Alaska Department of Transportation & Public Facilities

ANALYSIS OF CRASH CHARACTERISTICS ON FREEWAYS WITH DEPRESSED MEDIANS IN SOUTHCENTRAL ALASKA

Submitted by:
Ghulam H. Bham, Ph.D.
Brendan Hafele
Kaylin Jones

University of Alaska Anchorage
Anchorage, AK 99508

Sponsored by:
Alaska Department of Transportation and Public Facilities
Central Region, Anchorage, Alaska

May 2017

<table>
<tr><td colspan="4">REPORT DOCUMENTATION PAGE</td><td colspan="2">Form approved OMB No.</td></tr>
<tr><td colspan="6">Public reporting for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestion for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-1833), Washington, DC 20503</td></tr>
<tr><td>1. AGENCY USE ONLY (LEAVE BLANK)
4000(128)</td><td colspan="2">2. REPORT DATE
May 9, 2017</td><td colspan="3">3. REPORT TYPE AND DATES COVERED
Final - Sept. 2013 – Dec. 2016</td></tr>
<tr><td colspan="4">4. TITLE AND SUBTITLE
Analysis of crash characteristics on freeways with depressed medians in Southcentral Alaska</td><td colspan="2" rowspan="2">5. FUNDING NUMBERS
G00009184</td></tr>
<tr><td colspan="4">6. AUTHOR(S)
Ghulam H. Bham, PhD, Brendan Hafele, Kaylin Jones</td></tr>
<tr><td colspan="4">7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Alaska Anchorage
3211 Providence Drive
Anchorage, AK 99508</td><td colspan="2">8. PERFORMING ORGANIZATION REPORT NUMBER</td></tr>
<tr><td colspan="4">9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
State of Alaska, Alaska Department of Transportation and Public Facilities
Research, Development and Technology Transfer
2301 Peger Rd
Fairbanks, AK 99709-5399</td><td colspan="2">10. SPONSORING/MONITORING AGENCY REPORT NUMBER
4000(128)</td></tr>
<tr><td colspan="6">11. SUPPLENMENTARY NOTES
Performed in cooperation with Alaska University Transportation Center</td></tr>
<tr><td colspan="4">12a. DISTRIBUTION / AVAILABILITY STATEMENT
No restrictions</td><td colspan="2">12b. DISTRIBUTION CODE</td></tr>
<tr><td colspan="6">13. ABSTRACT (Maximum 200 words)
The characteristics of crashes on depressed medians of four freeways in Southcentral Alaska were examined under winter conditions. Cross-median crashes (CMC) were dispersed randomly along the freeways analyzed. CMC were 2.5 times likely to cause a severe injury crash compared to an in-median crash. Rollovers were 72.9%, a very high percentage, among all median crashes. Median slopes of 6H:1V (flatter) and 4:1/5:1 (steeper) were found to have similar frequency of cross-median and rollover crashes. On flatter slopes, higher frequency of non-rollover crashes was observed indicating reduced frequency of rollover crashes. With a median width of 32 ft (excluding inner shoulders), 54.7% of median crashes occurred. With a width of 36 ft, median crashes per mile were the highest for different crash types. As median width increased, in general, median crash frequency decreased. Two regression models were developed: a) Median rollover crashes were associated with severe injury crashes, driver inexperience, horizontal curves, median width between 26 and 40 ft, surface ice, and specific periods of the day, and b) CMC were associated with multiple vehicles, light trucks, after sunset on lighted roadways, and pavement rutting. Spatial analysis conducted identified nine top hotspots; five segments on New Seward Highway, three on Glenn Highway including location of median crashes, and one on Minnesota Drive. Six interchanges were identified for detailed examination.</td></tr>
<tr><td colspan="5" rowspan="2">14- KEYWORDS : Median Safety, Crash Severity, Driver Behavior, Median Crashes, Crossover Crashes, Rollover Crashes, Logistic Regression, Kernel Density, Hotspots</td><td>15. NUMBER OF PAGES
85</td></tr>
<tr><td>16. PRICE CODE
N/A</td></tr>
<tr><td>17. SECURITY CLASSIFICATION OF REPORT
Unclassified</td><td colspan="2">18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified</td><td colspan="2">19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified</td><td>20. LIMITATION OF ABSTRACT
N/A</td></tr>
</table>

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

EXECUTIVE SUMMARY

The project examined the crash patterns, and identified the crash contributing factors and the hotspots to reduce the frequency of cross-median and rollover crashes on freeways with depressed medians during the winter in Southcentral Alaska. This report presents the research findings of crashes analyzed on divided sections of the Glenn Highway, Minnesota Drive, the New Seward Highway, and the Parks Highway.

Crashes where a vehicle crosses the depressed median, continues into the opposing lanes, may collide with vehicles traveling in the opposite direction and termed as cross-median crashes were 2.5 times more likely to cause a severe injury (fatal and incapacitating) crash compared to an in-median crash. In-median crashes are median intrusion crashes where a vehicle comes to a stop in the median. Among all median crashes, compared to non-rollover crashes, rollover crashes had a very high percentage of 72.9%. Rollover crashes also have a higher percentage; 2.4% of fatal crashes compared to 1.1% for non-rollover crashes.

Median foreslope and width were examined using archived crash data. With respect to median slope, similar frequency of cross-median crashes was observed for flatter (6H:1V) and steeper slopes (4:1 and 5:1). Higher frequency of in-median crashes was observed for a flatter slope compared to steeper slopes. Frequency of rollover crashes was similar for both types of slopes. Higher frequency of non-rollover crashes was observed on a flatter slope, indicating that flatter slopes are associated with lower frequency of vehicle rollovers. Fifty-six percent of median crashes occurred when the median width was less than 33 ft. As median width increased, in general crash frequency decreased.

Two multinomial logistic regression models were developed: a) Rollover Crash Model and b) Median Crash Model. The models were developed to associate crash contributing factors to specific crash types. Statistically significant factors that predict median rollover crashes were: severe and possible injury crashes, horizontal curves; tangent sections at a grade and hillcrest, median width between 26 and 40 ft, driver inexperience and no improper driving, surface ice, and hours associated with low volume of traffic. The cross-median crashes were associated with severe crashes; multiple vehicle collisions, light trucks, after sunset on lighted roadways, and pavement rutting.

A spatial analysis technique, Kernel Density Estimation, was used to identify hotspots on the four freeways. Crash Factor Measure was used to rank the identified segments. From the top identified segments, five were found on the New Seward Highway, three on Glenn Highway and one on Minnesota Drive. The three segments on Glenn Highway were also found to be hotspots for median crashes. Based on the high frequency of crashes near interchanges, six interchanges (four on Glenn, one on Seward and one on Minnesota) were identified for detailed examination. The crash data analyzed represented corrected data for crash locations based on input from the DOT&PF.

Freeway segments with ‘S’ curves require further evaluations as those segments were found to be crash hotspots. Based on the high frequency of crashes near interchanges, review of freeway on- and off-ramp design is proposed.

Analysis of video data provided interesting results. Fifty-five percent of cross-median intrusions were found on freeway segments with a median slope of 6:1. And 60% of in-median intrusions were found on segments with median slopes of 4:1 and 5:1. Therefore, the steeper the slopes of the median, the harder it is for a vehicle to traverse the median. This is beneficial for preventing cross-median crashes. Cross-median crashes were dispersed randomly along the length of the four freeways from both archived data as well as drive through video data collected.

Countermeasures to reduce the frequency and severity of crashes were not in the scope of this study. This study recommends broad measures to reduce the frequency and severity of crashes. Timely information of hazardous road conditions, mainly due to winter weather, is of utmost importance to drivers. Up-to-date information on pavement condition specific to location can be very effective. Currently, this information is available via multiple sources: TV (news), radio (511), 511 website, Roadway Weather Information Systems (RWIS) with webcam available at specific locations, etc. Further improvement in dissemination of this information will be very useful for drivers.

