tolerance that is too small may separate the whole area to lots of small areas with little points fall into each area therefore can’t identify the hot spots at all. In this study, we tried different distances and find a tolerance distance of 0.5 mile can produce reasonable hot spot results. In addition, in most of the transportation safety studies, roadway is usefully split into one-mile segments for crash risk analysis. Therefore, using of a tolerance distance of 0.5 mile will integrate the crashes within the one-mile distance, which is also consistent with the traditional safety studies.

Step 2: Apply the “Collect Events” technique to count the collected crashes at each hot spot:

Collect Events tool combines integrated points. It creates a new output feature class containing all of the unique features in the inputted integrated feature class. It then adds a field named “ICOUNT” to give the sum of all crashes at each hot spot. Although this tool will work with polygon or line data, it is really only appropriate for event, incident, or other point feature data. In this study, for each year, the top 20 spots were identified.

3.2.3 Identify Hot Areas

Based on the identified hot spots, the areas with a cluster of hot spots were identified as hot areas. Each area would be further examined. The examined information includes but not limited to roadway geometric design, traffic control devices, nearby land use.

3.3 HOT SPOT ANALYSIS RESULTS

Overall, research team identified 10 large truck crash hot areas. Figure 3-3 mapped the locations of the identified hot areas. As showed in Figure 3-3, of all 10 large truck crash hot areas, Dallas has 3, Fort Worth, Houston, Austin, San Antonio, Waco, Laredo and Midland each has 1. Figure 3-4 present the locations of 3 hot areas in Dallas.

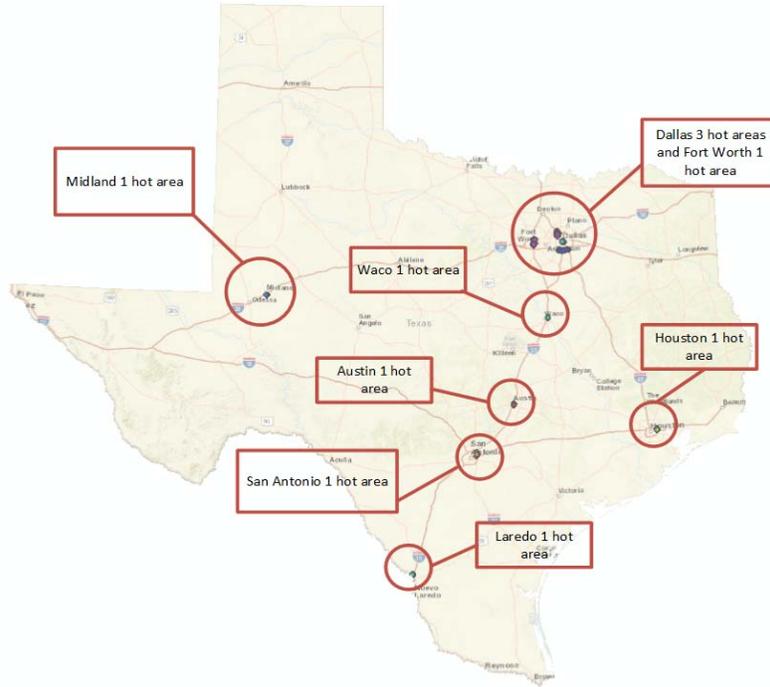


Figure 3-3: Ten Identified Large Truck Crash Hot Areas in Texas

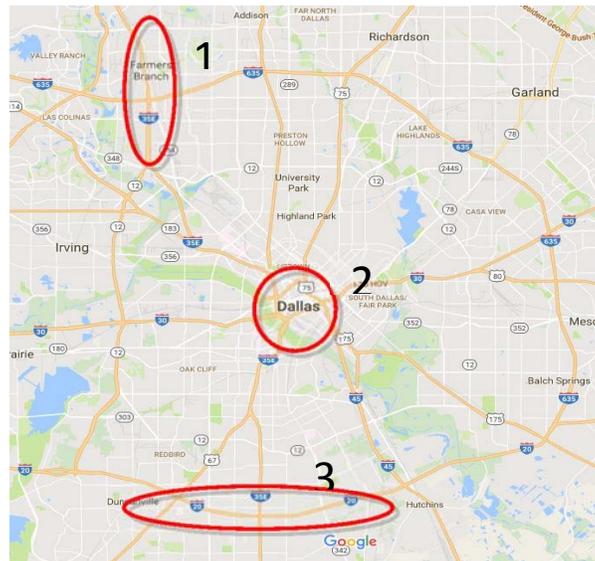


Figure 3-4: Four Large Truck Crash Hot Areas in Dallas

Table 3-4 summarized the information of all 10 large truck crash hot areas. Next step is to conduct a further study associated with these hot areas. The detailed analysis of those 10 hot areas will be presented one by one.

Table 3-4: Summary of the 10 Candidate Hot Areas

ID	Location	Number of Large Truck Crashes				
		Fatal	Incapacitating	Non-Incapacitating	Possible Injury	Total
1	North Dallas I-35	1	19	57	134	211
2	Downtown Dallas IH35E	4	5	39	110	158
3	South Dallas IH20	5	11	64	101	181
4	Houston IH610 @ US90	5	10	27	65	107
5	Austin IH35	2	6	26	45	79
6	San Antonio IH410 @ IH35	2	10	29	67	108
7	Laredo IH69W @ FM1472	1	6	22	63	92
8	Fort Worth IH35W	5	20	55	93	173
9	Waco IH35	4	11	13	18	46
10	Midland IH20	7	3	9	12	31

3.4 IN-DEPTH RISK ANALYSES AT 10 HOT AREAS

In the following sections, these 10 hot areas will be analyzed individually and following information will be provided for each area:

- Area map and brief description
- Crash tendency and severity distribution
- Collision diagrams developed
- Findings from the collision diagram analysis
- Summary of identified risk factor and possible countermeasures

3.4.1 Hot Area 1 North Dallas IH35

Hot Area 1 is located at North Dallas Interstate Highway 35 near Interstate Highway 635. This area stretches 8.3 miles on IH35. During 2011-2015, 211 crashes occurred, including 1 fatal and 18 incapacitating crashes. The last 5 years crash tendency and crash severity distribution are shown in Figure 3-5.

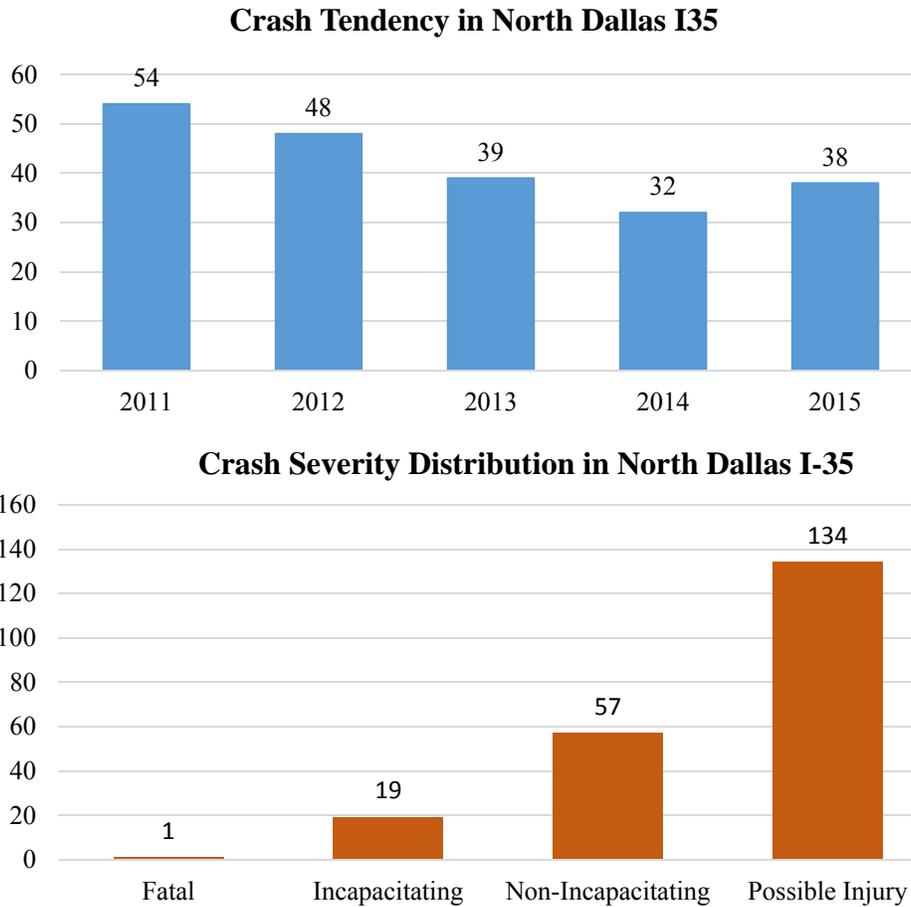


Figure 3- 5: Crash Tendency and Crash Severity Distribution at Hot Area 1

Due to the large size, 10 collision diagrams were developed for this area. Figure 3-6 shows the location of all crashes happened in this area, and the boundary of each section for developing collision diagram. Some isolated crashes were eliminated from the analysis, and finally 161 crashes were mapped for this area in total.

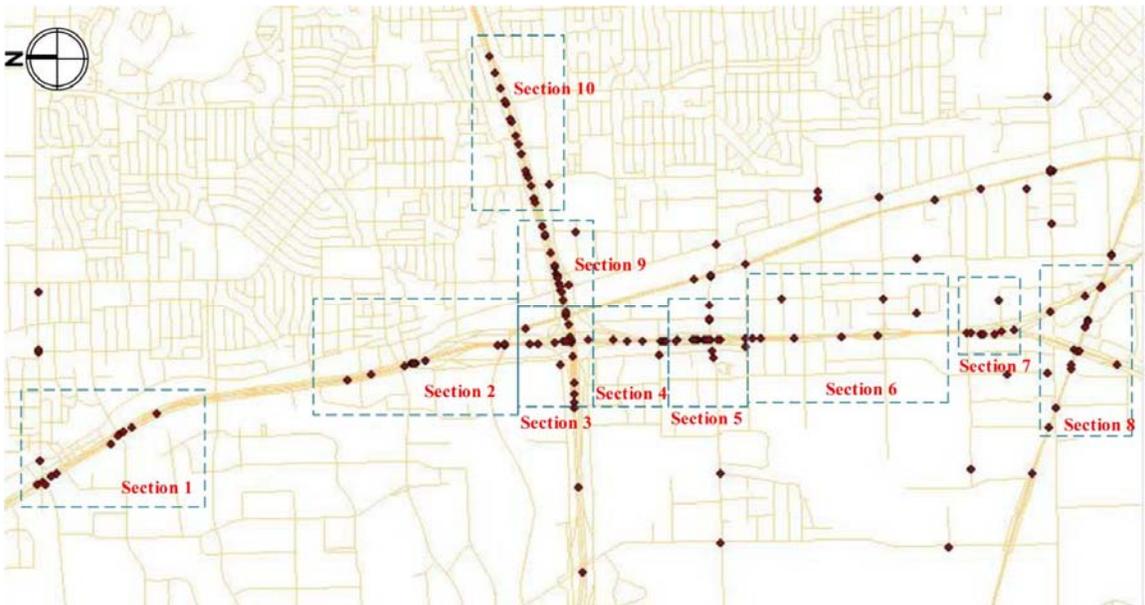
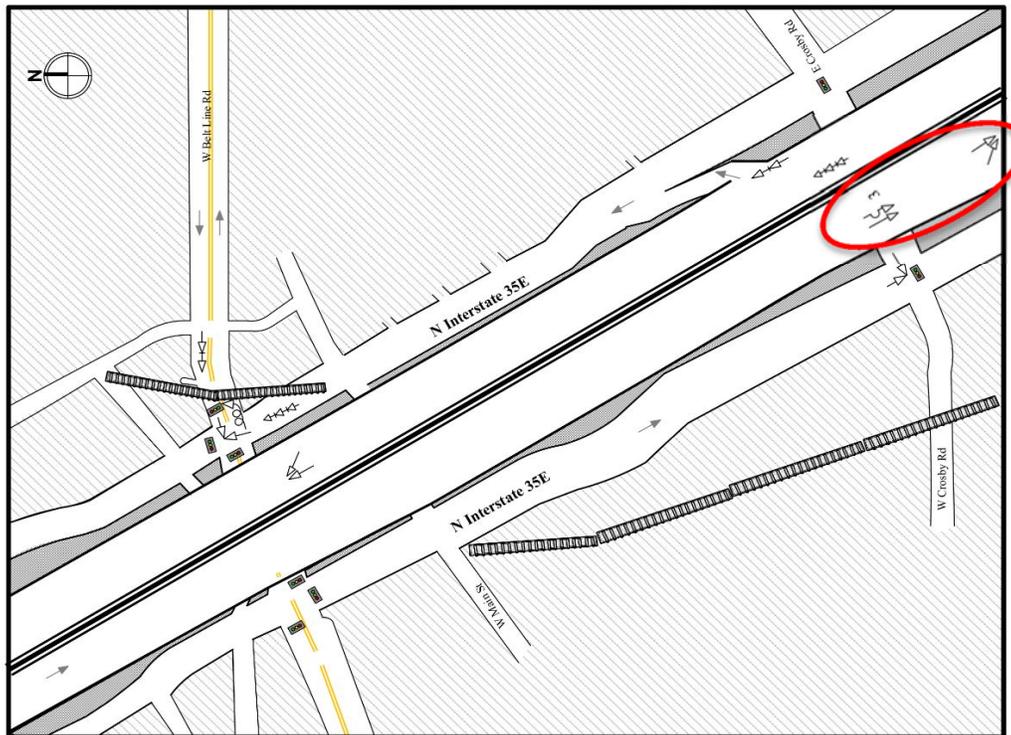


Figure 3- 6: Area Map and Collision Diagram Sections at Hot Area 1

3.4.1.1 Collision Diagram 1

Figure 3-7 is the collision diagram mapped for section 1. All 12 crashes in section 1 were occurred in year 2014, and 11 of them occurred when roadway constructions were presenting. Figure 3-7 is the developed collision diagram.



Legend	Crash type	Number	Legend	Crash type	Number
	Angle	2		T Bone	2
	Two Rear End	2		Sideswipe	3
	Three Rear End	2		Lost Control	1
Total : 12					

Figure 3- 7: Collision Diagram 1 for Hot Area 1 “North Dallas IH35”

After carefully reviewed all police reports, as well as surrounding roadway conditions, the research team discovered two major issues in this section.

Finding 1: angle or sideswipe crashes caused by narrow lanes (red circle in Figure 3-7)

Figure 3-8 shows the location where 3 sideswipe crashes occurred. After measured, lanes at this location were found to be relatively narrow, ranging from 9 to 9.5 ft. In addition, continuous construction work presented in this area at the time those crashes occurred.

Narrow lane normally generates high risk to drivers, especially to large truck drivers or other drivers around large trucks, which may cause angle, sideswipe or rear-end crash.

Possible countermeasures could be adding more signs or warning lights to provide warning to drivers, such as “SLOW TRAFFIC AHEAD, PREPARE TO STOP”, “WORK ZONE AHEAD”, and combine with flash yellow lights for extremely congested areas.



Figure 3- 8: Google Map Picture of the Location with high rate of Sideswipe Accidents

Finding 2: railway crossing close to a congested intersection

There is a railway level crossing in section 1 (see Figure 3-9). This railway crossing is not far upstream from an intersection. Although there is a sign of “DO NOT STOP ON TRACKS”, it is difficult for drivers to tell whether they could pass the tracks or not under congested traffic condition. It is especially hard for large truck with long trailer.

There was one incapacitating crashes occurred at this location. The large truck disregarded the No Truck Sign and tried to make left turn. Due to the congested traffic, it did make the turn and was hit by the train.

To reduce such risk at railway crossing, the following countermeasures could be implemented:

- Add more warning signs or bells to warn of approaching trains
- Add raised pavement marker to warn drivers of the tracks ahead
- Implement detectors on the road, when train approaching, automatically turn the downstream intersection light to green if there are vehicles are on tracks, so the vehicles can leave tracks and pass the intersection immediately.
- Educate both truck and passenger vehicle drivers on how to safely pass railway crossings

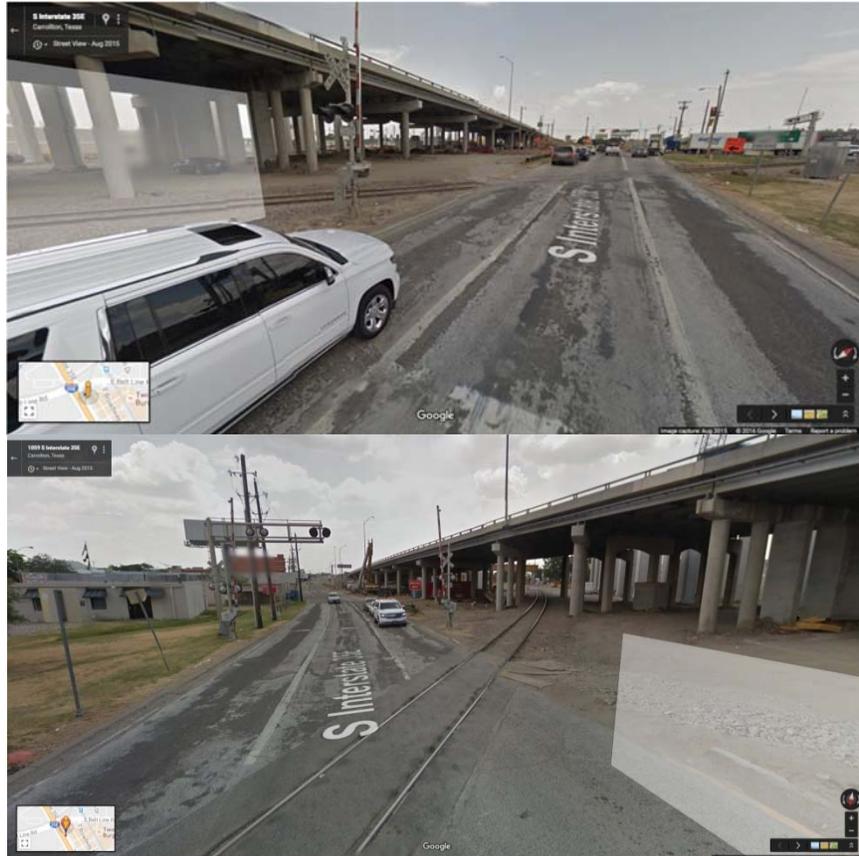
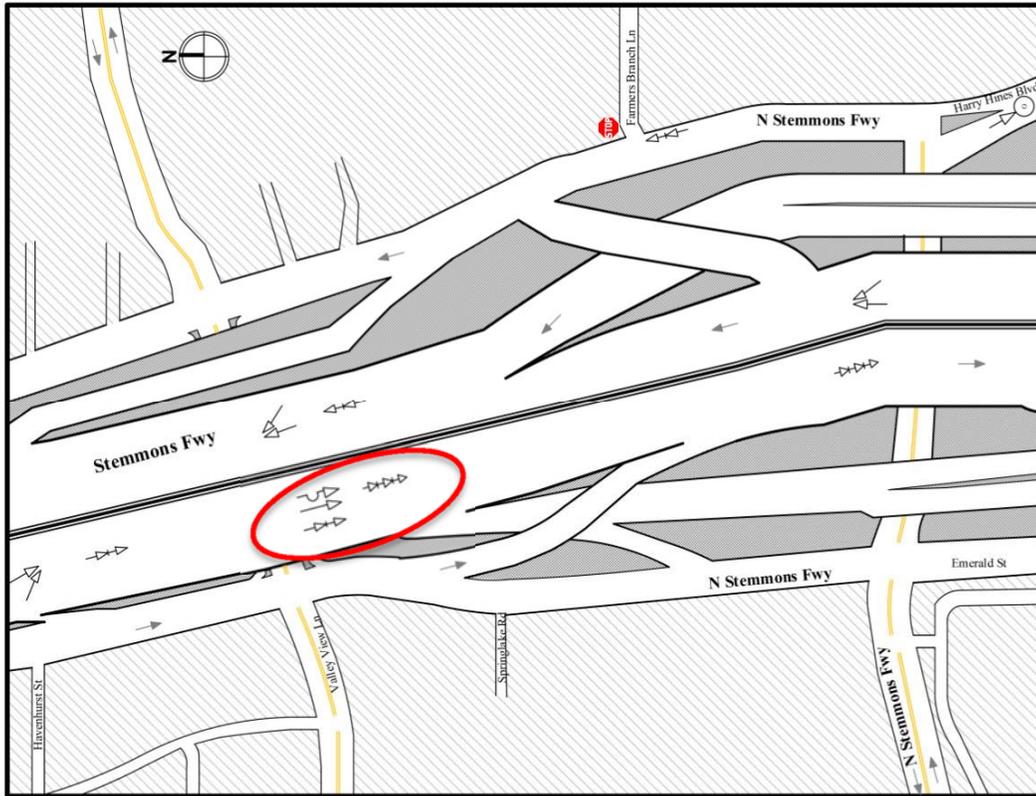


Figure 3-9: Google Map of the Problematic Location

3.4.1.2 Collision Diagram 2

Figure 3-10 is the collision diagram developed for section 2 of hot area 1. There are 11 crashes occurred in this section. Of all crashes, 50% of them happened in congested construction zones. And for those crashes not occurred in construction zones, all of them were caused by driver errors, such as following too close to another vehicle, or not pay enough attention to blind spot.



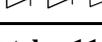
	Angle	3		Sideswipe	1
	Two Rear End	4		Object	1
	Three Rear End	2			
Total : 11					

Figure 3- 10: Collision Diagram 2 for Crash Hot Area 1“North Dallas IH35”

Finding 1: multiple rear-end and sideswipe crashes (red circle in Figure 3-10)

As marked in Figure 3-10, there are two rear-end crashes and 1 sideswipe crash occurred near one exit ramp. After reviewing the police reports, the two rear-end crashes were caused by unsafe speed, which may be relevant to the traffic congestion. The sideswipe crash happened because of the narrow lane caused by construction work.

3.4.1.3 Collision Diagram 3

Section 3 is a complicated interchange area (IH35@IH635). Figure 3-11 is the collision diagram developed for this section. It is found that angle crash is most common type of crash happened in this section. Moreover, most of the angle crashes occurred on entrance

or exit ramps. Reviewing police reports revealed the following possible issues.

Finding 1: traffic congestions near the ramps

Generally, entrance or exit ramps are dangerous locations at highway because there are lots of lane changes, which cause lots of conflicts. At the studied location, due to heavy traffic volume, the stop-and-go traffic near ramps causes rear end crash risk, especially for the trucks.

In addition, traffic congestion sometime causing queues in the entrance lane or exit lane, thereby some drivers intentionally merge late to avoid being in a long queue, which also lead to angle crashes. If a crash caused by passenger vehicle unsafely cut into large truck's lane, it is usually a severe crash. Possible countermeasures to reduce drivers' inappropriate behaviors near ramps include:

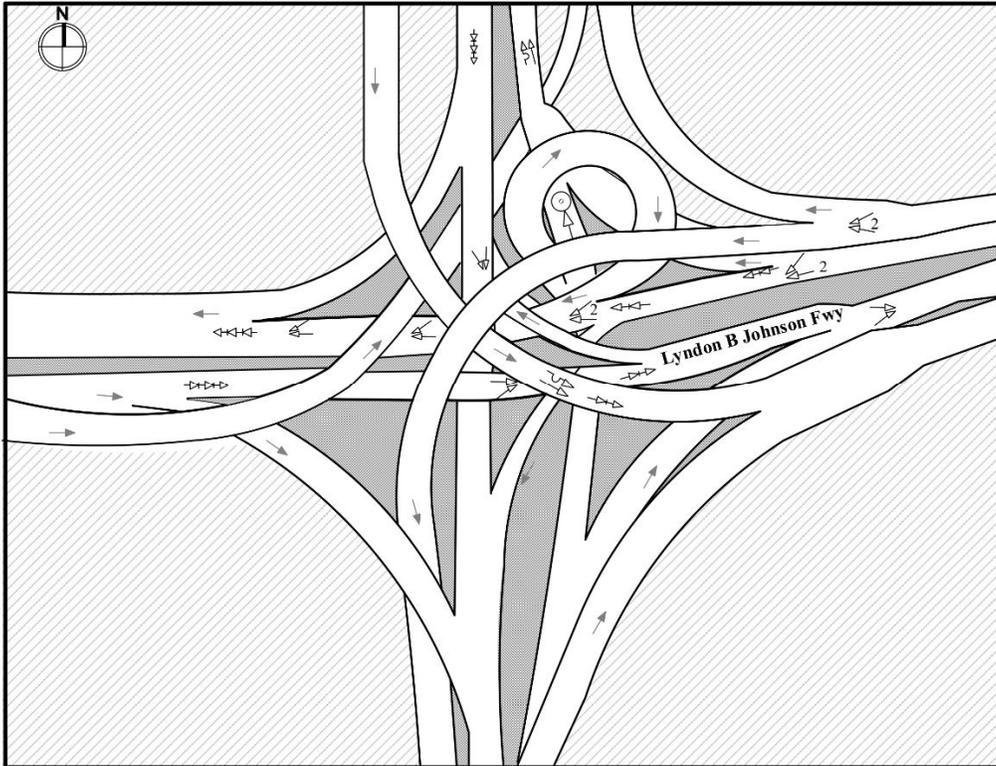
- Use raised barriers, such as pylons, at the exit or entry ramp locations to prevent the late merge
- Put advanced traffic signs, such as “traffic congestion ahead” with flashing lights, near entry and exit lanes
- Driver education for passenger vehicles on how to safely drive around the trucks

Finding 2: unsafe lane changes caused by drivers' confusion

There were 3 crashes caused by drivers' late lane change behavior. Due to the complicated and confusing lane configurations at the interchange, drivers may have no idea that they were on a lane lead to another highway until very late. This situation caused some drivers making sudden lane changes at the diverging point, which lead to crashes.

There are several countermeasures could be implemented to prevent such behavior and reduce crash risk.

- Add more noticeable traffic signs in advance to the interchange area to provide drivers more directions
- Use of pylons to prevent such late lane change behavior



Legend	Crash type	Number	Legend	Crash type	Number
	Angle	11		Sideswipe	2
	Two Rear End	5		Object	1
	Three Rear End	3			
Total: 22					

Figure 3- 11: Collision Diagram 3 for Hot Area 1“North Dallas IH35”

3.4.1.4 Collision Diagram 4

There were 12 crashes occurred in this section, including 6 rear-end crashes, 3 angle crashes, 1 left turn crash, 1 hit objective and 1 T-bone crash. Most of the rear-end crashes were due to driver following too closely to another vehicle at construction zone and/or under the congested traffic conditions. In addition, similar to section 1, 50% of the crashes occurred with the appearance of construction work.

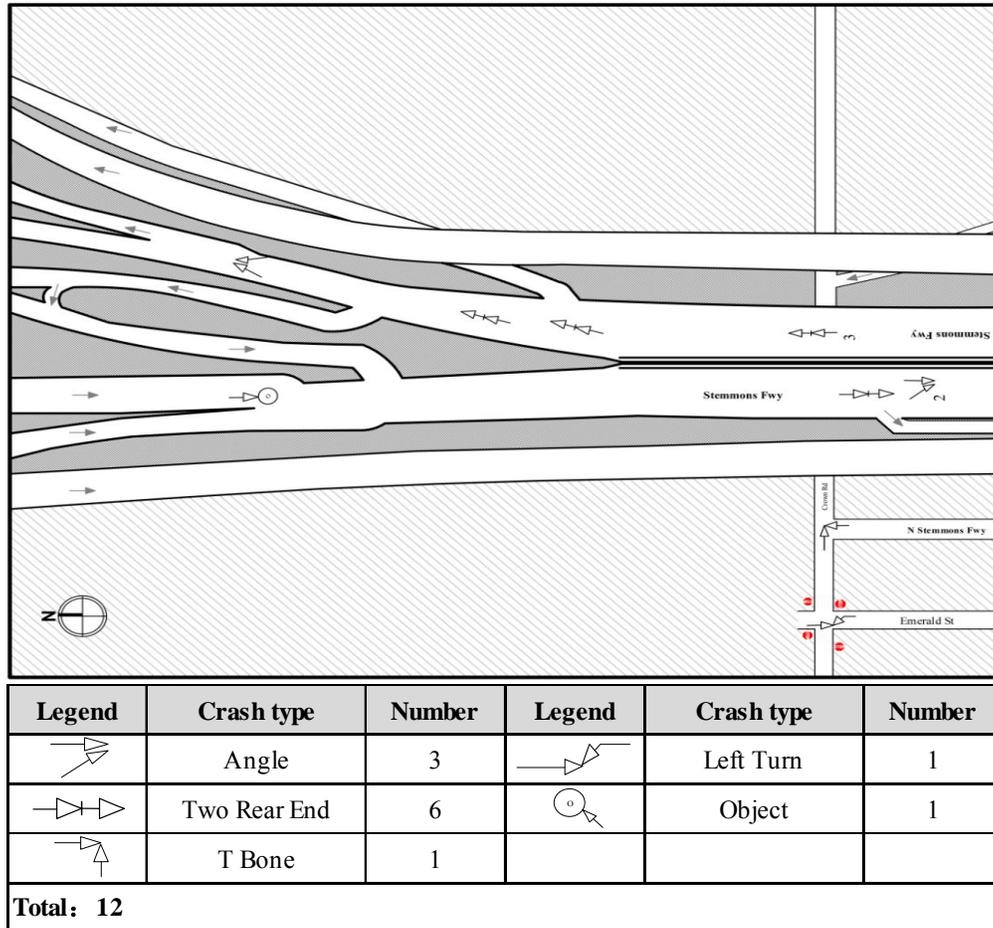
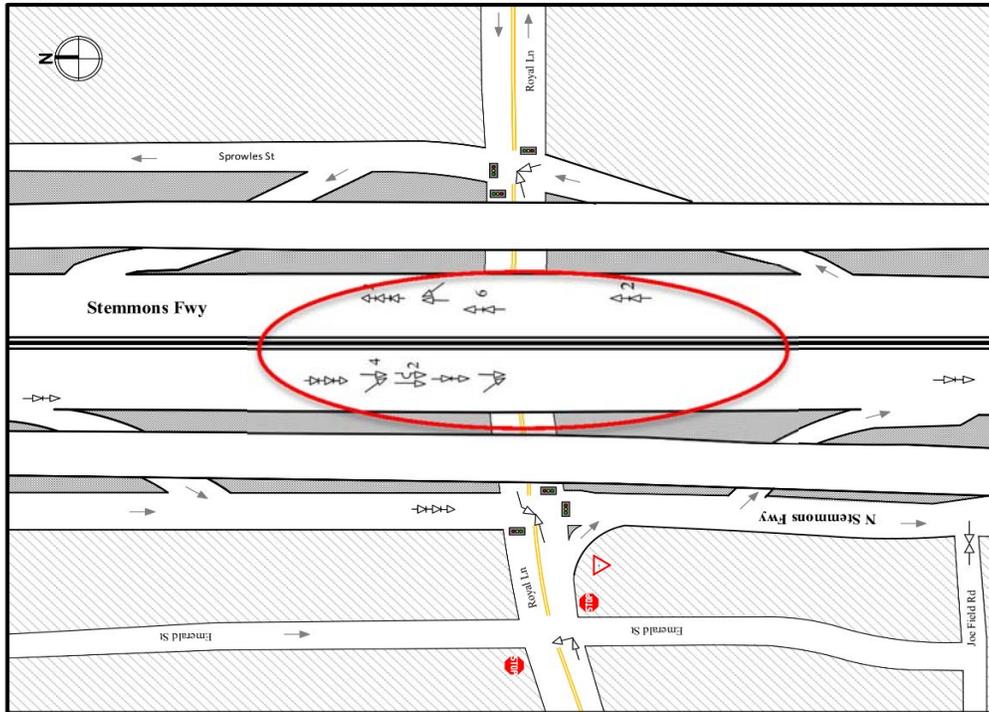


Figure 3- 12: Collision Diagram 4 for Large Truck Crash Hot Area 1 “North Dallas IH35”

3.4.1.5 Collision Diagram 5

Figure 3-13 is the collision diagram section 5, with a total of 27 crashes occurred during the past five years. It can be seen that, the most common type of crash at this location is rear-end crash, with a total number of 15 crashes. After examining the police reports, it was found that similar with previous sections, construction work and the resulting traffic congestion contributed to most of the crashes.

Finding 1: lots of rear-end, sideswipe and angle crashes (red circle in Figure 3-13)



Legend	Crash type	Number	Legend	Crash type	Number
	Angle	6		Sideswipe	2
	Two Rear End	11		Head On	1
	Three Rear End	4		Left Turn	1
	T Bone	2			
Total: 27					

Figure 3- 13: Collision Diagram 5 for Large Truck Crash Hot Area 1 “North Dallas IH35”

3.4.1.6 Collision Diagram 6

For section 6, 6 crashes occurred, including 4 angle crashes and 2 rear-end crashes. Figure 3-14 is the developed collision diagram. After carefully reviewed all police reports, as well as surrounding roadway conditions, no roadway related crash risk factor was noticed.

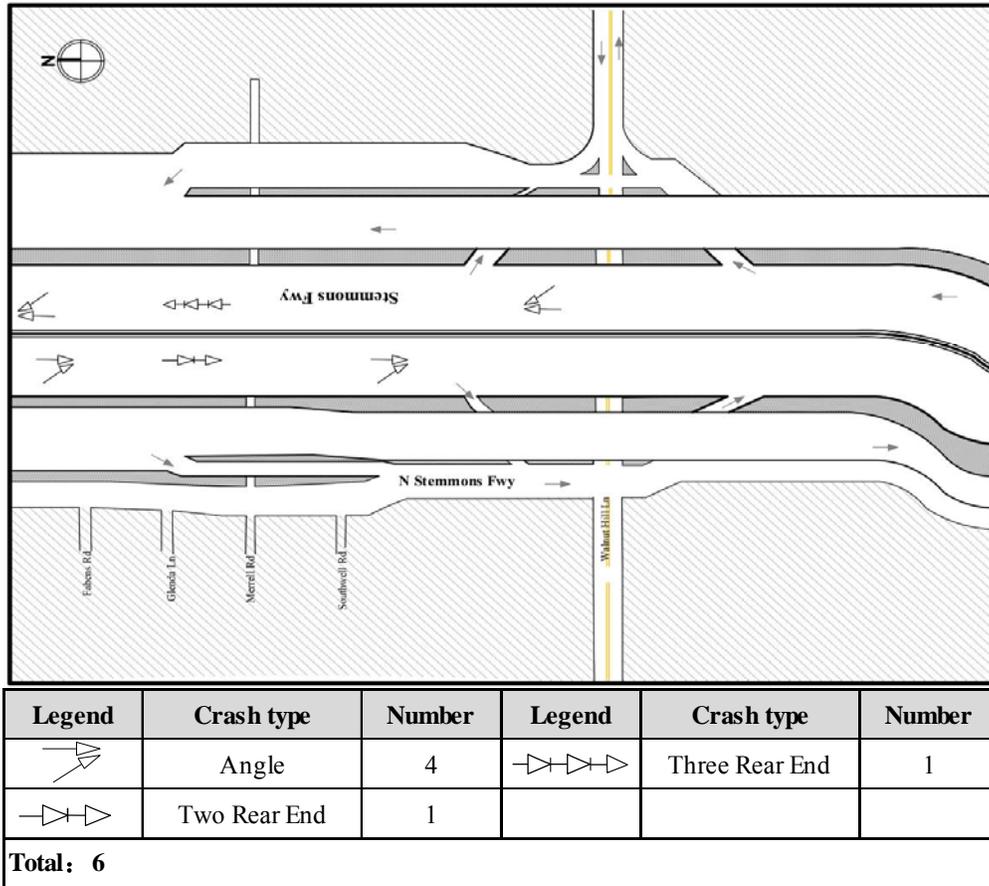


Figure 3- 14: Collision Diagram 6 for Large Truck Crash Hot Area 1 “North Dallas IH35”

3.4.1.7 Collision Diagram 7

Figure 3-15 is the developed collision diagram. For section 7, 10 crashes occurred, including 8 angle crashes, 1 rear-end crash and 1 sideswipe crash. Similar with section 6, most of the crashes occurred near ramps, and were caused by traffic congestion or driver’s error. There is one location with high frequency of large truck related crashes, i.e. 3 angle crashes and 1 sideswipe crash (please see the red circle in Figure 3-15)

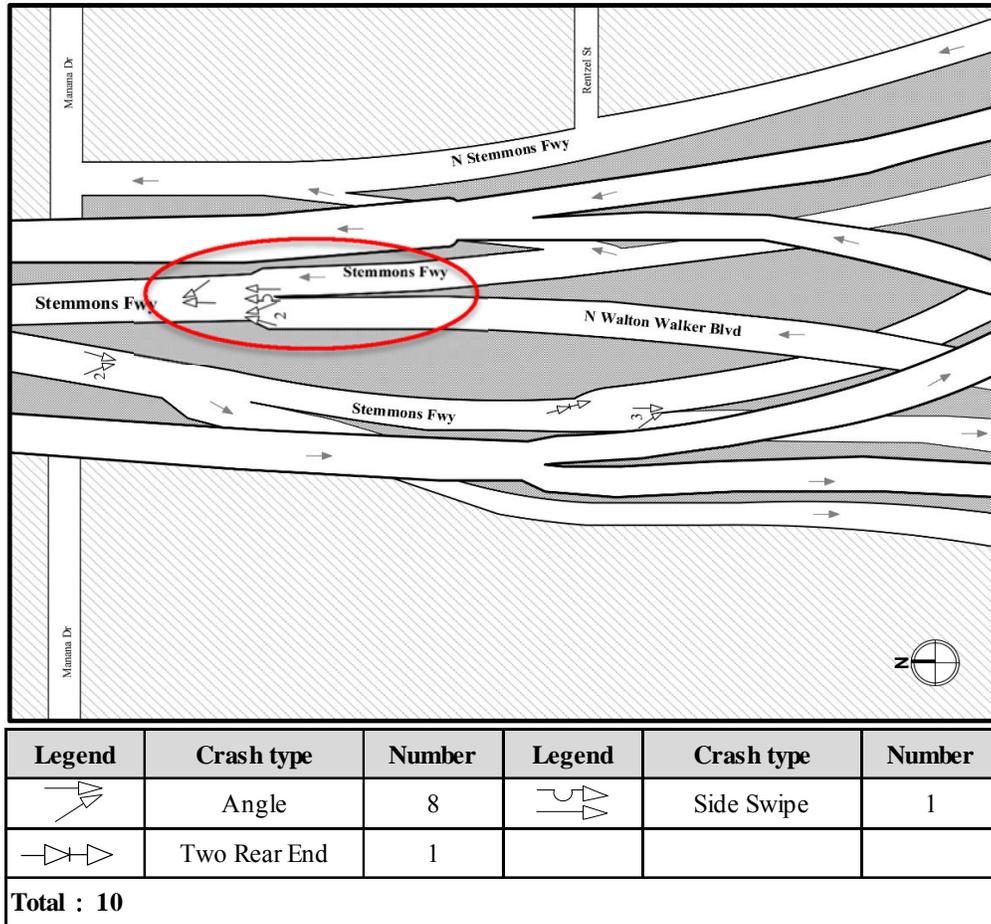


Figure 3-15: Collision Diagram 7 for Large Truck Crash Hot Area 1 “North Dallas IH35”

Figure 3-16 shows the Google map screen shot for this interchange area with 3 angle crashes and 1 sideswipe crash. From the picture, we can see there is a down slope at the merge point, which may cause unsafe speed, together with lane change movements, it causes high risk for crashes.



Figure 3- 16: Google Map of the Problematic Location

3.4.1.8 Collision Diagram 8

18 crashes occurred in section 8, including 2 incapacitating crashes. Figure 3-17 shows the developed collision diagram. Most of the rear-end crashes happened on highway were due to congestion or driver inattention. After reviewing all police reports, as well as surrounding roadway conditions, no roadway design problems contributing to large truck crash were discovered.

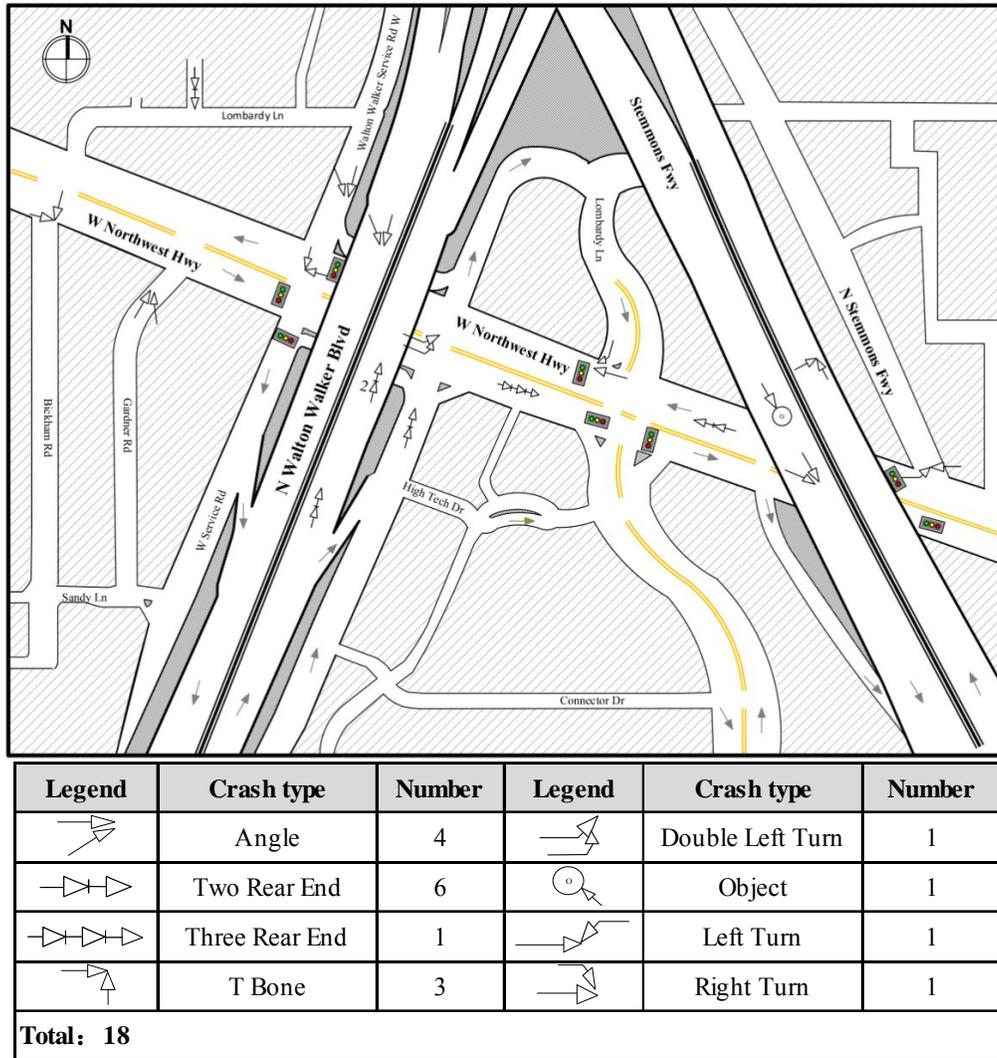


Figure 3- 17: Collision Diagram 8 for Large Truck Crash Hot Area 1 “North Dallas IH35”

3.4.1.9 Collision Diagram 9

Figure 3-18 shows the collision diagram developed for section 9. In total, 21 crashes occurred in this section, including 1 incapacitating crash. There is no roadway related risk factors identified.

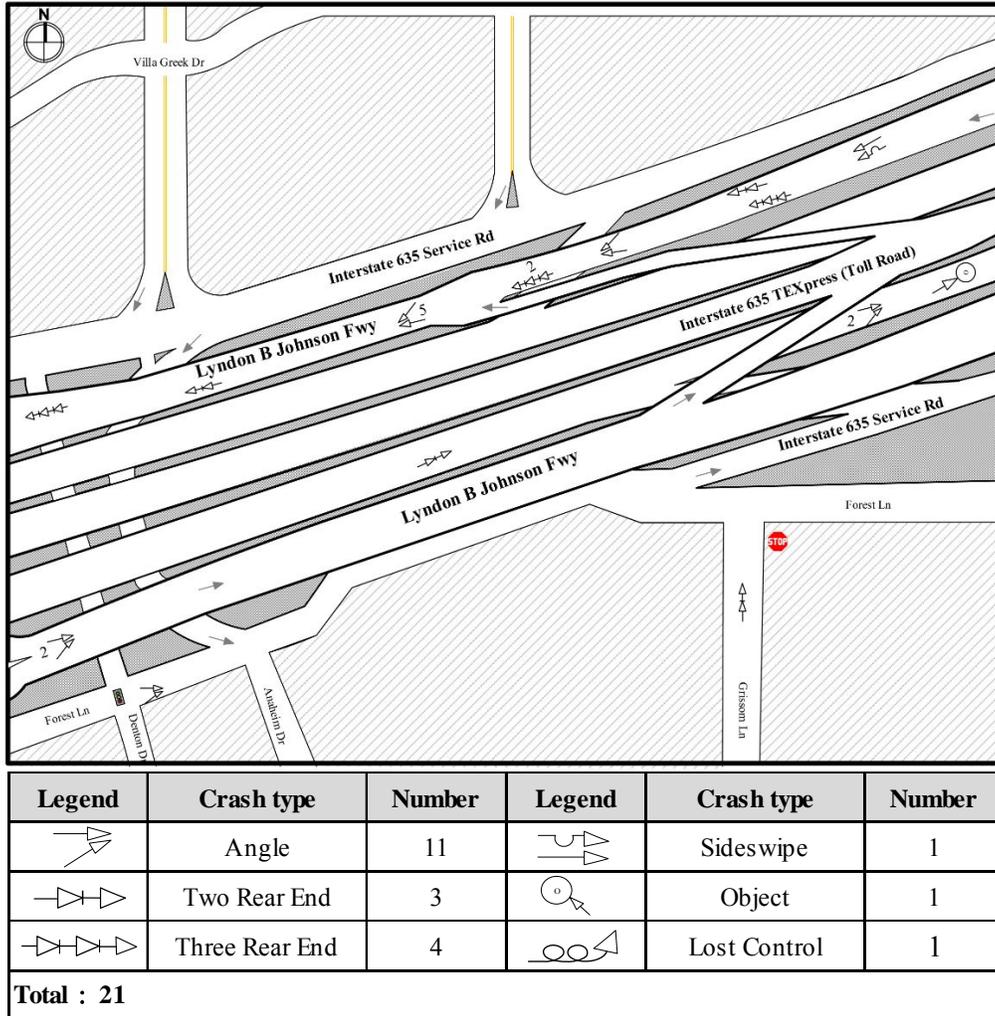


Figure 3- 18: Collision Diagram 9 for Large Truck Crash Hot Area 1 “North Dallas IH35”

3.4.1.10 Collision Diagram 10

Figure 3-19 is the developed collision diagram for section 10. In total, 22 crashes occurred in this section including 3 incapacitating crashes. Among all crashes, rear-end crash and angle crash are the two most common types. Angle crashes that occurred were caused by unsafe lane changes due to drivers’ inattention or errors. Similar to other sections in this area, there are high level of roadway constructions and traffic congestion.

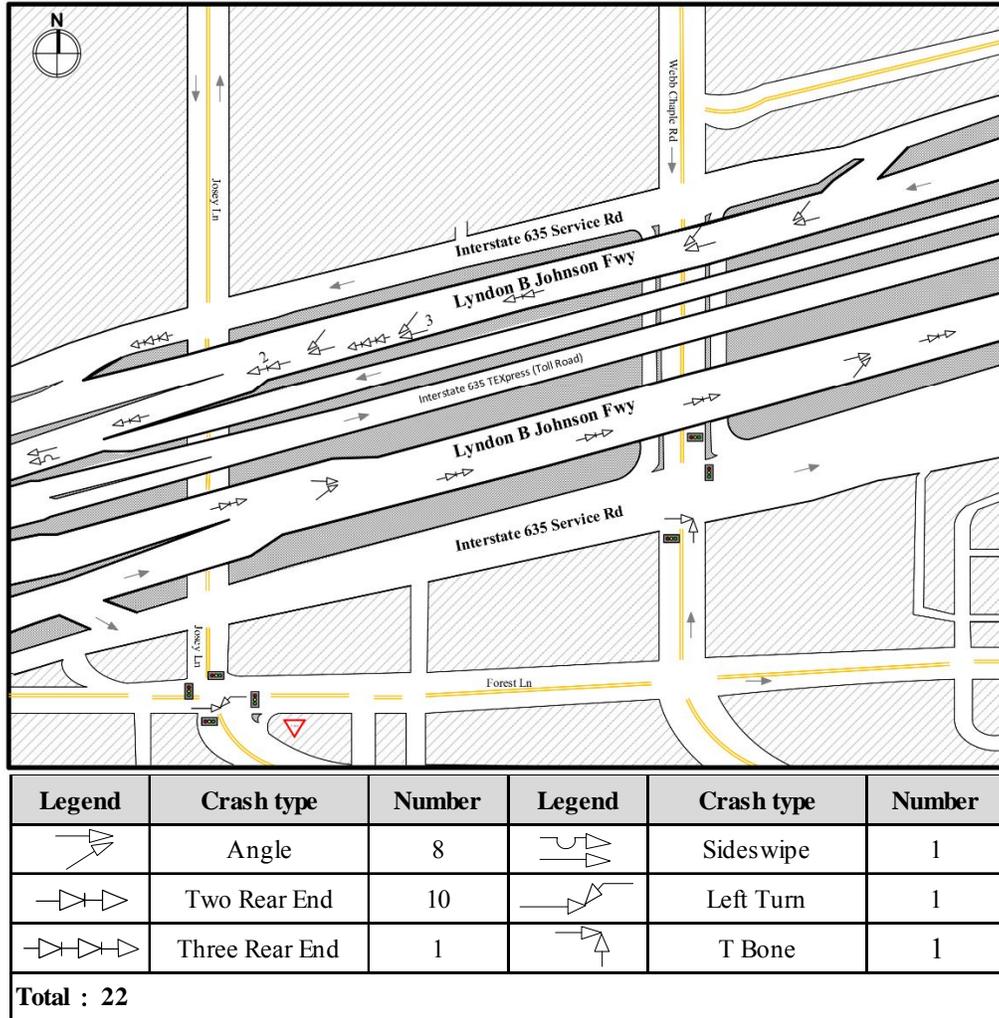
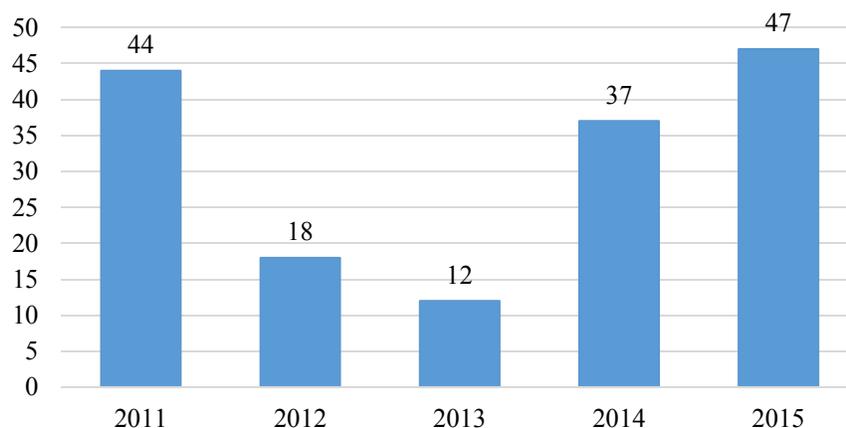


Figure 3- 19: Collision Diagram 10 for Large Truck Crash Hot Area 1 “North Dallas IH35”

3.4.2 Hot Area 2 Downtown Dallas IH35E

The second hot area with high frequency of large truck involved crashes is Dallas downtown area. From 2011 to 2015, there were 157 crashes occurred, including 4 fatal crashes and 5 incapacitating crashes. Some isolated crashes were eliminated from further analysis; therefore, 115 crashes were mapped for this area. Figure 3-20 shows the distribution of crash tendency and severity in the five years.

Crash Tendency in Downtown Dallas I-35E



Crash Severity Distribution in Downtown Dallas I-35E

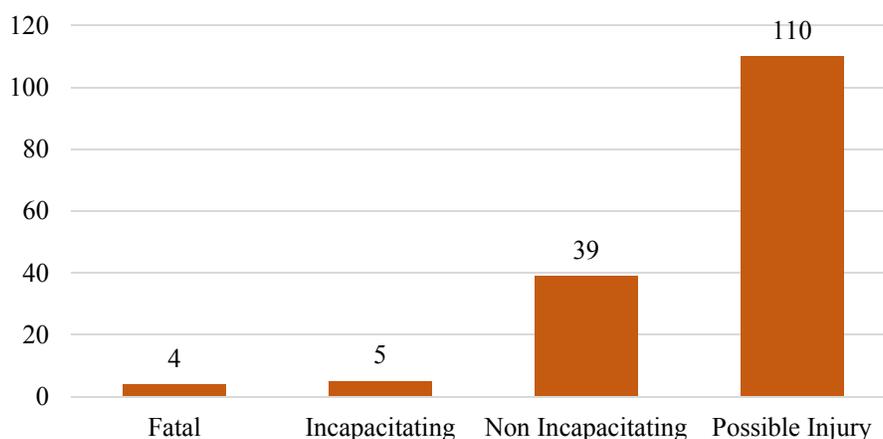


Figure 3- 20: Crash Tendency and Crash Severity Distribution at Hot Area 2

It is worth to mention that 2 fatal crashes were related to truck maintenance problems. Both trucks parked on shoulder due to mechanical issues, and passenger vehicles hit the rear of the trucks. Performing inspection and maintenance regularly could possible reduce the possibility of large truck having mechanical issues. In addition, when large truck parking on the shoulder or other roadside areas under emergency situation, it is very important to safeguard large truck, as well as other road users. According to the Federal Motor Carrier Safety Administration (FMCSA) regulations, CMV drivers should place either three-bidirectional reflective tri-angles or 3 liquid burning flares (6 fuses can be used instead) to the designated places (Federal Motor Carrier Safety Administration Regulations: Subpart C - Stopped commercial motor vehicles: § 392.22Emergency

signals; stopped commercial motor vehicles.).

For this area, 7 collision diagrams were developed. Figure 3-21 shows the crash locations as well as the boundaries of the sections for developing the collision diagrams. The analyses of these 7 collision diagrams developed for this area are presented in the following parts.

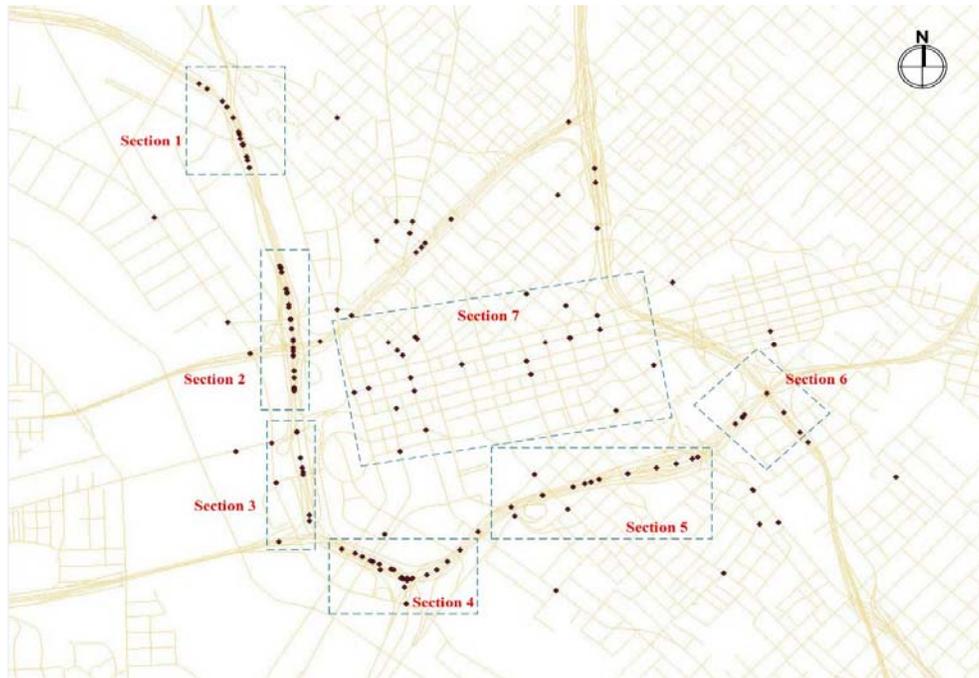


Figure 3- 21: Area Map and Collision Diagram Sections at Hot Area 2 “Downtown Dallas IH35E”

3.4.2.1 Collision Diagram 1

In section 1, 20 crashes occurred in 2011-2015, including 10 rear-end crashes, 9 angle crashes and 1 out of control crash. Figure 3-22 is the collision diagram for this section. The major types of crashes happened in this area were rear-end and angle crashes. After analyzing police reports, the reasons contributing to these crashes include roadway slopes and high traffic volume.

