EXPANDING THE OREGON MOTOR CARRIER SAFETY ACTION PLAN: BEST RETURN ON INVESTMENT

Final Report

PROJECT SPR 832

Oregon Department of Transportation

EXPANDING THE OREGON MOTOR CARRIER SAFETY ACTION PLAN: BEST RETURN ON INVESTMENT

Final Report

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16. Abstract: This study presents the results of an analysis on the impact of increased law enforcement on truck driver-at-fault crashes and identifies corridors that would make viable candidates for the Oregon MCSAP program. This was accomplished through a descriptive analysis of collected inspection data and Oregon crash data. Next, the safety performance of the program was determined by generating a safety performance function and estimated a crash modification factor. The safety performance analysis determined that the MCSAP program had a substantial impact on reducing truck driver-at-fault crashes. Using the crash modification factor, as well as estimates of the effects on law enforcement on truck driver-at-fault crash frequency, a benefit/cost analysis was conducted on several candidate corridors/segments. Three segments were identified as viable candidates for program expansion. Lastly, a survey was administered to law enforcement in Oregon to gauge their perception and willingness-to-adopt such a program in their jurisdiction. This report concludes by providing a comprehensive summary and specific recommendations.

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Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
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ft^2	square feet	0.093	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	m^2	meters squared	1.196	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	kilometers squared	km^2	km^2	kilometers squared	0.386	square miles	mi^2
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fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
~NOTE: Volumes greater than 1000 L shall be shown in m^3.									
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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DISCLAIMER

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1.0 INTRODUCTION

A key objective of Oregon's Commercial Vehicle Safety Plan is to reduce truck at-fault crashes through focusing attention on increased traffic enforcement to identify truck driver behaviors associated with high truck at-fault crash numbers in Oregon. In 2015, there were 1,336 truck crashes in Oregon, of which roughly half (712) were truck at-fault. Although the total number of truck crashes were 82 less than 2014, the number of fatalities increased from 20 to 54 during this time period.

In July 2016, the Motor Carrier Transportation Division (now known as the Commerce and Compliance Division), in collaboration with Oregon State University, implemented a state-funded pilot program called the Oregon Commerce and Compliance Division Safety Action Plan (Anderson, Hernandez, and Hedlund 2020). The program provided state funds for participating law enforcement agencies to conduct Level 2 truck inspections and identify unsafe driver behaviors in high-crash locations along I-5 (Portland area) and I-205. The benefits of the program were both clear-cut and strikingly effective. Continuing and expanding this program will require additional state funds. The best use of this funding requires research on the optimum level of effort required to achieve the results observed from the pilot program. This research effort aims to determine the level of law enforcement needed in order to achieve the best value in the reduction of truck at-fault crashes.

1.1 PROJECT OBJECTIVES

Given that state funds are limited, this research develops an implementation methodology that includes economic benefit/cost analyses and site-specific identification models to expand the program to viable corridors statewide. This is accomplished by utilizing results and data from the pilot program as a basis (Anderson et al. 2020). Focusing on the leading causes of truck crashes from previous and current ODOT research studies with increased enforcement (Anderson et al. 2020; Hernandez et al. 2020), along with education outreach, will provide all users of the Oregon Roadway System a safer roadway environment and more efficient use of enforcement efforts.

2.0 LITERATURE REVIEW

This chapter provides a review of literature pertaining to truck at-fault crashes and related safety countermeasures, traffic law enforcement, and cost effectiveness studies that have been effective in reducing crashes and fatalities. The goal of this comprehensive review is to identify some of the lessons learned from the implementation of various safety policies and initiatives related to truck at-fault crashes. This will help develop an implementation methodology for law enforcement that includes an economic benefit/cost analysis and a site-specific identification model as part of the Oregon Motor Carrier Safety Action Plan (OMCSAP).

The overall objective of the OMCSAP is to reduce truck at-fault crashes in Oregon. The motivation for this study comes from recent data. In 2015, nearly half of the 1,336 truck crashes in Oregon were truck at-fault and the number of fatalities nearly tripled from 2014 (Hernandez et al. 2019). Meticulous methods have been used to develop the OMCSAP in multiple steps. The first step consisted of a safety assistance program in which participating law enforcement agencies performed Level 2 inspections for any unsafe driving behavior from truck drivers along some of Oregon's major interstates. The law enforcement agencies which participated are summarized in Table 2.1, and their respective locations are displayed in Figure 2.1. During the course of the program, over 6,000 inspections were conducted. The analysis revealed that the leading causes of truck at-fault crashes are following too close, improper lane change, and failure to maintain the lane (Anderson, Hernandez, and Hedlund 2019). This verifies that an increase in traffic-related enforcement efforts could substantially reduce unsafe driving behaviors, which in return could reduce truck at-fault crashes. The following sub-chapters describe some of the recent studies found pertaining to truck at-fault crashes, related safety policies, traffic law enforcement efforts, and benefit/cost analyses.

Table 2.1: Participating Law Enforcement Agencies

Agency	Location
Clackamas County Sheriff's Office	Clackamas County, OR
West Linn Police Department	Clackamas County, OR
Oregon City Police Department	Clackamas County, OR
Scappoose Police Department	Columbia County, OR
Marion County Sheriff's Office	Marion County, OR
Salem Police Department	Marion County, OR
Multnomah County Sheriff's Office	Multnomah County, OR
Portland Police Bureau	Multnomah County, OR
Stanfield Police Department	Umatilla County, OR
Washington County Sheriff's Office	Washington County, OR
Tigard Police Department	Washington County, OR

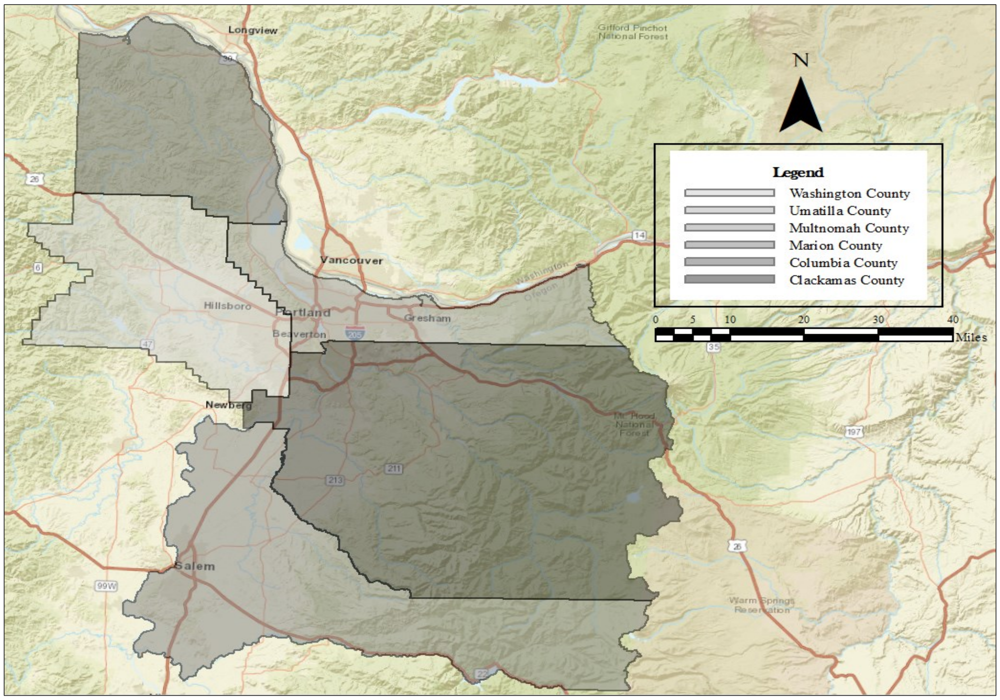

Figure 2.1: Locations of participating law enforcement agencies

2.1 SAFETY STUDIES

Chapter 2.1 presents summaries of recent studies relevant to truck at-fault crashes and the efforts implemented to reduce such crashes. This review is intended to develop an understanding and a familiarity of the procedures and methodologies used in the past. At the same time, notice will be taken on any limitations or weaknesses of these studies to provide insight on how to better accomplish this study’s objectives.

In 2004, the Federal Highway Administration conducted a research project in North Carolina to identify driver behaviors and roadway locations that produce critical combinations that lead to a crash between heavy trucks and passenger vehicles (Federal Highway Administration 2004). From 1994 to 1997, over 16,000 truck-car crashes resulted in the state’s database in the Highway Safety Information System. For these crashes, investigating officers assigned contributing factors to one or both drivers involved, from a list of 26 factors. A fault analysis was conducted from this data based on a code associated with each factor. According to this analysis, and unlike previous findings, the truck driver is more likely to be assigned fault in most cases – 48.0% versus 40.2% for a passenger vehicle driver. These findings reveal a need to target truck driver behavior just as much as passenger vehicle drivers. In the second part of the study, an average crash harm cost was attached to each crash based on injury severity: $3 million if fatal, $63,000 if nonfatal injury, and $2,250 per vehicle if no injury. The records were then categorized into a 462-cell matrix based on the descriptors of 11 facility types, seven crash types, and six location types. The total harm cost for each critical combination was calculated by multiplying the average crash harm cost to the frequency of crashes in a cell. The cells with the highest total harm cost identified the most critical combinations of facility type, crash type, and location type. In the end, this research found that the highest total harm cost resulted from angle crashes at stop/yield intersections on rural major roads, including minor arterials and major collectors. This facility was among the top 20 critical combinations and "angle collisions" were among the most common crash type. The findings of this research indicate high-impact areas for future countermeasure research related to car-truck crashes, but the results are only applicable to North Carolina and its population. This type of analysis could be implemented to data from any state or country but is restricted based on the specificity of the variables needed.

More recently, studies have begun to concentrate the analysis on assessing specific factors contributing to truck at-fault crashes and possible countermeasures. In 2014, Islam et al. (2014) examined truck at-fault crashes in Alabama that occurred between 2010 and 2012. The data was filtered from police reports. This resulted in a total of 8,171 truck at-fault crashes for this two-year period. The goal was to identify location specific factors associated with truck at-fault crashes to develop effective highway safety countermeasures and policy decisions. The researchers developed four separate random parameters logit models to estimate injury severity levels, distinguished by single (SV) or multi-vehicle (MV) and type of location (SV-rural, MV-rural, SV-urban and MV-urban). The random parameters logit model is able to incorporate the effects of randomness across the observations to better estimate the complex relationships among various factors, types of crashes, and types of locations. The study included three injury severity levels: possible/no injury, minor injury, and major injury. The independent variables included in the models ranged in categories including driver, vehicle, environmental, accident, and roadway characteristics. These results found differentiating levels of influences for several variables in the models. Some variables were significant in the urban locations, but not rural, and others were significant in one type of accident, but not the other. For example, if the driver was found to be fatigued at the time of the crash, the model estimated an increase in the probability of an injury in both rural SV and MV models, but there was no effect on any injury severity level in urban located crashes. The development of these results contributes additional knowledge that is unique to heavy trucks. These specific results are only applicable to Alabama because the data only consisted of the state's crash reports, but the methods are applicable to any dataset, state or national. This will help implement more effective truck safety policy decisions and safety programs that address the most prominent factors contributing to truck at-fault crashes.

In a similar manner, Rezapour and Ksaibati (2018) in Wyoming recognized the unique factors among single- and multi-vehicle crashes. This particular study investigated single-truck and multi-vehicle crashes separately and incorporated violation data, in addition to crash data. The addition of violation data was made as to identify specific features of drivers, vehicles, and time most at risk of severe truck crashes. The dataset was a combination of data from three major interstates in Wyoming, I-80, I-25, and I-90, where truck-related crash rates were highest. A total of 2,914 crashes, 1,371 single-truck and 1,543 multi-vehicle, were observed in these locations from 2011 to 2014. An ordinal logistic regression model was used to investigate the contributory factors to severe truck crashes and a multinomial logistic regression was used to identify contributing factors of risky drivers' violations that were underlying causes of truck-related crashes. For this study, violations of following too close, failing to drive within a single lane, and speeding too fast for conditions were the only violations included as part of this investigation. The results indicated that the residency of a driver, time and day of a violation, and types of vehicles are factors that most often contribute to involvement in risky violations. Based on these results, the recommendations to Wyoming Highway Patrol were to place more emphasis on these specific types of violations. An overall improvement of truck safety can be reached by implementing more targeted policies and regulations that encourage the trucking industry without compromising safety. This study recognized the shortcomings of using crash and violation data because there is a slight disadvantage of using police-reported crashes in road safety studies. They provide information about the individuals involved, vehicles, roadways, and traffic elements, but there can often be discrepancies among police officers, sometimes within police stations. This study still provides notable information of the factors most related to truck at-fault crashes.

In 2018, Bunn et al. (2019) analyzed state truck crash data from 2005 to 2014 in Kentucky. In this study, the researchers were concerned with crashes where the truck driver was definitively at-fault as a result of fatigue. The dataset consisted of a total of 7,538 truck at-fault crashes, where 284 listed sleepiness/fatigue as a contributing factor The researchers were interested in examining the association between truck at-fault crashes involving fatigue, and distances to the nearest rest area/truck stop. The hypothesis was that the probability of a truck at-fault crash involving fatigue increases with increased distance to rest areas/truck stops. The distances from crash locations to rest areas, truck stops, or weigh stations with rest havens, were categorized into three groups: less than 20 miles, at least 20 miles but less than 40 miles, and greater than or equal to 40 miles. A binary logit model was used, where the dependent variable was 1 if fatigue was a human factor involved in the crash, or 0 otherwise. The analysis compared the effect of fatigue to other possible human factors such as alcohol impairment, cell phone distraction, and speeding. This model was used to obtain the effect measure for the relation between crash contributing factors and the distance between crash site and rest area/truck stop. The results found that there was a higher proportion of sleepiness/fatigue-related truck crash cases where the distance from the crash location to the nearest rest area or truck stop was 20 miles to 39.9 miles compared to the controls. It was also noticed that sleepiness/fatigue-related truck crashes took place more frequently during nighttime hours, and the crashes were primarily single vehicle crashes. The researchers recognized that sleepiness/fatigue could be a difficult contributing factor to recognize because of coding bias by law enforcement, underreporting, or crashes resulting in fatalities. Still, this study contributes additional information of what areas traffic law enforcement and regulations should focus on, particularly for long-haul truck drivers that may be prone to at-fault crashes due to the lack of rest areas or truck stops in the vicinity.

2.2 LAW ENFORCEMENT STUDIES

Chapter 2.2 presents a comprehensive review of past studies involving law enforcement and the impact it has on road safety and crash frequency.

In 2007, Welki and Zlatoper (2007) sought to estimate the effect of a set of highway enforcement activities that took place over 27 years, from 1973 to 2000, in Ohio. The researchers collected data from various sources to depict the changes in traffic safety in Ohio. Overall, motor vehicle fatalities had a declining trend over this time period. Most of the crash patterns observed were correlated with the nation’s economy. Fatalities decreased during times of recession, which has been supported by previous studies. The total deaths declined by approximately 43% (2,385 in 1973 to 1,366 in 2000) (Welki and Zlatoper 2007). Three forms of an ordinary least squares regression model were used to estimate the effect of specific conditions and characteristics on the annual aggregate number of motor vehicle fatalities. One of the models did not include enforcement variables, another included all available variables, and the third included only a subset of variables. Comparing the first two models allowed the authors to explain the impact enforcement measures have on motor vehicle fatalities. There were four enforcement efforts accounted for in this study: speeding, seatbelt violations, alcohol impairment, and motor vehicle inspections. The remaining independent variables ranged in categories, including economic conditions, driver characteristics, and government regulations. Vehicle type was not a focus for this study. The researchers found conclusive evidence in all three models that laws regulating higher speed limits are associated with an increase in the number of fatalities. The only variable related to enforcement efforts that resulted as expected was alcohol impairment. Findings determined that if more arrests were made for driving under the influence, there were fewer motor vehicle fatalities. This research study provided a format to assess the effectiveness of highway law enforcement. It was able to collect a significant amount of data for Ohio for a longer time period. However, the study had multicollinearity issues, which created some difficulties in developing the inferences. Still, the methodology is valuable for this study if the influence of heavy trucks is included.

In Oregon, DeAngelo and Hansen (2014) analyzed the effect of a mass layoff of Oregon State Police that took place in February 2003. Due to statewide budget cuts that year, nearly 35% of state troopers were laid off. The goal of this study was to determine if traffic safety decreased as a result of less law enforcement. Oregon had a noticeable increase in injuries after the layoffs, while the trends in Washington and Idaho remained relatively consistent. The researchers studied three years before and after the layoff, 2000 to 2005, to determine if the Oregon State Police layoff was responsible for the increase in traffic injuries and fatalities. Various sources were combined to analyze the effect of the layoff, including citation data, crash data, records from the Census of Law Enforcement, administrative records from Oregon, Idaho, and Washington, and the Law Enforcement Officer Killed in Action records. Injuries and fatalities were considered under four different scenarios based on different city limits, outside or inside city-limits, and weather combinations, under dry or all-weather condition. The study found that the reduction in state police officers was associated with significant increases in traffic injuries and fatalities, ranging from 12% to 29%, varying on the type of injury and weather conditions. The probability of a fatality increased eight-fold, incapacitating injuries tripled, and visible injuries almost doubled. It was determined that the layoff of so many state troopers was associated with the rise in traffic injuries and fatalities on Oregon's highways. The researchers recommend utilizing other forms of enforcement, such as fine increases or regulated classes, to discourage dangerous driving behavior.

Makowsky and Stratmann (2011) studied the effect law enforcement has on traffic crashes. They studied the relationship between municipal budgetary shortfalls, traffic citations, and crashes that occurred in Massachusetts from 2001 to 2003. Only tickets related to traffic safety were included in the study. Speeding was the most commonly issued ticket during this time at approximately 39%. Seatbelt violations and failure to stop were the next most commonly issued tickets. An ordinary least squares regression model was used to examine the effects of law enforcement on traffic crashes. The model revealed that issuing 100 extra tickets can lead to four fewer crashes and 6.7 fewer traffic injuries, and for every 100 tickets written per mile, there were 14.3 fewer crashes per mile. The effect of tickets, however, on the number of fatalities was inconclusive. Still, these findings provided conclusive evidence that tickets are an effective method to reduce traffic crashes and injuries.

Santana (2014) determined the impact of overtime law enforcement on crash frequency in Michigan. The data used consisted of crash data and citation data from the Michigan Office of Highway Safety Planning, where the focus was on fatal or serious injury crashes related to impaired and unrestrained driving. 553 police agencies in the state were studied to identify individual characteristics for each jurisdiction. The researchers complied information on population, road length, number of bars, hours of enforcement, presence of media campaign, and other characteristics that influence crash frequency for these areas. A modified critical rate method was used to objectively establish means for the selection of agencies and time periods. 150 agencies were selected as being top priority and, in general, enforcement should be emphasized during weeks of the warmer months. The relationship between overtime law enforcement and crash occurrence was modeled using a trend analysis, in addition to a simple linear regression analysis, a Poisson model, and a negative binomial model. Overall, the results indicated that mandatory and optional impaired overtime traffic enforcement activities reduced fatal and serious injuries, as well as alcohol/drug-related crashes.

Only recently, efforts have been made to investigate the impact of traffic law enforcement on heavy truck related crashes (Mashhadi et al. 2017). In Wyoming, researchers from the University of Wyoming partnered with Wyoming DOT to identify the primary factors involved in high truck crash rates to reduce the high truck crash frequency in the state. The data used was a combination of citation, inspection reports, crash data, traffic data, and roadway geometry data for some of the state's highways (US-26, US-30, WY-59). The state highway patrol, state DOT, and the state's supreme court allowed open access to this data. Each highway was analyzed separately based on different traffic compositions and functional classifications. Different types of models were used to establish the relationship between truck crashes and different explanatory variables, including traffic, weather, geometric, and road characteristics. A binary logit model was used to determine the factors most influential in fatal crashes when the truck is at-fault. The results showed that the odds of an injury/fatal crash increased by 254% if the driver was distracted by cabin technologies; and, if the driver was fatigued at the time of the crash, the odds increased by 370%. Also, in comparison to truck drivers with no violation or one violation, truck drivers with a history of citations are 48% more likely to be involved in injury/fatal crashes. A temporal analysis was used to identify variables that were significant predictors on the number of truck crashes. A spatial analysis was used to evaluate the influence of geometric features and the effects of law enforcement on a mileage basis. This specific analysis helped reveal that truck crashes increased as the central angle of horizontal curves increased, as well as the length and rate of crest curves. The results also indicated that an increase in the length of horizontal curves or radii of horizontal curves can result in a reduction of truck crashes. Lastly, a crash hot spot analysis was conducted to examine the density of truck crashes and enforcement distribution on different route segments. Overall, the analyses revealed that locations with higher traffic citations experienced less truck crashes. It was noted that speed-related citations had a statistically significant impact on the reduction of truck crashes on all three interstates. Based on these analyses, the study recommended safety guidance programs to the Wyoming Highway Patrol, WYDOT, and the Wyoming trucking industry to target the most common contributing factors. Recommendations included expanding the trucks inspection programs, developing an outreach program for the trucking industry, and improved communication of hot spots in the area either at truck spots or through signage.

The majority of studies in this review recommend implementing safety enforcement programs, but no one guidebook was found that targeted truck at-fault crashes. However, the U.S. DOT recently published a guidebook for law enforcement titled *Speed Enforcement Program Guidelines* (National Highway Traffic Safety Administration 2008). The National Highway Traffic Safety Administration developed a manual on how to establish and maintain an effective speed enforcement program. The guidelines are focused on program planning, operations, adjudication, marking, and evaluation. One of the key takeaways from this guide was the need to perform and share periodic analysis of the program. Formal reports should review the impacts of the program on speeds and crashes and should continuously provide feedback to improve the program. These recommendations can be made to suit safety programs related to efforts in reducing truck at-fault crashes.

2.3 BENEFIT/COST STUDIES

Chapter 2.3 summarizes studies in relation to benefit/cost analyses and highway safety. This particular section showcases the need to examine the economic segment of policies and regulations. There have been no studies evaluating the cost effectiveness of law enforcement in relation to heavy truck inspections. This review is intended to provide an insight on the theoretical methods developed involving highway safety up to now.

In 2001, Ozbay et al. (2001) studied the transportation costs of the northern New Jersey highway network. The goal was to present a new methodology capable of estimating the full marginal transportation cost of the highway transportation system of the state. The focus was on marginal costs because they measure the actual increase in costs from an additional mile traveled. Ultimately, this estimation could assess the effectiveness of the transportation system by ensuring the prices paid by transportation users correctly reflect the true costs of providing transportation services. The researchers developed cost functions for users, infrastructure, and the environment. User costs include vehicle operating costs, such as fuel, oil, and vehicle maintenance. They also include costs accrued by congestion and accidents. Infrastructure costs describe the costs of maintaining the highway system. These costs are paid through fuel, vehicle registration fees, and other taxes. Environment costs were represented by air pollution and noise costs. The marginal cost value varies depending on the trip distance, degree of urbanization, and highway functional classification. The functions are used to determine if the user fees collected by the government are enough to provide the external costs of highway transportation, such as increased travel time, pollution, and accidents. The researchers were able to determine that the cost of a trip for a user using the northern New Jersey highway network is about 43 cents. To estimate this, the total dollar amount collected by the state through federal and state fees, and state and local tolls in 1998, was divided by the annual total number of trips made that year in New Jersey. The analysis estimated that the actual total cost to provide one trip on this system is $1.25. This indicated that the fuel tax would have had to increase from the $0.10 per gallon to $1.25. It might seem extreme, but in comparison to European countries, it would still be less. Table 2.2 displays the fuel prices and percent taxes of some European countries and the United States from 2000. The difference in the marginal cost value for peak and off-peak hours became more significant as distances were longer because the congestions costs would increase at the same time. It was also noticed that the marginal costs decreased as the distance of a trip on a freeway or expressway-type facility increased.

Table 2.2: Fuel Prices and Percent Taxes (2000)

Country	Percent Taxes	Tax	Price per Gallon
United Kingdom	76.8	3.295	$4.29
Netherlands	68.4	2.708	$3.96
France	72.7	2.661	$3.66
Italy	67.6	2.464	$3.64
Germany	70.7	2.418	$3.42
USA	24.1	0.419	$1.74
USA (Recommended)	47.3	1.563	$3.303

Source: Ozbay et al. (2001)

In 2009, the Victoria Transport Policy Institute began to compile information on transportation cost-benefit analyses. They developed a guidebook that is continuously updated with new information from recent studies as to improve upon the knowledge of highway transportation cost categories (Litman 2016). A cost is translated as anything that can be traded for the use of a resource, such as money, time, land, or simply the loss of an opportunity to enjoy a benefit. This guide describes costs and benefits as having a mirror image relationship: a cost can be defined as a reduction in benefits, and a benefit can be defined in terms of reduced costs. The chapters of this guide consist of comprehensive descriptions of various categories of costs and benefits related to transportation, including vehicle, travel time, parking, congestion, safety, and health. This guide encompasses the theoretical methodology behind a transportation cost-benefit analysis.

2.4 LITERATURE SUMMARY

Several studies have helped identify key contributing factors of crashes pertaining to heavy vehicles. Most recently, studies have begun to investigate the involvement of specific characteristics such as crash type and fatigue. However, previous studies have generally focused on any crashes involving heavy vehicles, but not many have targeted truck at-fault crashes specifically. This study would be one of the few and would be the first to implement a site-specific identification model to reduce truck at-fault crashes.

Additionally, the reviewed literature recognizes the effect that increased law enforcement citations have on reducing the number of motor vehicle crashes. Enforcement activities, patrol employment records, and budgets have been analyzed as a part of developing this relationship and these findings have helped establish effective strategies to reduce traffic crashes and injuries. Still, no studies have explicitly investigated heavy truck crashes, despite their prevalence and damage. This study could serve as a continuation of current research to target the gap in this area.

There are but a few studies that have investigated the economic aspects of transportation policies or initiatives. Further, there are no studies addressing the monetary effects of heavy truck crashes or related safety programs. This study would initiate the exploration in this field and would implement methodologies capable of reducing heavy vehicle crashes in an economically effective manner.

3.0 DATA COLLECTION AND DESCRIPTIVE ANALYSIS

Chapter 3.0 describes the data collected and presents a descriptive analysis of the collected data. This chapter identifies data trends, characteristics, and potential key inputs for the site-specific identification model.

3.1 INSPECTION/VIOLATION DATA

As part of the pilot program detailed in Chapter 2.0, if a truck driver exhibits unsafe driving behavior (e.g., speeding, following too close, unsafe lane change, etc.) in the presence of a law enforcement officer, the officer performs a traffic enforcement stop. This was accomplished by partnering with local law enforcement agencies through an Inter-Governmental Agreement. Partnering law enforcement agencies were summarized in Table 2.1 and locations were shown in Figure 2.1. All partnering law enforcement agencies with the exception of Salem Police Department, Scappoose Police Department, and Stanfield Police Department, are located in the Portland Metropolitan area.

From the start of the program (July 2016) through December 2019, there were a total of 6,436 traffic stops due to unsafe driving behavior. The unsafe drive behavior is recorded by the presiding officer, where the most occurring unsafe driving behaviors are shown in Figure 3.1[1] More than two-thirds of traffic stops were a result of speeding and approximately 25% were attributed to lane restriction violations. Each of the remaining observed unsafe driving behaviors did not account for more than 4%. There were other instances that prompted the traffic stop (e.g., flat tires, careless/reckless driving, expired plates, etc.), but only behaviors that account for greater than 1% of the total are included in Figure 3.1. In regard to light-related violations, these refer to any violation related to lighting attributes of the truck, ranging from no headlights, no taillights, prohibited lighting, turn signals, and cabin lights.

Although Figure 3.2 provides a general overview of the geographical regions where these stops are occurring, specific highways are represented more than others. In particular, three specific highway segments account for a substantial proportion of the total traffic stops. The locations of the 6,436 traffic stops are shown in Figure 3.2 and the frequency of traffic stops by highway are shown in Figure 3.3.[2] The large majority of traffic stops occurred on I-205 (68.7%), I-5 (9.2%), and I-84 (7.4%). A likely reason for this observation is a result of resources (law enforcement agencies) and roadway geometry (i.e., sufficient shoulder space for a truck to safely park).

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[1] In several instances, multiple unsafe driving behaviors were recorded for a single observation. Therefore, the percentages in Figure 3.1 do not necessarily sum to 100%. For example, if speeding and following to close were recorded as unsafe driving behaviors for the same traffic stop, it goes to counts for speeding and following too close.

[2] Violations resulting in traffic stops occurred on various highways; however, only highways in which inspections were overrepresented are shown in Figure 3.3.

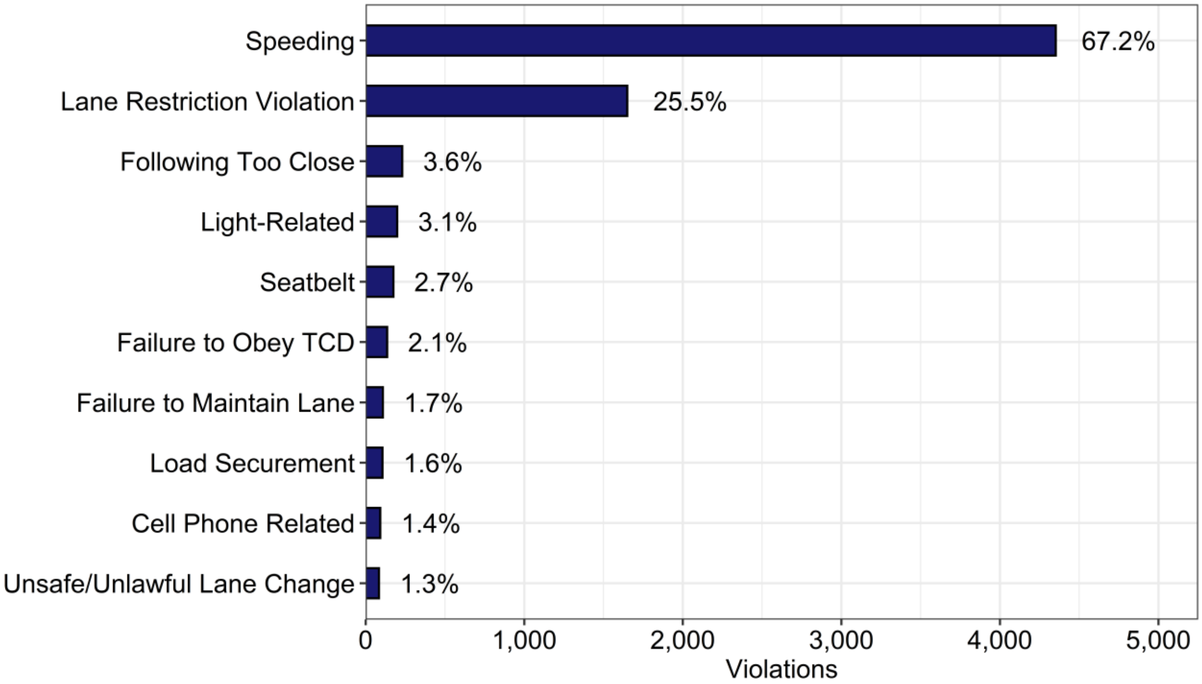

Figure 3.1: Frequency of most occurring unsafe driving behaviors

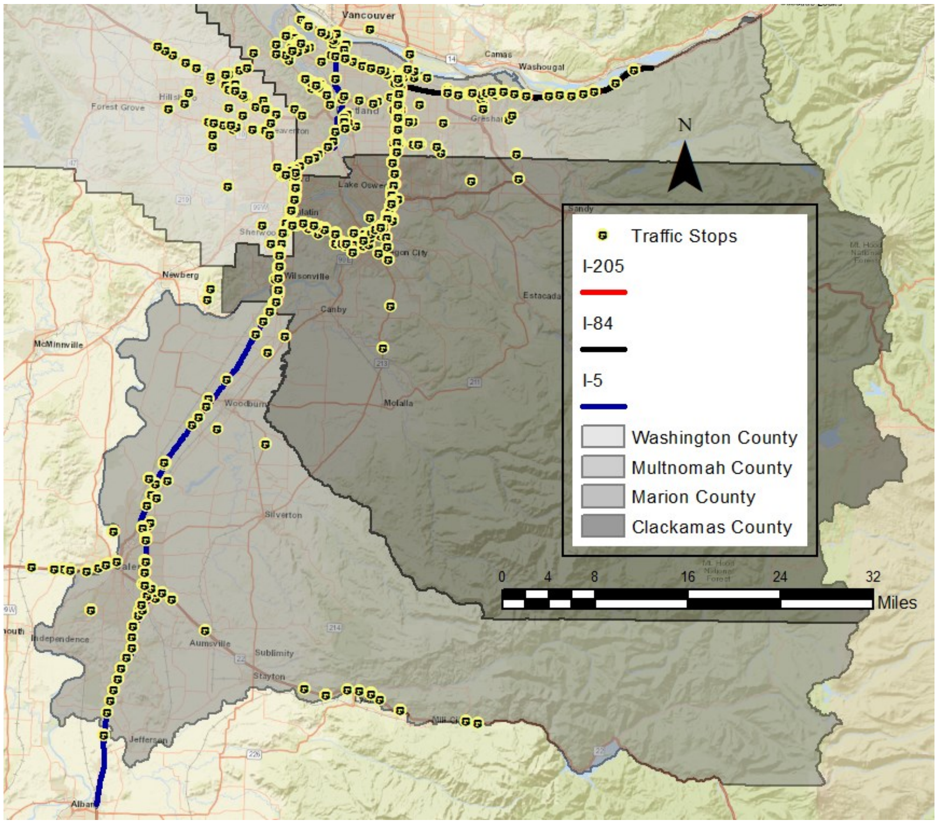

Figure 3.2: Locations of traffic stops due to traffic violations

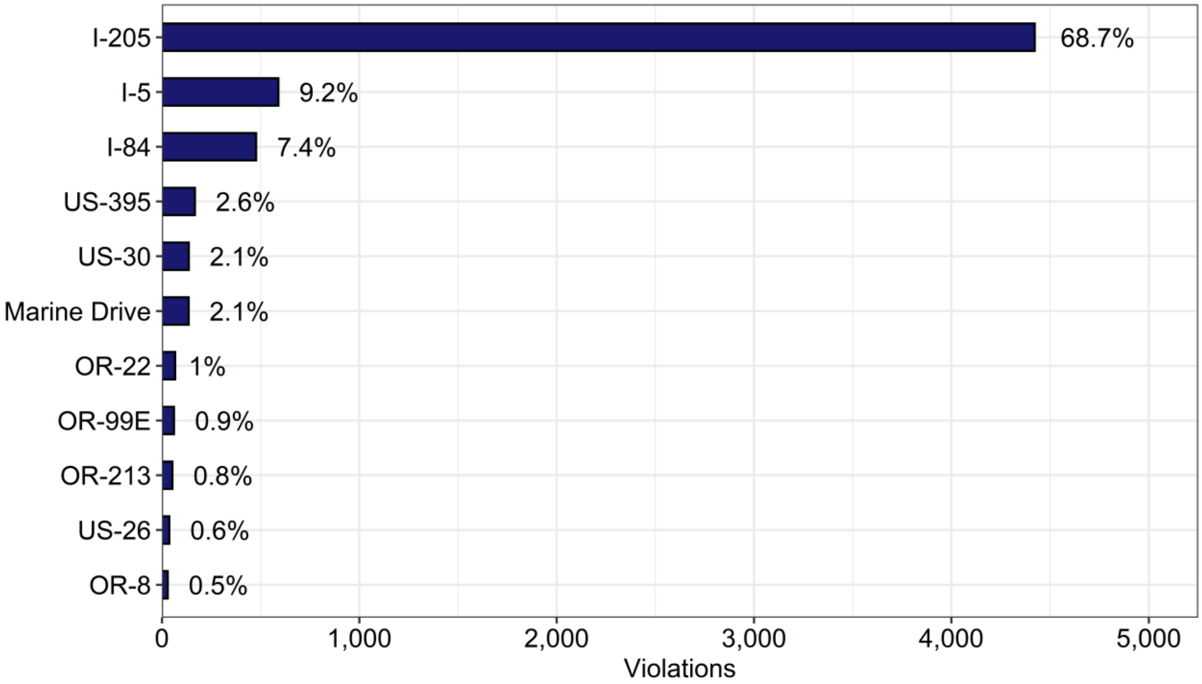

Figure 3.3: Frequency of violations leading to traffic stops by highway

Temporal trends over the three-plus years the program has been active is shown in Figure 3.4. There are certainly fluctuations in the number of traffic stops over the duration of the program, where the trend becomes more consistent with each year. Of particular note is the outlier in July 2017. It was confirmed from persons involved with the program that this outlier is a result of agreement renewals. In general, the summer months exhibit a decrease in the number of traffic stops compared to other parts of the year.

The program was extended through 2020 and data was obtained. However, due to general traffic behavior and freight-related behavior as a result of the COVID-19 pandemic, the data will not be used for analysis or evaluation of the program. A summary of 2020 trends, for both inspections and crashes, is provided in Appendix A.