Driver inexperience and perhaps overconfidence with four-wheel drive vehicles can be overcome with better training and educational material. Further, median treatments require research to propose a design appropriate for Alaskan conditions that prevent cross-median and rollover crashes. Further examination of crash data, especially crash severity, is proposed. Development of detailed statistical models for safety analysis are also recommended. Various issues were identified with crash reports which will help analysts improve examination of archived data to identify crash contributing factors, future safety programs, policies, and standards.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support for the project from the Department of Transportation and Public Facilities (hereinafter referred to as DOT&PF) in Alaska, Federal Highway Administration (FHWA), and the University Transportation Center at the University of Alaska Fairbanks. This study could not be possible without the continued help of DOT&PF in providing the crash data as well as in answering many questions from the researchers. Also, Sergeant Roy LeBlanc for taking the time to meet with the researchers and provide Anchorage Police Department's input on median crashes. The authors thank the DOT engineers Scott Thomas and Anna Bosin for their valuable input. Also, the hard work by Julie Waites in retrieving the crash reports is greatly appreciated. The following students are also acknowledged: Amanda Del Frate, Anne Rowland, Ayaz Ahmed, Dustin Spidal and Jacob Minturn, who worked on different aspects of the project.

COPYRIGHT

TABLE OF CONTENTS

PAGE

1. INTRODUCTION

1.1. GOAL AND PROBLEM STATEMENT

The goal of this research project was to assess safety on freeways with depressed medians in Southcentral Alaska. The two major concerns in terms of safety were: i) the number of aberrant vehicles that cross the median and collide with a vehicle traveling in the opposite direction, and ii) the frequency of rollover crashes and the role of the depressed median.

1.2. RESEARCH OBJECTIVES

The main objectives of this research project are:

1. Evaluate the performance of depressed medians in terms of crash characteristics during winter conditions specifically and during summer in general.
2. Identify crash contributing factors associated with median crashes; both cross-median and in-median crashes, and rollover crashes.
3. Identify hotspots on the freeways considered.
   3.1. Identify high crash locations of median intrusions.

1.3. RESEARCH SCOPE

The project scope was to assess the depressed medians in terms of crash costs, crash characteristics, their contributing factors, and the location of median crashes on specific freeways in Southcentral Alaska.

1.4. BACKGROUND

Federal Highway Administration (FHWA) defines a roadway departure crash as “a crash in which a vehicle crosses an edge line, a centerline, or otherwise leaves the traveled way.” In the United States, in 2013, 56% of fatal crashes involved roadway departure crashes (FHWA, 2014). These run-off-the-road include cross-median (or crossover) collisions and they tend to be more severe than other crash types (Neuman et al., 2003). A cross-median collision is a type of crash in which an errant vehicle departs the roadway, crosses a median and or barrier, but may not collide with traffic traveling in the opposite direction. According to the United States Department of Transportation (USDOT), 2 to 5% of Interstate crashes are cross-median crashes, 30% of which result in severe injuries or fatalities (USDOT, 2014). Median crashes can be classified as rollover or non-rollover crashes. The Fatality Analysis Reporting System (FARS) database indicates that rollover crashes account for 33% of all passenger vehicle fatalities in the United States (NHTSA, 2015). Lane et al. (1995) found that fatal cross-median crashes and rollover crashes were 20% and 25%, respectively, of all fatal crashes on median divided freeways in Canada.

The focus of this study is roadway departure crashes, especially median crashes, on divided expressways or freeways in Southcentral Alaska. In Alaska, an expressway or a freeway is a high-speed (≥ 50 mph), multilane, divided highway. These freeways typically utilize depressed medians that range from 24 to 64 ft. During the winter, and after a snow event with slippery road conditions, out-of-control vehicles can intrude these medians (see Figure F1 in the appendix). Depressed medians with snow serve as a refuge to absorb the impact of a crash and prevent vehicles from crossing the median. Without a depressed median, single-vehicle run-off-the-road crashes could evolve into multi-vehicle crashes traveling in the same direction. The depressed medians also serve as snow storage areas, allowing snow to be plowed on both sides of the road.

1.5. LITERATURE REVIEW

Several studies have been conducted on median crash frequency and severity (such as Lane et al. 1995; Shankar et al. 1998; Donnell et al. 2006; Hu et al. 2010; Lu et al. 2010; Hu et al. 2011; Graham et al. 2014; Harwood et al. 2014). From these studies, it is clear that different factors contribute to crash frequency and injury severity. In general, the presence of drugs/alcohol, inattentiveness, driver distraction, and other forms of driver behavior are responsible for 57% of crashes and play a role in 93% of all crashes (HSM 2010). Roadway design factors contribute to 34% of all crashes (AASHTO, 2010). By improving roadway design, the number of crashes can be reduced. However, there are design challenges. Building a median to prevent cross-median crashes may contribute to other crash types, such as rollovers. Roadway conditions and weather also affect median crash frequency, especially in winter weather where snow and ice can accumulate, creating more dangerous driving conditions.

NCHRP study 790 (2014) examined crash contributing factors that lead to median crashes. Loss of control of vehicles was a factor in 73% of median crashes. Geometric factors explored were horizontal curvature and vertical grade. The study reported that as the radii of horizontal curves decrease and as grade increases, median crash frequency increased. The presence of on- and off-ramps also increased median crash frequency. Wet or snowy roads compounded with other factors also increased the median crash frequency.

It will be intuitive to believe that crash frequency increases during the winter months. However, this was not the case. In a study conducted in Sweden, it was found that when accumulated snow was 40 centimeters or less, for every centimeter of snow, minor injury and severe injury (including fatal) crash frequency decreased by 3.0 and 3.5%, respectively (Brorsson et al. 1988). This occurred despite an increase in property damage only crashes. Overall, in the presence of precipitation, crash frequency decreased. Another study also attributed reduction in frequency of severe crashes to safer driving (Hu and Donnell, 2011).

Depressed medians appropriate for specific environments can prevent an errant vehicle from colliding with an oncoming vehicle traveling in the opposite direction. The American Association of State Highway and Transportation Officials (AASHTO) recommends a minimum median width of 36 feet (2011). The wider the median, the more time an errant vehicle has to change its path and avoid a cross-median crash. Where a sufficiently wide median cannot be provided, a median can be depressed to deflect an errant vehicle. However, a steeper median slope contributes to rollover crashes.

Median design and behavior of an errant vehicle and its interactions with roadway features is of significant concern. Median width and slope plays a crucial role in the prevention of cross-median crashes. Cross-median crashes are more likely to occur on traversable medians and medians without a barrier. A median slope shallower than 4:1 (horizontal (H): vertical (V)) is considered a traversable median, while a median with a slope between 4:1 and 3:1 has a non-recoverable slope. A vehicle can safely cross a median with a non-recoverable slope, but an errant vehicle is unlikely to recover from one. Recoverable foreslopes are 4:1 or flatter (Weaver et al., 1975). AASHTO (2011) recommends median slopes of 6:1 (H:V) to reduce the risk of rollovers and provide the driver with more recovery time. Graham et al. (2010) also suggested a flatter median slope of 6:1. A median, however, should be at least 50 feet wide to provide a proper recovery distance.

In general, as median width increases, a driver's recovery time and space also increases. When a median is 70 ft. or less in width, the probability of a fatal cross-median crash is 5.05 times more likely to occur when compared to wider medians (Hu and Donnell, 2011). Shankar et al. (1998) concluded that medians 60 ft. and greater in width evidenced lower frequency of crashes. Medians with widths between 30 and 40 feet are associated with most cross-median crashes.