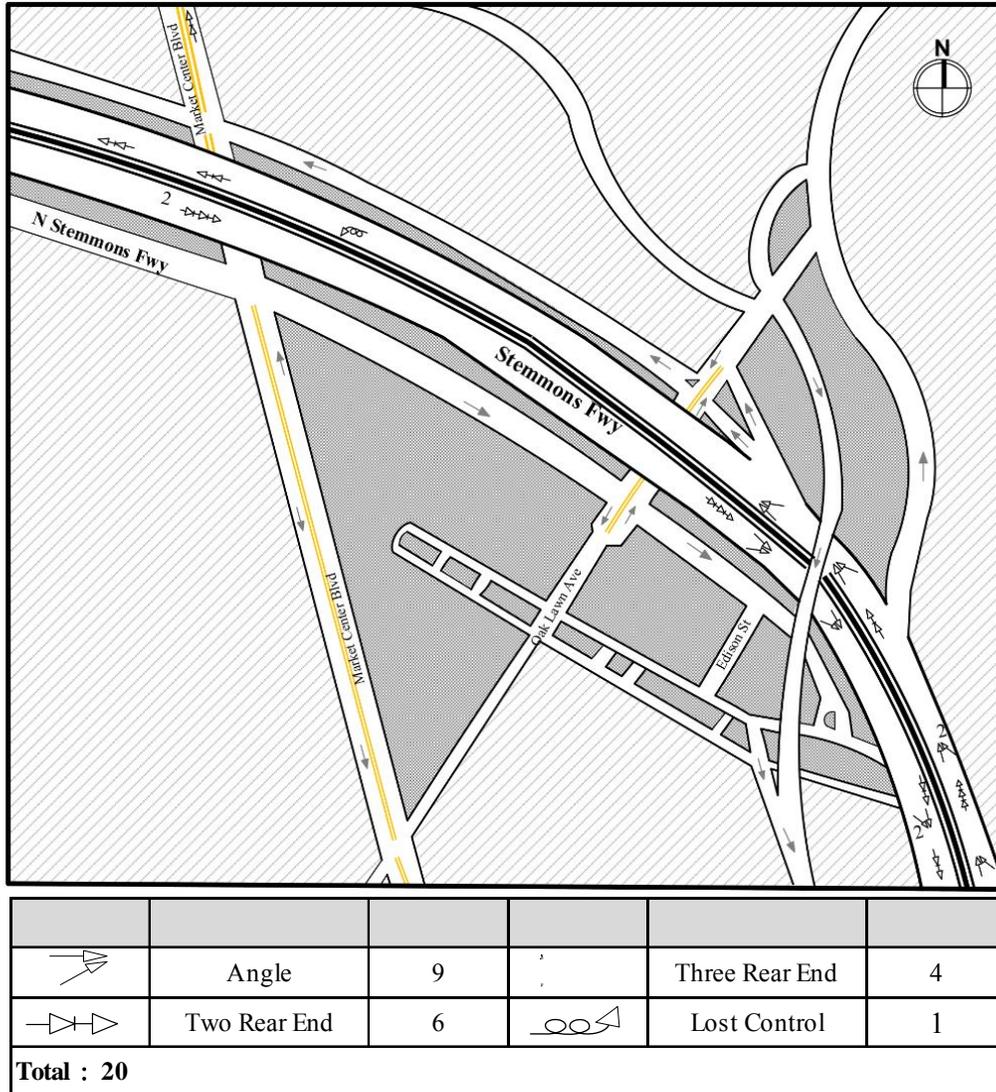
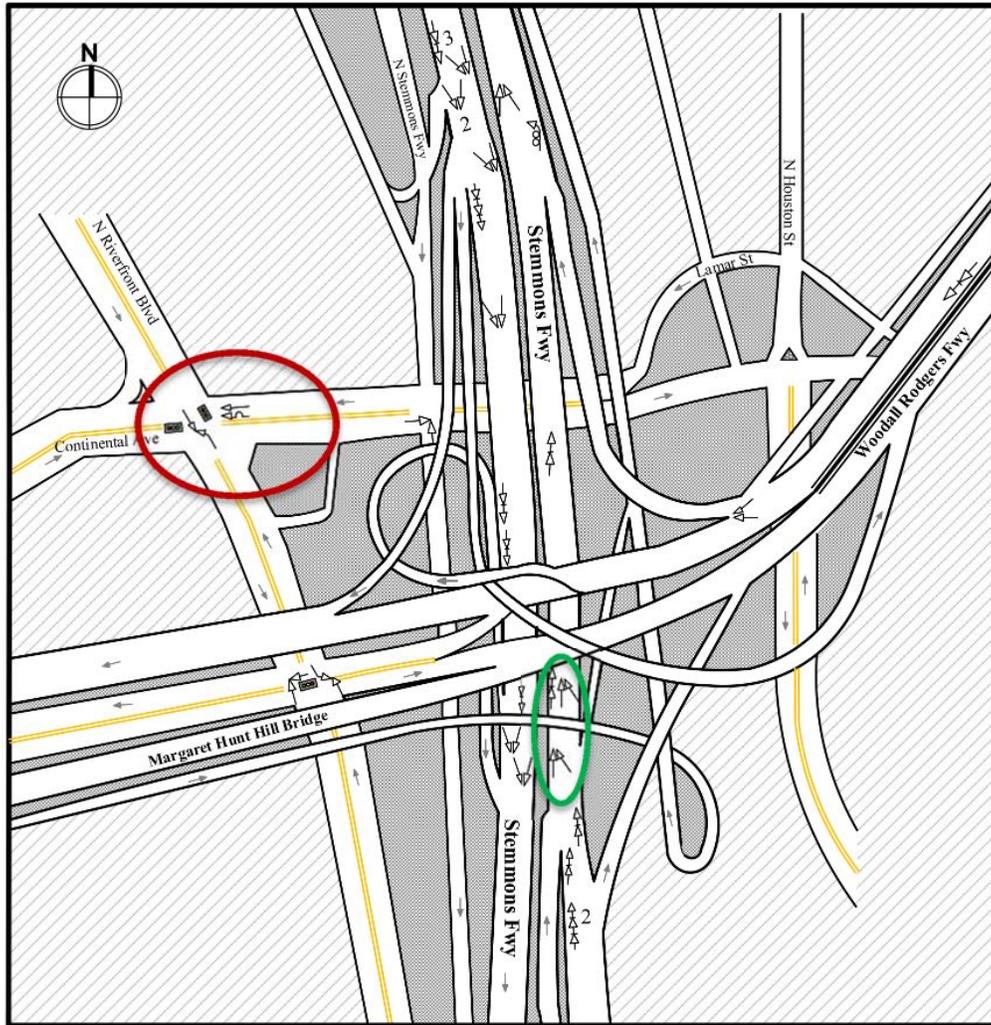


Figure 3- 22: Collision Diagram 1 for Crash Hot Area 2 “Downtown Dallas IH35E”

3.4.2.2 Collision Diagram 2

Section 2 has 32 crashes happened in 2011-2015. Figure 3-23 shows the collision diagram for this section. The major crash types were rear end crashes (14) and angle crashes (11). After reviewing the police reports, we found the high rate of angle crashes in this area were mostly due to drivers’ errors and unsafe lane changes, and the major reason for the rear end crashes was traffic congestion. In addition, we have following two findings at one signalized intersection and one interchange area.



Legend	Crash type	Number	Legend	Crash type	Number
	Angle	11		Sideswipe	1
	Two Rear End	11		T Bone	3
	Three Rear End	3		Left Turn	2
	Lost Control	1			
Total: 32					

Figure 3- 23: Collision Diagram 2 for Crash Hot Area 2 “Downtown Dallas IH35E”

Finding 1: unsafe intersection design (red circle in Figure 3-23)

There is one large skewed intersection in this area (N Riverfront Blvd @ Continental Ave). As show in Figure 3-24, this intersection has dual left-turn lanes operated with protected-permissive left turn signal phasing, which cause crash risks between left turn vehicle and through vehicle. To reduce heads on crash between left turn vehicle and

through vehicle, protected-only phasing is recommended.

In addition, there are several sideswipe crashes occurred when left turn vehicles turning abreast in the dual left-turn lanes. It is recommended to add turning guidelines on the pavement to prevent such crashes.



Figure 3- 24: Google Map of the Problematic Location

Finding 2: angle crashes at interchange (green circle in Figure 3-23)

Figure 3-25 is the location where 2 angle crashes and 1 rear-end crash occurred. It can be seen from picture that the merge distance is very short, which may cause lots of conflicts when vehicles merging into the main lane.

To reduce angle crashes near highway entrance ramps, following countermeasures could be implemented:

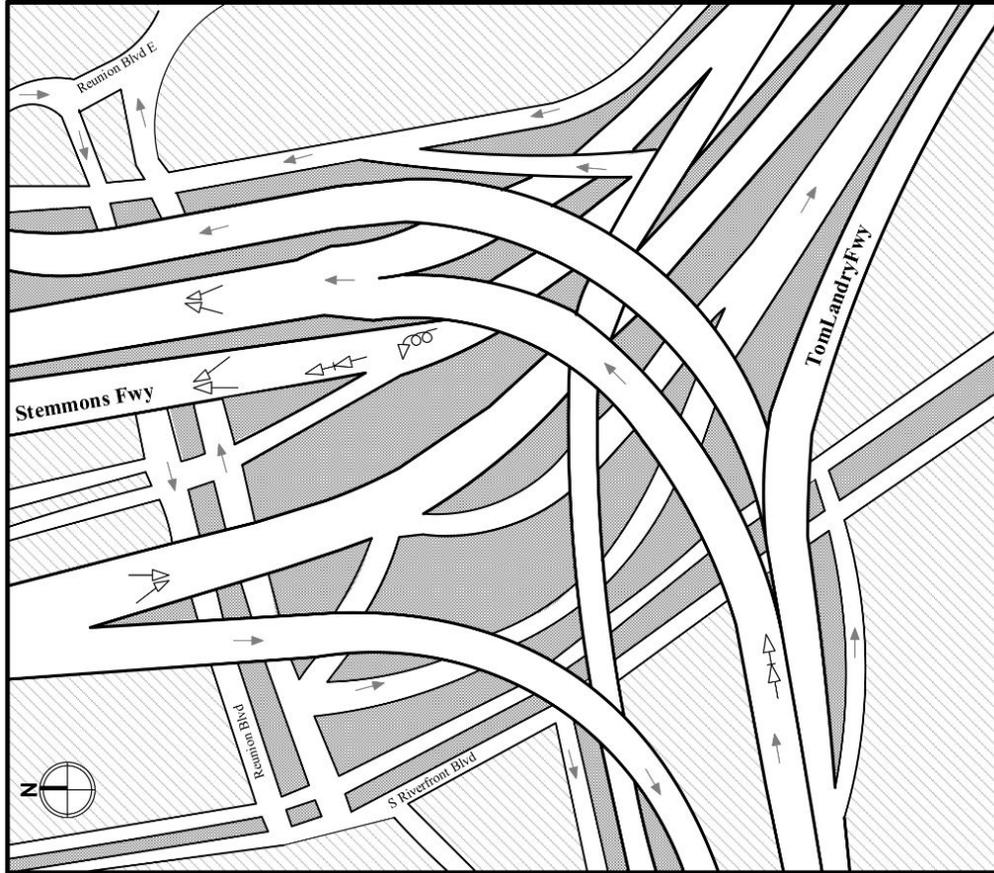
- Extend merge distance for on ramps
- Restrict large truck from the right-most lane



Figure 3- 25: Google Map of the Problematic Location

3.4.2.3 Collision Diagram 3

For section 3 in this area, 6 crashes occurred in 2011-2015, including 4 angle crashes and 2 rear end crashes. All Crashes were driver error related, no infrastructure related problems were found.

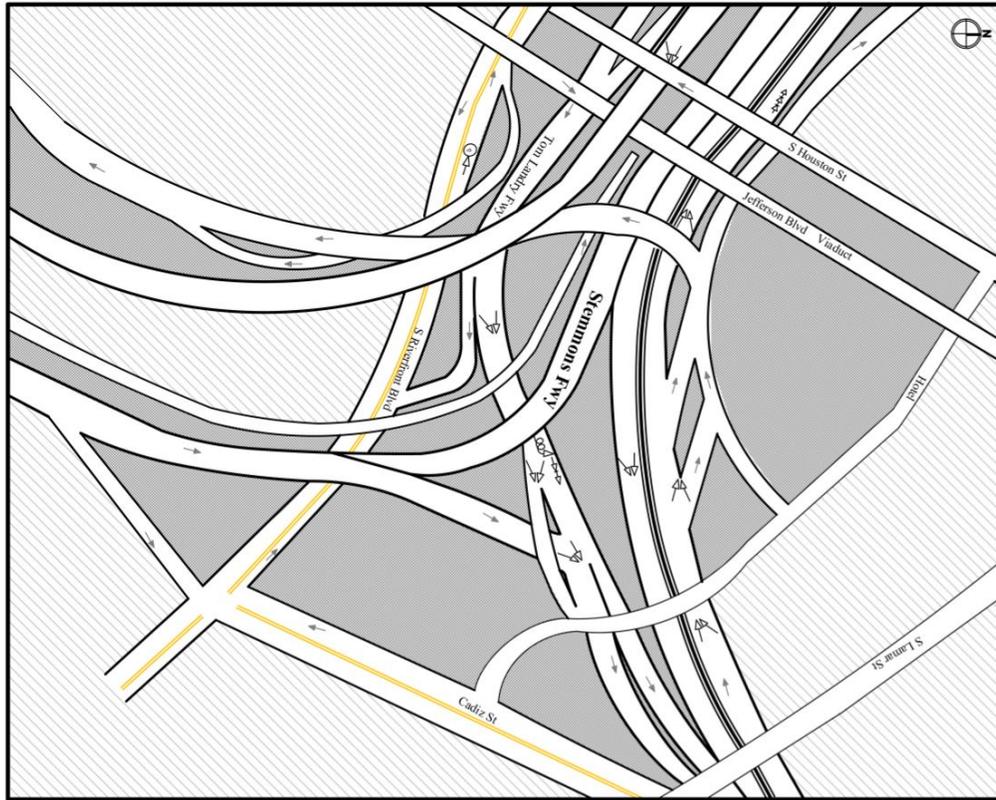


	Angle	4		Three Rear End	1
	Two Rear End	1			
Total : 6					

Figure 3- 26: Collision Diagram 3 for Crash Hot Area 2 “Downtown Dallas IH35E”

3.4.2.4 Collision Diagram 4

During 2011-2015, 12 crashes happened in section 4, and 8 of them were angle crashes. Figure 3-27 shows the developed collision diagram. After analyzing this section, one common highway design issue was identified.



Legend	Crash type	Number	Legend	Crash type	Number
	Angle	8		Pedestrian	1
	Two Rear End	1		Sideswipe	1
	Lost Control	1			
Total: 12					

Figure 3- 27: Collision Diagram 4 for Crash Hot Area 2 “Downtown Dallas IH35E”

Finding: late lane changes

There were 3 crashes involving inappropriate late lane change behavior. The main reasons causing late lane change include: 1) unclear signs for directions; 2) short merge distance; 3) drivers intentionally merge late to avoid long queues.

Although drivers’ error is the major contributing factor, some improvements on roadway design could also help prevent such error:

- Add more advanced traffic signs or pavement marker to indicate the lane configuration
- Use auxiliary lane to facilitate merging
- Install physical barriers, such as pylons, at the gore of the entrance ramps

3.4.2.5 Collision Diagram 5

Figure 3-28 is the collision diagram developed for this section. In this section, 14 large truck involved crashes occurred during the past 5 years. Although it is not a large number, some issues were identified.

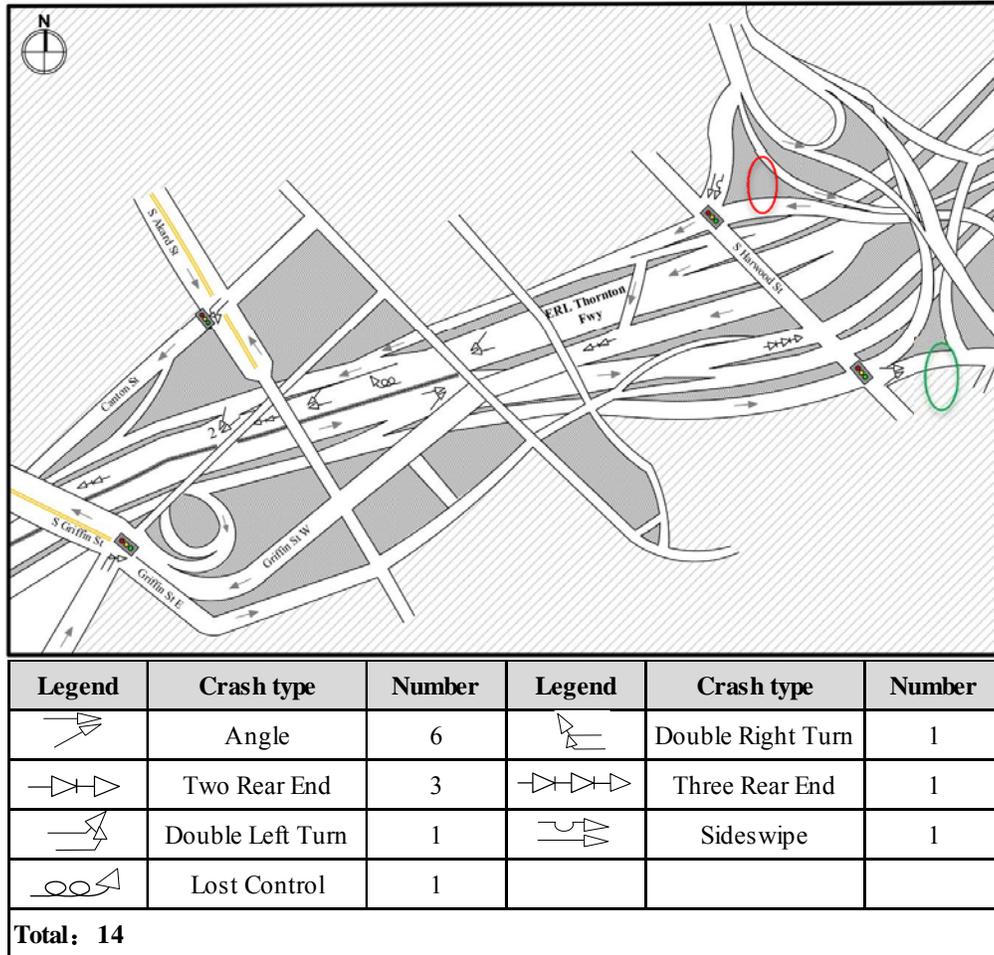


Figure 3- 28: Collision Diagram 5 for Crash Hot Area 2 “Downtown Dallas IH35E”

Finding 1: narrow lanes (red circle in Figure 3-28)

Following Figure 3-29 shows a street where a large truck sideswiped with another vehicle. From the picture, we can see that there is no pavement marking, and also the lane width is just 9.5 ft, which is less than the standard width.



Figure 3- 29: Google Map of the Problematic Location

Finding 2: short merge distance to right-turn lane (green circle in Figure 3-28)

As showed in Figure 3-30, the merge distance for vehicle changing to right turn lane is very short, especially for large truck, which may cause angle crashes. Also, there is no turning guide line for right turn vehicles.

The countermeasures could potentially improve this intersection include:

- Use dual-right turn lane to reduce the number of lane changes
- Conduct turning path analysis to ensure intersection layout can accommodate the turning movement of vehicles, especially large trucks
- Add more pavement markers for right turn only lane



Figure 3-30: Google Map of the Problematic Location

3.4.2.6 Collision Diagram 6

Figure 3-31 is the collision diagram developed for section. In this section, 8 large truck

involved crashes occurred during the past 5 years. Some interchanges in this section also have the same issue, as we mentioned before, that direction signs are not clear to drivers, thereby causing many late lane change behaviors, which increase the risk for angle or rear-end crashes.

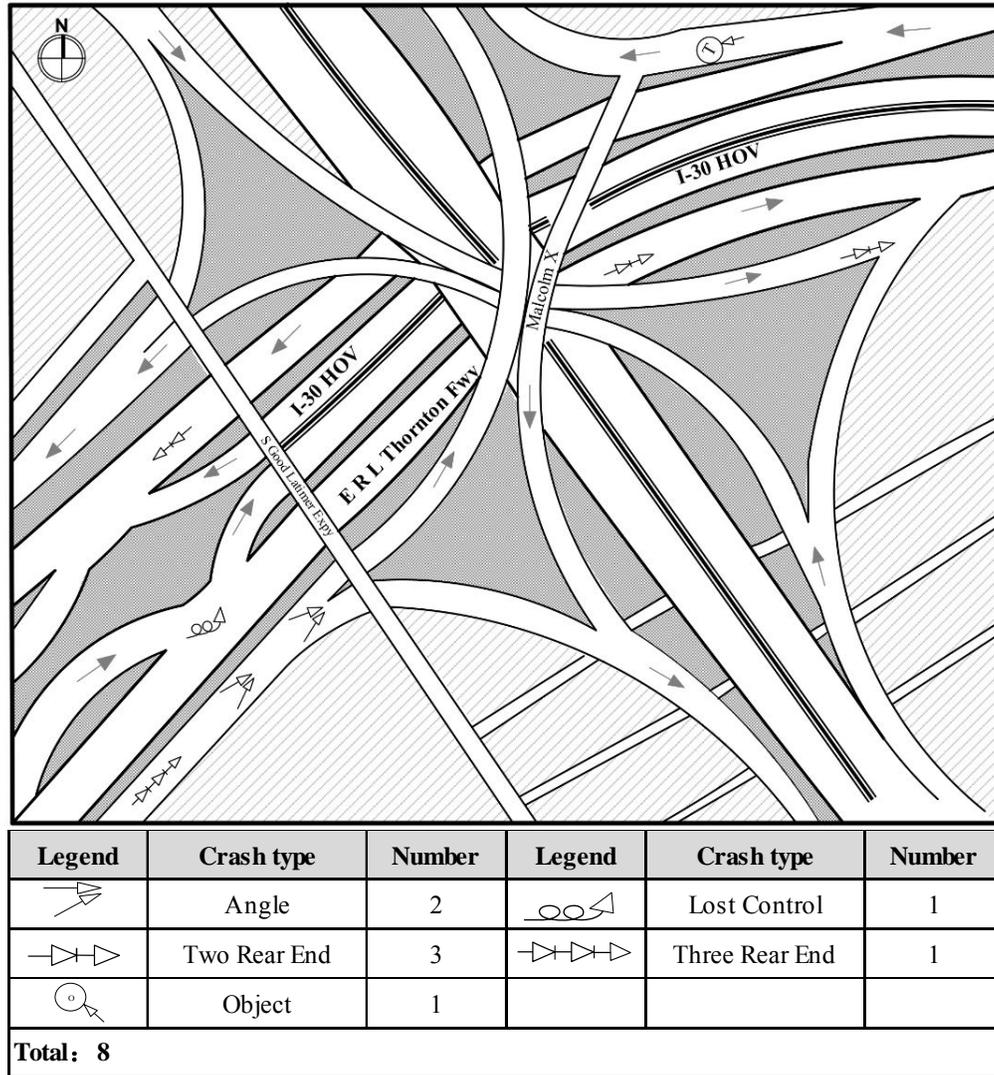


Figure 3- 31: Collision Diagram 6 for Crash Hot Area 2 “Downtown Dallas IH35E”2

3.4.2.7 Collision Diagram 7

Figure 3-32 is the collision diagram developed for section 7. In this section, 23 crashes occurred from 2011-2015. Among all crashes, there were 7 intersection T-bone crashes, 5 left-turn crashes. After reviewing police reports, it was noticed that most of the crashes were caused by drivers’ error, such as driver inattention and drivers failed yield to other

vehicles. No roadway related risk factor was identified.

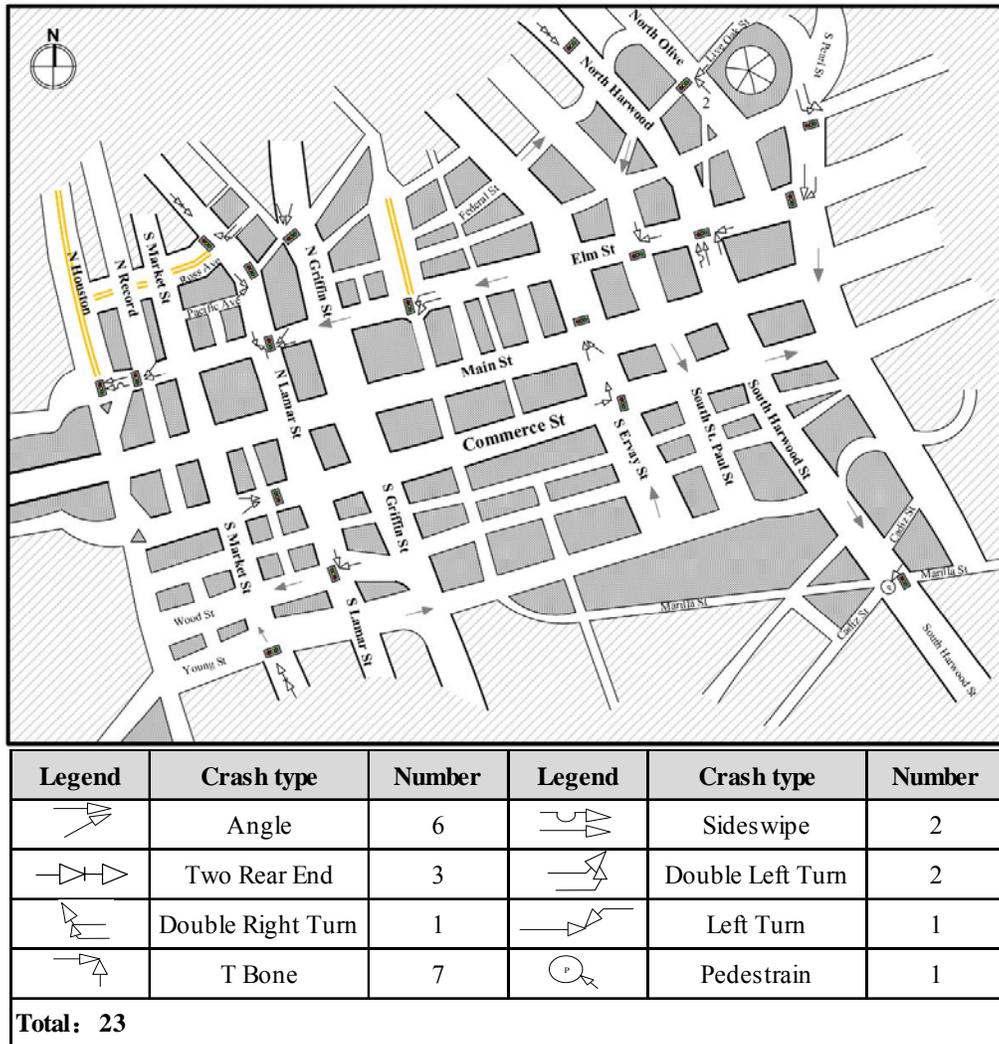
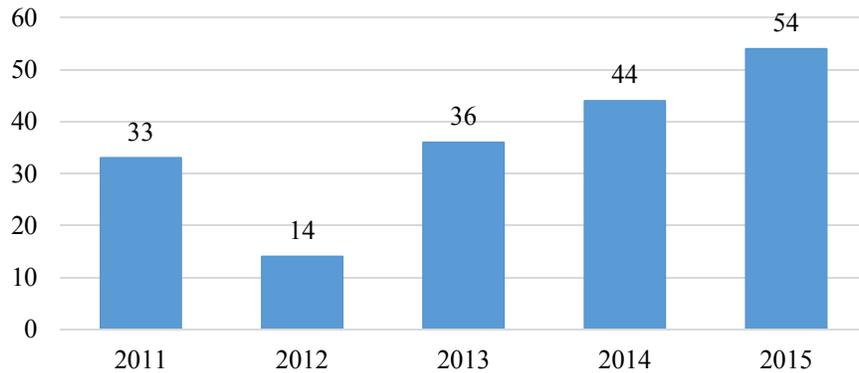


Figure 3- 32: Collision Diagram 7 for Crash Hot Area 2 “Downtown Dallas IH35E”

3.4.3 Hot Area 3 South Dallas IH20

South Dallas area at IH20 is another hot area we identified. In this area, 180 crashes were reported totally, including 5 fatal crashes, and 11 incapacitating crashes. Figure 3-33 shows the five-year crash tendency and crash severity distribution. Five collision diagrams were developed for this area. Figure 3-34 shows the location of the crashes happened in this area, and the boundaries of the sections for developing collision diagrams. Some isolated crashes were eliminated from the analysis, and finally, 157 crashes were mapped for this area in total.

Crash Tendency in South Dallas IH20



Crash Severity Distribution in South Dallas IH20

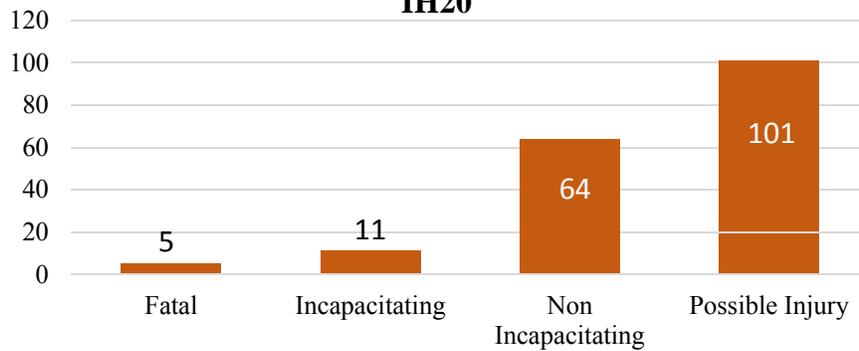


Figure 3- 33: Crash Tendency and Crash Severity Distribution at Hot Area 3

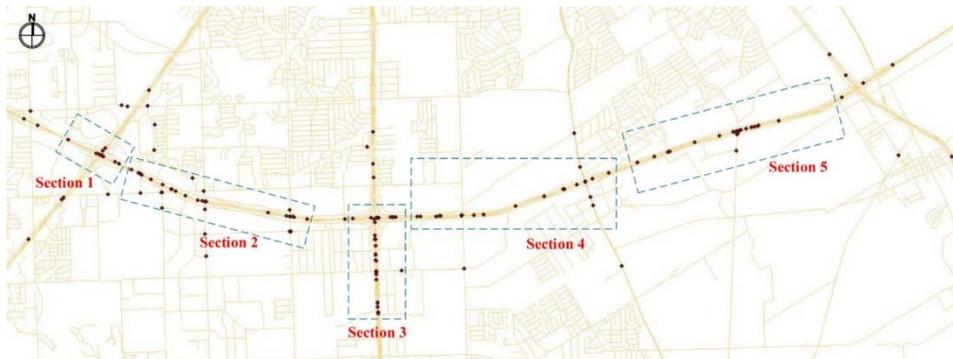
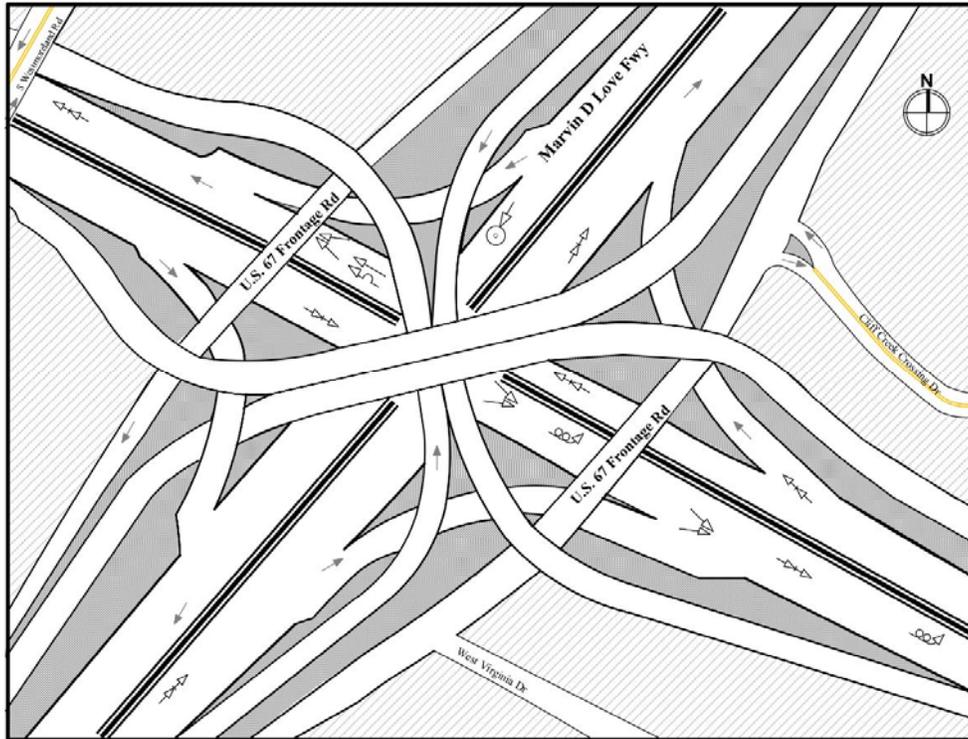


Figure 3- 34: Area Map and Collision Diagram Sections at Hot Area 3 “South Dallas IH20”

3.4.3.1 Collision Diagram 1

There were 14 crashes occurred in section 1. Figure 3-35 is the collision diagram. Among all crashes, rear-end crash has the largest number. By reviewing all crash reports, no roadway related risk factors were identified.



Legend	Crash type	Number	Legend	Crash type	Number
	Angle	3		Lost Control	2
	Two Rear End	7		Sideswipe	1
	Object	1			
Total: 14					

Figure 3- 35: Collision Diagram 1 for Large Truck Crash Hot Area 3 “South Dallas IH20”

3.4.3.2 Collision Diagram 2

Figure 3-36 is the collision diagram developed for section 2 at hot area 2. There were 45 crashes occurred within this section. Among all crashes, 17 were rear-end crashes, 12 were angle crashes, 4 were trucks out of control, and 6 were T-bone crashes. Most of the crashes occurred due to drivers’ errors. No roadway related risk factor was discovered.

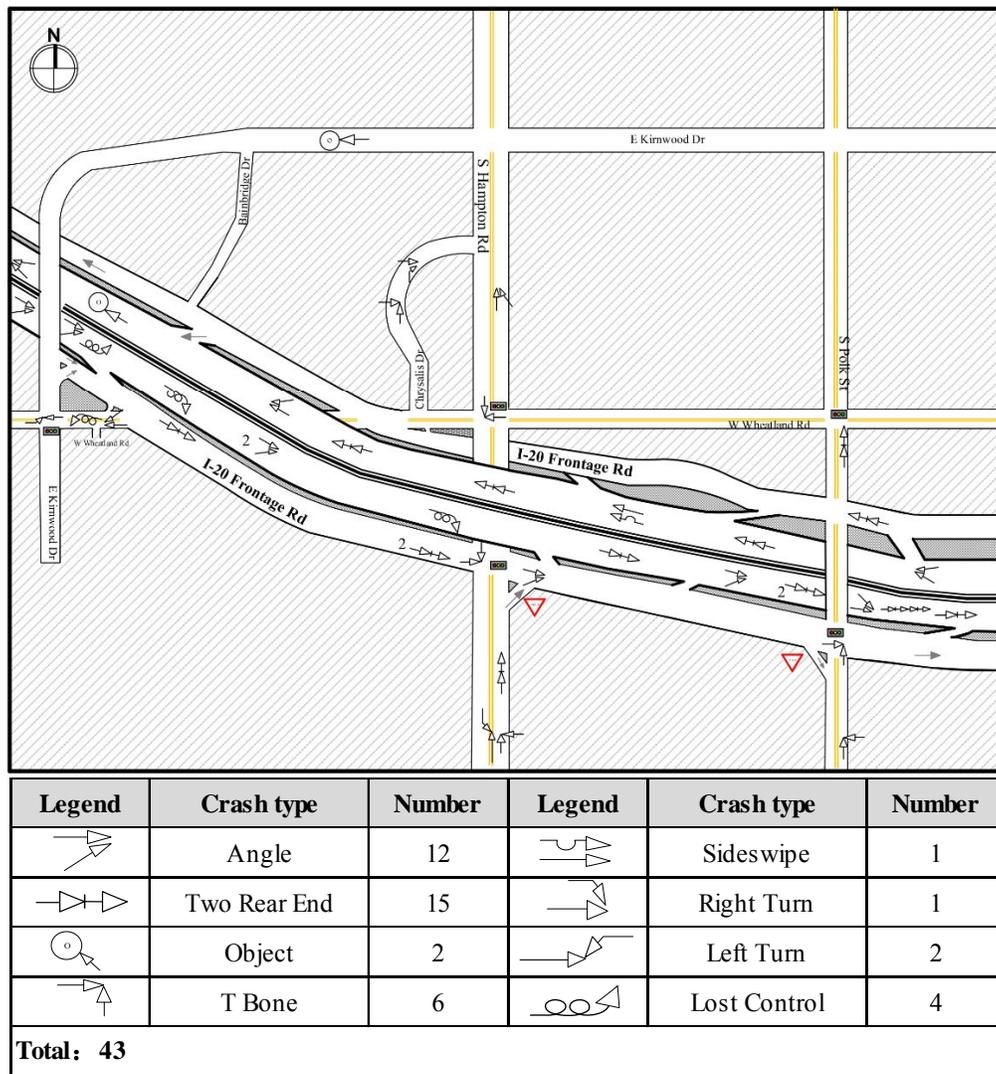


Figure 3- 36: Collision Diagram 2 for Large Truck Crash Hot Area 3 “South Dallas IH20”

3.4.3.3 Collision Diagram 3

In section 3, 37 crashes occurred during the past 5 years. Rear-end crash was the most frequently happened crash, followed by angle crash. Very unusual, 8 crashes were caused by vehicle out of control.

Finding: 8 trucks went out of control (red rectangle in Figure 3-37)

The high number of crashes caused by one vehicle out of control is very unusual. After carefully review police reports, we noticed that 6 crashes were caused by unsafe speed, 1 crash was caused by tire blew out, and 1 crash was caused by drunk driver. This result shows speeding is very common issue in this area. To prevent such type of crash, possible

countermeasures may include:

- Add more speed limit signs and warning signs
- Increase law enforcement to ticket speeding drivers in this area

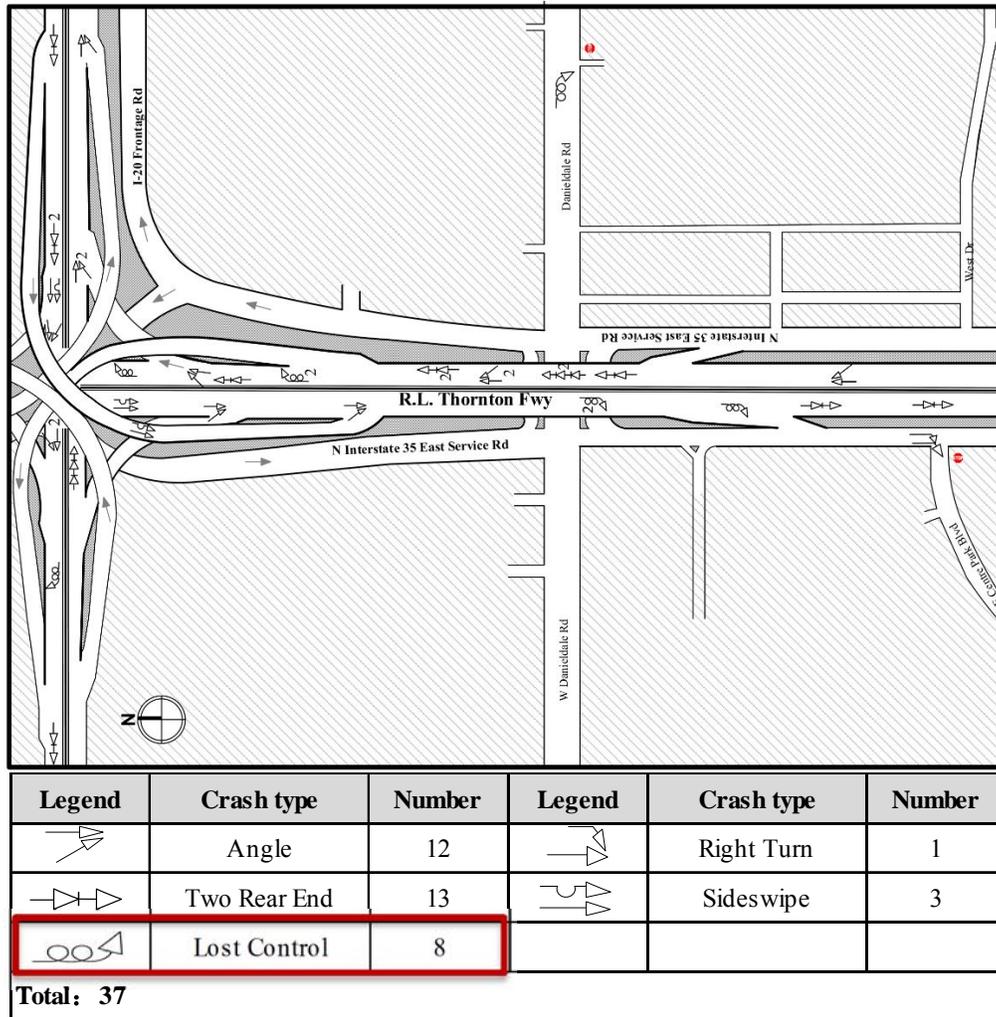


Figure 3- 37: Collision Diagram 3 for Large Truck Crash Hot Area 3 “South Dallas IH20”

3.4.3.4 Collision Diagram 4

Figure 3-38 is the collision diagram developed for section 4 of hot area 3. During 2011-2015, 27 large truck involved crashes occurred in this section. Of all 27 crashes, 10 were angle crashes. By examining the collision diagram, we noticed that most of the angle crashes (7 out of 10) happened near on-ramps or off-ramps.

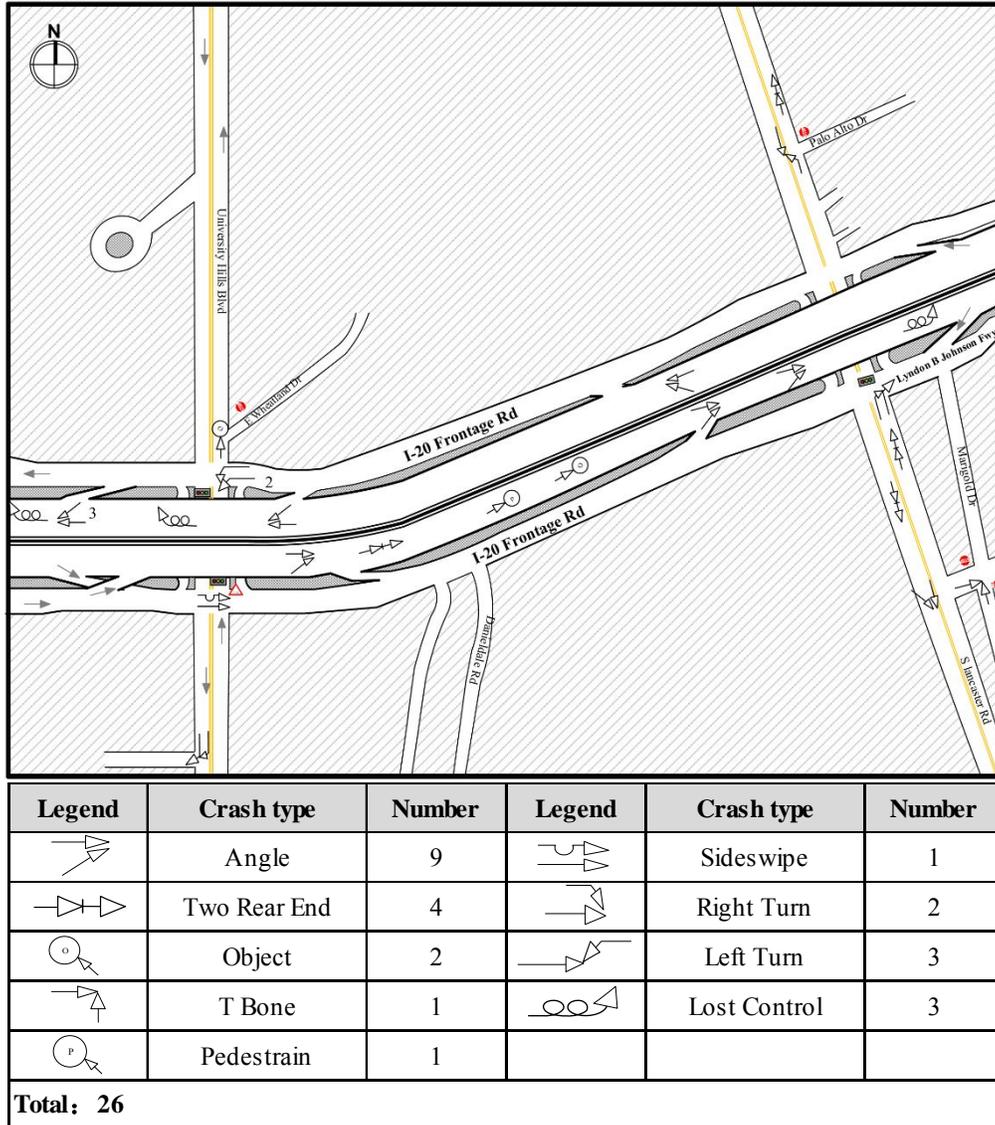


Figure 3- 38: Collision Diagram 4 for Large Truck Crash Hot Area 3 “South Dallas IH20”

Finding: short merge distance

Direct-taper design of on-ramp is widely applied in this area. When applying taper ramp, it is critical to provide enough distance for drivers to accelerate and merge into main lanes. We noticed that there is an on-ramp has quite short merge distance. The short distance makes merge difficult for vehicles, especially for the large trucks. Figure 3-39 is the picture of this ramp.

To reduce angle crashes near highway entrance ramps, following countermeasures could be implemented:

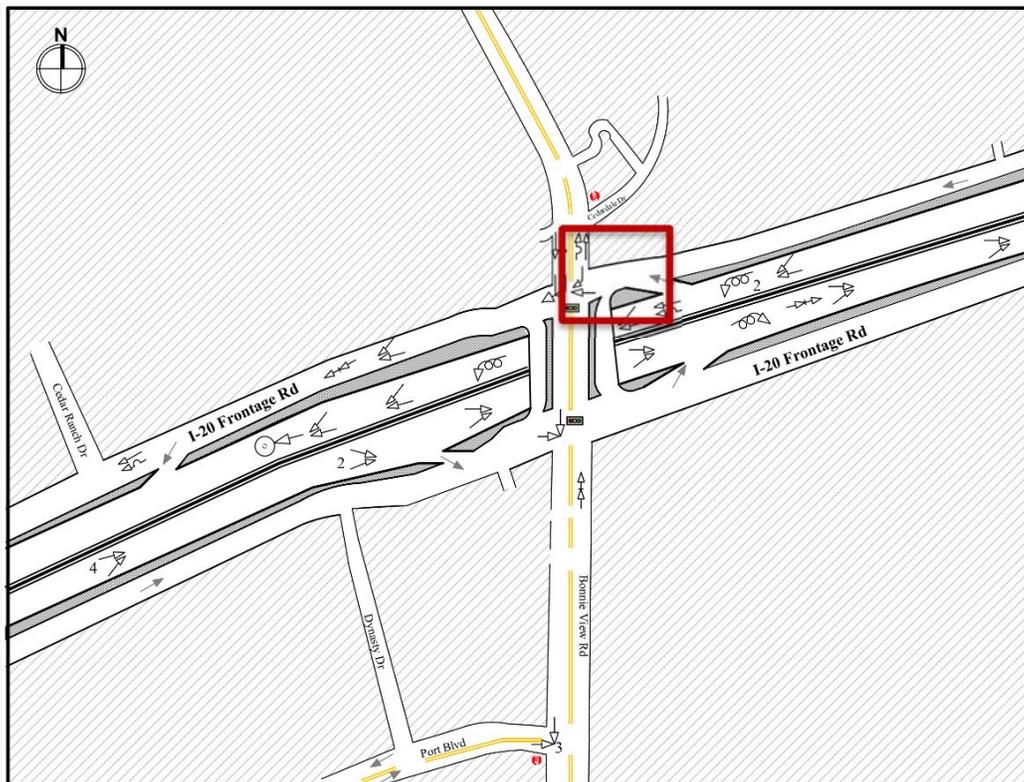
- Extend merge distance for on ramps
- Restrict large truck from the right-most lane



Figure 3- 39: Google Map of the Problematic Location

3.4.3.5 Collision Diagram 5

Figure 3-40 is the collision diagram developed for section 5. As showed, totally 33 crashes happened in this section. Research team studied all crash reports and locations where crashes occurred, and found two major issues.



Legend	Crash type	Number	Legend	Crash type	Number
	Angle	15		Sideswipe	4
	Two Rear End	3		Right Turn	2
	Object	1		Lost Control	4
	T Bone	4			
Total: 33					

Figure 3- 40: Collision Diagram 5 for Large Truck Crash Hot Area 3 “South Dallas IH20”

Finding 1: Lack of pavement markings

The T-intersection at Bonnie view Rd@ Port Blvd (Figure 3-41) has a very high percentage of truck volume. However, the roadway pavement markers have already worn away.



Figure 3- 41: Google Map of the Problematic Location

Finding 2: narrow receiving lane at intersection (red rectangle in Figure 3-42)

The intersection showed in Figure 3-42 also has no left-turn guide lines. This is a very common problem existing. In addition, the receiving lane for left turn is quite narrow (9.5ft).



Figure 3- 42: Google Map of the Problematic Location

Finding 3: bus stop may block drivers' view

There is a bus stop near a stop sign controlled intersection (see Figure 3-43), which could block drivers' view when city buses stop there. An accident happened at this location. In this accident, the driver of the passenger car stated that he cannot see truck approaching because the city bus obscured his visibility, then he failed to yield at the stop sign.

Possible solution could be move the bus stop to the downstream of the intersection, or replace the stop sign control with traffic signal control at this intersection.

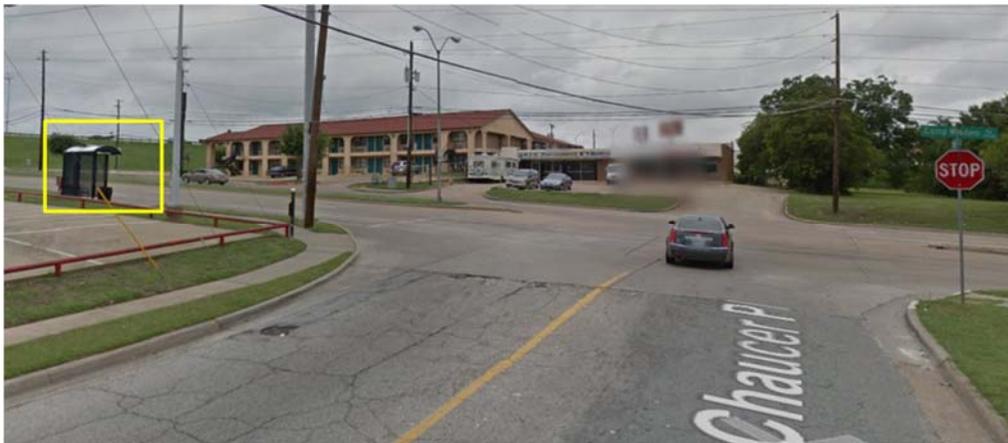
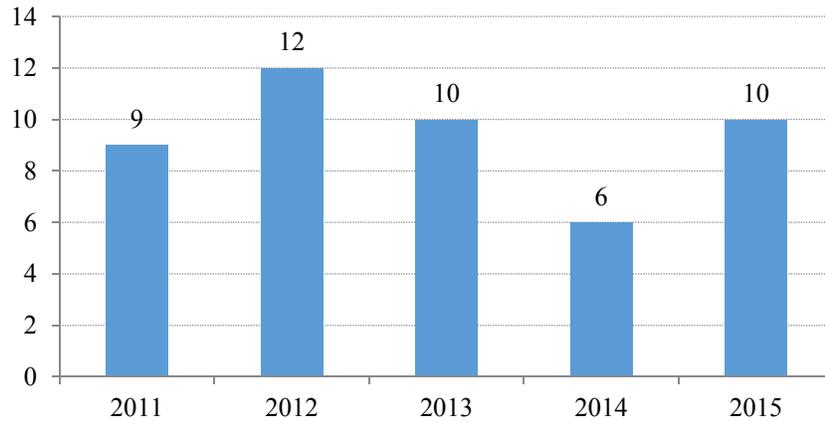


Figure 3- 43: Google Map of the Problematic Location

3.4.4 Hot Area 4 Houston IH610 @ US90

Hot Areas 4 locates at Houston IH610 and US90. From 2011 to 2015, 107 large truck-involved crashes occurred in this area. Same as previous hot areas, isolated crashes were eliminated from the analysis. The last 5 years crash tendency and crash severity distribution are shown in Figure 3-44. Finally, the whole area was separated into four sections. As showed in Figure 3-45, 93 crashes were mapped in 4 collision diagrams.