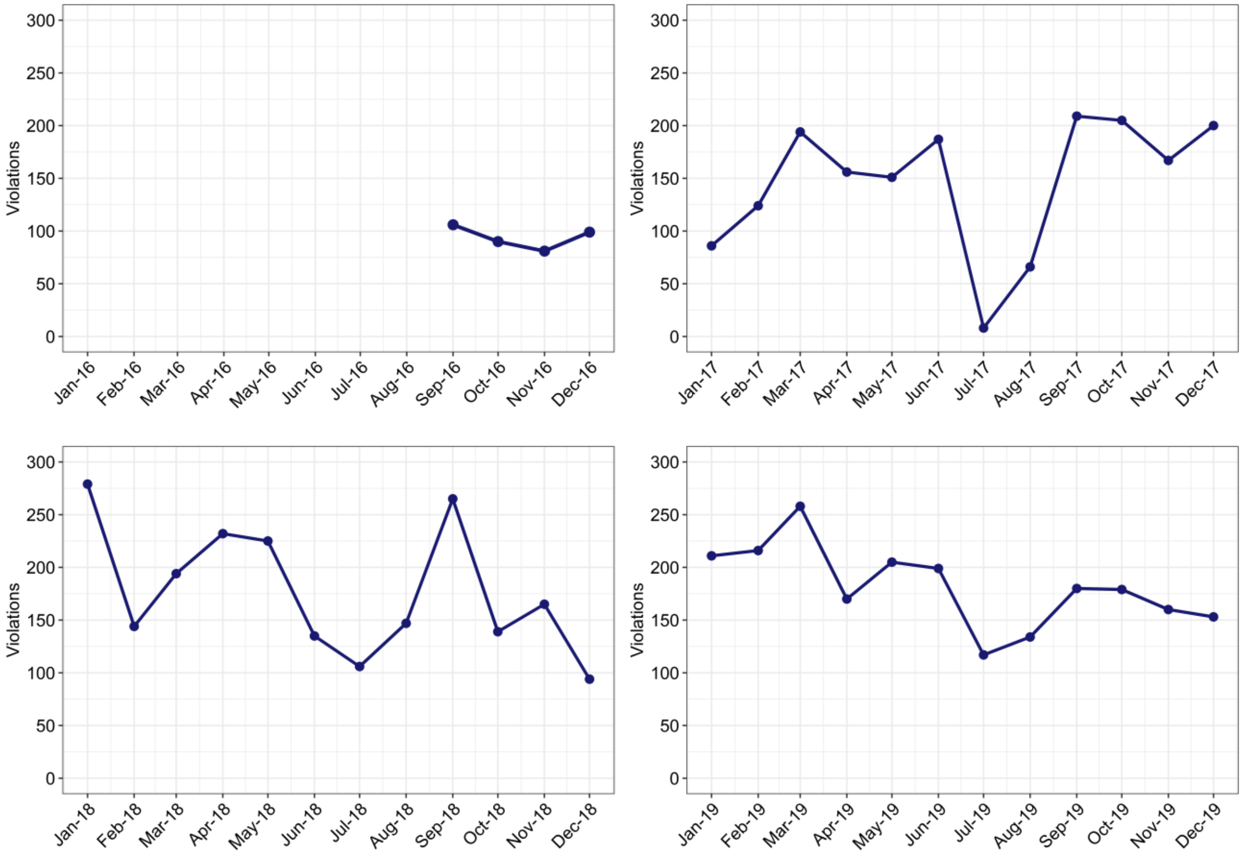

Figure 3.4: Number of traffic stops due to unsafe driving behaviors by month and year

3.2 OREGON CRASH DATA

To assess the efficacy of the program, Oregon crash data will be used to determine truck driver-at-fault crash trends. Oregon crash data is maintained by ODOT's Crash Analysis and Reporting Unit, where vehicle crashes that take place on city streets, county roads, and state highways are recorded. The available data represents 10 years of Oregon crash data at any given time. For the current study, the focus is explicitly on truck driver-at-fault crashes that took place between 2013 and 2019. The descriptive analysis does include crashes in which the truck was at-fault, but not necessarily the driver (e.g., mechanical defect). At the time of this analysis, 2019 crash data was not available.

Figure 3.5 shows the yearly distribution of truck at-fault crashes. From 2013 to 2014 crashes increased by about 3%. Truck at-fault crashes remained steady for another year. Then, from 2015 to 2016, crashes decreased from 23.2% to 10.5%, approximately a 55% decrease. There is also a 2.6% decrease from 2017 to 2018.

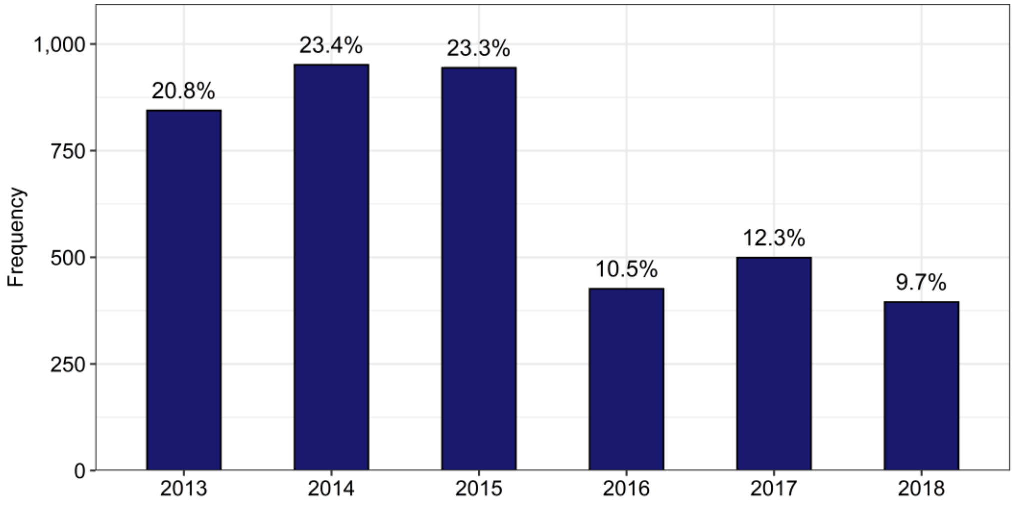

Figure 3.5: Truck at-fault crashes by year

The primary reason for such large decreases after 2015 stems from the manner in which ODOT crash data changed its reporting. Specifically, beginning in 2016, several crash characteristics began to be coded as 'NA' for no injury crashes. For driver-level crash cause, this new coding scheme leads to all no injury crashes being coded as 'No cause associated at this level.' In other words, fault cannot be determined for these later years for no injury crashes and, therefore, are not included in the presented statistics. This indicates that for years 2016 to 2018, only statistics on crashes in which an injury resulted are presented, as these are the crashes in the crash data with an associated cause. In future tasks, this will be considered, and the appropriate no injury crashes may be obtained from Oregon's Commerce and Compliance Division.

The Federal Motor Carrier Safety Administration (FMCSA) is consistently studying crash trends involving large trucks. In 2011, they noticed that the fatal crash rate was relatively steady, while the rates of crashes involving injuries and property damages had risen (Peterman 2017). As a result, the FMCSA established rigid regulations and limits on the trucking industry and its drivers. One of the major changes was on the hours-of-service (HOS) of truck drivers. A new regulation took effect in 2013 that required the 34-hour off-duty period cover two consecutive 1 a.m. - 5 a.m. periods, and drivers were only allowed to take the 34-hour "restart" once in a 168-hour (seven-day) span. The regulation entailed record-keeping of the hours driven each day and each week. Congress mandated that commercial drivers subject to HOS recordkeeping requirements should have vehicles equipped with electronic logging devices. Overall, the HOS rules were better enforced, and more truck drivers were discouraged from driving fatigued.

To further assess truck at-fault crash trends, crashes were plotted by month and day of the week as displayed in Figure 3.6 and Figure 3.7. Referring to Figure 3.6, the trends show that truck at-fault crashes are highest during early winter months, lowest in the spring months, and relatively steady during the late summer and fall months. In regard to day of the week, Figure 3.7 shows the highest number of crashes on Tuesdays and Thursdays, while fewer crashes happen on weekends. From Monday to Friday, the frequency of crashes is rather consistent, but from Friday to Saturday there is an 8.5% decrease.

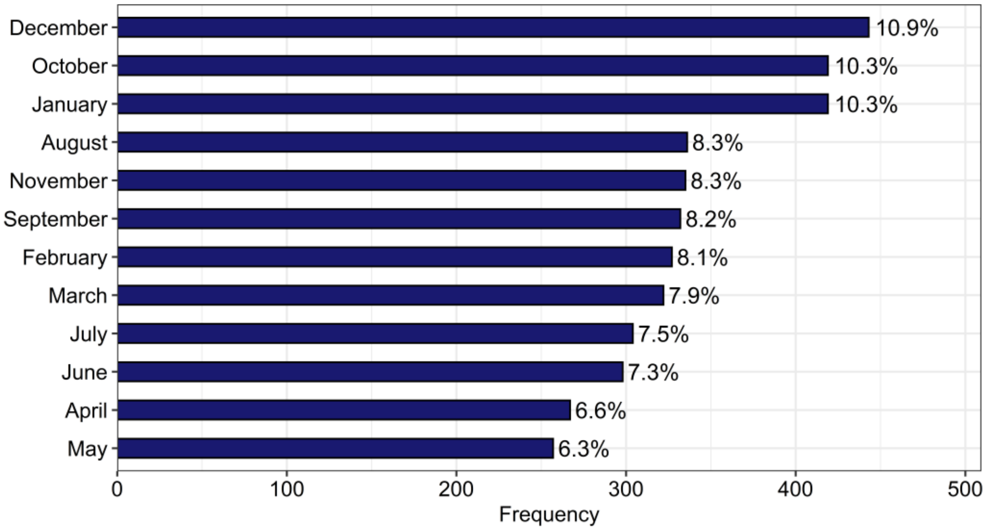

Figure 3.6: Truck at-fault crashes by month

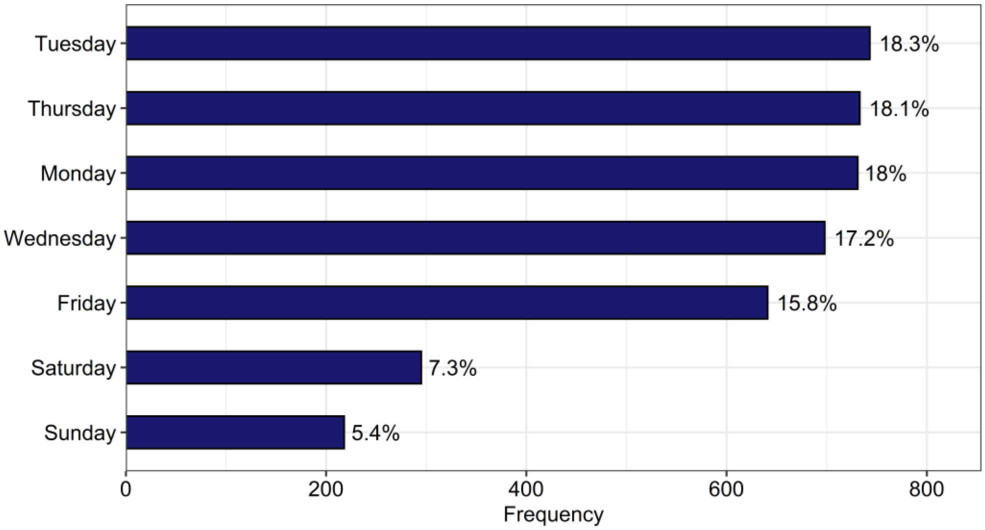

Figure 3.7: Truck at-fault crashes and day of the week

3.2.1 Crash Characteristics

Various crash characteristics are plotted to better understand truck at-fault crashes. Understanding crash trends are essential for identifying potential locations for the OMCSAP program to be implemented. Referring to Figure 3.8, approximately one-quarter of crashes are rear-end crashes and another quarter are fixed-object crashes. Figure 3.9 shows the reported driver-level crash cause. The leading causes, based on crash reports, are due to unsafe driving behaviors. Many previous studies have established the connection between driving behavior and the level of law enforcement. An increase in traffic-related enforcement efforts would improve driving behavior and reduce the overall number of truck at-fault crashes.

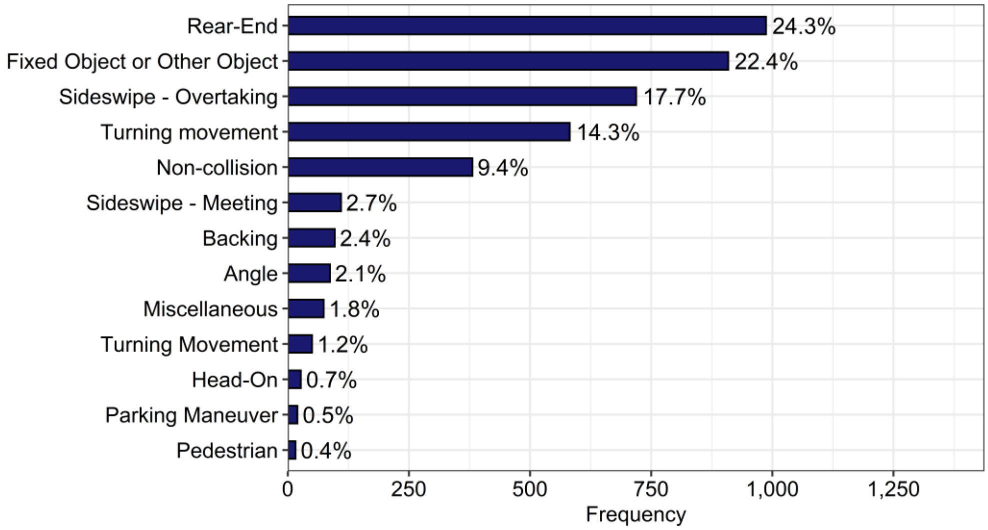

Figure 3.8: Truck at-fault crashes and crash type

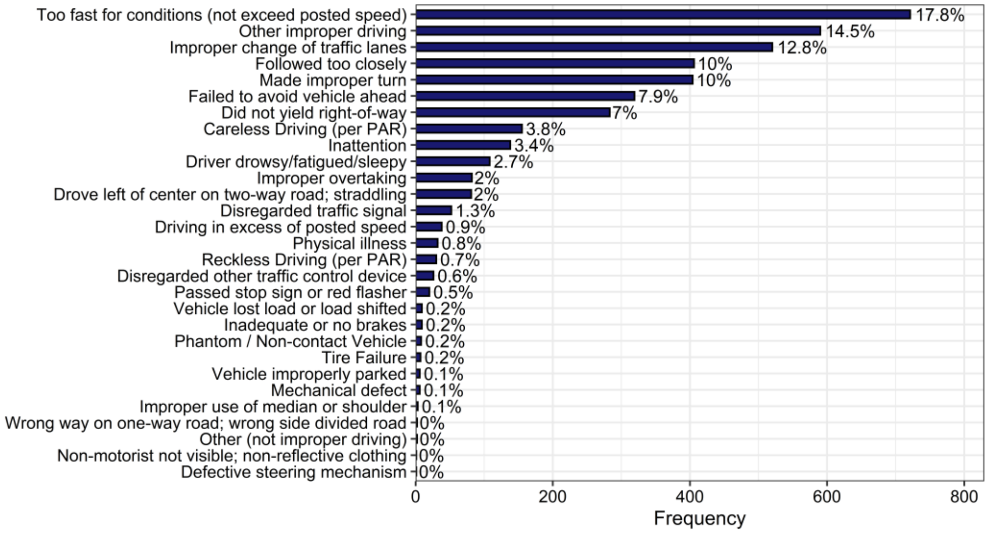

Figure 3.9: Frequency distribution of major crash causes for truck at-fault crashes

Figure 3.10 presents the distribution of the highest injury severity sustained from a crash based on the KABCO scale. The highest injury sustained refers to the highest injury severity recorded regardless of participant type. This scale was developed by the National Safety Council and is often used by law enforcement to classify crash and injury severity. Fewer than 2% of truck at-fault crashes resulted in a fatality and about 41% resulted in no injury.

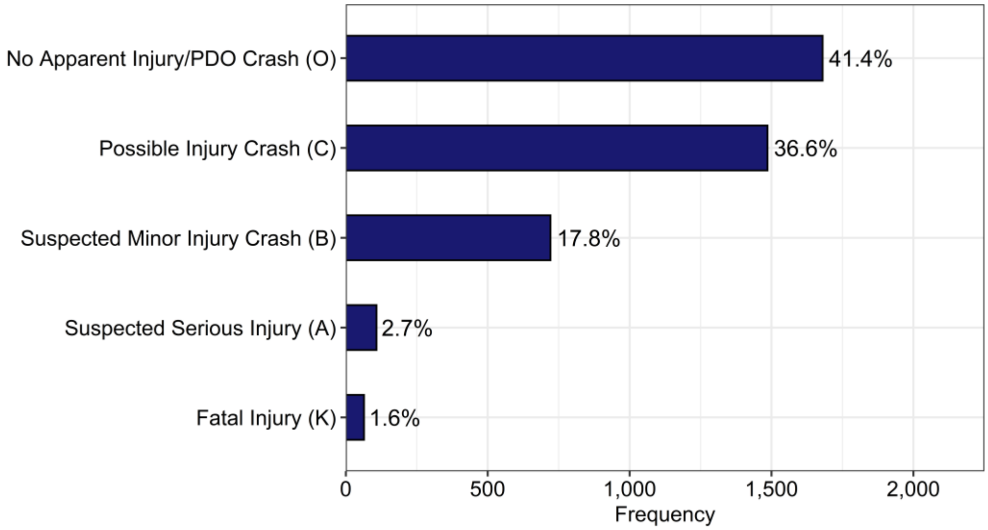

Figure 3.10: Truck at-fault crashes and highest injury sustained

3.2.2 Human Factors

According to the Highway Safety Manual, vehicle crashes are caused by various factors that can be categorized into groups, including human, roadway, vehicle, and environmental (American Association of State Highway and Transportation Officials 2010). For this study, characteristics for each of these categories are analyzed to effectively identify commonalities among truck at-fault crashes.

Figure 3.11 displays the distribution of drivers based on gender. The large difference among males and females is expected due to the trucking industry being predominately male. Slightly less than 10% of Oregon CDL holders were female in 2016 (Oregon Deparment of Motor Vehicles 2019). Figure 3.12 shows the distribution of drivers according to age. The majority of drivers involved in truck at-fault crashes are between 45 and 65 years old. This is also expected, as the median age of truck drivers in 2016 was 47.6 (U.S. Census Bureau n.d.). Figure 3.13 displays the distribution based on driver residency. Nearly 43% of drivers involved in truck at-fault crashes are from out-of-state, while about 48% are Oregon residents, of which 28% are within 25 miles from home and about 20% are 25 or more miles away from home.

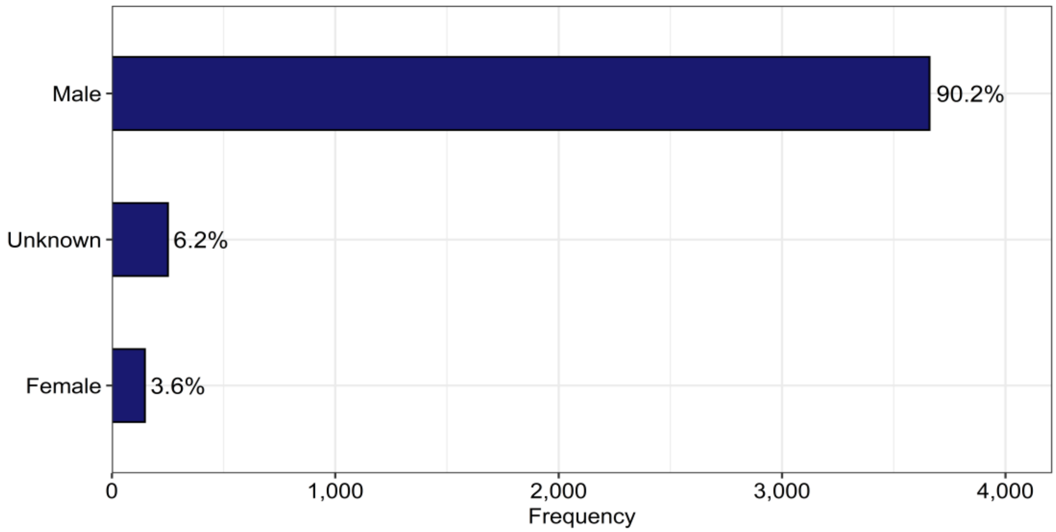

Figure 3.11: Truck at-fault crashes and driver gender

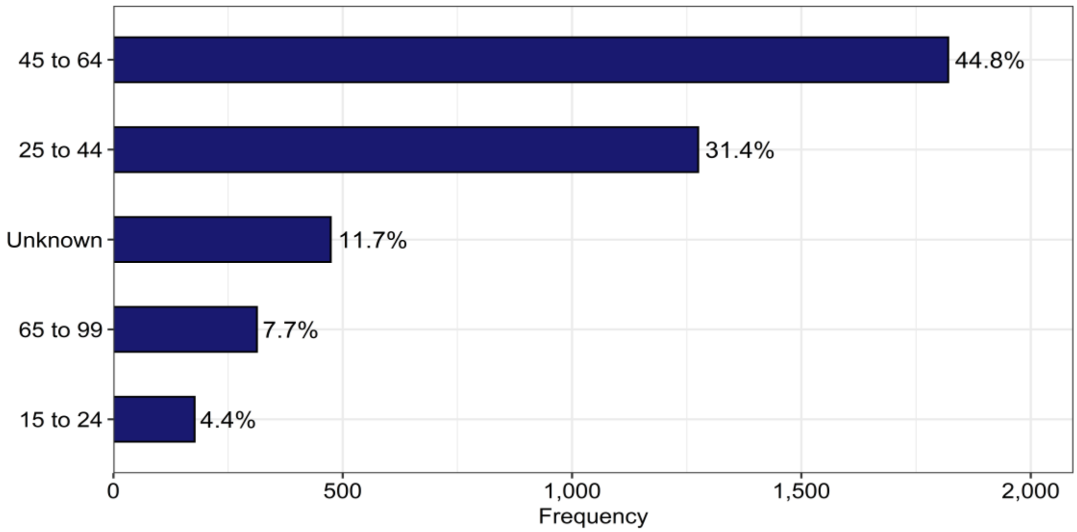

Figure 3.12: Truck at-fault crashes and driver age

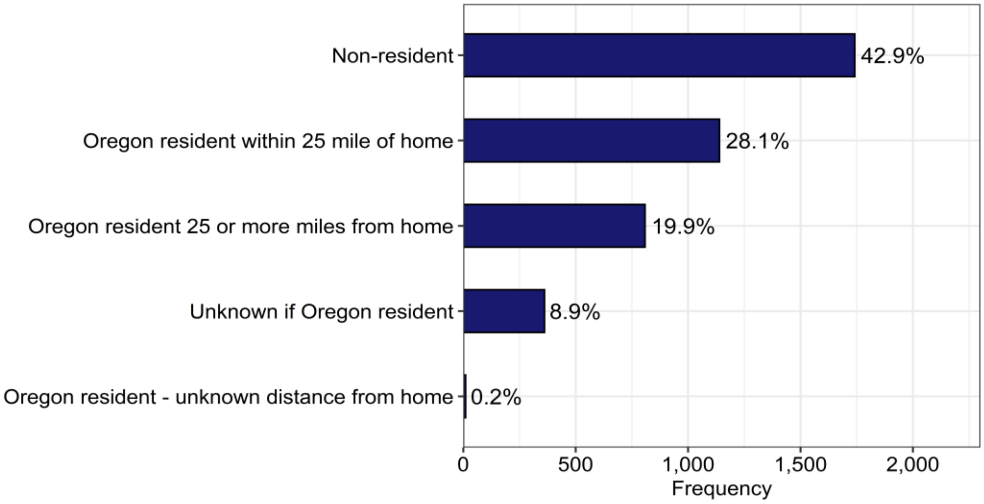

Figure 3.13: Truck at-fault crashes and driver residency

3.2.3 Roadway Characteristics

Another contributing factor to crashes are roadway characteristics. They are particularly important in depicting the risk associated with specific road conditions. Figure 3.14 illustrates the distribution of crashes according to roadway classification. This is influenced by the route preferences of heavy vehicle drivers, which typically drive most of their route on rural and urban interstates, or rural and urban arterials, which can often be state highways. They account for 35.5% and 33.5% of the crashes, respectively. In a similar manner, the distribution of roadway characteristics is also influenced by route preference (see Figure 3.15). If possible, drivers may be avoiding routes with a high number of horizontal curves or high grades. This helps explain why 42.4% of truck at-fault crashes occur on straight roadway segments.

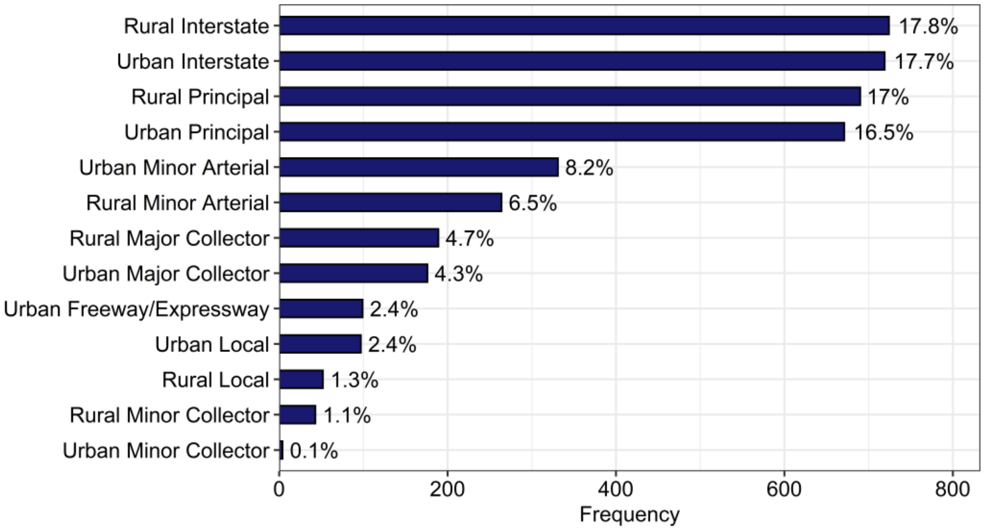

Figure 3.14: Truck at-fault crashes and roadway classification

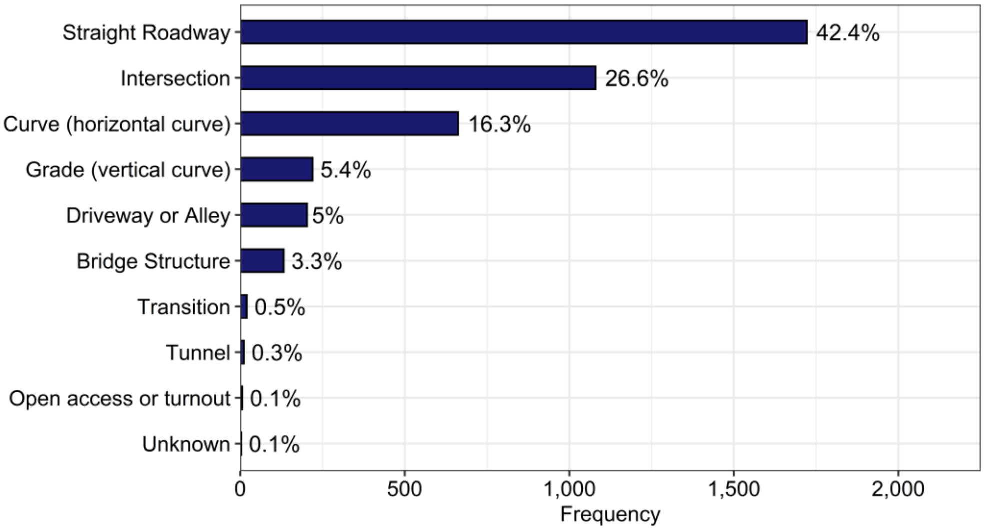

Figure 3.15: Truck at-fault crashes and roadway characteristic

3.2.4 Environmental Characteristics

Another key contributing factor to crashes are environmental characteristics. These include a variety of characteristics to describe the conditions in which crashes occur. Figure 3.16 reveals the distribution of road surface conditions. The most common condition was dry with about 67.3%, while wet, snow, or ice were present in 32.7% of crashes. This trend is supported by the frequency distribution of weather conditions shown Figure 3.17, where 61.8% of crashes occurred in clear conditions. The second most common condition was cloudy, accounting for about 15% of crashes. It is evident that the majority of truck at-fault crashes occur in dry, clear conditions, which are conditions that are often overrepresented in crash data.

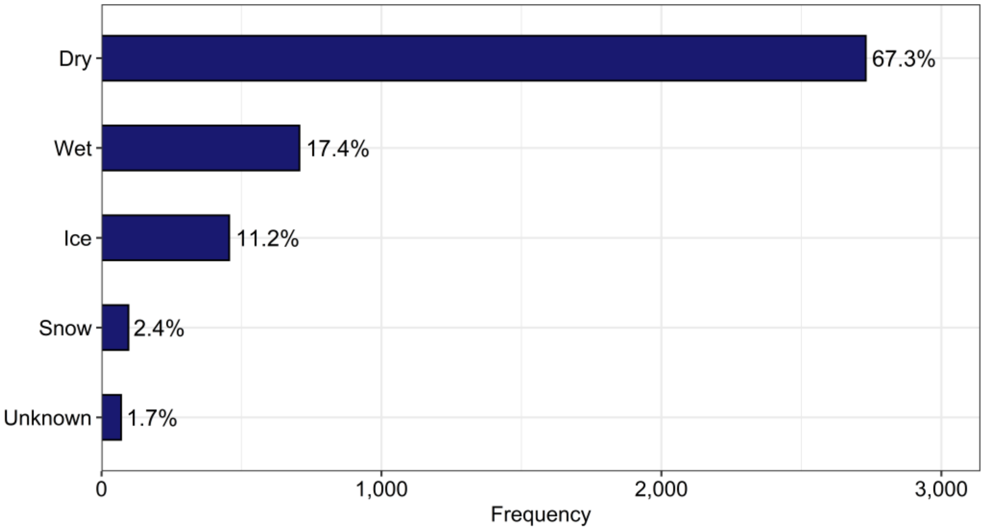

Figure 3.16: Truck at-fault crashes and road surface condition

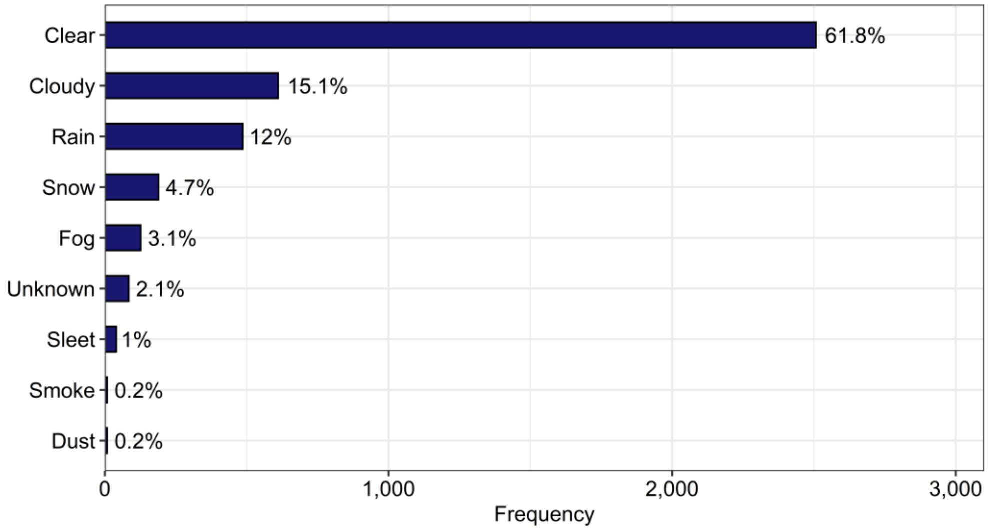

Figure 3.17: Truck at-fault crashes and weather condition

Lastly, light conditions were analyzed to depict the occurrences of truck at-fault crashes in the daylight versus the darkness (see Figure 3.18). Based on the distribution of crashes, the majority occur in daylight, approximately 69%, while 30.7% occur in fair or low light conditions.

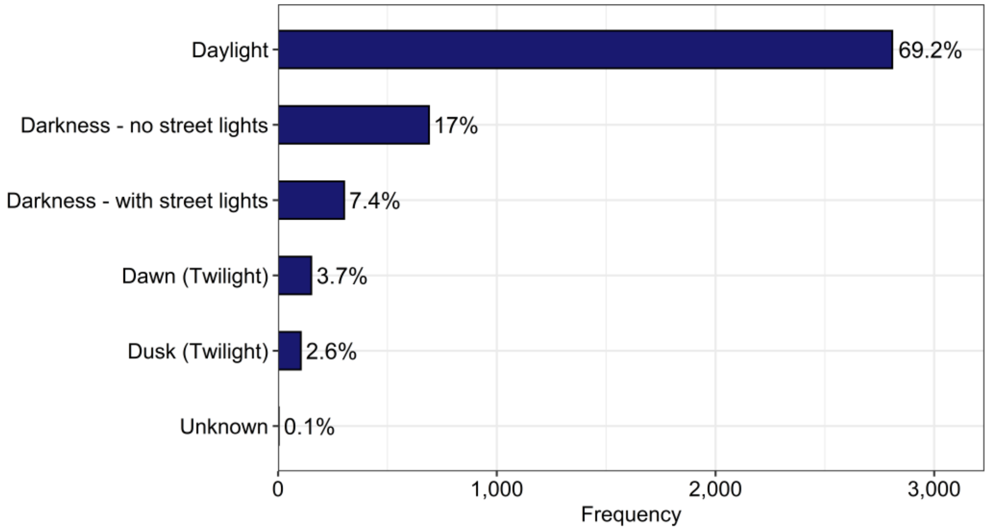

Figure 3.18: Truck at-fault crashes and lighting condition

3.2.5 Truck At-Fault Crashes and Highways

The final descriptive analysis is to visualize where these truck at-fault crashes are occurring. Although several maps were created based on driver-level crash cause, the trends followed that observed in Figure 3.19. Overall, the crashes are occurring on major freight routes in Oregon. Based on the geographical distribution, shoulder width, and potential participating law enforcement agencies, the high representation of crashes suggest there are highways that may serve as viable candidates for the program. To illustrate this, Figure 3.20 shows all highways in Oregon where at least 30 truck at-fault crashes were recorded from 2013 to 2018. Because of the change in crash coding in 2016, it is likely that these values are substantially higher (see Figure 3.5).

To understand each highway and assess conditions for the program, trends for each of the highways in Figure 3.20 are presented. Due to the work done previously on I-205 (Anderson et al. 2020), I-205 will not be a focus for the descriptive analysis.

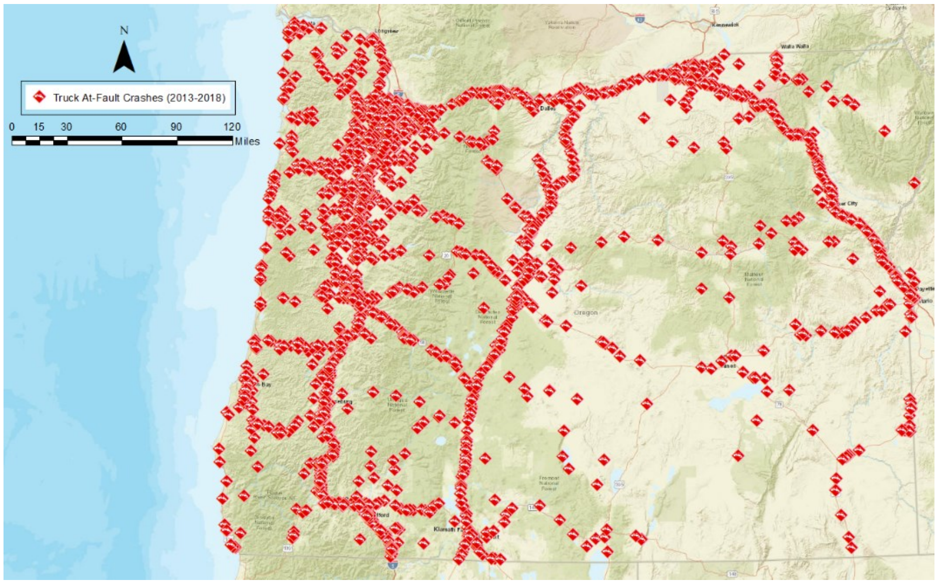

Figure 3.19: Geographical distribution of truck at-fault crashes in Oregon (2013 to 2018)

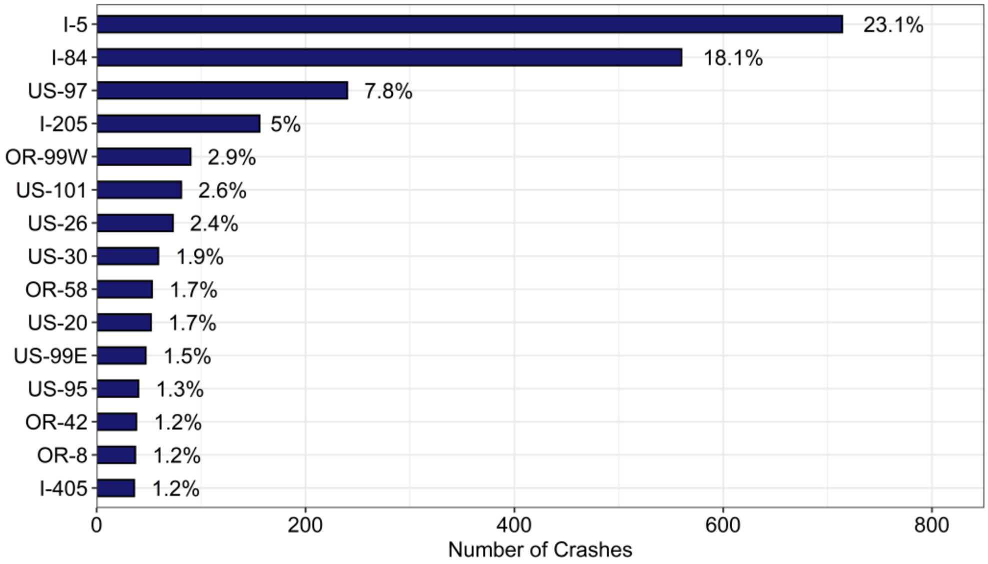

Figure 3.20: Truck at-fault crashes by highway

3.2.5.1 I-5

As shown in Figure 3.20, the most truck at-fault crashes occur on I-5. Figure 3.21 shows yearly trends for the entire interstate (Oregon-California border to the Oregon-Washington border). As stated previously, the steep decrease from 2015 to 2016 is likely a result of changes in the crash coding. Considering that, the trend is fairly consistent thereafter, with slight increases of injury at-fault crashes since 2016. Based on these trends, additional data will be gathered. Additionally, being that the program currently covers northern segments of I-5, trends for crashes that happened south of Albany are also shown in Figure 3.21. These trends are quite similar to those observed for the entire interstate, suggesting that the southern segments of I-5 be considered moving forward.