The Pennsylvania study also found that decreased median width and slopes flatter than 10H: 1V or steeper than 7H: 1V increased the frequency of severe crashes (Hu and Donnell 2011). Intuitively, the steeper the slope of the median, the harder it is for a vehicle to traverse the median. This is beneficial for preventing cross-median crash. However, it contributes to rollover crashes. For every unit increase in slope, there is a 5.8% increase in median rollover crashes (NCHRP 794 2014). Further, freeways with depressed medians have the highest proportion of minor injury crashes (Gattis et al. 2005).

Shoulders add additional recovery room for drivers in the case of run off-the-road crashes. Shoulders that are too wide, however, may cause a greater level of comfort and higher driving speeds, which could result in more severe crashes (Hosseinpour et al. 2013). Roadway and median design, as well as barriers, play an important role in preventing crashes and reducing the severity of crashes. The design of a median is a balancing act. The challenge of designing an effective median is compounded by both human and environmental factors.

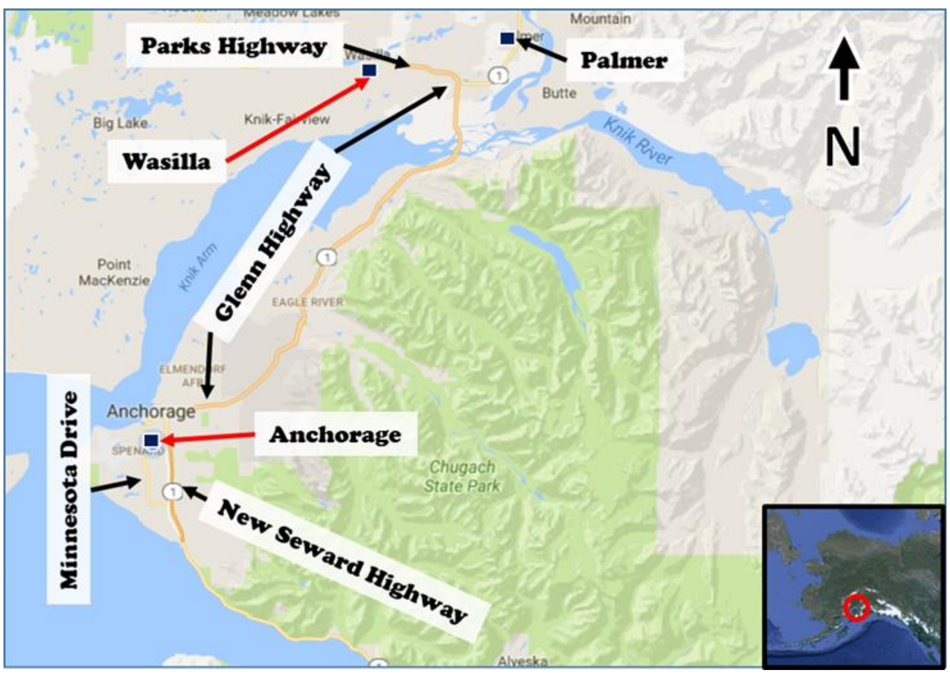

Figure 1.1 Location of the Four Freeways near Anchorage, Alaska

1.6. STUDY AREA AND DATA DESCRIPTION

In this study, crash data for four freeways: i) Glenn Highway, ii) Minnesota Drive, iii) New Seward Highway, and iv) Parks Highway were analyzed. Figure 1.1 shows these freeways as well as the major cities in Southcentral Alaska. The freeway sections considered in the study were divided with multi-lanes, and depressed medians. Minnesota Drive and the New Seward Highway are located within the Municipality of Anchorage. Glenn Highway connects Anchorage with other surrounding cities in the Anchorage Metropolitan Area. Glenn Highway merges with the Parks Highway and connects Anchorage with the Mat-Su (Matanuska-Susitna) Valley, part of the Anchorage Metropolitan Area. These freeways are heavily used by commuters from the cities of Anchorage, Eagle River, Palmer, Wasilla, etc. The Mat-Su Valley is located about 35 miles north of Anchorage. According to the United States Census Bureau, Alaska has seen an estimated increase of 4.5% in population since the 2010 census. Similarly, Anchorage has seen an estimated increase in population of 2.4% (USCB, 2017).

Crash data for this study were obtained from the following sources: archived crash data from an Access database, thematic maps, and police crash reports. Further, information was collected from freeway drive through video data. The details of the data sets used are provided in the following sections.

1.6.1. Archived Data

The DOT&PF provided the crash data, the crash reports, and the thematic maps for use with a Geographic Information System (GIS). Six years, 2007 to 2012, of crash data and crash reports were made available. Thematic map data were available from 2009 to 2012. Further information on crashes was obtained from interviewing the Anchorage Police Department (APD) as well as video recordings of driving the highways after a snowfall event.

The APD and the Alaska State Troopers prepared the crash reports. The reports had specific information about the crashes. Each report had various fields that the officers filled at the time of the crash. Among the fields, the most important were the first and second sequence of events in a crash, driver behavior, and the vehicle action. All of the fields with short answers or fill-in-the-bubble types of questions were included in the archived data file. The crash reports also had a section on the officers' narrative of the crash, and a diagram to determine whether a vehicle crashed in-the-median, crossed-the-median, and if it rolled over. This information was not available from the archived data, therefore were obtained by the researchers and integrated with the archived data to aid in identification of specific crash type. All crash reports provided to the researchers were redacted of any personal information.

1.6.2. Drive Through Video Data Collection

Drive-through video recordings were made at freeway speeds during the winters of 2013 through 2015. The purpose of the recordings was to determine the location and frequency of occurrence of median intrusions as they may not be reported to law enforcement. The recordings were made using video cameras equipped with a Global Positioning System (GPS). These videos were made within 24 hours after snow events while the tracks were still fresh to capture both the trajectory of the vehicle and its position in the median.

The videos enabled the researchers to collect information not available from crash reports. In Alaska, law enforcement is not required to be contacted in case of a property-damage-only crash that costs less than $2000 (Alaska Statues, 2016). Also, median crashes may not result in a collision. Therefore, video data can lead to a count for such crashes. The video data also collected evidence of the location where vehicles intruded the median.

1.6.3. Feedback From Law Enforcement

A number of researchers from the University of Alaska Anchorage met with Sergeant Roy LeBlanc, the Traffic Unit supervisor for APD. Sergeant LeBlanc discussed APD's jurisdiction as well as when officers complete a police report on a crash. He also provided possible causes of crashes and vehicle rollovers, and identified the process when dealing with different types of crashes.

Police reports by APD are generally only written if the vehicle was part of a crime, or there was enough damage to render the vehicle disabled. Non-disabling crashes and property-damage-only crashes, although they do not require a police report, are assumed to be called in by the vehicle driver or reported by others. These calls are recorded by APD's Computer-Aided Dispatch (CAD) system. Information such as the driver's name (if available), date, time, and location of the crash are recorded by the system. This information, however, was not available for the winters observed during the study due to backlog in data entry and the system being updated.

Sergeant LeBlanc reported seasonal variables and the snow berm as a factor in median crashes. He indicated that soft snow in the winter helps cushion the vehicles when they enter the median. However, as the spring's freeze/thaw cycle begins, the snow freezes into a hard structure. When a driver loses control as a result of winter weather, vehicles hit the snow berm and possibly rollover. He also indicated that in the summer, due to the lack of snow, vehicles have a tendency to cross the median.

It was noted that the APD patrols New Seward Highway, Minnesota Drive, and Glenn Highway up to the Knik River. The northern sections of the Glenn Highway and Parks Highway are patrolled by the State Troopers.

1.7. ANALYSIS OF CRASH DATA

For 2007 to 2012, 2531 crashes were retrieved from the archived data for the divided sections of the four freeways with depressed medians, presented in Table 1.1. It can be observed that about 2/3rd of crashes occurred on the Glenn Highway.