Crash Tendency in Houston IH10 @ IH 610



Crash Severity Distribution in Houston IH10 @ IH 610

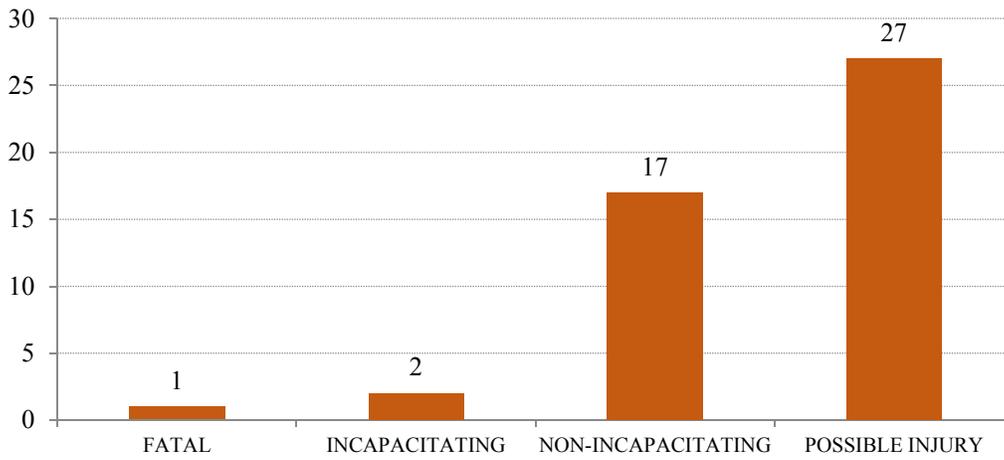


Figure 3- 44: Crash Tendency and Crash Severity Distribution at Hot Area 4

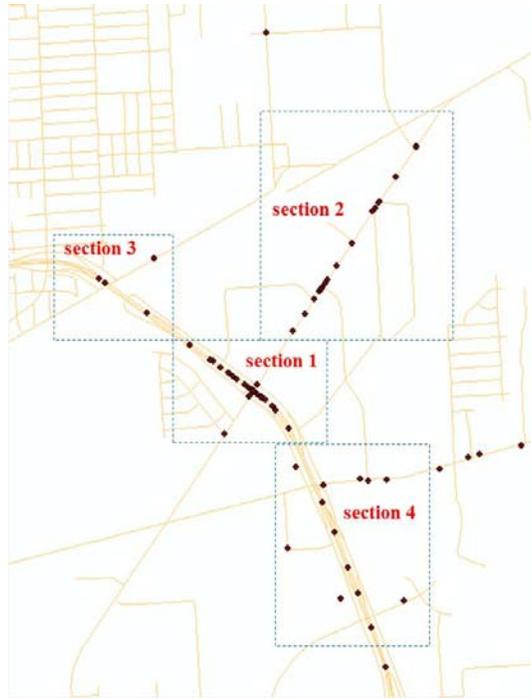
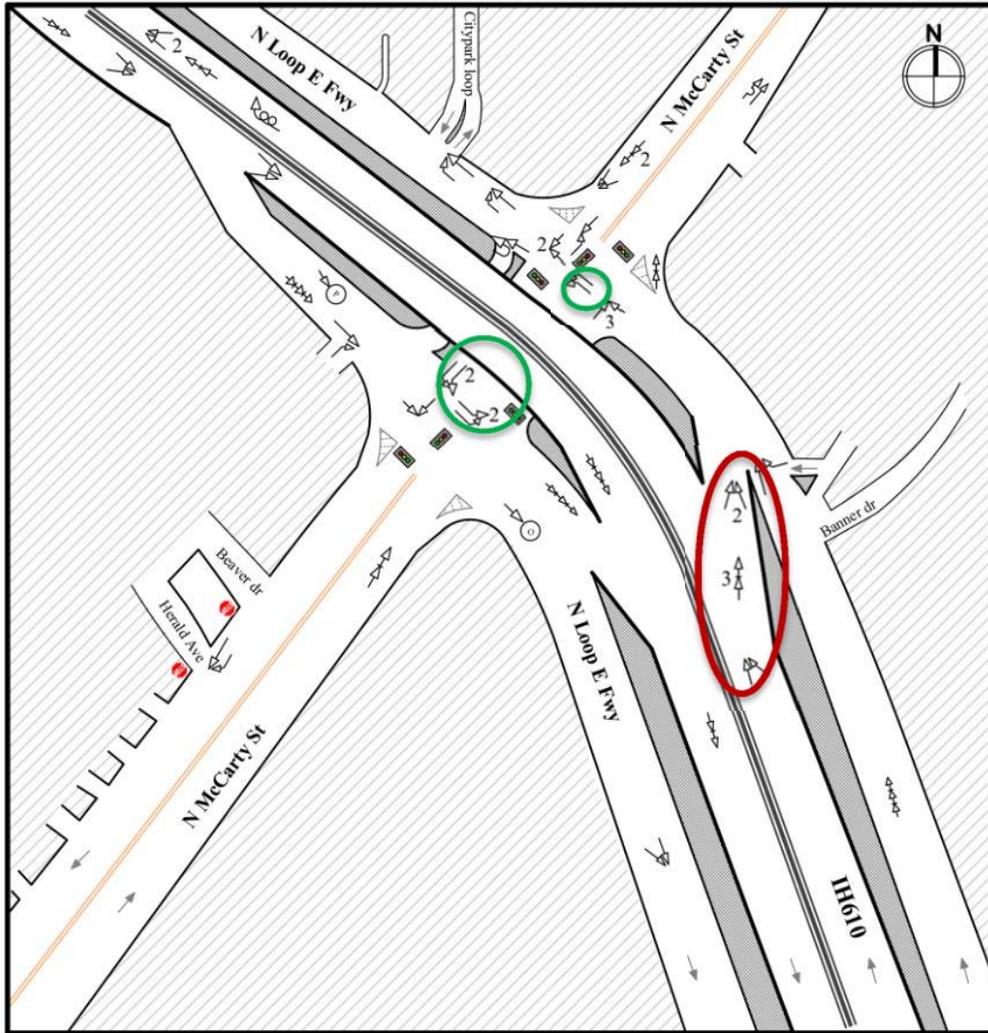


Figure 3- 45: Area Map and Collision Diagram Sections at Hot Area 4 “Houston IH610 @ US90”

3.4.4.1 Collision Diagram 1

45 crashes occurred in section 1 were mapped in the developed collision diagram. From Figure 3-46, it can be seen that the major types of the crash in this section are rear-end crash, angle crash, intersection T-bone crash, double left turn crash and right turn crash. Several roadway related crash risks were identified.



Legend	Crash type	Number	Legend	Crash type	Number
	Angle	9		T Bone	6
	Two Rear End	10		Sideswipe	1
	Object	1		Lost Control	1
	Double Left Turn	5		Right Turn	5
	U-Turn	1		Left Turn	1
	Three Rear End	4		Pedestrian	1
Total: 45					

Figure 3-46: Collision Diagram 1 for Large Truck Crash Hot Area 4 “Houston IH610 @ US90”

Finding 1: 6 rear-end and angle crashes (red circle in Figure 3-46)

There were 6 rear-end and angle crash occurred near off ramp of Northbound IH610.

Further examination shows the downstream intersection is congested and there has high truck volume. The congestion at intersection often caused queue on the off ramp. Sudden speed reduction may lead to rear-end or angle crash if drivers' inattention or unable to control their speed.

To reduce rear end crashes on ramp or near ramp location, radar speed signs and transverse rubber strips can be utilized.

Finding 2: 6 intersection crashes

There were 6 T-bone crashes occurred at the diamond intersection (N loop E Fwy @ N McCarty St.). After reviewing the police reports, we discovered that all crashes were caused by drivers running red light, which may be due to the poor visibility of the signal lights at this location. At this intersection, the sight distance for the NW bound approach is affected by the curve. In addition, the high volume of large trucks increases the chance that the drivers' view was blocked by the truck and cannot see the signal lights. To prevent such problem, some engineering countermeasures, such as adding near-side signal heads, could be implemented to increase signal visibility and decrease the chance of running red lights at the intersection. Further investigations are needed to identify the most cost-effective countermeasures.

Finding 3: 5 double left-turn crashes (green circle in Figure 3-46)

5 double left turn crashes occurred at the same intersection. After examining this intersection, we found that dual-left turn setting applies for all four directions. Heavy truck volume makes the dual-left turn movement more risky. In addition, the guide lines were almost worn off on the road, and the signage to assist drivers is also lacking. Please see Figure 3-47 for the pictures at this intersection.

To reduce double left-turn crash, pavement markings could be applied for turn lanes to clearly designate the path to be taken by drivers. In addition, designated signal light heads for each lane also can be implemented at this intersection to assist driver making turns.

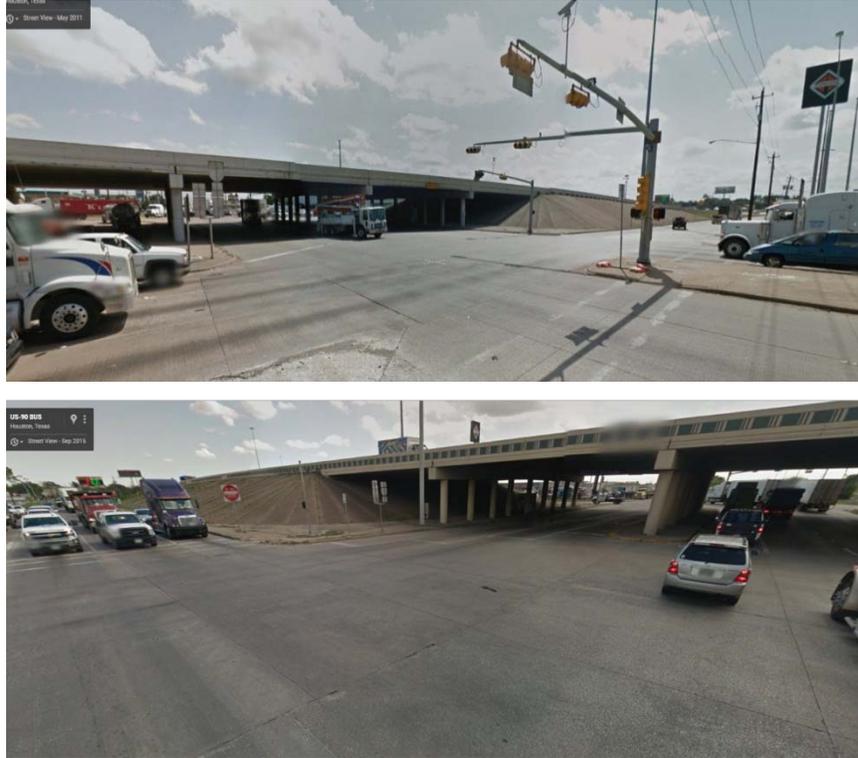


Figure 3- 47: Google Map of the Problematic Location

Finding 4: right-turn angle crashes (blue circle in Figure 3-46)

Right turn crash happens when right turning truck hits through vehicles on its right side. Due to its size, large truck makes much wider right turn than passenger vehicle. Also, it takes more time for large truck to complete turning movement. Sometimes, this type of crash is very likely to happen if passenger vehicle didn't notice the large truck was making turning or tried to pass it before it finishes the turning movement.

In this area, several locations have narrow lane and narrow openings for the access points at the right side of the roadway, which make truck unable to make right turn from the right-most lane, therefore increase the risk of right-turn crash. Figure 3-48 shows one location where the lane width is 10 ft.

To improve such situation, comprehensive swept path analysis should be conducted at such locations to ensure there is enough space for large trucks making right turns.



Figure 3- 48: Google Map of the Problematic Location

3.4.4.2 Collision Diagram 2

Section 2 is part of N McCarty Street between N Loop E freeway and Mesa Road. Figure 3-49 is the collision diagram developed for this section. A total of 29 crashes occurred in this section during the past 5 years.

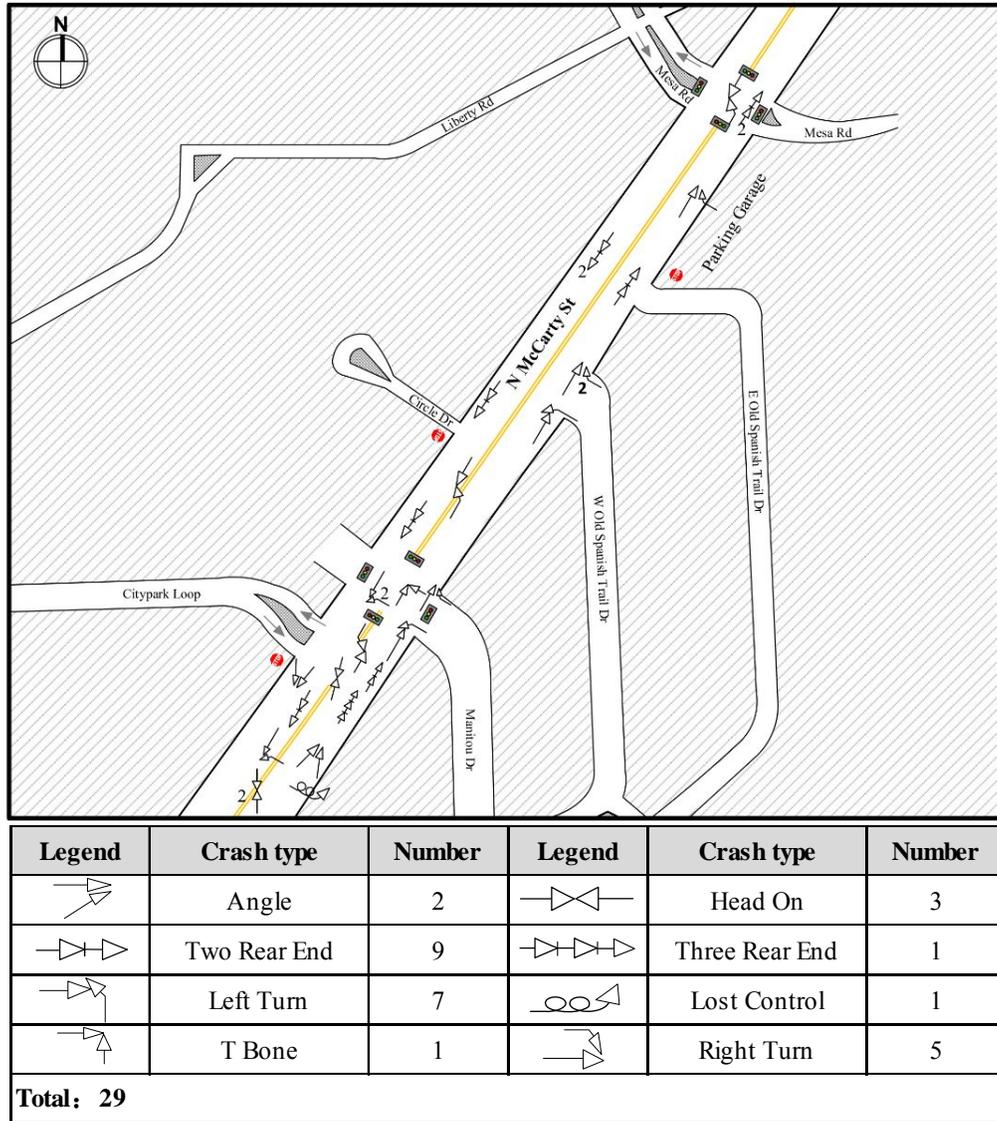


Figure 3- 49: Collision Diagram 2 for Large Truck Crash Hot Area 4 “Houston IH610 @ US90”

Finding 1: left turn and right-turn related crashes on McCarty Street

There is no median on McCarty Street (Figure 3-50), and two direction traffic was separated by double yellow lines. But there are many access points for truck shops, tire center or other business along this road (Figure 3-51). The drive-in and drive-out movements produce lots of conflict points along this street. In addition, it takes more time and space when truck turning right from minor streets. Several crashes occurred due to truck failed to yield through movements. Access management techniques, such as using directional opening with channelized left-turn lanes, are needed for controlling and



Figure 3-52: Google Map of the Problematic Location

Finding 4: Red-light running at small intersection with high truck volume

There were some crashes occurred due to red light running at some small intersections. Figure 3-53 shows one sample intersection. For such small intersection with heavy large truck volume, signal heads need to be more visible, so that they won't be blocked by the large trucks.



Figure 3-53: Google Map of the Problematic Location

3.4.4.3 Collision Diagram 3

Figure 3-54 is the collision diagram developed for section 3. There were 4 crashes occurred in this area, and no roadway related risk factor contributing to those crashes were detected.

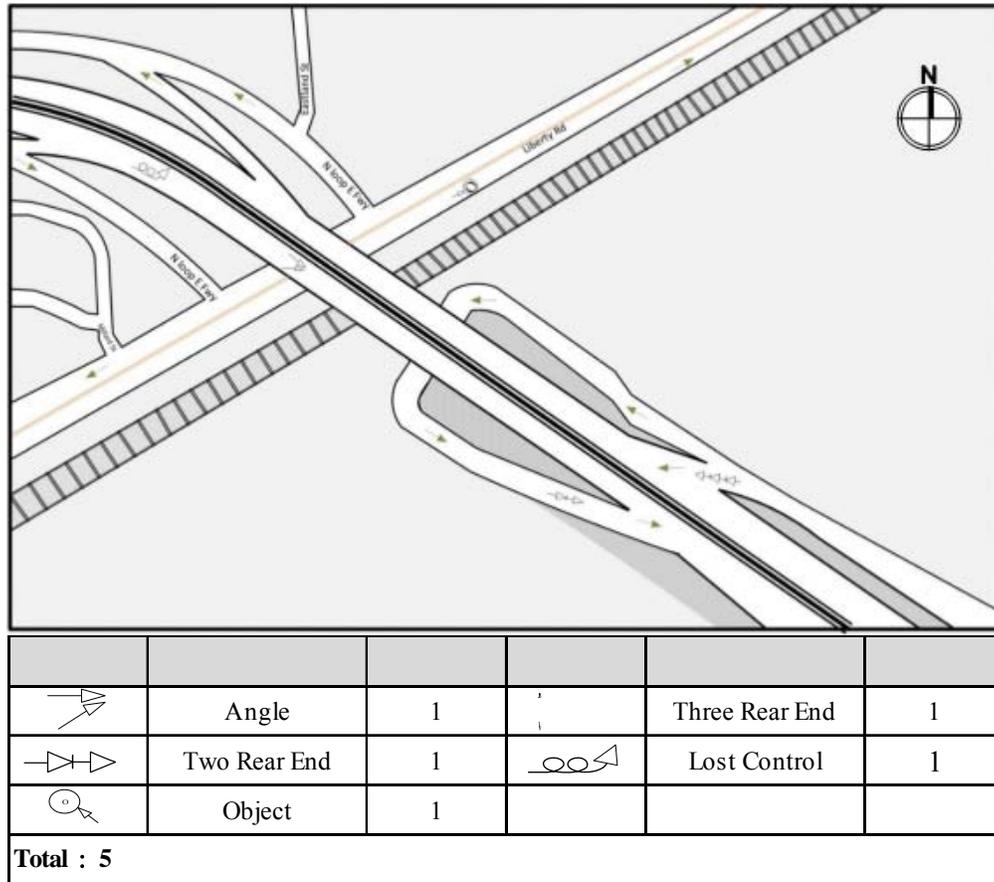


Figure 3- 54: Collision Diagram 3 for Large Truck Crash Hot Area 4 “Houston IH610 @ US90”

3.4.4.4 Collision Diagram 4

There were 15 crashes occurred during 2011-2015 in section 4. There is no roadway related issues were identified in this section.

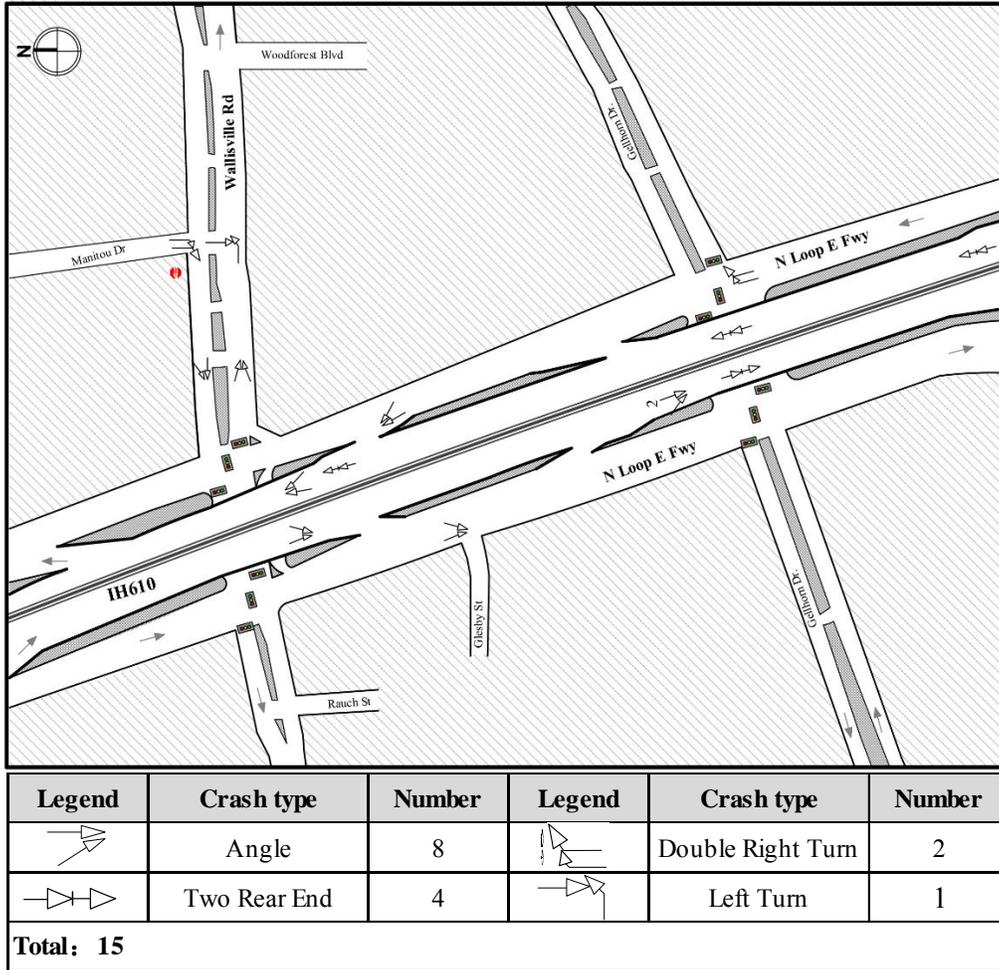
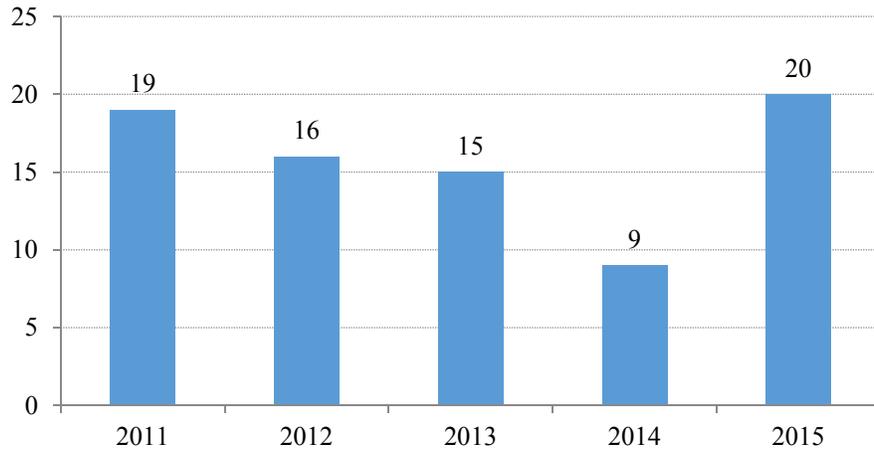


Figure 3-55: Collision Diagram 4 for Large Truck Crash Hot Area 4 “Houston IH610 @ US90”

3.4.5 Hot Area 5 Austin IH35

Hot area 5 is located at Austin Interstate Highway 35. This area stretches 2.86 miles on IH35. As shown in Figure 3-56, during the past 5 years, 79 crashes occurred, including 2 fatal and 6 incapacitating crashes. Some isolated crashes were eliminated from the analysis; therefore, 57 crashes were mapped for this area in total.

Crash Tendency in Austin IH35



Crash Severity Distribution in Austin IH35

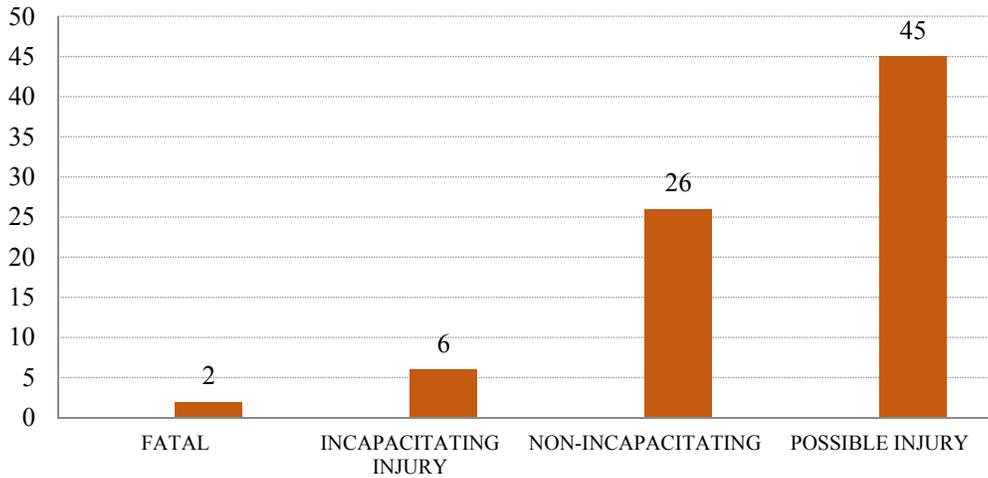


Figure 3-56: Crash Tendency and Crash Severity Distribution at Hot Area 5

Figure 3-57 shows the locations of all crashes happened in this area, and the boundary of each section for developing collision diagrams.

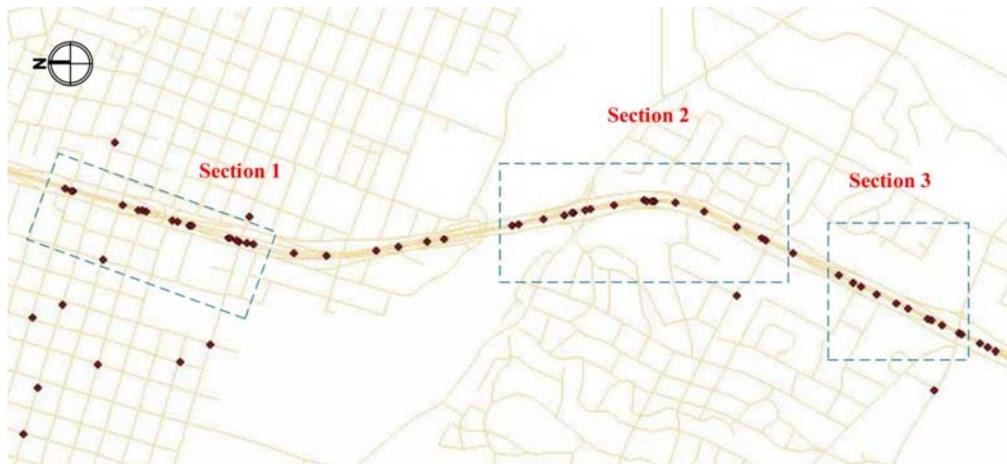


Figure 3- 57: Area Map and Collision Diagram Sections at Hot Area 5 “Austin IH35”

After finishing mapping all collision diagrams, we noticed that some issues are quite common at all three sections. Therefore, for this area, common findings will be introduced first, and followed by unique findings for each section.

Finding: high number of rear-end crashes

33 crashes out of 57 were rear-end crashes, which accounts for 57% of all crashes. By analyzing police reports, we found that congestion is the major cause for the high rate of rear-end crashes at this section. High percentage of truck volume also increase the risk of rear-end crash.

To reduce congestion, and further prevent rear-end crashes happened in this section, the following countermeasures may be applied:

- Educate both truck drivers and passenger vehicle drivers on safe distance and the importance of keeping longer headway during driving.
- Put stickers on trucks to warning other drivers keeping safe distance with large trucks, such as “DO NOT TAILGATE” or “IF YOU CAN READ THIS YOU ARE TOO CLOSE”
- Use flash yellow lights to warn drivers during the congested period, let drivers know slow traffic is expected, and they need to maintain a safe following distance
- Install ramp metering to control congestion at some high-risk locations

3.4.5.1 Collision Diagram 1

Figure 3-58 is the collision diagram developed for section 1. Overall, 15 crashes occurred. 66% of the crashes occurred around on ramp or off ramp areas. The majority of these crashes are rear end and angle crash. Except for the traffic congestion that caused high number of rear-end crashes at this location as we introduced early, some other roadway design related issues were also identified.

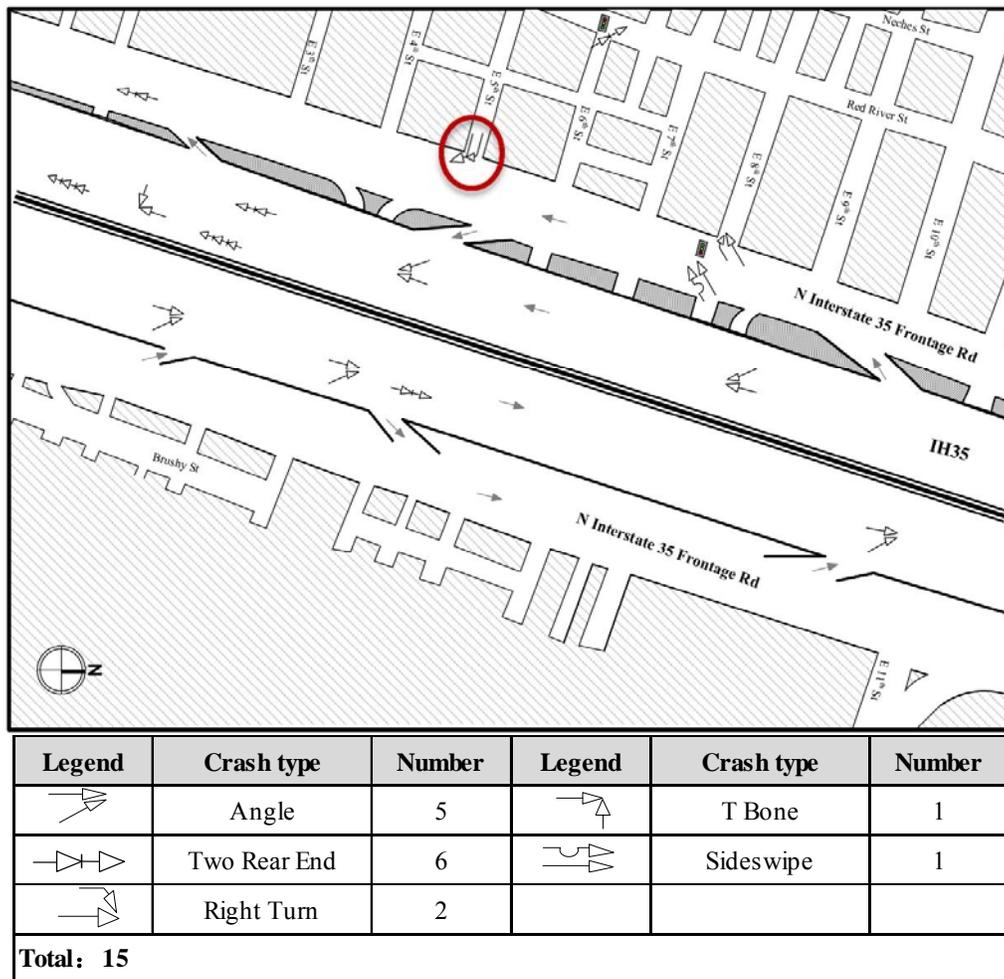


Figure 3- 58: Collision Diagram 1 for Large Truck Crash Hot Area 5 “Austin IH35”

Finding 1: dual right turning crashes (red circle in Figure 3-58)

In this section, some of the dual-right turn lanes are too narrow and there is no enough space for large trucks make turns. Figure 3-59 shows one sample location.



Figure 3- 59: Google Map of the Problematic Location

To solve this problem, following countermeasures could be considered:

- Conduct turning path analysis to facilitate large trucks' turning movements.
- Provide turning guide lines on the pavement
- Push back the stop lines of the crossing street to release more space for the right-turn trucks. Please see Figure 3-60.

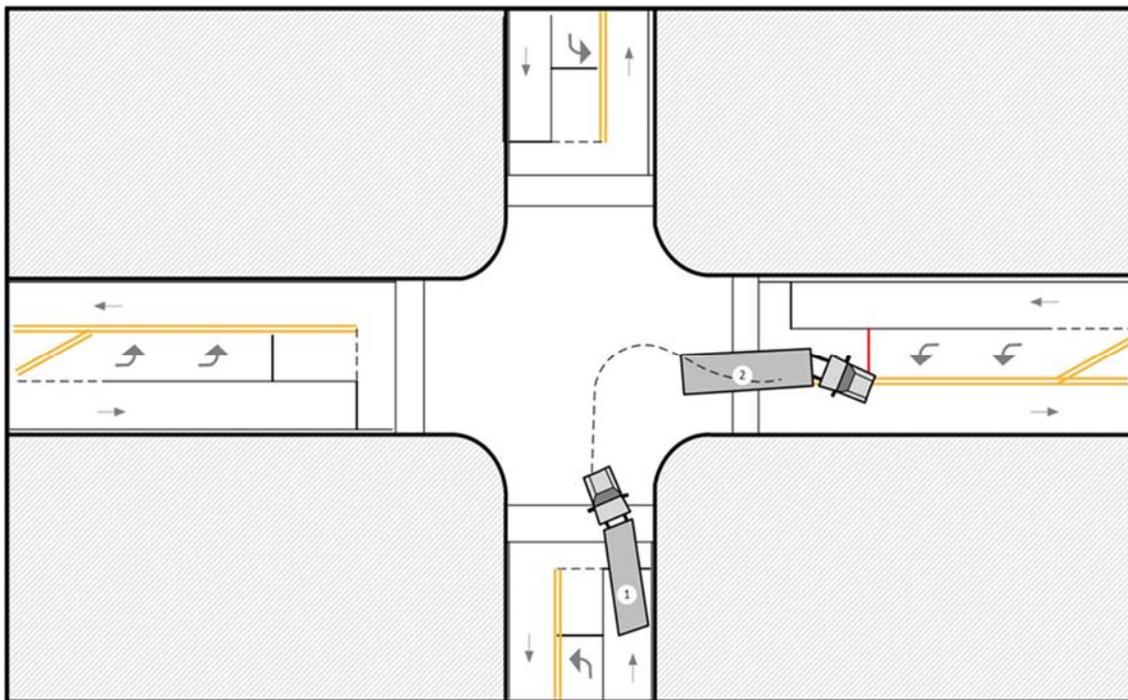


Figure 3-60: Push Back the Stop Lines of the Crossing Street for the Right-Turn Trucks

Finding 2: Turning related crashes

In this area, many intersections have no pavement marking, such as the location showed

in Figure 3-61. Lack of turning guide lines makes the turning more dangerous, which increase the possibility of crashes occurred. Add clear pavement markings in those locations are highly recommended.



Figure 3- 61: Google Map of the Problematic Location

3.4.5.2 Collision Diagram 2

Figure 3-62 is the collision diagram of section 2. In total, 7 crashes occurred, including 4 angle crashes, and 3 rear-end crashes. The main cause for those crashes is traffic congestion. No roadway related risk factors were identified.

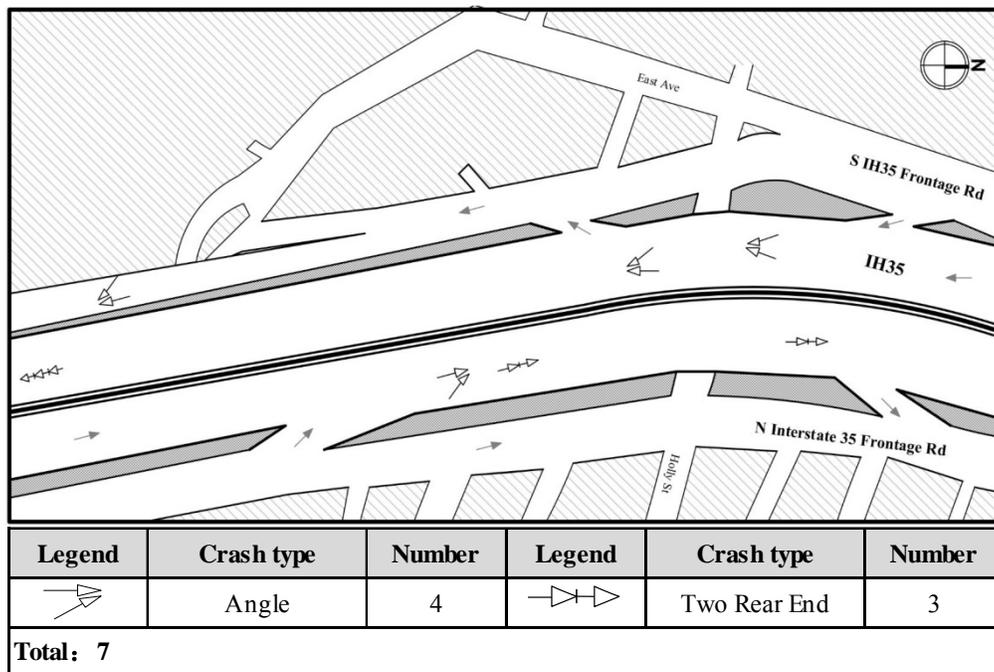


Figure 3-62: Collision Diagram 2 for Large Truck Crash Hot Area “Austin IH35”

3.4.5.3 Collision Diagram 3

1 fatal and 3 incapacitating crashes happened in this section. Similar with other sections in this area, rear-end crash is the most frequently occurred. 72% of the crashes that occurred in this diagram were rear end crashes. The reasons contributed to rear-end crashes include severe congestion, construction, narrow shoulder and high truck volume.

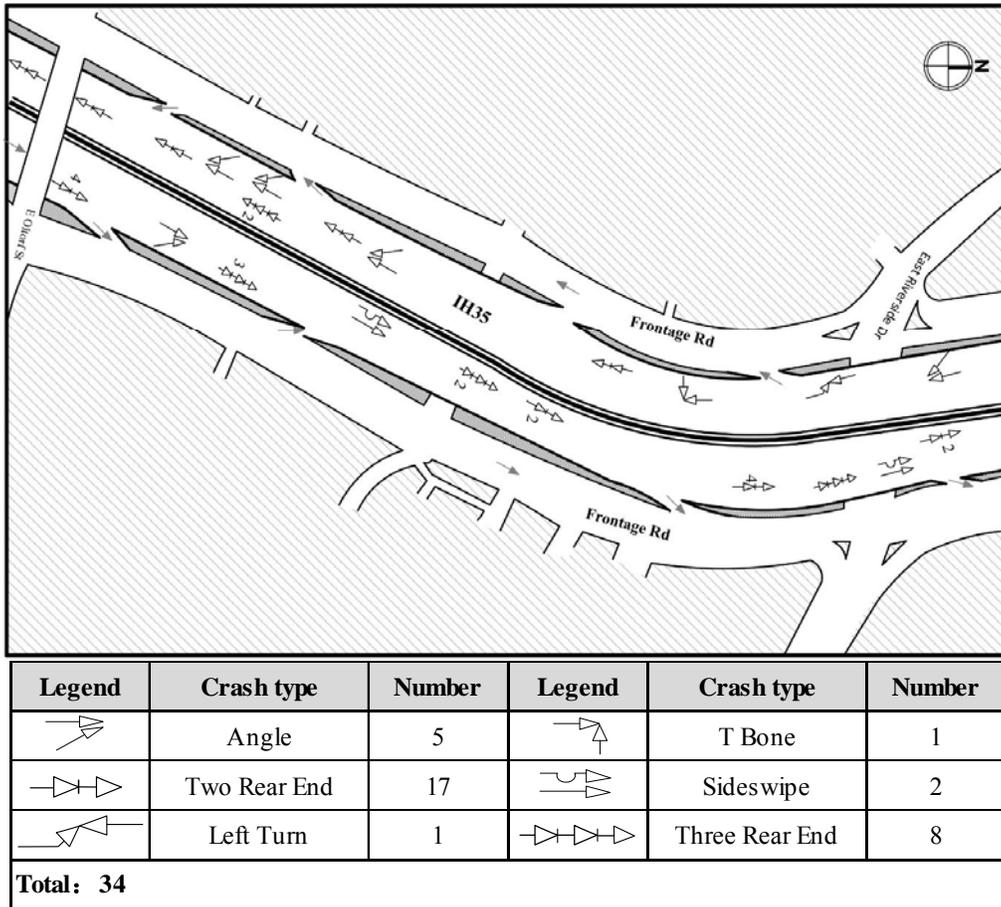


Figure 3- 63: Collision Diagram 3 for Large Truck Crash Hot Area 5 “Austin IH35”

Finding: 5 angle crashes

There were 5 angle crashes occurred in this area, and most of them happened near an entrance ramp. After search google map for the surrounding roadway design, it was found that the merge distance at this ramp is very short, which is about 115ft (see Figure 3-64). Such short merge distance not only makes large truck difficult to merge into highway, but also is very risky for passenger vehicle merging when trucks in the adjacent lane.

To reduce angle crashes near highway entrance ramps, following countermeasures could be implemented:

- Extend merge distance for on ramps
- Restrict large truck from the right-most lane

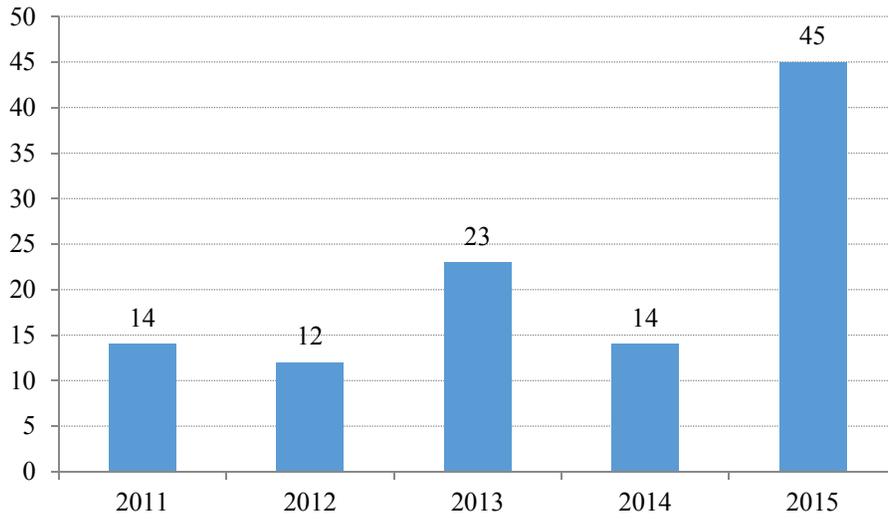


Figure 3- 64: Google Map of the Problematic Location

3.4.6 Hot Area 6 San Antonio IH410 @ IH35

Hot area 6 located in San Antonio Interstate Highway 410 @ Interstate Highway 35. Totally 108 crash happened in this area, including 2 fatal crashes and 10 incapacitating crashes. The five-year crash tendency and crash severity distribution are presented in the Figure 3-65.

Crash Tendency in SA IH410 @IH35



Crash Severity Distribution in SA IH410@ IH35

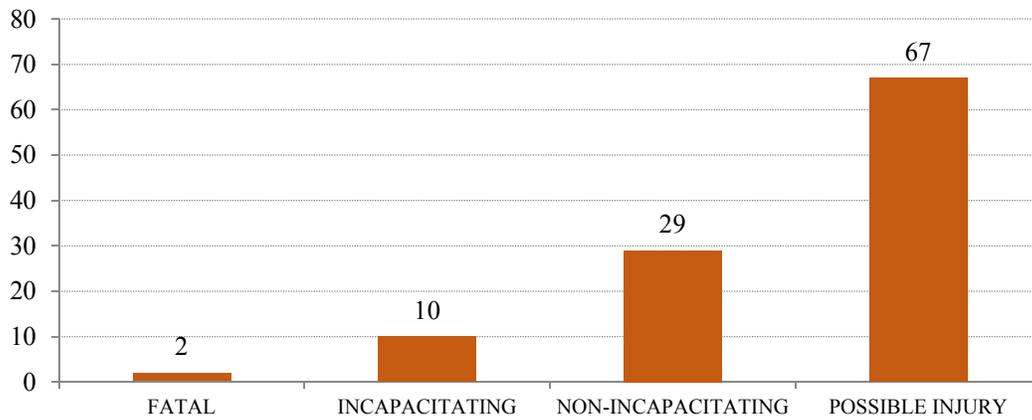


Figure 3- 65: Crash Tendency and Crash Severity Distribution at Hot Area 6

As showed in Figure 3-66, 4 collision diagrams were developed for this area.

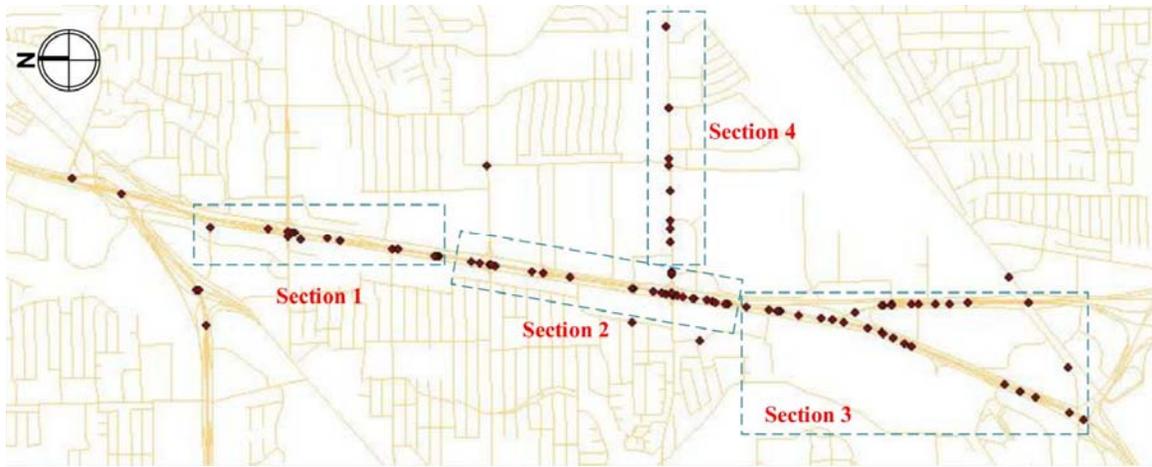


Figure 3- 66: Area Map and Collision Diagram Sections at Hot Area 6 “San Antonio IH410 @ IH35”

3.4.6.1 Collision Diagram 1

Figure 3-67 is the collision diagram developed for Section 1 of hot area 6. In this section, 15 crashes occurred during the past 5 years. Among all 15 crashes, 7 were rear end crashes and 5 were sideswipes. The main reasons contributing to crashes include driver inattention, driving at night and construction zone.

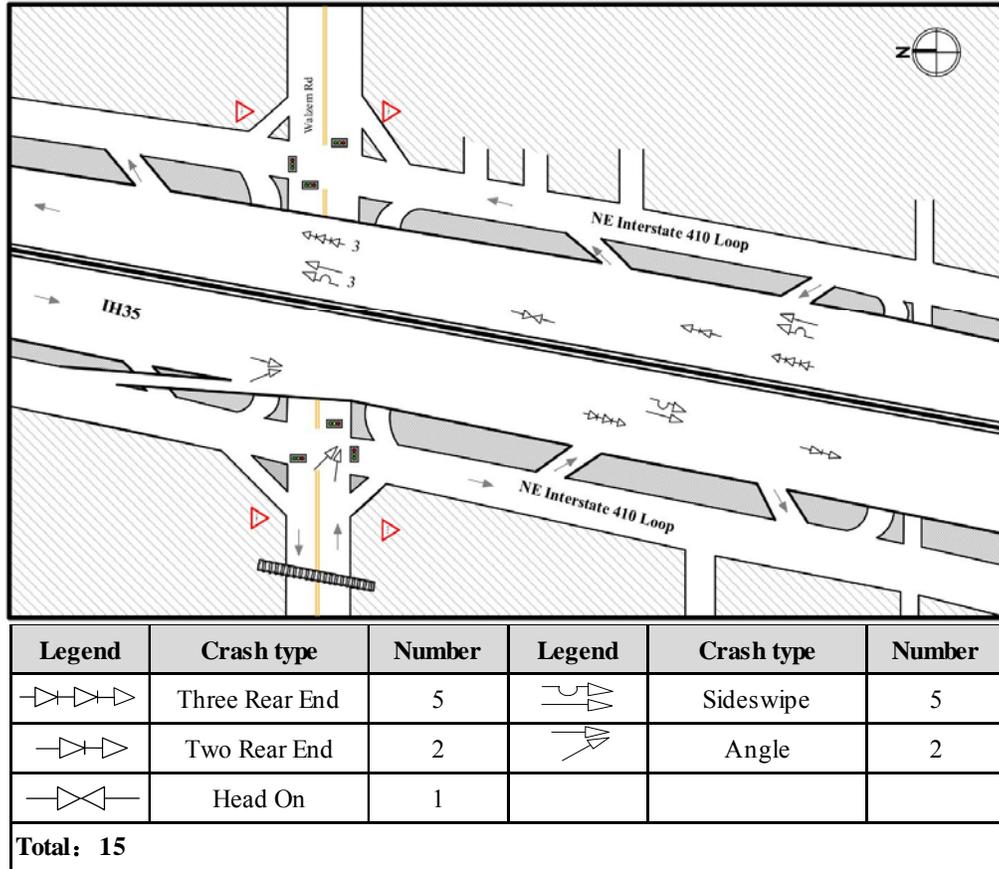


Figure 3- 67: Collision Diagram 1 for Large Truck Crash Hot Area 6 “San Antonio IH410 @ IH35”

Finding 1: narrow shoulder

Due to construction work, highways in this section have narrow shoulder. Figure 3-68 shows a section of the highway, where the shoulder width is 8.44ft.

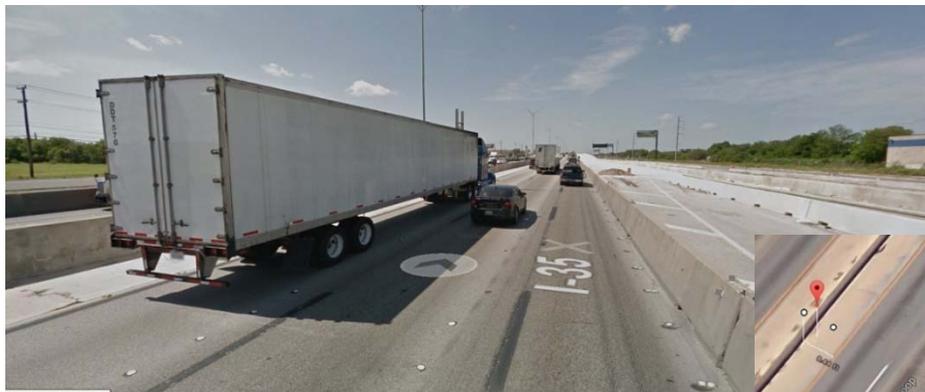


Figure 3- 68: Google Map of the Problematic Location

Finding 2: merge early on double white line

Many drivers merged early to cut into lanes, which caused many sideswipe crashes at this location (Figure 3-69). Placing some barriers could be able to stop drivers passing through the solid white line, and reduce crashes.



Figure 3- 69: Google Map of the Problematic Location

3.4.6.2 Collision Diagram 2

In 2011-2015, 40 crashes occurred in Section 2. The two major types of crashes occurred here were rear end and sideswipe crashes. The major reason was congestion caused by construction works. No other roadway related factors were detected in this section.

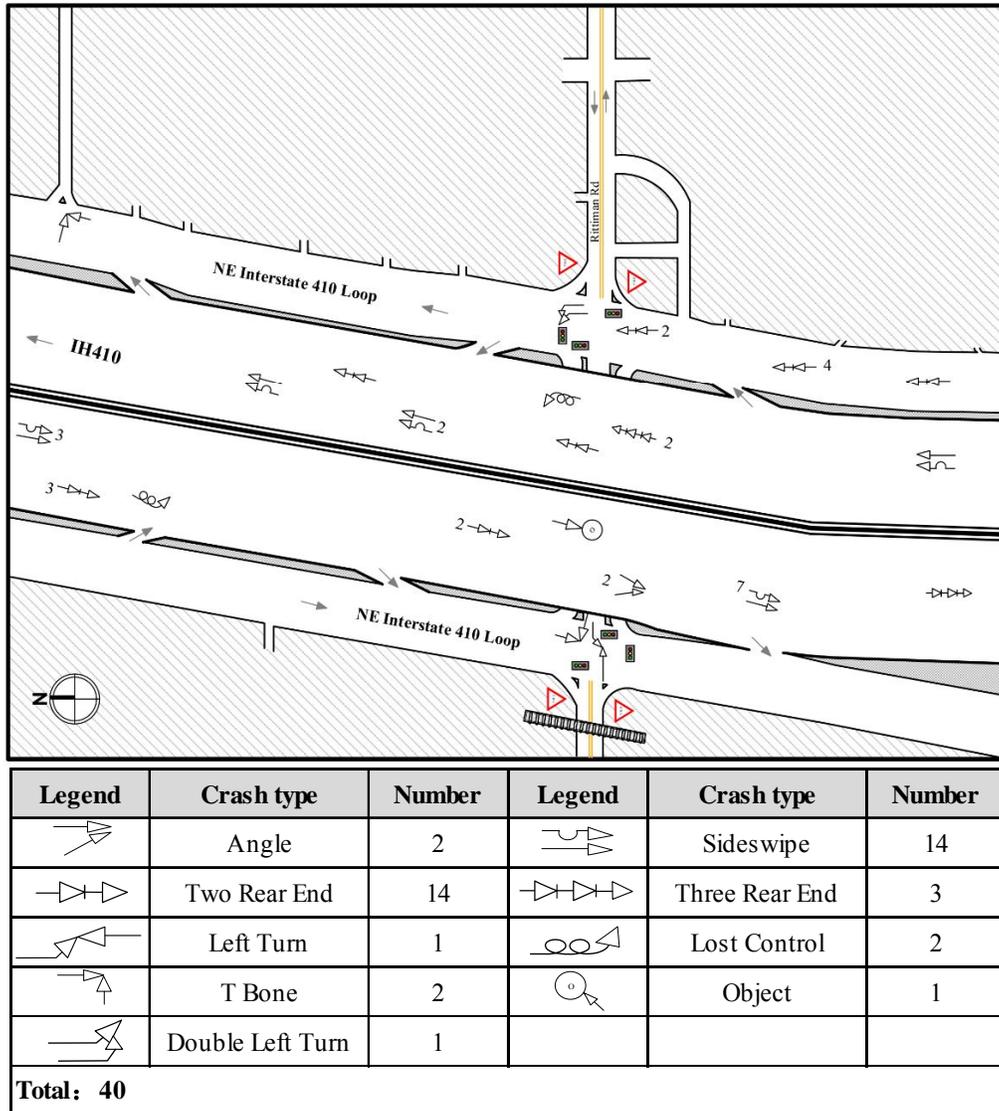


Figure 3- 70: Collision Diagram 2 for Large Truck Crash Hot Area 6 “San Antonio IH410 @ IH35”

3.4.6.3 Collision Diagram 3

Figure 3-71 is the collision diagram developed for section 3. There were 27 crashes occurred in this section, including 3 incapacitating crashes. Similar with other sections in this area, lots of construction works going on in this section. Combined with heavy truck volume, many rear-end and sideswipe crashes happened here.

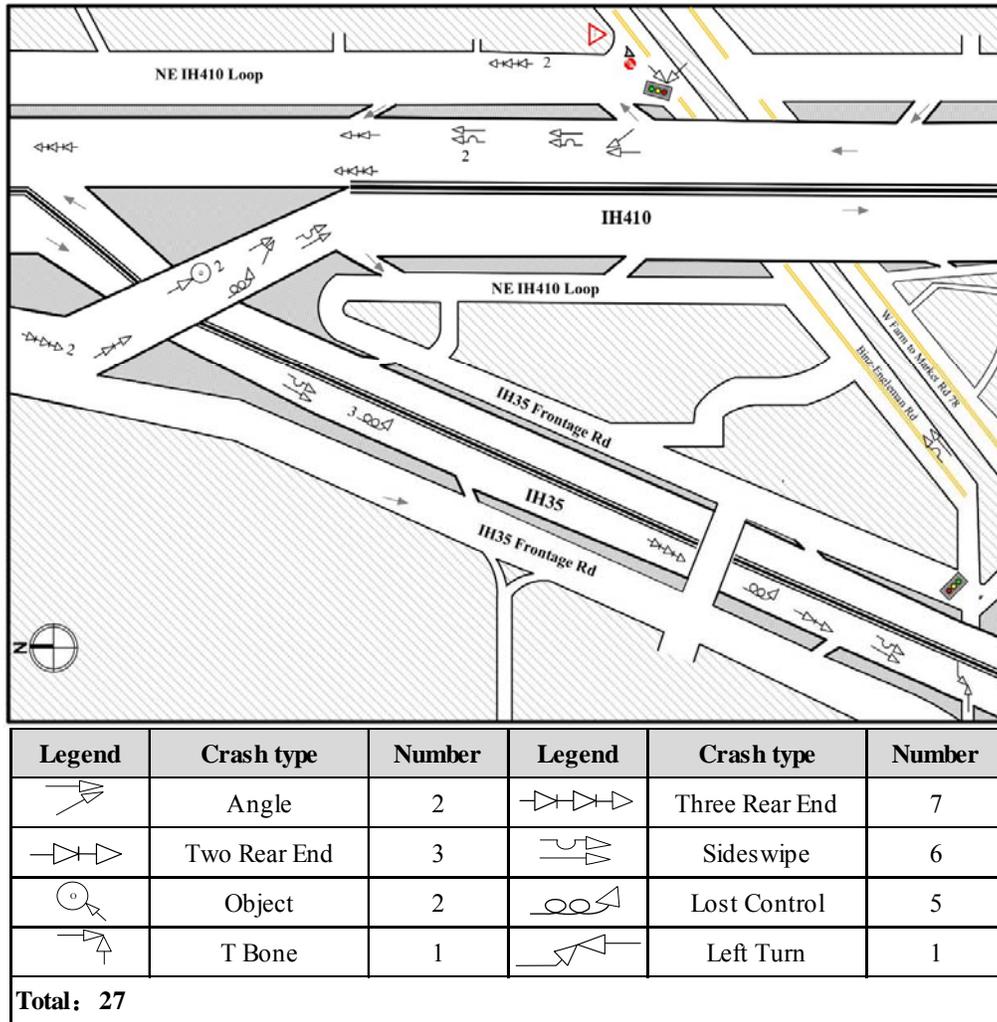


Figure 3- 71: Collision Diagram 3 for Large Truck Crash Hot Area 6 “San Antonio IH410 @ IH35”

3.4.6.4 Collision Diagram 4

Figure 3-72 is the collision diagram developed for section 4 of hot area 6. In this section, 14 crashes occurred during 2011-2015, including 2 incapacitating crashes. After reviewing crash reports, as well as investigating roadway conditions. Some roadway related crash risk factors were noticed.