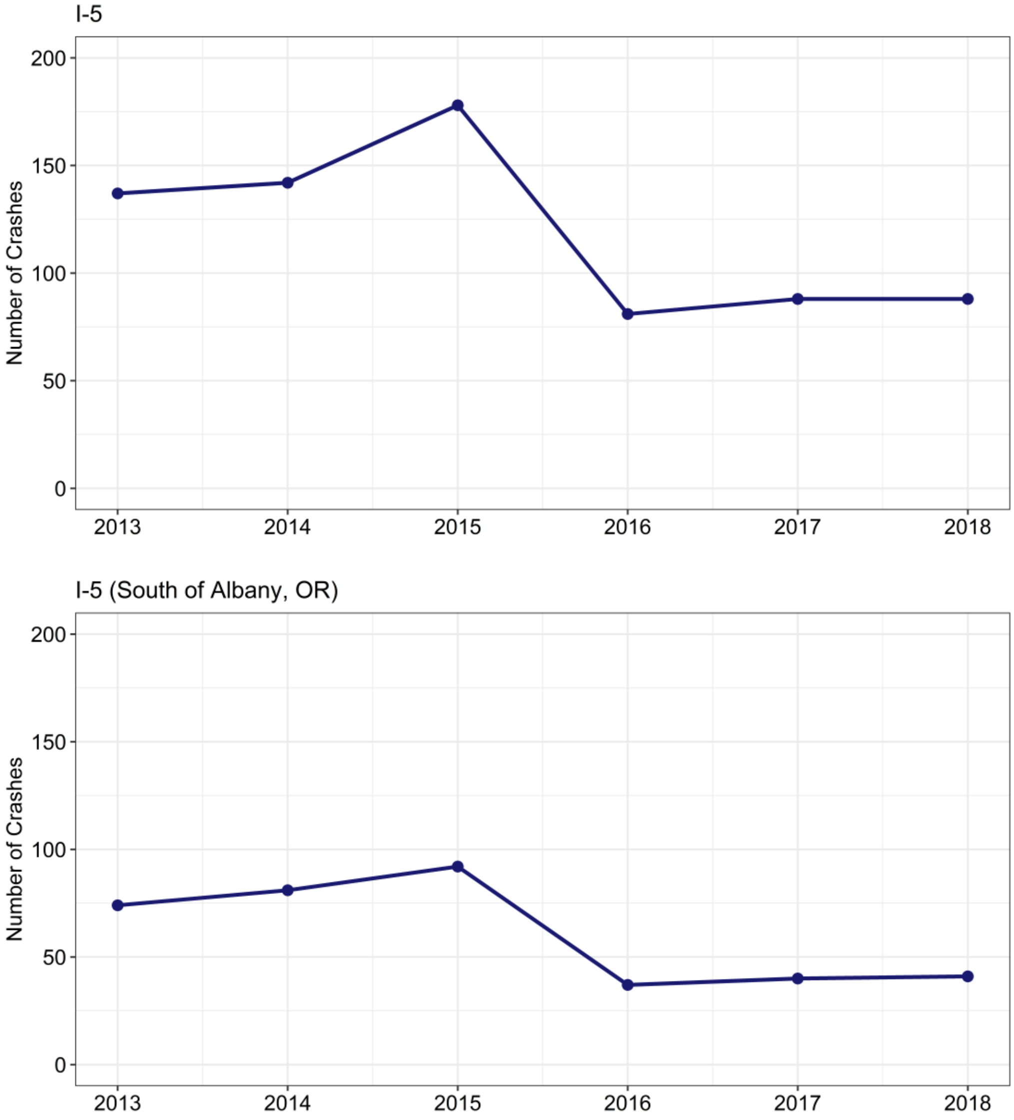

Figure 3.21: Yearly truck at-fault crash trends on I-5

3.2.5.2 I-84

I-84 accounts for the second highest proportion of truck at-fault crashes in which a highway number is given. Yearly trends for I-84 (the entire route in Oregon) are shown in Figure 3.22. Once more, a steep decrease is observed from 2015 to 2016, where increases are observed thereafter. Like I-5, specific segments of I-84 are currently part of the program; specifically, segments west of Cascade Locks. Therefore, to assess trends in Eastern Oregon, also see Figure 3.22. Noticeably, the trends are essentially identical. This finding is anticipated, as approximately 84% of crashes happened east of Cascade Locks where the program is not currently being implemented. Based on these statistics, and that the number of crashes in recent years is higher than shown, eastern I-84 will be considered moving forward.

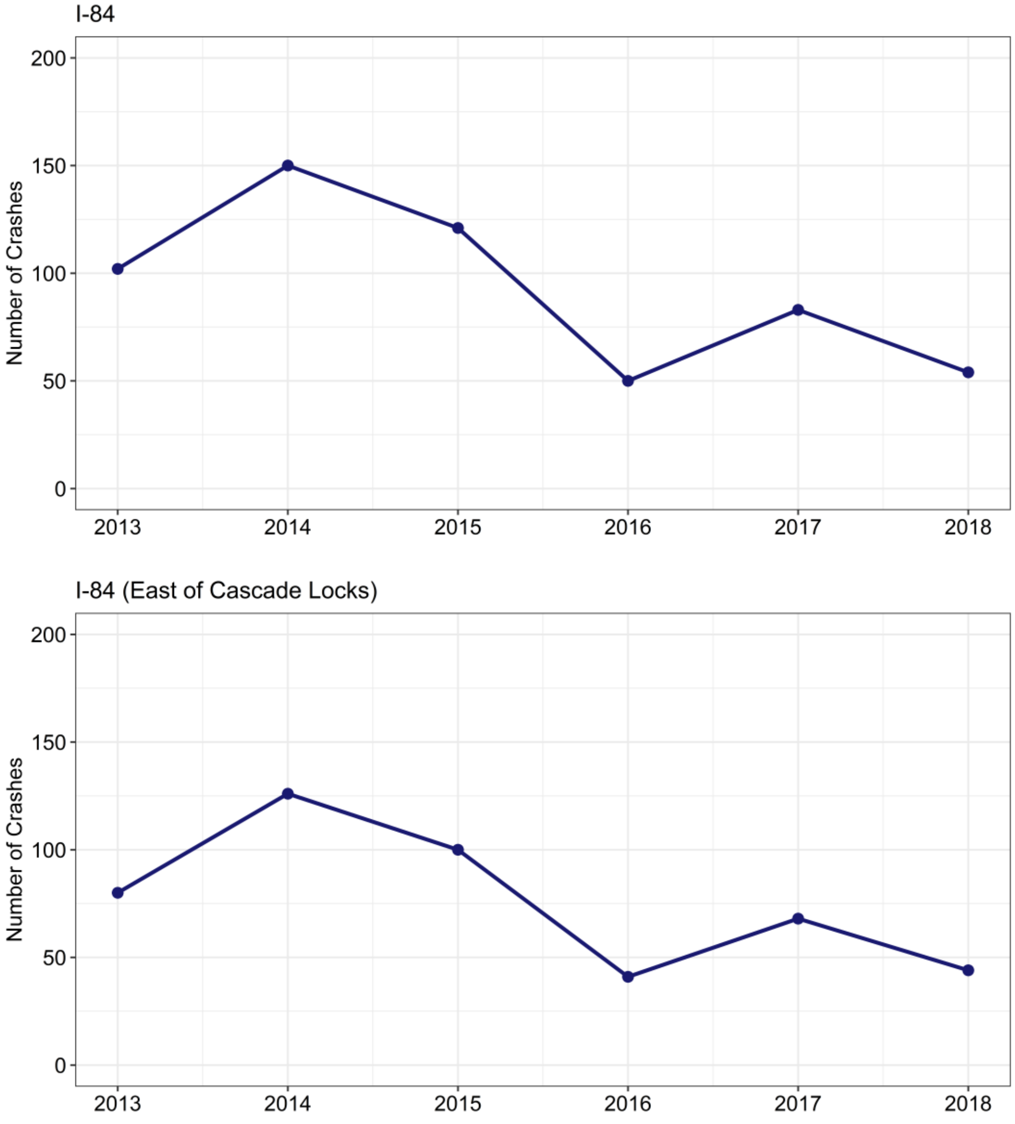

Figure 3.22: Yearly truck at-fault crash trends on I-84

3.2.5.3 U.S. Routes

Although some of the U.S. routes shown in Figure 3.23 (note that axes are not on the same scale, as to clearly specify trends on routes with lower number of crashes) are represented in the inspection data, it is marginal relative to the representation of the interstates. As the true number of trucks at-fault crashes is unknown, as previously stated, from 2016 to 2018, each of the routes in Figure 3.23 could be viable candidates. However, based on the sheer number of crashes shown, and trends in recent years, US-97, US-30, US-101, and US-20 appear to warrant additional investigation with information on no injury truck at-fault crashes. Consideration also needs to be paid to the geographical characteristics of each route. For example, US-101 may warrant the program to be implemented, but a large portion of the highway may not have the roadway geometry to accommodate such a program. This will be considered in the succeeding analyses.

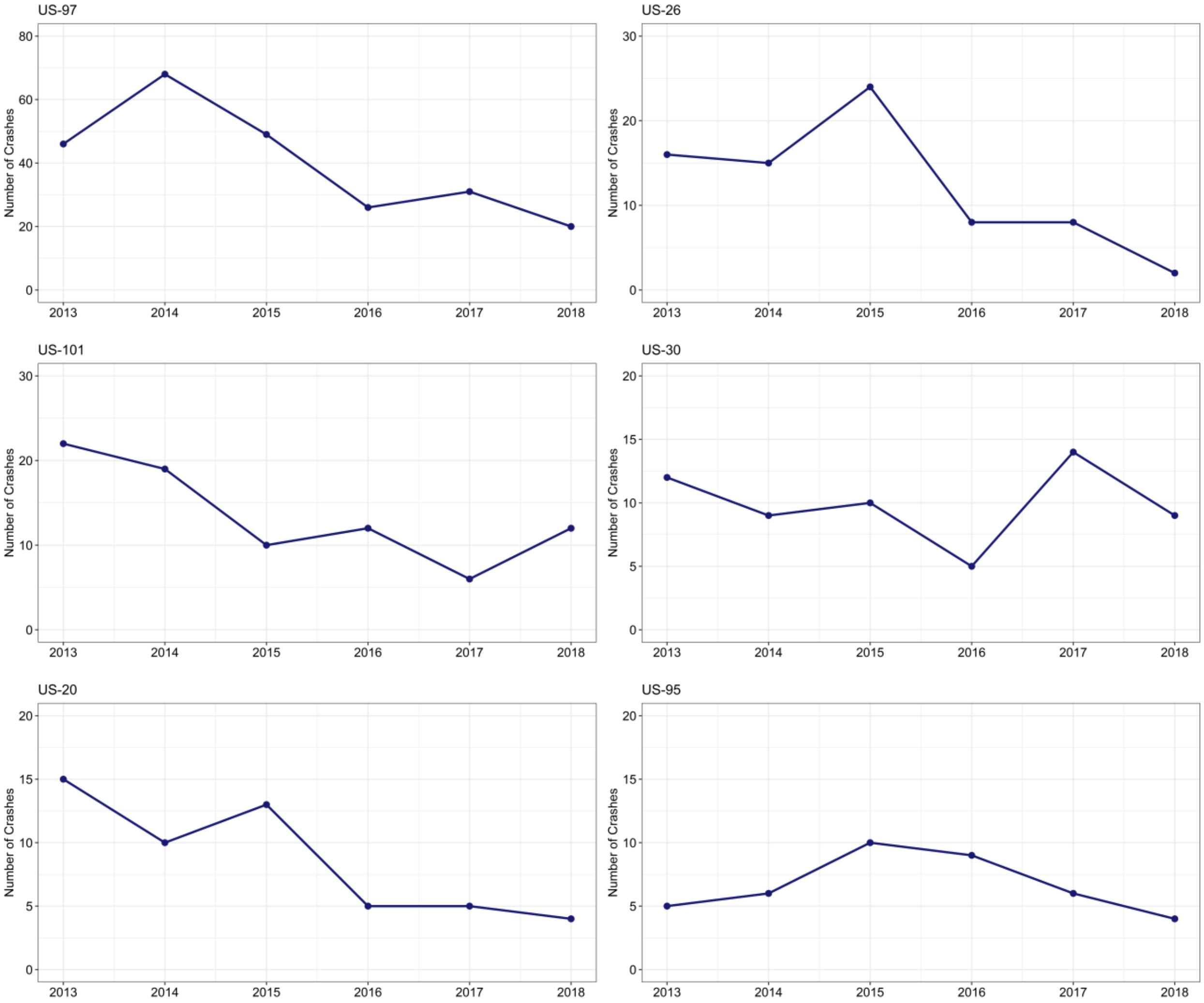

Figure 3.23: Yearly truck at-fault crash trends on U.S. routes in Oregon

3.2.5.4 Oregon State Routes

As with the U.S. routes shown, some of the Oregon State routes are also represented in the inspection data; however, it is again marginal relative to the representation of the interstates. Figure 3.24 shows the yearly crash trends on Oregon State routes that are overrepresented in the crash data. Once more, as the true number of trucks at-fault crashes is unknown from 2016 to 2018, each of the routes in Figure 3.24 could be viable candidates for the program. However, based on the sheer number of crashes shown, and trends in recent years, OR-99W, OR-99E, OR-42, and OR-8 appear to warrant additional investigation with information on no injury truck at-fault crashes. Note that the scales on the axes are different to improve readability of trends.

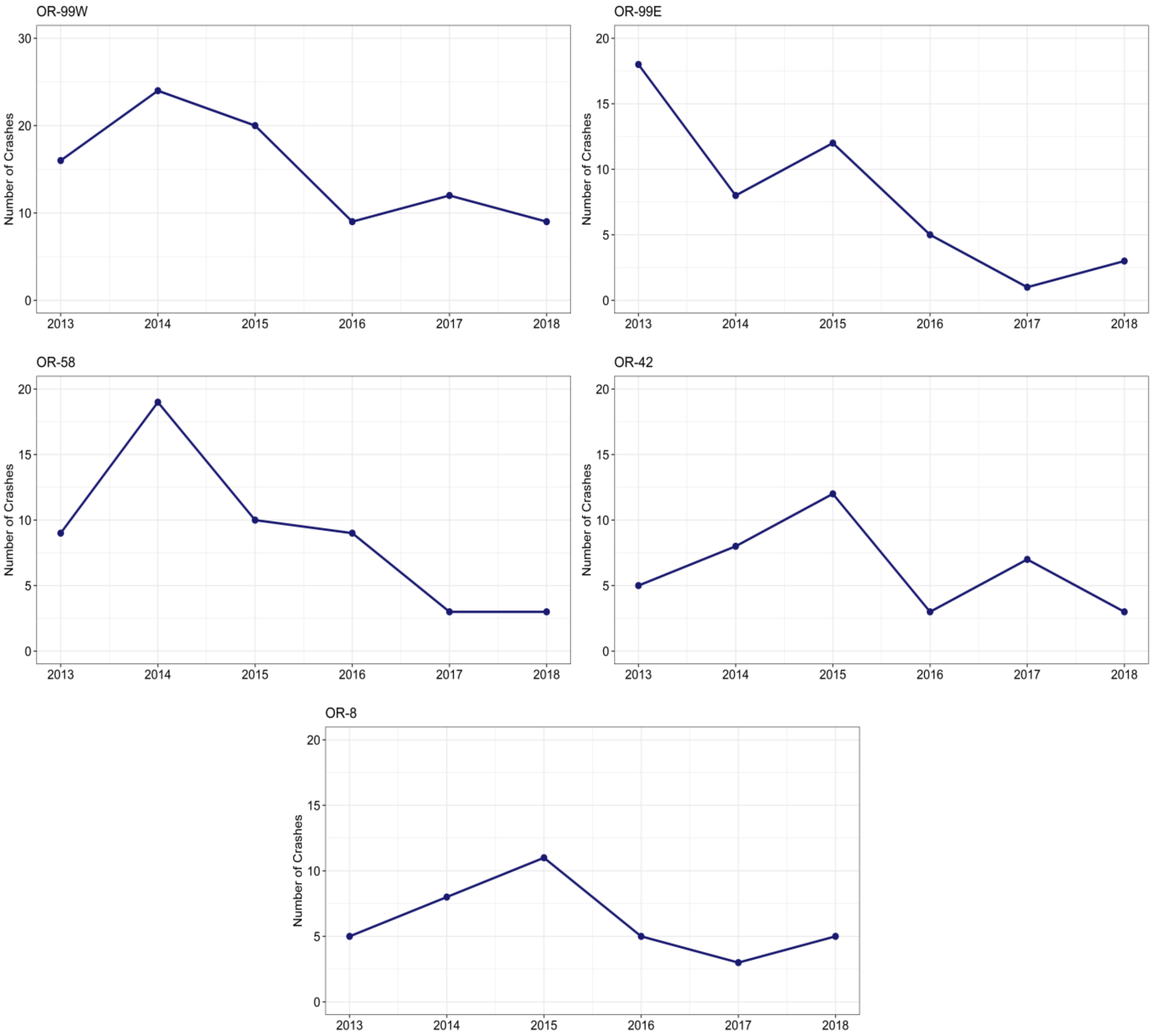

Figure 3.24: Yearly truck at-fault crash trends on Oregon state routes

3.3 CRASH COST DATA

As part of the site ranking method, specific costs must be known to conduct a benefit/cost analysis. Unfortunately, there is currently a lack of disaggregate data related to crash costs for trucks; therefore, research statistics are used where applicable.

Zaloshnja and Miller (2007) have the most current statistics on the average costs of medium/heavy truck crashes by varying levels of severity. The estimates are based on the injury severity profile from the 2001-03 period. The estimates include values related to medical costs, emergency services costs, property damage costs, costs due to lost productivity, value of pain and suffering, and the value of the quality of life that a family loses due to death or injury.

The estimates are presented in 2005 dollars, so they were converted to 2019 dollars using the consumer price index (CPI) inflation conversion factors (Bureau of Labor Statistics 2020):

$$\boldsymbol{C_{2019_s} = \frac{C_s}{CF}} \tag{3-1}$$

where:

C_{2019_s} is the average cost per crash for severity s in 2019 dollars,

C_s is the average cost per crash for severity s in 2005 dollars, and

CF is a conversion factor used to convert 2005 dollars to 2019 dollars.

Table 3.1 summarizes average truck-involved crash costs by severity.

Table 3.1: Summary of Truck-Involved Crash Costs

Crash Severity	Average Cost in 2005	Average Cost in 2019	Percent Change
No Injury	$15,114	$20,367	+34.75%
Non-Fatal Injury	$195,258	$263.116	
Fatal	$3,604,518	$4,857,197	

3.3.1 Travel Delay Costs

Each year, the American Transportation Research Institute (ATRI) publishes a report of the costs of motor carrier operations. The data is collected through surveys sent electronically to a representative group of for-hire carriers, which include truckload (TL), less than-truckload (LTL), and specialized fleets. The survey responses are weighted based on the industry-standard shares of the major for-hire trucking sectors. At the time of this document, the most recent version was published in November 2020 (Williams and Murray 2020). Based on their analysis, the average cost of operating a heavy truck, per mile, in 2019 was approximately $1.65, while the cost to operate for one hour was approximately $65.11. Table 3.2 and Table 3.3 show a breakdown of the variables considered when developing these costs and provide the change across several years. Travel delay costs to be used in the current study can be computed by using these rates and monetizing the time delayed based on average delays due to truck-involved crashes.

Torrey (2017) used the ATRI annual publication to estimate the average cost truck drivers experienced due to congestion in 2014. The result was approximately $4,546, but it varies depending on the number of miles a particular truck traveled in a particular area. The delay costs were aggregated by hours, months, state, county, and metropolitan area. Figure 3.25 shows an example of findings by displaying the cost of congestion per mile based on geographical area.

Table 3.2: Average Marginal Operating Costs per Mile (2011 to 2019)

Motor Carrier Costs	2011	2012	2013	2014	2015	2016	2017	2018	2019
Vehicle-Based									
Fuel Costs	$0.590	$0.641	$0.645	$0.583	$0.403	$0.336	$0.368	$0.433	$0.396
Truck/Trailer Lease or Purchase Payments	$0.189	$0.174	$0.163	$0.215	$0.230	$0.255	$0.264	$0.265	$0.259
Repair and Maintenance	$0.152	$0.138	$0.148	$0.158	$0.156	$0.166	$0.167	$0.171	$0.143
Truck Insurance Premiums	$0.067	$0.063	$0.064	$0.071	$0.074	$0.075	$0.075	$0.084	$0.068
Permits and Licenses	$0.038	$0.022	$0.026	$0.019	$0.019	$0.022	$0.023	$0.024	$0.023
Tires	$0.042	$0.044	$0.041	$0.044	$0.043	$0.035	$0.038	$0.038	$0.036
Tolls	$0.017	$0.019	$0.019	$0.023	$0.020	$0.024	$0.027	$0.030	$0.034
Driver-Based									
Driver Wages	$0.460	$0.417	$0.440	$0.462	$0.499	$0.523	$0.557	$0.596	$0.533
Driver Benefits	$0.151	$0.116	$0.129	$0.129	$0.131	$0.155	$0.172	$0.180	$0.160
Total	**$1.706**	**$1.634**	**$1.675**	**$1.704**	**$1.575**	**$1.591**	**$1.691**	**$1.821**	**$1.652**

Source: (Williams and Murray 2020)

Table 3.3: Average Marginal Operating Costs per Hour (2011 to 2019)

Motor Carrier Costs	2011	2012	2013	2014	2015	2016	2017	2018	2019
Vehicle-Based									
Fuel Costs	$23.58	$25.63	$25.78	$23.29	$16.13	$13.45	$14.50	$17.07	$15.62
Truck/Trailer Lease or Purchase Payments	$7.55	$6.94	$6.52	$8.59	$9.20	$10.20	$10.39	$10.45	$10.21
Repair and Maintenance	$6.07	$5.52	$5.92	$6.31	$6.23	$6.65	$6.58	$6.72	$5.62
Truck Insurance Premiums	$2.67	$2.51	$2.57	$2.89	$2.98	$3.00	$2.95	$3.32	$2.68
Permits and Licenses	$1.53	$0.88	$1.04	$0.76	$0.78	$0.88	$0.92	$0.95	$0.90
Tires	$1.67	$1.76	$1.65	$1.76	$1.72	$1.41	$1.50	$1.50	$1.42
Tolls	$0.69	$0.74	$0.77	$0.90	$0.79	$0.97	$1.05	$1.17	$1.34
Driver-Based									
Driver Wages	$18.39	$16.67	$17.60	$18.46	$19.95	$20.91	$21.97	$23.50	$21.01
Driver Benefits	$6.05	$4.64	$5.16	$5.15	$5.22	$6.18	$6.78	$7.10	$6.31
Total	**$68.20**	**$65.29**	**$67.01**	**$68.11**	**$63.00**	**$63.65**	**$66.64**	**$71.78**	**$65.11**

Source: (Williams and Murray 2020)

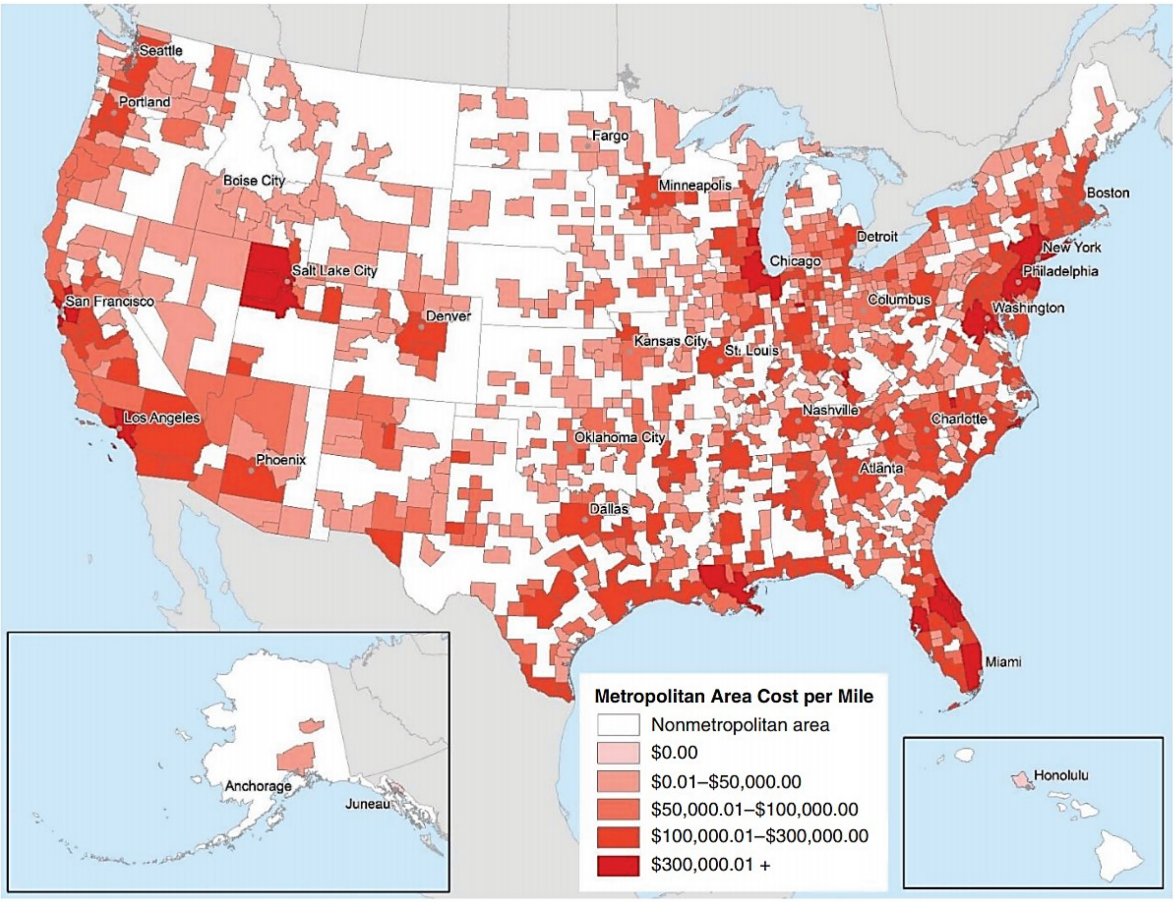

Figure 3.25: Metropolitan area cost of congestion per mile (Source: Torrey (2017))

3.4 OREGON SPATIAL DATA

As discussed in Chapter 3.1, it is clear that the large majority of traffic stops are occurring on highway segments that have ample space to conduct a traffic stop. Specifically, considering truck size, segments with shoulder space that can accommodate a parking truck and police officer. On this premise, spatial data related to shoulder width will be a vital component in evaluating if a highway segment is a viable candidate for the program.

Information on shoulder width is available across Oregon, as shown in Figure 3.26. Included in the data are the widths of both the left- and right-hand side of the roadways, both paved width and gravel width. Also included are highway identifiers through the use of a highway identification number. All shoulder widths are recorded in feet. A few large widths were observed, and after discussing with ODOT personnel, it was determined that these locations correspond to areas where there are side-of-the-road parking locations. An example of such a location represented in the shoulder width data is shown in Figure 3.27.

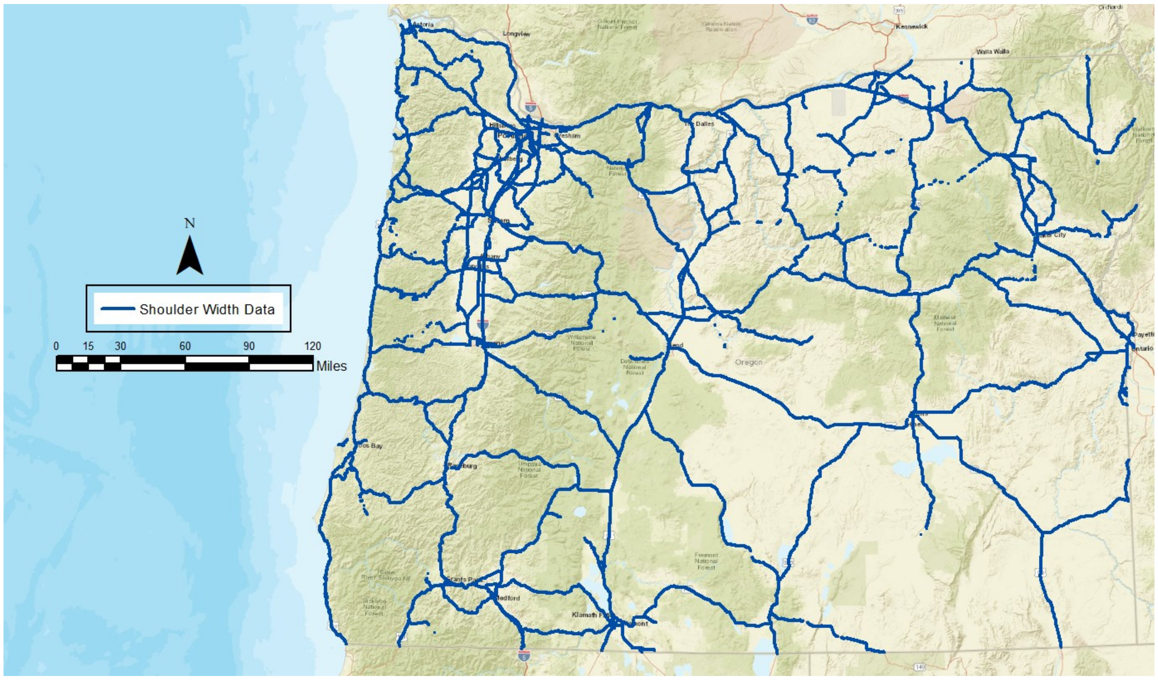

Figure 3.26: Highways with available shoulder width data

Figure 3.27: Example of location with large shoulder width due to side-of-the-road parking

Distributions of both the left- and right-hand shoulder widths are shown in Figure 3.28, while summary statistics are shown in Table 3.4. In general, the distributions are similar, but statistics do show there is variation within shoulder widths on the same side of the roadway. Although traffic stops occur on the right-hand side of the roadway, there are occasions in which vehicles are stopped on the left-hand side; therefore, left-hand side statistics are shown for completeness.

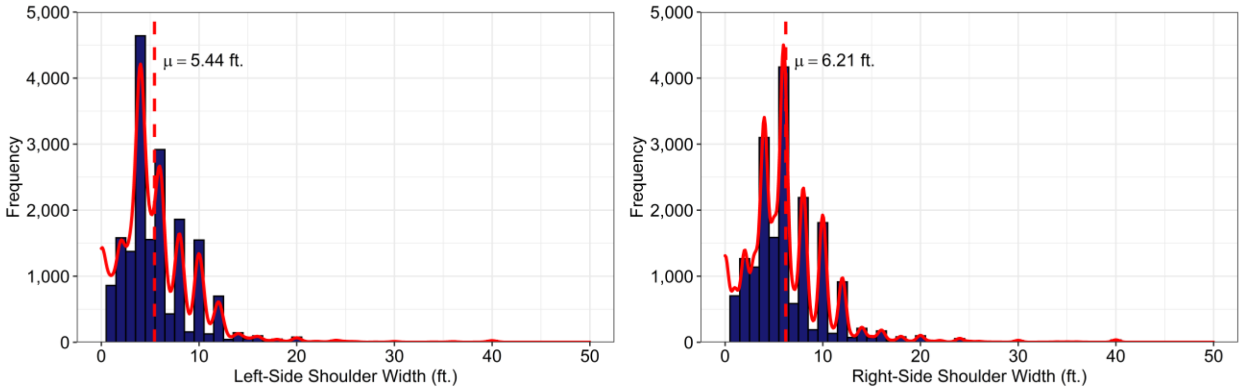

Figure 3.28: Shoulder width distribution on left- and right-hand side of roadway

Table 3.4: Statewide Shoulder Width Summary Statistics

	Left-Hand Side (ft.)	Right-Hand Side (ft.)
Mean	5.44	6.21
Standard Deviation	4.06	4.42
Median	4	6
Minimum	0	0
Maximum	62	75

Statistics for highways presented in Chapter 3.1 that experienced larger numbers of traffic stops are also presented. The first of these is I-205, which accounted for more than two-thirds of the total traffic stops. For this summary, only statistics on the right-hand side are shown and are shown for both directions of travel. As shown in Figure 3.29, the mean shoulder width on I-205 (in both directions) is noticeably greater than the statewide average. Also of note, direction plays a role in the mean shoulder width.

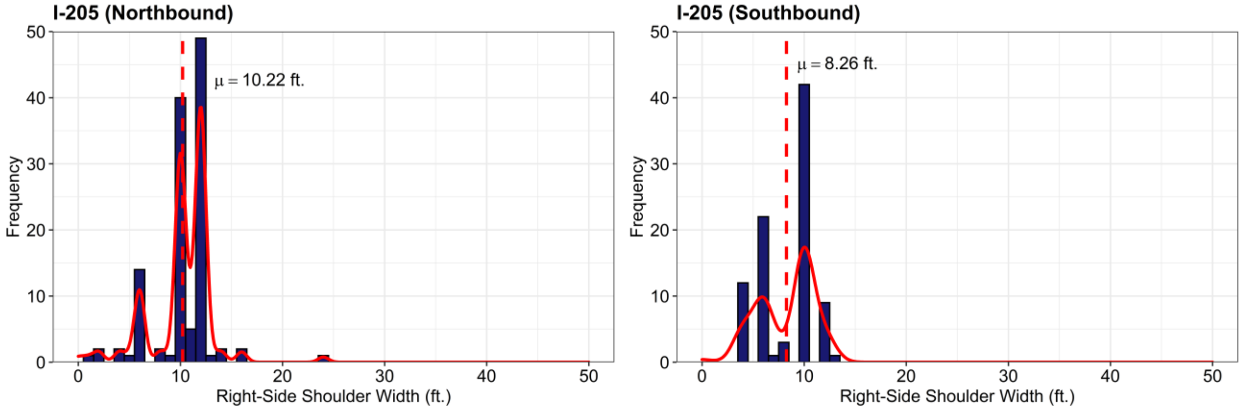

Figure 3.29: Shoulder width distribution on I-205

Two additional highways account for, relatively, large percentages of traffic stops compared to the remaining highways: I-5 and I-84. For I-5, shoulder width distribution is shown in Figure 3.30. Similar to I-205, these widths are noticeably greater than the statewide average. However, these widths do include segments in Southern Oregon that likely have larger widths than segments near the Portland Metropolitan area. It is possible that these Southern Oregon locations increase the overall average, while looking at the Northern Oregon locations (e.g., Tualatin-Sherwood Rd. and north), these averages may decrease. Also of note is the approximate 3 ft. difference in means between the north- and southbound directions.

The third highway is I-84, where shoulder width distributions are shown in Figure 3.31. On I-84, direction plays a vital role in the available land for shoulder use, as observed in the vast difference in mean shoulder width. A plausible explanation for this difference may be linked to the Columbia River being present on the right-hand side in the westbound direction, thereby limiting shoulder width.