Table 1.1 Crash Data by Freeways

Freeways	Length (miles)	Frequency	Percent
Glenn Highway	34.00	1679	66.34
New Seward Highway	9.87	455	17.98
Minnesota Drive	5.36	270	10.67
Parks Highway	4.16	127	5.02
Total	**53.39**	**2531**	**100**

The DOT&PF provided 1256 detailed police crash reports. Archived data for some of the crashes provided information related to a rollover in the median. In total, 340 median crashes contained specific information regarding the different crash types. On a freeway, median (intrusion) crashes were categorized into in-median and cross-median crashes. In an in-median crash, an errant vehicle enters the median and comes to a stop until it is removed by driving out without assistance or is towed out. In a cross-median crash, a vehicle enters the median, traverses and departs it to reenter roadway with traffic traveling in the opposite direction. Table 1.2 presents the frequency of these crashes subcategorized by crash severity, rollover and non-rollover information. The four levels of injury severity are based on the DOT&PF implementation of the KABCO scale (AASHTO, 2010). As of December 2016, no median barriers were installed on the sections of the freeways considered in the study.

Table 1.2: Median Crashes by Levels of Crash Injury Severity and Crash Types

Crash Severity	Cross-Median		In-Median		Total	Percent
	RO*	NRO+	RO	NRO		
Fatality (K)	2	1	4	0	7	2.05%
Incapacitating Injury (A)	2	6	13	1	22	6.47%
Non-Incapacitating/Possible Injury (B/C)	16	11	82	15	124	36.47%
Property Damage Only (O)	13	15	116	43	187	55.00%
Total	33	33	215	59	340	100%

* RO = Rollover, + NRO = Non-Rollover

Crash injury severity can be classified as severe or non-severe injury crashes. Severe injury crashes comprise of fatal and incapacitating injury (K&A) crashes. From Table 1.2, in terms of all median crashes, in-median crashes were 80.6% (274/340) whereas cross-median crashes were 19.4% (66/340). The percentage of severe crashes for cross-median crashes, however, was found to be high at 16.7% (11/66) compared to 6.6% for in-median crashes (18/274). Among all median crashes, the percentage of severe crashes was found to be 8.5% (29/340). A cross-median crash compared to an in-median and all crashes is therefore 2.5 and 1.95 times more likely to be a severe crash.

The total number of rollover crashes was very high at 72.9% (248/340), whereas non-rollover crashes were at 27.1% (92/340). The major reason for high percentage of rollover crashes was underreporting of non-severe non-rollover crashes. And reporting of every rollover crash on the other hand. This results in a very high percentage of rollover crashes. Archived data, however, listed them as median crashes. The review of individual police crash reports made this discovery possible, otherwise the corrected frequency of rollover crashes was not known. Out of the 2531 crashes analyzed from the archived crash database, rollover crashes were 520 (20.6%). Under-reporting of rollover crashes is clearly evident as they are noted on the police crash reports, but not indicated on the archived crash database.

Both in-median and cross-median crashes that resulted in a rollover were higher in fatal injury crashes at 2.4% (6/248) compared to non-rollover crashes at 1.1% (1/92). This indicates that rollover crashes result in higher frequency of fatal crashes. A reason for association of rollover crashes with fatal crashes is the prevalence of head and neck injuries (Jehle et al., 2007).

Further, Hall's (1980) analysis of FARS fatal rollover crashes found variation in rollover crash types by states and the highest rates were found in more sparsely populated states. Further, Viner (1995) analyzed US data on ran-off-the-road vehicle crashes and found that 46% of rural interstate fatal and severe injury crashes resulted from rollovers.

1.8. RESEARCH METHODOLOGY

Multinomial logistic regression (MLR) models were developed for different crash types to identify crash contributing factors associated with median crashes. A hybrid approach comprising of spatial analysis and hotspot identification and ranking technique was used to identify high crash locations. The hybrid approach used Kernel Density Estimation (KDE) to spatially analyze the crash data. KDE identified the segments with high frequency of crashes. These segments were then ranked using a hotspot identification measure, Crash Factor Measure (CFM), which incorporated both crash frequency and levels of injury severity based on crash costs specific to

Alaska. Further, collected video data were reviewed and analyzed, and the results helped identify the high crash locations as well as crash characteristics associated with median intrusions.

1.9. REPORT ORGANIZATION

Chapter 2 presents the results of application of MLR and the development of models to associate crash contributing factors with different crash types. Chapter 3 presents details of KDE and CFM and the results of hotspots identified on the freeways and the median intrusions. Chapter 4 presents the details of video data collection and analysis. Chapter 5 presents the summary, conclusions, and recommendations of this study.

2. CRASH CAUSALITY MODELS

2.1. BACKGROUND

Multinomial logistic regression (MLR) was used to identify the contributing factors related to different crash types for freeways in Southcentral Alaska. This chapter identifies the most likely factor(s) that lead to a crash. The chapter presents the methodological approach and the choice of models. This is followed by the description of data used in the analysis, the results, and the summary of the findings.

2.2. METHODOLOGY

2.2.1. Choice of Models

The choice of models was based on the crash types, categorized by crash location; the median, roadway, and roadside. The median crashes were further classified as in-median and cross-median. As presented earlier, high frequency of median rollover crashes was found on the freeways. Therefore, rollover crashes were analyzed specifically to identify the crash contributing factors.

MLR identifies the factor(s) that are likely to lead to a crash type given that a crash has occurred. This is a typical case of MLR with more than two dependent variables. MLR can handle multiple categorical variables. The conditional distribution of crash types (i.e., data based on the condition that a crash has occurred) provides insight on the relation between specific crash types and various environmental conditions, roadway features, driver behavior, vehicle characteristics, levels of injury severity, etc. Further details regarding the MLR model are presented below. It can be noted that individual models were developed to study the difference in terms of crash contributing factors that affect the different crash types.

2.2.2. Generalized Logistic Regression

Logistic regression is generally used to handle categorical data. It can handle bivariate response variables i.e., variables with two possible values and can be extended to handle a polytomous response variable 'Y' that takes a discrete set of values reflecting ‘r’ categories (‘r’ can be greater than two). Since the response variable is nominal (unordered), a generalized logit model was suitable. This approach frames 'r-1' logits for the response variable to compare each categorical level with a reference category.

Median crash types or rollover crash types, denoted by Y_i, were the response variables while geometric, traffic, environmental variables, etc. were the independent variables denoted by $X_{i1}, X_{i2}, X_{i3}, ...X_{ip}$, where ‘*i*’ denotes the observation and ‘*p*’ denotes the number of independent variables. It is assumed that $Y_i = (Y_{i1}, Y_{i2}, ...Y_{ir})^T$ has a multinomial distribution with index, $n_i = \sum_{j=1}^{r} Y_{ij}$ and parameter $(\pi_{i1}, \pi_{i2}, ..., \pi_{ir})^T$.

When the response categories 1, 2 …. *r* are inherently *unordered*, π_i is related to independent variables through a set of ‘*r-1*’ baseline-category logits. Taking *j** as the baseline category, the model is expressed as:

$$\log\left(\frac{\pi_{ij}}{\pi_{ij^*}}\right) = X_i^T \beta_j, \ j \neq j^*. \qquad (2.1)$$

where:
X_i^T is the transpose of independent variable vector X_i; and β_j is the coefficient vector for j^{th} level of the response variable.

Because the multiple levels '*r*' of the response variable in this analysis had no inherent ordering, '*r-1*' generalized logits were defined from this analysis as '*j*' takes the values from 1 to '*r*'. As X_i had length '*p*', this model had $(r-1)\times p$ parameters, which can be arranged as a matrix.