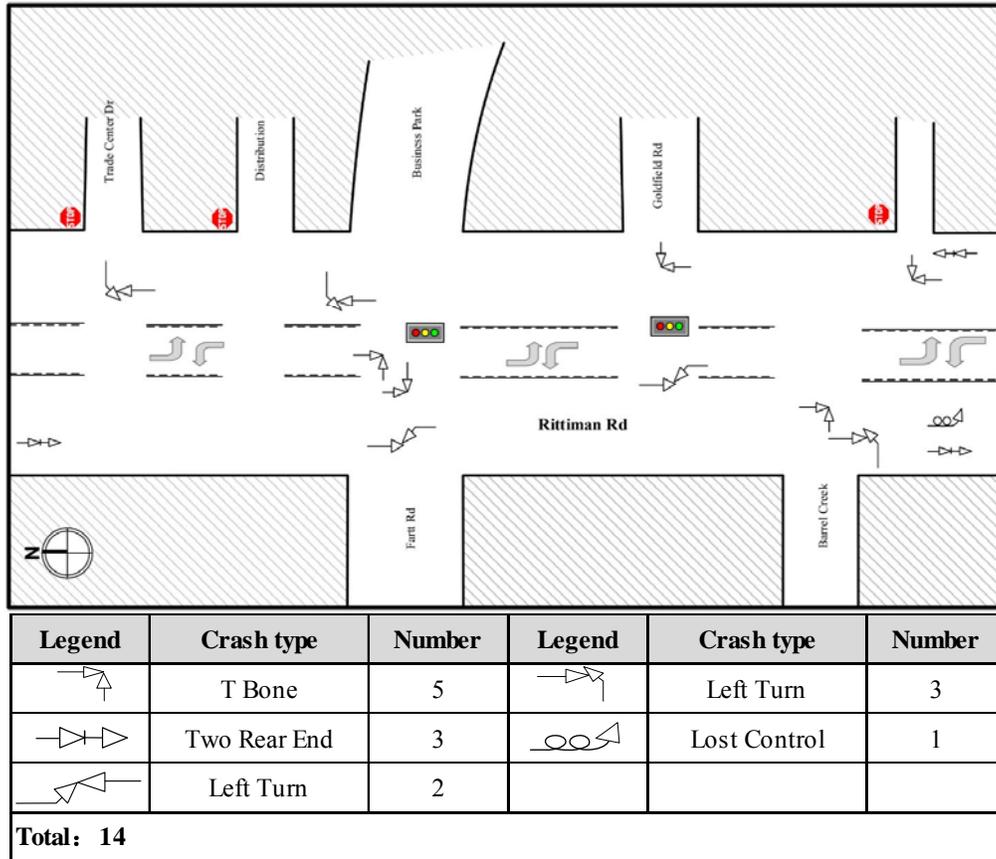


Figure 3- 72: Collision Diagram 4 for Large Truck Crash Hot Area 6 “San Antonio IH410 @ IH35”

Finding 1: Two Way Left Turn with Many Access Points and Heavy Truck Volume

This section is next to the IH 35, and there are many trucks every day. There is no median on Rittiman Road (Figure 3-72), and two direction traffic was separated by a two-way left-turn lane. But there are many access points with private driveways from hotel, food, gas station, and apartment. The drive-in and drive-out movements produce lots of conflict points along this street. In addition, it takes more time and space when truck turning right from minor streets. Several crashes occurred due to truck failed to yield through movements. Access management techniques, such as using directional opening with channelized left-turn lanes, are needed for controlling and reducing the conflict points.

Finding 2: large trucks block passenger car drivers’ view (See Figure 3-73)

Due to the heavy truck volume, passenger vehicle drivers’ view may be blocked by the large trucks, sometimes causing the following passenger vehicles run red light. To

address this problem, second signal lights could be placed at the inner side of the street, so that drivers could see traffic signal in sufficient advance.



Figure 3-73: Google Map of the Problematic Location

Finding 3: pavement markings worn away

At some roads, the pavement markings have been worn away, which causing confuse to drivers especially when they make turnings. Figure 3-74 shows the example roads.



Figure 3- 74: Google Map of the Problematic Location

3.4.7 Hot Area 7 Laredo IH69W @ FM1472

There were 92 crashes occurred in this section during 2011-2015. The crash tendency and

severity distribution are summarized in Figure 3-75.

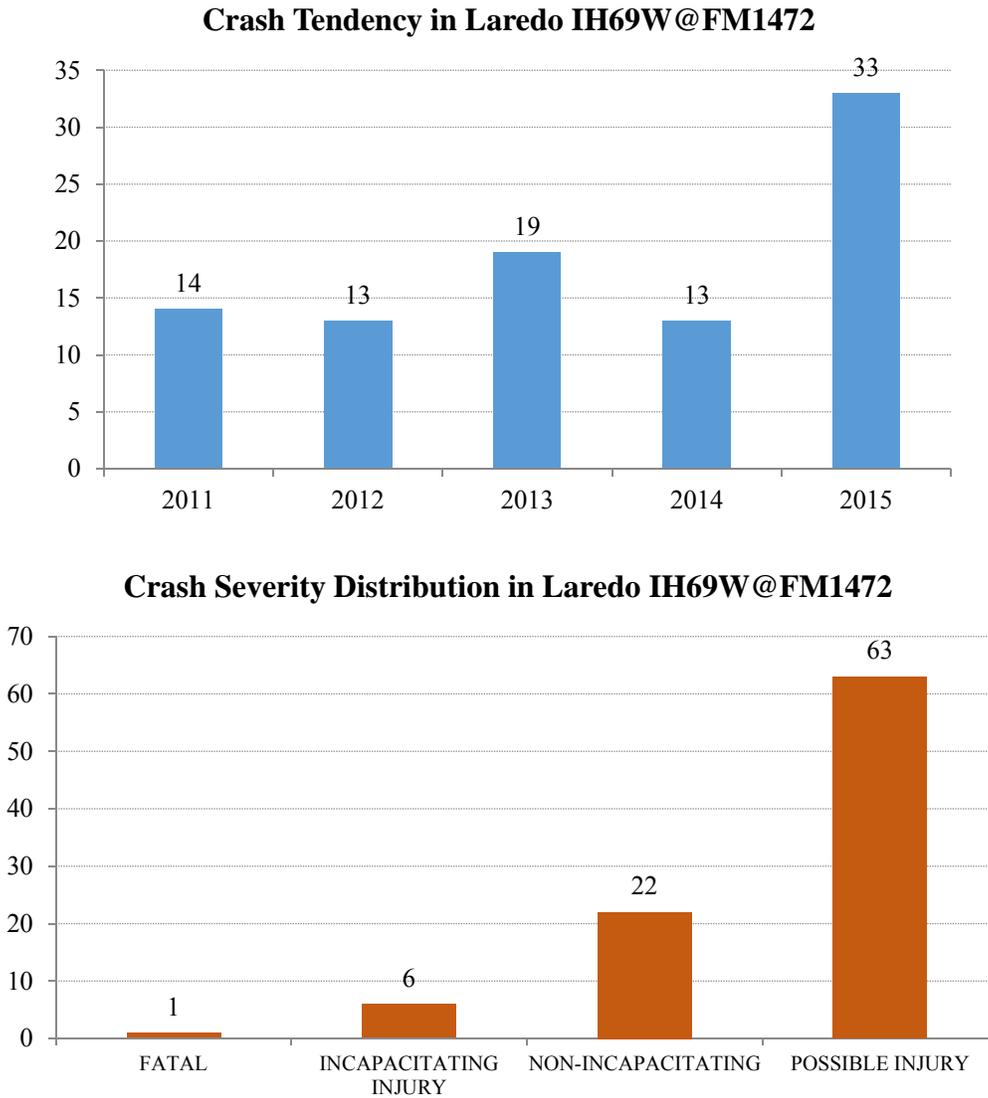


Figure 3- 75: Crash Tendency and Crash Severity Distribution at Hot Area 7

As seen in Figure 3-76, for Laredo area, 4 collision diagrams were developed. Some isolated crashes were eliminated from the analysis, and finally 71 crashes were mapped.

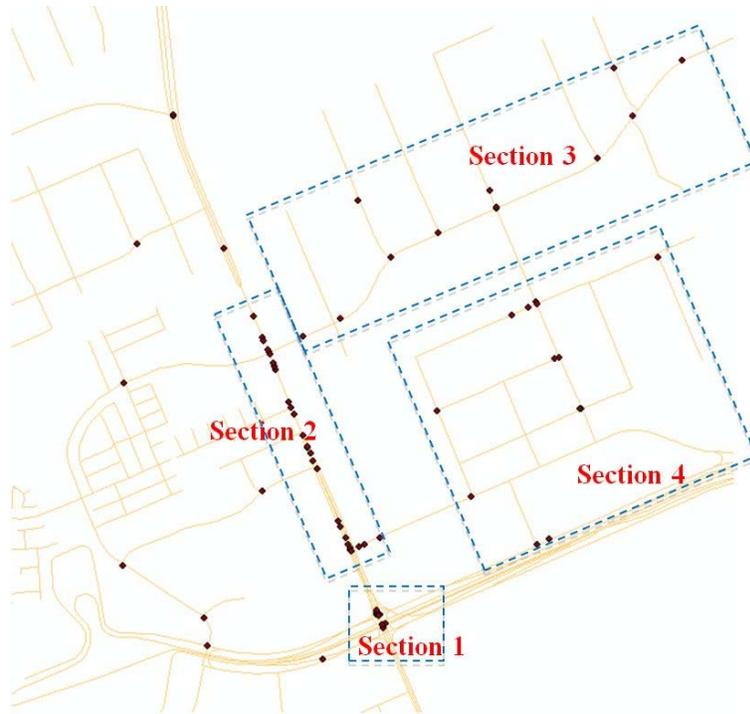


Figure 3- 76: Area Map and Collision Diagram Sections at Hot Area 7 “Laredo IH69W @ FM1472”

3.4.7.1 Collision Diagram 1

Section 1 is a diamond intersection under freeway. Figure 3-77 is the collision diagram for section 1. There were 22 crashes occurred in this section.

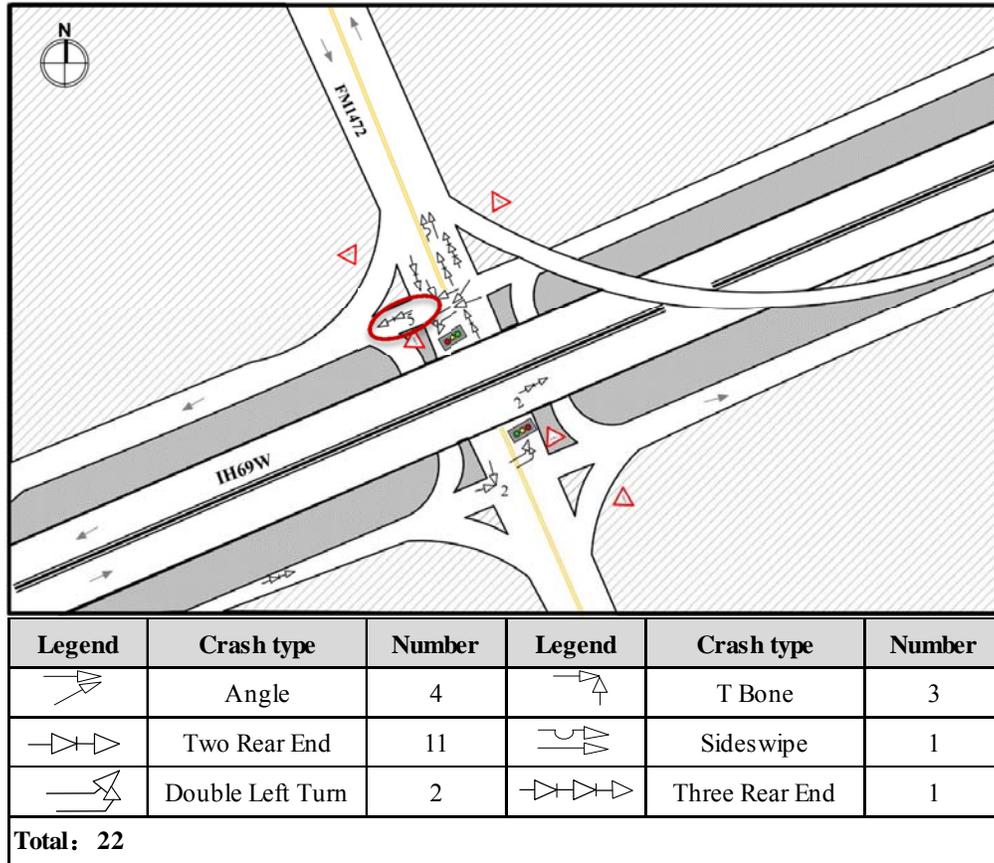


Figure 3- 77: Collision Diagram 1 for Large Truck Crash Hot Area 7 “Laredo IH69W @ FM1472”

Finding1: 5 rear-end crashes (red circle in Figure 3-77)

The high number of rear-end crashes occurred upstream of the intersection were due to the short merge distance for the right turn slip lane and the short distance from the intersection to the highway entrance ramp at the left side (please see Figure 3-78). Because of the short merge distance (200 ft.), after trucks making right turns on red, they need to quickly merge to the through lanes, which cause lots of conflicts with the through vehicles and make the approaching thought vehicles have to slow down when the traffic signal light is still green for them. As a result, many rear-end crashes occurred at the upstream locations of the through lane direction. In addition, after making right turn and merging to the through lane, if the truck needs to enter the freeway from the onramp at the left side, the distance for them to change to the most left lane is only about 500ft. Therefore, they have to make quick lane changes, which cause more conflicts with the through vehicles.



Figure 3- 78: Google Map of the Problematic Location

To improve the safety at this location, there are several potential countermeasures could be implemented:

- Lengthen current merge lane of the right turn slip lane to give truck more time to merge and make lane changes
- Prevent right-turn on red to reduce conflict points

Finding 2: 3 left turn related angle crashes

There were 3 left-turn related angle crashes occurred at an intersection in this section. From Figure 3-79, we can see the special lane configuration at this intersection (1 U-turn lane, 1 left turn only lane, 1 left turn and through shared lane, and 1 right turn only lane). Note that, since there are no through only lane, drivers accidently trapped in the left turn only lane tend to make a mistake that the adjacent lane is the through only lane and try to go through even if they are in the left turn only lane. This mistake will cause their vehicles colliding with the left-turn vehicles on the right side adjacent lane.

To prevent such type of crash, advanced sign on lane configuration should be provided to assist driver passing the intersection. The current pavement marker is 300ft away from

the intersection, which may not provide enough time for “trapped” drivers to make lane change. In addition, due to high percentage of large truck volume, current traffic sign is often blocked by the large trucks. Therefore, signs on intersection lane configuration should be placed on both side of the roadway to prevent the signs being blocked by large trucks.



Figure 3- 79: Google Map of the Problematic Location

In addition, there is no turning guide line for the dual left turn, which increase the possibility of double left crashes. (Figure 3-80)



Figure 3- 80: Google Map of the Problematic Location

3.4.7.2 Collision Diagram 2

In section 2, 19 crashes occurred in the past 5 years. Among them, 12 are rear-end crashes, which accounts for 63% of the total crashes. Please check Figure 3-81 for collision diagram. This section has a wide intersection with high truck volume.

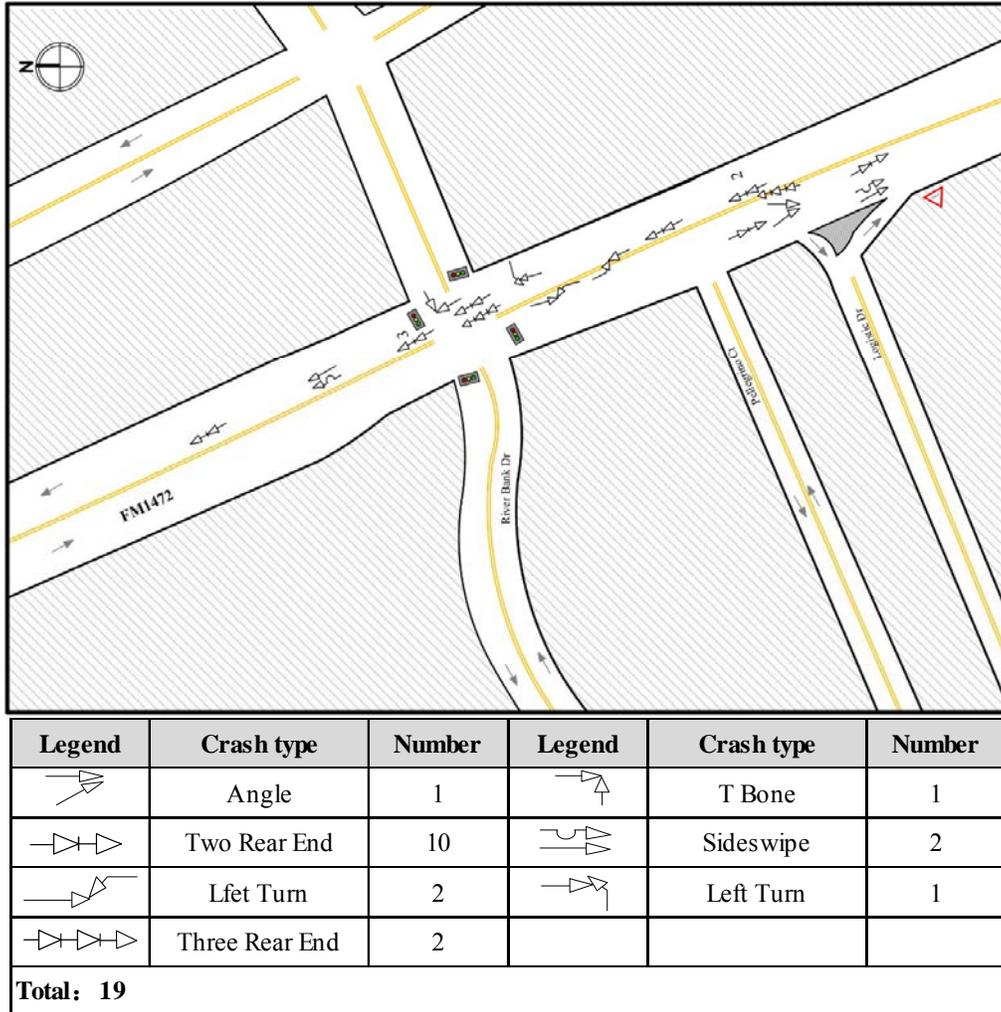


Figure 3- 81: Collision Diagram 2 for Large Truck Crash Hot Area 7 “Laredo IH69W @ FM1472”

Finding 1: 12 rear-end crashes (see Figure 3-82)

This is a very wide intersection, and the distance between stop line and traffic signal is 200ft. Right turn large trucks sometimes block the through lane, which caused rear-end or angle crashes with the through vehicles.

Adding channelized right turn lanes could reduce the chances that right turn large trucks block the through traffic, therefore reduce crash risk.



Figure 3- 82: Google Map of the Problematic Location

Finding 2: left turn crash reduced

In 2014, converting two-way left turn lanes to channelized left turn at directional opening has significantly reduced left turn crash involved large trucks. Since then, there is no left turn crash occurred.

3.4.7.3 Collision Diagram 3

Section 3 is a four-way stop sign controlled intersection. Figure 3-83 is the collision diagram for this section. Most crashes occurred due to drivers' inattention and failed to yield other vehicles. In addition, pavement markings were not clear at some locations.

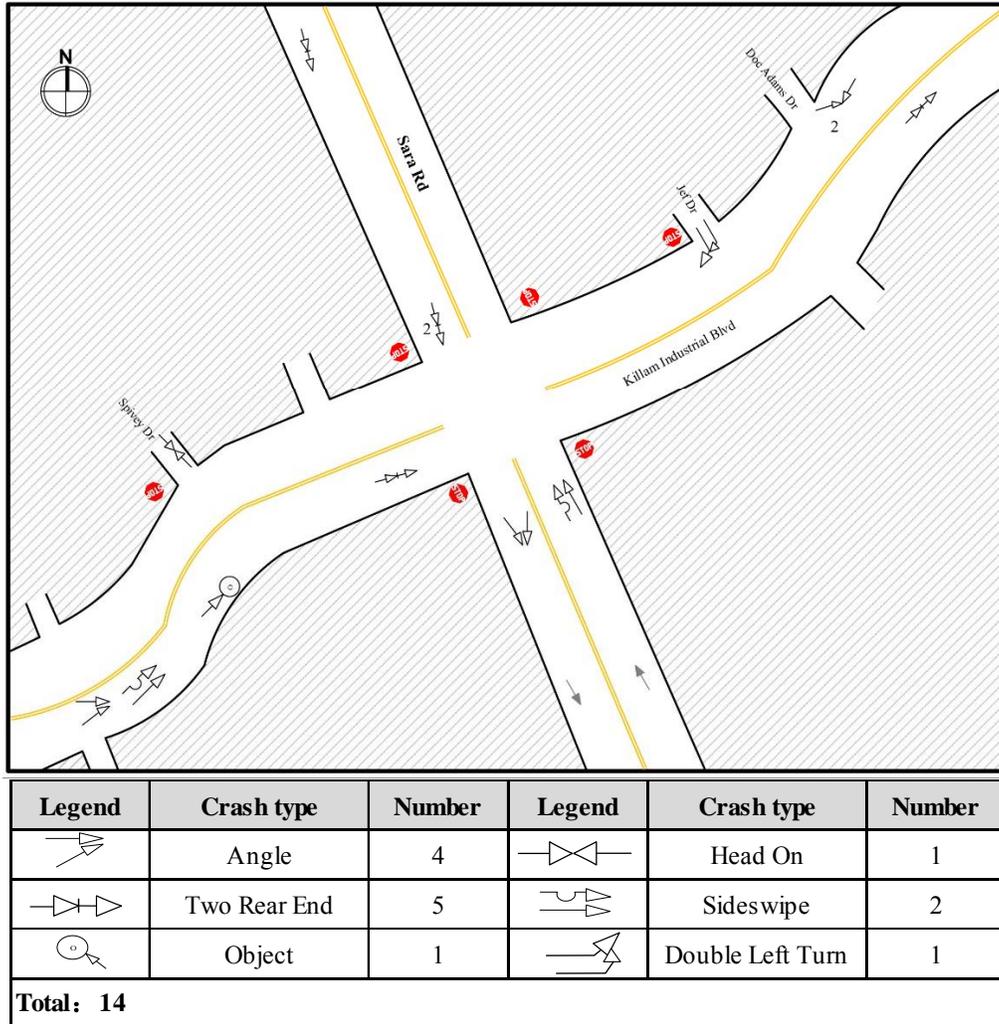
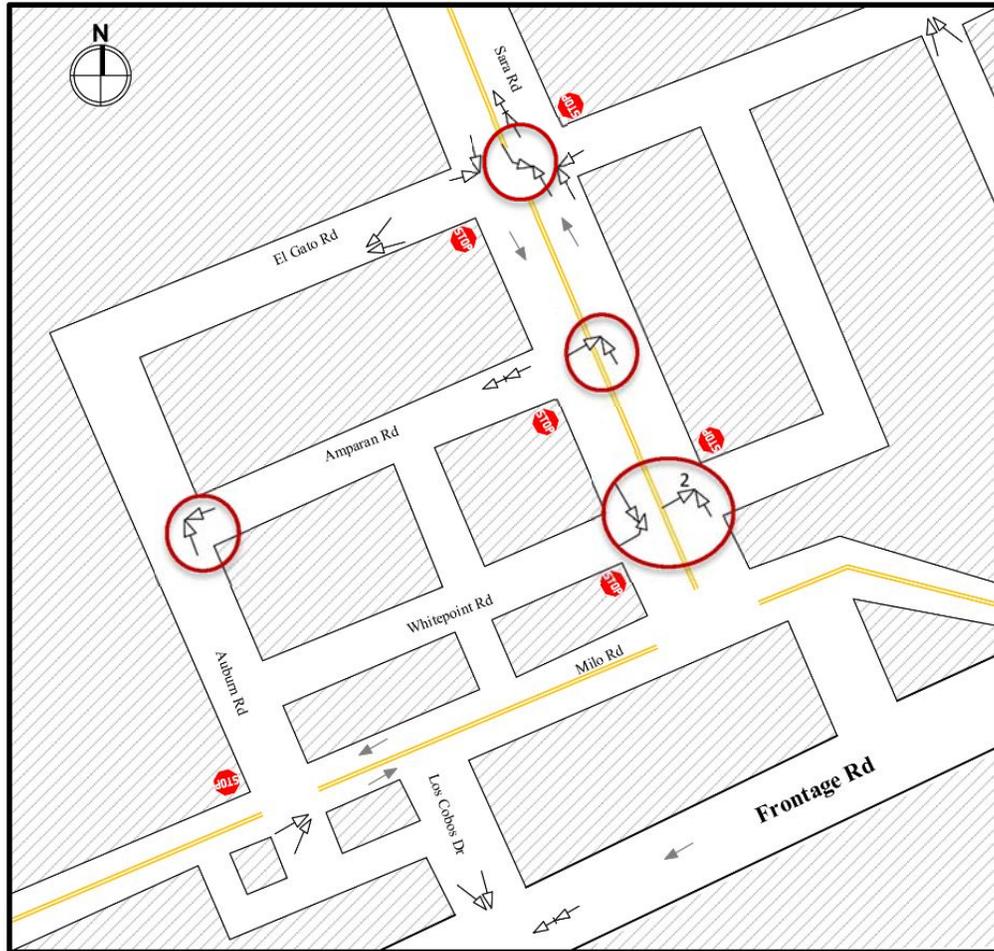


Figure 3- 83: Collision Diagram 3 for Large Truck Crash Hot Area 7 “Laredo IH69W @ FM1472”

3.4.7.4 Collision Diagram 4

Figure 3-84 is crash diagram developed for section 4. There are 15 crashes occurred, including 6 T-bone crashes, 4 angle crashes, 3 rear-end crashes and 2 left turn crashes.



Legend	Crash type	Number	Legend	Crash type	Number
	T Bone	6		Angle	4
	Two Rear End	3		Left Turn	1
	Left Turn	1			
Total: 15					

Figure 3- 84: Collision Diagram 4 for Large Truck Crash Hot Area 7 “Laredo IH69W @ FM1472”

Finding: 6 T-bone crashes (red circles in Figure 3-84)

In this section, there were 6 T-bone crashes occurred at an intersection with two-way stop sign because one vehicle did not stop at the stop sign (Figure 3-85).

To prevent such crashes: 1) stop sign should be made more visible, such as raise the signs or add flash light; 2) put stop signs on both side of the roadway to prevent the signs being blocked by the large trucks.



Figure 3- 85: Google Map of the Problematic Location

3.4.8 Hot Area 8 Fort Worth IH35W

Fort Worth at IH35W is another hot area with high number of large truck involved crashes. The five-year crash tendency and severity distribution are shown in Figure 3- 86.

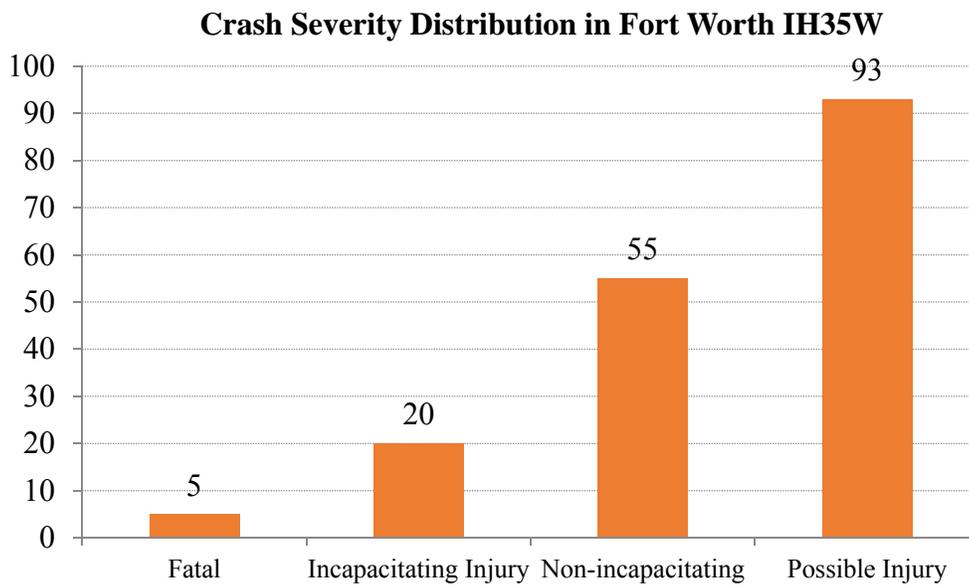
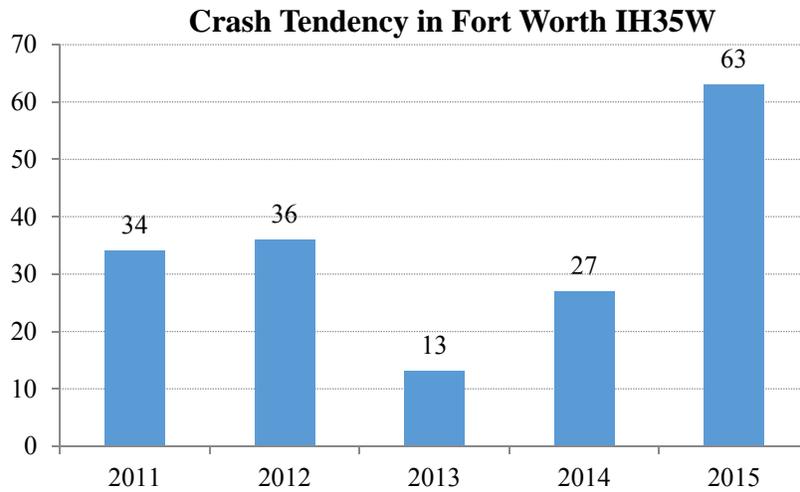


Figure 3- 86: Crash Tendency and Crash Severity Distribution at Hot Area 8

Figure 3-87 shows that seven collision diagrams developed for this area, with 126 crashes mapped in total.

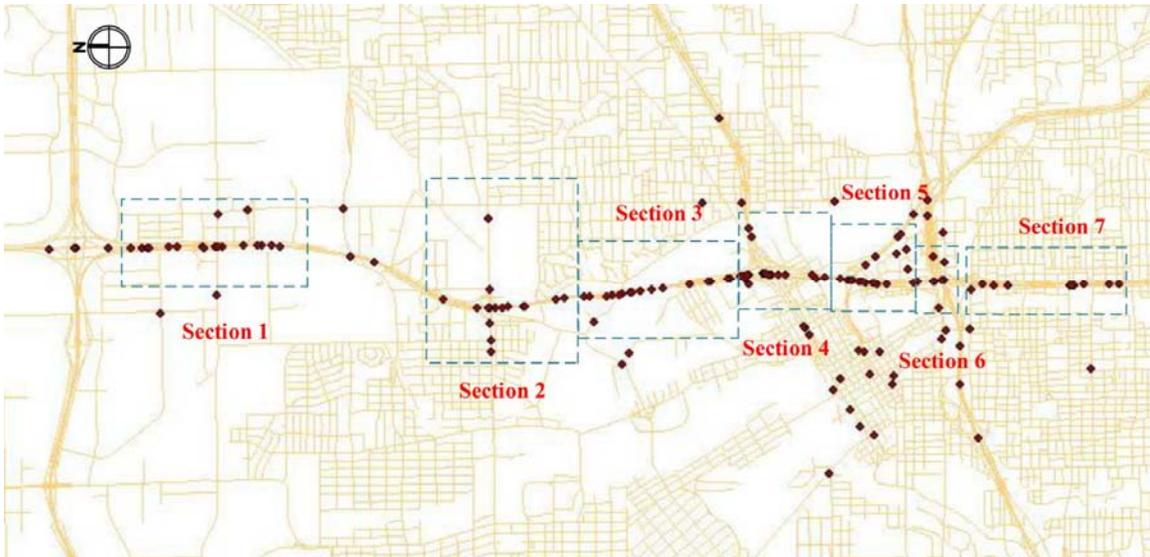


Figure 3- 87: Area Map and Collision Diagram Sections at Hot Area 8 “Fort Worth IH35W”

3.4.8.1 Collision Diagram 1

A total of 21 crashes occurred in section 1. Most of the crashes happened on highway due to traffic congestion, especially heavy traffic volume at weaving sections. No roadway related risk factors were identified.

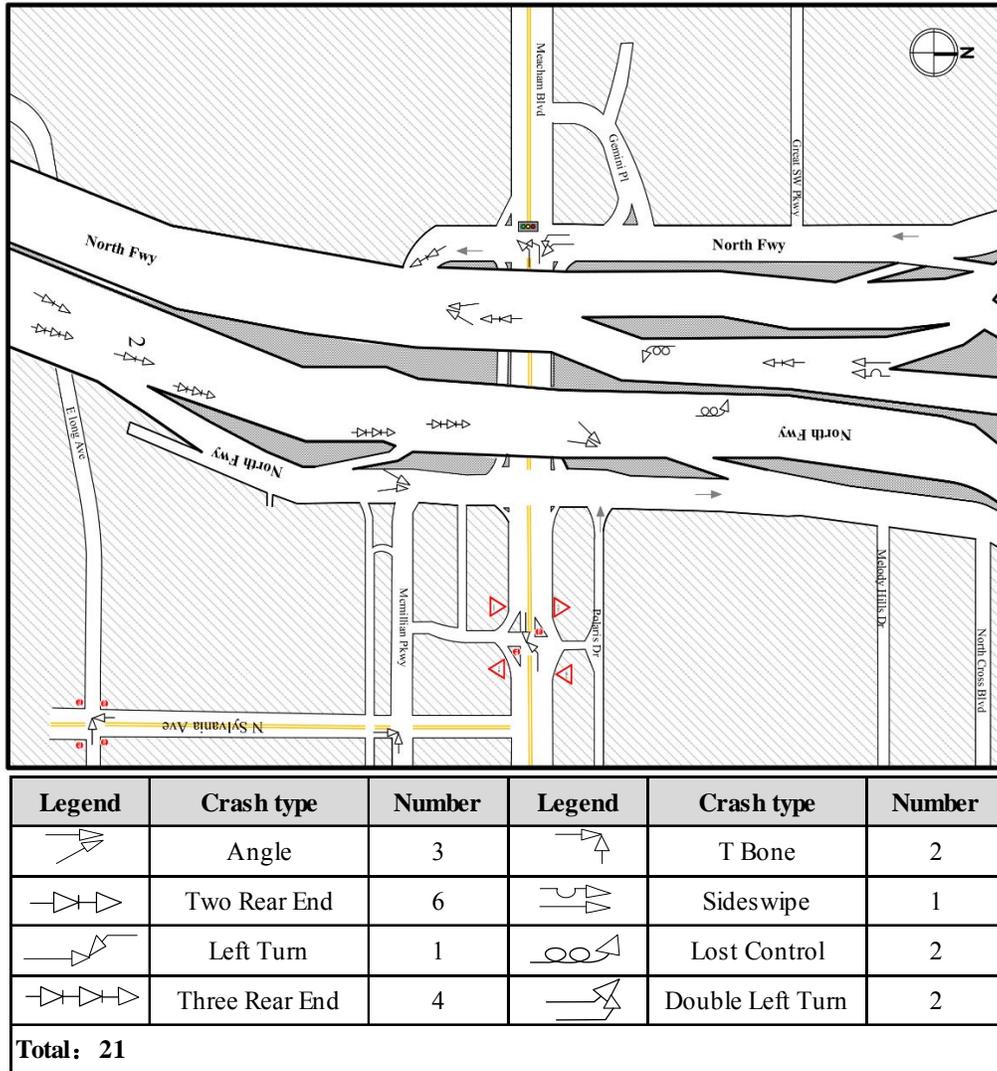


Figure 3- 88: Collision Diagram 1 for Large Truck Crash Hot Area 8 “Fort Worth IH35W”

3.4.8.2 Collision Diagram 2

Section 2 is this hot area has 20 crashes occurred during 2011-2015. Similar with section 1, most of the crashes happened on highway were due to traffic congestion.

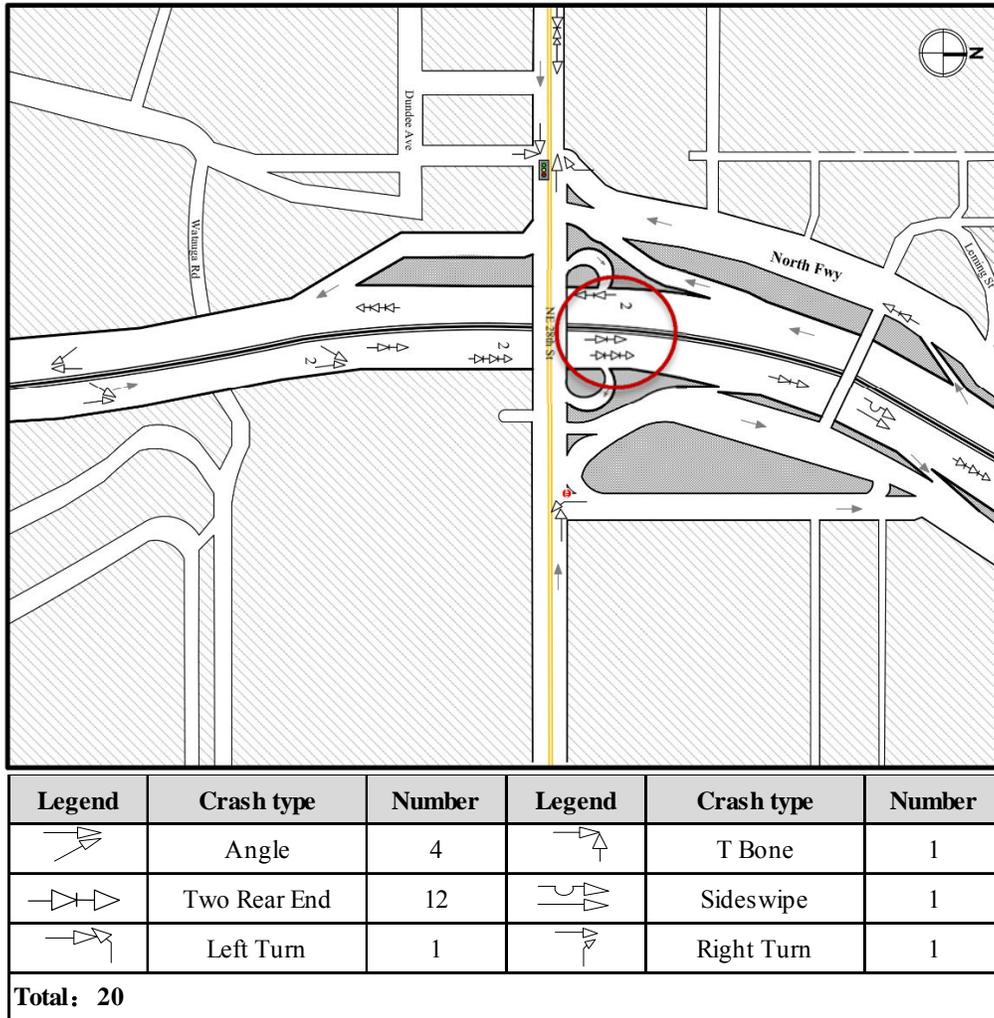


Figure 3- 89: Collision Diagram 2 for Large Truck Crash Hot Area 8 “Fort Worth IH35W”

Finding: rear-end crashes at interchanges (red circle in Figure 3-89)

There is one location under the bridge with quite short lane change distance for entering the on ramp to I-35, which caused 2 rear-end crashes. In 2015, construction work has been done to block this entrance ramp and this issue was solved.

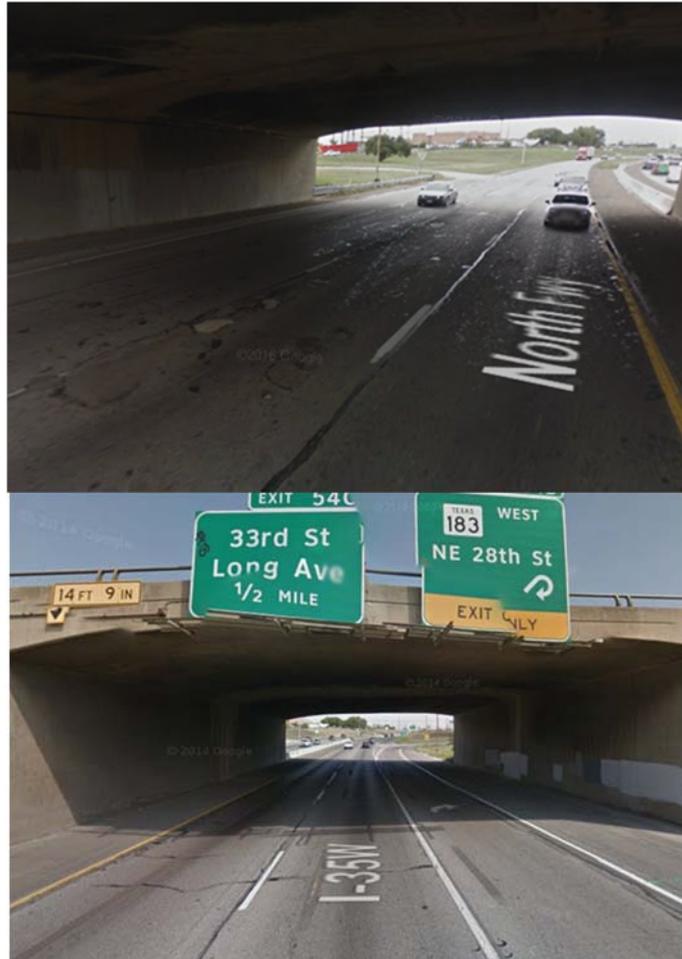


Figure 3- 90: Google Map of the Problematic Location

3.4.8.3 Collision Diagram 3

There were 23 crashes occurred in section 3 during 2011-2015. The major crash type was rear end crashes on highway caused by traffic congestion because of the construction work.

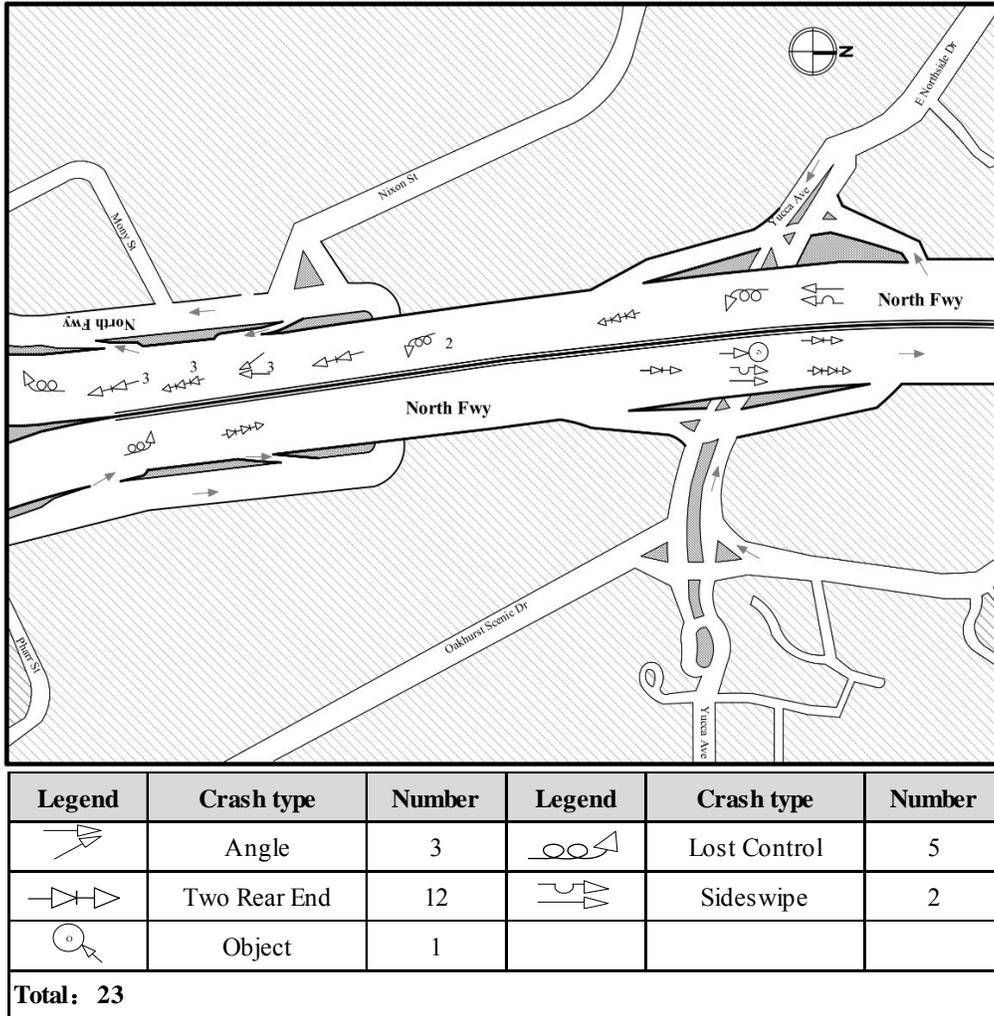


Figure 3-91: Collision Diagram 3 for Large Truck Crash Hot Area 8 “Fort Worth IH35W”

3.4.8.4 Collision Diagram 4

20 crashes occurred in this section in 2011-2015. Most of the crash were rear-end and angle crashes caused by traffic congestion.

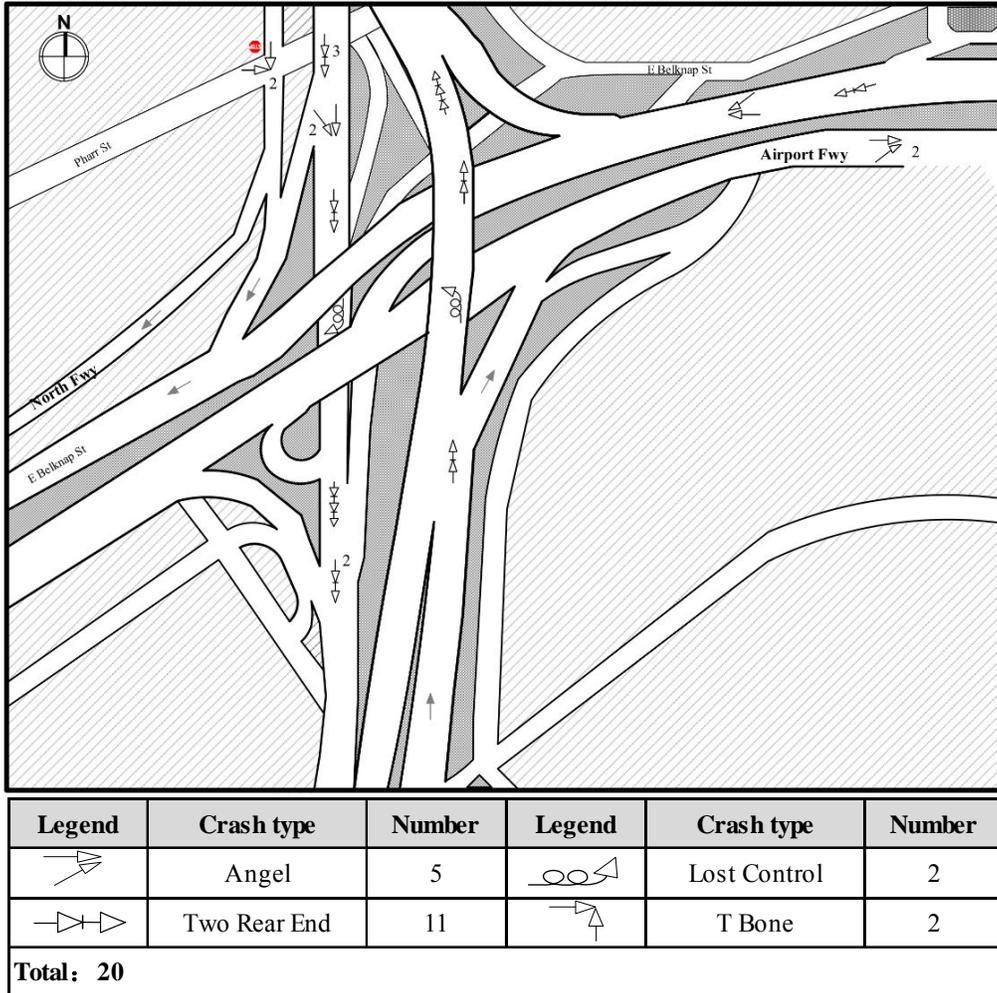


Figure 3- 92: Collision Diagram 4 for Large Truck Crash Hot Area 8 “Fort Worth IH35W”

Finding: short merge distance

Interchanges in this section have quite short merge distance (around 400ft). In addition, there is heavy truck volume around.

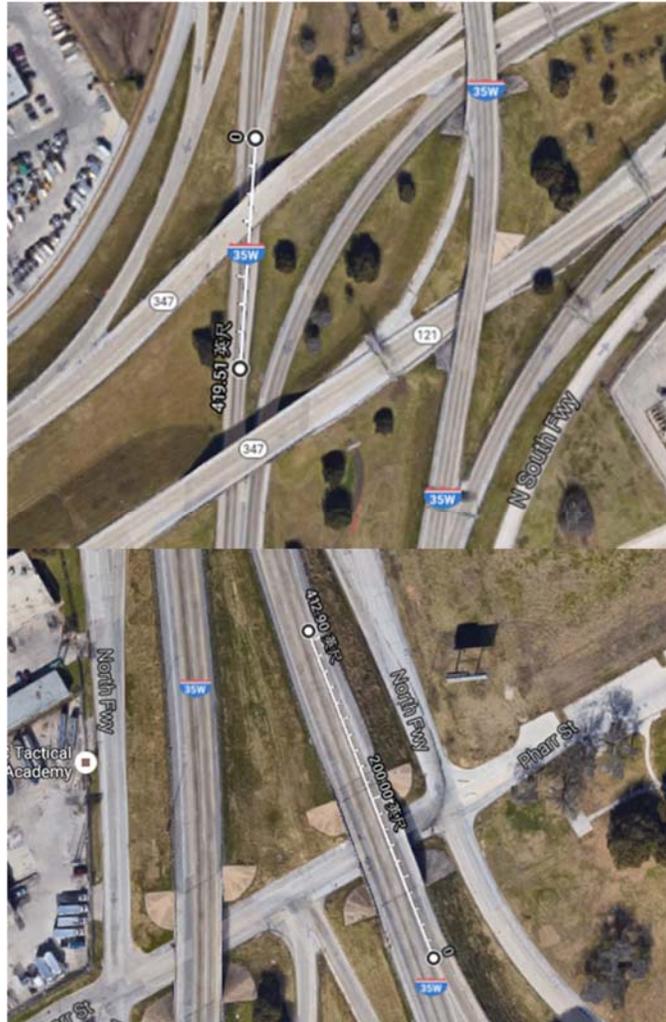


Figure 3- 93: Google Map of the Problematic Location

3.4.8.5 Collision Diagram 5

In this section, there were 19 crashes occurred. Similar to previous section in this area, most of the crashes are caused by traffic congestion. No roadway related risk factors were identified.

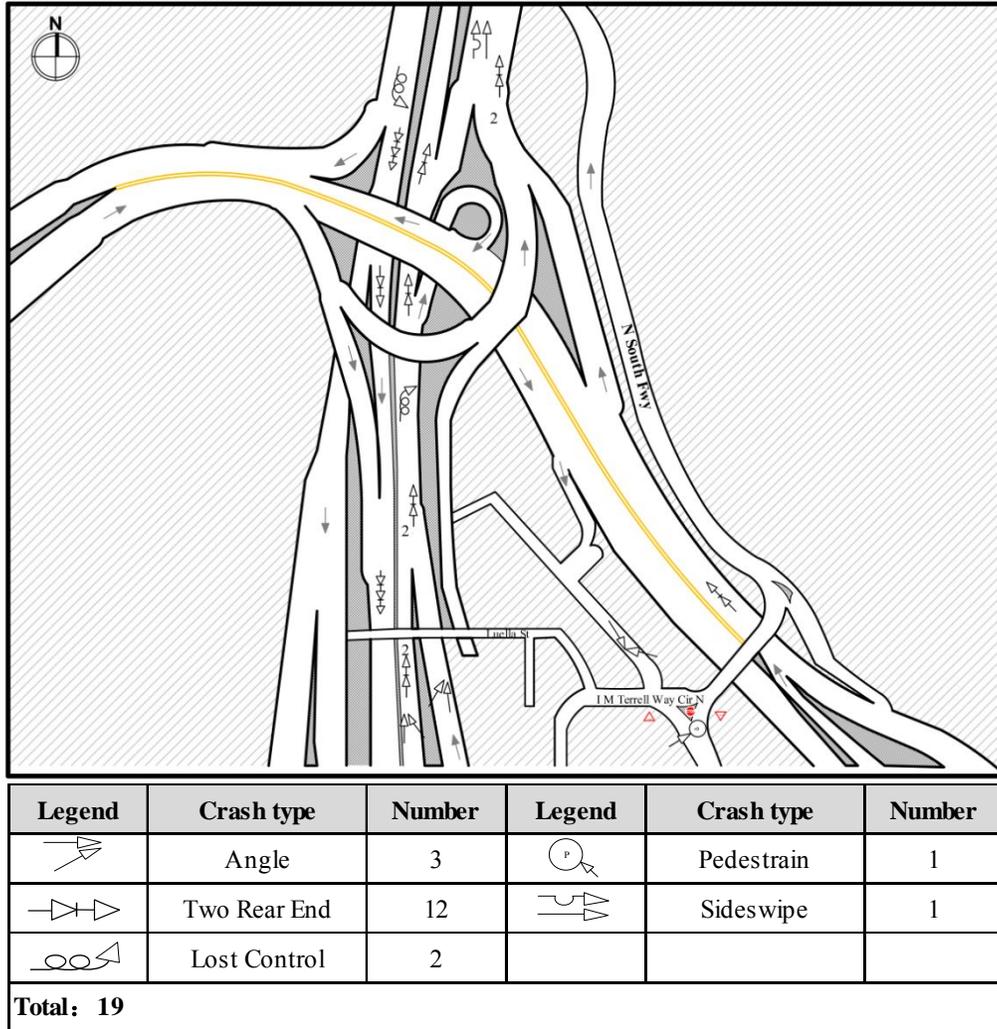


Figure 3- 94: Collision Diagram 5 for Large Truck Crash Hot Area 8 “Fort Worth IH35W”

3.4.8.6 Collision Diagram 6

In this section, there were 11 crashes occurred. No roadway related risk factors were identified.

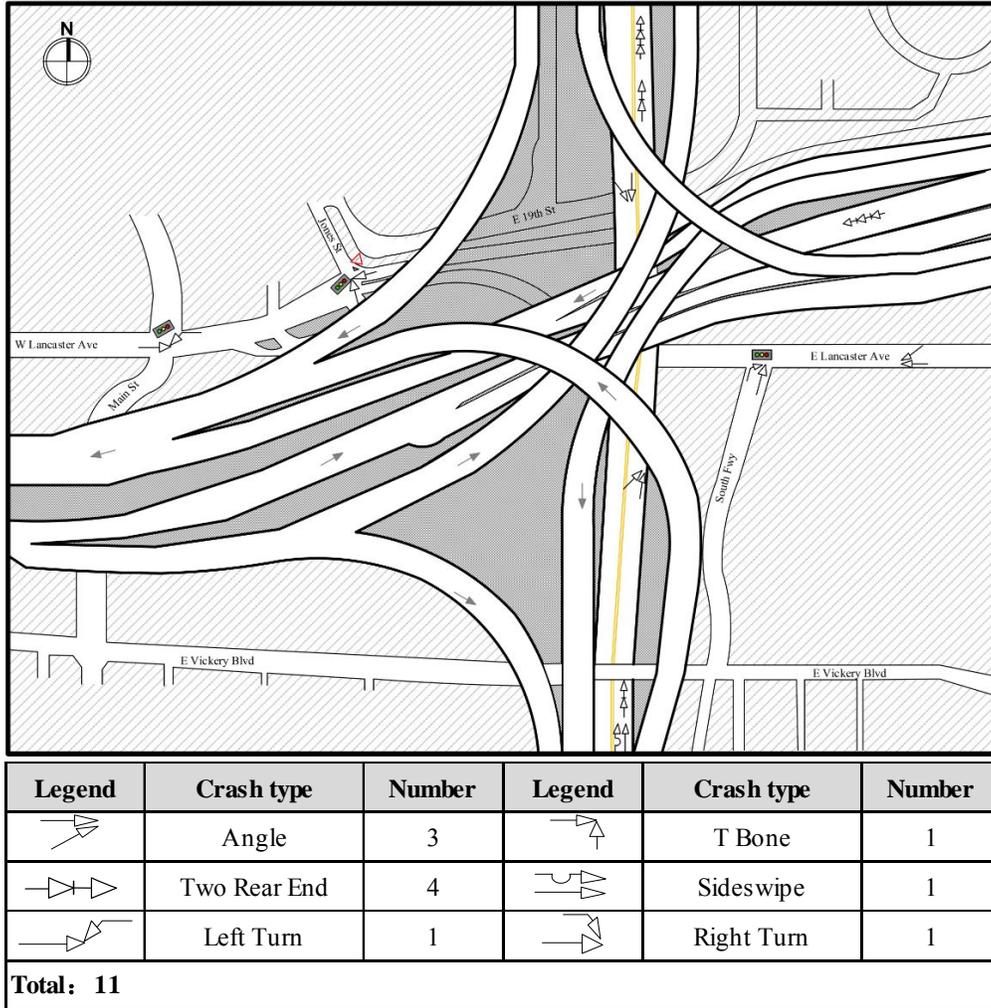


Figure 3- 95: Collision Diagram 6 for Large Truck Crash Hot Area 8 “Fort Worth IH35W”

3.4.8.7 Collision Diagram 7

In this section, there were 11 crashes occurred. Similar to previous section in this area, most of the crashes are caused by congestion. No roadway related risk factors were identified.