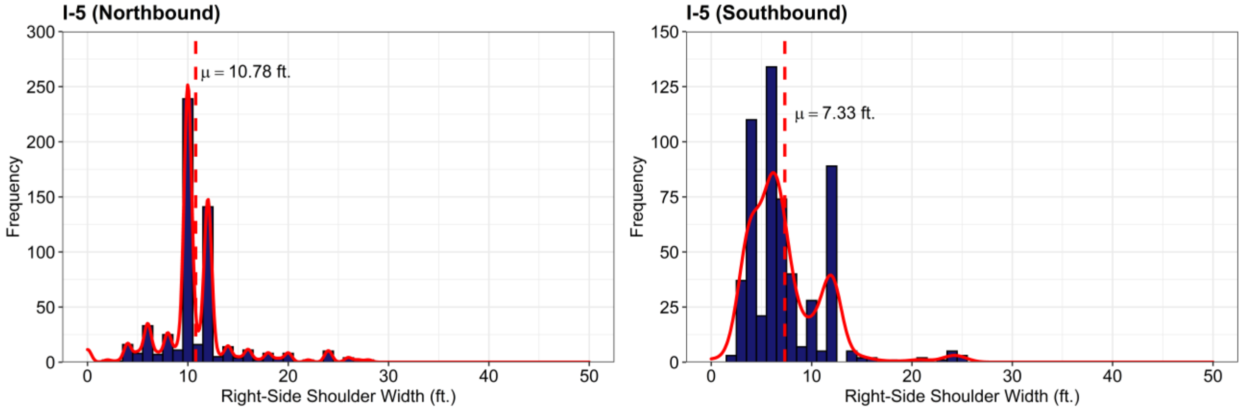

Figure 3.30: Shoulder width distribution on I-5

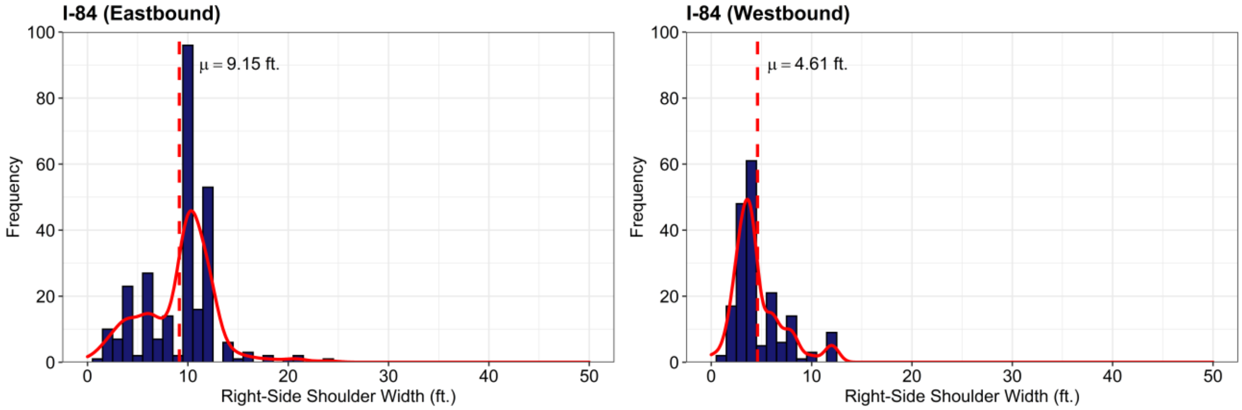

Figure 3.31: Shoulder width distribution on I-84

3.5 DATA SUMMARY

Regarding data obtained from the Oregon MCSAP program, participating law enforcement agencies (primarily in the Portland Metropolitan area) conduct traffic stops when observing unsafe driving behavior. Since the start of the program, there has been 6,436 traffic stops, where speeding and lane restriction violations are the primary causes. No other traffic violations account for more than 4% of the total traffic stops. In addition, these traffic stops are occurring, in majority, on three highways: I-205 (69%), I-5 (9%), and I-84 (7%). Over the duration of the program, a set of time-series plots show that consistency in traffic stops improves each year (i.e., reduced fluctuation in number of traffic stops from month-to-month). Importantly, data for 2020 is not included in the presented descriptive analysis due to irregular general traffic behavior and freight-related behavior as a result of the COVID-19 pandemic, and the priority of law enforcement in the Portland Metropolitan area due to sustained protests in Portland.

Oregon crash data from 2013 to 2018 was analyzed to identify key trends related to truck at-fault crashes. The key determination is related to identification of truck at-fault crashes, where all no injury crashes 2016-forward are coded as 'NA.' This results in observing large decreases in crash counts after 2015. In regard to the trends under this consideration, nearly one-third of crashes occurred in the mid-fall and winter months of October, December, and January, while the majority of crashes occurred on a weekday. The most occurring crash type is rear-end, which may be linked to the unsafe driving behaviors observed; particularly, speeding and following too close. This coincides with speed too fast for conditions accounting for the highest percentage of reported driver-level crash causes, followed by improper lane changing and following too closely. Roughly 90% of drivers were male and about 45% of drivers were 45 to 64 years old. In regard to residency, approximately 43% of drivers were non-residents. As anticipated, the majority of crashes happened on interstates and principal arterials, where most crashes occurred on straight roadway segments, horizontal curves, or an intersection. Lastly, in assessing the geographical distribution, the crash clusters are observed on major Oregon freight routes, some of which have been the focus of the program to-date. Based on this geographical distribution and an analysis of crashes by highways that were overrepresented, there are a number of highways that appear to be candidates for the site scoring model.

As for crash costs to be used in the site scoring model, crash harm metrics are used and converted to 2019 dollars using the consumer price index. This results in a change from 2005 dollars of about 35%. To account for travel delay costs, operating costs of a heavy truck were determined to be $1.65 per hour and $65.11 per mile in 2019.

Lastly, a key spatial dataset was summarized: shoulder width. As has been learned through the MCSAP project thus far, ample space to pull a truck over is necessary. Statistics show that the highways with a large number of traffic stops have considerably larger shoulder widths, on average, compared to the statewide average. These values can be used as benchmarks when developing the site scoring model and be used as a filter to eliminate potential candidates based on their capability of accommodating a parked truck.

4.0 SAFETY PERFORMANCE OF PROGRAM

To determine the safety performance of the program, a crash modification factor (CMF) was developed. The estimated CMF provides insight on the impact of the program on expected truck driver-at-fault crash frequency. The estimated CMF is used in the benefit/cost analysis detailed in Chapter 5.0

4.1 CRASH MODIFICATION FACTOR

To estimate a CMF, the Empirical Bayes approach was applied. The premise behind this approach is to estimate the number of crashes that would have occurred at some treatment site in the absence of said treatment. In the case of the current study, increased inspections. In this approach, the sum of the estimated expected crashes is compared to the actual number of crashes that were observed after the program took place. Being that the program began in September 2016, this work considers January 2017 to December 2019 as the after period (after treatment) and January 2013 to December 2015 as the before period (before treatment). This approach is considered as current practice for assessing treatments, as its primary advantage is the ability to account for effects related to regression to the mean (American Association of State Highway and Transportation Officials 2010; Gross, Persaud, and Lyon 2010; Monsere et al. 2016).

After collecting the necessary before and after data, and additional exposure-based characteristics (in this work, traffic volume, truck traffic volume, and shoulder width were used), a safety performance function (SPF) was developed. SPFs are developed based on econometric techniques for count data (e.g., crash frequency). There are two common count data models that are considered; albeit there are additional avenues depending on the structure of the data. For this work, due to data structure, the two common approaches were considered and developed. The models will be detailed here, as they are a key factor in Chapter 5.2.6.

The first of these is the Poisson model. In the Poisson model, the dependent variable, y_i, is taken from a Poisson distribution with parameter λ_i (often referred to as the Poisson parameter). Under this, the Poisson model is formulated as (Greene 2018):

$$\boldsymbol{P(y_i) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!}} \tag{4-1}$$

where:

$P(y_i)$ is the probability of average annual daily traffic (AADT) segment i having y_i crashes and

λ_i is the Poisson parameter for AADT segment i. The Poisson parameter, λ_i, is also equal to the expected number of crashes, $\mathrm{E}[y_i]$, on AADT segment i.

The presented formulation of the Poisson model is estimated by specifying the Poisson parameter as a function of explanatory variables (in this work, AADT, truck AADT, and shoulder width). This often takes the form of a log-linear model (Greene 2018):

$$\mathbf{ln}(\boldsymbol{\lambda_i}) = \boldsymbol{\beta X_i} \tag{4-2}$$

$$\boldsymbol{\lambda_i} = \boldsymbol{e^{\beta X_i}} \tag{4-3}$$

where:

$\boldsymbol{X_i}$ is a vector of explanatory variables (AADT, truck AADT, and shoulder width) and

$\boldsymbol{\beta}$ is a vector of parameters to be estimated.

Based on Eq. 4-3, the expected number of crashes on AADT segment i is represented as (Greene 2018):

$$\mathbf{E}[\boldsymbol{y_i} \mid \boldsymbol{X_i}] = \mathbf{Var}[\boldsymbol{y_i} \mid \boldsymbol{X_i}] = \boldsymbol{\lambda_i} = \boldsymbol{e^{\beta X_i}} \tag{4-4}$$

In essence, the Poisson model is a non-linear regression model; however, it is easier to estimate parameters using maximum likelihood and is the estimation approach used for SPF development in this work.

The Poisson model, albeit basic and easy to estimate, does have a major limitation: it cannot handle over- or under-dispersion. This is due to the Poisson model assuming that the expected mean and variance are equal: $\mathrm{E}[y_i] = \mathrm{Var}[y_i]$. If this assumption does not hold true, the data is considered under-dispersed ($\mathrm{E}[y_i] > \mathrm{Var}[y_i]$) or over-dispersed ($\mathrm{E}[y_i] < \mathrm{Var}[y_i]$). If dispersion is present and measures are not taken to account for it or correct it, parameter estimates will no longer be unbiased (i.e., true representations of the population parameters) and standard errors of the estimates will be incorrect (Wooldridge 2010).

To determine if this Poisson assumption holds, dispersion must be tested for. In most statistical software, a dispersion parameter is estimated to determine if the data is significantly over- or under-dispersed. However, it is possible to manually compute this dispersion parameter and generate visual assessments. This is particularly helpful if there are concerns of over- or under-dispersion, but the model is indicating there is no significance, or vice-versa. To manually compute a dispersion parameter, the following applies (Wooldridge 2015):

$$(\boldsymbol{n}-\boldsymbol{k}-\boldsymbol{1})^{-1}\sum_{\boldsymbol{i}=\boldsymbol{1}}^{\boldsymbol{n}}\frac{\hat{\boldsymbol{u}}_{\boldsymbol{i}}^{\boldsymbol{2}}}{\hat{\boldsymbol{y}}_{\boldsymbol{i}}}$$

(4-5)

where:

$\hat{y}_i$ is the exponential of the fitted value $\left(\hat{y}_i = e^{\hat{\beta}_0+\hat{\beta}_1 X_{i1}+\cdots+\hat{\beta}_k X_{ik}}\right)$,

$\hat{u}_i^2$ is the squared residual $(\hat{u}_i = y_i - \hat{y}_i)$, and

$(n-k-1)$ is the degrees of freedom given n observations and $k+1$ estimates.

If the result from Eq. 4-5 is equal to 1, the Poisson assumptions are met. If the result from Eq. 4-5 is greater than 1 or less than 1, there is over- or under-dispersion, and an alternate modeling approach is required. In developing the SPF in this work, as well as the model presented in Chapter 5.2.6, the alternate approach considered was a Negative Binomial model.

The functional form of the negative binomial model remains the same as the Poisson model presented in Eq. 4-5. What differs is the formulation of the Poisson parameter, λ_i (Greene 2018):

$$\mathbf{ln}(\boldsymbol{\lambda}_{\boldsymbol{i}}) = \boldsymbol{\beta X}_{\boldsymbol{i}} + \boldsymbol{\varepsilon}_{\boldsymbol{i}}$$

(4-6)

$$\boldsymbol{\lambda}_{\boldsymbol{i}} = \boldsymbol{e}^{\boldsymbol{\beta X}_{\boldsymbol{i}}+\boldsymbol{\varepsilon}_{\boldsymbol{i}}}$$

(4-7)

where:

$\boldsymbol{\varepsilon}_{\boldsymbol{i}}$ is a Gamma-distributed disturbance term with mean 1 and variance α.

The addition of $\boldsymbol{\varepsilon}_{\boldsymbol{i}}$ allows the variance to differ from the mean, thus overcoming the limitations of the Poisson assumptions (Greene 2018):

$$\mathbf{Var}[\boldsymbol{y}_{\boldsymbol{i}}] = \mathbf{E}[\boldsymbol{y}_{\boldsymbol{i}}]\big[\mathbf{1} + \boldsymbol{\alpha}\mathbf{E}[\boldsymbol{y}_{\boldsymbol{i}}]\big] = \mathbf{E}[\boldsymbol{y}_{\boldsymbol{i}}] + \boldsymbol{\alpha}\mathbf{E}[\boldsymbol{y}_{\boldsymbol{i}}]^{\mathbf{2}}$$

(4-8)

where:

α is referred to as the dispersion parameter. Model selection is dependent on this dispersion parameter and its significance.

Upon generating the appropriate SPF, the SPF is then used to estimate the number of crashes in the before period and the number of crashes in the after period. From these estimates, a CMF is computed. First, the expected number of crashes in the before period is determined:

$$\boldsymbol{N}_{\mathbf{Expected}_{\mathbf{T,B}}} = \boldsymbol{\gamma}\left(\boldsymbol{N}_{\mathbf{Predicted}_{\mathbf{T,B}}}\right) + (\mathbf{1} - \boldsymbol{\gamma})\boldsymbol{N}_{\mathbf{Observed}_{\mathbf{T,B}}} \tag{4-9}$$

where:

$N_{\text{Expected}_{\text{T,B}}}$ = expected average crashes in the before period (unadjusted Empirical Bayes estimate).

$N_{\text{Predicted}_{\text{T,B}}}$ = predicted number of crashes estimated by the SPF in the before period.

$N_{\text{Observed}_{\text{T,B}}}$ = observed number of crashes in the before period.

γ = weighted adjustment for SPF predictions based on the dispersion parameter.[3]

The weighted adjustment, as stated previously, is based on the dispersion parameter, and computed as:

$$\boldsymbol{\gamma} = \frac{\mathbf{1}}{(\mathbf{1} + \boldsymbol{\alpha})\sum \boldsymbol{N}_{\mathbf{Predicted}_{\mathbf{T,B}}}} \tag{4-10}$$

where:

α is the dispersion parameter for the SPF.

Next, the expected number of crashes after treatment are determined:

$$\boldsymbol{N}_{\mathbf{Expected}_{\mathbf{T,A}}} = \boldsymbol{N}_{\mathbf{Expected}_{\mathbf{T,B}}}\left(\frac{\boldsymbol{N}_{\mathbf{Predicted}_{\mathbf{T,A}}}}{\boldsymbol{N}_{\mathbf{Predicted}_{\mathbf{T,B}}}}\right) \tag{4-11}$$

where:

$N_{\text{Predicted}_{\text{T,A}}}$ is the predicted number of crashes by the SPF in the after period and all other terms have been defined previously.

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[3] The dispersion parameter has an inverse relationship with SPF weight; that is, if little dispersion is observed, more weight is place on the predicted crashes and less weight on the observed crashes (Monsere et al. 2016).

The final step is to determine the variance of $N_{\text{Expected}_{\text{T,A}}}$:

$$\mathbf{Var}\left[\boldsymbol{N}_{\mathbf{Expected}_{\mathbf{T,A}}}\right] = \boldsymbol{N}_{\mathbf{Expected}_{\mathbf{T,A}}}\left(\frac{\boldsymbol{N}_{\mathbf{Predicted}_{\mathbf{T,A}}}}{\boldsymbol{N}_{\mathbf{Predicted}_{\mathbf{T,B}}}}\right)(\mathbf{1} - \boldsymbol{\gamma})$$

(4-12)

4.2 RESULTS

It was determined that the data was not over- or under-dispersion; therefore, the SPF used for CMF development was based on a Poisson model. To ensure the Poisson model was appropriate, a dispersion parameter of 0.997 was computed. This value indicates no over- or under-dispersion. In addition, a dispersion test was conducted that resulted in a test statistic of -0.519 and associated p-value of 0.604. Based on this test, the null hypothesis that there is no dispersion cannot be rejected. Final SPF model specifications are shown in Table 4.1.

For SPF diagnostics, Figure 4.1 shows a cumulative residual (CURE) plot. To interpret the plot, if the line representing the cumulative residuals stays within the fitted bounds (red lines on the plot) and oscillates about zero, the SPF is said to have good fit over the range of the model (i.e., all crash values). In the case of the presented SPF, this holds true with the exception of the highest crash values, which leave some room for slight improvements. One potential avenue for addressing this is to include additional exposure-based variables in the SPF.

Table 4.1: Final Poisson Model Specifications for Estimating Truck Driver-at-Fault Crashes

Variable	Coefficient	Std. Error	t-statistic	p-value
Constant	-14.158	6.56	-2.16	0.031
Natural Logarithm of AADT	1.817	1.147	1.58	0.113
Natural Logarithm of Truck AADT	-0.711	1.106	-0.64	0.520
Shoulder Width (Right Side)	-0.010	0.029	-0.36	0.721
Model Summary				
Number of Observations	60			
Log-Likelihood at Convergence	-96.88			

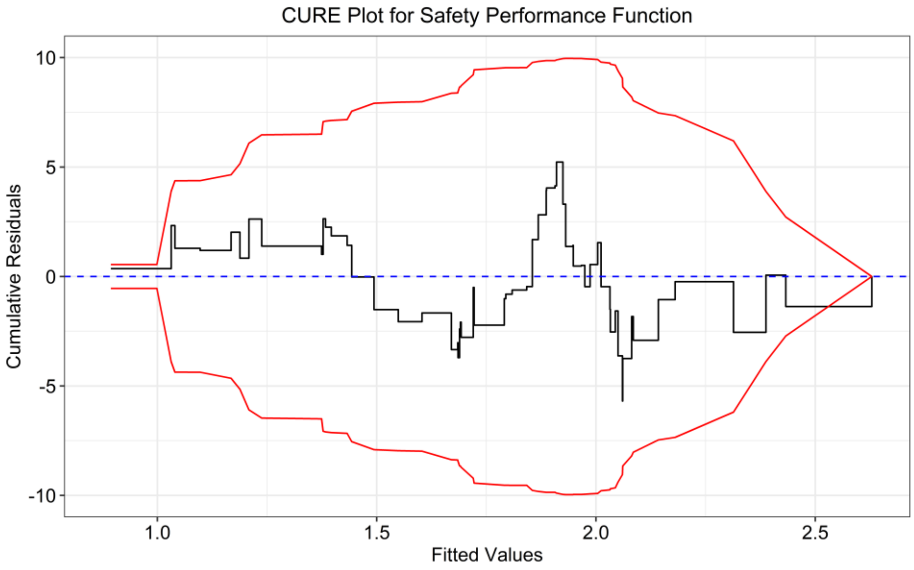

Figure 4.1: Cumulative residual (CURE) plot for truck driver-at-fault SPF model

Using the estimates in Figure 4.1, the truck driver-at-fault SPF can be expressed as follows:

$$\textbf{Expected Crashes} = e^{(-14.158+1.817(\mathrm{LNAADT})-0.711(\mathrm{LNTAADT})-0.010(\mathrm{SHLDWD}))} \tag{4-13}$$

where:

Expected Crashes is the predicted number of truck driver-at-fault crashes based on model estimates,

$LNAADT$ is the natural logarithm of AADT,

$LNTAADT$ is the natural logarithm of truck AADT, and

$SHLDWD$ is the right-side shoulder width in feet.

From this SPF, the Empirical Bayes summary is shown in Table 4.2.

Table 4.2: Empirical Bayes Summary for Truck Driver-at-Fault Crashes

Time Period	Observed Crashes	SPF Predicted Crashes
Before	104	103.995
After	63	125.118

The estimated parameters using the Empirical Bayes approach are shown in Table 4.3. The estimated CMF obtained through the Empirical Bayes before-after analysis is 0.50. The standard error of the estimated CMF is 0.08, with a 95% confidence interval of 0.34 to 0.65 (the confidence interval does not include the value 1). Being that the data was not found to be over- or under-dispersed, the SPF weight is equal to 1 and all emphasis is put on the predicted values.

Table 4.3: Parameter Estimates for Empirical Bayes Truck Driver-at-Fault Crash Analysis

Parameter	Estimate
$N_{\text{Expected,T,B}}$	104.00
$N_{\text{Expected,T,A}}$	125.12
$\text{Var}(N_{\text{Expected,T,A}})$	149.81
CMF	0.50
$\text{Var}(\text{CMF})$	0.01
$\text{SE}(\text{CMF})$	0.08
$95\%\ \text{C.I.}$	0.34, 0.65

The estimated CMF indicates that the treatment is expected to reduce the expected number of crashes by half. Although the descriptive analysis has shown that the program has had a positive impact on the observed number of crashes, it has not been by this amount. This CMF is likely over estimated due to limitations in the crash data; notably, the inability to discern driver-at-fault crashes for no injury crashes 2016-forward. As a result, the number of crashes in the after period are lower than the actual value, which biases the estimated CMF. Although Oregon's Commerce and Compliance Division (CCD) has data on these types of crashes, geospatial information needed to fuse the crash, traffic volume, and other exposure characteristics is currently not available. Based on the presently available data, this is the best estimate to be obtained and will be the estimate used to determine the potential benefit of the program in the coming chapters.

Moving forward, this illustrates the benefits of some of the crash codes that are no longer used. Additionally, as it relates specifically to truck crashes, CCD could be a substitute if additional crash-related variables are coded; namely, geospatial information in the form of geocoordinates and driver injury severity. If these types of changes are not feasible, a methodology to fuse CCD data and Oregon's statewide data with a high level of accuracy can be developed. This would allow the analyst to obtain the benefits of each database.

4.3 SAFETY PERFORMANCE SUMMARY

To determine the overall benefit of the program, a crash modification factor was estimated using the data from I-205. This site was chosen due to its success over the duration of the program and the amount of traffic violation/inspection data available at this location. Although the characteristics of this facility differ from some of the highway selected for analysis, it provides a general estimate of the effects on the expected number of crashes. Using an Empirical Bayes approach, a CMF of 0.50 was estimated, with a 95% confidence interval of 0.34, 0.65 (does not include the value 1.0). This indicates that implementation of the program is expected to decrease the number of truck driver-at-fault crashes by half. This estimated CMF is based on ODOT crash data, in which certain limitations are present. Specifically, for the after data (2017 to 2019), the analyst cannot discern at-fault for no injury crashes. As a result, in a study such as this, any no injury crash in which the truck driver was at-fault is not included. Unfortunately, this leads to the after period having fewer observed crashes and a CMF that is likely overestimating the effects of the program. With that in mind, the presented estimate is the best estimate to be obtained based on the current structure of ODOT crash data. It should also be noted that the CMF was estimated on an interstate, which does differ from some of the facilities considered for analysis.

Moving forward, it is recommended to revisit how certain crash characteristics are coded. Additionally, developing a methodology that can fuse various Oregon crash databases with a high level of accuracy is another viable route, where the analyst can gain the benefits of all sources, each of which contain some information that the other does not. In the case of the current study, this would be to fuse Oregon crash data with crash data from ODOT’s Commerce and Compliance Division. In regard to CMF estimation, if data permits, developing several facility-type-specific CMFs is recommended.

5.0 BENEFIT/COST SITE RANKING

This chapter looks at potential corridors where the program could be implemented and the estimated benefit of the program. This analysis was completed using data provided by CCD, as this data was consistent across all years of crash data (2013 to 2019) in that all no injury crash types were included in the crash counts.

To assess the benefits, this work uses a benefit/cost ratio. Costs include crash-related costs, while benefits stem from potential savings based on the CMF estimated in Chapter 4.0 and a quantification of the number of potential participating law enforcement agencies adjacent to the corridor.

5.1 HIGHWAY SELECTION

To identify potential corridors to be part of the OMCSAP program, the primary metric assessed was the number of truck driver-at-fault crashes from 2013 to 2019 (the three years before the program was implemented and the three years after the program was implemented). After a descriptive analysis, eight highways, based on the number of crashes were considered (see Table 5.1 and Figure 5.1).[4] Expectedly, the two major interstates in Oregon experienced the most truck driver-at-fault crashes over the study period: I-84 and I-5. The interstates were followed by, in order: US-97/US-197 (Oregon State Highway 004), US-101, OR-99W, US-97 (Oregon State Highway 042), OR-58, and US-20. With the exception of US-20, US-101, and OR-99W, these are all major freight corridors in Oregon. Figure 5.2 shows the selected highways for analysis.

Figure 5.3 shows the yearly trends of the selected highways. With the exception of OR-58, OR-99W, and US-97 (042), all highways have, on average, an increasing trend of driver-at-fault crash over the past several years.

Due to the length of some of these corridors, they were disaggregated into segments (discussed further in the following sub-chapters) based on crash frequency by milepost.

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[4] I-205 is not included here, as it has been the primary focus of the program since its inception. Additionally, I-205 was used as the benchmark and to estimate a crash modification factor.

Table 5.1: Number of Truck Driver-at-Fault Crashes by Highway from 2013 to 2019

Highway	Oregon State Highway Number	Number of Crashes
I-84	002/006	678
I-5	001	487
US-97/US-197	004	280
US-101	009	116
OR-99W	091	113
US-97	042	102
OR-58	018	95
US-20	007	78

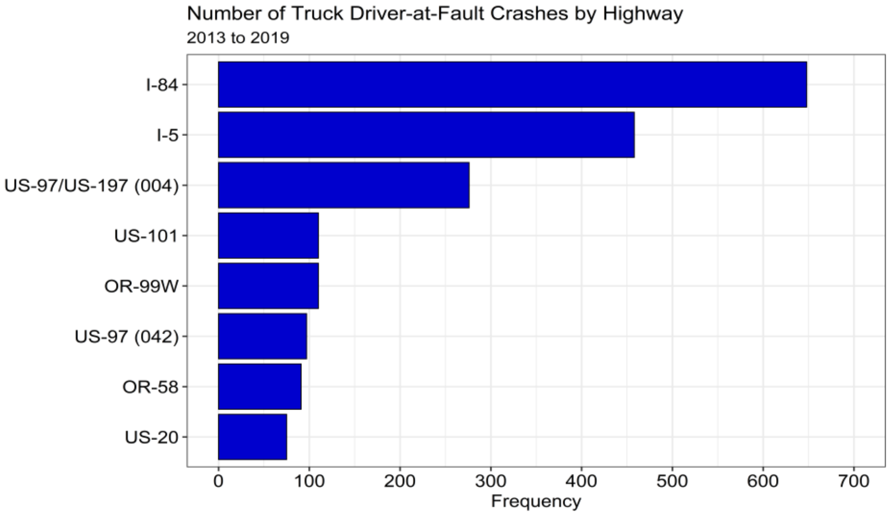


Figure 5.1: Highways with the highest number of truck driver-at-fault crashes

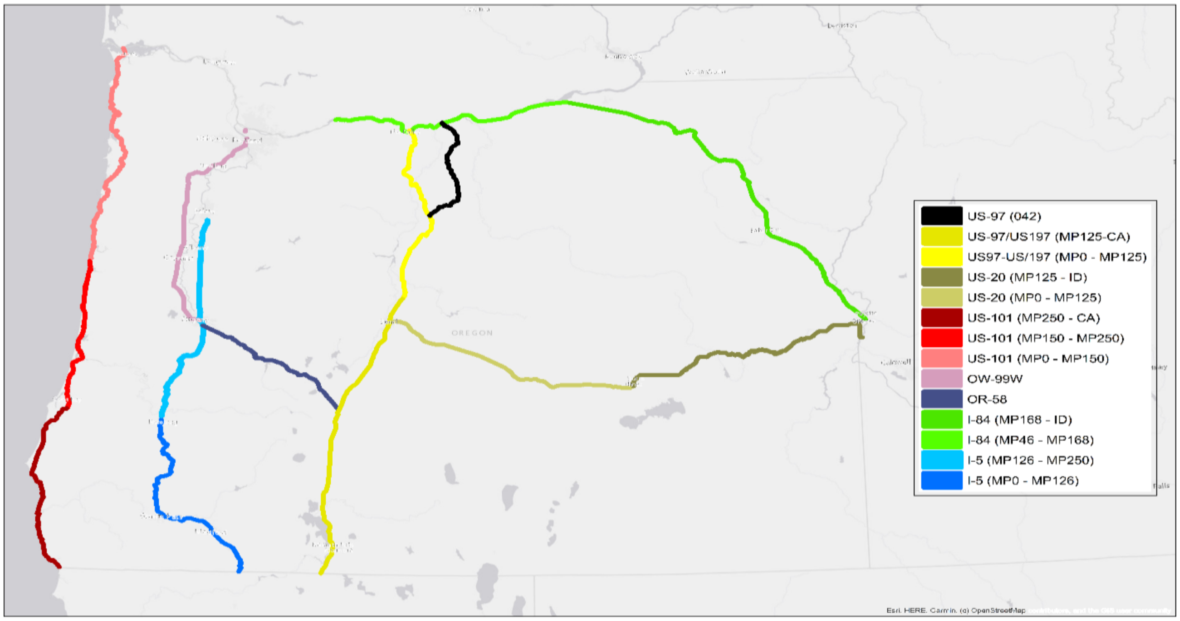
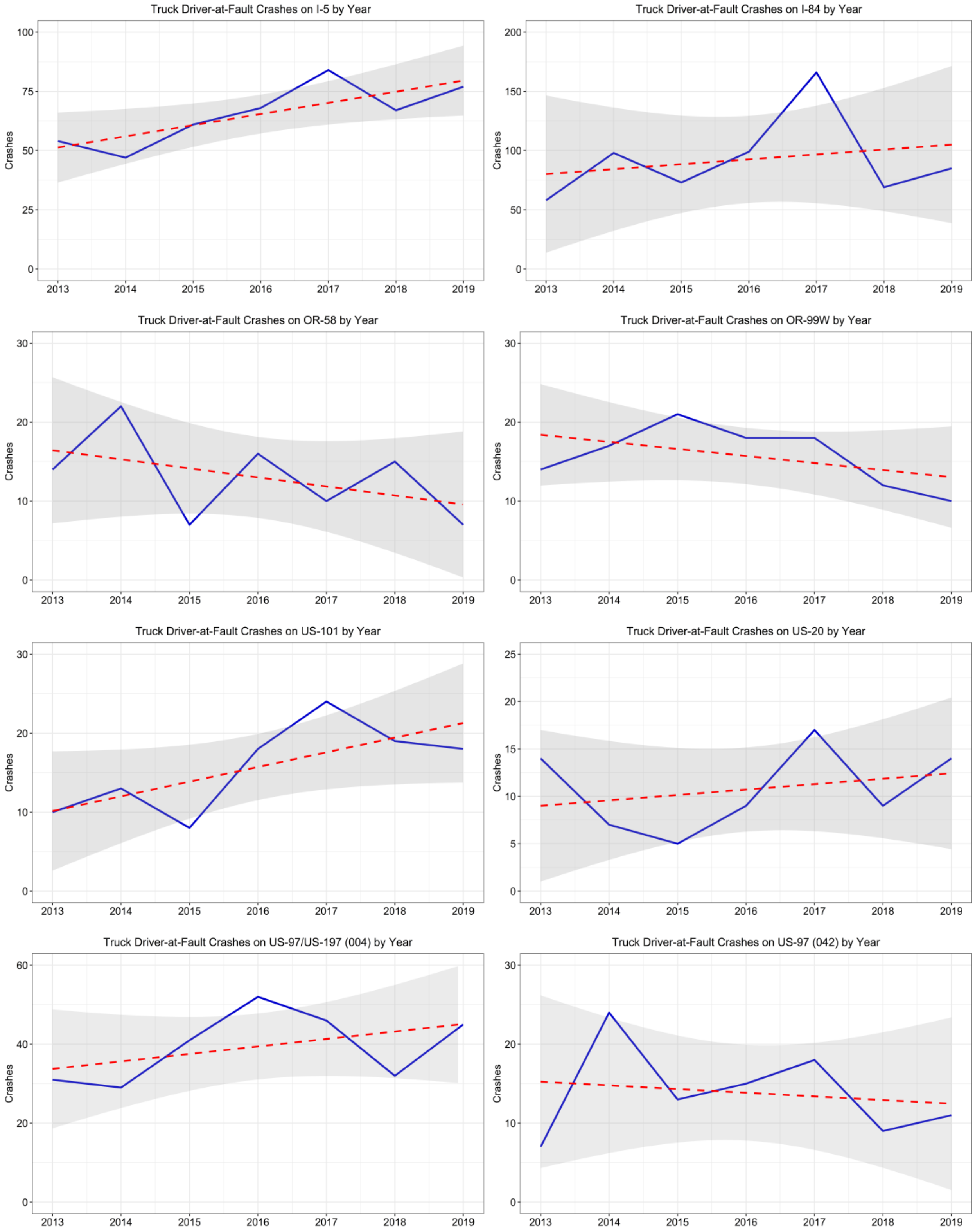


Figure 5.2: Location of select highways considered for analysis


Truck Driver-at-Fault Crashes on I-5 by Year

Truck Driver-at-Fault Crashes on I-84 by Year

Truck Driver-at-Fault Crashes on OR-58 by Year

Truck Driver-at-Fault Crashes on OR-99W by Year

Truck Driver-at-Fault Crashes on US-101 by Year

Truck Driver-at-Fault Crashes on US-20 by Year

Truck Driver-at-Fault Crashes on US-97/US-197 (004) by Year

Truck Driver-at-Fault Crashes on US-97 (042) by Year

Figure 5.3: Truck driver-at-fault crashes by highway and year

5.2 CRASH COSTS AND BENEFITS

5.2.1 Crash Costs Based on Crash Severity

To determine the crash-related costs, several costs were considered. The first cost considered was the cost of the crash based on severity of the crash, as detailed in Chapter 3.3. The most current metrics on average costs of medium/heavy truck crashes by varying levels of severity are provided by Zaloshnja and Miller (2007). In these metrics, costs related to medical costs, emergency services costs, property damage costs, costs due to lost productivity, value of pain and suffering, and the value of the quality of life that a family loses due to death or injury are included.

With the estimates given in 2005 dollars, all prices were converted to 2019 dollars (the most recent year of crash data) using the consumer price index (CPF) inflation conversion factors (Bureau of Labor Statistics 2020):

$$\boldsymbol{C_{2019_s} = \frac{C_s}{CF}}$$

(5-1)

where:

C_{2019_s} is the average cost per crash for severity s in 2019 dollars,

C_s is the average cost per crash for severity s in 2005 dollars, and

CF is a conversion factor used to convert 2005 dollars to 2019 dollars.

After converting, the average costs based on severity are summarized in Table 5.2.

Table 5.2: Estimated Cost of Crashes Based on Severity

Severity	2005 Dollars	2019 Dollars
No Injury	$15,114	$20,367
Injury	$195,258	$263,116
Fatal	$3,604,518	$4,857,197

5.2.2 Crash Costs Due to Travel Delay

Crash costs due to travel delay are adopted from Hagemann et al. (2013). In the estimates provided by Hagemann et al. (2013), costs are for delay only and include characteristics such as time-of-day, crash duration, and severity. For more detail on how these metrics are computed, the reader is referred to Hagemann et al. (2013). Similar to the costs based on severity, the delay costs are not in the most recent currency values; therefore, delay costs in 2010 dollars were converted to 2019 dollars using Eq. 5-1.

5.2.3 Crash Costs Due to Emissions

Also included are crash costs based on emissions. These costs were again adopted from Hagemann et al. (2013). In the estimates provided by Hagemann et al. (2013), emissions costs are based on emission estimates and prices from a traffic simulation and emissions model where emissions are linked to travel delay. Only the unit costs of each emission type are considered based on length of delay. For more detail on how these metrics are computed, the reader is referred to Hagemann et al. (2013). Once more, estimates are provided in 2010 dollars and converted to 2019 dollars using Eq. 5-1.

5.2.4 Crash Costs Due to Excess Fuel Burn

The final crash cost considered is that due to excess fuel burn. As with the previous crash cost estimates, these were adopted from Hagemann et al. (2013). In this process, Hagemann et al. (2013) estimate the total excess fuel burned due to crashes and monetize it. For additional detail on how these metrics are computed, the reader is referred to Hagemann et al. (2013). Tantamount to delay and emissions costs, these metrics are given in 2010 dollars and converted to 2019 dollars using Eq. 5-1.

A summary of crash costs due to delay, emissions, and excess fuel burn is given in Table 5.3.

5.2.5 Cost per Inspection

The final cost is the cost per inspection, or the investment required by ODOT to implement the program at one of the corridors considered for analysis. The cost per inspection (i.e., the amount paid to the presiding officer) is \$113.75. Although this cost is not included in this analysis, it is necessary to determine the investment required to achieve the presented crash cost reductions. With I-205 being the benchmark, the average monthly and average quarterly number of inspections was determined during the after period used to estimate the CMF (2017 to 2019). Monthly, there was an average of 168 inspections with an associated average monthly cost of \$19,152. Quarterly, there was an average of 505 inspections with an associated quarterly cost of \$57,570. When summarizing the results, these values will be used to compare the estimated reductions with the estimated investment required to achieve those reductions.