In this model:

- The k^{th} element of β_j can be interpreted as the increase in log-odds of falling into category j versus category j^* resulting from a one-unit increase in the k^{th} independent variable, holding the other independent variables constant.
- Any of the categories can be chosen to be baseline and the model will fit equally well, only the values and the interpretation of the coefficients will change. In the present study, the base variable selected had the biggest sample size.
- For the non-baseline categories, $j \neq j^*$, π_i can be calculated from β as:

$$\pi_{ij} = \frac{\exp(X_i^T\beta_j)}{1+\sum_{k\neq j^*}\exp(X_i^T\beta_k)} \tag{2.2}$$

- For the baseline category, π_i can be calculated from β as:

$$\pi_{ij^*} = \frac{1}{1+\sum_{k\neq j^*}\exp(X_i^T\beta_k)} \tag{2.3}$$

For this study, MLR modeling was carried out using SPSS V24.

2.2.3. Models Developed

Two models were developed a) Rollover Crash Model, and b) Median Crash Model. Table 2.1 shows a summary of the models developed. For the Rollover Crash Model, three dependent variables were defined, i) median rollover, ii) roadside rollover, and iii) roadway non-rollover crashes. The last category was used as the base category for comparison with rollover crashes. Median rollover crash data included both in-median and cross-median rollover crashes. Roadway non-rollover crash category was used instead of roadway rollover due to limited number of rollover crashes. The three categories provided data of ample sample size to develop a stable model that also fits the data.

Table 2.1. Models Developed, Dependent Variables and Base Categories

Rollover Crash Model	**Median Crash Model**
Dependent Variables	
Median Rollover crash	Cross-Median Rollover crash
Roadside Rollover crash	Cross-Median Non-Rollover crash
-	In-Median Rollover crash
Base Categories	
Roadway Non-Rollover crash	In-Median Non-Rollover crash

The basis for the Rollover Crash Model was the crash locations on the 'trafficway', shown in Figure 2.1, and the classification of crashes as rollover and non-rollover. Per Figure 2.1, the crash locations were labeled as median, roadside, and roadway. As shown in Figure 2.1, for the freeways modeled, median crashes occurred between the 'Road with Shoulders' and the 'Roadway' (note: for this study, all four freeways considered have shoulders on both sides). Roadway crashes included crashes on the right shoulder, and Roadside crashes occurred in the space between the edge of the Roadway and the Property Line.

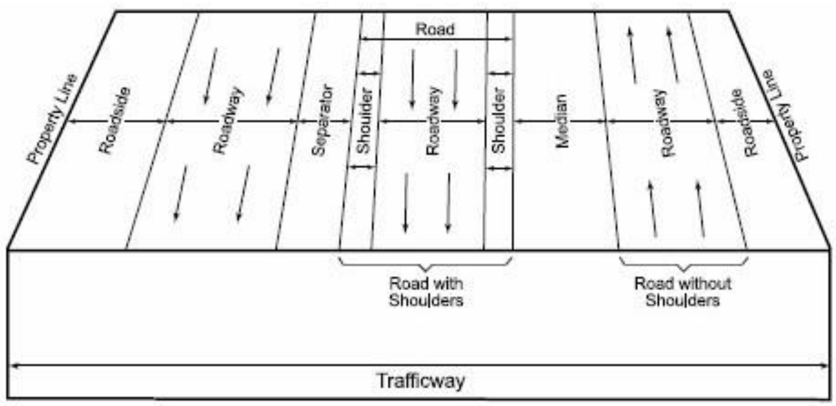

Figure 2.1. Trafficway: Roadside, Roadway, and Median defined (AMVCR, 2014).

For the Median Crash Model, four dependent variables were defined, i) cross-median rollover, ii) cross-median non-rollover, iii) in-median rollover, and iv) in-median non-rollover crashes. The last category was used as the base category for comparison with other crash types. The logit models, therefore, estimated the risk of other crash types compared with in-median non-rollover crashes.

There are similarities as well as differences in median rollover versus roadside rollover crashes. Both rollover crashes occur as a result of a vehicle run-off-the-road. However, the direction that these vehicles leave the highway and the design of median versus the design of the embankment are different.

2.3. DATA DESCRIPTION AND ANALYSIS

Data for the four freeways from 2007 to 2012 were combined and used in the analysis. Several data sets were integrated: crash, vehicle, person, traffic, environmental and highway geometry, median design, and pavement performance. The crash data included road surface condition (dry, wet, ice, snow, etc.), weather (clear, rain, snow, etc.), light conditions (dark, daylight, twilight, etc.), levels of crash severity, etc. Person data reported restraint type, driver's age, gender, alcohol consumption, etc. Highway geometry data contained information related to alignment (straight, curve, grade, level, hillcrest), and type (nonjunction, crossover), etc. The data were merged for analysis using crash number and mileposts as the main keys to produce a final data set.

Presented in the appendix, Tables T1 and T2 show the frequency and percentage of independent variables and various sub-categories for the two models developed. Table T1 presents a total of 1347 crashes; 248 median rollovers, 214 roadside rollovers, and 885 roadway non-rollover crashes. Table T2 presents a total of 340 crashes; 215 in-median rollovers, 59 in-median non-rollovers, 33 cross-median rollovers, and 33 cross-median non-rollover crashes. To identify rollover and non-rollover crashes, information from crash reports and archived data were used. The total length of the freeways analyzed in this study is 53.3 miles.

Different criteria were used to address multicollinearity for variables in the study. In case of multicollinearity, a small change in the model or data may lead to erratic changes in the estimate of coefficients of individual predictors. However, multicollinearity does not reduce the reliability of the model, but may not produce valid results for individual predictors. Variance inflation factor (VIF) and cross-tabulation analyses were used to check for multicollinearity for the different variables. A VIF value of 100 or greater can be a cause for concern (Kutner et al., 2004). None of the variables in the data, however, were found to be correlated.

2.3.1. Analysis of Parameter Estimates: Logistic Regression Models

The relationship between the dependent and the independent variables can be understood from the intercept and the parameter estimates of the model. Maximum likelihood method was used to estimate these parameters. Testing individual factors globally and controlling for other factors determines the significance of each variable. Many variables can represent causes of an effect, and the responsible variables for an effect can be selected based on the goodness-of-fit. Several goodness-of-fit tests were therefore carried out: likelihood ratio, Pearson, and deviance. Further, standard errors for the logistic regression coefficients were checked to verify if any values were greater than 2.

Variables selected for model development depended upon the quality of the data provided, the purpose of the variables, and the significance of the variables. For MLR models, forward stepwise selection was used to select the significant variables for the final model. Stepwise selection is a variable selection process in which the variables are added or removed at each level. It adds new variables at each step and evaluates the significance of existing variables in the model with the addition of each new variable. This process can eliminate previously selected variables that become superfluous in relation to other variables. Likelihood ratio was used to retain and remove a variable from consideration. The goal was to eliminate from the MLR models insignificant variables, thus focus mainly on the most significant variables in the overall model.

For the MLR models, the results were interpreted in terms of the odds ratio. The odds ratio interprets the actual effects of estimated coefficients. The odds ratio of an estimated coefficient indicates how the odds of an event were affected by a crash. For example, the estimated coefficient β_1 associated with an independent variable, X, represents the change in the log odds from X = 0 to 1. Therefore, the values of coefficients must be transformed to their original scale (odds ratio) in order to interpret the actual effects of variables. The odds ratio was obtained by exponentiating the value of the coefficient associated with the variable. Examples to determine the odds ratio are presented in the results section. The relationship between the estimated coefficient and the odds ratio, therefore, provides the foundation for interpretation of results from logistic regression models.

For MLR, an odds ratio greater than one (or positive estimate of coefficients) increases the likelihood of crash types other than crashes that represent the base category. An odds ratio of less than one (or negative estimate of coefficients) increases the likelihood of a crash that belongs to the base category.

2.4. RESULTS

Tables 2.2 to 2.4 present the results of MLR models developed, along with corresponding p-values for different variables. Based on the p-values, the statistical significance of variables is considered at three different levels: .001, .01, and .05. The results for only significant variables are presented. Additional variables considered in the analysis are presented in Tables T1 and T2 (in the appendix).