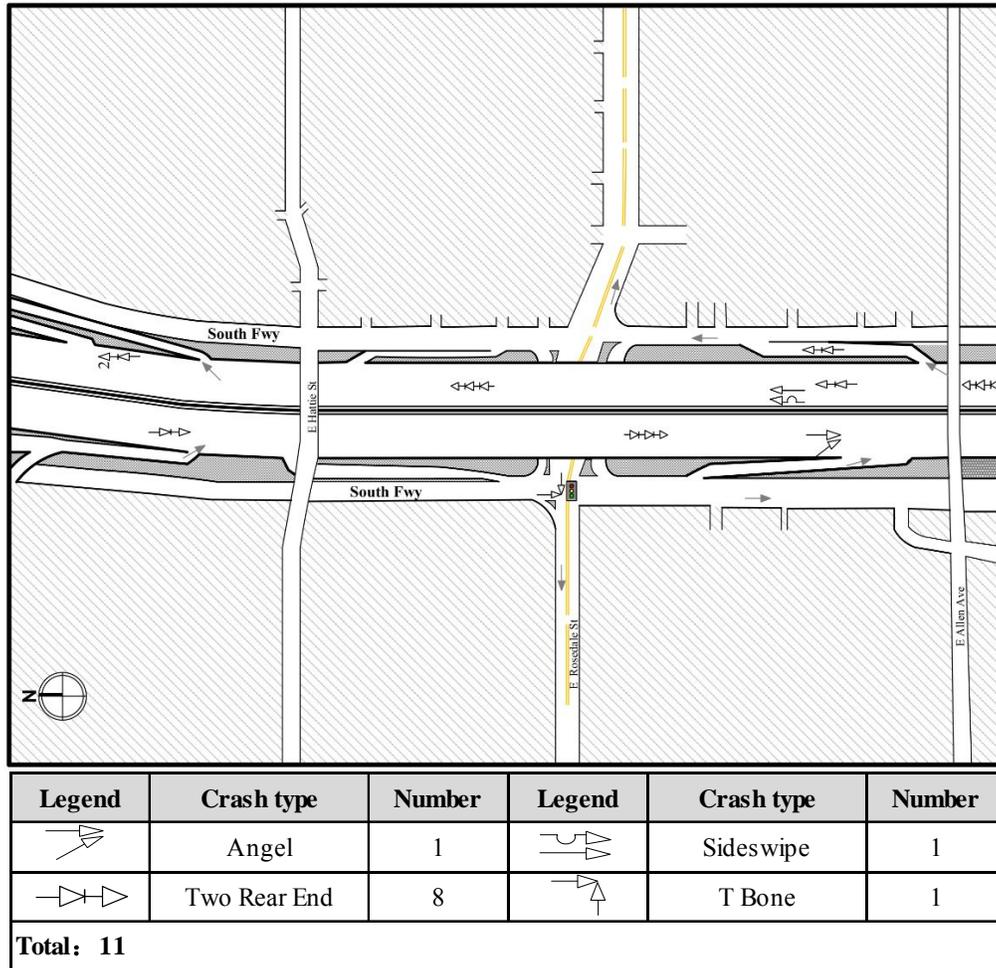
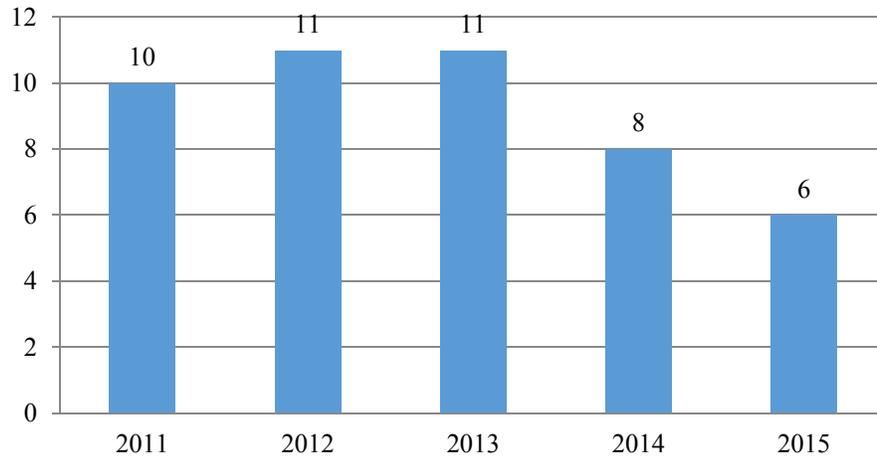


Figure 3- 96: Collision Diagram 7 for Large Truck Crash Hot Area 8 “Fort Worth IH35W”

3.4.9 Hot Area 9 Waco IH35

There were 46 crashes occurred in Waco hot area during the past 5 years, including 4 fatal crashes and 9 incapacitating crashes. Figure 3-97 shows the detailed information related to crash tendency and crash severity distribution. Two collision diagrams were developed to analyze this area. Figure 3-98 shows two sections of this area. Since hot area 9 is a relatively small area and the two sections are very similar, rather than introduce collision diagram for each section, the research team analyzed both sections together.

Crash Tendency in Waco IH 35



Crash Severity Distribution in Waco IH 35

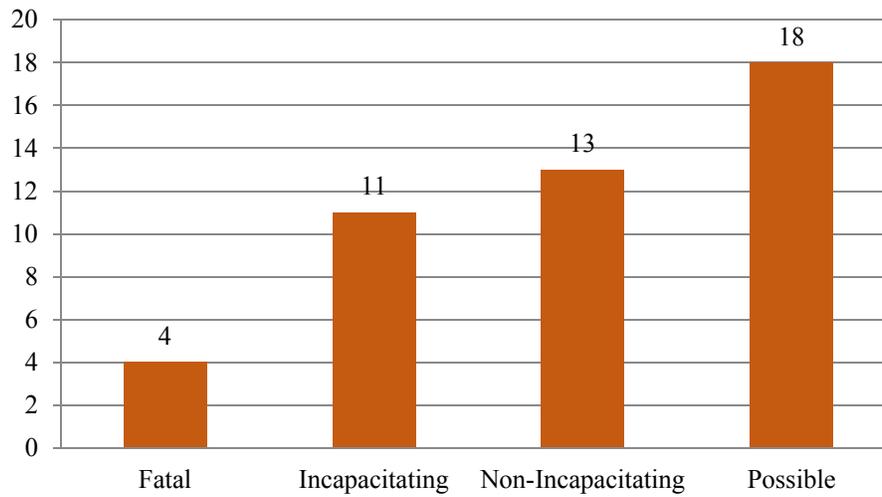


Figure 3-97: Crash Tendency and Crash Severity Distribution at Hot Area 9



Figure 3- 98: Area Map and Collision Diagram Sections at Hot Area 9 “Waco IH35”

Figure 3-99 is collision diagram for section 1, while Figure 3-100 is collision diagram for section 2.

3.4.9.1 Collision Diagram 1

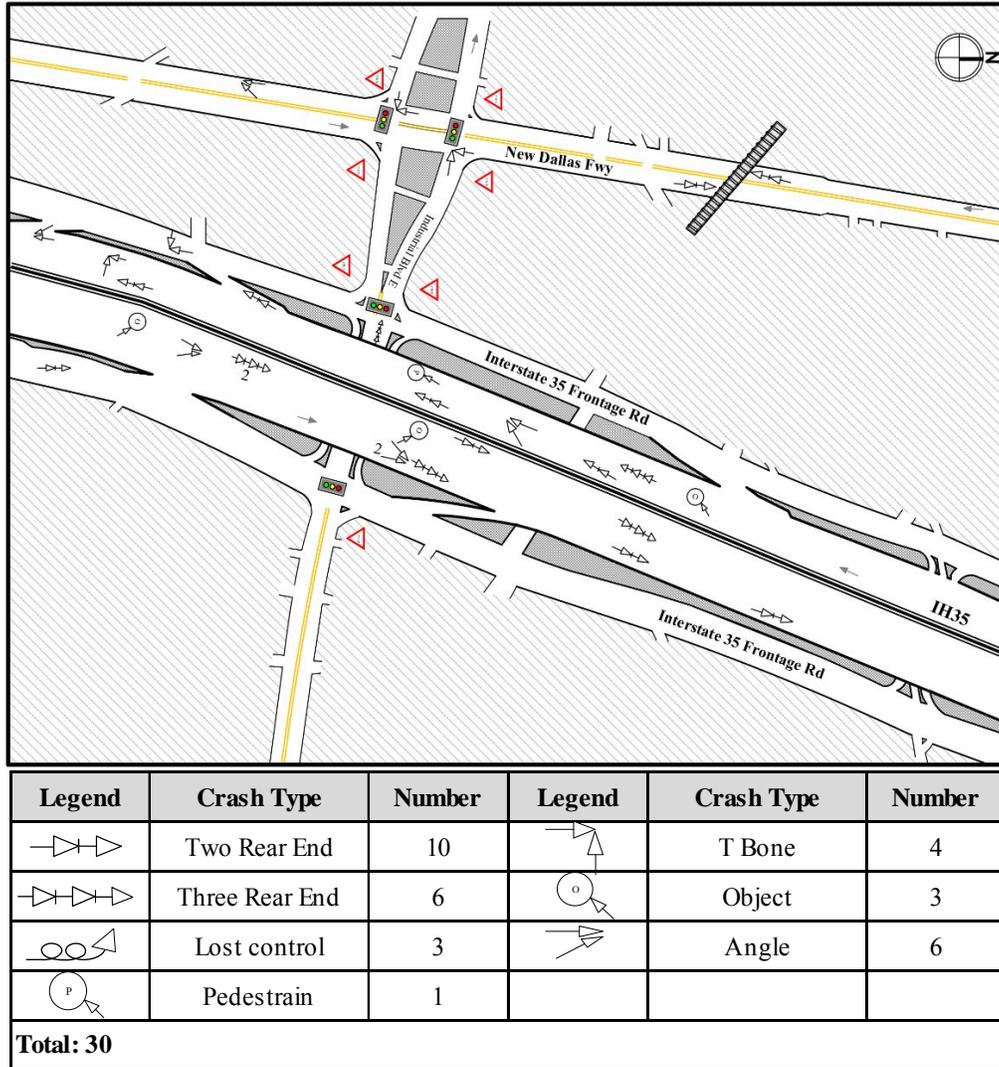


Figure 3- 99: Collision Diagram 1 for Large Truck Crash Hot Area 9 “Waco IH35”

3.4.9.2 Collision Diagram 2

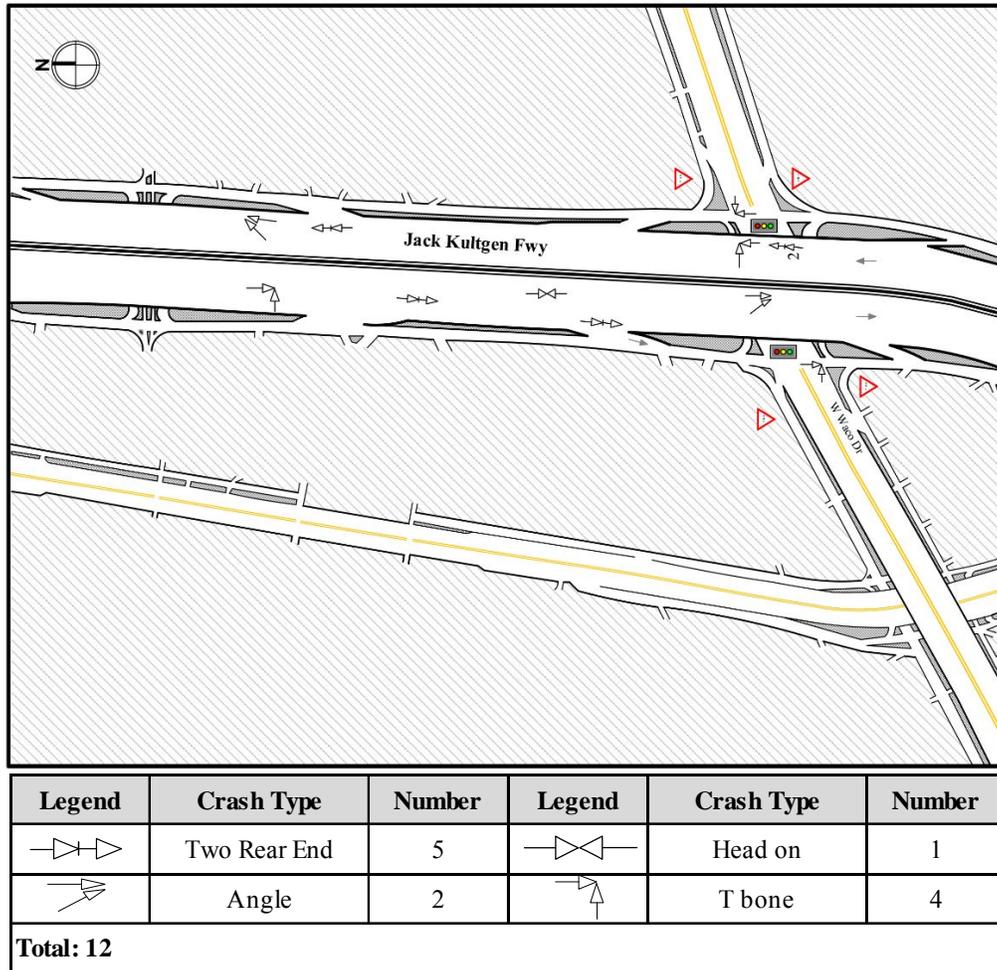


Figure 3- 100: Collision Diagram 2 for Large Truck Crash Hot Area 9 “Waco IH35”

Finding 1: environmental issues

In this area, the high percentage of fatal and incapacitating crashes were caused by environmental related issues. By analyzing crash data, we concluded:

- 40% of the crashes that occurred had a variation of rain, sleet, hail, or snow present and 5 Crashes were a direct result of weather related contributing factors
- 25% of the crashes that occurred under the dark condition with no lighting.

Finding 2: short merge distance

Similar with other hot area, short merge distance is another risk factor for large truck crashes at this location.

Finding 3: wrong way crash

Some roadways in this section are lack of signage, which may cause wrong way crashes. Figure 3-101 shows two locations may cause wrong way crashes. Locations like this should add more “ONE WAY” sign or “NO RIGHT TURN”.



Figure 3- 101: Google Map of the Problematic Location

Finding 4: lack of pavement markings

Similar to other locations, there is lack of pavement markings, which makes driver difficult to stay in a single lane and caused many troubles for vehicles, especially large trucks to make turns.

3.4.10 Hot Area 10 Midland IH20

Compared with other nine hot areas, hot area 10 in Midland is much smaller, yet has very high number of fatal and incapacitating crashes. As shown in Figure 3-102, of all 30

crashes occurred in 2011-2015, 7 were fatal crashes and 3 were incapacitating crashes.

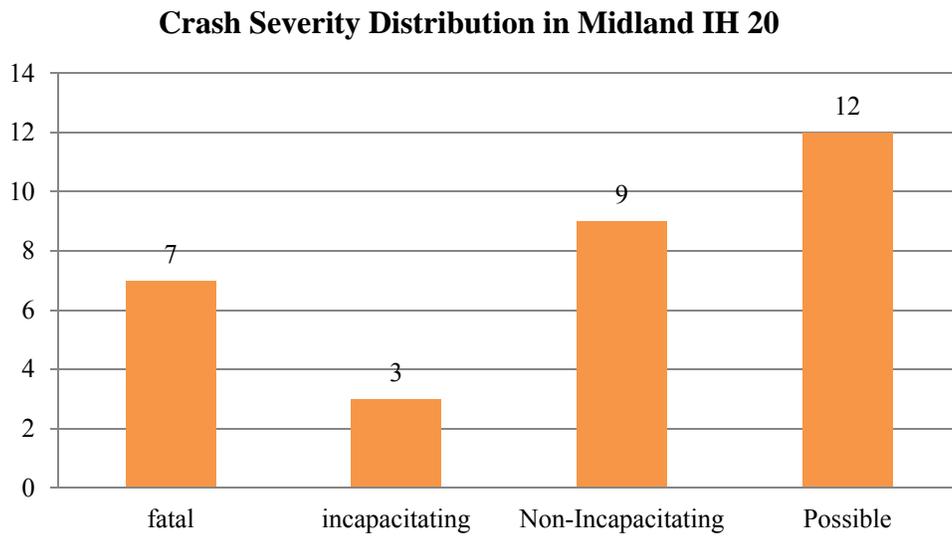
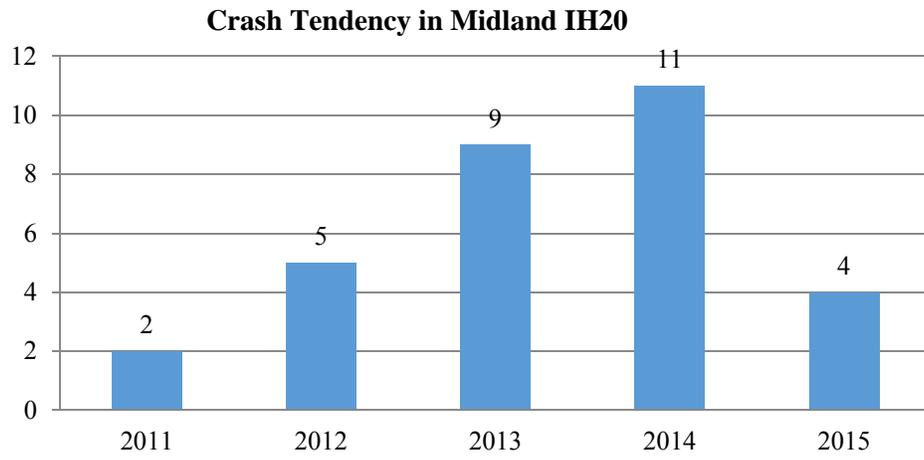


Figure 3-102: Crash Tendency and Crash Severity Distribution at Hot Area 10

Figure 3-103 shows the collision diagram developed for Midland IH20@Rankin Highway.

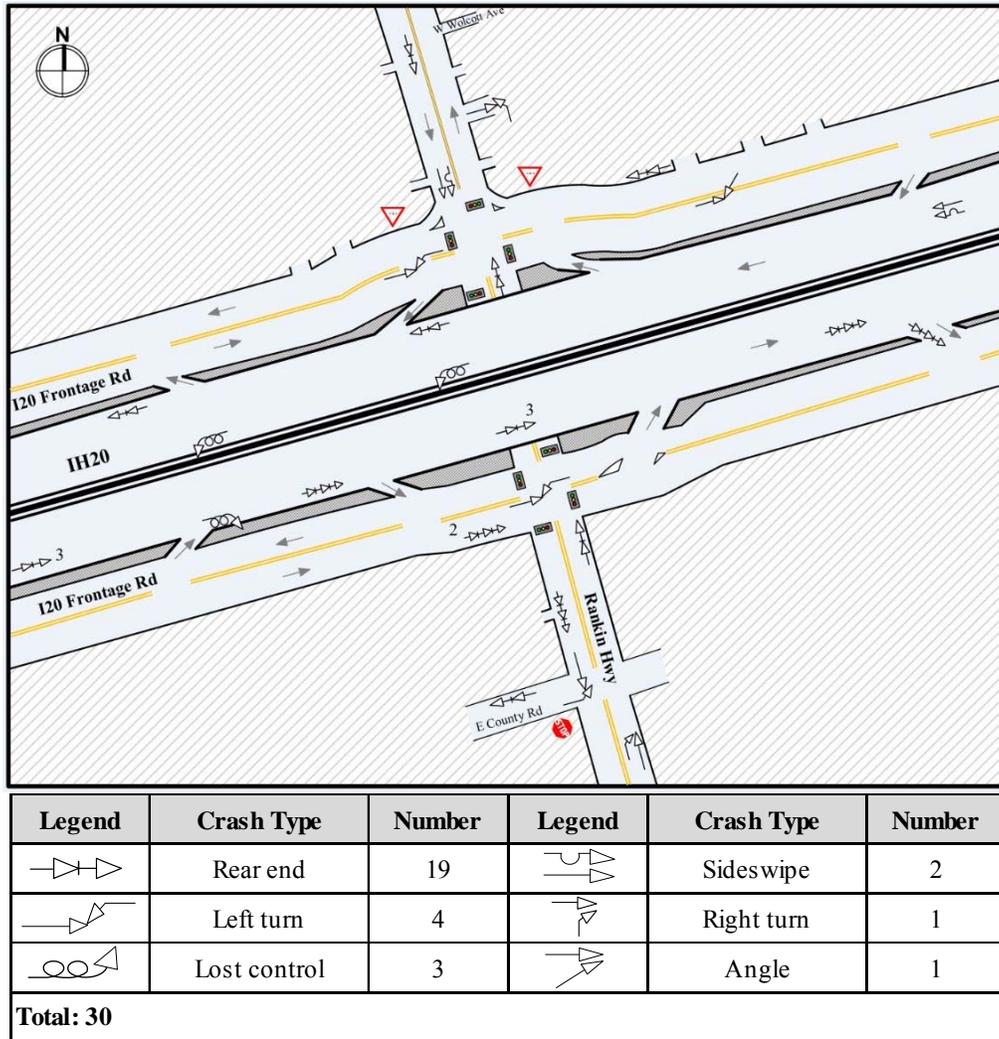


Figure 3-103: Collision Diagram for Large Truck Crash Hot Area 10 “Midland IH20”

Finding 1: confusing two-way frontage road design

There are lots of conflict points at two-way frontage road, especially between vehicle trying to enter the highway ramp and the opposing through vehicle. Although there is a “YIELD” sign for the opposing through traffic, however, due to the small size of yield sign and high speed limit (45mph), some drivers may miss it, then collide with the opposing turning vehicles that is going to enter the highway ramp. Figure 3-104 shows a crash happened at an example location.

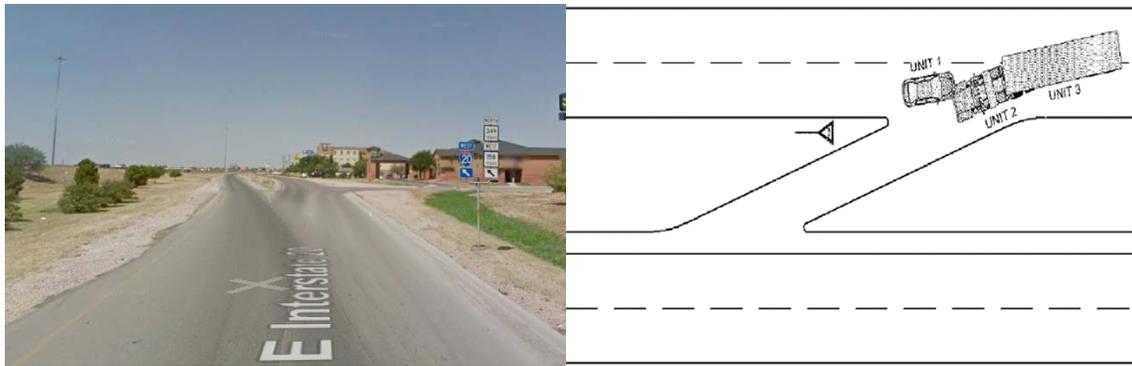


Figure 3- 104: Google Map of the Problematic Location and Sample Accident Occurred Here

Possible countermeasures to reduce crash risk at two-way frontage road include:

- Add more traffic signs and actuated flash lights to the frontage road traffic
- Convert two-way frontage road to one-way frontage road
- Reduce speed limits on frontage roads around on ramps and off ramp locations to reduce the likelihood and severity of crashes
- Educate drivers on who has the right away and how to operate on a two-way frontage road

Finding 2: Driving behavior problems

Comparing with other hot areas, driver behavior problems are much severe in Midland, which include: 1) do not wear seatbelt, 2) driving with cellphone on hand, 3) driving when fatigue, 4) driving under influence.

Of all 7 fatal crashes and 3 incapacitating crashes occurred, one crash caused by driver inattention, also driver not wear seatbelt, 1caused by fatigue driver and one crash caused by driver checking cellphone.

Finding 3: Truck illegal parking

There were trucks illegally parked at shoulder (Figure 3-105) or roadside grass areas. Install raised shoulders with curbs could potentially prevent such illegal parking events.



Figure 3- 105: Google Map of the Problematic Location

Finding 4: High rear-end crashes

There were 19 rear-end crashes occurred in this hot area. After reviewing police reports, it has been noticed that this area was undergoing construction during 2013-2014. Most of the rear-end crashes occurred during construction period. Figure 3-106 shows the crash tendency, and we can see there is a big drop on crash number in 2015.

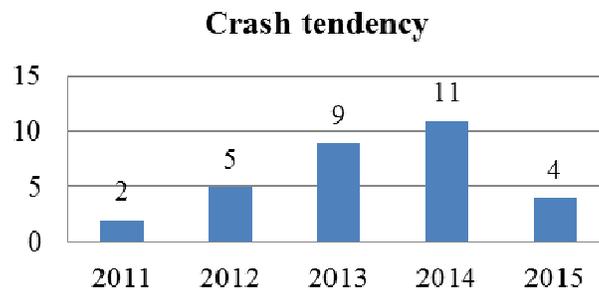


Figure 3- 106: Rear-end Crash Tendency in 2011-2015

3.5 SUMMARY

By analyzing 10 selected hot areas, following 14 risk factors were identified, along with potential countermeasures:

1. Two-way frontage road design
 - Add more traffic signs and actuated flash lights to the frontage road traffic
 - Convert two-way frontage road to one-way frontage road

- Reduce speed limits on frontage roads around on ramps and off ramp locations to reduce the likelihood and severity of crashes
 - Educate drivers on who has the right away and how to operate on a two-way frontage road
2. Truck parking without appropriate protection
- Install raised shoulders with curbs that could potentially prevent illegal parking events on the local frontage roads
 - Enhance law enforcement and monitoring of illegal parking and enforce proper protection (hazard signal flashers, warning triangles)
 - Provide more parking and rest areas for truck drivers to rest and and enhance truck maintenance related regulations
3. Truck maintenance
- Perform inspection and maintenance regularly could possible reduce the possibility of large truck having mechanical issues.
 - Enhance law enforcement on large trucks and their respective companies and agencies to ensure that all procedures are being done properly.
4. Driver behavior problems, such as speeding, not wear seatbelt, driving with cellphone, fatigue and DUI.
- Increase law enforcement of all illegal driver behavioral issues that occur such as speeding, not wearing a seatbelt, driving with cellphone, fatigue and DUI
 - Educate drivers on what to do and what not to do while on the road
5. Visibility of signal heads and traffic signs for locations with heavy truck volume
- Raise signal heads according to regulations
 - Use designated signal light heads for each lane to assist driver making turns
 - Put intersection lane control signs/ stop signs on both sides of the road
 - Add flashing beacons to the stop sign at non-signalized intersection

6. Short merge distance at highway entrances
 - Extend merge distance
 - Use auxiliary lanes to connect the on ramp and off ramp
7. Late merge behavior caused by drivers confusing about interchange lane configuration
 - Add more advanced traffic signs or pavement marker to indicate “diverging ahead” and the lane configurations
 - Install physical barriers, such as pylons, at the gore of the exit ramps
8. Fail to control speed at highway off ramps
 - Install radar speed sign at off ramps
 - Install transverse rumble strips at highway off ramps
 - Add flashing beacon at off ramp speed advisor sign
 - Install automated speed enforcement
9. Intersection with dual left turn or dual right turn
 - Provide clear turning guide lines on the pavement
 - Install designated signal light heads for each lane also can be implemented at this intersection to assist driver making turns.
 - Provide training/education to both truck and passenger car drivers
10. No enough turning space for trucks making right turn
 - Conduct turning path analysis to make sure large trucks can make turn safely
 - Provide clear turning guide lines on the pavement
 - Push back the stop lines of the crossing street to release more space for the right-turn trucks
 - Channelize right turns (use right turn slip lanes)
11. Lack of clear pavement markings
 - Provide clear pavement markings especially for the locations with narrow lanes or dual right/left-turn lanes

12. Narrow lane

- Install advanced signaling and signage to let road users know that congestion and construction ahead
- Install rumble strips

13. Construction and congestion

- Install advanced signaling and signage to let road users know that congestion and construction ahead

14. Two way left design for location with many access points and heavy truck volume

- Apply access management techniques (right-in/right-out) to eliminate left-turns at some access points
- Add median and install the directional left turn openings

CHAPTER 4 CRASH DATA BASED COMPREHENSIVE CRASH RISK ANALYSIS

In this chapter, two different methods, i.e. descriptive analysis and statistical model based analysis, have been used for comprehensive truck risk analysis. By conducting descriptive analysis, crash risk factors related to driver, vehicle, roadway and environmental conditions have been analyzed. After that, Ordered Probit model was developed to identify the significant factors contributing to the large truck crash severity.

Same as the collision diagram based in depth crash risk analysis, five years' truck crash data (from year 2011 to year 2015) was collected from Crash Records Information System (CRIS). This database contains records of 85,184 large truck crashes and more than 170 attributes for each crash record, including information about the drivers, vehicles, characteristics of the crashes, roadway conditions, and environmental conditions.

4.1 DESCRIPTIVE ANALYSIS

The following part provides simple descriptive statistics about large truck involved crashes in Texas. Characteristics of the driver crashes, roadway conditions, and environmental conditions were considered. Same analysis was conducted for all crashes, as well as KA crashes (Fatal and Incapacitating crashes) to investigate how the factors contribute to crashes with different severity levels.

4.1.1 Environmental Factors

Environmental factors include the day of week and time of day crash occurred, weather condition, light condition and surface condition.

Day of week

Figure 4-1 shows the distribution of crashes happened on different day of week. We can see from this figure that weekend has lower number of crashes. However, for all crashes, 6% occurred on Sunday and 8.31% occurred on Saturday. However, for KA crashes, 8.13% occurred on Sunday and 10.20% occurred on Saturday, both higher. The results indicate it tends to be more severe when large truck involved crash occurred on weekend.

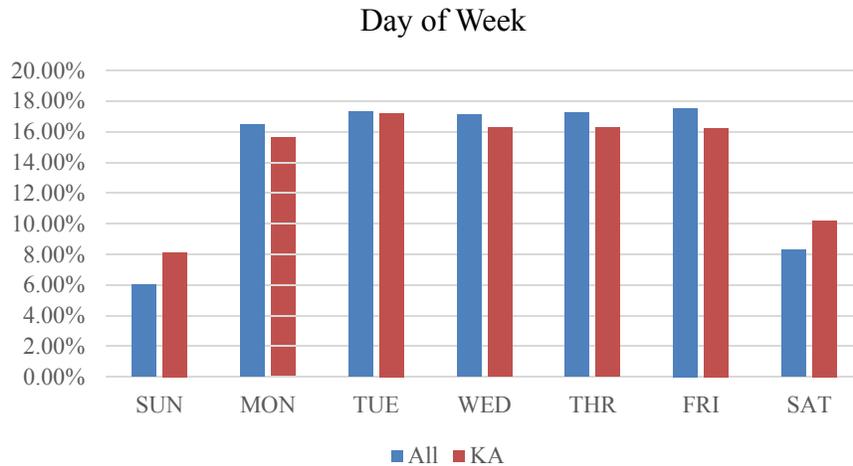


Figure 4-1: Crash Distribution on Each Day of Week

Time of Day

To study the distribution of the time that crashes occurred, we separated one day into 6 time periods:

- Midnight Morning: 12:00 AM – 2:59 AM
- Early Morning: 3:00 AM – 5:59 AM
- Peak Morning: 6:00 AM – 8:59 AM
- Mid-day: 9:00 AM – 2:59 PM
- Evening Peak: 3:00 PM – 6:59 PM
- Late Night: 7:00 PM – 11:59 PM

Figure 4-2 shows the crash distribution on each time period. Compared with all crashes, a higher number of KA crashes happened during 7:00 pm to 8:59 am, which means if a crash happens during 7:00 pm to 8:59 am, it is more likely to have high level of injury severity.

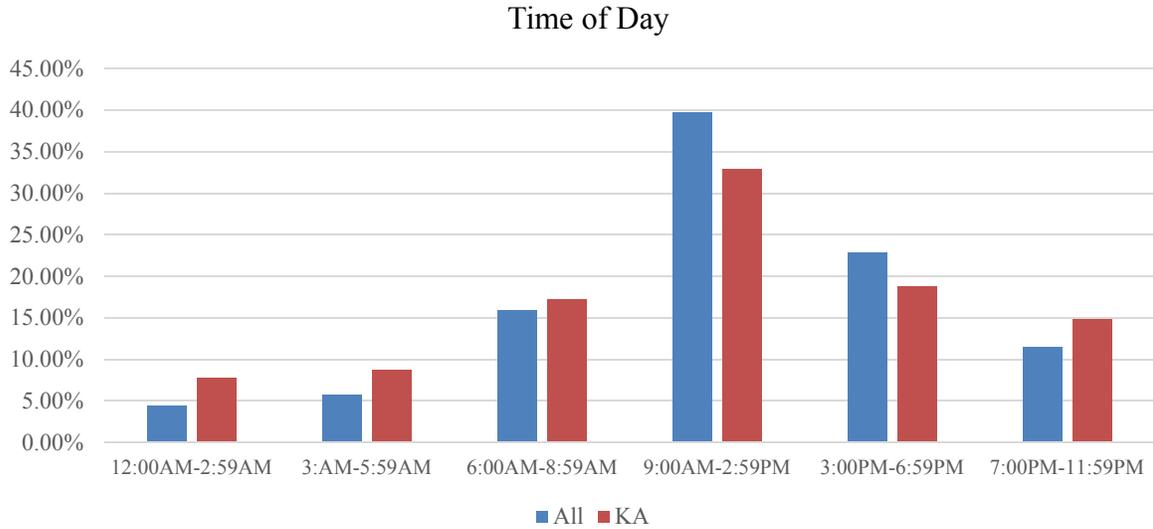


Figure 4-2: Crash Distribution on Time of Day

Weather condition

Figure 4-3 shows the distribution of crashes occurred under different weather conditions. From this figure we can see, most of crashes occurred in clear condition. There is no big difference between the distributions of all crashes and KA crashes.

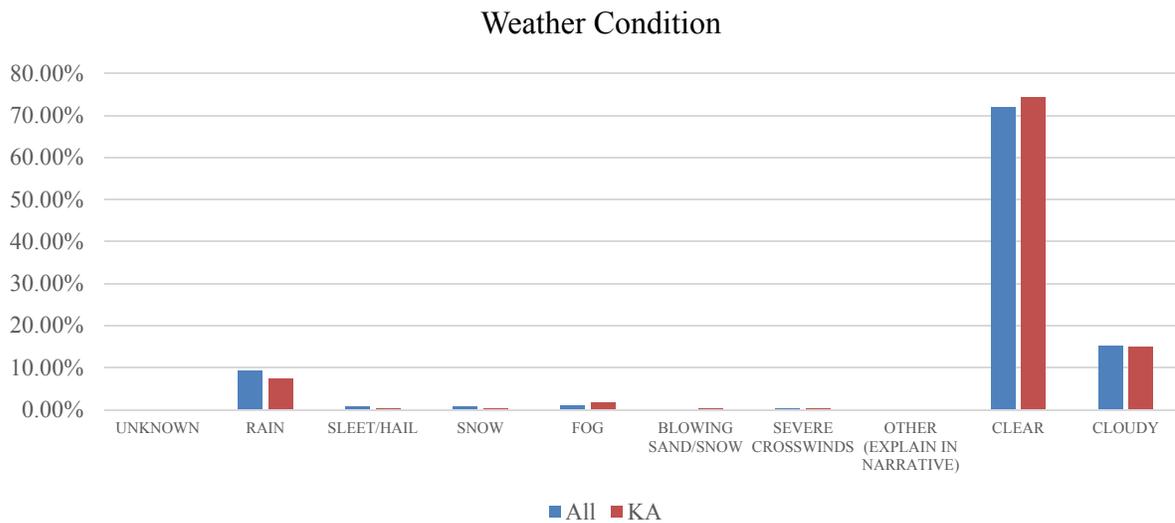


Figure 4-3: Crash Distribution on Different Weather Conditions

Light condition

Figure 4-4 shows the distribution of crashes occurred under different light conditions. It

can be seen that both all crash and KA crash happened more frequently on daylight condition. However, the percentage of KA crash occurred during “dark not lighted” is higher than all crash occurred during same condition. This result shows dawn and dark may increase the crash severity.

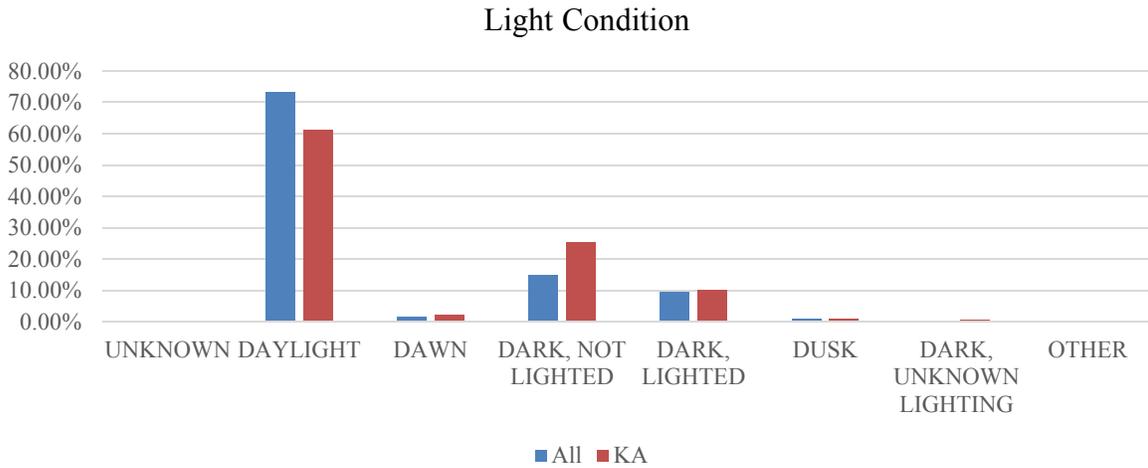


Figure 4-4: Crash Distribution on Different Light Conditions

Surface condition

Figure 4-5 shows the distribution of crashes occurred under different surface conditions. Most of the crashes occurred on dry surface.

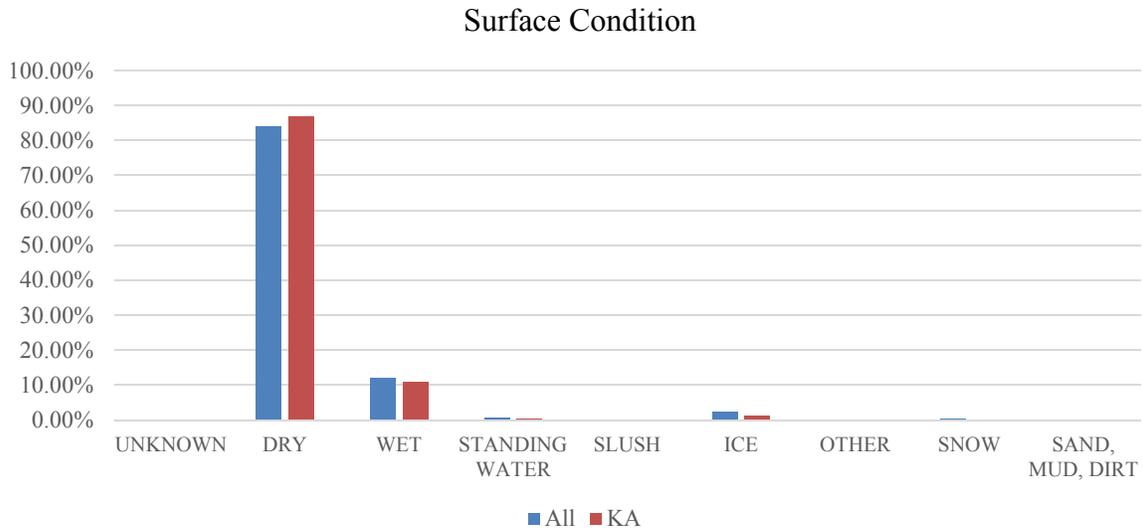


Figure 4-5: Crash Distribution on Different Surface Conditions

4.1.2 Roadway related factor

In this study, roadway related factors, including road classification, roadway functional system and road alignment, were analyzed.

Road classification

Figure 4-6 shows the road classification when crash occurred. It can be seen, 36.82% of large truck crashes happened on Interstate Highway, while only 27% of large truck KA crash happened on Interstate Highways. For all large truck involved crashes, 48.52% and 13.14% occurred on US & State Highways and Farm to Markets Roads, while for large truck KA crashes, these two numbers are 57.22% and 15.18%, both higher. It indicates that crashes occurred on US & State Highways or Farm to Markets Roads have high possibility to be KA crashes.

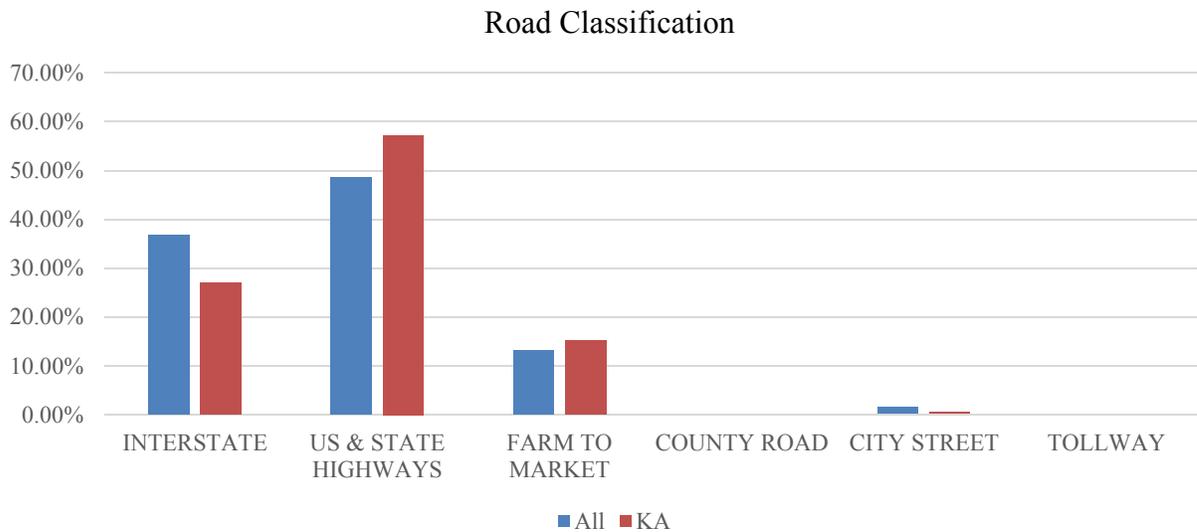


Figure 4-6: Crash Distribution on Different Road Classifications

Roadway functional system

Figure 4-7 is the distribution of large truck crashes and large truck KA crashes on different roadway functional system. It can be seen that the rural roadways have higher percentage of KA crashes than all crashes, while urban roadways have lower percentage of KA crashes than all crashes.

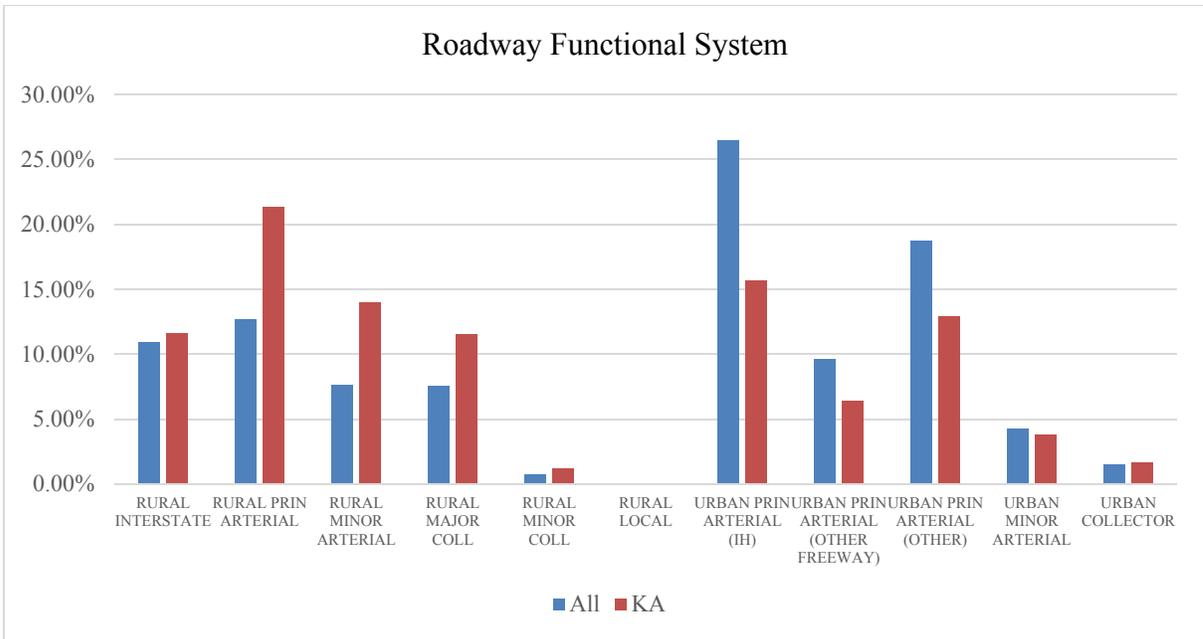


Figure 4-7: Crash Distribution on Different Roadway Functional Systems

Road Alignment

Figure 4-8 shows the crash distribution on different road alignment conditions. It can be seen, that the percentage of large truck KA crashes occurred on grade or curve are higher than all crashes occurred on grade or curve. This result shows that the crash tends to be more severe when it happens on roads with grade or curve.

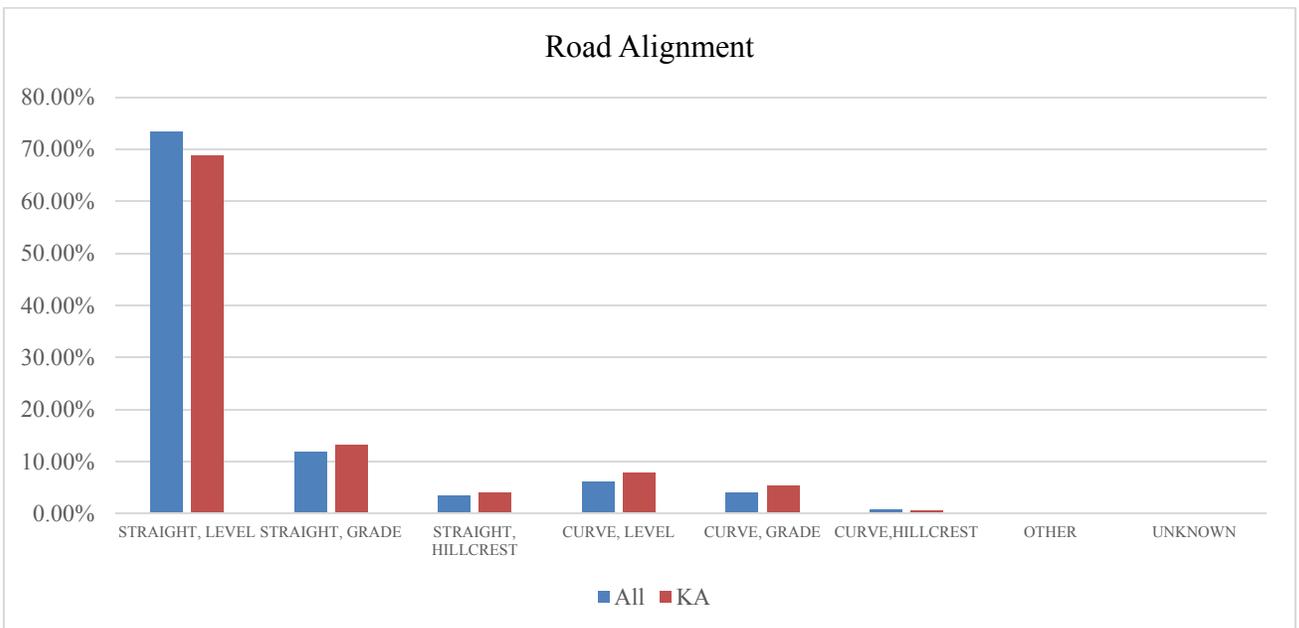


Figure 4-8: Crash Distribution on Different Roadway Alignments

4.1.3 Driver related factors

Fatigue, alcohol, drug and wrong-way driving are four driver related risk factors contributing to large truck involved crashes. From Figure 4-9, we can see, 6.57% of the total crashes are caused by these four driver related factors, however, 20.46% of the KA crashes are caused by these four driver related factors. The big difference indicates that if a crash is caused by one of these four driver related factors, it has a large chance to be KA crashes.

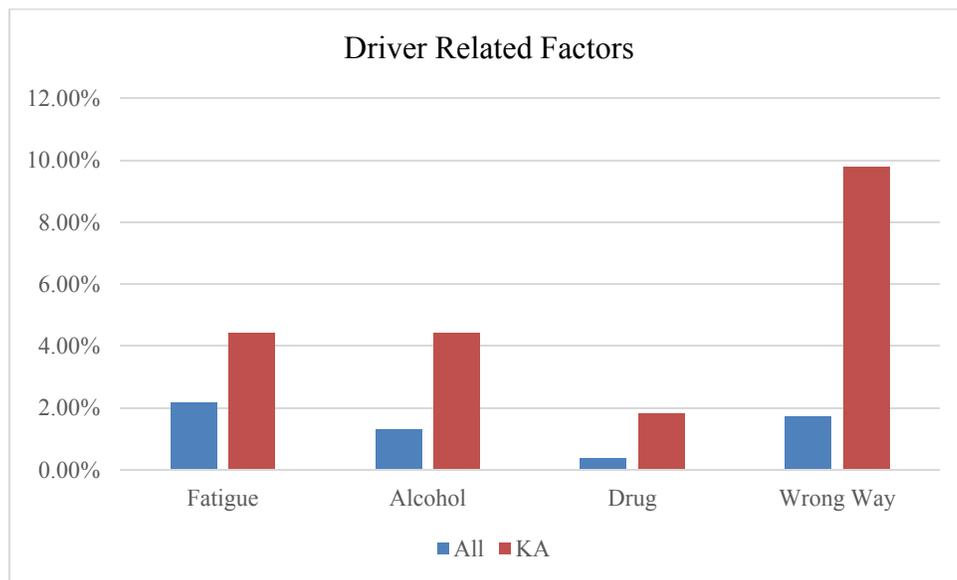


Figure 4-9: Percentage of Crash Caused by Driver Related Factors

4.2 Crash Severity Analysis

The objective of this approach is to further investigate the potential risk factors that contribute to the severity of large truck crashes by using advanced statistical model. Crash severity analysis has the distinct advantage of taking into account of different influencing factors, including driver-related contributing factors and individual crash characteristics.

4.2.1 Methodology

Here, the *ordered probit model* was used to analyze large-truck crash data due to the ordered nature of the injury severity levels. Also, the ordered probit model can identify statistically-significant relationships between explanatory variables (e.g., roadway-related factors, environment-related factors, driver-related factors, and crash locations in this

study) and a dependent variable (crash severity level in this study). In addition, it discerns unequal differences between ordinal categories in the dependent variable. In statistics, the ordered probit model is a generalization of the popular probit model that is used when there are more than two outcomes of an ordinal dependent variable.

First, the ordered probit model was built around a latent regression model:

$$y^* = \sum \beta_i X_i + \varepsilon, \quad (1)$$

where y^* is the dependent variable that is unobservable and represents the severity of large-truck crashes; X_i is another explanatory variable that influences the severity of large-truck crashes; β_i is the coefficients for X_i ; and ε is the error term.

In this study, y represent the variable of the severity level of a large truck crash.

Specifically, following five severity levels for crashes were considered in the model:

$$\begin{aligned} y = 0 & \quad \text{Not Injured} \\ y = 1 & \quad \text{Possible Injury} \\ y = 2 & \quad \text{Non-incapacitating Injury} \\ y = 3 & \quad \text{Incapacitating Injury} \\ y = 4 & \quad \text{Fatal} \end{aligned} \quad (2)$$

Based on the ordered probit model, y can be determined by the unobserved variable y^* as follows:

$$\begin{aligned} y = 0 & \quad \text{if } y^* \leq 0, \\ y = 1 & \quad \text{if } 0 < y^* \leq \mu_1, \\ y = 2 & \quad \text{if } \mu_1 < y^* \leq \mu_2, \\ y = 3 & \quad \text{if } \mu_2 < y^* \leq \mu_3, \\ y = 4 & \quad \text{if } y^* \geq \mu_3, \end{aligned} \quad (3)$$

The μ s are unknown parameters that must be estimated with β s. If ε is assumed as

normally distributed across observations and its mean and variance are normalized to 0 and 1, respectively, then we have the following probabilities:

$$Prob(y = 0) = \Phi\left(-\sum \beta_i X_i\right) \quad (4.1)$$

$$Prob(y = 1) = \Phi\left(\mu_1 - \sum \beta_i X_i\right) - \Phi\left(-\sum \beta_i X_i\right), \quad (4.2)$$

$$Prob(y = 2) = \Phi\left(\mu_2 - \sum \beta_i X_i\right) - \Phi\left(\mu_1 - \sum \beta_i X_i\right) \quad (4.3)$$

$$Prob(y = 3) = \Phi\left(\mu_3 - \sum \beta_i X_i\right) - \Phi\left(\mu_2 - \sum \beta_i X_i\right) \quad (4.3)$$

$$Prob(y = 4+) = 1 - \Phi\left(\mu_3 - \sum \beta_i X_i\right) \quad (4.4)$$

The parameters of the β s and μ s can be obtained based on the maximum likelihood method. According to Equation (1), when $\beta_i > 0$, y^* will increase with the increment of X_i , thereby will increase the probability of y being the high severity level. On the other hand, when $\beta_i < 0$, y^* will decrease with the increment of X_i , thereby will increase the probability of y being the low severity level.

4.2.2 Data description

The *dependent variable* for the developed ordered probit model was the severity of large-truck crashes. As we mentioned before, five different severity levels for crashes were considered in the model. Figure 4-10 shows the distribution of large truck crash injury severity of the sample data.

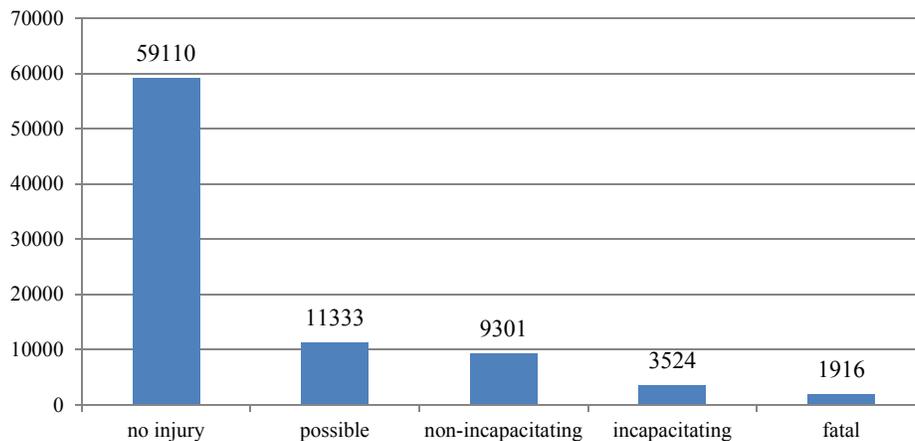


Figure 4-10: Distribution of Large Truck Crash Injury Severity

The independent variables were selected from over 170 attributes of the large-truck crash data. Variables related to the roadway, environment, and driver’s characteristics were examined in a variety of initial model formulations. Before determining the specifications for the final model, correlated variables were removed except for the most significant ones. For example, road surface conditions (dry, wet, and ice-covered) and weather conditions (clear, rain, and snow) were correlated factors, and the weather-condition factors was kept in the model, while the surface-condition factors were removed. Also, variables that were found to have low statistical significance were removed in a sequential variable elimination process. According to this process, the following factors were selected as potential independent variables in the model.