Table 5.3: Estimated Crash Costs Due to Delay, Emissions, and Excess Fuel Burn

Estimated Delay Time Cost per Crash

Road Type	Fatal (2010 Dollars)	Fatal (2019 Dollars)	Injury (2010 Dollars)	Injury (2019 Dollars)	No Injury (2010 Dollars)	No Injury (2019 Dollars)	Average for Road Type (2010 Dollars)	Average for Road Type (2019 Dollars)
Urban Interstate/Expressway	$163,792	$194,245	$61,395	$72,810	$52,175	$61,876	$55,121	$65,369
Urban Arterial	$11,760	$13,946	$3,328	$3,947	$2,649	$3,142	$2,876	$3,411
Urban Other	$7,086	$8,403	$2,628	$3,117	$2,222	$2,635	$2,351	$2,788
Rural Interstate/Principal Arterials	$11,303	$13,404	$3,860	$4,578	$3,258	$3,864	$3,458	$4,101
Rural Other	$2,421	$2,871	$821	$974	$684	$811	$729	$865
Average for all Road Types	**$39,602**	**$46,965**	**$14,508**	**$17,205**	**$12,280**	**$14,563**	**$12,996**	**$15,412**

Estimated Cost of Emissions per Crash

Road Type	Fatal (2010 Dollars)	Fatal (2019 Dollars)	Injury (2010 Dollars)	Injury (2019 Dollars)	No Injury (2010 Dollars)	No Injury (2019 Dollars)	Average for Road Type (2010 Dollars)	Average for Road Type (2019 Dollars)
Urban Interstate/Expressway	$3,019	$3,580	$1,132	$1,342	$962	$1,141	$1,016	$1,205
Urban Arterial	$584	$693	$165	$196	$132	$157	$143	$170
Urban Other	$172	$204	$64	$76	$54	$64	$57	$68
Rural Interstate/Principal Arterials	$718	$852	$245	$291	$207	$245	$220	$261
Rural Other	$238	$282	$81	$96	$67	$79	$72	$85
Average for all Road Types	**$951**	**$1,128**	**$338**	**$401**	**$285**	**$338**	**$302**	**$358**

Estimated Cost of Excess Fuel Burn

Road Type	Fatal (2010 Dollars)	Fatal (2019 Dollars)	Injury (2010 Dollars)	Injury (2019 Dollars)	No Injury (2010 Dollars)	No Injury (2019 Dollars)	Average for Road Type (2010 Dollars)	Average for Road Type (2019 Dollars)
Urban Interstate/Expressway	$6,544	$7,761	$2,453	$2,909	$2,084	$2,471	$2,202	$2,611
Urban Arterial	$1,801	$2,136	$510	$605	$406	$481	$440	$522
Urban Other	$545	$646	$202	$240	$171	$203	$181	$215
Rural Interstate/Principal Arterials	$1,194	$1,416	$408	$484	$344	$408	$365	$433
Rural Other	$499	$592	$169	$200	$141	$167	$150	$178
Average for all Road Types	**$2,147**	**$2,546**	**$757**	**$898**	**$636**	**$754**	**$675**	**$801**

Source: Hagemann et al. (2013)

5.2.6 Benefits

As outlined in Chapter 4.0, the primary benefit is based on the effectiveness of the program and the estimated crashes it can reduce. This was accomplished by computing a crash modification factor (CMF) on I-205. The estimated CMF captures effects due to changes in overall traffic volume, truck traffic volume, and shoulder width. As such, quantifiable benefits for these characteristics are accounted for. For this analysis, the estimated CMF is used to assess the reduction in overall crash costs.

Another primary benefit is the effect of the number of potential participating law enforcement agencies on the expected number of crashes. Simply quantifying their impact on the number of crashes is difficult and is likely to vary. Therefore, in this work, a crash frequency model was developed to determine the effects of the number of potential participating law enforcement agencies on the expected number of crashes. This was accomplished using the Negative Binomial modeling framework (see Chapter 4.1 for a detailed presentation of the Negative Binomial model). The determined effects are used as multipliers to the estimated CMF to account for the benefit (overall crash cost reduction) based also on potential participating law enforcement agencies.

First, the number of potential law enforcement agencies were identified adjacent to all considered segments. Based on the current program, and the Oregon State Police unable to participate, only county- and local-level law enforcement agencies were considered. Table 5.4 shows the number of adjacent law enforcement agencies by analysis segment. Using these segments and number of law enforcement agencies, the data was prepared for modeling.

Table 5.4: Number of Potential Participating Law Enforcement Agencies by Analysis Segment

Highway (Segment)	Oregon State Highway Number	Number of Potential Participating Law Enforcement Agencies
I-5 (MP0 - MP126)	001	9
I-5 (MP126 - MP-250)	001	10
I-84 (MP46 - MP168)	002	4
I-84 (MP168 - ID)	006	9
OR-58	018	3
OR-99W	091	17
US-101 (MP0 - MP150)	009	13
US-101 (MP150 - MP250)	009	7
US-101 (MP250 - CA)	009	5
US-20 (MP0 - MP125)	007	4
US-20 (MP125 - ID)	007	5
US-97/US-197 (MP0 - MP125)	004	5
US-97/US-197 (MP125 - CA)	004	6
US-97	042	2

Best fit model specifications for the effects of the potential number of law enforcement agencies on the expected number of crashes are shown in Table 5.5. The variables included in the CMF are included in this model as to control for their effects while obtaining the effects of the number of law enforcement agencies. As observed, the effects on the expected number of crashes for all law enforcement indicators are negative (i.e., decrease in the expected number of crashes). However, unlike linear regression models, or other ordinary least squares estimated models, the coefficients cannot be readily interpreted in terms of quantifiable effects. Being that count data models are log-linear regression models, an incidence rate ratio can be computed by exponentiating the estimated coefficient. The result is a multiplicative factor that indicates the change in the expected number of crashes.

Table 5.6 tabulates the incidence rate ratios for all model variables and Figure 5.4 illustrates them visually. Notice that all variables with a negative coefficient have an incidence rate ratio of less than one, while positive coefficients have an incidence rate ratio greater than one. Of interest are the incidence rate ratios for the law enforcement indicators, each of which indicate a reduction in the expected number of crashes. For this work, the incidence rate ratios are used as a multiplicative factor on crash cost after accounting for the reduction in crash costs based on the estimated CMF. For example, if the total crash cost is \$100, the estimated CMF indicates that if treatment occurred the expected crash costs would be \$50 (CMF of 0.50). This price, however, does not include the effects of the number of participating law enforcement agencies. Therefore, say there are three agencies along the segment, the \$50 is then multiplied by the incidence rate ratio for three agencies, 0.682, resulting in a monetary value of roughly \$40. Based on this example, the expected crash costs after implementing the program at a location where there are three participating agencies are expected to reduce to \$40 from \$100 (a 60% decrease in the expected crash costs). This process is applied to each analysis segment to determine the segments with the lowest benefit/cost ratio (i.e., the highest reduction in crash costs).

Table 5.5: Negative Binomial Model Specifications for Effects of Law Enforcement Agencies

Variable	Coefficient	Std. Error	t-statistic	p-value
Constant	-0.159	0.672	-0.24	0.813
Right side shoulder width (ft)	0.007	0.010	0.68	0.496
Natural Logarithm of AADT	-0.419	0.102	-4.13	0.000
Natural Logarithm of truck AADT	0.522	0.135	3.88	0.000
Number of Law Enforcement Agencies				
1 if 3, 0 otherwise	-0.383	0.309	-1.24	0.215
1 if 4, 0 otherwise	-0.694	0.271	-2.57	0.010
1 if 5, 0 otherwise	-1.831	0.260	-7.06	0.000
1 if 6, 0 otherwise	-0.779	0.270	-2.88	0.004
1 if 7, 0 otherwise	-2.284	0.320	-7.15	0.000
1 if 9, 0 otherwise	-0.260	0.264	-0.99	0.324
1 if 10, 0 otherwise	-0.754	0.319	-2.37	0.018
1 if 13, 0 otherwise	-2.210	0.319	-6.93	0.000
1 if 17, 0 otherwise	-1.247	0.301	-4.14	0.000
Dispersion Parameter				
α	0.997	0.144	6.95	0.000
Model Summary				
Number of Observations	2,561			
Log-likelihood at convergence	-1,637.27			

Table 5.6: Incidence Rate Ratios

Variable[5]	Incident Rate Ratio
Constant	0.853
Right side shoulder width (ft)	1.007
Natural Logarithm of AADT	0.658
Natural Logarithm of truck AADT	1.685
Number of Law Enforcement Agencies	
1 if 3, 0 otherwise	0.682
1 if 4, 0 otherwise	0.499
1 if 5, 0 otherwise	0.160
1 if 6, 0 otherwise	0.459
1 if 7, 0 otherwise	0.102
1 if 9, 0 otherwise	0.771
1 if 10, 0 otherwise	0.471
1 if 13, 0 otherwise	0.110
1 if 17, 0 otherwise	0.287

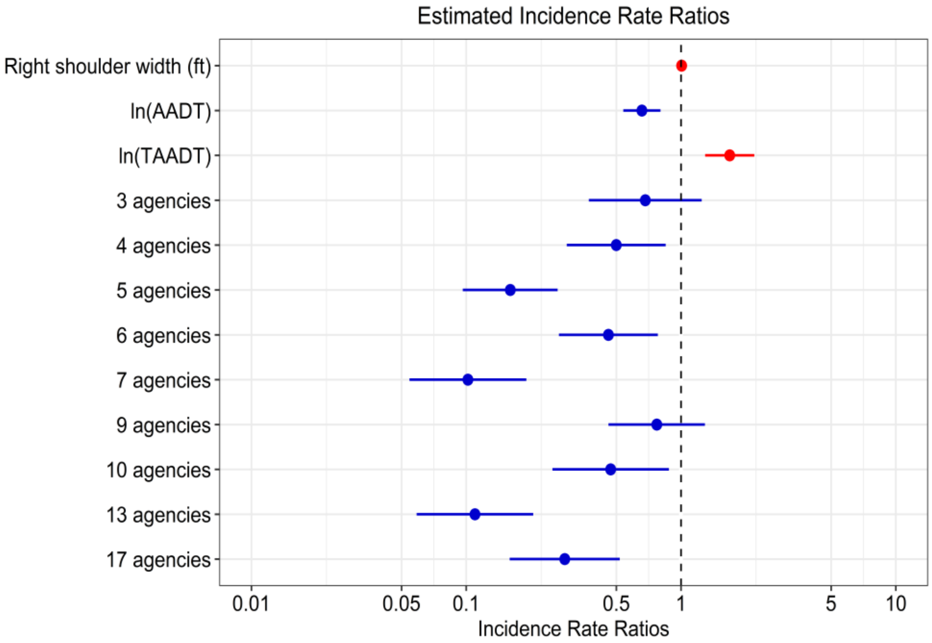


Figure 5.4: Estimated effects on expected number of crashes

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[5] Note that the segment with two agencies is not included, as it is the reference category. This has to be done to properly specify the model. However, a model with no intercept was estimated so that all agency indicators could be included. In doing this, the reference category then takes the place of the constant and results in the same coefficient and same incidence rate ratio as the constant in Table 5.6. Therefore, for the segment with two agencies, the incidence rate ratio associated with the constant was used.

5.3 RESULTS

Results will be presented individually for each highway and the segments along that highway, after which all results will be summarized, compared, and assessed to the investment costs detailed in Chapter 5.2.5. In this chapter, benefit is described as the estimated reduction in crash costs based on the CMF and on the number of potential participating law enforcement agencies.

5.3.1 I-5

With the program currently consisting of I-5 from Salem to the Washington border, this work only considers I-5 south of Salem. Due to the length of this corridor, the number of crashes by milepost were plotted to determine how/if the segment should be disaggregated. Based on the crash distribution by milepost, see Figure 5.5, two distinct segments on I-5 were considered: (1) I-5 from MP 0 (the Oregon-California border) to MP 126 (just north of Roseburg, OR) and (2) MP 126 (just north of Roseburg, OR) to MP 250 (just south of Salem, OR).

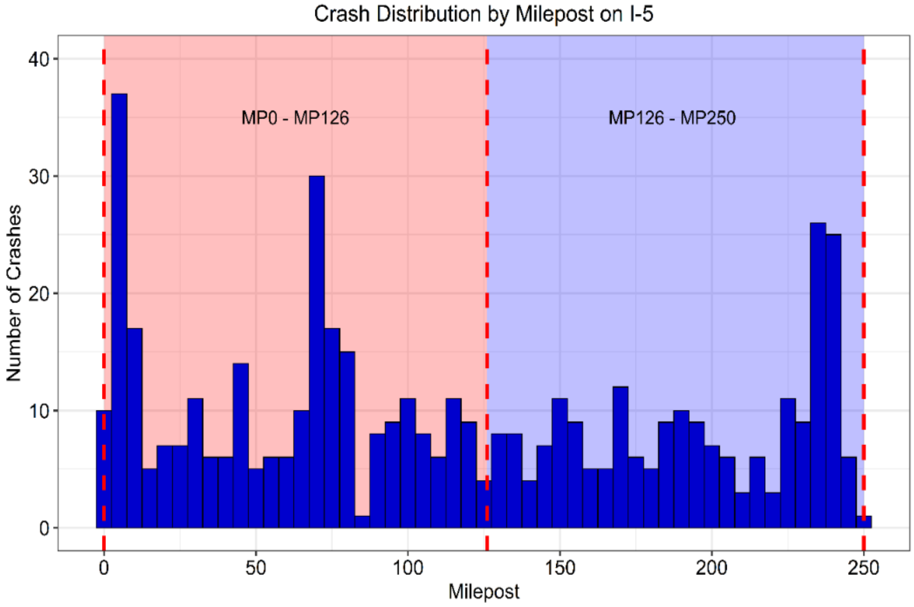

Figure 5.5: Crash distribution by milepost on I-5

5.3.1.1 I-5 (MP 0 – MP 126)

This segment is 126 miles in length and experienced 275 truck driver-at-fault crashes from 2013 to 2019, of which five were fatal, 60 involved a non-fatal injury, and 210 resulted in no injury. The number of potential participating law enforcement agencies along this segment is nine with an associated incidence rate ratio of 0.771. Based on these numbers, the total estimated crash cost is approximately $45.6 million, with an anticipated benefit (reduction in crash cost) of about $28 million, a 62% decrease. The benefit/cost ratio for this segment is 0.614. A summary of all costs and benefits on this segment is shown in Table 5.7.

Table 5.7: Summary of Crash Costs and Benefits on I-5 (MP0 - MP126)

Total Number of Crashes	275
Number of Crashes by Severity	
No Injury Crashes	210
Injury Crashes	60
Fatal Crashes	5
Crash Costs Based on Severity	
Cost of No Injury Crash	$4,277,070
Cost of Injury Crash	$15,786,962
Cost of Fatal Crash	$24,285,985
Crash Costs due to Delay	
Cost of Delay (No Injury)	$811,385
Cost of Delay (Injury)	$274,660
Cost of Delay (Fatal)	$13,404
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$51,553
Estimated Emissions Cost (Injury)	$17,460
Estimated Emissions Cost (Fatal)	$4,260
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$85,680
Estimated Excess Fuel Costs (Injury)	$29,040
Estimated Excess Fuel Costs (Fatal)	$7,080
Number of Law Enforcement Agencies	9
Total Crash Costs	**$45,644,540**
Expected Cost if Program Was Implemented (CMF)	$22,822,270
Expected Cost due to Number of Law Enforcement Agencies	$17,596,577
Benefit	**$28,047,093**
Benefit/Cost Ratio	**0.614**

5.3.1.2 I-5 (MP 126 – MP 250)

This segment is 124 miles in length and experienced 212 truck driver-at-fault crashes from 2013 to 2019, of which three were fatal, 60 involved a non-fatal injury, and 149 resulted in no injury. The number of potential participating law enforcement agencies along this segment is 10 with an associated incidence rate ratio of 0.471. Based on these numbers, the total estimated crash cost is approximately $48.4 million, with an anticipated benefit (reduction in crash cost) of about $37 million, approximately a 77% decrease. The benefit/cost ratio for this segment is 0.765. A summary of all costs and benefits on this segment is shown in Table 5.8.

Table 5.8: Summary of Crash Costs and Benefits on I-5 (MP126 - MP250)

Total Number of Crashes	212
Number of Crashes by Severity	
No Injury Crashes	149
Injury Crashes	60
Fatal Crashes	3
Crash Costs Based on Severity	
Cost of No Injury Crash	$3,034,683
Cost of Injury Crash	$15,786,962
Cost of Fatal Crash	$14,571,591
Crash due to Delay	
Cost of Delay (No Injury)	$9,219,451
Cost of Delay (Injury)	$4,368,583
Cost of Delay (Fatal)	$582,734
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$169,988
Estimated Emissions Cost (Injury)	$80,548
Estimated Emissions Cost (Fatal)	$10,741
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$368,248
Estimated Excess Fuel Costs (Injury)	$174,544
Estimated Excess Fuel Costs (Fatal)	$23,282
Number of Law Enforcement Agencies	10
Total Crash Costs	**$48,391,355**
Expected Cost if Program Was Implemented (CMF)	$24,195,677
Expected Cost due to Number of Law Enforcement Agencies	$11,384,286
Benefit	**$37,007,068**
Benefit/Cost Ratio	**0.765**

5.3.2 I-84

Similar to I-5, a portion of I-84 was already part of the program. As such, this work considers I-84 from MP 46 to the Idaho border. Due to the length of this corridor, the number of crashes by milepost were plotted to determine how/if the segment should be disaggregated. Based on the crash distribution by milepost, see Figure 5.6, two distinct segments on I-84 were considered: (1) MP 46 (just east of Cascade Locks) to MP 168 (the junction with US-730) and (2) MP 168 (the junction with US-730) to the Idaho border.

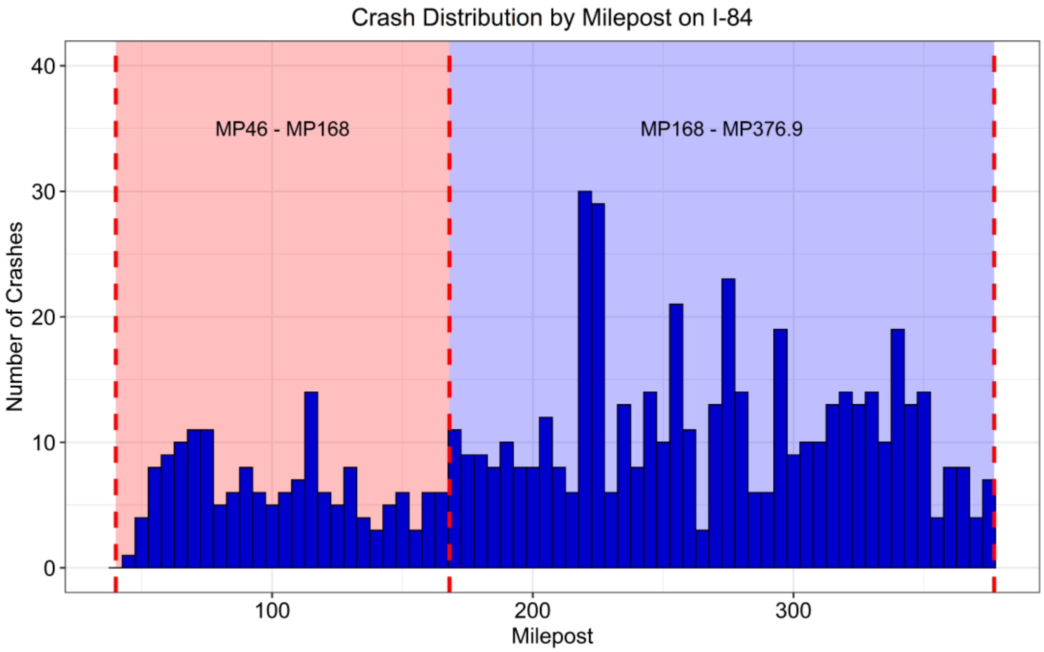

Figure 5.6: Crash distribution by milepost on I-84

5.3.2.1 I-84 (MP 46 – MP 168)

This segment is 122 miles in length and experienced 176 truck driver-at-fault crashes from 2013 to 2019, of which three were fatal, 31 involved a non-fatal injury, and 142 resulted in no injury. The number of potential participating law enforcement agencies along this segment is four with an associated incidence rate ratio of 0.499. Based on these numbers, the total estimated crash cost is approximately $26.5 million, with an anticipated benefit (reduction in crash cost) of about $19.9 million, approximately a 75% decrease. The benefit/cost ratio for this segment is 0.750. A summary of all costs and benefits on this segment is shown in Table 5.9.

Table 5.9: Summary of Crash Costs and Benefits on I-84 (MP46 - MP168)

Total Number of Crashes	176
Number of Crashes by Severity	
No Injury Crashes	142
Injury Crashes	31
Fatal Crashes	3
Crash Costs Based on Severity	
Cost of No Injury Crash	$2,892,114
Cost of Injury Crash	$8,156,597
Cost of Fatal Crash	$14,571,591
Crash Costs due to Delay	
Cost of Delay (No Injury)	$548,651
Cost of Delay (Injury)	$141,907
Cost of Delay (Fatal)	$40,213
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$34,860
Estimated Emissions Cost (Injury)	$9,021
Estimated Emissions Cost (Fatal)	$2,556
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$57,936
Estimated Excess Fuel Costs (Injury)	$15,004
Estimated Excess Fuel Costs (Fatal)	$4,248
Number of Law Enforcement Agencies	4
Total Crash Costs	**$26,474,699**
Expected Cost if Program Was Implemented (CMF)	$13,237,349
Expected Cost due to Number of Law Enforcement Agencies	$6,611,758
Benefit	**$19,862,941**
Benefit/Cost Ratio	**0.750**

5.3.2.2 I-84 (MP 168 – Idaho Border)

This segment is about 209 miles in length and experienced 502 truck driver-at-fault crashes from 2013 to 2019, of which eight were fatal, 110 involved a non-fatal injury, and 384 resulted in no injury. The number of potential participating law enforcement agencies along this segment is nine with an associated incidence rate ratio of 0.771. Based on these numbers, the total estimated crash cost is approximately $78.1 million, with an anticipated benefit (reduction in crash cost) of about $48 million, approximately a 61% decrease. The benefit/cost ratio for this segment is 0.614. A summary of all costs and benefits on this segment is shown in Table 5.10.

Table 5.10: Summary of Crash Costs and Benefits on I-84 (MP168 - Idaho Border)

Total Number of Crashes	502
Number of Crashes by Severity	
No Injury Crashes	384
Injury Crashes	110
Fatal Crashes	8
Crash Costs Based on Severity	
Cost of No Injury Crash	$7,820,928
Cost of Injury Crash	$28,942,764
Cost of Fatal Crash	$38,857,576
Crash Costs due to Delay	
Cost of Delay (No Injury)	$1,483,676
Cost of Delay (Injury)	$503,543
Cost of Delay (Fatal)	$107,236
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$94,268
Estimated Emissions Cost (Injury)	$32,010
Estimated Emissions Cost (Fatal)	$6,816
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$156,672
Estimated Excess Fuel Costs (Injury)	$53,240
Estimated Excess Fuel Costs (Fatal)	$11,328
Number of Law Enforcement Agencies	9
Total Crash Costs	**$78,070,057**
Expected Cost if Program Was Implemented (CMF)	$39,035,029
Expected Cost due to Number of Law Enforcement Agencies	$30,097,045
Benefit	**$47,973,012**
Benefit/Cost Ratio	**0.614**

5.3.3 OR-58

OR-58 is not currently part of the program; therefore, the entire length of the highway was considered for analysis. Unlike the previous two highways, the length of OR-58 is less than 100 miles and was not split into multiple segments. The crash distribution by milepost is shown in Figure 5.7. OR-58 runs from Southeast Eugene to US-97 (about 45 miles south of Crescent, OR) and is approximately 86 miles.

From 2013 to 2019 there were 91 truck driver-at-fault crashes, of which four were fatal, 24 involved a non-fatal injury, and 63 resulted in no injury. The number of potential participating law enforcement agencies along this segment is three with an associated incidence rate ratio of 0.682. Based on these numbers, the total estimated crash cost is approximately $27.1 million, with an anticipated benefit (reduction in crash cost) of about $17.9 million, approximately a 66%

decrease. The benefit/cost ratio for this segment is 0.659. A summary of all costs and benefits on this segment is shown in Table 5.11.

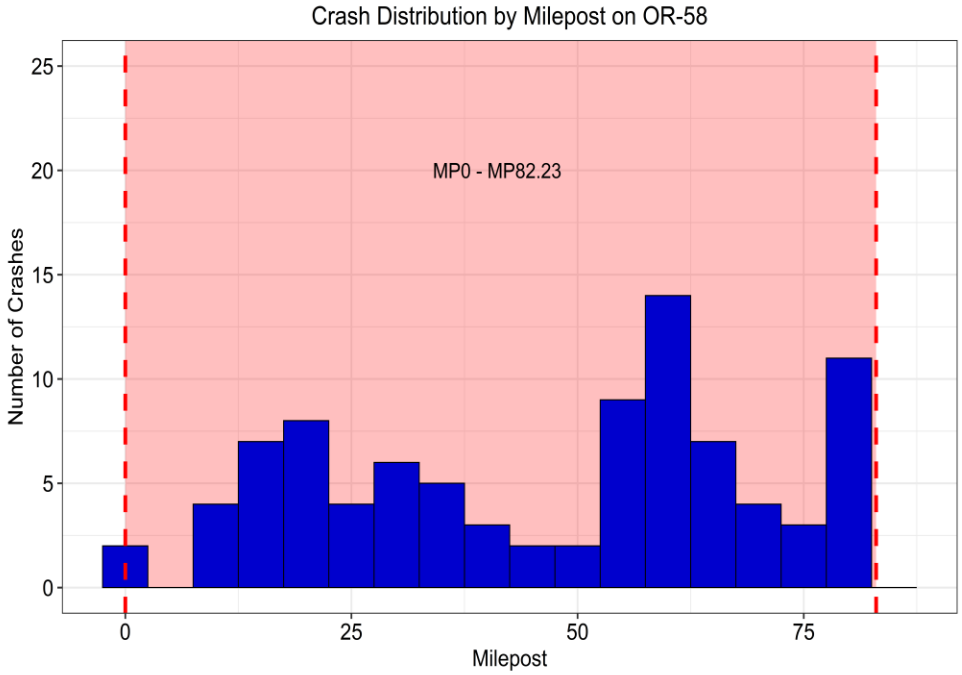

Figure 5.7: Crash distribution by milepost on OR-58

Table 5.11: Summary of Crash Costs and Benefits on OR-58

Total Number of Crashes	91
Number of Crashes by Severity	
No Injury Crashes	63
Injury Crashes	24
Fatal Crashes	4
Crash Costs Based on Severity	
Cost of No Injury Crash	$1,283,121
Cost of Injury Crash	$6,314,785
Cost of Fatal Crash	$19,428,788
Crash Costs due to Delay	
Cost of Delay (No Injury)	$243,416
Cost of Delay (Injury)	$109,864
Cost of Delay (Fatal)	$53,618
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$15,466
Estimated Emissions Cost (Injury)	$6,984
Estimated Emissions Cost (Fatal)	$3,408
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$25,704
Estimated Excess Fuel Costs (Injury)	$11,616
Estimated Excess Fuel Costs (Fatal)	$5,664
Number of Law Enforcement Agencies	3
Total Crash Costs	**$27,095,630**
Expected Cost if Program Was Implemented (CMF)	$13,547,815
Expected Cost due to Number of Law Enforcement Agencies	$9,240,431
Benefit	**$17,855,199**
Benefit/Cost Ratio	**0.659**

5.3.4 OR-99W

OW-99W is not currently part of the program; therefore, the entire length of the highway was considered for analysis. The length of OR-99W is about 124 miles and was not split into multiple segments. The crash distribution by milepost is shown in Figure 5.8. OR-99W runs from Eugene to Portland.

From 2013 to 2019 there were 109 truck driver-at-fault crashes, of which one was fatal, 31 involved a non-fatal injury, and 77 resulted in no injury. The number of potential participating law enforcement agencies along this segment is 17 with an associated incidence rate ratio of 0.287. This segment has the highest number of potential law enforcement agencies, as it runs through several local municipalities and counties. Based on these numbers, the total estimated crash cost is approximately $15 million, with an anticipated benefit (reduction in crash cost) of about $12.9 million, approximately an 86% decrease. The benefit/cost ratio for this segment is 0.856. A summary of all costs and benefits on this segment is shown in Table 5.12.

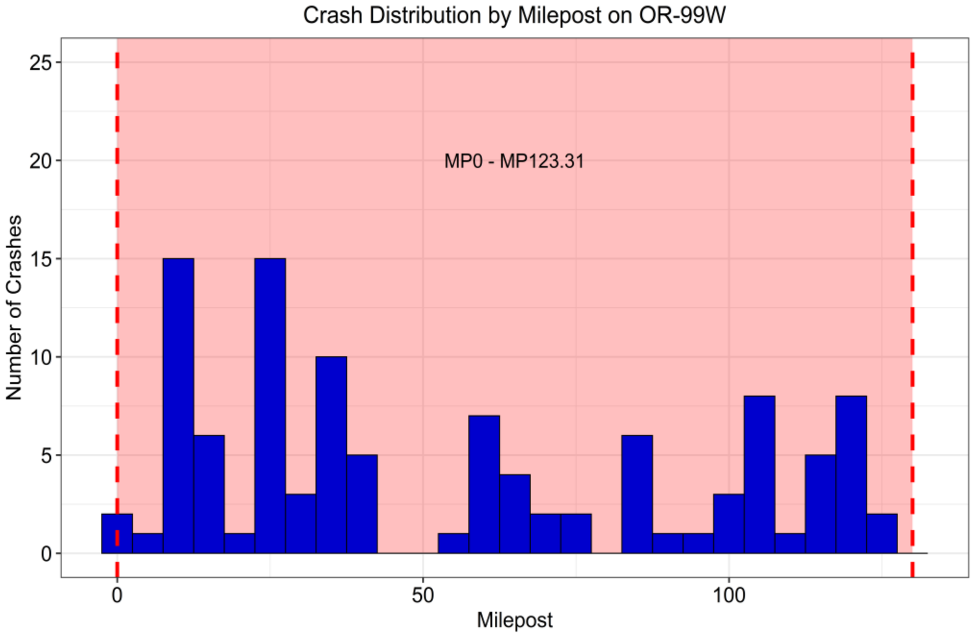

Figure 5.8: Crash distribution by milepost on OR-99W

Table 5.12: Summary of Crash Costs and Benefits on OR-99W

Total Number of Crashes	109
Number of Crashes by Severity	
No Injury Crashes	77
Injury Crashes	31
Fatal Crashes	1
Crash Costs Based on Severity	
Cost of No Injury Crash	$1,568,259
Cost of Injury Crash	$8,156,597
Cost of Fatal Crash	$4,857,197
Crash Costs due to Delay	
Cost of Delay (No Injury)	$241,896
Cost of Delay (Injury)	$122,349
Cost of Delay (Fatal)	$13,946
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$12,089
Estimated Emissions Cost (Injury)	$6,076
Estimated Emissions Cost (Fatal)	$693
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$37,074
Estimated Excess Fuel Costs (Injury)	$18,755
Estimated Excess Fuel Costs (Fatal)	$2,136
Number of Law Enforcement Agencies	17
Total Crash Costs	**$15,037,068**
Expected Cost if Program Was Implemented (CMF)	$7,518,534
Expected Cost due to Number of Law Enforcement Agencies	$2,160,467
Benefit	**$12,876,600**
Benefit/Cost Ratio	**0.856**

5.3.5 US-101

US-101 is currently not part of the program. As such, this work considers the entire length of the corridor. US-101 is one of two highways considered that runs the length of state (north-south). Due to this, the number of crashes by milepost were plotted to determine how the segment should be disaggregated. Based on the crash distribution by milepost, see Figure 5.9, three distinct segments on US-101 were considered: (1) MP 0 (Oregon-Washington border at Astoria, OR) to MP 150 (Seal Rock), (2) MP 150 (Seal Rock) to MP 250 (just south of Coos Bay), and (3) MP 250 (just south of Coos Bay) to the California border.

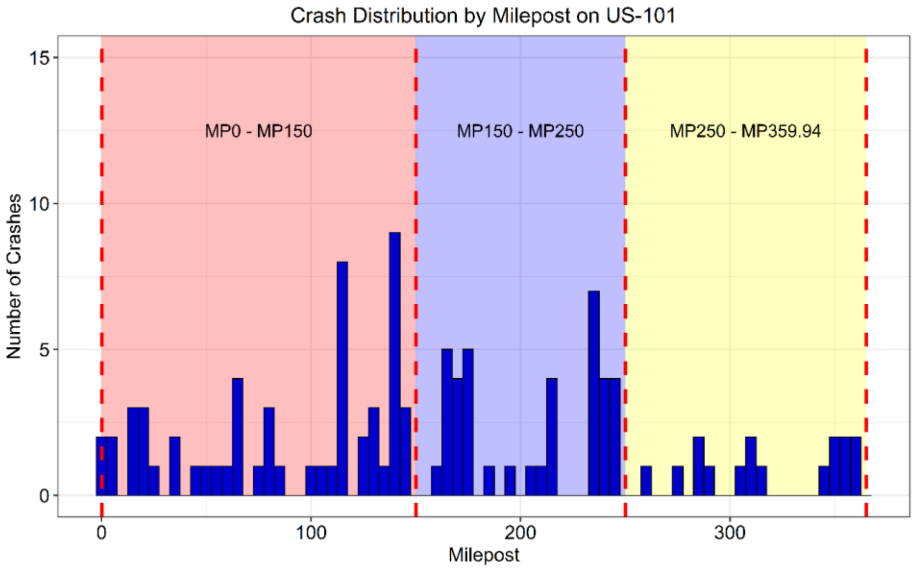

Figure 5.9: Crash distribution by milepost on US-101

5.3.5.1 US-101 (MP 0 – MP 150)

This segment is 150 miles in length and experienced 55 truck driver-at-fault crashes from 2013 to 2019, of which zero were fatal, 13 involved a non-fatal injury, and 42 resulted in no injury. The number of potential participating law enforcement agencies along this segment is 13 with an associated incidence rate ratio of 0.110. This was the second highest number of law enforcement agencies, as this segment also runs through several local coastal municipalities and counties. Based on these numbers, the total estimated crash cost is approximately $4.3 million, with an anticipated benefit (reduction in crash cost) of about $4.1 million, approximately a 95% decrease. This was the largest observed anticipated decrease. The benefit/cost ratio for this segment is 0.945 and was the highest computed ratio. A summary of all costs and benefits on this segment is shown in Table 5.13.

Table 5.13: Summary of Crash Costs and Benefits on US-101 (MP0 - MP150)

Total Number of Crashes	55
Number of Crashes by Severity	
No Injury Crashes	42
Injury Crashes	13
Fatal Crashes	0
Crash Costs Based on Severity	
Cost of No Injury Crash	$855,414
Cost of Injury Crash	$3,420,509
Cost of Fatal Crash	$0
Crash Costs due to Delay	
Cost of Delay (No Injury)	$162,277
Cost of Delay (Injury)	$59,510
Cost of Delay (Fatal)	$0
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$10,311
Estimated Emissions Cost (Injury)	$3,783
Estimated Emissions Cost (Fatal)	$0
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$17,136
Estimated Excess Fuel Costs (Injury)	$6,292
Estimated Excess Fuel Costs (Fatal)	$0
Number of Law Enforcement Agencies	13
Total Crash Costs	**$4,313,512**
Expected Cost if Program Was Implemented (CMF)	$2,156,756
Expected Cost due to Number of Law Enforcement Agencies	$236,700
Benefit	**$4,076,812**
Benefit/Cost Ratio	**0.945**

5.3.5.2 US-101 (MP 150 – MP 250)

This segment is 100 miles in length and experienced 38 truck driver-at-fault crashes from 2013 to 2019, of which zero were fatal, 17 involved a non-fatal injury, and 21 resulted in no injury. The number of potential participating law enforcement agencies along this segment is seven with an associated incidence rate ratio of 0.102. This was the lowest estimated incidence rate ratio (e.g., highest decrease in the expected number of crashes). Based on these numbers, the total estimated crash cost is approximately $5.1 million, with an anticipated benefit (reduction in crash cost) of about $4.8 million, approximately a 95% decrease. This was the largest observed expected decrease with the first segment of US-101 (both segments have approximately the same estimated incidence rate ratio). The benefit/cost ratio for this segment is 0.949 and was the highest computed ratio. A summary of all costs and benefits on this segment is shown in Table 5.14.

Table 5.14: Summary of Crash Costs and Benefits on US-101 (MP150 - MP250)

Total Number of Crashes	38
Number of Crashes by Severity	
No Injury Crashes	21
Injury Crashes	17
Fatal Crashes	0
Crash Costs Based on Severity	
Cost of No Injury Crash	$427,707
Cost of Injury Crash	$4,472,973
Cost of Fatal Crash	$0
Crash Costs due to Delay	
Cost of Delay (No Injury)	$81,139
Cost of Delay (Injury)	$77,820
Cost of Delay (Fatal)	$0
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$5,155
Estimated Emissions Cost (Injury)	$4,947
Estimated Emissions Cost (Fatal)	$0
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$8,568
Estimated Excess Fuel Costs (Injury)	$8,228
Estimated Excess Fuel Costs (Fatal)	$0
Number of Law Enforcement Agencies	7
Total Crash Costs	**$5,086,537**
Expected Cost if Program Was Implemented (CMF)	$2,543,268
Expected Cost due to Number of Law Enforcement Agencies	$258,989
Benefit	**$4,827,548**
Benefit/Cost Ratio	**0.949**

5.3.5.3 US-101 (MP 250 – California Border)

This segment is about 115 miles in length and experienced 16 truck driver-at-fault crashes from 2013 to 2019, of which zero were fatal, 8 involved a non-fatal injury, and 8 resulted in no injury. The number of potential participating law enforcement agencies along this segment is five with an associated incidence rate ratio of 0.160. Based on these numbers, the total estimated crash cost is approximately $2.3 million, with an anticipated benefit (reduction in crash cost) of about $2.2 million, approximately a 92% decrease. The benefit/cost ratio for this segment is 0.920. A summary of all costs and benefits on this segment is shown in Table 5.15.