The p-values for deviance for both models equaled 1. The p-values for Pearson statistic for Median and Rollover Crash models equaled 0.974 and 0.907, respectively. A high p-value for deviance and Pearson statistic indicated that the models fit the data well. The values of likelihood ratio tests for both models were significant, indicating a good fit. These results collectively verified the goodness-of-fit of the models.

2.4.1. Rollover Crash Model

Tables 2.2 and 2.3 present the MLR results of median rollover and roadside rollover crashes, respectively with roadway non-rollover as the base category. In Table 2.2, representing median rollover versus roadway non-rollover crashes (base category), the variable 'Hours' significantly predicted whether the crash was a median rollover or a roadway non-rollover crash, and the estimate = 1.420, odds ratio (OR) = exponent (1.420) = 4.138, $p < 0.001$. The variable compares *Night/Early Morning (12 am – 6 am (0-6 hrs))* with the reference case *Afternoon (3 – 7 pm (15-19 hrs).* The positive coefficient of estimate and the odds ratio indicates that as day changes from early morning to afternoon, the odds of a median rollover crash compared to roadway non-rollover crash is 4.138. In other words, the odds of a median rollover crash compared to a roadway non-rollover crash is 4.14 times higher during the early morning hours. Similarly, the risk of crash occurrence during 10 am to 3 pm (*Night/Early Morning*) and 7 pm to midnight (*Late Evening*) are almost 2 to 2.5 times higher for median rollover crashes compared to roadway non-rollover crashes. This in general indicates that during time periods of low volume of traffic when drivers can travel at their desired speeds, the risk of median rollover crashes is higher compared to roadway non-rollover crashes. The association of low volume of traffic and median rollover crashes is also evident from the variable AADT. The odds ratio for volume *between 8k* and *32k* vehicles/day was 2.414, which indicates that median rollover crashes are 2.4 times more likely compared to roadway non-rollover crashes.

In Table 2.3, again Hour significantly predicted roadside rollover crashes versus roadway non-rollover crashes. The significant hours are from midnight to 6 am (*Night/Early Morning*) and from 6 to 10 am (*Morning*). The estimates are positive and the odds ratio decrease from 3.8 to 2.1, indicating the risk is higher during early morning and decreases as traffic volume increases during the morning peak period.

In Tables 2.2 and 2.3, the levels of Crash Severity i.e. *fatal/incapacitating injury* (K&A) and *non-capacitating/possible injury crashes* (B&C) were found to be significant and with positive coefficients for both median and roadside rollover crashes. The risk of a *fatality/incapacitating injury* was found to be 3.7 times higher for a median rollover crash when compared to a roadway non-rollover crash. Similarly, for a roadside rollover crash the risk of a *fatality/incapacitating injury* was found to be 2.5 times when compared to a roadway non-rollover crash. For median and roadside rollover crashes, the risks of *non-capacitating injury/possible injury* crashes were 1.98 and 1.6 times, respectively when compared to roadway non-rollover crashes.

Median Width was analyzed. The width used in the analyses excluded width of the inner roadway shoulder. Median Width was found to be significant with positive coefficients for both median and roadside rollover crashes (Tables 2.2 and 2.3). Median and roadside rollover crashes were 3.3 and 5.4 times more likely to occur compared to roadway non-rollover crashes with median widths between *greater than 32 ft* and *40 ft*. Median rollover crashes were also 2.7 times more likely to occur with a median width between *26 ft* and *32 ft* when compared to roadway non-rollover crashes. More details of the median width and its relation with K&A crashes is provided in Section 5.1 of this report.

In terms of Human Circumstances or simply driver behavior, several traits of drivers significantly predicted median and roadside rollover crashes. The traits found to be statistically significant were: *driver inexperience, unsafe speed, no improver driving*, *unknown* and *miscellaneous*. *Miscellaneous* was used in the tables to represent the following driver behaviors: ill, fell asleep, improper driving, emotional, making a lane change, drove off road, following too closely, etc. The frequency and percentage of crashes associated with each trait are presented in Tables T1 and T2 in the appendix. Except *Miscellaneous*, all other traits found significant were associated with both median and roadside rollover crashes. The odds ratios range from 1.8 to 7.2, *unsafe speed* with the lowest and *driver inexperience* with the highest odds ratios for both types of rollover crashes. Although the results were consistent, *no improper driving* was found to be significant for both rollover crash types with odds ratios of 2.4 and 4.2 for median and roadside rollover crashes, respectively.

The variable Road Characteristics was statistically significant in Tables 2.2 and 2.3; results indicate that freeways with horizontal *curve* and *level* grade were prone to median and roadside rollover crashes. The coefficient of estimates are positive. And the odds ratios are 2.2 and 2.3 (computed as exponents of 0.792 and 0.834, respectively) and indicate that positive coefficients (or odds ratio >1) increase the likelihood of median and roadside rollover crashes compared to roadway non-rollover crashes. The results also indicate that freeways with horizontal *curve* and *straight* segments on a *hillcrest* and a *gradient* are prone to median rollover crashes. The coefficient of estimates are positive. And the odds ratios are 2.09 and 1.87 (computed as exponents of 0.736 and 0.624), respectively indicate that positive coefficients of estimate (or odds ratio >1) increase the likelihood of median rollover crashes by 2.09 and 1.87 times, respectively, compared to roadway non-rollover crashes. A similar pattern was observed for roadside rollover crashes in Table 2.3. This finding is consistent with other studies such as Jonsson et al. (2009), Pande and Abdel-Aty (2009), and Bham et al. (2012). They found that single-vehicle collisions were more closely associated with highway geometry and vertical profile.

Surface condition is an important variable on highways in Alaska. During the winter, the highways can be slippery due to the presence of ice, snow, sleet, and slush. In Table 2.2, *ice*, *snow*, and *slush* were found to be significant, with positive coefficients of estimate, and odds ratios of 2.61 and 1.98. Therefore, with *ice, snow,* and *slush,* the risk of median rollover crashes were 2.61 and 1.98 times higher compared to roadway non-rollover crashes. Similarly, in Table 2.3, for roadside rollover crashes, *ice, snow, slush,* and *'other' miscellaneous* surface conditions were significant with positive coefficients i.e. the risk of roadside rollover crashes ranged was 2.26 to 3.44 times higher compared to roadway non-rollover crashes. These results clearly indicate that with ice, snow, and slush, both median as well as roadside rollover crashes are more likely to occur.

As the variable Gender was found to be significant, the interaction between Gender and Age groups was evaluated. For roadside rollover crashes, the interaction was found to be significant for females between the ages of 21 and 25 years. In Table 2.3, a positive coefficient indicates that the risk of a roadside rollover crash was 2.7 times higher compared to a roadway non-rollover crash for a driver between the ages of 21 and 25 years.

Table 2.3 presents the result of evaluation of variable, Speed Limit. Speed limit ranges from 60–65 mph on the four freeways. Two speed limits were tested, 60 and 65 mph. For roadside rollover crashes, a speed limit of 65 mph was found to be significant with a positive coefficient, indicating higher risk with an odds ratio of 2.61 times compared to roadway non-rollover crashes.

As many crashes occur near interchanges (also presented in the next two chapters), a variable was defined to evaluate the significance of distance between a crash and the interchange. For every crash, the distance from the interchange was determined. This distance was divided into three categories as presented in Table T1 (in the appendix). The variable, Near Overpass, is significant with a positive coefficient (Table 2.2) indicating the risk of median rollover crashes to be 1.78 (1/.562) times higher compared to roadway non-rollover crashes. The median rollover crashes were positively associated with a distance between (*greater than*) *0.75 miles* and *2.5 miles* from the interchange. This indicates crash occurrence before and after the interchanges due to possible high frequency of weaving and lane changing. Also, perhaps caused by ease in referencing location of crashes.