Traffic Control

Traffic control method means the control method at an intersection, such as signal light, stop sign, yield sign, and flashing light. Table 4-1 shows the description of traffic control variables. Table 4-2 shows the distribution of different traffic control methods.

Table 4- 1: Description of Traffic Control Variables

Variable	Description	Mean	Std. Deviation
Traffic Control			
none	1 if no traffic control, 0 otherwise	0.1135	0.3172
stop	1 if traffic control is stop sign, 0 otherwise	0.05687	0.2316
signal	1 if traffic control is signal light, 0 otherwise	0.1329	0.3395
yield	1 if traffic control is yield sign, 0 otherwise	0.02511	0.1565
flashing	1 if traffic control is flashing light, 0 otherwise	0.00657	0.08081
		4	

Table 4- 2: Distribution of Traffic Control Variables

Variable	Crash Injury Severity					Total	Percent
	No injury	Possible	Non-incapacitating	Incapacitating	Fatal		
Traffic Control							
none	7176	1257	842	280	115	9670	11.35%
stop	3120	662	610	267	185	4844	5.69%
signal	8432	1612	908	292	81	11325	13.29%
yield	1487	299	230	83	40	2139	2.51%
flashing	355	89	65	25	26	560	0.66%
flashing	355	89	65	25	26	560	0.66%

Location of First Harmful Event

Location of first harmful event refers to where the first harmful event (point of impact) occurred in relation to the roadway, such as on road, off road, shoulder, and median. Shown as Figure 103, the distribution of the location of first harmful event shows that first harmful event occurred on road, off road, on median, and on shoulder accounted for about 82%, 13%, 4%, and 1%, respectively, of the total observations. Figure 4-11 shows the pie chart of the first harmful event variable.

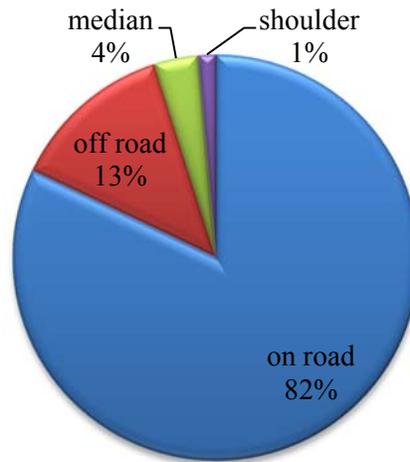


Figure 4-11: Distribution of location of first harmful events

Table 4-3 shows the description of location of first harmful event variables. Table 4-4 shows the distribution of different locations of first harmful event.

Table 4- 3: Description of Location of First Harmful Event Variables

Variable	Description	Mean	Std. Deviation
<i>Location of First Harmful Event</i>			
onroad	1 if crash occurred on road, 0 otherwise	0.8203	0.3839
shoulder	1 if crash occurred on shoulder, 0 otherwise	0.0139	0.1171
median	1 if crash occurred on median, 0 otherwise	0.03519	0.1843
offroad	1 if crash occurred off road, 0 otherwise	0.1302	0.3365

Table 4- 4: Distribution of Location of First Harmful Event Variables

Variable	Crash Injury Severity					Total	Percent
	No injury	Possible	Non-incapacitating	Incapacitating	Fatal		
<i>Location of First Harmful Event</i>							
onroad	48725	9631	7179	2783	1561	69879	82.03%

shoulder	757	124	134	97	72	1184	1.39%
median	2067	361	390	118	62	2998	3.52%
offroad	7530	1217	1598	526	221	11092	13.02%

Roadway Functional System

Roadway functional system variable represents roadway function for crashes occurred on the state highway system. The roadway system contains roadway such as urban interstate highway, urban arterial, and rural arterial. Table 4-5 shows the description of roadway functional system variables. Table 4-6 shows the distribution of different roadway functional system variables.

Table 4- 5: Description of Roadway Functional System

Variable	Description	Mean	Std. Deviation
<i>Roadway Functional System</i>			
uih	1 if urban interstate highway, 0 otherwise	0.2643	0.441
rpa	1 if rural principle arterial, 0 otherwise	0.1268	0.3327
uopa	1 if urban other principle arterial, 0 otherwise	0.2833	0.4506
uma	1 if urban minor arterial, 0 otherwise	0.05765	0.2331
rma	1 if rural minor arterial, 0 otherwise	0.1586	0.3653

Table 4- 6: Distribution of Roadway Functional System Variables

Variable	Crash Injury Severity					Total	Percent
	No injury	Possible	Non-incapacitating	Incapacitating	Fatal		
<i>Roadway Functional System</i>							
uih	16220	3403	2043	567	284	22517	26.43%
rpa	6934	1189	1519	697	462	10801	12.68%
uopa	17196	3645	2243	751	299	24134	28.33%
uma	3517	621	477	211	85	4911	5.77%
rma	8547	1526	1985	919	534	13511	15.86%

Roadway Characteristics

Road alignment, curb, median, and shoulder were considered in roadway characteristics category. Road alignment represents the geometric characteristics of the roadway at the crash site. Table 4-7 shows the description of road alignment variables. Table 4-8 shows the distribution of different road alignment variables.

Table 4- 7: Description of Road Alignment Variables

Variable	Description	Mean	Std. Deviation
Road Alignment			
strailevel	1 if road alignment is straight level, 0 otherwise	0.7348	0.4414
straigrade	1 if road alignment is straight grade, 0 otherwise	0.119	0.3238
straihillcrest	1 if road alignment is straight hillcrest, 0 otherwise	0.03388	0.1809
curlevel	1 if road alignment is curve level, 0 otherwise	0.06087	0.2391
curgrade	1 if road alignment is curve grade, 0 otherwise	0.04088	0.198
curhillcrest	1 if road alignment is curve hillcrest, 0 otherwise	0.007654	0.08715

Table 4- 8: Distribution of Road Alignment Variables

Variable	Crash Injury Severity					Total	Percent
	No injury	Possible	Non-incapacitating	Incapacitating	Fatal		
Road Alignment							
strailevel	44121	8288	6444	2478	1264	62595	73.48%
straigrade	6857	1377	1190	432	283	10139	11.90%
straihillcrest	1848	457	364	135	82	2886	3.39%
curlevel	3396	649	712	269	159	5185	6.09%
curgrade	2256	431	504	179	112	3482	4.09%
curhillcrest	435	107	73	24	13	652	0.77%

For roadway design characteristics, shoulder, curb and median were considered as independent variables. Left and right shoulder and curb were analyzed separately. Table 4-9 shows the description of roadway design variables. Table 4-10 shows the distribution of different shoulder, curb, median and lane width variables.

Table 4- 9: Description of Roadway Design Variables

Variable	Description	Mean	Std. Deviation
Shoulder Type Left			
shoulderln	1 if no left shoulder, 0 otherwise	0.1529	0.3599
shoulderl	1 if left shoulder exists, 0 otherwise	0.8035	0.3973
Shoulder Type Right			
shoulderrn	1 if no right shoulder, 0 otherwise	0.1175	0.322
shoulderr	1 if right shoulder exists, 0 otherwise	0.8381	0.3684
Curb Type Left			
curbln	1 if no left curb, 0 otherwise	0.8415	0.3652
curbl	1 if left curb exists, 0 otherwise	0.1579	0.3169
Curb Type Right			
curbrn	1 if no right curb, 0 otherwise	0.838	0.3684

curbr	1 if right curb exists, 0 otherwise	0.09964	0.2995
Median Type			
medn	1 if no median, 0 otherwise	0.3848	0.4866
medup	1 if median type is unprotected, 0 otherwise	0.2673	0.4425
medp	1 if median type is positive barrier, 0 otherwise	0.3003	0.4584
medop	1 if median type is one-way pair, 0 otherwise	0.00579	0.07593
Width			
Lane Width	The width of travel lanes in feet	12.27	1.466
Left Shoulder Width	The width of left shoulder in feet	9.542	6.904
Right Shoulder Width	The width of right shoulder in feet	13.37	8.146

Table 4- 10: Distribution of Roadway Design Variables

Variable	Crash Injury Severity					Total	Percent
	No injury	Possible	Non-incapacitating	Incapacitating	Fatal		
Shoulder Type Left							
shoulderln	9458	1833	1172	409	150	13022	15.29%
shoulderl	47235	9029	7639	2893	1650	68446	80.35%
Shoulder Type Right							
shouldern	7333	1352	891	324	109	10009	11.75%
shoulderr	49307	9503	7922	2977	1683	71392	83.81%
Curb Type Left							
curbln	48935	9518	8257	3178	1793	71681	84.15%
curbl	7306	1263	738	256	83	9646	11.32%
Curb Type Right							
curbrn	48665	9535	8227	3176	1784	71387	83.80%
curbr	6486	1049	653	220	80	8488	9.96%
Median Type							
medn	21915	4024	4026	1798	1018	32781	38.48%
medup	16000	2747	2539	941	541	22768	26.73%
medp	18223	3937	2405	686	328	25579	30.03%
medop	391	54	38	10	1	494	0.58%

Environmental Factors

Of weather characteristics, clear, cloudy, and rain conditions accounted for about 72%, 15%, and 9%, respectively, of the total observations. Figure 4-12 shows the pie chart of the weather condition variable.

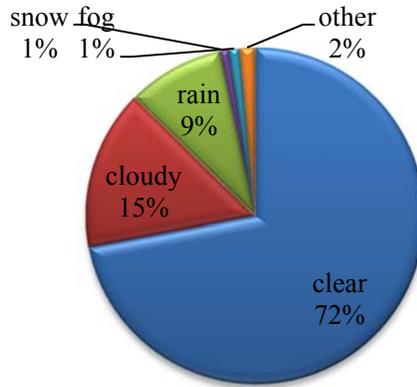


Figure 4-12: Distribution of Weather Condition Characteristics

Table 4-11 shows the description of weather condition variables. Table 4-12 shows the distribution of different weather conditions.

Table 4- 11: Description of Weather Condition Variables

Variable	Description	Mean	Std. Deviation
Weather Characteristics			
clear	1 if clear, 0 otherwise	0.8739	0.3319
rain	1 if raining, 0 otherwise	0.0925	0.2897
snow	1 if snowing, 0 otherwise	0.009051	0.09471
blowing	1 if blowing sand, 0 otherwise	0.001644	0.04051
fog	1 if fog, 0 otherwise	0.009802	0.09852

Table 4- 12: Distribution of Weather Condition Variables

Variable	Crash Injury Severity					Total	Percent
	No injury	Possible	Non-incapacitating	Incapacitating	Fatal		
Weather Characteristics							
clear	51468	9998	8126	3153	1700	74445	87.39%
rain	5624	1014	832	259	151	7880	9.25%
snow	616	68	68	13	6	771	0.91%
blowing	87	15	22	9	7	140	0.16%
fog	492	112	134	62	35	835	0.98%

Of light characteristics, daylight, dark not lighted, and dark lighted conditions accounted for about 73%, 15%, and 9%, respectively, of the total observations. Figure 4-13 shows the pie chart of the light condition variable.

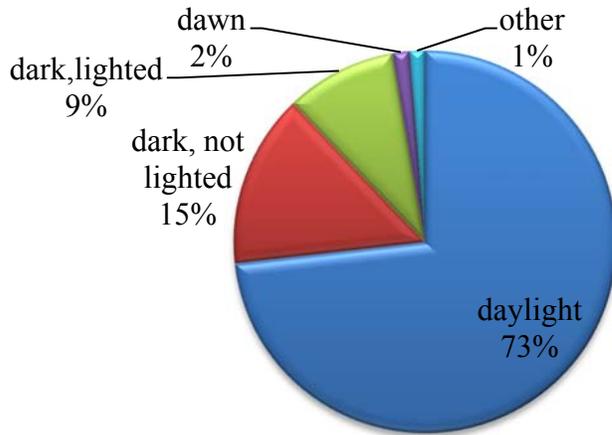


Figure 4-13: Distribution of Light Condition Characteristics

Table 4-13 shows the description of light condition variables. Table 4-14 shows the distribution of different light conditions.

Table 4- 13: Description of Light Characteristics

Variable	Description	Mean	Std. Deviation
Light Characteristics			
daylight	1 if incident occurred when daylight, 0 otherwise	0.732	0.4429
darknolight	1 if incident occurred when dark not lighted, 0 otherwise	0.1469	0.354
dawn	1 if incident occurred when dawn, 0 otherwise	0.01419	0.1183
darklight	1 if incident occurred when dark lighted, 0 otherwise	0.09388	0.2917
dusk	1 if incident occurred when dusk, 0 otherwise	0.00880	0.09342

Table 4- 14: Distribution of Light Characteristics

Variable	Crash Injury Severity					Total	Percent
	No injury	Possible	Non-incapacitating	Incapacitating	Fatal		
Light Characteristics							
daylight	44038	8584	6412	2265	1059	62358	73.20%
darknolight	8058	1364	1707	810	573	12512	14.69%
dawn	740	158	187	79	45	1209	1.42%
darklight	5476	1096	883	331	211	7997	9.39%
dusk	543	87	78	22	20	750	0.88%

Driver Related Factors

Figure 4-14 shows the distribution of driver related factors. Among the total 85,184 large truck crashes, there were 1,858 crashes occurred due to driver fatigue; 1,103 crashes occurred due to drunk driving; 305 crashes occurred due to driver under drug influence; 1,478 crashes occurred due to driver driving on the wrong way.

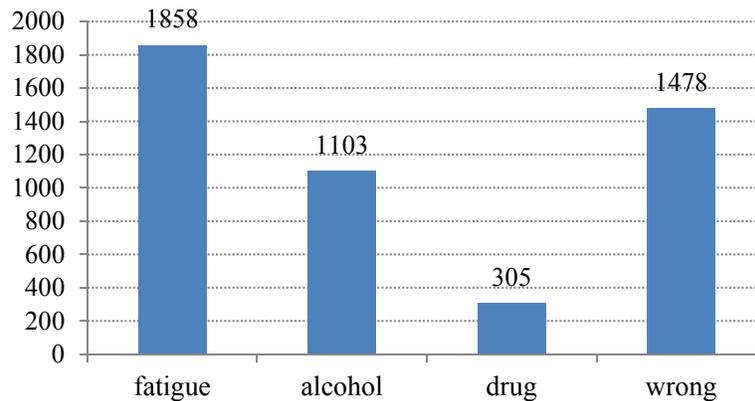


Figure 4-14: Distribution of Driver Related Factors

Table 4-15 shows the description of driver related factors. Table 4-16 shows the distribution of different driver related factors.

Table 4- 15: Description of Independent Variables

Variable	Description	Mean	Std. Deviation
Crash Contributing Factors			
fatigue	1 if driver under influence of fatigue, 0 otherwise	0.0218	0.1461
drug	1 if driver under influence of drug, 0 otherwise	0.0035	0.05973
alcohol	1 if driver under influence of alcohol, 0 otherwise	0.0129	0.1131
wrong	1 if wrong way driving, 0 otherwise	0.0173	0.1306

Table 4- 16: Distribution of Location of First Harmful Event Variables

Variable	Crash Injury Severity					Total	Percent
	No injury	Possible	Non-incapacitating	Incapacitating	Fatal		
Crash Contributing Factors							
fatigue	966	268	384	165	75	1858	2.18%
drug	113	32	61	32	67	305	0.36%
alcohol	508	135	219	111	130	1103	1.29%
wrong	556	137	252	215	318	1478	1.74%

4.2.3 Results

Fifty-five variables were considered in the modeling, and Table 1 provides definitions and values for each one. The estimated results for the large-truck crash-severity model are provided in Table 4-18. According to the modeling results, only 26 of the variables have significant impacts on the severity of large-truck crashes, and their impacts are discussed below.

Table 4- 17: Results of the Ordered Probit Model

Variable		Value	Std. Error	p value
traffic control	flashing	0.12028	0.05073	0.0241
	signal	-0.10884	0.01404	0.0000
location	offroad	-0.05563	0.01342	0.0002
	shoulder	0.19859	0.03491	0.0000
weather	rain	-0.08389	0.01509	0.0000
	snow	-0.33374	0.05003	0.0000
	blowing	0.02469	0.09973	0.0189
light	dawn	0.21707	0.03436	0.0000
	darknolight	0.1358	0.01235	0.0000
	darklight	0.11902	0.01502	0.0000
road alignment	straigrade	0.06556	0.01323	0.0000
	straihillcrest	0.13831	0.02299	0.0000
	curlevel	0.08705	0.01791	0.0000
	curgrade	0.11917	0.02136	0.0000
functional system	rpa	0.20208	0.01515	0.0000
	rma	0.1681	0.01666	0.0000
	uopa	0.07125	0.01207	0.0000
curb type left	curbl	-0.15583	0.01802	0.0000
curb type right	curbr	-0.10643	0.02385	0.0000
	medp	-0.08834	0.01428	0.0000
median type	medup	-0.07214	0.01305	0.0000
	medop	-0.18507	0.06249	0.0058
fatigue	fatigue	0.34308	0.02708	0.0000
alcohol	alcohol	0.50227	0.03452	0.0000
drug	drug	0.74341	0.06364	0.0000
wrong way	wrong	0.82247	0.02944	0.0000
intercept	μ_1	0.5642	0.0139	0.0000
intercept	μ_2	1.0128	0.0142	0.0000
intercept	μ_3	1.6225	0.0149	0.0000
intercept	μ_4	2.1374	0.0166	0.0000
<i>Log likelihood</i>			-81800.82 (df=30)	
<i>Log likelihood at zero</i>			-104033.6	
<i>Chi-square</i>			44465.56	
<i>Chi-square p value</i>			<0.00001	
<i>Pseudo R-Squared(ρ^2)</i>			0.2137	
<i>Sample size</i>			85,184	

Traffic Control

Table 4-17 indicates that the large-truck crashes that occurred at intersections with flashing lights tended to be more severe and the large-truck crashes that occurred at intersections that had signal lights tended to be less severe. These results are reasonable because flashing lights usually are installed at rural intersections with high speed limits, and traffic signals will effectively reduce the risk of crashes at these intersections.

Location of First Harmful Event

The location of the first harmful event of a large-truck crash was related directly with the severity of the crash. Table 4-17 indicates that large-truck crashes that occurred off the road usually were less severe than those that occurred on the road. This is reasonable, because large-truck crashes that occur off the road usually are due to the truck hitting a fixed object or overturning. The severity of these types of crashes is relatively low because the large truck is likely to be moving at a slow speed at the off-road locations. Large-truck crashes that occur on shoulder tend to be more severe than crashes that occur on the road. It is because this type of crash usually is the result of the large truck hitting a vehicle parked on the shoulder, which usually results in fatal injuries.

Weather Characteristics

Table 4-17 indicates that the severity level of a large-truck crash decreased significantly during rain or snow, whereas the severity level increased significantly when there is blowing sand. This is to be expected because truck drivers usually drive slower in rain and snow than they do when the weather is clear. However, blowing sand reduces the driver's range of visibility, which, in turn, may reduce the driver's reaction time when unexpected traffic situations occur.

Light Characteristics

Large-truck crashes that occur at night and at dawn tend to be more severe than crashes that occur during the day. This is reasonable because the visibility at night and at dawn is low, and this has an adverse effect on the driver's reaction time. In addition, truck drivers tend to be more tired and drowsier at night and at dawn.

Road Alignment

Compared to a straight and level road segment, steep road segment and curved road segment are more likely to result in more severe large-truck crashes. Crashes that occur at the crest of a hill are the most severe among all of the road alignment conditions. This is because large-truck drivers have limited sight distance when approaching the road segments with a grade, a curve, or the crest of a hill. In addition, it is difficult for a large-truck driver to brake sufficiently at the crest of a hill. Hummer et al. (2009) examined curve collision characteristics and identified some potential countermeasures for curve collisions, e.g., including providing advance warning prior to the curve, enhanced curve delineation or pavement markings, installation of a shoulder, and centerline rumble strips.

Roadway Functional System

Urban interstate highways tend to have less severe truck crashes than other roadway types, including urban other principle arterials (uopa), rural other principle arterials (rpa), and rural minor arterials (rma). In addition, truck crashes that occur on a rural principle arterial have the highest severity level, followed by those that occur on rural minor arterials (rmas). These observations are reasonable because truck drivers usually drive at a higher speed on rural roadways, especially on the rural principle arterial. In addition, urban interstate highways have better access control and usually are safer than other types of roadways.

Types of Curbs and Medians

Table 18 indicates that curbs and medians can help reduce the severity of large-truck crashes. When a crash occurs, the curb and the median can help prevent the large truck from running off the road or running to the opposite side of the road, and these preventive measures can lead to less severe crashes. Gattis et al. (2005) examined the safety impact of medians on four-lane highways in Arkansas. The results showed that roadways with no median had a much higher crash rate and more crashes that were fatal or resulted in incapacitating injuries.

Crash Contributing Factor

- Driver related factors

Considering the factors that contribute to the occurrence of large-truck crashes, it was found that truck drivers who were fatigued and/or using alcohol or drugs were more likely to be involved in severe large-truck crashes. Fatigue, alcohol, and drug can affect the brain and other parts of the nervous system and slow down a person's activity or responsiveness. Thus, drivers' reflexes and decision making can be affected and lead to risky driving situations. Helander (2002) examined DUI countermeasures in California and found that the effective countermeasures in reducing alcohol-impaired driving included laws that set a minimum drinking age, impounding vehicles, requiring the use of seat belts, and others. According to the National Cooperative Highway Research Program (NCHRP) Report 500 (2014), strategies for reducing fatigue-related crashes include increasing the efficiency of using existing parking spaces, creating additional parking spaces, and the installation of rumble strips on new and existing roadways.

- Other contributing factors

The modeling results also indicated that large-truck crashes caused by wrong-way driving are the most severe crashes. This is because most of the wrong-way driving crashes are head-on crashes, the most severe type. Cooner et al. (2004) provided guidelines and recommendations for applying wrong-way countermeasures and treatments. For example, use of lowered DO NOT ENTER and WRONG WAY signs mounted together on the same post at the locations with high risk of wrong-way driving. It also has been found that left-side exit ramps on freeways increase the probability of wrong-way driving. Thus, left-side exit ramps should be avoided in future freeway construction and the existing left-side exit ramps must have reflectorized wrong-way pavement arrows installed. Wrong-Way Detection and Warning Systems could be used to warn drivers of wrong-way driving.

4.2.4 Conclusion and recommendations

In this chapter, we investigated the factors that influence the severity of large-truck crashes. A comprehensive set of truck-crash data was collected in Texas from 2011 to 2015, and an ordered probit model was developed for analyzing the severity of crashes.

The modeling results showed that there are 26 variables that have significant impacts on the severity of large-truck crashes. The following items are the key findings, along with some corresponding recommendations:

- Compared to intersections with other types of traffic control, intersections with traffic signals have significantly less probability of having severe, large-truck crashes. So, traffic signals should be installed (instead of stop signs or flashing lights) at intersections that have a high risk of truck crashes.
- Night and dawn driving conditions can increase the severity of large-truck crashes. Thus, lights should be added at high-risk roadway locations and activated at night and at dawn.
- Curbs and medians effectively can reduce the severity of large-truck crashes. Adding curbs and medians at high-risk roadway sections can effectively prevent large-truck rollover crashes and reduce the severity of crashes.
- Grades and curved roads can increase the severity of large-truck crashes. Use of warning signs at the crests of hills and at curves and reducing the speed limit for large trucks on rural arterials can be effective countermeasures.
- Drivers under the influence of drugs, alcohol, and fatigue also can have significant impacts on the severity of large-truck crashes. Installation of rumble strips on newly constructed and existing roadways and strengthening law enforcement could be countermeasures for preventing DUI- and fatigue-related crashes.
- Wrong-way driving is the most significant factor related to the severity of large-truck crashes. To prevent such crashes, traffic signs and pavement markings should be implemented on exit ramps, particularly on left-side exits, newly constructed ramps, and locations with a history of wrong-way accidents.

4.3 SUMMARY

In this chapter, two types of crash risk analysis have been conducted: descriptive analysis and statistical model based analysis. By conducting descriptive analysis, crash risk factors related to driver, vehicle, roadway and environmental conditions have been

analyzed. After that, Ordered Probit model was developed to identify the significant factors contributing to the large truck crash severity.

CHAPTER 5: SURVEY TRUCK DRIVERS

The objective of “Survey Truck Drivers” is to solicit large truck drivers’ inputs about the crash risk factors identified as well as their opinions on how to prevent large truck involved crashes. The information collected through the survey was used to validate and refine the research findings, such as the identified crash risk factors and the potential countermeasures for preventing or mitigating large truck involved crashes.

For this purpose, a survey was developed which includes three parts: 1) crash risk factors, 2) countermeasures and 3) general questions. To ensure that wide range of large truck drivers will participate, two different approaches were adopted to execute this survey:

1. Distribute survey questionnaires to large truck drivers through their companies. In total, 1 companies and 1 public agency agreed to participate in our survey and 68 surveys were collected.
2. Interview large truck drivers directly at truck stops in Houston. The research team visited the 10 truck stops in Houston area and 61 surveys were collected in total.

In total, 129 surveys were received for further analysis. This chapter documents the design of survey questionnaire, the survey plan as well as survey results analysis.

5.1 SURVEY DESIGN

This survey was designed to solicit truck drivers’ opinions on the identified crash risk factors in Chapter 3, the strategies for improving large truck safety and the implementation barriers. The survey questionnaire includes three parts:

1. Crash risk factors are factors which could cause or contribute to large truck involved crashes. These risk factors were identified during the literature review and hotspot analysis conducted by research team.
2. Countermeasures are methods to prevent or mitigate large truck crashes. Similar to the crash risk factors, these countermeasures were identified during the literature review and hotspot analysis stage.
3. General questions include two multiple choice questions about truck drivers’ turning behaviors and three open-ended questions on issues regarding hours of service and suggestion to improve safety.

In part 1, large truck drivers were asked to give a score (0 to 10) to 20 identified risk factors based on their driving experience. 0 means they believe the factor has no risk, while 10 means the factor is extremely risky. In part 2, similar with part 1, drivers were requested to score the effectiveness of 26 potential countermeasures.

In addition, basic information about respondents includes gender, age, and driving experience was also listed in survey as optional questions. Please check the Appendix for detailed survey questionnaire.

5.2 SURVEY PLAN

Two different approaches have been adopted for distributing the designed survey questionnaire to the truck drivers. The first approach is to contact large truck companies and distribute survey questionnaire through their respective companies. The research team contacted a number of truck companies, and Walmart and City of Houston Public Works participated in our survey voluntarily. In the end, 39 surveys were received from City of Houston Public Works and 29 surveys were received from Walmart, totaling 68.

To ensure enough number of survey responses, the second approach was adopted, which was to interview truck drivers at various truck stops throughout the city of Houston. For this approach, two graduate research assistants have gone to 10 truck stops in Houston on December 14, 15, and 19, 2016. The detail information of truck stops visited is listed in Table 5-1, and the locations were mapped on Google Map in Figure 5-1. In addition, Figure 5-2 presents the pictures of student research assistants interviewing large truck drivers.

Table 5- 1: Locations for Conducting Truck Driver Interview

No.	Truck Stop	Address	Date	# of interviews
1	Love's Travel Stop	210 Patton Street, Houston, TX 77009	12/14/2016	17
2	Polit Travel center	4440 N McCarty St. Houston, TX 77013	12/14/2016	7
3	Love's Travel Stop	3940 N McCarty St, Houston, TX 77013	12/14/2016	8
4	Texas Truck Stop	8772 Market Street Rd, Houston, TX 77029	12/15/2016	4
5	Stripes #1042	1402 Federal Road, Houston, TX 77015	12/15/2016	8
6	Sunmart	1731 Federal Road, Houston, TX 77015	12/15/2016	6
7	Flying J Pilot Truck Stop	1201 Pasadena Freeway Frontage Rd, Pasadena, TX 77506	12/15/2016	2
8	Truckers' Paradise	9221 Wallisville Rd, Houston, TX 77013	12/15/2016	4
9	Flying J Travel Plaza #729	15919 North Freeway Houston, TX 77090	12/15/2016	2
10	Summart #131	24985 I-10 W Katy, TX 77494	12/19/2016	3
Total				61

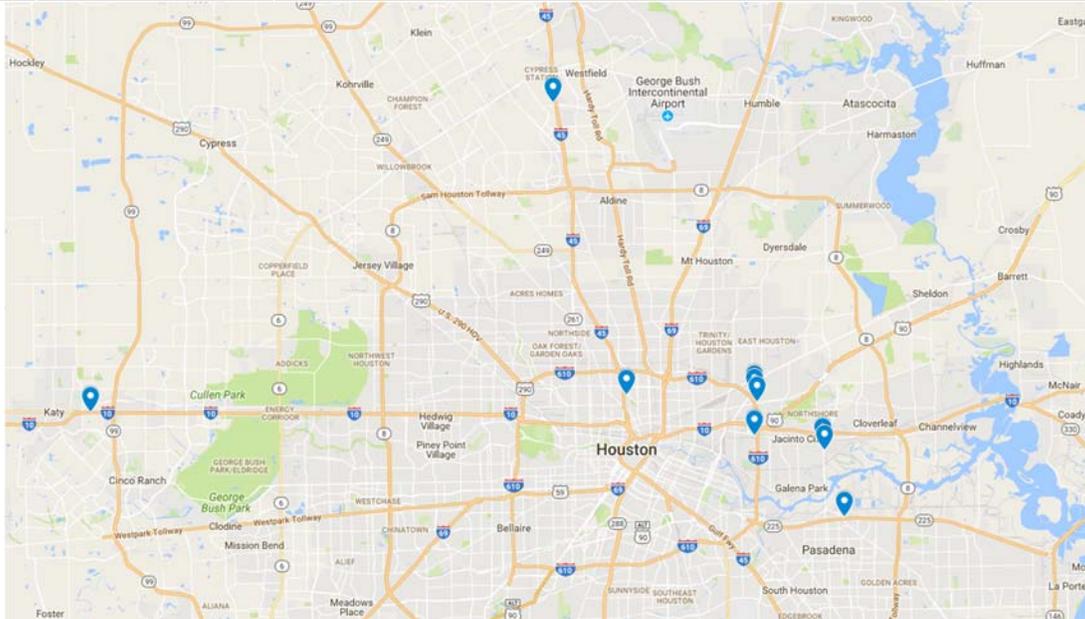


Figure 5-15: Truck Stop Locations for Field Interview



Figure 5- 2: Research Assistants Interviewing Large Truck Drivers

In total, 61 truck drivers were interviewed. Adding the 68 surveys collected from truck companies, totally 129 survey responses were received.

5.3 SURVEY RESULTS ANALYSIS

The first step to analyze the collected surveys was to input all the answers for each survey into an excel file. Those answers to open-ended questions were all compiled and summarized as key findings.

5.3.1 Driver Information

The Driver information aspect of the survey details the driver's age, gender and driving experience. Some drivers participating in the survey were willing to provide that information while others didn't feel comfortable doing so.

Gender

Among all 129 respondents, 108 provided their genders. Figure 5-3 below shows the gender distribution of all large truck drivers surveyed.

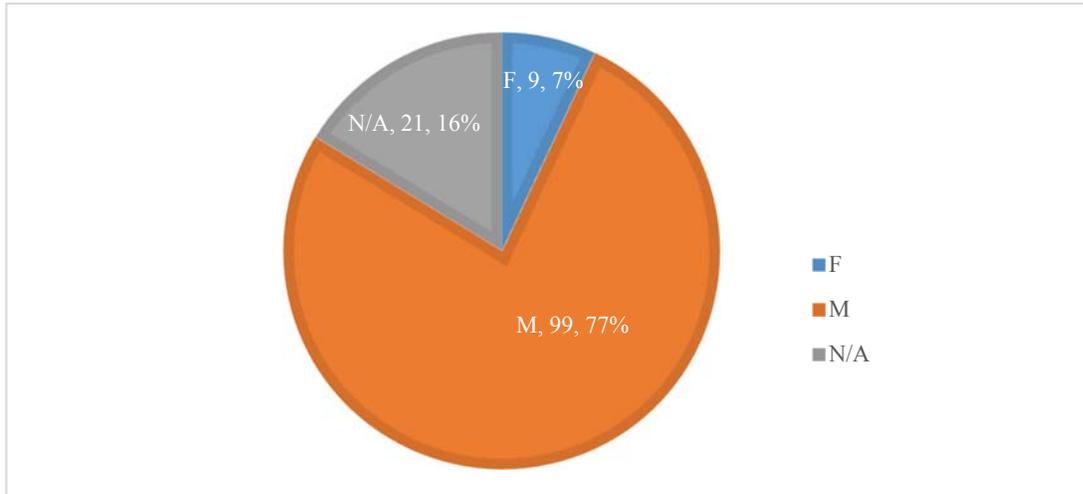


Figure 5- 3: Survey Results of Gender

Age

Based on general industry standards, as well as literature review, ages were separated into four groups: 20-29, 30-45, 46-60 and 61-75. 83 truck drivers answered this question, and other 46 drivers did not share their ages. The age distribution is presented in Figure 5-4. It can be seen that the majority of truck drivers responded to our survey are between 30 to 60.

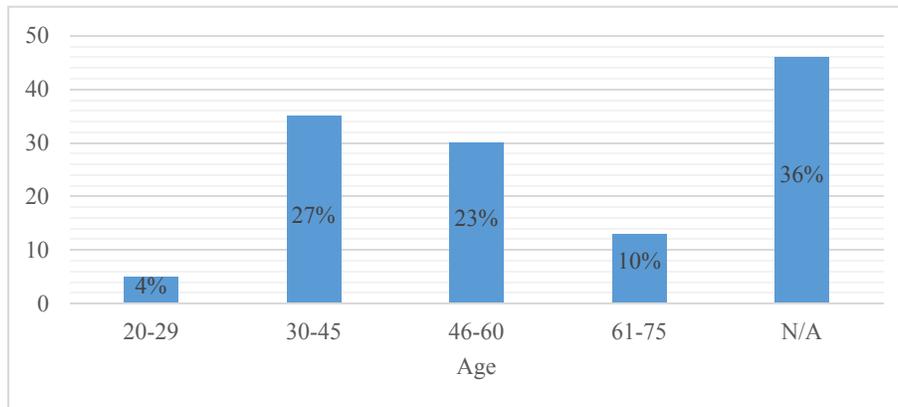


Figure 5-4: Survey Results of Age

Driving Experience

125 out of 129 truck drivers responded to this question. Figure 5-5 shows the driving experience distribution among all drivers. 31% of truck drivers surveyed have 11 to 20 years driving experience, 20% of truck drivers have 6 to 10 years driving experience and 33% of drivers have more than 20 years driving experience.

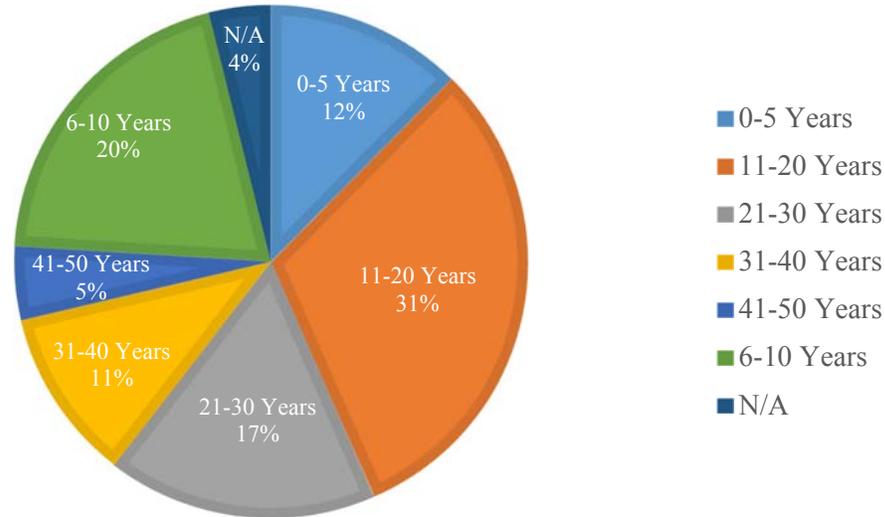


Figure 5-5: Survey Results of Driving Experience

5.3.2 Risk Factor Results

Crash Risk Factors were identified during Chapter 2 literature review and Chapter 3 Crash Risk Analysis. 20 risk factors were selected in our survey, which include engineering related risk factors, driver related factors and vehicle related factors. To validate those risk factors, truck drivers were requested to give scores (0-10) to each one representing their opinions on how risky they are. 0 means driver believes one factor has no risk, while 10 means one factor is extremely risky.

In addition, there was also an open-ended question at the end of this part, asking drivers to list any risk factors not included in our survey. The results of this open-ended question are presented in key findings part.

Table 5-2 below listed all 20 questions as well as numbers of respondents answered to each score. Average scores of each question were also calculated and presented in Table 5-2. N/A represents that answer being inconclusive.

Table 5- 2: Survey Results of Risk Factors

Question	Score	0	1	2	3	4	5	6	7	8	9	10	N/A	Average
1. Short merge distance at highway entrance		0	0	0	2	0	8	5	7	17	14	56	20	8.70
2. Two-way frontage road		2	2	4	5	3	11	4	11	20	14	24	29	7.19
3. Narrow lane on highway		2	1	5	2	7	12	11	9	15	20	40	5	7.53
4. Narrow shoulder on highway		3	4	5	7	7	11	8	7	24	14	33	6	7.02
5. Traffic congestion near interchanges or ramps		1	1	5	3	8	13	10	8	23	20	33	4	7.42
6. Parking on highway shoulders		4	0	2	1	4	9	14	15	15	21	35	9	7.63
7. Poor truck maintenance		4	0	0	3	0	8	3	12	20	19	58	2	8.36
8. Speeding		3	1	0	2	2	7	10	17	10	16	53	8	8.12
9. Not wearing seatbelt		7	6	2	6	5	11	13	11	9	17	37	5	6.88
10. Distraction by the use of cellphone		2	0	2	3	1	1	2	11	11	14	78	4	8.84
11. Fatigue		2	0	1	0	1	5	9	6	17	17	66	5	8.68
12. Drunk driving		2	0	0	0	0	1	4	8	10	16	85	3	9.20
13. Other vehicles cut you off		0	0	1	0	1	6	2	10	16	23	65	5	8.90
14. Dual or triple left-turn at intersection		4	3	5	7	4	9	8	18	27	20	15	9	6.80
15. Dual right-turn at intersections		4	0	7	5	3	7	11	16	26	21	20	9	7.10
16. Not enough space for making turns		2	0	1	1	2	2	6	17	27	23	43	5	8.31
17. No or poor pavement markings		2	1	2	0	4	5	7	22	20	25	35	6	7.94
18. Right turn on red		6	4	10	8	6	14	11	10	16	17	18	9	6.16
19. Poor pavement condition		1	2	0	2	5	9	18	13	18	18	39	4	7.74
20. Continuous two-way left turn lane with many access points for exits/entrances		4	3	3	6	8	13	7	14	19	19	27	6	6.97

Table 5- 3: Tukey's HSD Test Results on Crash Risk Factors

Factor Name	Factor Score	Type of Risk Factor	Rank
Drunk Driving	9.2	Driver Related	1
Other Vehicles cut you off	8.89	Driver Related	
Distraction by Cellphone use	8.85	Driver Related	
Short merge distance at highway entrance	8.71	Engineering Related	
Fatigue	8.68	Driver Related	
Poor truck maintenance	8.36	Vehicle Related	
Not enough space for making turns	8.31	Engineering Related	
Speeding	8.12	Driver Related	2
No or poor pavement markings	7.94	Engineering Related	
Poor pavement condition	7.74	Engineering Related	3
Parking on highway shoulders	7.63	Driver Related	4
Narrow lane on highway	7.53	Engineering Related	
Traffic congestion near interchanges or ramps	7.42	Engineering Related	
Two-way frontage road	7.19	Engineering Related	5
Dual right-turn at intersections	7.09	Engineering Related	
Narrow shoulder on highway	7.02	Engineering Related	6
Continuous two-way left turn lane with many access points for exits/entrances	6.97	Engineering Related	
Not wearing seatbelt	6.88	Driver Related	7
Dual or triple left-turn at intersection	6.79	Engineering Related	
Right turn on red	6.16	Engineering Related	8

After comparing the average scores of each question, the research team found that the differences among the scores of different questions were not large enough to distinguish them easily. Therefore, to determine whether any of those means are statistically significantly different from each other, a statistical test, Tukey's HSD (honest significant difference) test is used. Tukey's HSD can be used on raw data or in conjunction with an ANOVA (post-hoc analysis) to find means that are significantly different from each other. In another word, by applying **Tukey's HSD** test, all questions can be categorized into different ranking groups based on the scores they received, and the average score of the questions in one group is significantly different with average scores of the questions in other groups.

In this project, SPSS® statistical package was used to conduct **Tukey's HSD** test, and the results were showed in Table 5- 3. The top group with highest average score contains seven risk factors were selected to be the riskiest factors by truck drivers surveyed. Those seven risk factors and average score for each one are:

- Question 12: Drunk driving (9.19)
- Question 13: Other vehicles cut you off (8.89)
- Question 10: Distraction by the use of cellphone (8.84)
- Question 1: Short merge distance at highway entrance (8.68)
- Question 11: Fatigue (8.67)
- Question 7: Poor truck maintenance (8.36)
- Question 16: Not enough space for making turns (8.31)

Based on the survey responses received, the results of those top seven risk factors were discussed as follows.

Question 12: Drunk Driving

Drunk driving was identified to be the riskiest factor by truck drivers. 85 truck drivers responded to this question gave score 10, which means they feel drunk driving is extremely risky. 16 drivers gave 9 and 10 drivers gave 8 to this question respectively. In total, 111 truck drivers gave scores of 8 or higher than 8, which accounts for 86% of the total number of truck drivers surveyed.

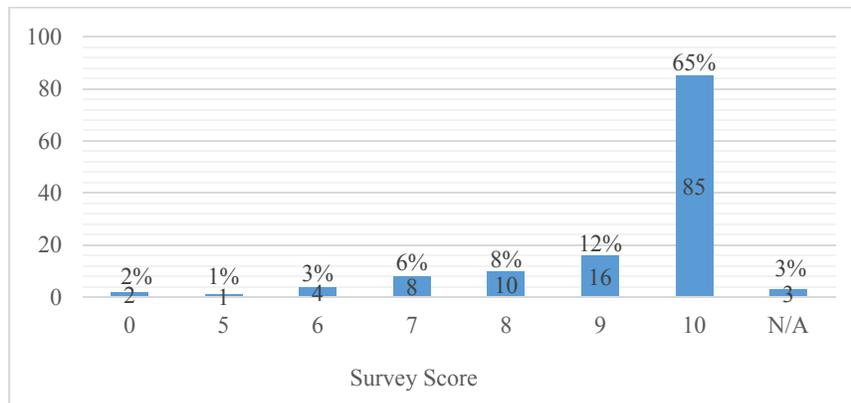


Figure 5- 16: Survey Results of Drunk Driving

Question 13: Other Vehicles Cut You Off

The second risky factor truck drivers agree is “*Other vehicles cutting you off*”. 65 of the drivers identified this risk factor as a 10 which is extremely risky. This also accounts for 52% of all surveys for this risk. 23 of the drivers identified this risk as a score of 9, and 16 of the drivers identified this risk as a score of 8. Figure 5-7 shows the survey results for this factor.

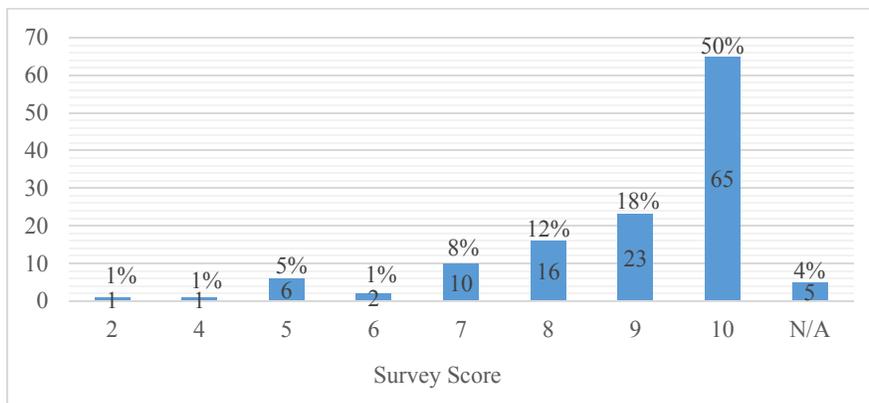


Figure 5- 17: Survey Results of Other Vehicles Cut Off

Question 10: Distraction by the Use of Cellphone

“*Distraction by the use of cellphone*” is another factor drivers identified as very risky. Majority (87%) of truck drivers gave scores of 7 or higher to this factor. To be more specific, 78 drivers scored this risk factor 10, which is extremely risky; 14 drivers scored 9; 11 drivers scored 8 and 11 drivers scored 7. Figure 5-8 is the survey results for this risk factor, showing the numbers of truck drivers support each score.

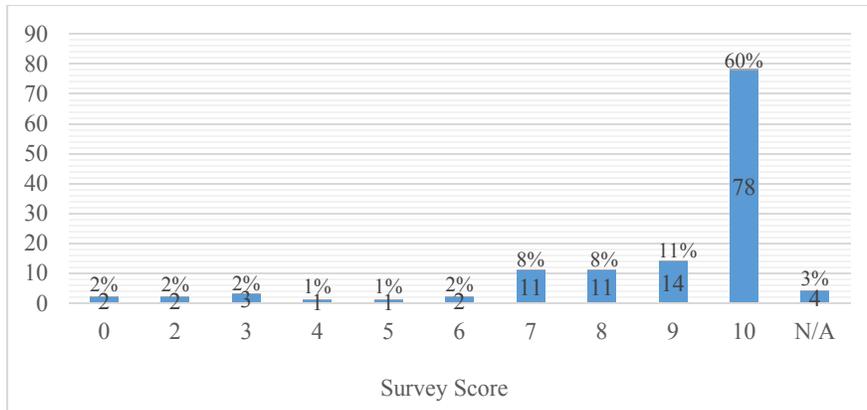


Figure 5- 18 Survey Results of Distraction by Cellphone Use

Question 1: Short Merge Distance at Highway Entrance

“Short merge distance at highway entrance” is the riskiest factor related to roadway design identified by truck drivers. 109 out of 129 truck drivers gave their scores to this question. Among all answered drivers, 56 rated it at 10, which accounts for 43% of all surveys. Figure 5-9 represents truck drivers’ opinion on how risky short merge distance at highway entrance is.

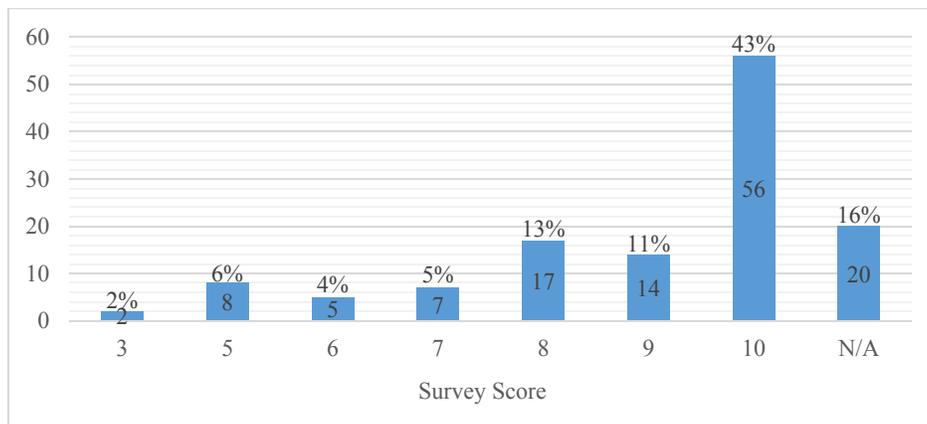


Figure 5- 19: Survey Results of Short Merge Distance

Question 11: Fatigue

“Fatigue” is also identified very risky by large truck drivers. 66 drivers gave a full score to this factor, which accounts for 51% of total truck driver surveyed. Only 9 drivers gave a score lower than 5. Figure 5-10 shows the survey results for fatigue.

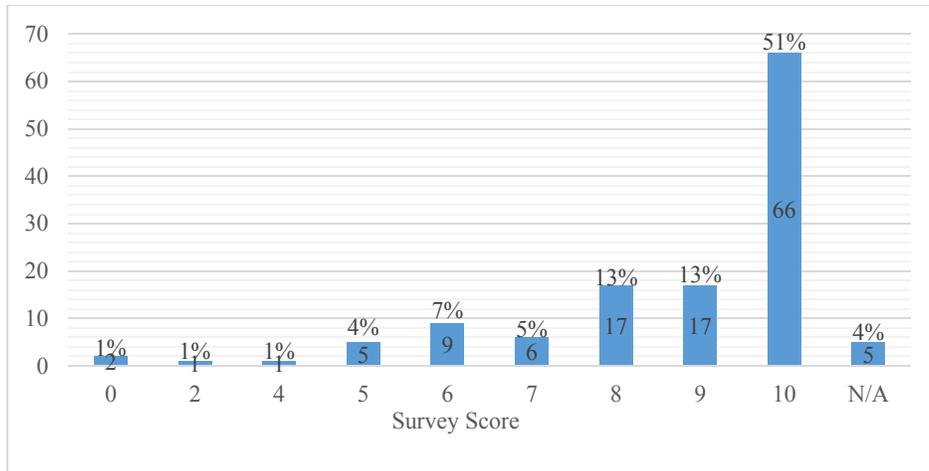


Figure 5 -10: Survey Results of Fatigue

Question 7: Poor Truck Maintenance

Truck drivers surveyed believes “*poor truck maintenance*” is very risky, and may contribute to large truck involved crashes. Majority of drivers gave scores higher than 7. Figure 5-11 shows the detailed survey results.

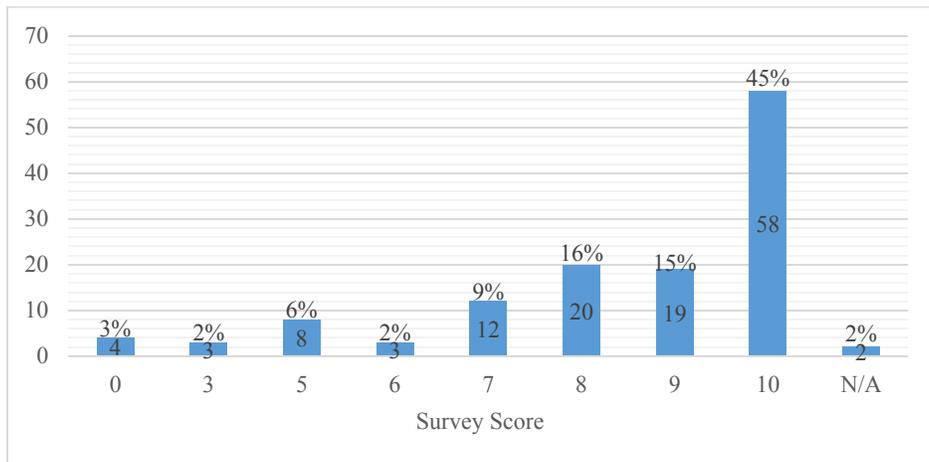


Figure 5- 20: Survey Results of Poor Truck Maintenance

Question 16: Not Enough Space for Making Turns

Due to the its size, large truck needs more space to make turns, therefore, it doesn’t surprise us when truck drivers identified “*not enough space for making turns*” as top risky factors. In addition, based on the hot spot risk analysis in Chapter 3, it was found that turning spaces not enough are very common in Texas. Figure 5-12 shows the detailed survey results for this risk factor.

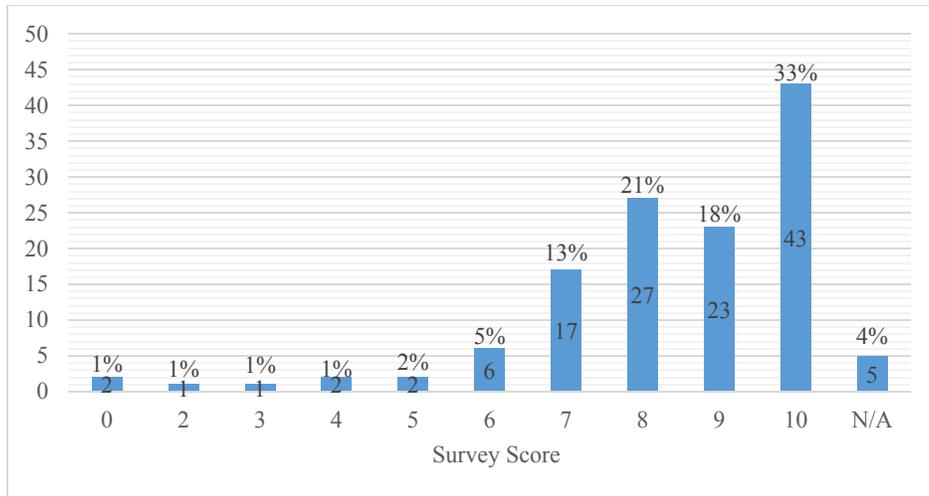


Figure 21: Survey Results of Not Enough Space for Making Turns

5.3.3 Countermeasure Results

Similarly, Countermeasures selected in this part were proposed based on literature review. The countermeasures include engineering related countermeasures, law enforcement related countermeasures, road user education, and emergency Response related countermeasures.

Drivers were required to give a score between “0-10” to represent their opinions on the effectiveness of each countermeasure. 0 means drivers don’t believe one countermeasure could reduce large truck involved crashes, while 10 means they believe one countermeasure definitely can reduce large truck crashes. The results for 129 surveys are shown as Table 5-4.