Table 5.15: Summary of Crash Costs and Benefits on US-101 (MP250 - CA Border)

Total Number of Crashes	16
Number of Crashes by Severity	
No Injury Crashes	8
Injury Crashes	8
Fatal Crashes	0
Crash Costs Based on Severity	
Cost of No Injury Crash	$162,936
Cost of Injury Crash	$2,104,928
Cost of Fatal Crash	$0
Crash Costs due to Delay	
Cost of Delay (No Injury)	$30,910
Cost of Delay (Injury)	$36,621
Cost of Delay (Fatal)	$0
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$1,964
Estimated Emissions Cost (Injury)	$2,328
Estimated Emissions Cost (Fatal)	$0
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$3,264
Estimated Excess Fuel Costs (Injury)	$3,872
Estimated Excess Fuel Costs (Fatal)	$0
Number of Law Enforcement Agencies	5
Total Crash Costs	**$2,346,823**
Expected Cost if Program Was Implemented (CMF)	$1,173,412
Expected Cost due to Number of Law Enforcement Agencies	$188,051
Benefit	**$2,158,773**
Benefit/Cost Ratio	**0.920**

5.3.6 US-20

US-20 is currently not part of the program. As such, this work considers the entire length of the corridor. Due to the length of this highway, the number of crashes by milepost were plotted to determine how/if the segment should be disaggregated. Based on the crash distribution by milepost, see Figure 5.10, two distinct segments on US-20 were considered: (1) MP 0 (Bend, OR) to MP 125 (just south of Hines, OR and Burns, OR) and (2) MP 125 (just south of Hines, OR and Burns, OR) to the Idaho border.

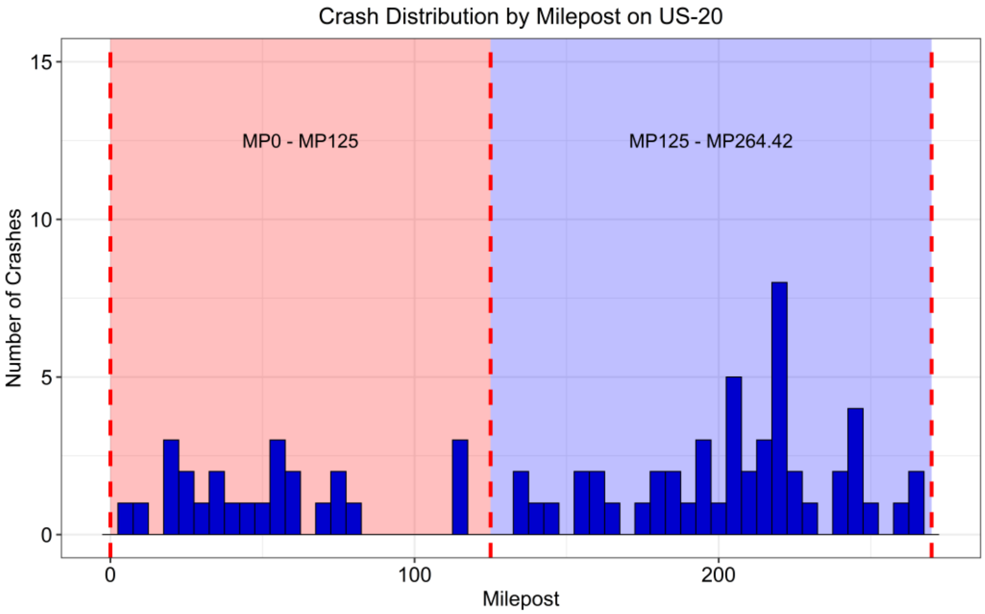

Figure 5.10: Crash distribution by milepost on US-20

5.3.6.1 US-20 (MP 0 – MP 125)

This segment is 125 miles in length and experienced 25 truck driver-at-fault crashes from 2013 to 2019, of which two were fatal, three involved a non-fatal injury, and 20 resulted in no injury. The number of potential participating law enforcement agencies along this segment is four with an associated incidence rate ratio of 0.499 (about the same effect as the estimated CMF). Based on these numbers, the total estimated crash cost is approximately $11 million, with an anticipated benefit (reduction in crash cost) of about $8.3 million, approximately a 75% decrease. The benefit/cost ratio for this segment is 0.750. A summary of all costs and benefits on this segment is shown in Table 5.16.

Table 5.16: Summary of Crash Costs and Benefits on US-20 (MP0 - MP125)

Total Number of Crashes	25
Number of Crashes by Severity	
No Injury Crashes	20
Injury Crashes	3
Fatal Crashes	2
Crash Costs Based on Severity	
Cost of No Injury Crash	$407,340
Cost of Injury Crash	$789,348
Cost of Fatal Crash	$9,714,394
Crash Costs due to Delay	
Cost of Delay (No Injury)	$77,275
Cost of Delay (Injury)	$13,733
Cost of Delay (Fatal)	$26,809
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$4,910
Estimated Emissions Cost (Injury)	$873
Estimated Emissions Cost (Fatal)	$1,704
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$8,160
Estimated Excess Fuel Costs (Injury)	$1,452
Estimated Excess Fuel Costs (Fatal)	$2,832
Number of Law Enforcement Agencies	4
Total Crash Costs	**$11,048,830**
Expected Cost if Program Was Implemented (CMF)	$5,524,415
Expected Cost due to Number of Law Enforcement Agencies	$2,759,321
Benefit	**$8,289,509**
Benefit/Cost Ratio	**0.750**

5.3.6.2 US-20 (MP 125 – Idaho Border)

This segment is approximately 160 miles in length and experienced 50 truck driver-at-fault crashes from 2013 to 2019, of which two were fatal, 10 involved a non-fatal injury, and 38 resulted in no injury. The number of potential participating law enforcement agencies along this segment is five with an associated incidence rate ratio of 0.160. Based on these numbers, the total estimated crash cost is approximately $13.4 million, with an anticipated benefit (reduction in crash cost) of about $12 million, approximately a 92% decrease. The benefit/cost ratio for this segment is 0.920. A summary of all costs and benefits on this segment is shown in Table 5.17.

Table 5.17: Summary of Crash Costs and Benefits on US-20 (MP125 - ID Border)

Total Number of Crashes	50
Number of Crashes by Severity	
No Injury Crashes	38
Injury Crashes	10
Fatal Crashes	2
Crash Costs Based on Severity	
Cost of No Injury Crash	$773,946
Cost of Injury Crash	$2,631,160
Cost of Fatal Crash	$9,714,394
Crash Costs due to Delay	
Cost of Delay (No Injury)	$146,822
Cost of Delay (Injury)	$45,777
Cost of Delay (Fatal)	$26,809
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$9,329
Estimated Emissions Cost (Injury)	$2,910
Estimated Emissions Cost (Fatal)	$1,704
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$15,504
Estimated Excess Fuel Costs (Injury)	$4,840
Estimated Excess Fuel Costs (Fatal)	$2,832
Number of Law Enforcement Agencies	5
Total Crash Costs	**$13,376,027**
Expected Cost if Program Was Implemented (CMF)	$6,688,013
Expected Cost due to Number of Law Enforcement Agencies	$1,071,819
Benefit	**$12,304,208**
Benefit/Cost Ratio	**0.920**

5.3.7 US-97/US-197 (004)

US-97/US-197 (004) is the second of two highways that runs the length of state (north-south). The number of crashes by milepost were plotted to determine how the segment should be disaggregated. Based on the crash distribution by milepost, see Figure 5.11, two distinct segments on were considered: (1) MP 0 (Oregon-Washington border just east of The Dalles, OR) to MP 125 (just south of Redmond, OR) and (2) MP 125 (just south of Redmond, OR) to the California border.

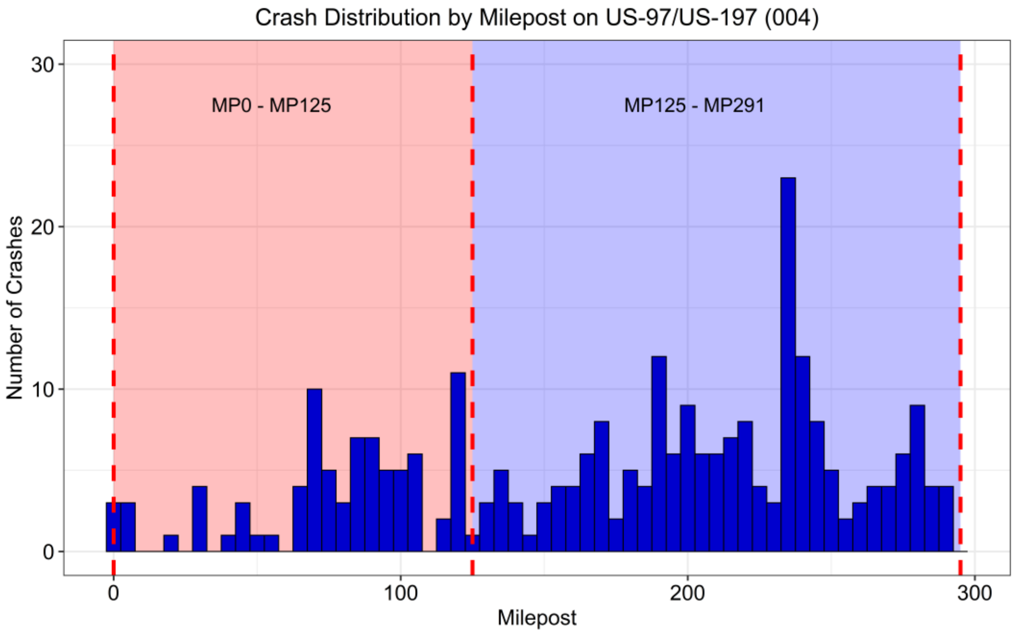

Figure 5.11: Crash distribution by milepost on US-97/US-197 (004)

5.3.7.1 US-97/US-197 (MP0 - MP125)

This segment is 125 miles in length and experienced 25 truck driver-at-fault crashes from 2013 to 2019, of which zero were fatal, 20 involved a non-fatal injury, and 62 resulted in no injury. The number of potential participating law enforcement agencies along this segment is five with an associated incidence rate ratio of 0.160. Based on these numbers, the total estimated crash cost is approximately $6.9 million, with an anticipated benefit (reduction in crash cost) of about $6.4 million, approximately a 92% decrease. The benefit/cost ratio for this segment is 0.920. A summary of all costs and benefits on this segment is shown in Table 5.18.

Table 5.18: Summary of Crash Costs and Benefits on US-97/US-197 (004) (MP0 - MP125)

Total Number of Crashes	82
Number of Crashes by Severity	
No Injury Crashes	62
Injury Crashes	20
Fatal Crashes	0
Crash Costs Based on Severity	
Cost of No Injury Crash	$1,262,754
Cost of Injury Crash	$5,262,321
Cost of Fatal Crash	$0
Crash Costs due to Delay	
Cost of Delay (No Injury)	$239,552
Cost of Delay (Injury)	$91,553
Cost of Delay (Fatal)	$0
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$15,220
Estimated Emissions Cost (Injury)	$5,820
Estimated Emissions Cost (Fatal)	$0
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$25,296
Estimated Excess Fuel Costs (Injury)	$9,680
Estimated Excess Fuel Costs (Fatal)	$0
Number of Law Enforcement Agencies	5
Total Crash Costs	**$6,912,196**
Expected Cost if Program Was Implemented (CMF)	$3,456,098
Expected Cost due to Number of Law Enforcement Agencies	$553,873
Benefit	**$6,358,323**
Benefit/Cost Ratio	**0.920**

5.3.7.2 US-97/US-197 (MP 125 – California Border)

This segment is approximately 160 miles in length and experienced 194 truck driver-at-fault crashes from 2013 to 2019, of which three were fatal, 40 involved a non-fatal injury, and 151 resulted in no injury. The number of potential participating law enforcement agencies along this segment is six with an associated incidence rate ratio of 0.459. Based on these numbers, the total estimated crash cost is approximately $29.1 million, with an anticipated benefit (reduction in crash cost) of about $22.4 million, approximately a 77% decrease. The benefit/cost ratio for this segment is 0.770. A summary of all costs and benefits on this segment is shown in Table 5.19.

Table 5.19: Summary of Crash Costs and Benefits on US-97/US-197 (004) (MP125 - CA Border)

Total Number of Crashes	194
Number of Crashes by Severity	
No Injury Crashes	151
Injury Crashes	40
Fatal Crashes	3
Crash Costs Based on Severity	
Cost of No Injury Crash	$3,075,417
Cost of Injury Crash	$10,524,642
Cost of Fatal Crash	$14,571,591
Crash Costs due to Delay	
Cost of Delay (No Injury)	$583,425
Cost of Delay (Injury)	$183,106
Cost of Delay (Fatal)	$40,213
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$37,069
Estimated Emissions Cost (Injury)	$11,640
Estimated Emissions Cost (Fatal)	$2,556
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$61,608
Estimated Excess Fuel Costs (Injury)	$19,360
Estimated Excess Fuel Costs (Fatal)	$4,248
Number of Law Enforcement Agencies	6
Total Crash Costs	**$29,114,875**
Expected Cost if Program Was Implemented (CMF)	$14,557,438
Expected Cost due to Number of Law Enforcement Agencies	$6,682,273
Benefit	**$22,432,602**
Benefit/Cost Ratio	**0.770**

5.3.8 US-97 (042)

The final highway considered for analysis was US-97 (042). Of all the highways considered, this was indeed the shortest in length at about 68 miles. US-97 (042) runs from Biggs Junction at the Washington Border to the US-197 junction. Still, the crash distribution by milepost, see Figure 5.11, was plotted.

From 2013 to 2019 there were 93 truck driver-at-fault crashes, of which 1 was fatal, 14 involved a non-fatal injury, and 78 resulted in no injury. The number of potential participating law enforcement agencies along this segment is two with an associated incidence rate ratio of 0.853. This was the lowest number of participating law enforcement agencies and attributed to its rural location. Just one local municipality was considered and the county sheriff's office. The estimated incidence rate ratio was also the highest; albeit, it was still less than one (indicating a reduction in the estimated number of crashes). Based on these numbers, the total estimated crash cost is approximately $10.6 million, with an anticipated benefit (reduction in crash cost) of about $6.1 million, approximately a 57% decrease. Although a substantial anticipated decrease in crash costs, this was the lowest decrease of the segments considered for analysis. The benefit/cost ratio for this segment is 0.573. A summary of all costs and benefits on this segment is shown in Table 5.20.

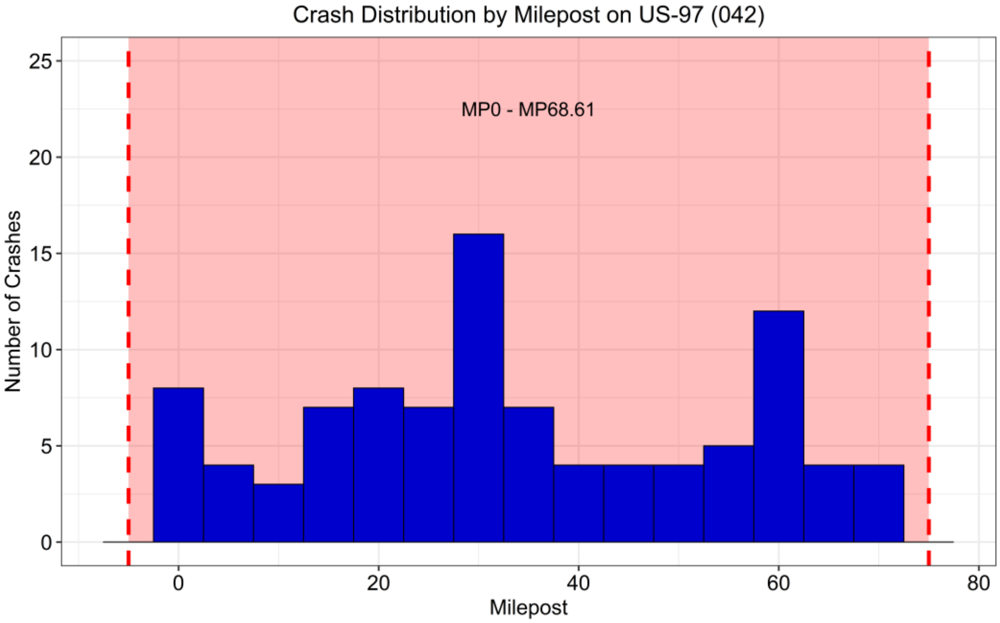

Figure 5.12: Crash distribution by milepost on US-97 (042)

Table 5.20: Summary of Crash Costa and Benefits on US-97 (042)

Total Number of Crashes	93
Number of Crashes by Severity	
No Injury Crashes	78
Injury Crashes	14
Fatal Crashes	1
Crash Costs Based on Severity	
Cost of No Injury Crash	$1,588,626
Cost of Injury Crash	$3,683,625
Cost of Fatal Crash	$4,857,197
Crash Costs due to Delay	
Cost of Delay (No Injury)	$301,372
Cost of Delay (Injury)	$64,087
Cost of Delay (Fatal)	$13,404
Crash Costs due to Emissions	
Estimated Emissions Cost (No Injury)	$19,148
Estimated Emissions Cost (Injury)	$4,074
Estimated Emissions Cost (Fatal)	$852
Crash Costs due to Excess Fuel Burn	
Estimated Excess Fuel Costs (No Injury)	$31,824
Estimated Excess Fuel Costs (Injury)	$6,776
Estimated Excess Fuel Costs (Fatal)	$1,416
Number of Law Enforcement Agencies	2
Total Crash Costs	**$10,572,401**
Expected Cost if Program Was Implemented (CMF)	$5,286,201
Expected Cost due to Number of Law Enforcement Agencies	$4,509,428
Benefit	**$6,062,973**
Benefit/Cost Ratio	**0.573**

Each segment, based on the CMF and the effects of number of law enforcement agencies, is anticipated to have substantial reductions in crash costs if the program was implemented. A full summary is provided in Table 5.21, and the highest impacts based on the benefit/cost ratio and monetized benefit are shown in Figure 5.13 and Figure 5.14, respectively.

Due to some segments having the same number of potential participating law enforcement agencies, the benefit/cost ratio was the same. That said, however, the total benefit (reduction in crash costs) from a monetary perspective differed based on the number of crashes observed on that segment, with the interstate segments having the highest potential monetary savings. For instance, the benefit/cost ratio on I-84 (MP 46 – MP 168) is the same on US-20 (MP 0 – MP 125): 0.499. However, the overall reductions from a monetary perspective are much greater for the former at approximately $20 million (compared to $8.3 million for the latter). This was the overall trend and dependent on the estimated crash costs; ultimately, the higher the estimated crash costs, the higher the anticipated reductions.

Based on the anticipated monetary savings, the top three locations are I-84 (MP 168 - ID), I-5 (MP 126 – MP 250), and I-5 (MP 0 – MP 126). Referring back to Chapter 5.2.5, where average monthly and quarterly costs for inspections based on I-205 were provided, results suggest that a monthly investment of $19,152 (or quarterly investment of $57,570) can reduce crash costs up to approximately $47.9 million on I-84 (MP 168 - ID), up to $37 million on I-5 (MP 126 – MP 250), and up to $28 million on I-5 (MP 0 – MP 126). The first non-interstate that can serve as a viable location for the program is US-97/US-197 (MP 125 - CA), which a monthly investment of $19,152 (or quarterly investment of $57,570) can reduce crash costs up to $22.4 million.

There are a few things that need to be pointed out about these possible savings. The first is regarding the CMF, which suggests the total crash costs are cut in half before any other factor is considered. This CMF is based on crash data with certain limitations and could be overestimating the reduction. Additionally, the CMF was computed on an interstate, which differs from some of the facilities considered for analysis. Secondly, the multiplicative factor is based on model estimations of the number of law enforcement agencies, which were the same for some highways based on them having the same number of law enforcement agencies. Lastly, the investment assumes that at a minimum these are the number of inspections being given each month or quarter.

Table 5.21: Summary of Analysis Segments

Highway (Segment)	OR Hwy Number	Length (mi)	Truck VMT[a]	Enforcement Agencies	IRR[b]	B/C[c]	Benefit
I-5 (MP0 - MP126)	001	126	881,648	9	0.771	0.614	$28,047,963
I-5 (MP126 - MP-250)	001	124	1,192,624	10	0.471	0.765	$37,007,068
I-84 (MP46 - MP168)	002	122	710,017	4	0.499	0.750	$19,862,941
I-84 (MP168 - ID)	006	209	915,022	9	0.771	0.614	$47,973,012
OR-58	018	86	120,745	3	0.682	0.659	$17,855,199
OR-99W	091	124	141,313	17	0.287	0.856	$12,876,600
US-101 (MP0 - MP150)	009	150	131,924	13	0.110	0.945	$4,076,812
US-101 (MP150 - MP250)	009	100	123,872	7	0.102	0.949	$4,827,548
US-101 (MP250 - CA)	009	115	83,252	5	0.160	0.920	$2,158,773
US-20 (MP0 - MP125)	007	125	88,331	4	0.499	0.750	$8,289,509
US-20 (MP125 - ID)	007	140	93,388	5	0.160	0.920	$12,304,208
US-97/US-197 (MP0 - MP125)	004	125	145,970	5	0.160	0.920	$6,358,323
US-97/US-197 (MP125 - CA)	004	160	304,739	6	0.459	0.770	$22,432,602
US-97	042	68	84,576	2	0.853	0.573	$6,062,973

[a] Truck VMT for 2019

[b] Incidence rate ratio

[c] Benefit/cost ratio

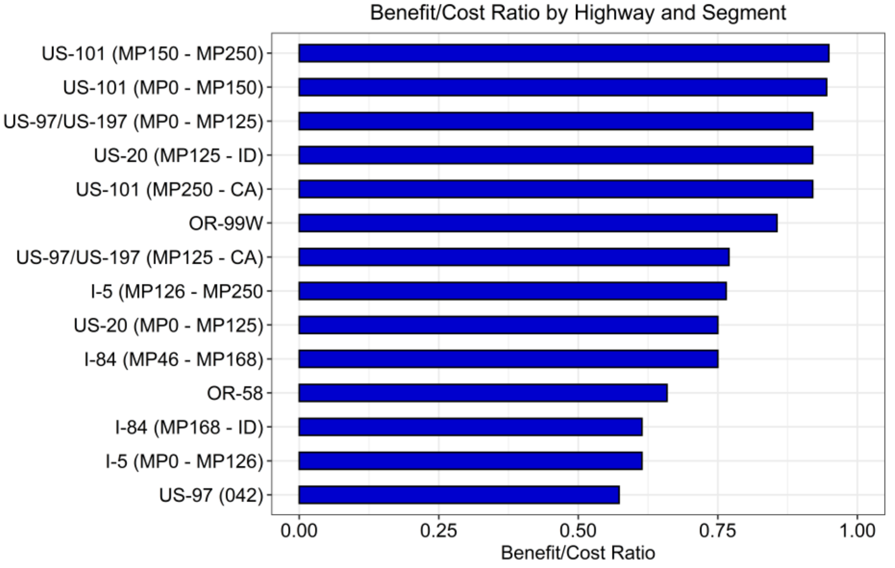

Figure 5.13: Benefit/cost ratio by highway and segment

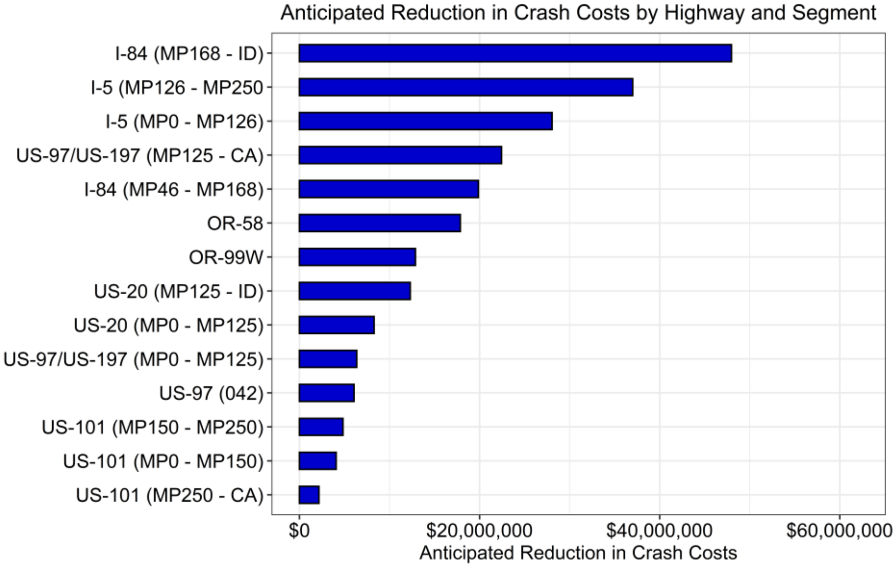

Figure 5.14: Anticipated reduction in crash costs by highway and segment

5.4 SUMMARY

Eight highways were selected for analysis based on the number of truck driver-at-fault crashes that occurred from 2013 to 2019. Following highway selection, various crash-related costs were identified, including the crash costs due to severity, crash costs due to delay, crash costs due to emissions, crash costs due to excess fuel burn, and the estimated investment cost based on the average number of inspections and the price paid for those inspections. One additional cost was determined through a modeling framework: the expected change in crashes (therefore crash cost) due to the number of potential participating law enforcement agencies. To quantify these effects, as to relate to cost, incident rate ratios were computed from final model specifications. These provide a multiplicative factor that can be used with the CMF to determine the overall anticipated crash cost reduction. This reduction was referred to as a benefit in this work. The effects varied, with some lower number of agencies having a greater impact than a higher number of agencies. It is expected that this is a result of unobservable site-specific characteristics that are being captured in these parameter estimates. It is recommended that additional modeling frameworks be applied to better account for this.

Results from the benefit/cost analysis show that all segments are anticipated to have a substantial reduction in crash costs were the program to be implemented. There were two metrics presented, the first of which is the benefit/cost ratio. The highest benefit/cost ratio was computed for US-101 (MP 150 – MP 250) at 0.949, indicated an expected 95% reduction in crash costs. This trend was observed for all US-101 segments, US-20 (MP 125 - ID), and US-97/US-197 (MP 0 – MP 125), each with a benefit/cost ratio of greater than 0.900. Although the anticipated crash reductions are significant, the monetary value is much less compared to some of the highways with lower benefit/cost ratios. This is a result of the aforementioned highways not experiencing as many crashes as those with lower benefit/cost ratios. The largest anticipated reductions were observed on the interstates, ranging from approximately \$19.9 million to roughly \$48 million. Also with a large anticipated monetary reduction is US-97/US-197 (MP 125 - CA) at about \$22 million. Based on historical inspection trends, as well as the price per inspection, on I-205, average monthly and quarterly costs of \$19,152 and \$57,570, respectively, were estimated. Assuming, that a minimum, this number of inspections occur each month, or quarter, the crash cost reductions can be up to the aforementioned values

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6.0 LAW ENFORCEMENT SURVEYS

To gauge law enforcement perception and willingness to adopt such a program in Oregon a survey was administered via Qualtrics to various agencies throughout the state. To accomplish this, a robust list of key law enforcement personnel (i.e., county Sheriffs and police chiefs) that make department decisions was developed. The list contained 150 law enforcement agencies adjacent to corridors that would make viable candidates for the program. Of the 150 law enforcement agencies, contact information was obtained for 91. Contact information included direct emails, when available, and representative emails of a respective agency. The final survey included responses from 22 law enforcement representatives, a response rate of about 24%.

The survey consisted of 9 questions with an average completion time of 3 minutes and 20 seconds. Law enforcement representatives were asked direct question related to Level 2 truck inspections and their willingness to adopt such a program. Respondents were first asked if their agency currently has officers trained, or are planning to have them trained, to conduct North American Standard Level 2 commercial motor vehicle inspections. If the answer to this question was ‘Yes,’ they were then asked how many, on average, Level 2 inspections are conducted by their officers on an annual basis and how many officers are currently trained to conduct such an inspection. The officers were then asked how willing their agency is to participate in such a program if state funds were provided.

If the answer to the first question was ‘No,’ respondents were asked about the reason for not having officers trained, or are planning to have them trained, to conduct such inspections. Respondents in this category were then asked how willing they would be in participating in such a program if state funds were provided.

To conclude, all survey respondents were asked to give their agency name, city, and county.

This chapter summarizes the survey results obtained from the 22 law enforcement representatives.

6.1 SURVEY RESULTS

The first question asked was “Does your agency currently have officers trained or are planning to have them trained to conduct North American Standard Level 2 commercial motor vehicle inspections?” Results from this question are shown in Figure 6.1. Of the 22 respondents, the vast majority indicated they do not have officers trained, or are planning to have them trained, to conduct Level 2 inspections (17 of the 22 respondents), while just five answered ‘Yes.’

For those that answered ‘Yes,’ just two provided a response on the average number of inspections given on an annual basis, both of which indicated that zero inspections are conducted. When asked how many officers are trained to conduct Level 2 inspections, one stated zero and the one state that just one officer was trained. In regards to how willing their agency is in participating in such a program if state funds were provided, just three respondents provided an answer. Two stated that their agency would be 'Somewhat Likely' willing to participate and one stated that their agency would be 'Extremely Likely' to participate.

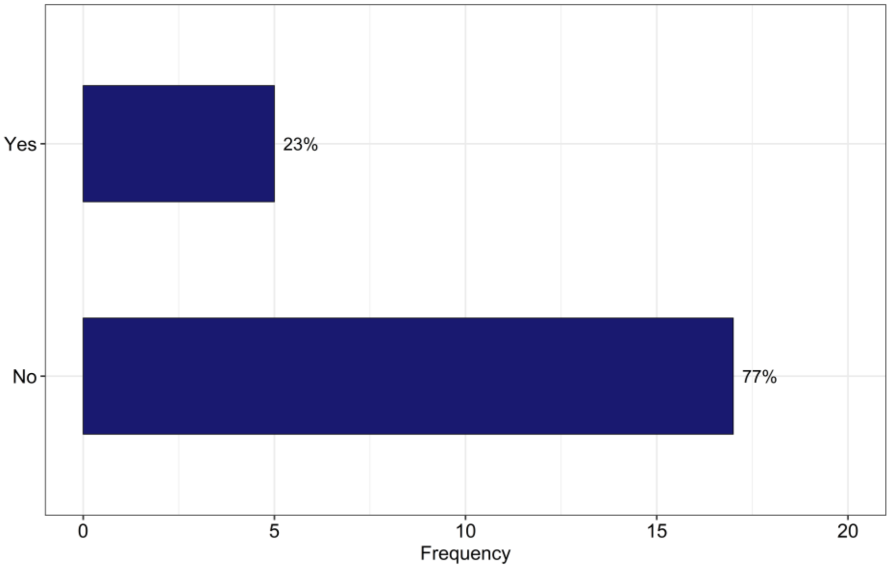

Figure 6.1: Does your agency currently have officers trained or are planning to have them trained to conduct North American standard level 2 commercial motor vehicle inspections?

As stated previously, the majority of responses were 'No.' Those that answered 'No' were asked *"Would you say the reason for not having trained officers or/are planning to have them trained to conduct North American Level 2 commercial motor vehicle inspections is: (Please enter your reason(s) below)."* Of the 17 respondents, 13 provided an answer to this question, where responses were somewhat varied. A summary of responses is given in Table 6.1.

Of the 13 responses, five were related to staffing or funding/budget. Two responses were related to truck crash frequency, specifically that few truck-involved crashes occur, and truck at-fault crash rate is low; hence, having officers trained for Level 2 inspections is not justified.

The remaining responses all varied. One respondent indicated that have officers trained for Level 2 inspections add *"little to no value."* This respondent, as did five others, indicated that police are underfunded and understaffed; therefore, are "*worried about other greater concerns that truck inspections at this time."* The respondent went on to say that *"Level II inspection is tedious, time consuming and confusing."*

A representative from the Ashland Police Department stated that their office had trained Level 2 inspectors and had one for 20 years. According to the respondent, their office was recently told that all Level 2 inspectors did not meet the federal requirement and all inspections had to stop. In a similar comment, a representative from the Gilliam County Sheriff's Office stated that there are too many rules and regulations for their inspectors. This respondent went on to say, *"Train them and let them go and do the job while being managed by their supervisors."*

One respondent simply stated their agency has very little contact with commercial motor vehicles, while another said this type of inspection is the responsibility of the Oregon State Police.

One response was from an Oregon State Police representative, in which they indicated that there were Level 2 inspectors, but federal changes no longer recognized Oregon Level 2 inspectors and inspections. As a result, Oregon State Police was left with about seven Level 1 inspectors, where there is currently less than five.

Table 6.1: Summary of Responses for Not Having Trained Officers and/or Planning to Have Them Trained

Agency	City	County	Response
The Dalles Police	The Dalles	Wasco	It adds little to no value. Police are underfunded, understaffed and worried about other greater concerns than truck inspections at this time. The Level II inspection is tedious, time consuming and confusing.
Polk County Sheriff's Office	Dallas	Polk	Not enough staff.
Milton-Freewater Police Department	Milton-Freewater	Umatilla	Budgetary
Gervais	Gervais	Marion	Funding
Pendleton Police Department	Pendleton	Umatilla	We are a municipal agency that has very little contact with commercial motor vehicles.
Milwaukie Police Department	Milwaukie	Clackamas	Small agency with not enough officers to staff this sort of thing.
Ashland Police Department	Ashland	Jackson	We had trained Level 2 inspectors, one for 20 years, but in 2019 we were told all Level 2 inspectors didn't meet the federal requirement and had to stop the inspections.
Douglas County Sheriff's Office	Roseburg	Douglas	This type of inspection should be done at the state level (OSP).
Cottage Grove Police Department	Cottage Grove	Lane	We do not have the staffing to expand to this duty.
Gilliam County Sheriff's Office	Condon	Gilliam	Too many rules and regulations for our inspectors. Train them and let them go out and do the job while being managed by their supervisors.
Silverton Police Department	Silverton	Marion	Few traffic crashes involving trucks in our city.
Roseburg Police Department	Roseburg	Douglas	Very low truck at fault crash rate in our city to justify.
Oregon State Police	Salem	Marion	Our patrol troopers were once certified Level II truck inspectors. However, when the Feds no longer recognized Oregon Level II inspectors and inspections, we were left with approximately seven Level I truck inspectors. Currently, we have less than five Level I truck inspectors.

To conclude, all respondents that indicated ‘No’ were also asked their willingness to participate in such a program if state funds were to be provided. As with the reasons for not having officers trained, or planning to have them trained, responses varied. For a summary, see Figure 6.2 (note that some respondents chose to answer this question without giving a reason in Table 6.1). Half of the responses indicated neutrality, as six respondents indicated their agency would be neither likely nor unlikely to adopt the program. Of those that were not neutral, the responses were split between being likely and unlikely to adopt: four stating that their agency would be extremely or somewhat likely to adopt and five stating that their agency would be extremely or somewhat unlikely to adopt.

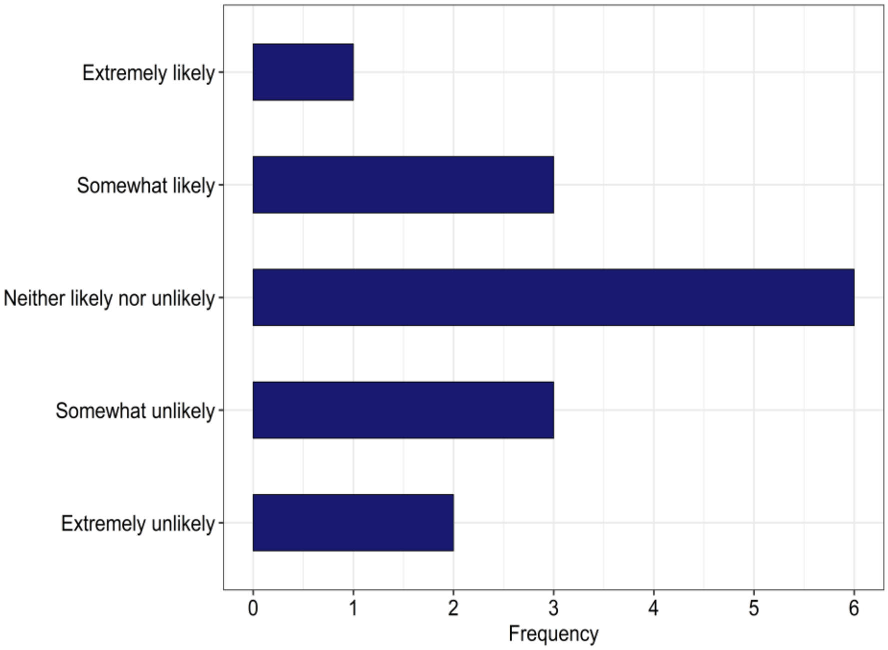

Figure 6.2: If agency does not have trained officers or/are planning to have them trained, how willing would their agency be in participating in the program if state funds were provided?