In Southcentral Alaska, freeways with depressed medians have a typical foreslope that ranges from 4:1 to 6:1. These slopes are within the range of 4:1 to 7:1 in which both rollovers and cross-median crashes are most prevalent (NCHRP 794, 2014). Median Slope was found statistically significant. The estimated coefficient was positive, indicating that the risk of a median rollover crash was 1.97 (1/.507) times higher for 6:1 slope compared to 4:1 and 5:1 for a roadway non-rollover crash. This indicates that median rollover crashes were positively associated with slopes of 6:1. More discussion on median slope to follow in Section 5.1.

For variable Vehicle Type, for both median as well as roadside rollover crashes, *light truck, bus, single unit truck, and semi* were found to be significant with positive coefficients of .367 and .443, and odds ratios of 1.44 and 1.56. This indicates that the risk of median and roadside rollover crashes was 1.44 and 1.56 times higher compared to roadway non-rollover crashes, respectively for these vehicle types. A closer look at the break down in different vehicle types indicated that *light trucks* (only 4 tires) make up the majority of these vehicle types. When crash data were carefully examined, out of 340 median crashes, *light trucks* were involved in 184 (54.1%) of these crashes. *Light trucks* were also involved in 56.9% of all rollover median crashes. These *light trucks* represent the majority of pickups in this vehicle class type. And possibly represents overconfident drivers in four-wheel drive vehicles.

In Table 2.3 for roadside rollover crashes, vehicle actions *skidding* and *out of control* vehicles were found to be significant. The coefficient of estimate is positive with an odds ratio of 1.77, which indicates that when a vehicle *skids* or gets *out of control* the risk of a roadside rollover crash is 1.77 times higher compared to a roadway non-rollover crash.

2.4.2. Median Crash Model

Median intrusion crashes consist of cross-median and in-median crashes classified by rollover and non-rollover crashes. MLR was used to associate the crash contributing factors with these crash types, and the results are presented in Table 2.4 with in-median non-rollover crashes as the base category. Several factors were found statistically significant at different levels and they are presented in the following.

In terms of Crash Severity, *Fatal and incapacitating injury* (K&A) crashes were significant for two out of the four crash types in Table 2.4. Cross-median non-rollover crashes with the highest percentage (21.2%) of K&A crashes, with an odds ratio of 42.9, indicated high risk of a (K&A) crash compared to an in-median non-rollover crash. Similarly, cross-median rollover crashes were positively associated with K&A crashes with an odds ratio of 22.7 compared to in-median non-rollover crashes. Further, cross-median rollover crash was positively associated with *non-*

incapacitating and *possible injury* (B/C) crashes with an odds ratio of 4.5 compared to in-median non-rollover crashes. Both in-median crash types were not found to be significant as they had relatively low percentage of K&A crashes; (1/59) 1.7% and (17/215) 7.9% for in-median non-rollover and rollover crashes.

The variable, Vehicle Type, significantly predicted whether the crash was a cross-median rollover or in-median non-rollover crash. This is the effect of different types of vehicles. The coefficient of estimate was negative for cross-median rollover crashes. This indicates that cross-median rollover crashes were 5.46 (1/.183) times at risk compared to in-median non-rollover crashes when driving a *light truck, bus, single unit truck, and semi*. When data were analyzed specifically for Vehicle Type, *light trucks* were involved in 75.8% (25/33) of cross-median crashes. As mentioned previously, *light trucks* represent the majority of pickups in this vehicle class type.

Collision Type was found significant for cross-median non-rollover crashes. With a positive coefficient for *multiple vehicles'* collision, the odds ratio for cross-median non-rollover crashes was found to be 20.5 when compared with in-median non-rollover crashes. This indicates high risk of *multiple vehicles* in a collision when a cross-median non-rollover crash occurs. *Multiple vehicles* collision represented 57.6% of cross-median non-rollover crashes compared to single vehicle collisions. For *multiple vehicles* collision, the vehicle types were almost equally divided between light trucks and passenger vehicles. Based on the odds ratio, a high risk of K&A injury collision with vehicles traveling in the opposing direction is also indicated for cross-median non-rollover crashes.

Rutting was found to be significant with a positive coefficient for cross-median rollover crashes. This indicates that the risk of cross-median rollover crashes is 9.9 times higher with a pavement rut depth of *0.125 in. or less* when compared to in-median non-rollover crashes.

The variable Surface was found to be statistically significant with a positive coefficient for cross-median rollover crashes. This indicated that several road surface conditions (including wet, water, etc.), cross-median rollover crashes were 4.5 times higher at risk of occurrence compared to in-median non-rollover crash. This indicates that cross-median rollover crashes are sensitive to pavement surface conditions. The association of rollover crashes with pavement conditions is also evident from Tables 2.2 and 2.3.

The variable Light, with a positive coefficient was found significant for the crash type cross-median non-rollover crashes. When the freeway was *dark - lighted*, the risk of cross-median non-rollover crashes was 5.6 times higher when compared to in-median non-rollover crashes.

The coefficients for Median Slope were found to be negative and positive for cross-median non-rollover and in-median rollover crashes, respectively. The negative association shows that cross-median non-rollover crashes are associated with median slope of 6:1 and an odds ratio of 3.56 (1/.281) compared with in-median non-rollover crashes. For in-median rollover crashes, the coefficient was positive, which indicated that in-median rollover crashes were 2.16 times more at risk of occurrence compared to in-median non-rollover crashes when median slope was either 4:1 or 5:1. This indicates that a crash is more vulnerable to a rollover with a median slope of 4:1 or 5:1, and non-rollover crashes were associated with 6:1 slope. However, since the frequency and percentage of rollover crashes associated with the different slopes is so similar in this study, it is difficult to distinguish a clear trend. This is apparent when the results are compared with the Rollover Crash Model presented earlier.

2.5. SUMMARY

Two multinomial logistic regression models were developed. With only one model, a few variables would have been found to be associated with different crash types. The two models complemented the results and, as a result, several variables were found to be statistically significant and associated with different median crash types. The identified variables contribute significantly and increase the risk of these crash types.

The most important variables that contribute to the risk of median rollover crashes were identified to be the hours associated with low volume of traffic, median widths of 26 to 40 ft, driver inexperience and no improper driving, horizontal curves, straight section on gradients and hillcrest, and ice on the pavement. These crashes were associated with severe and possible injury crashes.

Cross-median non-rollover crashes were found to be at high risk of multiple vehicle crashes and severe injury crashes. Cross-median rollover crashes were associated with light trucks. They were also found to be associated with rutting, and dark but lighted roadways.

Roadside rollover crashes were associated with non-severe injury crashes. Different hours of the day, horizontal curves with gradients and hill crest, driving behaviors such as unsafe speed, driver inexperience, and no improper driving, pavement surface with ice, snow and slush, and females between the ages of 21 and 25 years.