Table 5- 4: Survey Results of Countermeasures

Questions	Scores	0	1	2	3	4	5	6	7	8	9	10	NA	Average
1. Clear pavement markings at intersections		1	0	0	1	3	5	2	5	17	31	63	1	8.84
2. Increase the turning radius at intersections		1	0	2	0	0	5	4	14	16	25	55	7	8.64
3. Provide channelized right-turn lanes		4	2	0	1	2	10	5	20	23	18	39	5	7.81
4. Use of raised shoulder with curb		9	5	3	5	10	12	6	16	25	16	15	7	6.30
5. Apply double stop signs or place stop signs on both sides of the road, or add flashing beacons with stop signs		5	0	0	8	7	13	11	15	13	10	42	5	7.27
6. Add intersection lane configuration warning signs on both sides of the road or overhead		3	0	0	3	5	10	8	18	21	16	40	5	7.78
7. Add safety lighting at intersection		2	1	2	1	2	10	4	13	25	24	40	5	8.04
8. Add flashing beacons at rural non-signalized intersection		4	0	1	1	4	7	4	9	23	30	44	2	8.17
9. In dual left turn, use protected only phasing		3	0	1	4	1	15	4	7	28	28	35	3	7.87
10. Push back stop lines to allow more space for trucks making right turns		6	0	2	0	0	4	10	10	22	24	46	5	8.11
11. Install speed advisory signs at on ramps and off ramps		6	1	2	1	1	6	4	10	30	31	28	9	7.79
12. Extend merge distances for ramps		3	0	1	1	0	2	7	12	17	29	48	9	8.48
13. Use auxiliary lanes when merge distance not adequate		3	1	2	0	1	5	3	14	27	21	43	9	8.25
14. Install barriers at congested merge and diverge areas		3	0	2	2	2	8	2	9	9	26	60	6	8.45
15. Add advanced dynamic traffic signs		5	0	1	2	2	7	6	16	29	25	31	5	7.79
16. Add more speed limit signs and warning signs		7	3	3	1	7	7	9	18	22	25	23	4	7.09
17. Increase use of heavy truck lane restrictions		15	6	1	6	0	11	7	18	16	25	15	9	6.27
18. Install center and shoulder rumble strips to assist drivers keeping in lane		2	1	2	3	1	14	9	13	16	17	44	7	7.82
19. Implement intelligent rollover warning system at curves		8	0	4	1	6	11	12	11	22	19	28	7	7.10
20. Place stickers on the back of trucks		10	0	5	7	3	12	10	14	23	18	22	5	6.65
21. Add more "ONE WAY" or "NO RIGHT TURN" signs on freeway or frontage road		5	1	2	3	6	11	6	19	27	18	24	7	7.21
22. Increase speed enforcement		4	4	3	6	2	14	6	19	23	18	23	7	6.98
23. Increase inspection of large trucks		7	6	2	4	4	10	9	15	20	17	25	10	6.81
24. Educate other road users on how to drive safely around large trucks		0	0	1	1	2	6	2	8	21	20	63	5	8.78
25. Conduct public information and education (PI&E) campaigns on heavy truck operation/performance limitations, rules, crash experience, and restrictions		1	0	2	4	1	4	4	9	18	18	63	5	8.57
26. Create adequate storage for truck inspection stations in and around ports of entry		8	1	4	1	5	10	11	5	20	15	42	7	7.36

Table 5- 5: Tukey's HSD Test Results on Countermeasures

Countermeasures	Factor Score	Type of Risk Factor	Rank	
Clear pavement markings at intersections	8.84	Engineering Related	1	
Educate other road users on how to drive safely around large trucks	8.78	Road User Education Related		
Increase the turning radius at intersections	8.64	Engineering Related		
Conduct public information and education (PI&E) campaigns on heavy truck operation/performance limitations, rules, crash experience, and restrictions	8.57	Road User Education Related		
Extend merge distances for ramps	8.48	Engineering Related		
Install barriers at congested merge and diverge areas	8.45	Engineering Related		
Use auxiliary lanes when merge distance not adequate	8.25	Engineering Related		
Add flashing beacons at rural non-signalized intersection	8.17	Engineering Related		
Push back stop lines to allow more space for trucks making right turns	8.11	Engineering Related		
Add safety lighting at intersection	8.04	Engineering Related		
In dual left turn, use protected only phasing	7.87	Engineering Related		
Install center and shoulder rumble strips to assist drivers keeping in lane	7.82	Engineering Related		
Provide channelized right-turn lanes	7.81	Engineering Related		
Install speed advisory signs at on ramps and off ramps	7.79	Engineering Related		
Add advanced dynamic traffic signs	7.79	Engineering Related		
Add intersection lane configuration warning signs on both sides of the road or overhead	7.78	Engineering Related		2
Create adequate storage for truck inspection stations in and around ports of entry	7.36	Engineering Related		
Apply double stop signs or place stop signs on both sides of the road, or add flashing beacons with stop signs	7.27	Engineering Related	3	
Add more "ONE WAY" or "NO RIGHT TURN" signs on freeway or frontage road	7.21	Engineering Related		
Implement intelligent rollover warning system at curves	7.1	Engineering Related	4	
Add more speed limit signs and warning signs	7.09	Law Enforcement Related		
Increase speed enforcement	6.98	Law Enforcement Related	5	
Increase inspection of large trucks	6.81	Law Enforcement Related	6	
Place stickers on the back of trucks	6.65	Road User Education Related	7	
Use of raised shoulder with curb	6.3	Engineering Related		
Increase use of heavy truck lane restrictions	6.27	Law Enforcement Related		

To find the most effective countermeasure group, Tukey's HSD test was also conducted for the survey results of countermeasure part, and the result was showed in Table 5-5. Finally, based on Tukey's HSD test results, top 16 most effective countermeasures were selected, which are:

1. Question 1: Clear pavement markings at intersections, such as adding turning guidelines on pavement to prevent sideswipe crashes (8.84)
2. Question 24: Educate other road users on how to drive safely around large trucks (8.78)
3. Question 23: Increase the turning radius at intersections (8.64)
4. Question25: Conduct public information and education (PI&E) campaigns on heavy truck operation/performance limitations, rules, crash experience, and restrictions (8.57)
5. Question 12: Extend merge distances for ramps (8.48)
6. Question 14: Install barriers at congested merge and diverge areas (8.45)
7. Question 13: Use auxiliary lanes when merge distance not adequate (8.25)
8. Question 8: Add flashing beacons at rural non-signalized intersection (8.17)
9. Question 10: Push back stop lines to allow more space for trucks making right turns (8.11)
10. Question 7: Add safety lighting at intersection (8.04)
11. Question 9: In dual left turn, use protected only phasing (7.87)
12. Question 18: Install center and shoulder rumble strips to assist drivers keeping in lane (7.82)
13. Question 3: Provide channelized right-turn lanes (7.81)
14. Question 11: Install speed advisory signs at on ramps and off ramps (7.79)
15. Question 15: Add advanced dynamic traffic signs, such as “TRAFFIC CONGESTION AHEAD, BE PREPARED TO STOP” etc. with flashing beacons near highway entrances, exits, construction zones or other congested areas (7.79)
16. Question 6: Add intersection lane configuration warning signs on both sides of the road or overhead (7.78)

Each of the top 16 most effective countermeasures then were analyzed. Truck driver's responses to those questions will be introduced one by one.

Question 1: Clear pavement markings at intersections, such as adding turning guidelines on pavement to prevent sideswipe crashes

Pavement markings are used to convey messages to roadway users, and also used to alert users to potentially hazardous conditions ahead. Figure 5-13 shows the scores and numbers of drivers support each score. It can be seen, 92% truck drivers gave scores higher than 5, which means they believe that clear pavement markings can greatly help them to identify the road size and direction exactly especially when they are driving

during night time.

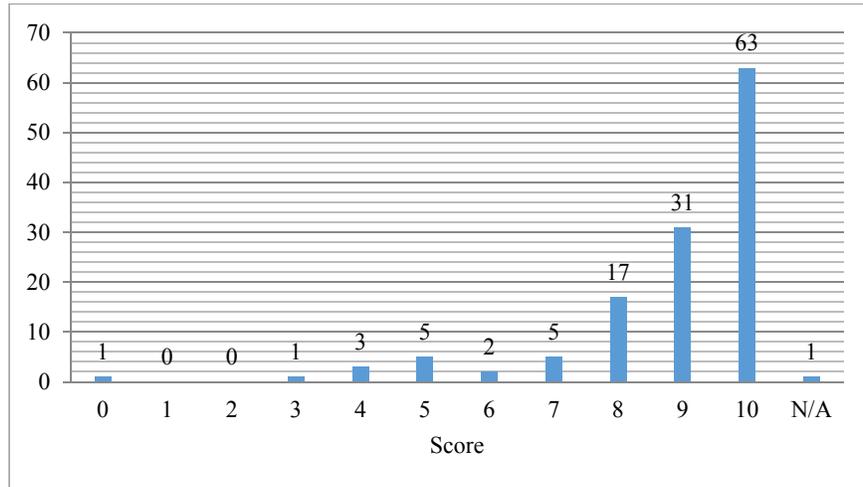


Figure 22: Survey Results of Clear Pavement Markings

Question 24: Educate other road users on how to drive safely around large trucks

Figure 5-14 shows drivers' opinion on Question 24. It can be seen that 114 drivers gave scores higher than 5, means they believe educating other road user could reduce large truck involved crashes. The number shows that majority of large truck drivers participating in the survey thought other road users don't know or know very limit about large truck, and need to be educated on how to drive safely around large trucks.

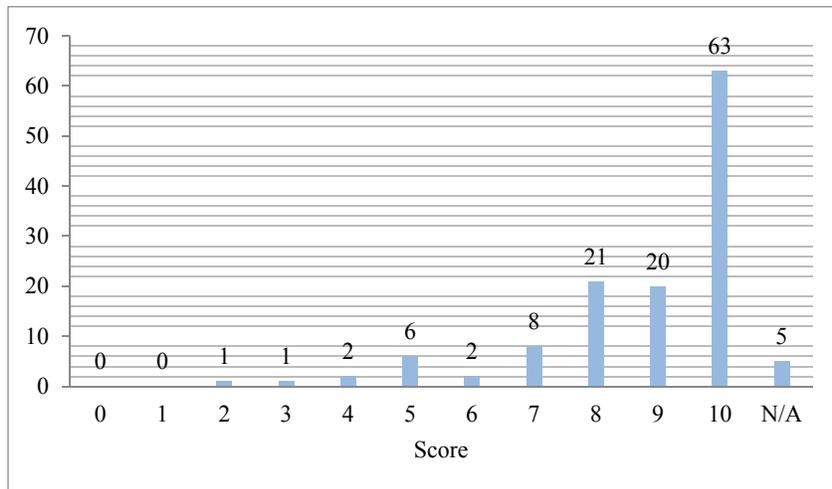


Figure 23: Survey Results of Educate Other Road Users

Question 2: Increase the turning radius at intersections

It can be seen from Figure 5-15 that most of truck drivers thought that increase the turning radius at the intersection is an effect way to reduce crash. During interviews, some drivers mentioned that the turning radius are not enough so they usually take 2 lanes to make turns.

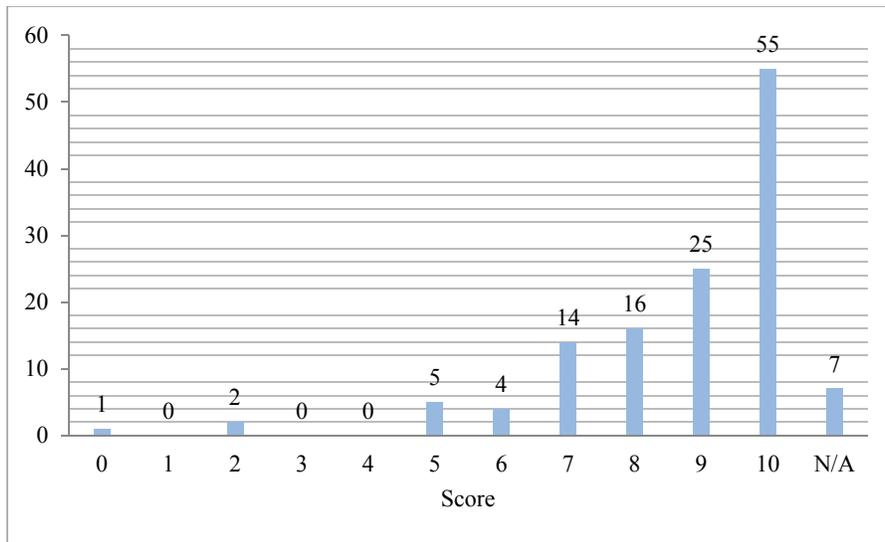


Figure 24: Survey Results of Increase the Turning Radius

Question 25: Conduct public information and education (PI&E) campaigns on heavy truck operation/performance limitations, rules, crash experience, and restrictions

90% truck drivers gave scores higher than 5, means they thought the crashes can be prevented by conducting public information and education campaigns. Traffic safety programs that include highly visible public information and education (PI&E) campaigns that accompany law enforcement efforts have proven to both increase positive public impressions toward police activities and result in safer driving habits.

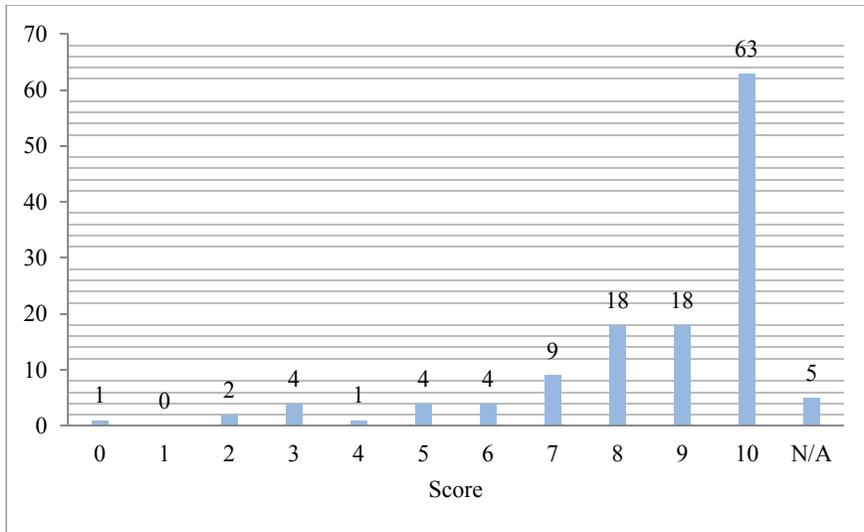


Figure 25: Survey Results of PI&E Campaigns on Large Truck

Question 12: Extend merge distances for ramps

For the ramps with short merge distances, the crashes are very likely to be occurred especially for large truck. 94% truck drivers gave scores higher than 5, means they thought it is very effective to avoid crashes by extends merge distances for ramps.

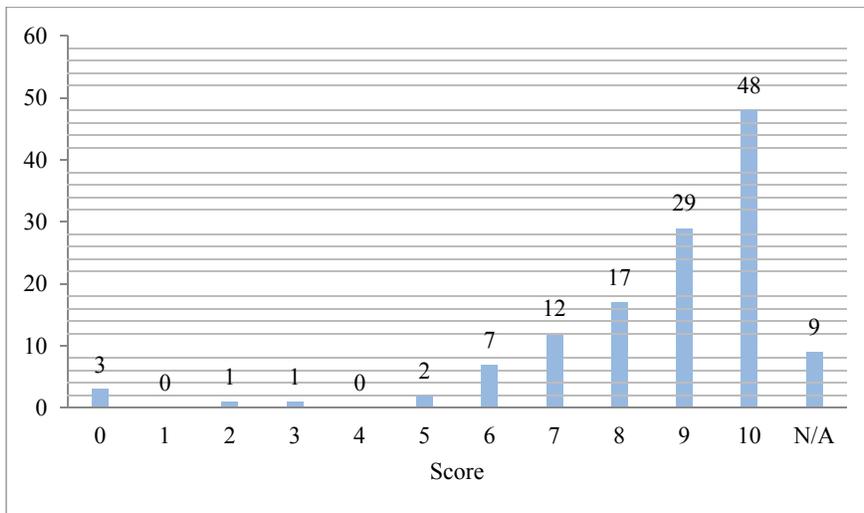


Figure 26: Survey Results of Extend Merge Distances for Ramps

Question 14: Install barriers at congested merge and diverge areas

Truck drivers agreed that install barriers at congested merge and diverge areas is very useful to prevent unsafe lane change behaviors. Especially, other vehicles can't cut off in front the large trucks if the barriers installed. Figure 5-18 shows the truck drivers'

responses on its effectiveness.

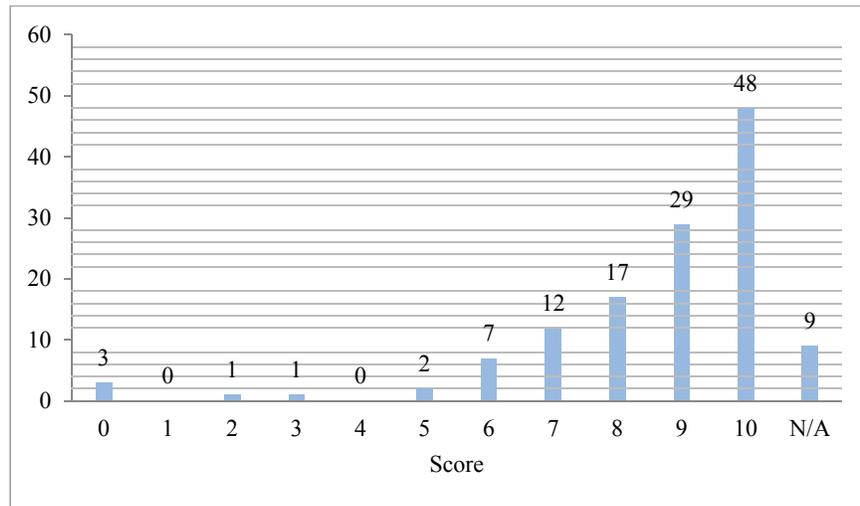


Figure 27: Survey Results of Install Barriers at Congested Merge/Diverge

Question 13: Use auxiliary lanes when merge distance not adequate

Using auxiliary lane is another effective way to reduce crash caused by short merge distance. It can be seen from Figure 5-19 that 108 surveyed truck drivers scored it 6 or higher, which means they believe it has the potential to reduce large truck involved crashes.

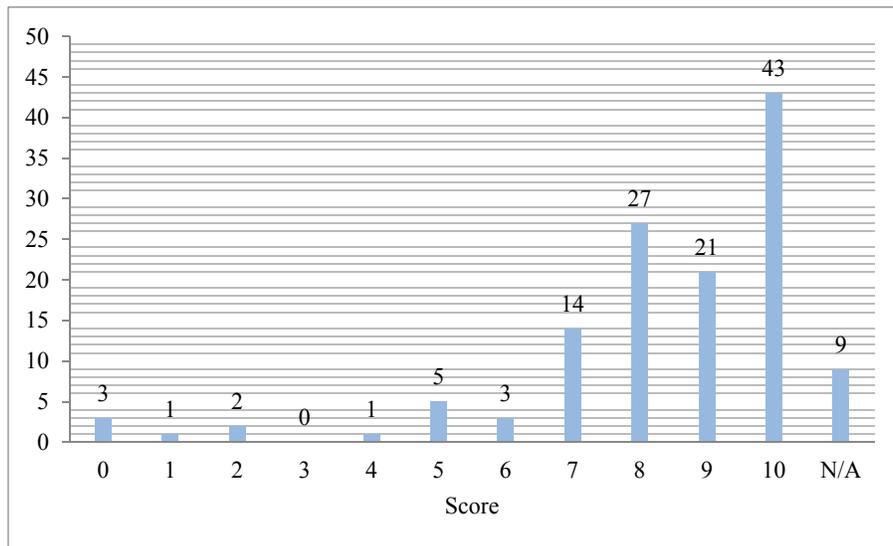


Figure 28: Survey Results of Use Auxiliary Lanes

Question 8: Add flashing beacons at rural non-signalized intersection

In rural areas, typically the only source of lighting is provided by vehicles' headlights. Flashing beacons can warn drivers when they pass an intersection especially at night time, therefore reduce the possibility of running red light. Flashing beacons also can supplement other traffic control devices where additional emphasis and warning for drivers is desired. Based on their driving experience, truck drivers believe adding flashing beacons is effective to reduce truck crashes.

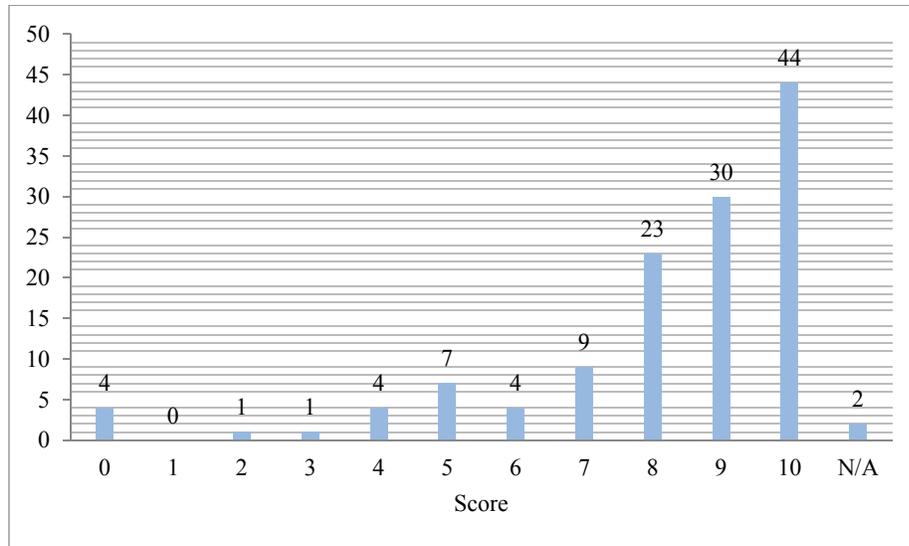


Figure 29: Survey Results of Add Flashing Beacons at Rural Intersection

Question 10: Push back stop lines to allow more space for trucks making right turns

90% truck drivers gave scores higher than 5 to this countermeasure, means they believe pushing back stop line can provide more turning space so that large trucks can make turn safely.

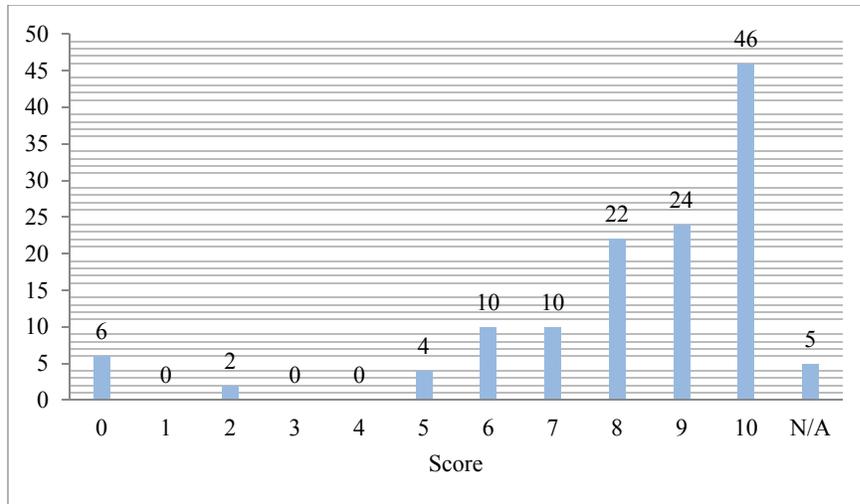


Figure 30: Survey Results of Push Back Stop Lines

Question 7: Add safety lighting at intersection

85% truck drivers thought this is effective to reduce crashes. Intersection crashes during nighttime may occur due to drivers being unable to see conflicting traffic or because the driver is unaware of the intersection until it is too late to avoid a collision, especially in the rural area. Roadway lighting provides greater intersection visibility of the intersection, signs, and markings. Lighting is best for intersections with a high number of nighttime crashes. In particular, rear-end, right angle, and turning crashes may suggest that drivers are unaware of the intersection.

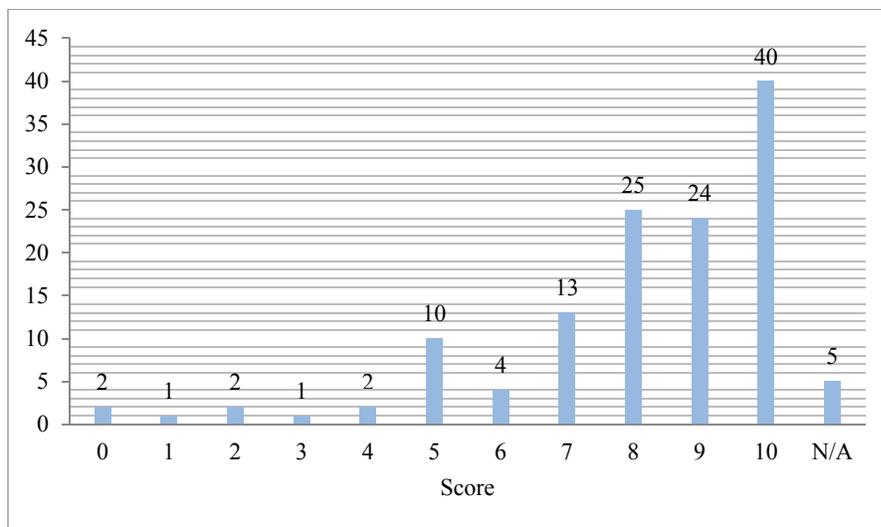


Figure 31: Survey Results of Add Safety Lighting at Intersection

Question 9: In dual-left turn, use protected only phasing

Large trucks need more time and more space to make left turns. 81% truck drivers thought protected phasing is effective because this countermeasure can provide truck drivers more time to make left turn safely. Protected only operation assigns the right-of-way to drivers turning left at the intersection and allows turns to be made only on a green arrow display. This operation provides for efficient left-turn movement service; however, the added left-turn phase increases the lost time within the cycle length and may increase delay to the other movements.

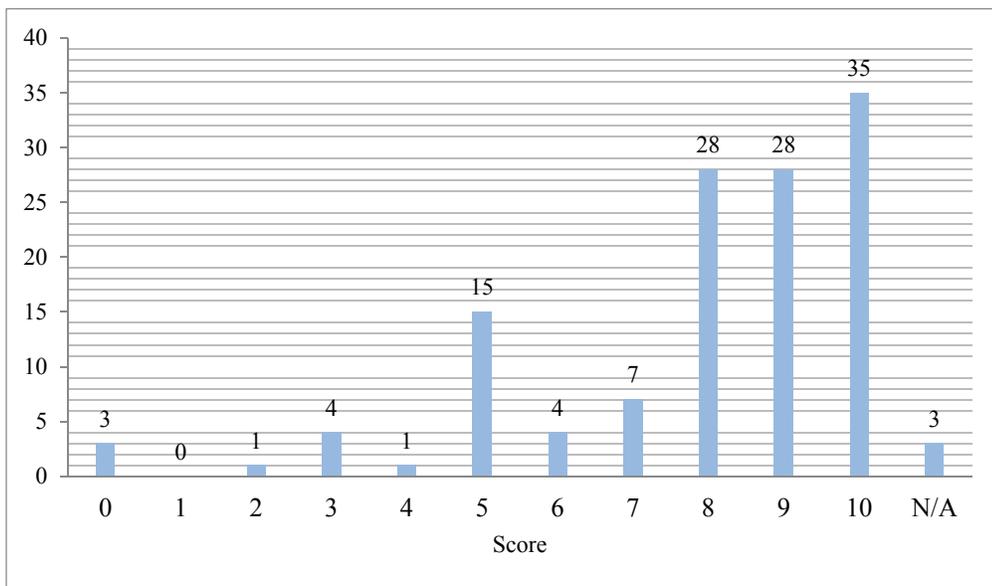


Figure 32: Survey Results of Protected Only Phasing for Dual Left Turn

Question 18: Install center and shoulder rumble strips to assist drivers keeping in lane

Rumble strips are a series of milled or raised elements of a paved roadway that can be installed at or near the center line, as well as shoulder. It alerts drivers through vibration and sound when the vehicle has traveled left or right of the travel lane. 81% truck drivers gave scores higher than 5 to this countermeasure, means they thought it is effective to assist drivers keeping in a single lane. A center line rumble strip is a low-cost safety treatment that can help keep an inattentive driver safely in the driving lane to avoid such a crash.

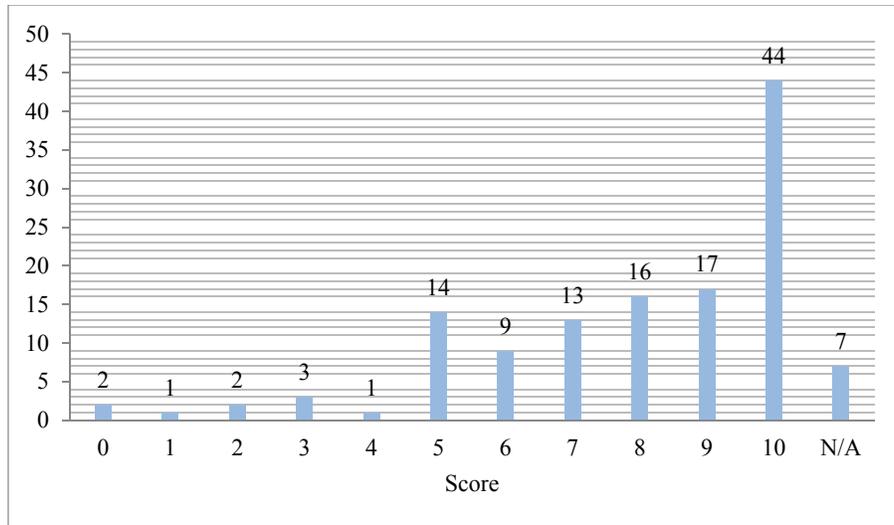


Figure 33: Survey Results of Install Rumble Strips

Question 3: Provide channelized right-turn lanes

The channelized right turn lanes used to permit the use of large curb return radii to accommodate turning vehicles for large trucks, without unnecessarily increasing the intersection pavement area. Figure 5-25 shows truck drivers' opinions on channelized right-turn. 85% truck drivers thought this is effective by giving scores higher than 5 to this countermeasure.

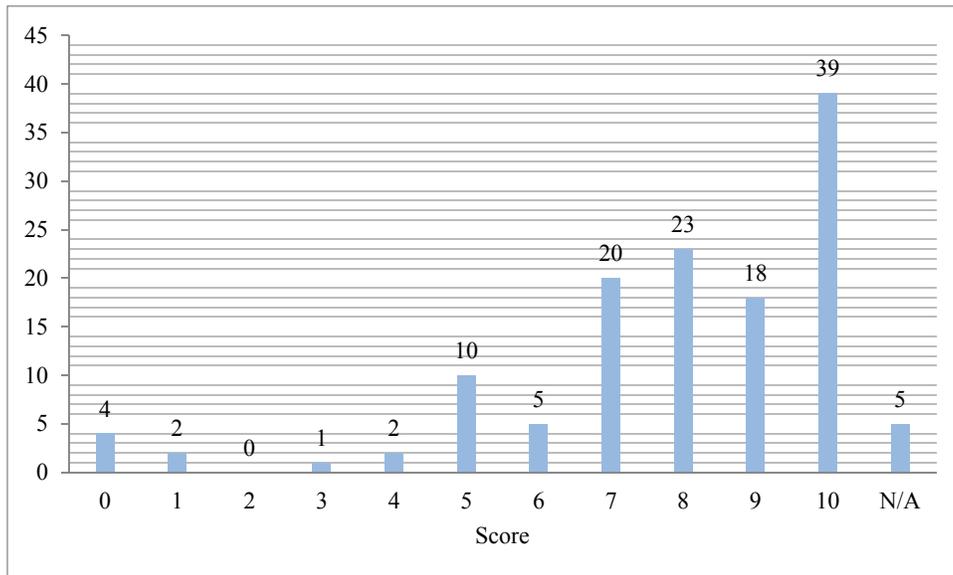


Figure 34: Survey Results of Channelized Right-Turn

Question 11: Install speed advisory signs at on ramps and off ramps

Figure 5-26 is the survey results of Question 11. 86% truck drivers gave scores higher than 5 to this countermeasure means they agreed that speed advisory signs can warn drivers before they enter or after they exit from highway.

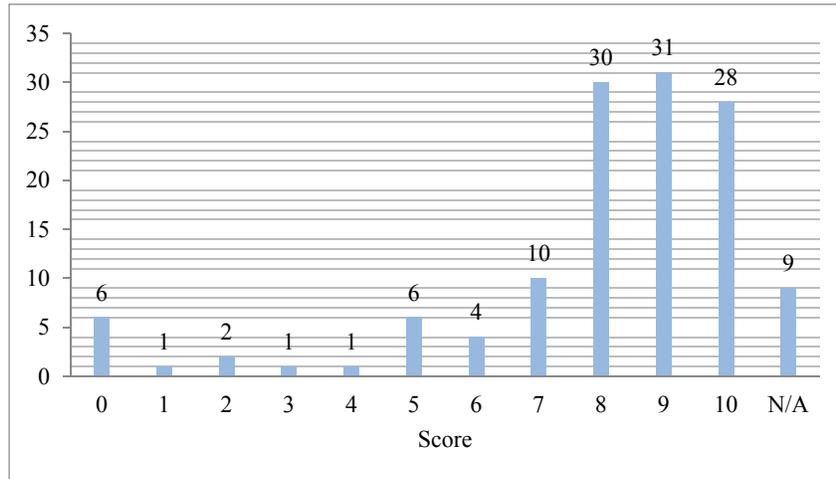


Figure 35: Survey Results of Install Speed Advisory Signs on/off Ramps

Question 15: Add advanced dynamic traffic signs, such as “TRAFFIC CONGESTION AHEAD, BE PREPARED TO STOP” etc. with flashing beacons near highway entrances, exits, construction zones or other congested areas

Figure 5-27 is the survey results for question 15. It can be seen that 107 truck drivers gave scores higher than 5 to this countermeasure. They believe advanced dynamic traffic signs could attract drivers’ attention on current traffic condition, therefore reduce crash risk.

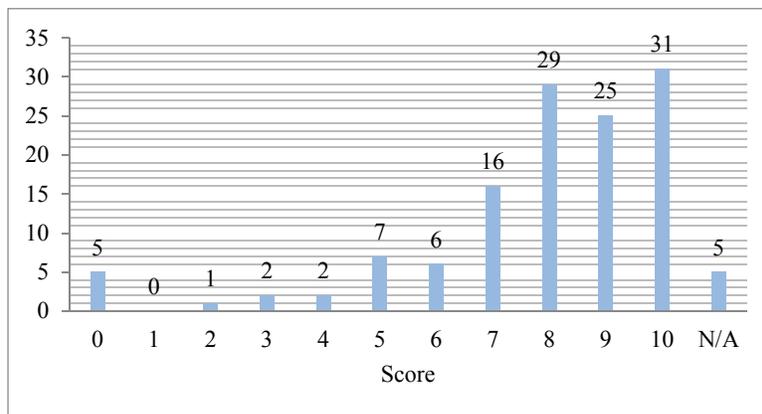


Figure 36: Survey Results of Add Advanced Dynamic Traffic Signs

Question 6: Add intersection lane configuration warning signs on both sides of the road or overhead

83% truck drivers gave scores higher than 5 to this countermeasure, means they believe that it is effective because it can improve the visibility for both truck and other vehicles drivers.

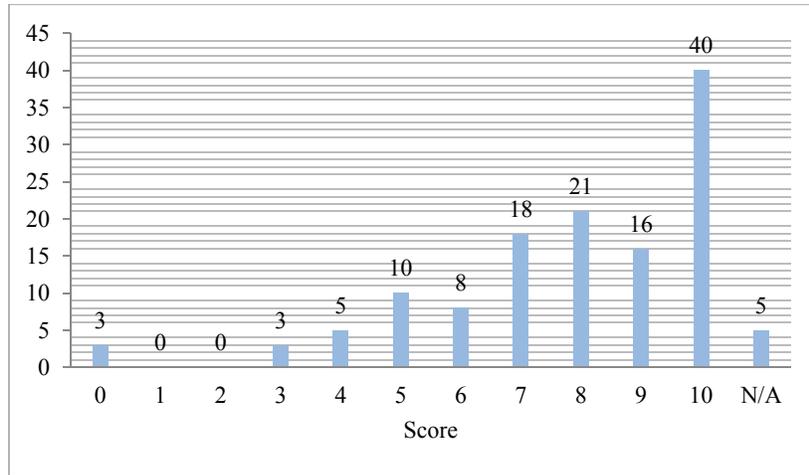
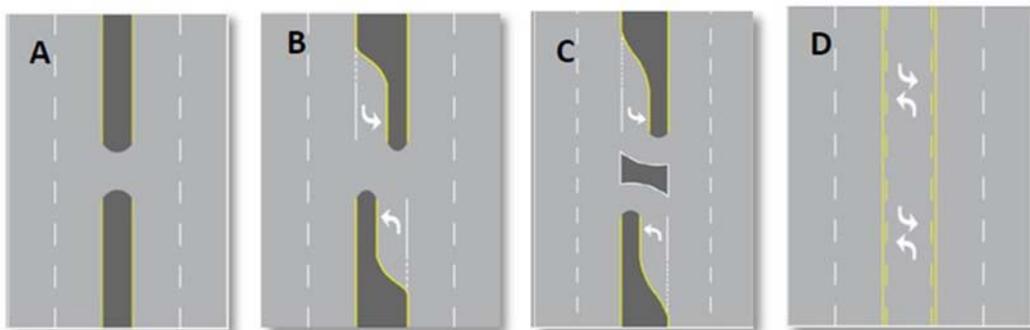


Figure 37: Survey Results of Add Signs on Both Sides of the Road/Overhead

5.3.4 General Questions Results

General questions include two multiple choice questions about truck drivers' turning behaviors and three open-ended questions on issues regarding hours of service and suggestion to improve safety. Findings from three open-ended questions will be summarized in next part together with other findings during interview.

General Question 1: In your opinion, which design is safer for making left turn? (Assuming enough turn space).



Below are the results of the surveys based on the answers given. 9 surveys drivers gave multiple answers, so their score was counted as an inconclusive answer and gave them a score of N/A. As shown in the chart, only 48% of truck drivers chose answer B, which is the safer selection for the scenario given.

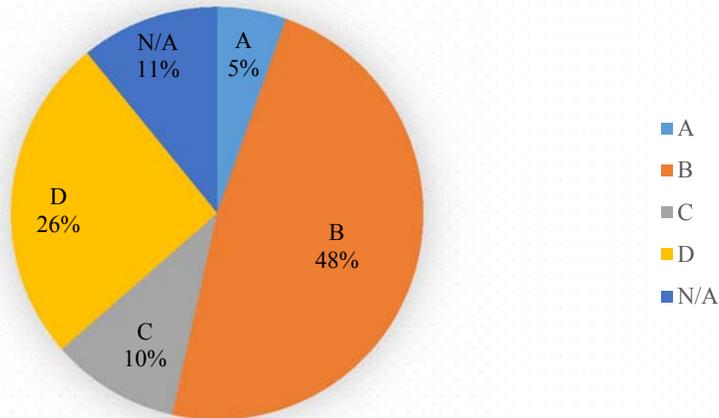


Figure 5- 38: Survey Result of Making Left Turn

Question 2: When making a right turn, which of the following represents your typical turning path?

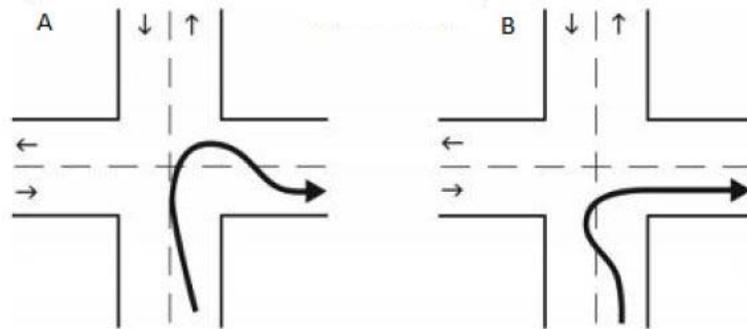


Figure 5-30 shows the results of truck drivers' answers to this question. It can be seen that with an overwhelming amount, 70% of drivers selected the incorrect turning path for making a proper right turn. Only 25% of drivers selected the correct choice A (The High Road Online CDL Training Program). The number of drivers that selected incorrectly raises concern.

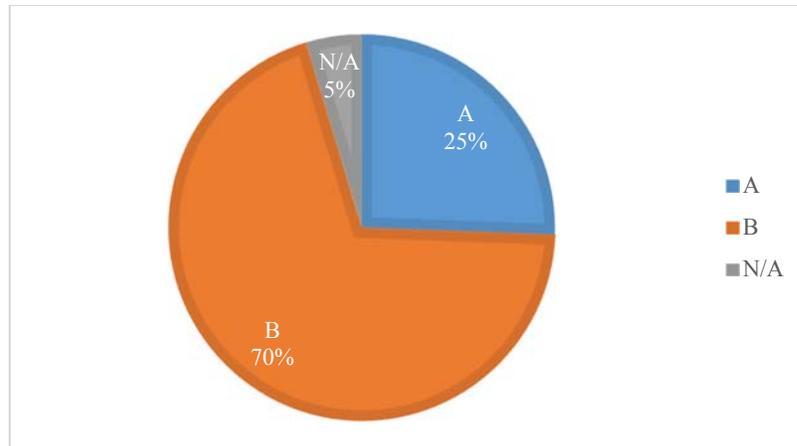


Figure5- 39: Survey Result of Making Right Turn

5.3.5 Key Findings

During the interviews, except for answering survey questionnaire, large truck drivers also shared their opinions on crash risk factors, possible countermeasures for reducing large truck related crashes, and some other suggestions related to truck safety. The key findings are categorized and summarized as follows.

5.3.5.1 Risk Factors

During the interview, we asked large truck drivers to think about the risk situations they face during driving, especially some may end up with collisions. Following are some risk factors large truck drivers mentioned:

- Some truck drivers think that weather is an important risk factor.
- Some drivers believe excessive cell phone use contributes to crashes
- Some truck drivers think that there are too many bad drivers and not enough education for passenger vehicle drivers about how to safely driving around the large trucks
- Some truck drivers think truck drivers need more training and driving experience (2-3 Months) before being able to drive truck independently on the road.
- Sometime, the shadows of the roadside objects will cause the truck to misjudge if a car is actually there, which may be very risky.

5.3.5.2 Suggestions on Possible Countermeasures

Large truck drivers also brought some suggestions which may possibly reduce large truck related crashes.

Electronic Logging (Hours of Service) Related Countermeasures

Regarding Electronic Logging (E-Logging), majority of truck drivers don't agree with E-Logging because they feel that it prohibits drivers from getting the necessary rest. In their opinion they feel that they should take a rest when they actually get tired instead of when E-Logging suggests. In addition, majority of truck drivers think that E-Logging is very unrealistic and don't take into account the real-world events that can occur. Following are some specific criticisms on E-Logging (Hours of Service):

1. E-Logging doesn't stop the 14-hour clock, so it hard for truck drivers to comply this law when they drop a load or unload at some shippers who take long time (more than 2 hours) to load and unload.
2. The 14-hour rule encourages fatigued driving because it's saying that a driver has 14 hours to drive 11 hours, this encourages drivers not to stop to refresh. It is because off-duty time does not extend the 14-hour period. Off duty time should not be included in the 14 hours. This would allow more breaks for stretching and getting a quick nap.
3. Logging system with 12 hours on and 12 hours off could be better.
4. For E-logging, extra time are needed and should be given to drivers for finding parking places
5. The restart should be 48 hours after consecutive hours off duty instead of 34 hours

Engineering related countermeasures

1. Assign 2 exclusive lanes for trucks would be helpful for reducing the truck crashes.
2. When an intersection has multiple turn lanes, move the signs or pavement markings further back so that a truck can have enough time to safely get into the proper lane
3. Add speed bumps on off ramps
4. There are too many signage inconsistencies (Sign says that right lane closed

but left lane is really closed)

5. Implement electronic speed monitoring

Fatigue related countermeasures

1. Truck drivers think that taking a nap when they feel tired is the most effective way to prevent drowsiness when driving. Some drivers feel that they need more drivers to assist with driving duties. They also mentioned providing free coffee to truck drivers may also help.
2. Truck drivers think not all truck stops are secure, and suggest securer truck stops. This could hinder drivers from getting adequate sleep.
3. Drivers have a hard time resting on the road because of the noise, or if they're resting a loud truck pulls next to a sleeping driver and wakes them up. Closed off parking areas (noise cancelling walls-concrete) would be a good idea.

Law Enforcement related countermeasures

1. Enhance the law enforcement.
2. Some truck drivers feel as though police unfairly target them while on the road. They think police should focus on passenger cars the same way as they look after large trucks.

Vehicle related countermeasures

1. Trucks should be inspected more often and faulty brakes cause fires, which is a hazard.
2. Fine the company when inspection isn't up to date for the truck
3. Restrict drivers from being able to access cell phones, and use hands free devices when making phone calls
4. Truck drivers need to inspect their trucks before starting drive, especially the tire conditions.
5. Signal lights on the truck need to be more visible
6. Some truck drivers fell that the automatic braking system on new model trucks that automatically break on curves are dangerous and doesn't account for real world environments

Tips to our road users

1. Truck drivers suggest that when passing a truck, to pass on the left side where there is less of a blind spot
2. Don't follow too closely
3. Stay off the phone
4. Respect the truck drivers and the trucks
5. Don't stop suddenly in front of a truck
6. Don't weave in and out of traffic
7. Use your blinkers
8. Don't make unsafe lane changes
9. Truck drivers ask that the passenger vehicles Be patient with truck drivers
10. Be willing to reduce your speed and increase your speed when necessary (such as entering and exiting highway)
11. When the truck is at maximum capacity there should room for 5 cars between the truck and the next car
12. Whenever you get on the side of a truck, don't stay there because a truck may need to change lanes for a road debris
13. If you must use your phone use Bluetooth and handset
14. All drivers should take a course on semi-trucks before they renew license
15. Recommend that in high school driving education, teach students to drive semi-trucks (on a controlled course) before teaching them to drive a car to show them what truck drivers go through and could make them more responsible drivers
16. Include questions into the driver license test regarding driving safely around large trucks

Other Findings

1. Truck drivers should change to the diet that won't make them tired or drowsy when they driving.

5.4 SUMMARY

The primary goal of conducting truck driver survey is to collect truck drivers' inputs to

validate crash risk factors and possible countermeasures identified from the crash risk analysis. In addition, it will help us to gain a better understanding of the issue and barriers truck drivers face when they are on the road and behind the wheel. In total, 129 survey questionnaires were collected for analysis.

20 risk factors were selected based on literature review and findings from the hot area analysis. By conducting Tukey's HSD test on survey results, top 7 risky factors were identified and analyzed. Among those 7 risk factors, 4 are directly related to human errors, include "Drunk driving", "Other vehicles cut you off", "Distraction by the use of cellphone" and "Fatigue". Two risk factors "Short merge distance at highway entrance" and "not enough space for making turns" are roadway design related.

For the survey results of countermeasures, 14 engineering countermeasures and 2 education countermeasures were the top 16 effective countermeasures suggested by the truck drivers. Over 90% truck drivers believe the most effective and economical countermeasure is making clear pavement markings, which can help them to identify the road size and direction exactly especially when they are driving during night time. It was also found that two educational countermeasures ranked top 2 and 4 respectively, which means most truck drivers believe all other road users do not understand the basics of large truck, they hope the drivers can understand large truck and truck drivers by education so that the crashes can be prevented. Engineering related countermeasures can be categorized to roadway design and traffic devices, signal and lighting. In addition, truck drivers agreed that some sideswipe crashes can be prevented by increasing the turning radius, channelized right-turn lanes or push back stop lines. Survey results also shows that crashes occurred at on ramp areas can be prevented by extending merge distances or use auxiliary lanes. All these 14 engineering countermeasures will be evaluated by cost-benefit analysis in next chapter.

Two multiple choice questions were designed to understand truck drivers' safe operation knowledge on making turns. Only 25% of drivers answered question 2 correctly. These results indicate that a large percentage of the truck drivers don't understand the correct ways to execute right turns safely, which rises concerns, and shows the necessary to reinforce trainings to truck drivers.

CHAPTER 6 COST BENEFIT ANALYSIS

6.1 INTRODUCTION

According to the identified risk factors in Chapters 3 and 4, and based on the literature review results in Chapter 2 and the survey results in Chapter 5, four categories of countermeasures for preventing or mitigating large truck involved crashes were recommended :

- engineering related countermeasures
- traffic law enforcement related countermeasures
- road user education related countermeasures
- emergency response related countermeasures

Engineering related countermeasures include the use of innovative or existing traffic signs, lights, control devices, or roadway geometric design techniques for reducing the risk of truck crashes. Based on the results of literature review and survey, twelve engineering related countermeasures were identified and recommended. The cost and benefit analysis of each countermeasure will be introduced later.

Traffic law enforcement plays an import role in preventing fatal and injury crashes. In this study, five law enforcement related countermeasures were identified for cost-benefit analysis. They are alcohol interlocks, speed camera, red light camera, safety audit of motor carriers and roadside truck inspection.

Road user education has the potential to improve road safety by raising community awareness and by influencing road user behavior and community attitudes. Two different types of countermeasures were recommended: 1) disseminate the truck related road safety information through print out material, such as such as flyers, brochures, information sheets, wallet-sized plastic cards, and posters and 2) increase the awareness of safely sharing the road with trucks through electronic media, such as website and social media. Since there is a lace of direct cost and benefit information for these specific countermeasures, the cost and benefit of other road user education programs found from the literature will be discussed.

Emergence response related countermeasures could not prevent a crash happen, however, reducing emergence response time could possibly reduce the crash severity level and increase the survival rate. Three emergency response related countermeasures have been identified. They are installing eCall in all large trucks, employing advanced life support quick response vehicle (QRV) and providing traffic signal preemption for emergency vehicles.

In this chapter, the method for cost benefit analysis will be introduced at first. After that, the cost and benefit analysis for different types of countermeasures will be presented.

6.2 METHODOLOGY – COST BENEFIT ANALYSIS

The Cost-Benefit (C/B) analysis has been widely used to evaluate transportation improvement alternatives. It provides a measure of the dollars of expected benefit of an alternative for each dollar spent on that alternative. Cost-Benefit comparisons are possible when the benefits of an improvement can be assigned a monetary value. The B/C ratio is simply the equivalent benefit of an alternative divided by the equivalent cost of that alternative. If the benefits of an alternative exceed its costs, the improvement is economically justifiable. The higher the ratio is, the greater the benefits are relative to the costs.

For benefit analysis, either crash reduction factor (CRF) or crash severity level reduction will be used to measure the benefit of each countermeasure. According to Federal Highway Administration (FHWA), a crash reduction factor (CRF) is the percentage crash reduction that might be expected after implementing a given countermeasure at a specific site. CRFs listed in this report are either cited from FHWA's report or other previous studies. If one countermeasure has different crash reduction factors according to different existing studies, the relative lower one would be adopted in cost-benefit analysis. Crash severity level reduction represents the possibility of a change of crash severity level from fatal crash to incapacitating crash.

For cost analysis, different categories of countermeasures have different methods to estimate. For engineering related countermeasures, cost of each countermeasure contains cost of material and cost of labor and installation, and maintenance cost in some cases. The cost is based on per unit of the facility being used.

For countermeasures related to emergency response, the cost is based on the minimum number of item, device or system to be installed and their associated unit cost for each of them. Based on the total number of items needed, the total costs of the countermeasures were estimated. Their benefits are estimated based on the reduced emergency response time and the correspondent increased survival rates.

Following parts present the details of the cost benefit analysis for each category of countermeasures.

6.3 COST BENEFIT ANALYSIS FOR ENGINEERING RELATED COUNTERMEASURES

Engineering related countermeasures include the use of innovative or existing traffic signs, lights, control devices, or roadway geometric design techniques for reducing the risk of truck crashes. Previous studies recommended a list of countermeasures for different crash risk factors. By conducting the hot spot analysis in Chapter 3, the most common risk factors contributing to the truck crashes in Texas were identified. By surveying large truck drivers in Chapter 4, the possible countermeasures for reducing those risk factors were identified and recommended.

According to the survey results, truck drivers believe that 13 specific engineering related countermeasures in following five categories were identified as the most effective countermeasures and selected for cost benefit analysis:

- traffic signs
- traffic lights and control devices
- intersection lighting
- roadway geometric design
- pavement marking

Costs associated with implementing engineering related countermeasures may contain material cost, labor cost for installation or construction, and maintenance cost for some countermeasures. In this study, the estimated cost is the “total unit cost” which is calculated by adding material cost and labor cost together for one “unit” of each countermeasure. For example, the cost of adding a traffic sign is the cost for adding one

sign and the cost of adding pavement marking is the cost for installing pavement marking for one mile. Maintenance cost is also provided when applicable. The costs of implementing engineering related countermeasures is gathered by conducting literature review, searching internet information and contacting some traffic control device vendors or agencies which have experiences on construction projects.

Benefit of each engineering related countermeasure is measured by the crash reduction factor (CRF) that a specific countermeasure could achieve.

One thing need to be mentioned here, is that engineering related countermeasures are usually applied to a specific roadway location/segment. Therefore, it is infeasible to calculate the state-wide costs. However, based the provided “total unit cost”, the total roadway segment or area cost can be estimated when a specific study location is selected.

Following are the introductions of different types of engineering related countermeasures, and their cost-benefit analysis.

6.3.1 Traffic Signs

Based on literature review and large truck drivers survey, the application of three types of traffic signs were identified for reducing the large truck involved crashes.

Use of advanced dynamic traffic signs, such as “TRAFFIC CONGESTION AHEAD, BE PREPARED TO STOP” etc. with flashing beacons at locations near highway entrances, exits, construction zones or other locations where significant traffic congestion is expected

Based on hot spot analysis results, it was found that many rear-end crashes occurred at freeway entrances, exits and construction zones during the peak hours. Traffic warning signs in advance of the congested areas will alert the drivers and prevent the rear-end crashes. The cost for installing a stationary dynamic sign is \$15,000 including the labor cost for installation, while the cost of a portable dynamic traffic sign is \$47,000 including the labor cost. It costs \$2,000 to maintain the signs. (Solano Transportation Authority)

According to Desktop Reference for Crash Reduction Factors published by USDOT, the crash reduction factor CRF for using dynamic traffic signs is 15%, which mean 15% of rear-end crashes at these areas can be avoided by using such traffic signs.



Add intersection lane control signs on both sides of the road or overhead



Lane control signs will make it easy for drivers to stay in the correct lanes and eliminating sudden lane change movements. From hot spot analysis, it has been found that side-swipe and angle crashes often occurred at intersections with no lane control signs or with lane control sign at one side but poor visibility. Especially at some location with high truck volumes, lane control signs could be blocked by the truck. To assure drivers could see the lane configuration signs and driving correctly, especially at some location with high truck volumes, lane control signs could be installed at both side of the road. It costs \$655 to install one lane control sign, and \$18.57 to maintain per year (SafetySign.com). The CRF for using lane configuration signs is 10%-20% (FHWA, 2008).

6.3.2 Traffic Lights and Control Devices

Two types of countermeasures are related to traffic lights and control devices were proved to be effective for reducing large truck related crashes by both previous studies and truck driver survey.

Add flashing beacons to the stop sign at rural non-signalized intersection

According to the hot spot analysis, at rural non-signalized intersection, many T-bone crashes occurred due to large truck driver not seeing the stop sign. Also, because of the low traffic volume and high speed limit at rural area, such crashes are usually very server. To prevent such crashes caused by failure to yield at stop signs, flashing beacons can be installed on the stop signs at those intersections to catch drivers' attention to the stop signs. The total cost of adding a flashing beacon and base is \$2,243 (SafetySign.com, GlobalIndustrial.com). The maintenance cost for one flashing beacon is \$155 (Wise, J,

2005). According to crash reduction factors clearinghouse, crash reduction factor of installation of flashing beacons can vary from 5% to 58%. (FHWA, 2008)

Install pylon at congested merge and diverge areas

Hot spot analysis shows large truck crashes may occur at merge or diverge area due to an early merge in or a late merge out behaviors. Pylon can prevent drivers merging too early or too late. Pylon is also called delineators, channelizing devices or tubular markers. Compare with concrete barriers, pylon is cheaper to install and more portable. The cost of installing a pylon is \$140 (USDOT) and the maintenance cost is \$9 per pylon per year (Shamanth P. Kuchangi et al. 2013). By applying this countermeasure, we can expect a crash reduction factor of 27% (NYDOT, 2012). Figure 1 shows an example of installing pylon at merge area.



Figure 6- 1: Pylon at Merge and Diverge Area

Install radar speed sign at off ramps

Radar speed sign has been proved to have the ability to alarm drivers and reduce their speed. It has been widely used at school zones, work zones, parks or community neighborhoods, etc. It can also be implemented at highway off ramps where traffic tends to exceed safe speed.

Radar speed sign can be mounted permanently or semi-permanently, and directly hard-wired to its electric service. The high intensity LED speed sign can get the attention of oncoming drivers. Each of these designs feature a full matrix high intensity LED display with 18 " characters. The 18 " character is appropriate for higher posted speeds (40 MPH and above) and is readable to 1250 feet.



It costs \$8,491 to install one radar speed indicator sign and base (Chang, 2004), and \$875 per year to maintain it (Jiang, 2011). The benefit of adding safety lighting at intersection can be measured by a CRF of 41%. (ODOT, 2015).

6.3.3 Intersection Lighting

Add lighting at intersection

According to Texas Crash Records Information System (CRIS), in Texas, 15% of large truck involved crashes occurred under dark without light condition during 2011 to 2015. Furthermore, dark without light condition has more possibility to lead to fatal and incapacitating crashes. Adding lighting could reduce the crash possibility at those intersections. The cost of adding one light with pole is \$4,638 (LightMart.com, E-Comolight) and the maintenance cost is \$980 per light per year (myledlightingguide.com). The benefit of adding safety lighting at intersection can be measured by a CRF of 17%. (FHWA, 2008)

6.3.4 Roadway Geometric Design

Large trucks need more space to merge or make turns, therefore geometric design with insufficient space may be contributing to large truck involved crashes. According to hot spot analysis results as well as truck driver survey results, it was found that locations with short merge distance or insufficient turning radius are very common in Texas. Following are three countermeasures targeting to solve those issues, thereby reducing large truck involved crashes.