6.2 SURVEY SUMMARY

From a list of 150 agencies, contact information was obtained for 91, of which 22 participated in the survey (a response rate of approximately 24%). The survey consisted of nine questions with an average completion time of 3 minutes and 20 seconds. Survey respondents were asked direct questions related to Level 2 truck inspections in their jurisdiction. The majority of respondents indicated that they do not currently have trained officers for Level 2 inspections, or plan to train officers (just five indicated that they do).

The 17 respondents that indicated they do not have trained officers, or plan to train officers, were provided an opportunity to comment on why this is the case, 13 elected to do so. Responses represented various areas throughout Oregon, with funding/budget and/or staffing being the leading reason why. Other reasons included the lack of truck crashes in their area, changes in federal requirements, and it not being the responsibility of their agency. The same 17 respondents were also asked how willing their agency would be to participate if state funds were to be provided, of which 15 answered. The majority of responses were neutral, while the same number of respondents indicated they were likely and unlikely to participate (four likely and five unlikely).

7.0 COST ALLOCATION

To determine the appropriate cost allocation, crash trends and costs on I-205, as well as the benefits for potential corridors, were considered. Appendix B illustrates the analyses conducted for this work. Despite data limitations and the resulting crash modification factor, it is known that the program has worked as intended: reduce the number of truck driver-at-fault crashes (Anderson et al. 2020). Considering I-205, the highway that accounted for approximately two-thirds of all inspections, Figure 7.1 shows the general trend between inspections and crashes; specifically, as increases in inspections occur (points on the red line) decreases in crashes occur (valleys in the blue line).

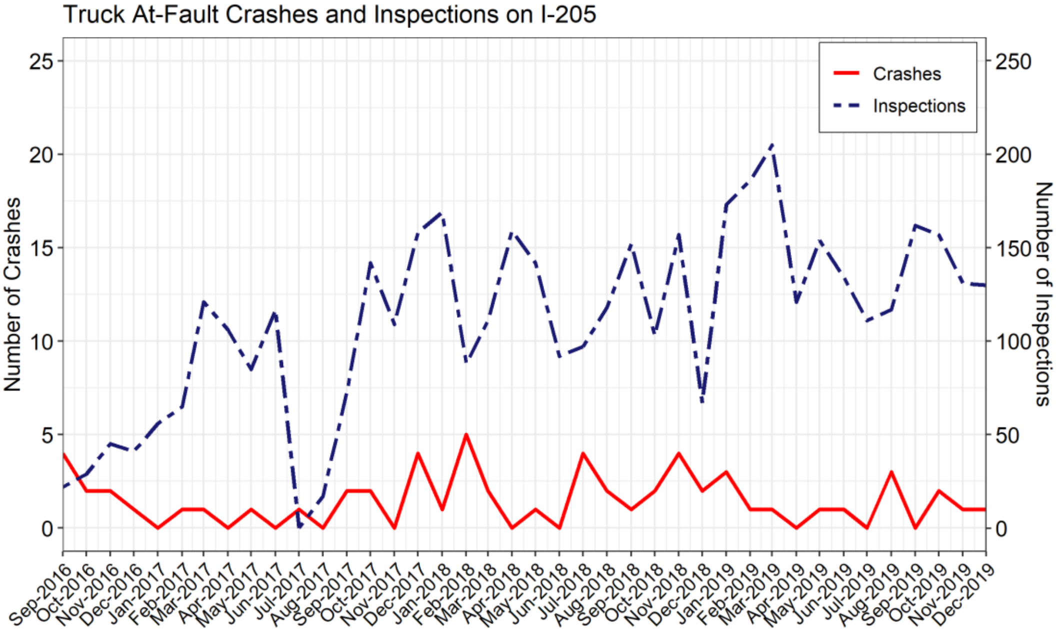

Figure 7.1: Truck Driver-at-Fault Crashes and Inspections on I-205

A summary of inspections by highway and year is given in Table 7.1. Other than I-205, the dollars spent each year are less than the monthly, or quarterly, average of $19,152 and $57,570, respectively. Although some of these highways did experience a decrease in truck driver-at-fault crashes, the number of crashes were small. Due to small sample sizes, both for crashes and inspections, it is difficult to make inference on the effectiveness of the program on these corridors. See Appendix B for a visual summary of the various models that were generated for each of these highways.

Table 7.1: Summary of Inspections and Cost by Highway

Highway	Number of Inspections				Inspection Cost			
	2016	2017	2018	2019	2016	2017	2018	2019
I-205	137	1,049	1,455	1,781	$15,584	$119,324	$165,506	$202,589
I-5 (MP250 – WA)	49	257	100	184	$5,574	$29,234	$11,375	$20,930
I-84 (MP0 – MP46)	26	97	318	36	$2,958	$11,034	$36,173	$4,095
Marine Drive	41	70	18	49	$4,664	$7,963	$2,048	$5,574
US-395	8	73	63	23	$910	$8,304	$7,166	$2,616
US-30	40	22	48	27	$4,550	$2,503	$5,460	$3,071
OR-22	1	18	36	12	$114	$2,048	$4,095	$1,365
OR-99E	4	21	9	27	$455	$2,389	$1,024	$3,071
OR-213	4	20	8	21	$455	$2,275	$910	$2,389
US-26 (MP53 – MP74)	12	10	15	0	$1,365	$1,138	$1,706	$0
OR-8 (MP3 – MP18)	7	19	3	0	$796	$2,161	$341	$0
OR-217	3	0	3	3	$341	$0	$341	$341
OR-10	1	5	2	0	$114	$569	$228	$0
Other[a]	43	92	47	19	$4,891	$10,465	$5,346	$2,161

[a] Includes non-highway routes

It should be noted, the mechanism in which funds are received and distributed changed in late 2019, which could impact some of the results herein. Keep in mind that from Chapter 5.0 the identified corridors with the highest potential monetary savings were I-5 segments, I-84 segments, and US-97. That said, an effective cost allocation mechanism should now consider the newly accepted federal MCSAP program funds, resources, restrictions, and policies. Survey results from participating Oregon law enforcement agencies indicated their willingness to participate in such a program, but a barrier to doing so were based on lack of staffing and availability of such funds (See Section 8 - Summary and Recommendations)

8.0 SUMMARY AND RECOMMENDATIONS

The objective of this study was to evaluate the Oregon MCSAP program and where to expand the program to for optimal returns. This was accomplished through various research tasks. First, a literature review was conducted to determine current practices in three specific areas: overall safety, safety related to law enforcement, and studies that implemented benefit/cost methods. In the safety review, it was determined that few studies focus on truck at-fault crashes explicitly and their crash frequency or injury severity contributing factors. In general, truck-involved crashes, regardless of fault, make up most of the literature in this regard. Considering law enforcement related studies, the literature was consistent regarding the positive effects of increased law enforcement on reducing crashes. It was also discovered that no studies explicitly focused on truck crashes. Lastly, regarding benefit/cost studies, the literature is sparse. Most importantly, no studies were found that address monetary effects of truck crashes and/or related safety programs.

Upon completion of the literature review, the remaining tasks consisted of data-driven approaches to evaluate the MCSAP program and determine how to obtain the best return on investment. First, data collection was conducted and followed by a descriptive analysis of the data to be used. Next, safety performance of the program was assessed by computing a crash modification factor. After assessing the safety performance of the program, a benefit/cost analysis was conducted to assess the viability of potential corridors to be part of the program moving forward. Following these analyses, a survey was administered to decision makers at law enforcement agencies across Oregon, with an emphasis on agencies surrounding the corridors presented in Chapter 5.3. To conclude, an assessment of how to best allocate funding based on the analysis findings was provided.

The following sub-chapters summarize the results of each of the analyses. Recommendations follow the analysis summaries.

8.1 DATA COLLECTION AND DESCRIPTIVE ANALYSIS

Before any analysis, a comprehensive data collection process and descriptive analysis was conducted. Data collected as part of the MCSAP program was obtained first. The data showed that since the start of the program (September 2016) through December 2019, there were a total of 6,436 traffic violations that lead to Level 2 truck inspections. The leading violations were speeding and lane restriction violations, and no other traffic violation accounted for more than 4% of the total traffic stops. It was also determined that these traffic stops occurred primarily on I-205 (69%), I-5 (9%), and I-84 (7%).

After collecting and analyzed the MCSAP data, Oregon crash data was collected and analyzed. For the descriptive analysis, Oregon crash data from 2013 to 2018 was considered (2019 data was not available at the time of analysis). It was discovered that crash data from 2016-forward was coded differently so that all no injury crashes were coded as ‘NA’ for the driver-level crash cause code. Due to this, large decreases in crashes were observed after 2015. Under this consideration, about 33% of crashes occurred in the fall and winter months of October, December, and January, while the majority of crashes occurred on a weekday. Rear-end crashes were the most occurring crash type. Driver-level crash causes most observed were speeding too fast for conditions, improper lane changing, and following too closely. About 90% of drivers were male, 45% were 45 to 64 years old, and 43% were non-Oregon residents. The majority of truck at-fault crashes occurred on interstates and arterials on straight segments, horizontal curves, and at intersections. In assessing the geographical distribution of crashes, the majority of crash clusters were observed on major Oregon freight routes.

Next, truck crash costs were obtained and summarized to be used in the benefit/cost site ranking model. For this, crash harm metrics were obtained from previous work and converted to 2019 dollars using the consumer price index. To conclude the data collection and descriptive analysis, data on shoulder width was collected. Based on knowledge of the program, ample space to pull a truck over is necessary. Statistics showed that highways which had a higher number of traffic stops had much larger shoulder widths, on average, compared to the statewide average.

8.2 SAFETY PERFORMANCE OF PROGRAM

To determine the overall benefit of the program, a crash modification factor was estimated using the data from I-205. This site was chosen due to its success over the duration of the program and the amount of traffic violation/inspection data available at this location. Although the characteristics of this facility differ from some of the highway selected for analysis, it provides a general estimate of the effects on the expected number of crashes. Using an Empirical Bayes approach, a CMF of 0.50 was estimated, with a 95% confidence interval of 0.34, 0.65 (does not include the value 1.0). This indicates that implementation of the program is expected to decrease the number of truck driver-at-fault crashes by half. This estimated CMF is based on ODOT crash data, in which certain limitations are present. Specifically, for the after data (2017 to 2019), the analyst cannot discern at-fault for no injury crashes. As a result, in a study such as this, any no injury crash in which the truck driver was at-fault is not included. Unfortunately, this leads to the after period having fewer observed crashes and a CMF that is likely overestimating the effects of the program. With that in mind, the presented estimate is the best estimate to be obtained based on the current structure of ODOT crash data. It should also be noted that the CMF was estimated on an interstate, which does differ from some of the facilities considered for analysis.

8.3 BENEFIT/COST SITE RANKING

Eight highways were selected for analysis based on the number of truck driver-at-fault crashes that occurred from 2013 to 2019. Following highway selection, various crash-related costs were identified, including the crash costs due to severity, crash costs due to delay, crash costs due to emissions, crash costs due to excess fuel burn, and the estimated investment cost based on the average number of inspections and the price paid for those inspections. One additional cost was determined through a modeling framework: the expected change in crashes (therefore crash cost) due to the number of potential participating law enforcement agencies. To quantify these effects, as to relate to cost, incident rate ratios were computed from final model specifications. The effects varied, with some lower number of agencies having a greater impact than a higher number of agencies. It is expected that this is a result of unobservable site-specific characteristics that are being captured in these parameter estimates.

Results from the benefit/cost analysis show that all segments are anticipated to have a substantial reduction in crash costs were the program to be implemented. There were two metrics presented, the first of which is the benefit/cost ratio. The highest benefit/cost ratio was computed for US-101 (MP 150 – MP 250) at 0.949, indicating an expected 95% reduction in crash costs. This trend was observed for all US-101 segments, US-20 (MP 125 - ID), and US-97/US-197 (MP 0 – MP 125), each with a benefit/cost ratio of greater than 0.900. Although the anticipated crash reductions are significant, the monetary value is much less compared to some of the highways with lower benefit/cost ratios. This is a result of the aforementioned highways not experiencing as many crashes as those with lower benefit/cost ratios. The largest anticipated reductions were observed on the interstates, ranging from approximately $19.9 million to roughly $48 million. Also with a large anticipated monetary reduction is US-97/US-197 (MP 125 - CA) at about $22 million. Based on historical inspection trends, as well as the price per inspection, on I-205, average monthly and quarterly costs of $19,152 and $57,570, respectively, were estimated. Assuming, that a minimum, this number of inspections occur each month, or quarter, the crash cost reductions can be up to the aforementioned values.

8.4 LAW ENFORCEMENT SURVEYS

From a list of 150 agencies, contact information was obtained for 91, of which 21 participated in the survey (a response rate of approximately 23%). The survey consisted of nine questions with an average completion time of 3 minutes and 17 seconds. Survey respondents were asked direct questions related to Level 2 truck inspections in their jurisdiction. The majority of respondents indicated that they do not currently have trained officers for Level 2 inspections, or plan to train officers (just five indicated that they do).

The 16 respondents that indicated they do not have trained officers, or plan to train officers, were provided an opportunity to comment on why this is the case, 12 elected to do so. Responses represented various areas throughout Oregon, with funding/budget and/or staffing being the leading reason why. Other reasons included the lack of truck crashes in their area, changes in federal requirements, and it not being the responsibility of their agency. The same 16 respondents were also asked how willing their agency would be to participate if state funds were to be provided, of which 14 answered. The majority of responses were neutral, while the same number of respondents indicated they were likely and unlikely to participate (four each).

8.5 RECOMMENDATIONS AND FUTURE WORK

Based on the analysis, the following recommendations are made.

8.6 DESCRIPTIVE ANALYSIS

Although 2020 data was collected, it was not analyzed as part of this work due to irregular traffic behavior due to the COVID-19 pandemic. It is recommended to conduct a descriptive analysis of this data to determine how the program performed during this period (e.g., did changes in law enforcement priority lead to substantial decreases in the number of inspections). Although data is not available at this point, it is also recommended that crash data and truck volume data during this period also be analyzed, then compared to the years prior.

From a crash data perspective, a key limitation in the Oregon crash data was identified. Beginning in 2016, the manner in which several crash data characteristics are coded was changed. A primary change was the coding of no injury crashes, where various crash characteristics are simply denoted as 'NA' for a no injury crash. This can be particularly problematic when conducting analyses on at-fault behavior, as at-fault cannot be determined for no injury crashes. As a result, when conducted at-fault analyses, the total number of at-fault crashes are being undercounted and can impact the analysis results. This was a key factor in this work; thus, a key recommendation is to continue to code no injury crashes for certain crash characteristics as to be able to determine fault.

8.7 SAFETY PERFORMANCE

The recommendations here follow that of Chapter 8.6, specifically the limitations in the Oregon crash data. It is known that the program is effective at reducing truck at-fault crashes, as illustrated in previous work and the descriptive analysis, but the ability to most accurately quantify that effectiveness through a crash modification factor requires data that specific crash types for all severities can be determined. Although a crash modification factor was estimated, it is likely overestimating the effects of the program due to this limitation.

For some of the analyses, data from Oregon's Commerce and Compliance Division (CCD) was used, but that too does not have key pieces of information. Geospatial information, such as crash coordinates, in the CCD data would be extremely beneficial for this type of application. This also offers an avenue for future research that can focus on methods to fuse these two data sources (Oregon crash data and CCD data). This would give researchers and safety engineers the best of both datasets and the ability to complement one with the other if certain safety information is not present.

8.8 BENEFIT/COST SITE RANKING

A key input for the benefit/cost site ranking models was the crash modification factor, where limitations were discussed previously. Additionally, information on crash costs are a vital component of such an analysis and guide the final benefit/cost approximations. With that in mind, the most recent cost metrics for several key crash costs are becoming outdated. To accommodate this, crash costs are converted to current dollars using the consumer price index. Although this can provide good estimates, it is recommended to derive crash costs that reflect recent ancillary costs (e.g., insurance, hospitalization, delay, etc.).

8.9 LAW ENFORCEMENT SURVEYS

Although the response rate exceeded expectations in this work, a large sample size would provide further insight on the perception of inspections from Oregon law enforcement agencies. Of the 150 identified agencies, contact information was obtained for just 60%. Working more closely with CCD to obtain additional contacts, or have CCD contact representatives, is recommended to gather more observations.

This may also be an opportunity for CCD, or ODOT, to hold a workshop with law enforcement agencies in Oregon. The workshop can focus on truck driver-at-fault safety, reported causes, the costs of these crashes, how the program has been effective thus far, and how to best allocate funds for optimal safety returns. OSU and PSU could work in conjunction with this.

8.10 COST ALLOCATION

Due to changes in the funding mechanism (participation in the Federal MCSAP Program), it is recommended to revisit the cost allocation piece of this work. Currently, it is unknown how similar, or dissimilar, the funding process will be. This includes, most notably, the costs of inspections. Additionally, as part of this project, several statistical models were fit for each of the highways as to generate a relationship between inspections and crashes. However, due to lack of supplemental exposure data, each of the models underperformed and parameter estimates were unstable. Similar to previous recommendations, methods to fuse CCD crash data with Oregon crash data and/or collecting geospatial information for CCD data can be helpful tools for such analyses. With the new funding mechanism, it also recommended, similar to that of Chapter 8.9, to conduct a workshop with CCD, ODOT, and law enforcement agencies to determine the best method for resource allocation. OSU and PSU could work in conjunction with this.

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APPENDIX A

2020 INSPECTION AND CRASH TRENDS

Appendix A provides a summary of 2020 trends. These trends, due to changes in traffic behavior as a result of the COVID-19 pandemic, were not included in the analysis.

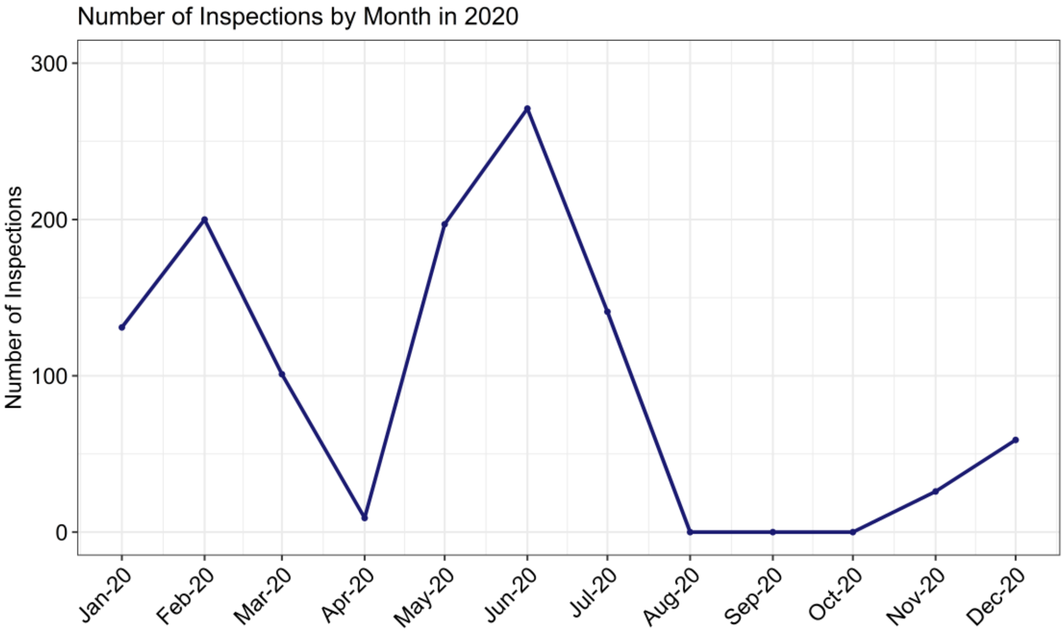

Figure A.1: Number of inspections by month in 2020

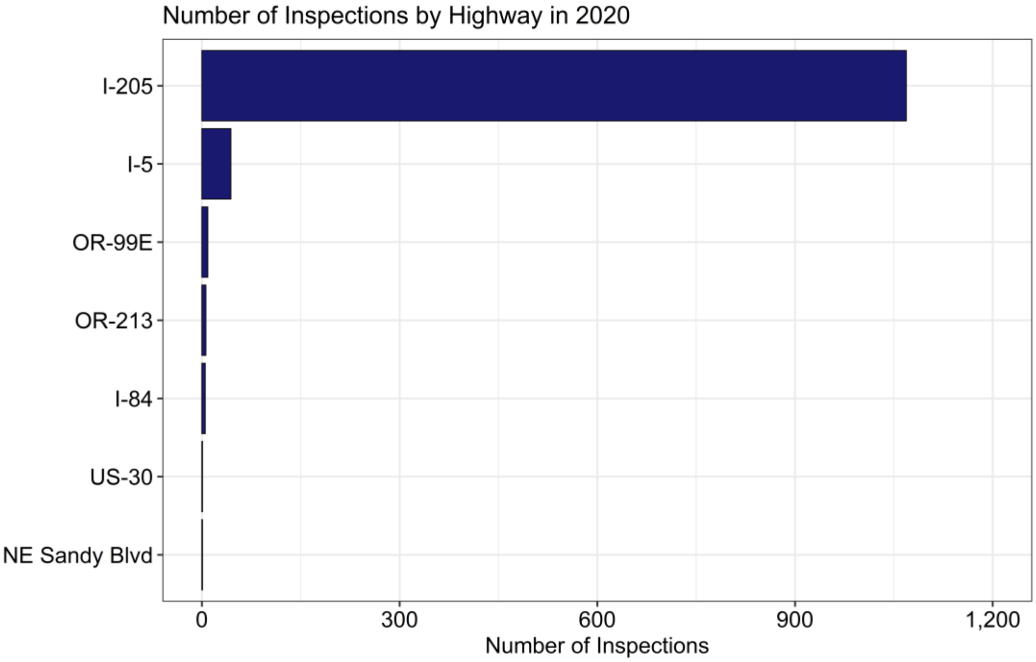

Figure A.2: Number of inspections by highway in 2020

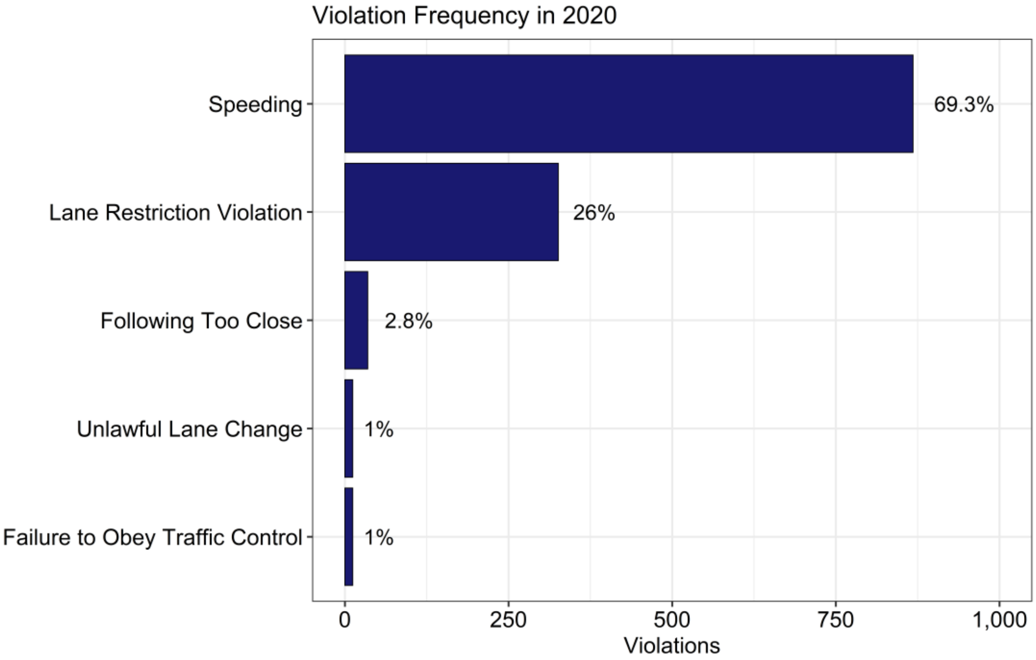

Figure A.3: Violation frequency in 2020

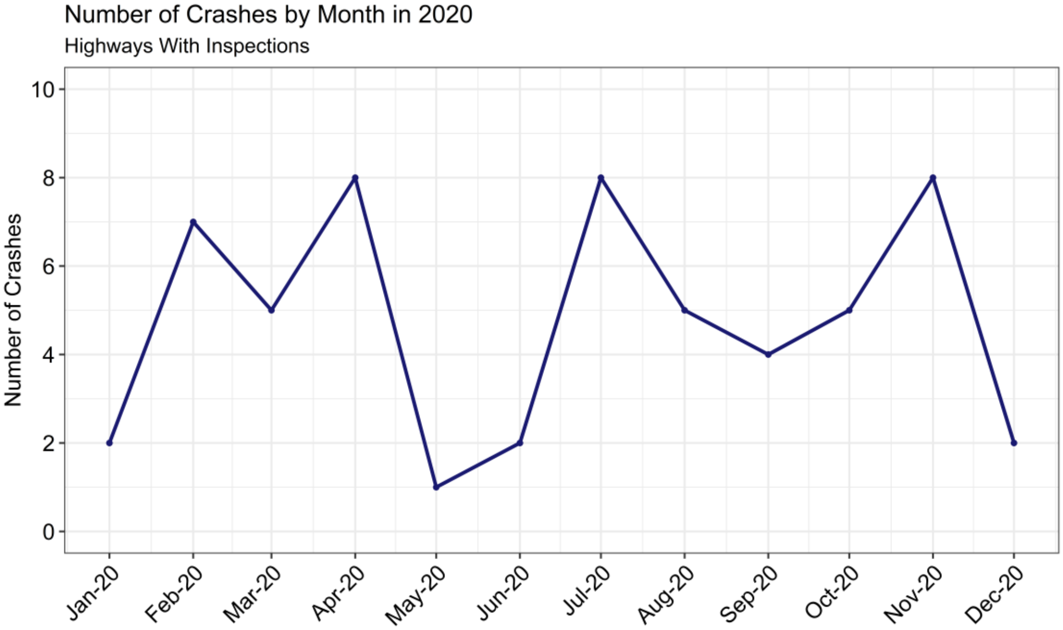

Figure A.4: Number of crashes by month in 2020 (Only highways in which inspections occurred are considered)

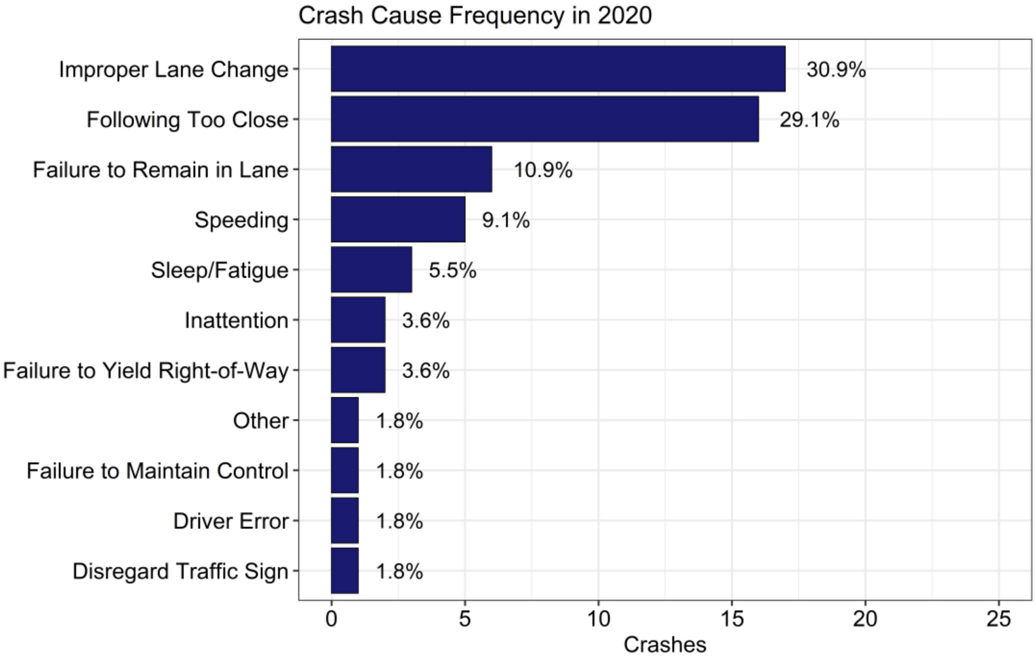

Figure A.5: Number of crashes by recorded crash cause in 2020

APPENDIX B

Appendix B provides a summary of the crash frequency and inspection trends on highways in which inspections occurred. Appendix B also presents a fitted model, visually, for each highway using the Poisson regression model. These results were not included in the analysis due to small samples sizes (for both crashes and inspections, or one or the other) and lack of controlling variables in the regression model.

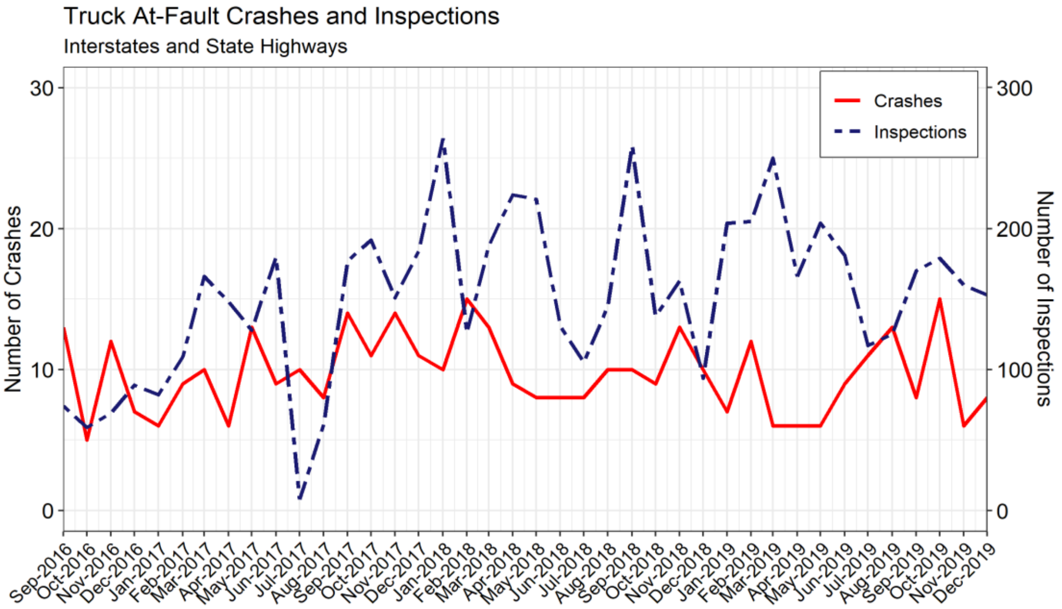

Figure B.6: Truck at-fault crashes and inspections on interstates and state highways

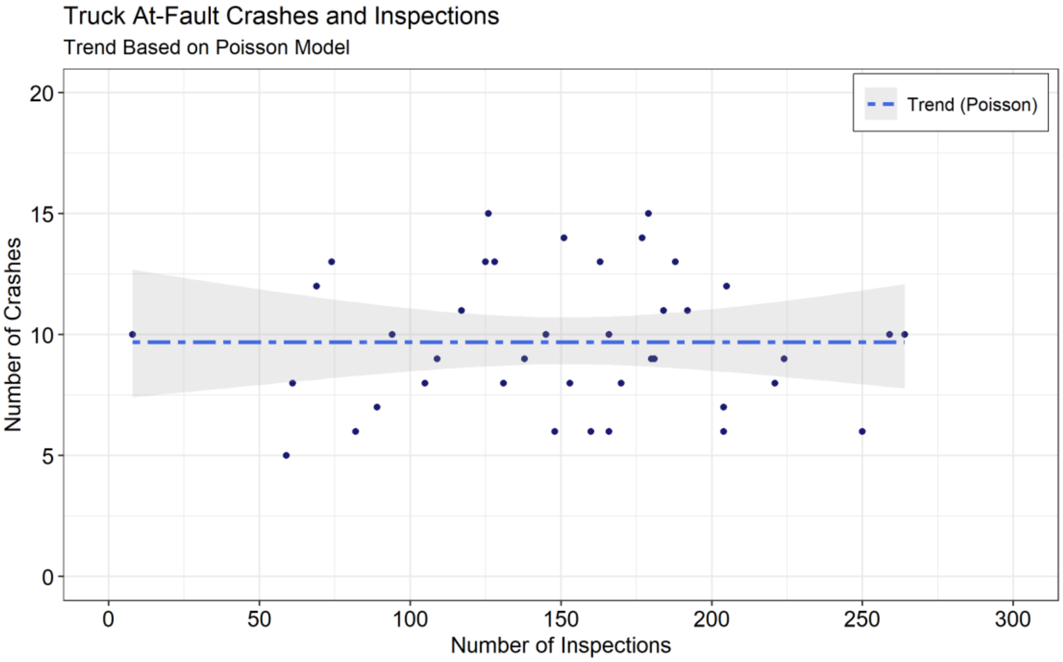

Figure B.7: Relationship between truck at-fault crashes and inspections on interstates and state highways

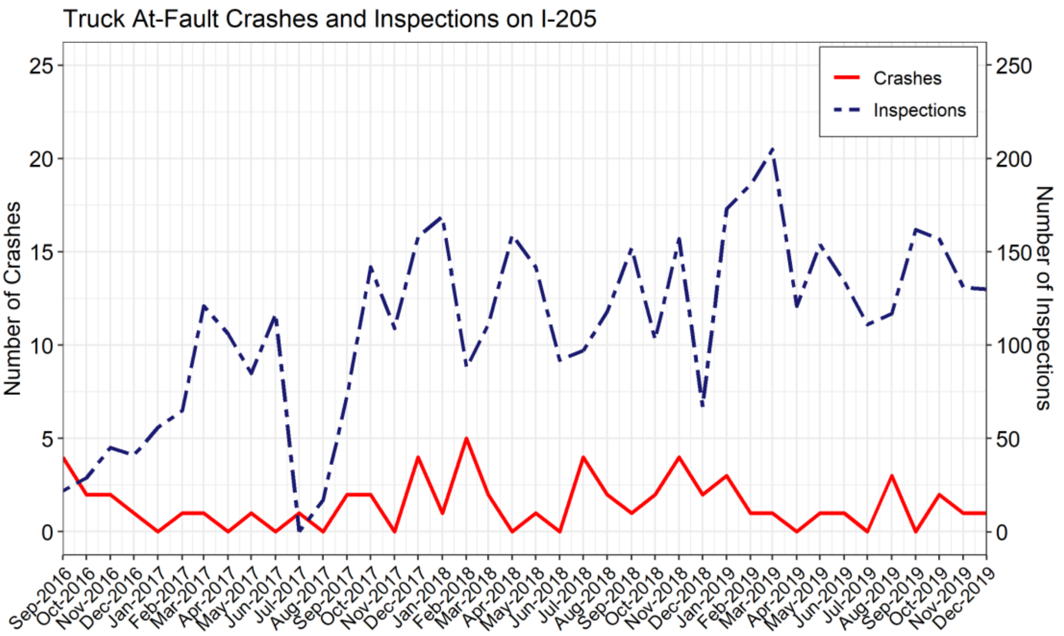

Figure B.8: Truck at-fault crashes and inspections on I-205

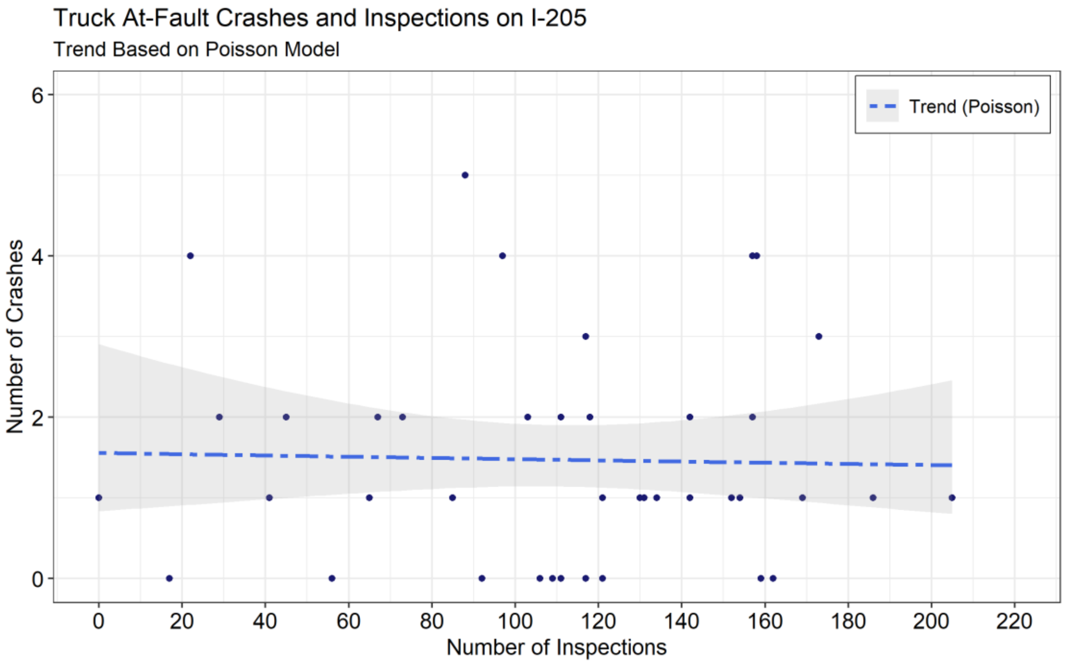

Figure B.9: Relationship between truck at-fault crashes and inspections on I-205

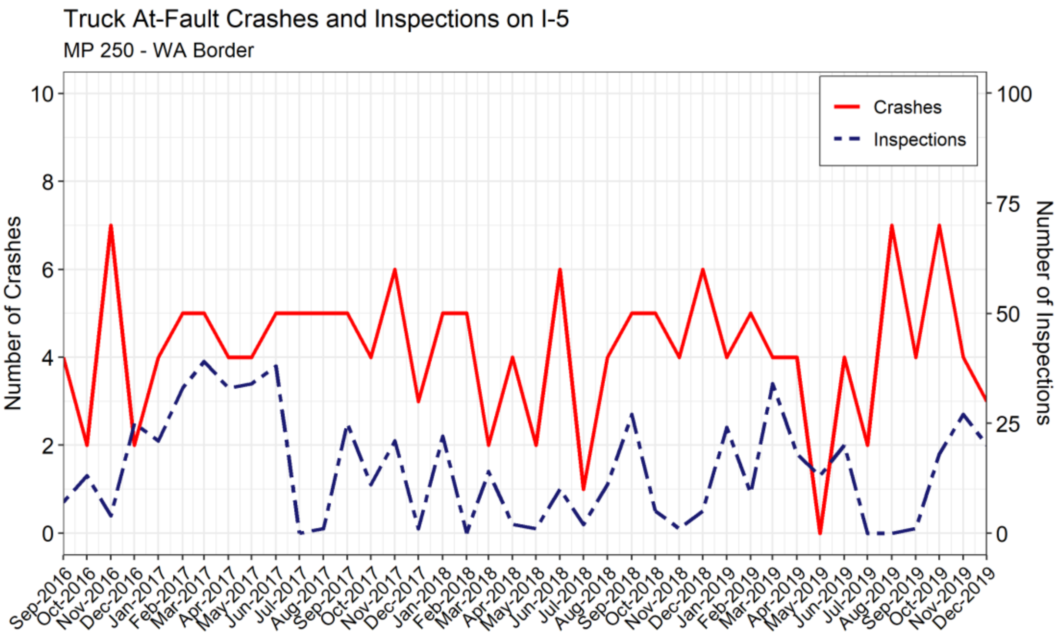

Figure B.10: Truck at-fault crashes and inspections on I-5

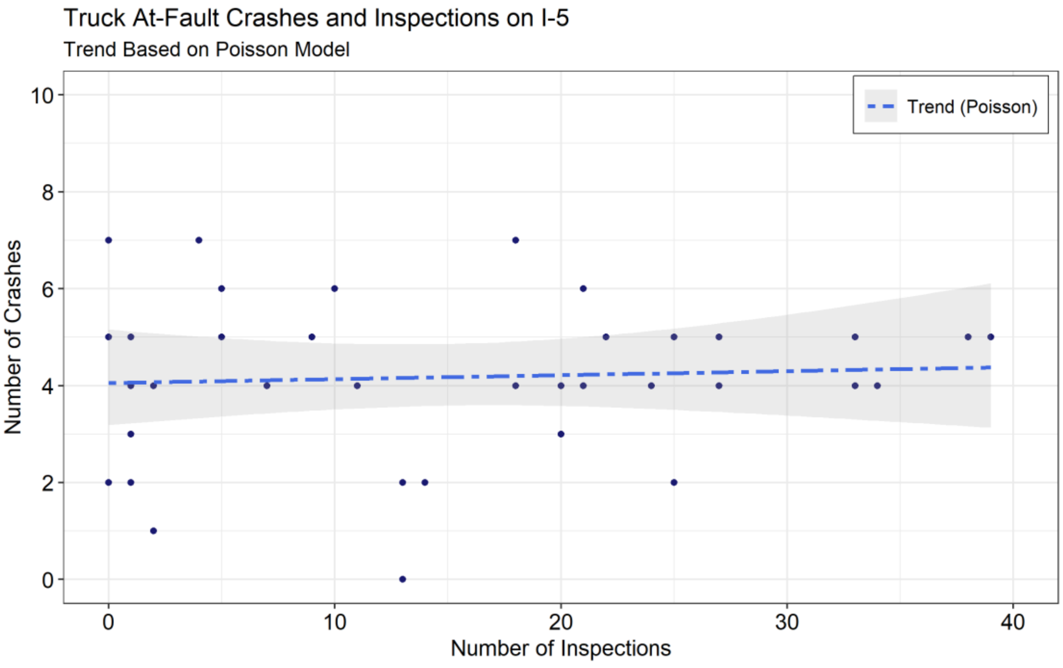

Figure B.11: Relationship between truck at-fault crashes and inspections on I-5

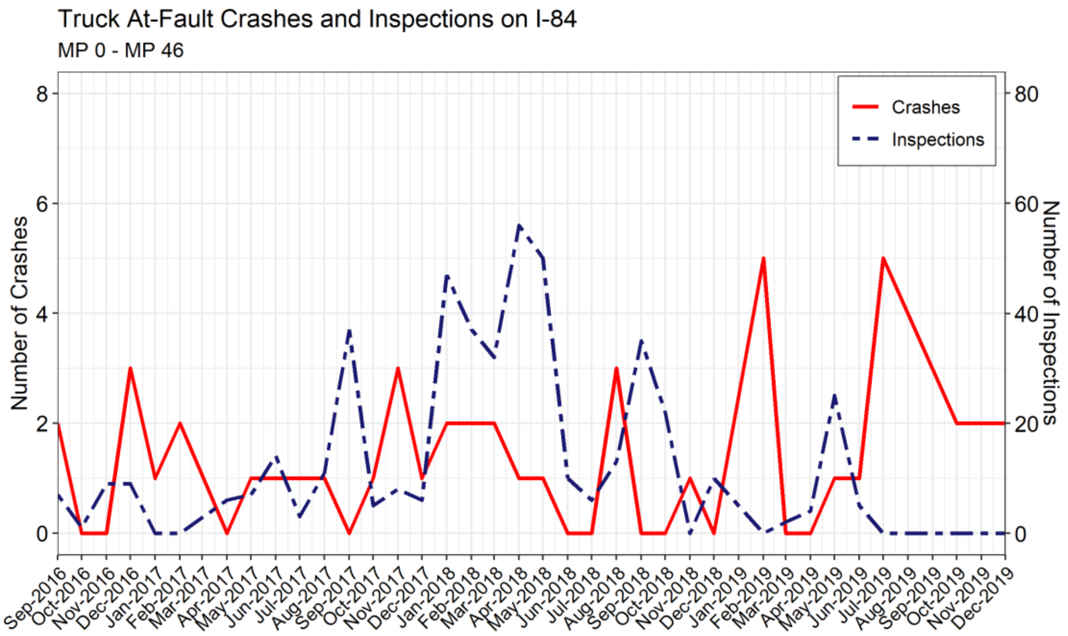

Figure B.12: Truck at-fault crashes and inspections on I-84

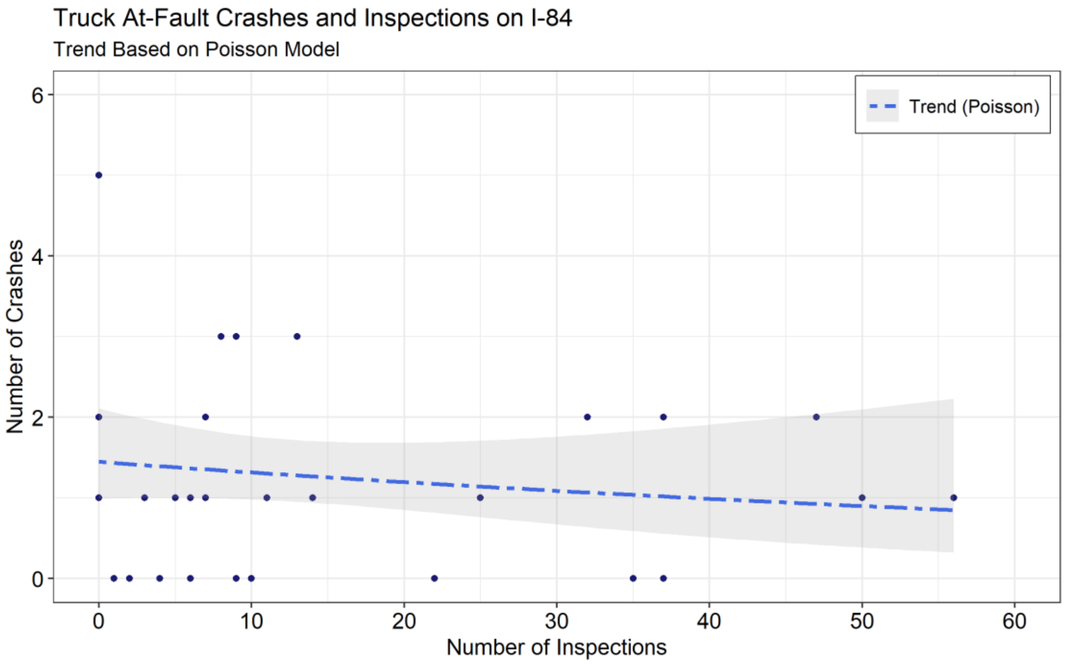

Figure B.13: Relationship between truck at-fault crashes and inspections on I-84

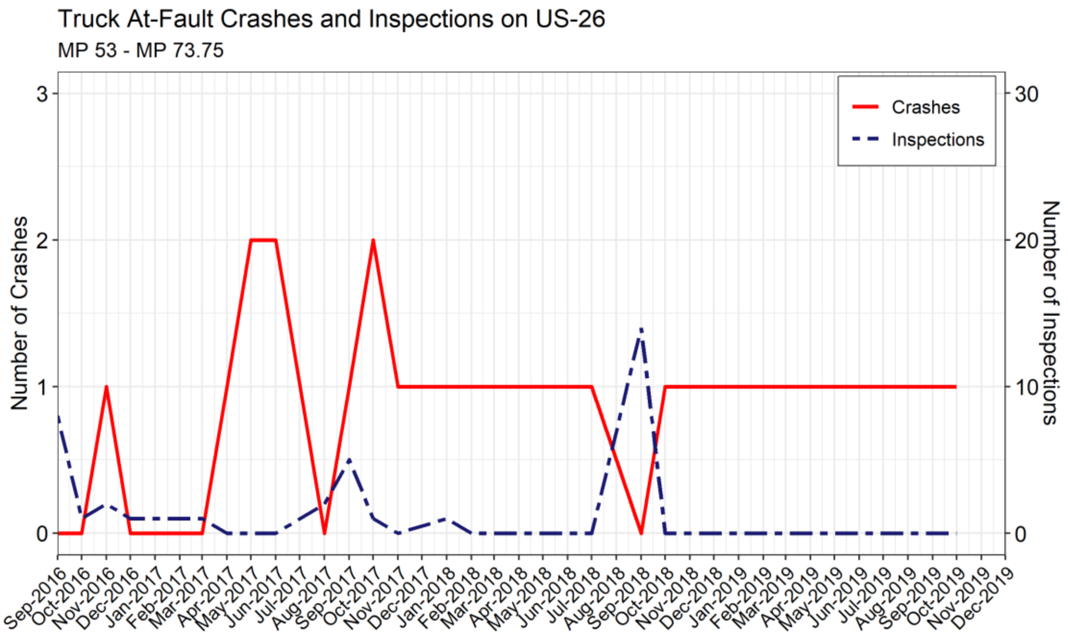

Figure B.14: Truck at-fault crashes and inspections on US-26

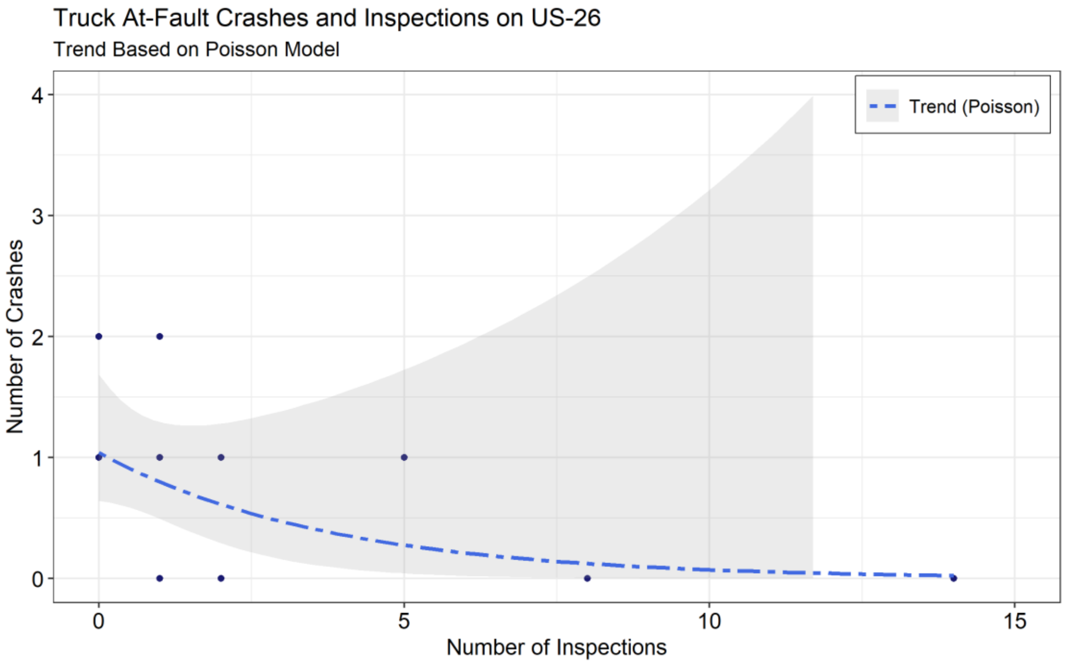

Figure B.15: Relationship between truck at-fault crashes and inspections on US-26

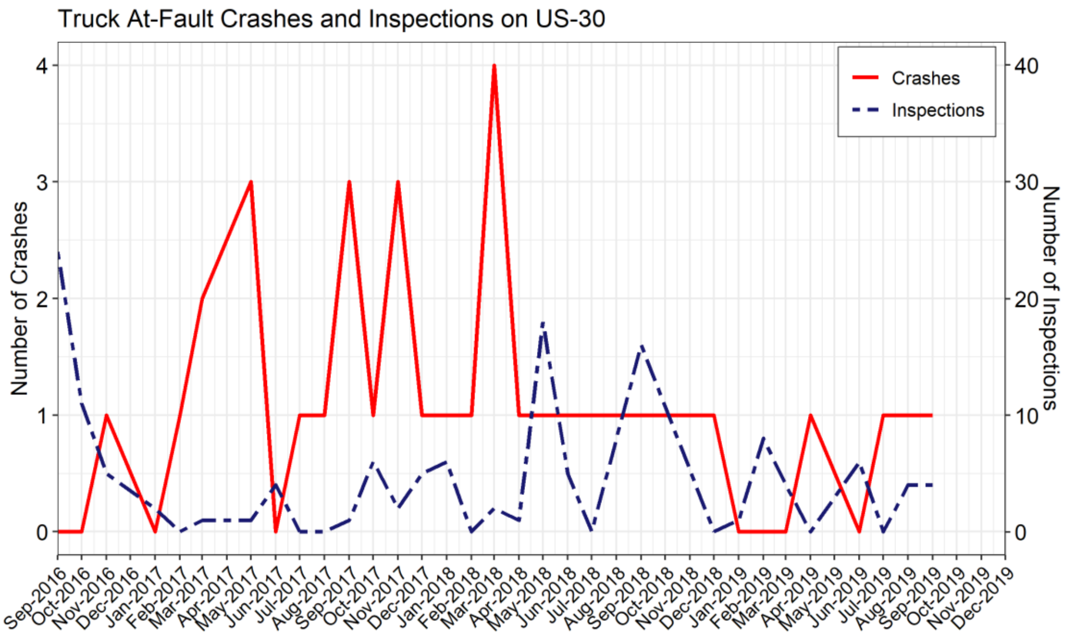

Figure B.16: Truck at-fault crashes and inspections on US-30

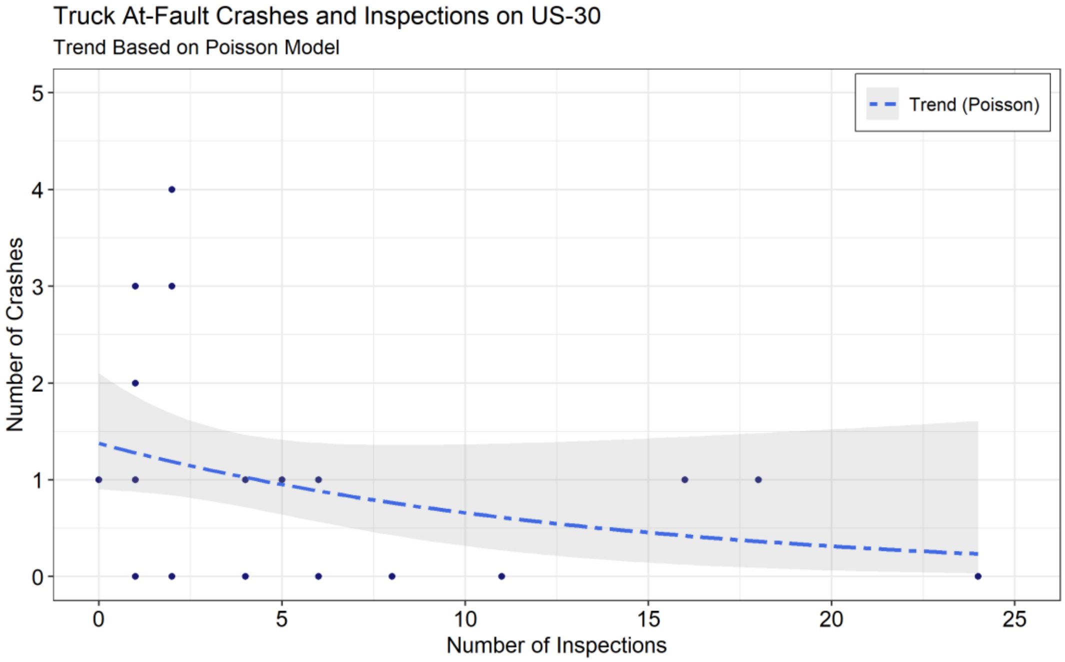

Figure B.17: Relationship between truck at-fault crashes and inspections on US-30

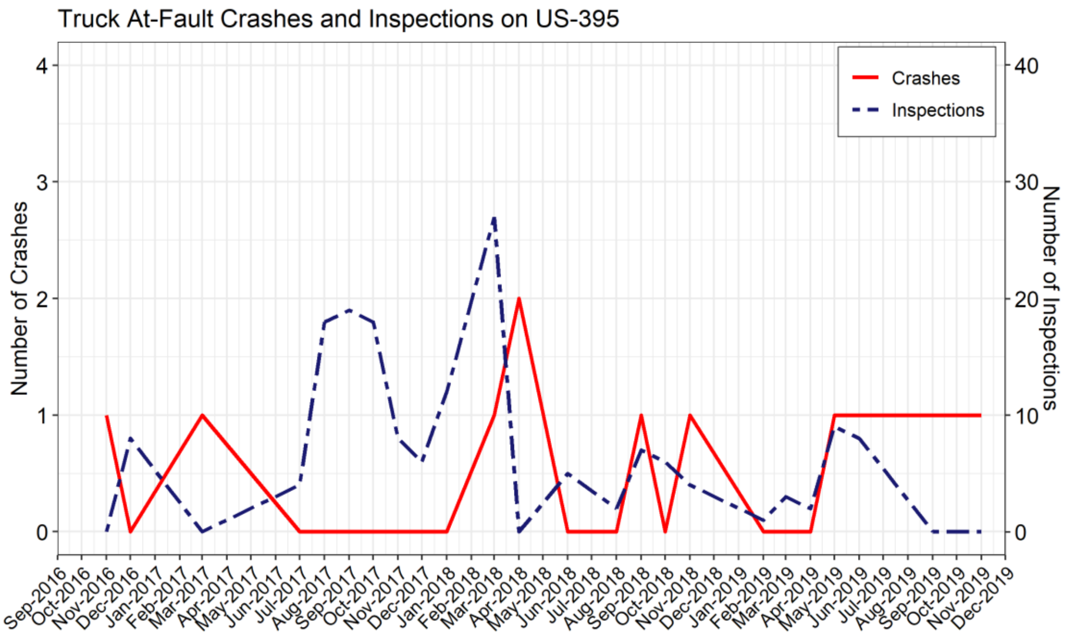

Figure B.18: Truck at-fault crashes and inspections on US-395

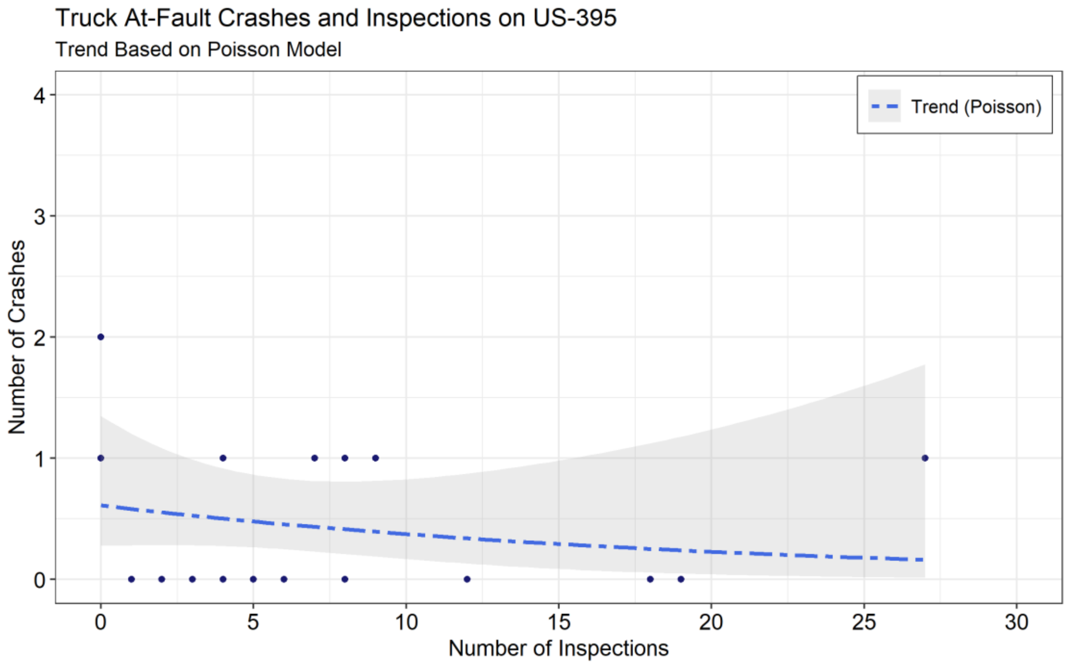

Figure B.19: Relationship between truck at-fault crashes and inspections on US-395

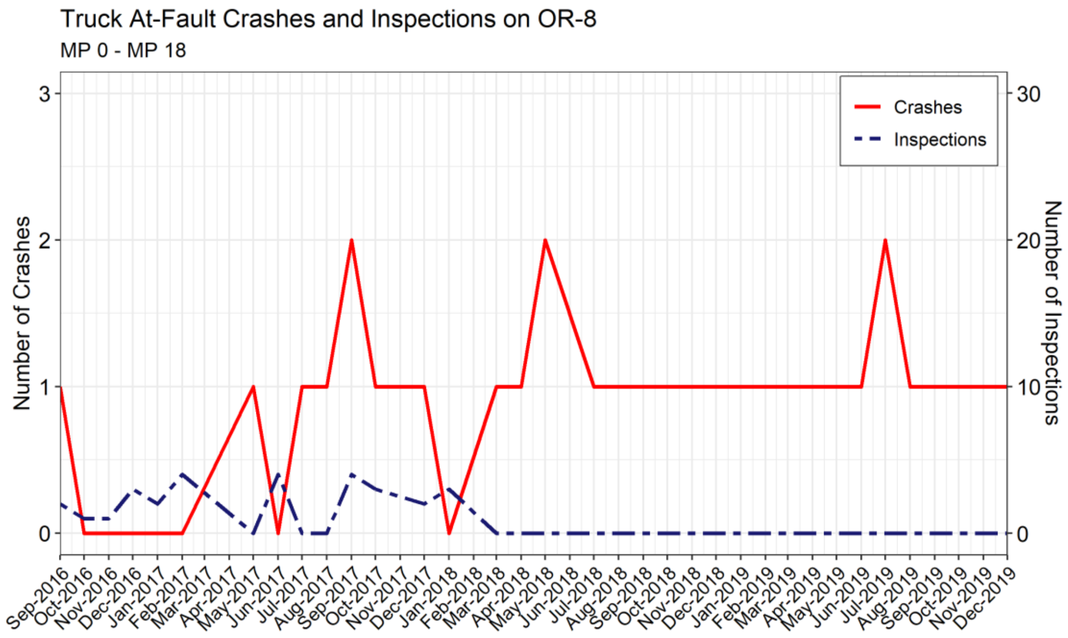

Figure B.20: Truck at-fault crashes and inspections on OR-8

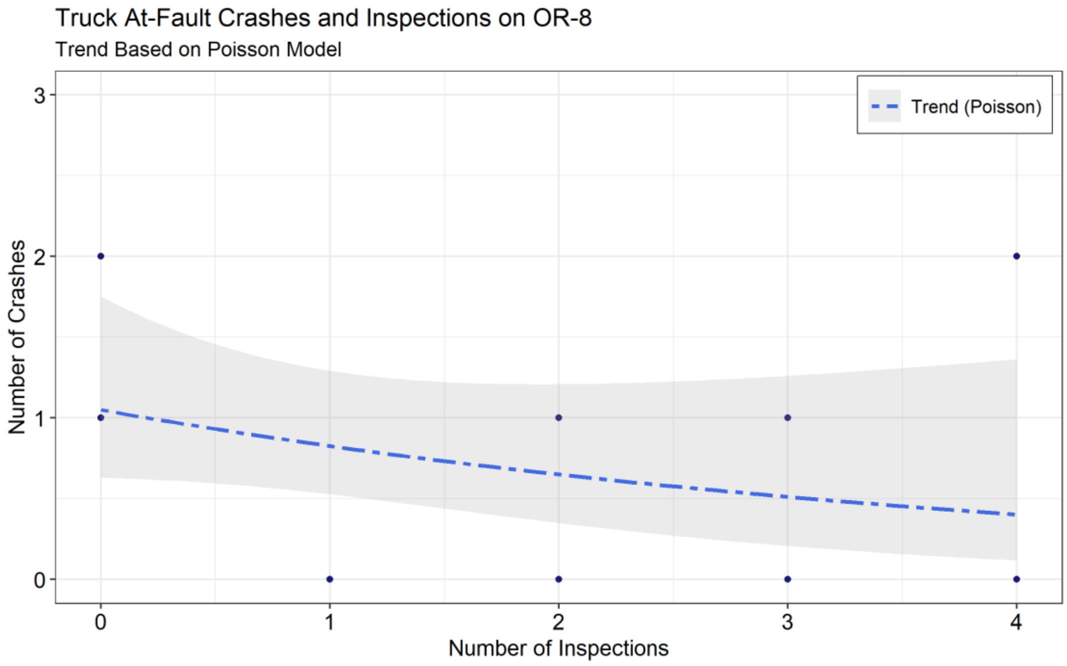

Figure B.21: Relationship between truck at-fault crashes and inspections on OR-8

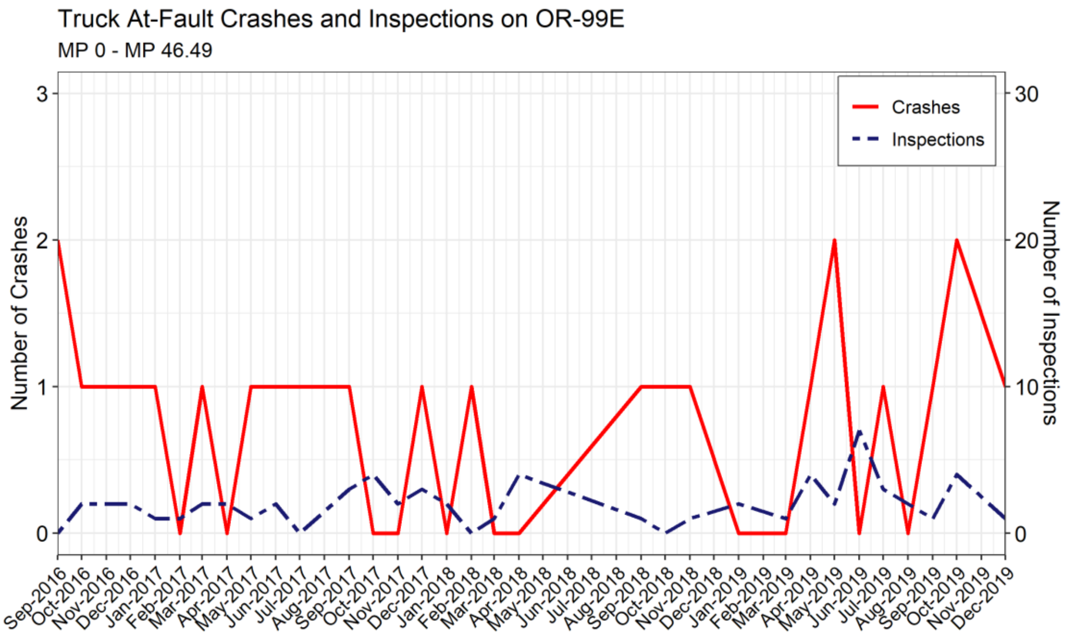

Figure B.22: Truck at-fault crashes and inspections on OR-99E

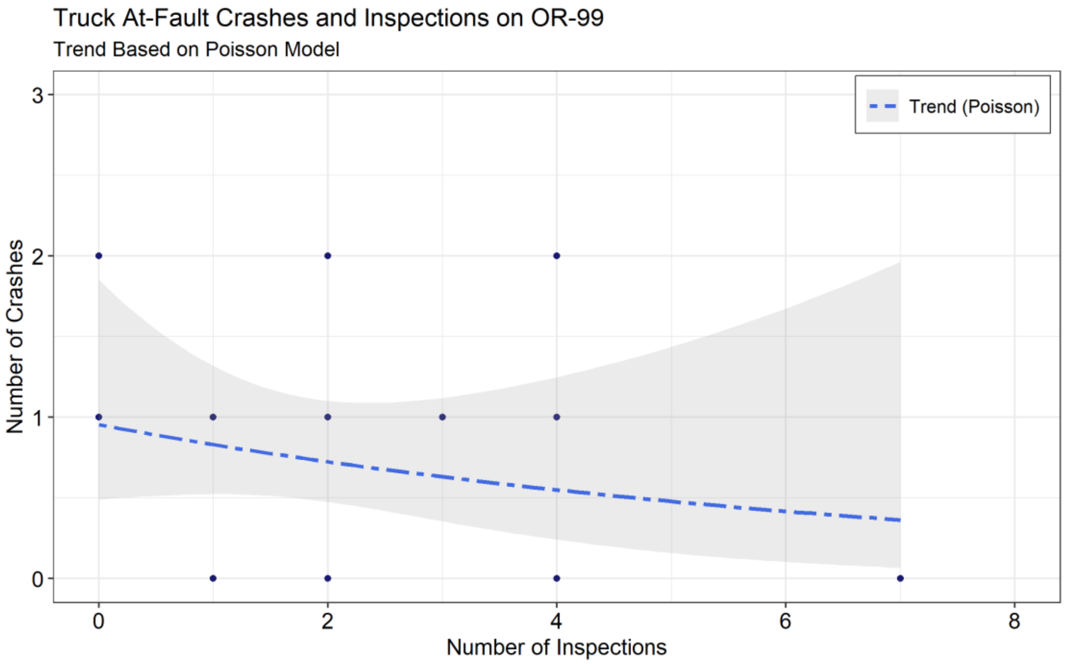

Figure B.23: Relationship between truck at-fault crashes and inspections on OR-99E

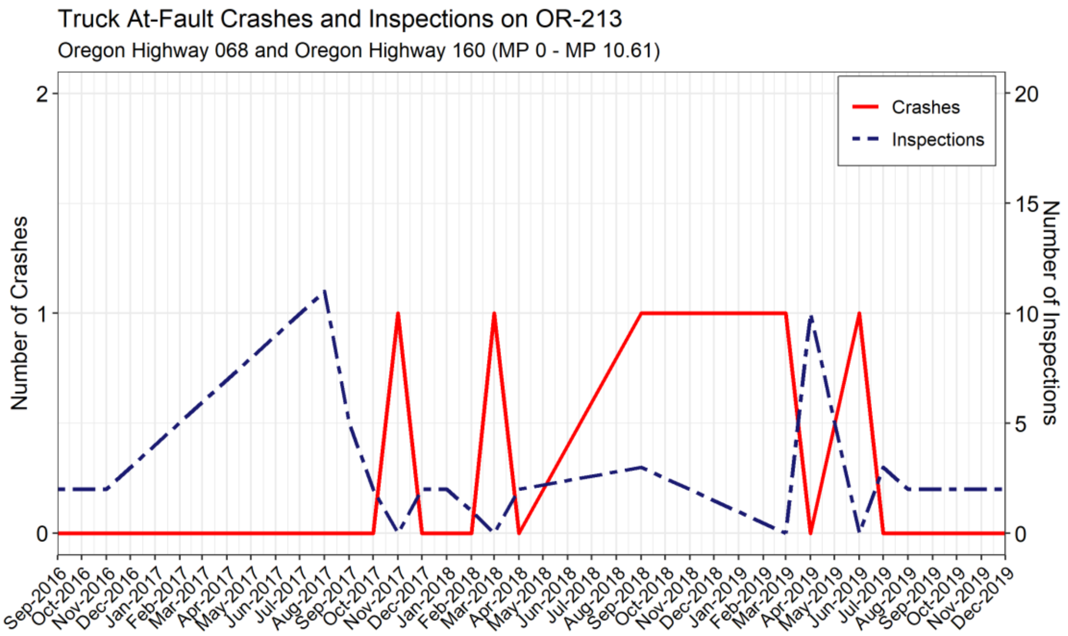

Figure B.24: Truck at-fault crashes and inspections on OR-213

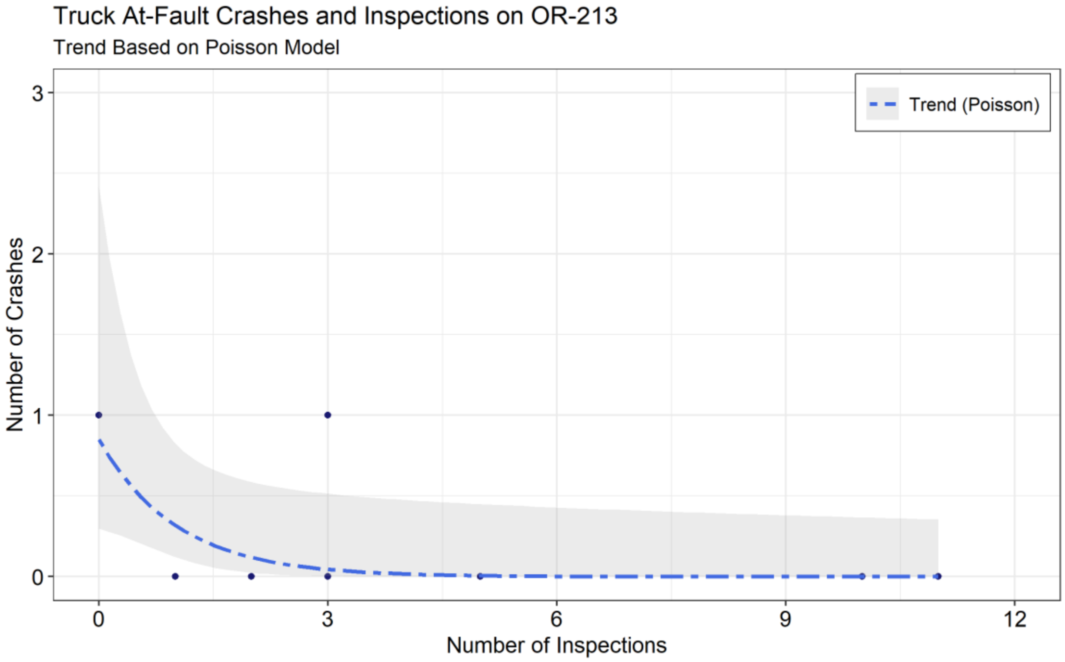

Figure B.25: Relationship between truck at-fault crashes and inspections on OR-213