Extend merge distance for freeway on ramps

Short merge distance at freeway on ramps is very common in Texas. It generates safety risk for drivers merging into main lanes, especially for large truck drivers. Providing proper distance for merging traffic to speed up and merge into the traffic flow on the freeway main lane is critical for the safe merging behaviors at the freeway on ramps. The cost of extend merge distance for ramps is \$6,847.65 for 100 feet (CDOT, AIA Engineers Ltd), and the CRF is 7%. (AASHTO HSM, 2014)

Use auxiliary lane at freeway on ramps

Using auxiliary lane is another countermeasure can be considered when merge distance at freeway on ramp is not adequate. Figure 2 below shows one such type of auxiliary lane,

which is the extra lane connected between on and off ramps. It allows drivers to safely merge into traffic while also preventing bottlenecks caused by the intensive interactions between exiting and entering traffic with the main lane through traffic at these locations.

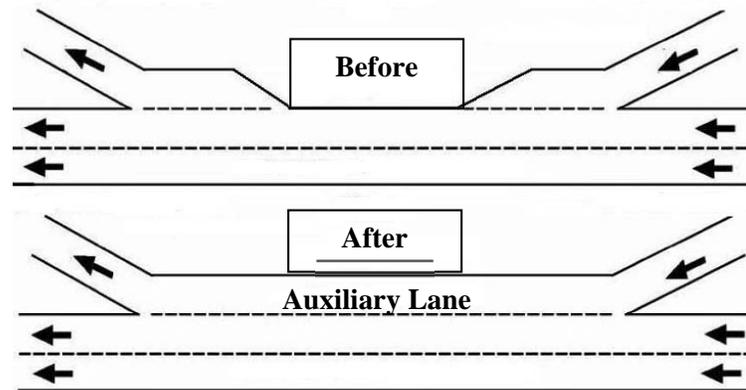


Figure 6- 2: Before and After the Construction of Auxiliary Lane

The cost of incorporating auxiliary lanes is based on many factors. Costs can range from \$50,000 to \$100,000 for a simple shoulder conversion to over \$1 million for more complex retrofits. The conversion of shoulders to speed change lanes reduces the cost when compared to widening the roadway, as that method may require additional right-of-way. Also, any construction work completed on an at-grade road is lower than on an elevated freeway, due to the design, construction time, and material costs. The average cost for adding one auxiliary lane is \$349,400 per mile (CDOT, AIA Engineers Ltd), and the expected CRF is 26% (FHWA, 2008)

One example of adding auxiliary lane is a project implemented by Minnesota DOT (MnDOT) in 2007. MnDOT added an auxiliary lane one mile long I-394 at Louisiana Street at a cost of \$2.6 million, which brought a B/C ratio of 8:1.

Channelized right-turn lanes

Channelized right-turning lanes are separated from the rest of the intersection by painted lines or raised barriers, usually in the shape of a triangular island. Figure 3 illustrates an intersection with channelized right turn lanes. Channelized right-turn lanes are expected to reduce rear-ends collisions involving right turning and through vehicles on the same approach, as the speed differential between the two will be reduced. At intersections with substantial truck volumes, channelized right turn lane permits the use of large turning

radii to accommodate large trucks, without unnecessarily increasing the intersection pavement area. It will also provide more protection for large trucks when they are turning on red. It is generally accepted that channelized right turn lanes improve safety for motor vehicles at intersections where they are used. It has been found to decrease right-turn crashes by 50% and all intersection crashes by 25% (Chandler, et al., 2013). The other benefits include:

- (a) Separation of decelerating right-turn vehicles,
- (b) A reduction in rear-end collisions involving right-turning vehicles and following through vehicles due to improved signal operation,
- (c) Through vehicles will experience less delay if right turning vehicles do not have to decelerate in a through lane,
- (d) Higher right-turn capacity, shorter green time, and less delay for following through vehicles,

The cost of channelized right turn lanes is approximately \$19,900 for 300 feet (CDOT, AIA Engineers Ltd), and the expected CRF is 35% (FHWA, 2008).

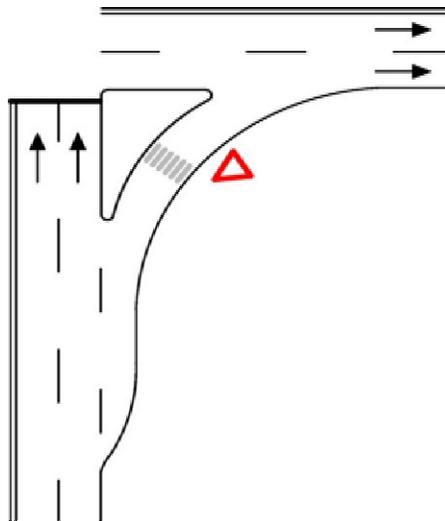


Figure 6- 3: Typical Channelized Right-Turn Lanes

6.3.5 Pavement Markings

Surprisingly, improve pavement marking was selected to be the most effective countermeasure by the truck drivers based on the survey results. It proved our finding during hot spot analysis that lots of roads in Texas are lace of clear pavement markings

delineating different lanes and guiding turnings. During the hot spot analysis in Chapter 3, the research team found that no clear pavement marking has contributed to several large truck involved crashes. Except for clear pavement markings, we also suggest “push back stop line marking” at intersections with inadequate space for large trucks making safe right turns. Furthermore, “install rumble strips” is also recommended for reducing large truck involved crashes.

Clear pavement markings

Pavement markings regulate and guide traffic movements to promote safety, and are widely accepted as being beneficial to drivers. Providing clear pavement marking is a very cost-effective roadway safety treatment in terms of reducing crashes and providing guidance to drivers. It is ranked as No.1 safety countermeasure by truck drivers surveyed. According to the survey results that 87% of the truck drivers (111 out of 128 survey results) scored over 8 out of 10 for its effectiveness. Table 6-1 provides the estimation of costs and benefit of different pavement marking according to the information collected from the traffic control device vendors and roadway construction contractors.

Table 6- 1: Cost of Different Pavement Markings

Types	Unit	Cost*	CRF (%)**
Lane Marking	60 feet (6-inch White)	\$189.72	32
Median Marking	60 feet (4-inch Yellow)	\$121.9	
Left/Right Turn Arrow Marking	2 Arrows	\$359.98	
Two way Left Turn Marking + Restriping	1 Mile	\$25,000-\$40,000	

*Source: Ennis-Flint America, LightMart.Com

**Source: USDOT Desktop Reference for Crash Reduction Factors

Push back stop line marking

Stop lines emphasize the stop condition and indicate where to stop. According to MUTCD, stop lines should be a minimum of 4’ in advance of a marked crosswalk. Place no closer than 4’ from the nearest edge of the intersecting travel way and no more than 30’. At the intersections with limited space, if a car stop at the stop line and a large truck try to turn right from the cross street, it may crash into the car at the stop line or on its left side due to the large turning radius of the truck and the limited space. By pushing back the stop line on the most left side of the lane will allows large truck to make turn more easily (please see figure 4). The cost is \$86.3 per 15 feet. The CRF information is unavailable due to lack of research on this topic.

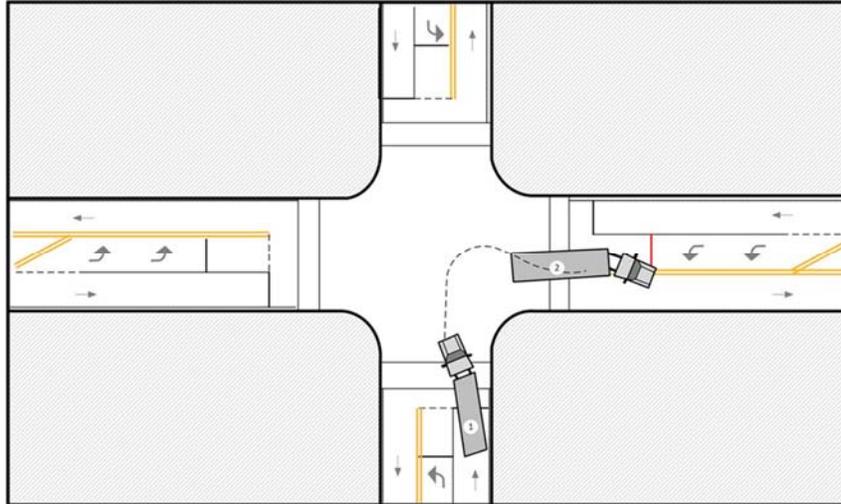


Figure 6- 4: Intersection with pushed back stop lines

Install center and shoulder rumble strips

Rumble strips are installed as a low-cost safety countermeasure that can reduce single-vehicle run-off-road and cross-center line crashes. Rumble strips, whether center line, edge line, or shoulder, alert inattentive or drowsy motorists whose vehicles have drifted out of their travel lane. As motor vehicle tires pass over the rumble strips, the drifting motorist receives auditory and tactile warnings to correct their path of steering. The rumble strips can reduce the fatal and injury crashes significantly. For head-on and opposite direction sideswipe collisions, NCHRP Report 641 documents that milled center line rumble strips provide statistically significant reductions in fatal and injury crashes: 38%-50% on rural two-lane roads, 37%-91% on urban two-lane roads. For single vehicle run-off-road injury crashes, NCHRP Report 641 documents that milled shoulder and edge rumble strips provide statistically significant reductions in fatal and injury crashes: 10%-24% on rural freeways, 26%-46% on two-lane rural roads. Unit prices have been estimated to range between \$0.10 and \$1.20 per linear foot (about \$500 to \$6000 per mile). (USDOT)

Install transverse rumble strips at highway off ramps

Roadways (or Transverse) rumble strips (RRS) are raised bars that are placed across the travel lane and used as a warning device to supplement signing and alert drivers of the need to reduce speed. Generally, limit rumble strips to a maximum height or depth of ½ in to minimize the jarring action to vehicles and the interval between two sets of rumble strips is 90’.



Figure 6- 5: Transverse Rumble strip (USDOT, 2015)

Normally, a group of rumble strips are applied, and the spacing between strips are 6’ to 4.5’ in in each set (Figure 6-5, Figure 6-6). Usually, white thermoplastic materials are used to create raised bars for RRS.

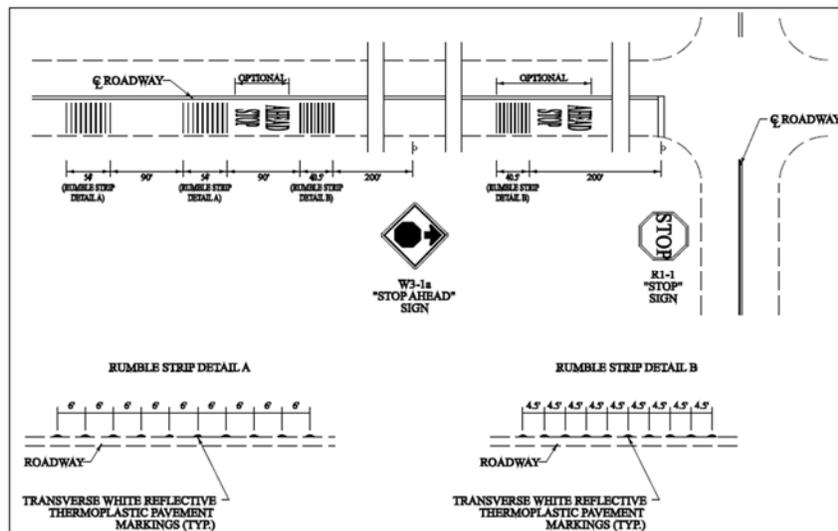


Figure 6- 6: Transverse Rumble strip (source: Guidelines for Application of Rumble Strips)

It costs \$56.3 for a rumble strip of 12’ long (USDOT, 2005), and it can bring a CRF of 28%. (ODOT, 2015).

Table 6-2 summaries the final cost-benefit analysis results of all engineering related countermeasures.

Table 6- 2: Cost Benefit Analysis Result of Engineering Countermeasures

No.	Counter Measures	Counter Measures (Item Needed)	Unit	Cost_Material *	Cost_Labor +Installation	Total Unit Cost	Maintenance Cost/ Device/ Year	CRF (%)
1	Traffic Sign	Add advanced dynamic traffic signs	1	15,000 ⁽⁵⁾	Included	510	2,000 ⁽⁵⁾	15 ⁽²¹⁾
		Add intersection lane control warning signs on both sides of the road or overhead	1	480 ⁽⁶⁾	175 ⁽⁶⁾	655	18.57 ⁽¹⁾	10-20 ⁽²¹⁾
2	Traffic Light and Control Devices	Add flashing beacons at rural non-signalized intersection	1	2,068 ⁽⁷⁾	175 ⁽⁶⁾	2,243	155 ⁽⁴⁾	5-58 ⁽¹⁸⁾
		Install pylon at congested merge and diverge areas	1	70 ⁽⁸⁾	70 ⁽⁸⁾	140	9 ⁽²⁾	27 ⁽²⁰⁾
		Install radar speed sign at highway off ramps	1	8,494 ⁽⁹⁾	Included	8,494	875 ^(10,11)	41 ⁽²¹⁾
3	Road-way Geometric Design	Extend merge distance for ramps	100'	6,847.65 ⁽¹²⁾	Included	6,847.65	NA	7 ⁽²²⁾
		Add Auxiliary Lanes	100'	49,243 (bridge) 6,617.42 (on ground) ⁽¹⁰⁾	Included	49,243 (bridge) 6,617.42 (on ground)	NA	26 ⁽²¹⁾
		Channelized right-turn lanes	100'	6,633.33 ⁽¹²⁾	Included	6,633.33	NA	35 ⁽¹⁹⁾
4	Intersection Lighting	Add lighting at intersection	1(250watt/hr)	2,319 ⁽¹³⁾	2,319 ⁽¹³⁾	4,638	980 ^(14, 15)	17 ⁽²¹⁾
5	Pavement Marking	Lane Marking	100'	316.2	Included	316.2	NA	32 ⁽²¹⁾
		Median Marking	100'	203.17 ⁽¹⁶⁾	Included	203.17	NA	
		Left/Right Turn arrow Marking	2 Arrows	179.99 ⁽¹⁶⁾	179.99 ⁽¹³⁾	359.98	NA	
		Two way Left Turn Marking + Restriping	100'	473.48-757.58 ⁽¹⁶⁾	Included	473.48-757.58	NA	NA
		Push back stop line marking	100'	575.33 ⁽¹⁶⁾	Included	575.33	NA	NA
		Center and Shoulder Rumble Strips	100'	94.7-113.64 ⁽⁸⁾	Included	94.7-113.64	NA	14-17 ⁽²¹⁾
		Transverse Rumble strip	10@12' long	563.04 ⁽¹⁷⁾	Included	563.04	NA	28 ⁽²¹⁾

Sources:

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6.4 COST BENEFIT ANALYSIS FOR TRAFFIC LAW ENFORCEMENT

Traffic law enforcement has been defined as the area of activity aimed at controlling road user behavior by preventative, persuasive and punitive measures in order to affect the safe and efficient movement of traffic (Organization for Economic Co-operation and Development, 1974). The main objective of road law enforcement is to increase road users' perception of the risk being caught (European Transport Safety Council 1999). Efficient enforcement strategies are, therefore, not about increasing the amount of fines, but about increasing the chance of being caught as perceived by the drivers (ETSC, 2016). It has been estimated that traffic law enforcement reduced road injury accidents by 20% to 25% (Assumand Ingebrigtsen, 1990). And it is suggested that this accident reduction potential could be even higher at 40% (Evans 1991).

There are three ways in which traffic enforcement techniques are used to achieve adherence to traffic laws. Firstly, by deterring unsafe road user behavior, secondly, by educating the public to adopt safer road user behavior and lastly, by punishing, when necessary, those road users who breach traffic laws (Solomon1988). Road user education is often used to support traffic law enforcement activities. For some countermeasures, driver education program regarding to the specific countermeasure is mandatory for the violators.

In this study, the cost and benefit of following two categories of traffic law enforcement related countermeasures were investigated:

1. General countermeasures targeting all road users: Alcohol interlocks, red-light cameras, and speed cameras
2. Special countermeasures targeting motor carries and truck drivers: safety audit of motor carriers and roadside truck inspection.

For these three traffic law enforcement countermeasures targeting all road users, the detailed cost benefit analysis is conducted for each of them. For the two countermeasures targeting motor carries and truck drivers, their cost and benefit will be discussed based on the information collected from the literature.

6.4.1 General Traffic Law Enforcement Countermeasures Targeting All Road Users

For general traffic law enforcement, there are nine cost components typically involved in developing, implementing, and maintaining an intervention (Jeanne Ringel et, al. 2015), which are:

- **Publicity** - Costs associated with these strategies can include advertising or outreach strategies in printed media (magazines and newspapers), outdoor media (billboards), radio, and television announcements.
- **Police or highway patrol time** - For each relevant countermeasure, we estimate the number of police officers typically involved in each procedure, as well as the time invested to carry out an enforcement strategy from beginning to end and multiply it by an hourly salary per police.
- **Court system** - Alcohol related countermeasures require offenders to interact with the court system. This requirement generates cost of additional time of judges, court personnel, and prosecutors.
- **Department of motor vehicles (DMV)** - Cost for in-person license renewal, reinstating drivers' licenses and license plates after DWI charges.
- **Equipment** - Equipment costs include acquisition, replacement, and maintenance costs paid by individuals and by states.
- **Fines and fees** - Fines and fees of relative countermeasures are seen as state revenue. When calculating the total cost, this revenue should be minus. The result could be negative, which means the revenue is larger than the cost of implementing this countermeasure. As a result, the benefit cost ratio is also negative.
- **Probation** - Cost of further supervision of alcohol related offenders by probation officers.
- **Education programs** - States often require DWI offenders to undergo educational programs along with other penalties. We included a cost to the state for providing these programs, as well as revenue to the state when an offender pays a fee to attend these programs.

- **Program management** - Some centralized management would be needed for these interventions to be implemented across an entire state. The model has a rough estimate for program management costs based on wages plus benefits of government office workers.

The costs for a traffic law enforcement related countermeasure may include one or more of those nine components. For example, alcohol interlock countermeasure only contains equipment and program management costs. In addition, the publicity cost and program management cost remain the same no matter what countermeasure is implemented.

6.4.1.1 Alcohol interlock

An alcohol interlock is an electronic device that prevents the use of a vehicle if alcohol is detected in a breath sample. The driver breathes into the alcohol interlock before starting the vehicle. The alcohol interlock analyses the breath sample and if alcohol is detected the vehicle will not start.

Alcohol interlocks are an effective countermeasure in the fight against drunk driving. A study conducted by the Road Traffic Agency in Finland found that 6% of the drivers who had benefited from a rehabilitation program with alcohol interlock committed another drink driving offence compared to 30% among other drivers who had not been driving with an alcohol interlock (Vehmas A. et al. 2013).

Cost of alcohol interlock countermeasure contains two components, which are equipment installation fee and calibration and monitoring fee. It is assumed that one alcohol interlock is installed in the car of convicted drunk drivers. Generally, an alcohol interlock costs approximately \$70 to \$150 to install and around \$60 to \$80 per month for device monitoring and calibration. (Wutke, Shelly. 2014).

Crash reduction factor of alcohol interlock is 0.24. The total benefit of using alcohol interlock is \$57,797,000 and total cost is \$124,000. So, the benefit cost ratio (B/C ration) is about 464.67 (Ringel et al. 2015).

6.4.1.2 Speed camera

Speed cameras, also called photo radar or automated speed enforcement, operate similarly, recording a vehicle's speed using radar or other instrumentation and taking a

photograph of the vehicle when it exceeds a threshold limit. Speed cameras can reduce crashes substantially. Prior reviewers concluded that speed cameras and speed detection technologies are effective at reducing traffic crashes and injuries (Pilkington and Kinra, 2005)

Cost of speed camera contains the acquisition, installation, operation, and maintenance fees. Based on the literature review, the cost of speed camera is \$70,416 per camera per year (Ringel et al. 2015).

Crash reduction factor of speed camera is 0.12. The total benefit of using alcohol interlock is \$425,535,000 and considering the revenue collected from the fines, the total cost is \$ -181,252,000. So, the benefit cost ratio (B/C ration) is about -2.35 (Ringel et al. 2015).

6.4.1.3 Red-light camera

Automated right-light cameras take photographs of vehicles entering the intersection on a red light. An analysis on 14 large US cities with red light camera enforcement programs showed an average annual city-wide rate of fatal red light running crashes declined by 35% (Hu, McCartt, and Teoh, 2011).

Same as speed camera, cost of red light camera contains the acquisition, installation, operation, and maintenance fees. Based on the literature review, the cost of red light camera is \$70,416 per camera per year (Ringel et al. 2015).

Crash reduction factor of speed camera is 0.17. The total benefit of using alcohol interlock is \$219,144,000 and considering the revenue collected from the fines, the total cost is \$ -15,416,000. So, the benefit cost ratio (B/C ration) is about -14.22 (Ringel et al. 2015).

Table 6-3 summarizes the benefit cost analysis results of the three general law enforcement countermeasures.

Table 6- 3: Cost Benefit Analysis Results for Law Enforcement Countermeasures

Intervention Name	CRF	Benefit \$/year	Cost \$/year	B/C Ratio
Alcohol Interlocks	0.24	57,797,000	124,000	464.67
Speed Camera	0.12	425,535,000	-181,252,000	-2.35
Red Light Camera	0.17	219,144,000	-15,416,000	-14.22

Source: Costs and Effectiveness of Interventions to Reduce Motor Vehicle–Related Injuries and Deaths

6.4.2 Special Countermeasures Targeting Motor Carriers and Truck Drivers

In this study, two specific truck safety programs, i.e. safety audit program and roadside inspection program were investigated. For estimating the benefits of these types of truck safety programs, both direct benefits and deterrence effect needs to be taken into account. For the cost estimation, both government program cost and costs to motor carriers needs to be considered.

6.4.2.1 Safety audit

Safety Audit involves an overhaul of the system of audits of the safety practices of motor carriers. At first, an initial "Safety Review" or SR was conducted by sending the inspectors to the operating bases of selected firms and question managers about safety related procedures and policies such as those governing maintenance, and driver hiring and training. At this stage, they do not actually inspect any equipment or test drivers. If a firm is found to be unacceptable a return visit is made. These visits, termed "Compliance Reviews" or CRs, are much more detailed. Firms can be fined and, in extreme circumstances, banned from offering service if they did not pass the CR.

According to a previous study conducted by Moses and Savage (1995), following key findings regarding the benefit and cost of this program were obtained:

1. Benefit: accident improvement occurs for 91% of firms that receive an unsatisfactory SR rating in a given year
2. Benefit: For the firms that improved their audit rating, the average accident rate reduction was 42.69%, which implies that the reportable accident rate drops from the 1.29 accidents per million miles typical for unsatisfactory firms to 0.74.
3. Benefit: It is suggested that the deterrence effect is about 25% of the direct effects

of this program. Thus, it results additional 25% benefits.

4. Cost: The management time cost to the firm of an SR was estimated as \$90, and \$875 for the subsequent CR.
5. Cost: To improve the operating quality, the firm will have about 6% increase in its costs for buying better trucks, providing better maintenance, hiring better drivers, or undertaking better training of existing drivers. These additional costs were estimated to be 8¢ per mile and about \$1,200 per truck.
6. Cost: the expected costs of an audit are $$(111 + 138T)$ each year for the next nine years, where T is the number of trucks a firm owns.
7. Cost: the government cost is estimated based the government budget
8. B/C Ratio: the safety audit program has a benefit-cost ratio of **4.2:1** under a wide variety of assumptions.

Overall, it is a very cost- effective program. It collects accurate information on accident experience, and requests the worst firms to improve. To further improve its effectiveness, Moses and Savage (1995) provides following suggestions:

1. The SR and CR should focus on a few questions that have been shown to be strongly related to actual accident experience, such as the questions deal with accident reporting and drivers' hours-of-service compliance.
2. It should target specific types of firms for auditing, such as small, general-freight firms because they have relatively high accident rates.

6.4.2.2 Roadside inspection

There are three levels of roadside inspections. It checks the truck drivers as well as vehicles. At a level I inspection, inspector will check brakes, lighting, tires, coupling devices, steering, windshield wipers, and load securement. Inspectors also check whether drivers possess correct licenses, have adhered to hours-of-service rules, and are not under the influence of alcohol or drugs. Level I inspections account for 65% of all inspections. There is also a level II inspection. It is a curtailed version of the level I inspection. They account for 28% of inspections. Finally, 6.5% of inspections are level III, where only the driver is inspected. If serious faults are found, the vehicle and/or the driver can be placed out-of-service.

According to a previous study conducted by Moses and Savage (1995), following key findings regarding the benefit and cost of this program were obtained:

1. Benefit: it is estimated that as an upper bound 1,544 accidents are avoided each year as a direct result of the roadside inspection program. Using mid-range assumptions 967 accidents are avoided.
2. Benefit: It is suggested that the deterrence effect is about 25% of the direct effects of this program. Thus, it results additional 25% benefits.
3. Cost: The typical roadside inspection delays the vehicle by 31.5 minutes, which is roughly equivalent to a 20-mile drive.
4. Cost: If driver is placed out-of-service, the consequent loss of productivity to the trucking firm averages 4 hours.
5. Cost: If vehicles placed out-of-service: brake out-of-service actions cause an average delay of 1.25 hours; lighting out-of-service action therefore requires a delay of 1.5 hours; more serious problems that involve wheels, tires, suspension, and steering cause an average delay of 3 hours;
6. Cost: a truck can expect to receive a roadside inspection once every five years. The expected annual costs to the firm are $47.2T$, where T is the number of trucks a firm owns.
7. Cost: the government cost is estimated based the government budget
8. B/C Ratio: the safety audit program has a benefit-cost ratio of **1.5:1** under the most favorable assumptions, but it is somewhat questionable whether it shows any net social benefits under more moderate assumptions.

Overall, it is relatively expensive to government and there are substantial costs to motor carriers due to the delays and lost productivities that caused. To make this program more efficient, it was suggested that:

1. It should concentrate on inspections of drivers and detecting brake deficiencies.
2. New technologies could be applied for a shorter inspection at less predictable locations.

6.5 COST BENEFIT ANALYSIS FOR ROAD USER EDUCATION

Road user education has the potential to improve road safety by raising community awareness and by influencing road user behavior and community attitudes. The use of mass media information campaigns has also been shown to improve road safety (Elliott, 1993). These campaigns increase awareness of road safety problems, stress the importance of, and need for, road safety countermeasures and can ensure that road users are aware of the risks associated with violating road traffic laws.

By conducting survey, it was mentioned by lots of truck drivers that many other road users don't have the appropriate knowledge to drive safely around large trucks. Also, by reviewing crash reports, it also be found that most of time, it was passenger vehicle drivers' fault which causing truck-involved crashes. Therefore, specific educations are very necessary. Other road users should be familiar with the physical capabilities and maneuvers of large size trucks, and know how to drive around them. In this study, two types of countermeasures were recommended. First is to disseminate the truck related road safety information through printed material, such as flyers brochures, information sheets, wallet-sized plastic cards, and posters for general public information on this safety topic. The printed material can be distributed through mail by the licensing authority agencies. It also can be distributed through driver safety schools and rental car agencies. Second is to increase the awareness of safely sharing the road with trucks through electronic media, such as website and social media. Instructional video on safely driving around large truck will be made and put on different transportation agency's websites and social media pages.

Although there is a lack of direct cost and benefit information for conducting the special education program on safely driving around large truck, many general education programs have been implemented and evaluated for their costs and benefits. Texas Traffic Safety Task Force Report "*Solutions for Saving Lives on Texas Roads*" (TxDOT, 2016) provided the detailed cost and benefit for five driver behavior education programs, which are summarized in Table 6-4. It can be seen that road user education would be a very important and effective countermeasure to improve traffic safety and prevent traffic crashes.

Table 6- 4: Detail Costs and Benefits for Road User Education Program

		Safety Belt Education and Enforcement	Impaired Driving Education and Enforcement	New Traffic Safety Education and Enforcement	Motorcycle Safety Education and Enforcement	Texas High School Traffic Safety Education
Benefit	Potential Serious Injuries Prevented per year	110–575	120–180	120–290	40–80	70–165
	Potential Lives Saved Over 5-year Campaign	175–650	300–450	100–275	75–125	50–125
	Potential Lives Saved per year	35–130	60–90	20–55	15–25	10–25
	Potential Crashes Prevented per year	Lack of restraint use	1,545–2,300	4,195–9,800	145–315	2,585–6,000
	Estimated Cumulative Benefit	\$2.1 billion	\$1.7 billion	\$1 billion	\$0.4 billion	\$0.6 billion
Cost	<ul style="list-style-type: none"> Click-it-or-Ticket campaign \$24M/year Enforcement \$7.2M/year 	<ul style="list-style-type: none"> Drink Drive Go to Jail campaign \$4M/year Safe Ride Vouchers \$1M/year Enforcement \$4.8M/year 	<ul style="list-style-type: none"> Zero Excuses Campaign: Distracted Driving \$4M/year Speed-related \$4M/year Work Zone \$4M/year Pedestrian Safety \$4M/year Enforcement \$7.2M/year 	<ul style="list-style-type: none"> Look Twice for Motorcycles \$2M/year Helmet Safety \$2M/year Impaired Motorcycle Riding \$2M/year Enforcement \$1.6M/year 	<ul style="list-style-type: none"> Texas High School campaign \$600K/year Friday Night Lights campaign \$400K/year Teens in the Driver Seat programs \$500K/year Project Celebration \$1.5M/year 	
	Potential Return for Every \$1 Spent (B/C ratio)	• 13:1	• 35:1	• 9:1	• 11:1	• 37:1

Source: TxDOT, Solutions for Saving Lives on Texas Roads, 2016

6.6 COST BENEFIT ANALYSIS FOR COUNTERMEASURES REDUCING EMERGENCY RESPONSE TIME

Emergency medical service plays a vital role after crashes happen. Effective response time can mean the difference between life and death for those involved in accidents and crashes. The less time it takes the higher possibility to save lives. Reducing emergency response time can't prevent crashes occur, but can reduce crash severity level therefore increase higher survival rate and lower the number of fatalities.

According to national database, average emergency response time 8 minutes and 15 seconds (2011). The EMS response time can be faster by considering some factors such as; reduce the travel delay and notification time and also improve the accessibility of the EMS vehicles. By conducting literature review, three countermeasures have been identified to have the potential to reduce emergency response time, which are:

- Installation of eCall features in all large truck
- Advanced life support Quick Response Vehicle (QRV)
- Traffic Signal Preemption for Emergency Vehicle

Detailed cost benefit analysis for each of these countermeasures is given in the following sections. Emergency response time is highly associated with accident survival rate or probability. The following figure 6-7 shows the relationship between survival rate and response time. The longer the response time, the lower will be the survival probability. Therefore, for countermeasures targeting reducing emergency response time, the survival probability as well as the reduction severity level from K to A was used as a criterion to evaluate their benefit.

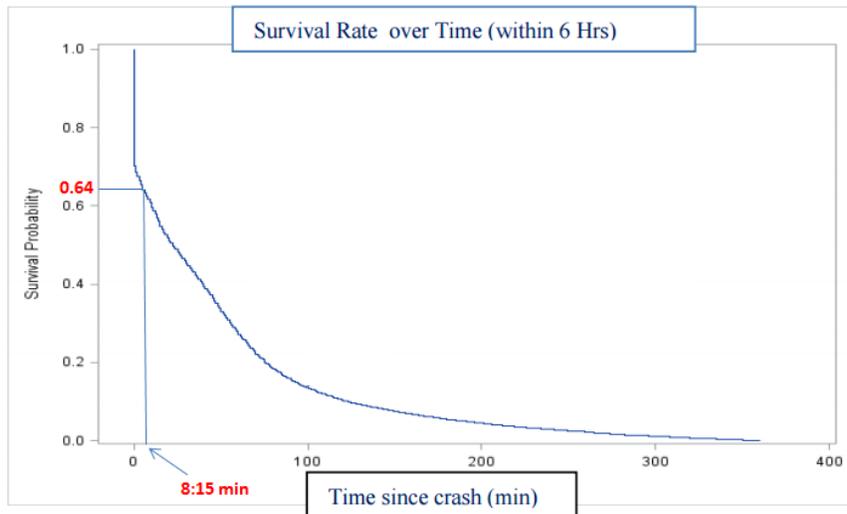


Figure 6- 7: Relationship between Emergency Response Time and Survival Possibility (Jingshu Wu, 2013)

6.6.1 Install eCall

[eCall](#) is an in-vehicle machine-to-machine (M2M) emergency call system designed to bring rapid assistance to drivers involved in collisions. In the event of a serious road incident, an eCall-equipped car automatically dials 991 (emergency number) and gives emergency operators information about the accident, including GPS coordinates, the time of the incident and the vehicle identification number. Operators can then dispatch appropriate assistance, which will speed up the response times of emergency services by 40% in urban areas and by as much as 50% in rural locations (Gemalto Inc., 2013). The following Figure 6-8 shows the four steps of eCall system after the crash.

- Step 1: The vehicle involved in accident,
- Step 2: eCall signal system responses to Satellite,
- Step 3: From Satellite the information passes to 911 emergency centers,
- Step 4: Emergency assistance dispatched to the crash area.

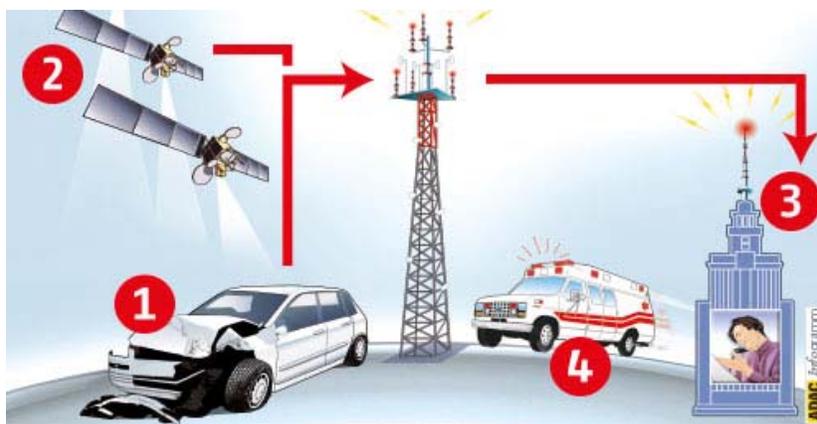


Figure 6- 8: eCall System for Rapid Assistance

(Source: European Auto Industry Association (ACEA))

According to data from the Institute of Automotive Engineer Assessor, it only costs \$106.14 (2015) to install one eCall device to one truck. Given the total number of large truck registered in Texas (821,564) (TXDMV.GOV, 2015), the total cost to install eCalls to all large truck in Texas is \$87.20 Million.

A study conducted by Wu (2013) revealed the relationship between emergency response time and survival possibility, which showed in Figure 6-7. It can be seen that the survival possibility increases with the reducing of emergency response time. Average emergency response time. Since eCall system can reduce the response time by 40% (Gemalto Inc., 2013), therefore it can reduce the emergency response time from 8.25 minutes to 4.95 minutes. According to Figure 6-7, it is observed that survival probability can be increased by 4% by saving response time by 3.3 minutes.

Total number of fatalities per year by large truck crashes in Texas is 532 (FMCSA, 2014) and with the increased survival rate, installing eCall can save 22 lives per year from fatality to incapacitating injury (K to A). The value for severity level reduction from fatality to incapacitating injury level (K to A) is \$2.61Million (Zaloshnja, E., and Miller, T, 2002); resulting total \$57.42 Million per year in considered as benefit.

If we assume that eCall has a service life for 5 years, therefore, the present value of total benefit for 5 years can be calculated using the equation (1);

$$NPV = \sum_{t=1}^T \left(\frac{Bt}{(1+r)^t} \right) \dots\dots\dots (1)$$

Here,

Service life $T=5$ years,

Discount rate $r= 5\%$,

Annual benefit, $B_t= \$57.42$ Million

So, the present value of total benefit for 5 years for eCall will be \$248.05 Million, and the benefit and cost ratio is $(248.05/87.20 = 2.84)$ for the initial year and from the next year and so on. There is no cost or very minimum cost involved with it, however, the benefit will continue for every year for long term perspective.

6.6.2 Advanced Life Support Quick Response Vehicle (ALS QRV)

An ALS QRV is an integrated Fire/EMS system. Usually, this SUV type vehicle is not staged continuously in a traditional fire station or municipal location during daytime and to drive around the city. According to Federal Motor Carrier Safety Administration, it is found that most of the large truck fatal accident occurs during 6am- 6pm of the day and 12pm-3pm has the highest peak. QRV mobility time can be allocated based on the day time accident probability. QRV are available to respond to calls for service throughout the city and these crews will always be ready to respond to an emergency in a moment's notice.

ALS QRVs are able to access to more challenging scenes (on road or off road) such as muddy or snowy road, downgrade, hilly etc. and hence it has quick accessibility to the crash area. They also can go the places where an ambulance can't have accessibility. QRVs can travel over tough terrain more quickly, and capable to transport patients from crash areas to the ambulance faster and have a guaranteed immediate paramedic response with advanced life support (ALS) equipment and other essential medical equipment. QRVs have the ability to reduce emergency response time. Recently, QRVs have been used in Oregon, Colorado and a few in California successfully. Figure 6-9 shows an example of ALS QRV.



Figure 6- 9: QRV (right) vs. traditional EMS (left)

6.6.2.1 Cost analysis

The cost of one QRV includes following part: (Lindberg, A. 2011)

- Vehicle Cost for Ford SUV= \$40, 000;
- Medical equipment cost=\$ 21,167
- Electronics equipment cost=\$12,992
- Total for vehicle and equipment cost: \$(40,000+21,167+12,992) = \$74,159/
Vehicle
- Maintenance Cost per year=\$2,939
- Paramedic average salary per year = \$ 42,000

It is proposed that adding one QRV in every existing EMS station in Texas, so the total number of QRVs will be 1475 which is equal to the total number of EMS station (Texas Fire Department). It is assumed that a QRV has a service life of 5 years with periodic maintenance. Here, it has been considered maintenance cost and paramedic annual salary for five years and vehicle with equipment cost only for the first year. The cost for all QRV with equipment will be \$109.39 Million. Yearly maintenance cost for all QRV is \$4.33 Million and Paramedic salary for all QRV is \$61.95 Million per year. Similar, the present value of total cost for 5 years can be calculated using equation 2.

$$NPV = \sum_{t=1}^T \left(\frac{C_t}{(1+r)^t} \right) + C_0 \quad \dots\dots\dots (2)$$

Here,

Service life T=5 years,

Discount rate $r= 5\%$,

Initial cost, $C_0= \$109.39$ Million

Annual cost, $C_t= \$ 66.28$ Million]

So, the total cost five years for 1475 number of QRV will be \$344.20 Million.

6.6.2.2 Benefit analysis

After 5 years' cost was calculated, the next step is to determine 5 years' benefit generated by implementing QRVs. As we mentioned before, the average emergency response time is 8 min 15 sec. Study showed QRVs are able to reduce the response time by 27.62% which make them capable to get the scene in 5 min 45 sec minutes (Anderson, DW, et.al, 2015). From Figure 6-7, it is found that survival probability increased by 3% for implementation of QRVs.

QRVs can make quick response to not only large truck involved crashes, but all motor vehicle crashes. According to Texas Motor Vehicle Traffic Crash Facts, 2015, the total number of fatalities by motor vehicle traffic crashes in Texas is 3531. With the increased survival rate, QRVs can save 106 lives per year from fatality or killed to incapacitating injury (K to A). The value for severity level reduction from fatality to incapacitating injury level (K to A) is \$2.61 Million (Zaloshnja, E., and Miller, T., 2002); the annual benefit is \$276.66 Million. Using the following equation; total benefit for 5 years has been calculated;

$$NPV = \sum_{t=1}^T \left(\frac{Bt}{(1+r)^t} \right) \dots\dots\dots (3)$$

Here,

Service life $T=5$ years,

Discount rate $r= 5\%$,

Annual benefit, $B_t= \$ 276.66$ Million

So, the total benefit for 5 years for QRV will be \$1195.17 Million.

6.6.2.3 Benefit and Cost ratio and other benefit of QRV

From the above cost benefit analysis, the benefit and cost ratio is $(1195.17/344.20 = 3.47)$. For the first year, there is only equipment cost and from the next year and so on, there is only paramedic salary and maintenance cost. But the benefit will continue for every year for long term perspective.

6.6.3 Traffic Signal Preemption for Emergency Vehicle

Traffic signal preemption is a type of system that allows the normal operation of traffic lights to be preempted. The following Figure 6-10 shows the most common use of the system that manipulates traffic signals in the path of an emergency vehicle by halting conflicting traffic and allowing the emergency vehicle right-of-way to help reduce response times and enhance traffic safety. It is very useful in urban areas especially in high traffic volume intersection. Traffic signal preemption reduces response time and also crash at intersection.



Figure 6- 10: Emergency Vehicle Signal Preemption

Source: FHWA, Traffic Signal Timing Manual

It costs \$5,000 (Paniati, J.F. and Amon, M, 2006) to apply traffic signal preemption in one intersection. It is reported that having emergency vehicle signal preemption could save 30 to 45 seconds (Paniati, J.F. and Amon, M, 2006) at a high volume signalized intersection. Considering an emergency route normally has to pass 3 to 6 signalized intersections, applying emergency vehicle signal preemption could save around 70

seconds, therefore resulting 14% to 23% time decreases from existing emergency time (Paniati, J.F. and Amon, M, 2006).

One example of implementing traffic signal preemption is Plano, Texas. Plano has 100% (Paniati, J.F. and Amon, M, 2006) preemption coverage. Based on their assessment, there is a 10-20% reduction in response time and the system has allowed them to set and achieve a response time goal of 90 % of arrivals within 6 minutes and 59 seconds even as the traffic levels have grown (Paniati, J.F. and Amon, M, 2006). The city is now serving 7.5square miles per station instead of the anticipated 5.6 square miles (Paniati, J.F. and Amon, M, 2006). The benefit to the city is that it is currently operating 10 stations compared with the 13 that had been forecast resulting in a capital cost savings for the city of approximately \$9 million and an annual operating cost savings of approximately \$7.5 million (Paniati, J.F. and Amon, M, 2006).

Table 6- 5: Detail Costs and Benefits for EMS Countermeasures

Countermeasures	Unit Cost	Maintenance cost and others	Total Cost	NPV of Five Years' Total Benefit	B/C	Comments
eCall	\$106.14	NA	\$87.20 Million	\$248.05 Million	2.84:1	Feasible option
Advanced Life Support Quick Response Vehicle (ALS QRV)	\$74,159	\$66.28 Million/vehicle/year	\$344.20 Million	\$1195.17 Million	3.47:1	Feasible option
Traffic Signal Preemption for Emergency Vehicle	\$5,000/Vehicl e/intersection	NA	Varies for size of the city and route of EMS	Ref. Plano, Tx	Ref. Plano, Tx	90 % of arrivals within 6 min and 59 sec Ref. Plano, Tx

6.7 SUMMARY

In this chapter, four categories of countermeasures for preventing or mitigating large truck involved crashes were recommended, including engineering related countermeasures, traffic law enforcement related countermeasures, road user education related countermeasures, emergency response related countermeasures. Information regarding the Cost-benefit analysis has been provided and detailed Cost-benefit analysis has been conducted for some countermeasures.

Among all proposed countermeasures, some simple engineering related countermeasures are very low cost, yet high CRFs, such as adding clear pavement markings, installing speed advisory traffic signs, etc. The most suitable countermeasure can be selected for improving the safety of a specific roadway segment. A summary table including costs and CRFs for all engineering related countermeasures was provided for reference.

Traffic law enforcement countermeasures require the participation of police officers, education road user, which bring a very high cost. However, the collected fines will offset the overall costs and make traffic law enforcement very beneficiary. In addition, safety audit of motor carriers is a more cost-effective countermeasure than the roadside truck inspection.

Emergency response time is the key factors for survival rates after crash occurred. Three countermeasures were proposed for reducing emergency response time. The cost and the benefit response time reduction were calculated for each countermeasure.

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CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

The primary goals of this research project as described in Chapter 1 have been achieved. This research systematically analyzed the risk factors of large truck- crashes in Texas by two different approaches: 1) collision diagrams based in-depth risk analysis at 10 identified hot areas and 2) comprehensive truck crash data analysis. As a result, following fourteen risk factors related to roadway conditions, traffic control, drivers and vehicle characteristics were identified:

- Roadway conditions
 - Short merge distance at highway entrance
 - Insufficient turning space for trucks making right turn
 - Narrow lane
 - Dual left turn or dual right turn with heavy truck volume
 - Two-way frontage road design
 - Two way left design for locations with many access points and heavy truck volume
- Traffic control related
 - Visibility of signal heads and traffic signs
 - No clear pavement markings
 - Construction and congestion
- Drivers and vehicle characteristics
 - Late lane change behavior at highway diverge area
 - Fail to control speed at highway off ramp
 - Truck parking on shoulder without protection
 - Truck maintenance
 - Driver behavior problems

These identified risk factors were validated by a survey conducted to the truck drivers. According to these risk factors, twenty three different safety countermeasures related to traffic engineering, traffic law enforcement, road user education, emergency response, were identified and their costs and benefits were discussed. In this research, the information about the percentages of crashes that can be reduced (Crash Reduction Factor) by implementing different countermeasures and their Benefit and Cost (B/C) ratios were provided. It was found that the identified countermeasures are all cost-effective based on their high Crash Reduction Factor (10%-39%) and Benefit and Cost (B/C) ratios (1.5:1– 464.67:1).

The studies led to a number of findings and recommendations associated with truck crash prevention and mitigation. First, from the traffic engineering point of view, if an intersection or roadway segment has heavy truck volume, following are recommended:

- Increase the visibility of traffic signal heads and traffic signs,
- Provide clear turning guide lines on the pavement for the dual left-turn/right-turn lanes,
- Use channelized right turn design to provide more protection to trucks when they are running on red,
- Avoid using two way left-turn lane design and, instead, installing raised medians with full or directional openings to better control the location and amount of traffic conflicts,
- Avoid using two-way frontage road because it will cause drivers' confusion on the right of way rules.

In addition, enhancing the traffic law enforcement for both truck drivers and general road users can effectively prevent the large truck involved crashes. New technologies, such as alcohol interlocks, red-light cameras, and speed cameras are highly recommended due to their high B/C ratios (great than 12%). Furthermore, to reduce truck crash risk, education is essential not only to large truck drivers, but also to other roadway users. According to the literature, providing road user education on safely driving around the trucks has great potential in improving truck safety. Finally, emergency response time is the key factor for survival rates after crash occurred. To lower the fatalities of large truck crash, three new

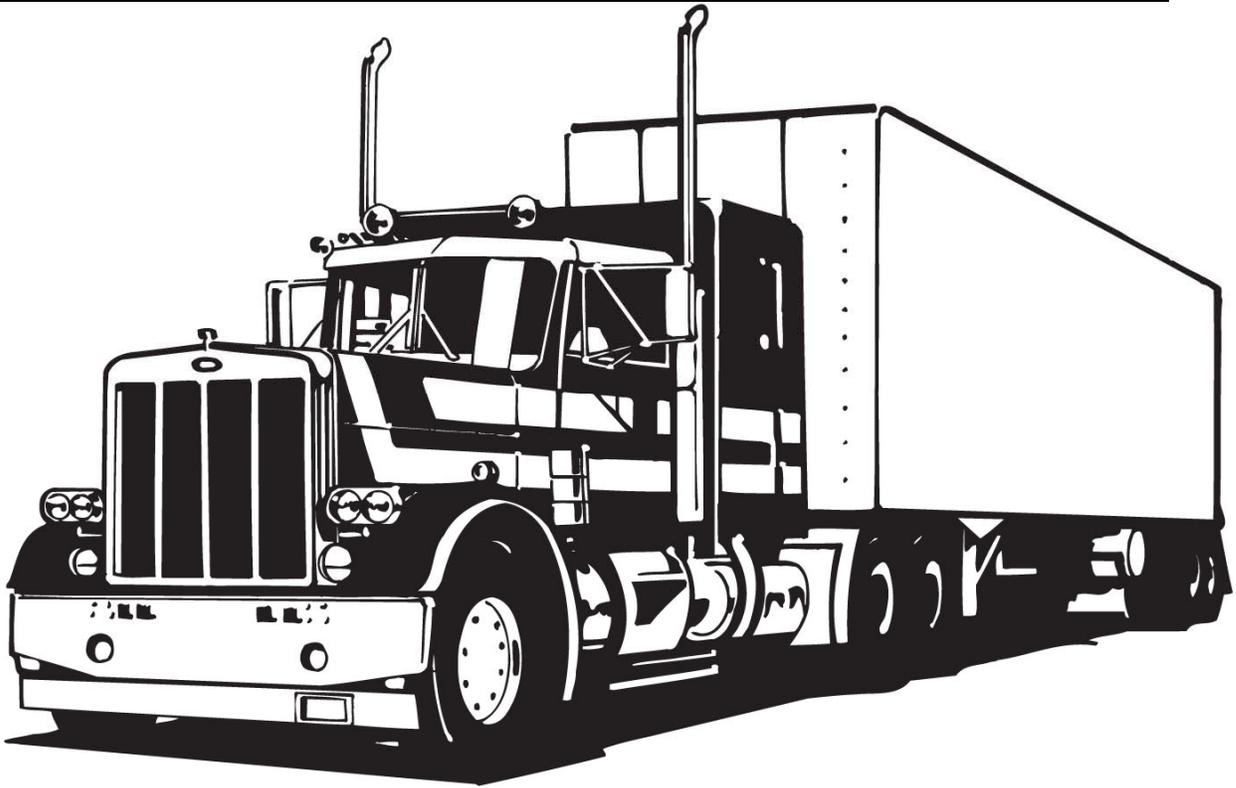
technologies based countermeasures, eCall, Advanced Life Support Quick Response Vehicle (ALS QRV), and Traffic Signal Preemption for Emergency Vehicle, are recommended. These countermeasures have shown great benefits in term of reducing emergency response time, crash fatality rate and the associated cost.

**TEXAS DEPARTMENT OF
TRANSPORTATION**

RESEARCH PROJECT 0-6911

Development of Systemic Large Truck Safety Analyses*

DRIVER SAFETY SURVEY



Instruction

This survey is to solicit large truck drivers' inputs about truck safety issues they face as well as their opinions on how to prevent large truck crashes.

This survey contains 3 parts, and it will take you approximately 5 -10 minutes to finish.

INFORMATION USED FOR ACADEMIC RESEARCH ONLY. NO PERSONAL INFORMATION WILL BE SHARED OR RELEASED.

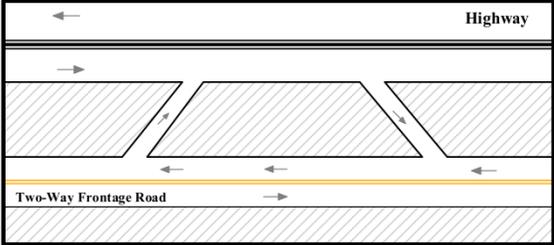
*A Large Truck, as defined by the US Department of Transportation, is any vehicle with a gross weight rating greater than 10,000 pounds.

Age (optional): _____ Gender: M F

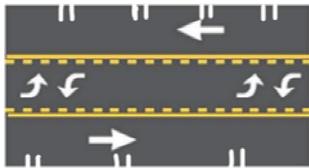
Years of truck driving: _____ years

PART 1: Crash Risk Factors

Crash risk factors are the factors which could cause or contribute to the truck crashes. Please rate the following identified risk factors.

Crash Risk Factors														
	No Risk					Extremely Risky								
	0	1	2	3	4	5	6	7	8	9	10			
Short merge distance at highway entrance														
Two-way frontage road														
														
Narrow lane on highway														
Narrow shoulder on highway														
Traffic congestion near interchanges or ramps														
Parking on highway shoulders														
Poor truck maintenance														
Speeding														
Not wearing seatbelt														
Distraction by the use of cellphone														
Fatigue														
Drunk driving														
Other vehicles cut you off														

Dual or triple left-turn at intersection																				
Dual right-turn at intersections																				
Not enough space for making turns																				
No or poor pavement markings																				
Right turn on red																				
Poor pavement condition (i.e. pot holes or cracks in surface)																				
Continuous two-way left turn lane with many access points for exits/entrances																				

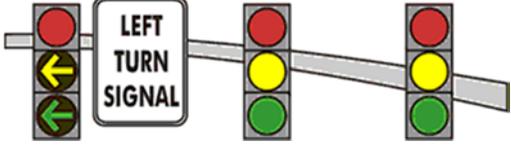


Based on your own driving experience, are there any other risk factors not included in the table above? If yes, please list them and explain below.

PART 2: Countermeasures

Countermeasures are methods to prevent or mitigate large truck crashes. Please rate the following countermeasures according to their effectiveness.

Countermeasures												
	Not Useful					Very Useful						
	Useful	0	1	2	3	4	5	6	7	8	9	10
Clear pavement markings at intersections, such as adding turning guidelines on pavement to prevent sideswipe crashes												
Increase the turning radius at intersections												
Provide channelized right-turn lanes 												
Use of raised shoulder with curb												
Apply double stop signs or place stop signs on both sides of the road, or add flashing beacons with stop signs 												
Add intersection lane configuration warning signs on both sides of the road or overhead												
Add safety lighting at intersection												
Add flashing beacons at rural non-signalized intersection												
In dual left turn, use protected only phasing												

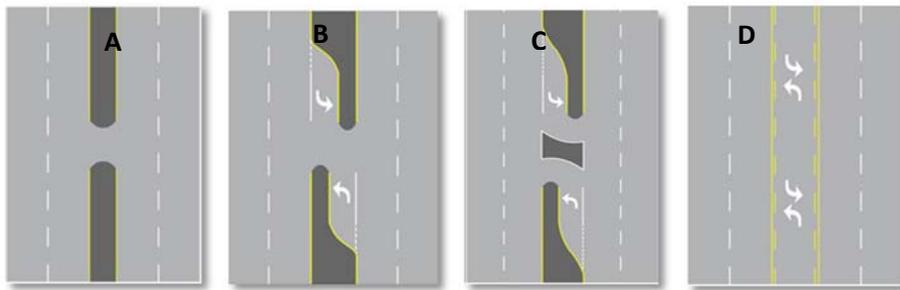
																			
<p>Push back stop lines to allow more space for trucks making right turns</p>																			
<p>Install speed advisory signs at on ramps and off ramps</p>																			
<p>Extend merge distances for ramps</p>																			
<p>Use auxiliary lanes when merge distance not adequate</p>																			
<p>Install barriers at congested merge and diverge areas</p> 																			
<p>Add advanced dynamic traffic signs, such as “TRAFFIC CONGESTION AHEAD, BE PREPARED TO STOP” etc. with flashing beacons near highway entrances, exits, construction zones or other congested areas</p>																			
<p>Add more speed limit signs and warning signs</p>																			
<p>Increase use of heavy truck lane restrictions</p>																			
<p>Install center and shoulder rumble strips to assist drivers keeping in lane</p>																			
<p>Implement intelligent rollover warning system at curves</p>																			

																			
Place stickers on the back of trucks such as “IF YOU CAN READ THIS YOU ARE TOO CLOSE”																			
Add more “ONE WAY” or “NO RIGHT TURN” signs on freeway or frontage road																			
Increase speed enforcement																			
Increase inspection of large trucks																			
Educate other road users on how to drive safely around large trucks																			
Conduct public information and education (PI&E) campaigns on heavy truck operation/performance limitations, rules, crash experience, and restrictions																			
Create adequate storage for truck inspection stations in and around ports of entry																			

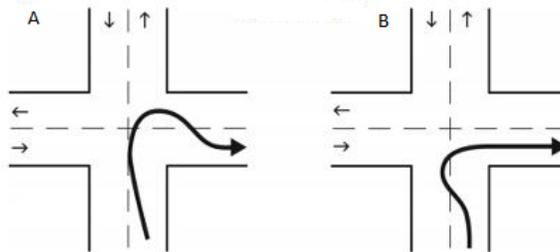
If you have any other comments on how to reduce truck crashes, please list below.

PART 3: General Questions

1. In your opinion, which design is safer for making left turn? (assuming adequate turn radii)



2. When making a right turn, which of the following represents your typical turning path?



3. What safety tips would you give to passenger car drivers to safely share roads with large trucks?

Blank area for answer to question 3.

4. What would be the most effective way to prevent driving with fatigue or drowsiness?

5. Any comments on the following Hour of Service regulations?

- 1) 30-minute rest break during the 8 hours of service
- 2) Maximum of 11 hours driving after 10 consecutive hours off duty
- 3) 60-hour/7-day and 70-hour/8-day driving limits
- 4) "Restart" 60 or 70 hour clock after having at least 34 consecutive hours off duty
- 5) Record driving hours to prevent fatigue



ACKNOWLEDGEMENT

WE APPRECIATE YOUR PARTICIPATION IN THE SURVEY. IF YOU HAVE ANY QUESTIONS OR COMMENTS RELATED TO THE SURVEY, FEEL FREE TO CONTACT:

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