Table 2.2. Multinomial Logistic Regression: Parameter Estimates and Odds Ratio for Rollover Crash Model

Variable	Categories	Reference	Estimates	Std. Error	Wald	[b]p-value	[c]OR = Exp(B)	95% CI for Exp(B)	
								[c]LB	[c]UB
MEDIAN ROLLOVER[a]									
Intercept			-6.253	0.820	58.110	0.000			
Hours	0 - 6 hrs – Night/Early Morning	15 - 19 hrs - Afternoon	1.420	0.303	21.940	**0.000**	4.138	2.284	7.497
	19 - 24 hrs – Late Evening		0.898	0.275	10.690	*0.001*	2.455	1.433	4.205
	10 - 15 hrs – Morning/Afternoon		0.674	0.252	7.157	*0.007*	1.962	1.197	3.215
Crash Severity	Fatality/Incap. Injury	Property Damage Only	1.309	0.334	15.390	**0.000**	3.702	1.925	7.119
	Non-capacitating injury/possible injury		0.682	0.173	15.561	**0.000**	1.978	1.409	2.776
Median Width	> 32 - 40 ft	> 40 - 64 ft	1.684	0.495	11.572	0.001	5.389	2.042	14.223
	26 - 32 ft		0.991	0.382	6.731	*0.009*	2.695	1.274	5.700
Human Circumstances	Driver Inexperience	Distraction	1.553	0.384	16.380	**0.000**	4.724	2.227	10.019
	No Improper Driving		0.897	0.280	10.278	*0.001*	2.452	1.417	4.244
	Unknown		0.692	0.291	5.645	0.018	1.997	1.129	3.533
	Unsafe Speed		0.621	0.284	4.785	0.029	1.860	1.067	3.243
Road Characteristics	Curve/Level	Straight/Level, Unknown	0.792	0.251	9.958	*0.002*	2.208	1.350	3.610
	Curve/Hillcrest/Grade		0.736	0.246	8.986	*0.003*	2.088	1.290	3.378
	Straight/Hillcrest/Grade		0.624	0.214	8.499	*0.004*	1.866	1.227	2.839
AADT	8k – 32k vehs/day	> 48k – 63k vehs/day	0.881	0.344	6.560	0.010	2.414	1.230	4.739
Surface	Ice	Dry	0.958	0.213	20.162	**0.000**	2.606	1.715	3.958
	Snow, Slush		0.681	0.280	5.927	0.015	1.975	1.142	3.417
Near Overpass	> .75 – 2.5 mi	0 – 2.5 mi	0.576	0.242	5.635	0.018	1.778	1.106	2.860
Median Slope	6:1	4:1, 5:1	0.680	0.290	5.501	0.019	1.974	1.118	3.483
Vehicle Type	Light Trucks, Bus, SU, Semi	Passenger Cars, Motorcycle, Misc.	0.367	0.165	4.938	0.026	1.443	1.044	1.995

a). The base category is: ROADWAY NON-ROLLOVER. b). Statistical significance: $p < .001$ (bold), $p < 0.01$ (italics), & $p < 0.05$ (normal). c) OR = odds ratio, LB = lower bound, UB = upper bound.

Table 2.3. Multinomial Logistic Regression: Parameter Estimates and Odds Ratio for Rollover Crash Model

Variable	Categories	Reference	Estimates	Std. Error	Wald	[b]p-value	OR = Exp(B)	95% CI for Exp(B)	
								LB	UB
ROADSIDE ROLLOVER[a]									
Intercept			-6.611	0.916	52.083	0.000			
Hours	0 - 6 hrs – Night Early Morning	15 - 19 hrs - Afternoon	1.336	0.309	18.647	**0.000**	3.802	2.074	6.970
	6 - 10 hrs - Morning		0.747	0.260	8.267	*0.004*	2.111	1.268	3.512
Human Circumstances	Driver Inexperience	Distraction	1.971	0.463	18.092	**0.000**	7.176	2.894	17.792
	Unknown		1.573	0.363	18.821	**0.000**	4.820	2.368	9.808
	No Improper Driving		1.435	0.364	15.521	**0.000**	4.199	2.056	8.572
	Miscellaneous		1.397	0.374	13.979	**0.000**	4.042	1.944	8.405
	Unsafe Speed		1.209	0.363	11.122	*0.001*	3.350	1.646	6.817
Road Characteristics	Curve/Level	Straight/Level, Unknown	0.834	0.268	9.705	*0.002*	2.302	1.362	3.889
	Curve/Hillcrest/Grade		0.791	0.256	9.531	*0.002*	2.205	1.335	3.642
Surface	Ice	Dry	1.235	0.238	27.014	**0.000**	3.438	2.158	5.477
	Snow, Slush		0.896	0.311	8.272	*0.004*	2.449	1.330	4.510
	Miscellaneous		0.815	0.299	7.415	*0.006*	2.260	1.257	4.064
Gender * Age	Female * 21-25 yrs	Female * 26-35 yrs	0.984	0.352	7.806	*0.005*	2.675	1.341	5.333
Crash Severity	Fatality/Incap. Injury	Property Damage Only	0.896	0.386	5.374	0.020	2.449	1.148	5.224
	Non-capacitating Injury/Possible Injury		0.494	0.185	7.148	*0.008*	1.639	1.141	2.353
Vehicle Type	Light Trucks, Bus, SU, Semi	Passenger Cars, Motorcycle, Misc.	0.443	0.177	6.269	0.012	1.558	1.101	2.205
Speed Limit	65 mph	60 mph	0.960	0.386	6.193	0.013	2.613	1.226	5.566
Median Width	> 32 - 40 ft	> 40 - 64 ft	1.199	0.534	5.047	0.025	3.316	1.165	9.439
Vehicle Action	Skidding/Out of Control	Straight Ahead	0.671	0.322	4.327	0.038	1.956	1.039	3.679

a). The base category is: ROADWAY NON-ROLLOVER. b). Statistical significance: $p < .001$ (bold), $p < 0.01$ (italics), & $p < 0.05$ (normal).

Table 2.4. Multinomial Logistic Regression: Parameter Estimates and Odds Ratio for Median Crash Model

Variable	Categories	Reference	Estimates	Std. Error	Wald	[b]p-value	OR = Exp(B)	95% CI for Exp(B)	
								LB	UB
CROSS-MEDIAN ROLLOVER[a]									
Intercept			-2.099	0.768	7.468	*0.006*			
Vehicle Type	Motorcycle, Passenger Cars, Misc.	Light Trucks, Bus, SU, Semi	-1.696	0.530	10.226	*0.001*	0.183	.065	0.519
Crash Severity	Fatality/Incap. Injury	Property Damage Only	3.121	1.270	6.045	0.014	22.676	1.883	273.032
	Non-incapacitating, Possible Injury		1.504	0.528	8.128	*0.004*	4.500	1.600	12.655
Rutting (in)	0 - .125 - Lowest	> .125 - .362 - Low	2.288	0.822	7.741	*0.005*	9.855	1.966	49.390
Surface	Other, Missing, Water, Wet	Ice	1.515	0.710	4.557	0.033	4.549	1.132	18.279
CROSS-MEDIAN NON-ROLLOVER[a]									
Intercept			-2.258	0.836	7.297	0.007			
Collision Type	Multiple Vehicles	Single Vehicle	3.020	0.717	17.737	**0.000**	20.482	5.024	83.492
Crash Severity	Fatality/Incap. Injury	Property Damage Only	3.761	1.251	9.045	*0.003*	42.994	3.706	498.738
Light	Dark - lighted	Daylight	1.730	0.659	6.892	*0.009*	5.643	1.550	20.538
Median Slope	4:1, 5:1	6:1	-1.271	0.627	4.101	0.043	0.281	0.082	0.960
IN-MEDIAN ROLLOVER[a]									
Intercept			0.584	0.442	1.746	0.186			
Crash Severity	Non-incapacitating, Possible Injury	Property Damage Only	0.820	0.350	5.496	0.019	2.271	1.144	4.510
Median Slope	4:1, 5:1	6:1	0.770	0.334	5.305	0.021	2.159	1.122	4.157

a). The base category is: IN-MEDIAN NON-ROLLOVER. b). Statistical significance: $p < .001$ (bold), $p < 0.01$ (italics), & $p < 0.05$ (normal).

3. SPATIAL ANALYSIS AND HOTSPOT IDENTIFICATION

3.1. INTRODUCTION

High severity injury crashes are a major concern for transportation agencies. Highway segments that experience a high frequency of severe injury crashes, termed as hotspots, blackspots or identification of sites with promise, require treatments to reduce the risk of such crashes in the future. This chapter uses spatial analysis and hotspot identification measures to examine crash patterns and identify and rank highway segments most vulnerable to high frequency of severe injury crashes. The focus of crashes data analysis were the four main freeways shown in Figure 1.1.

3.2. LITERATURE REVIEW

A literature review of past studies was performed to identify the best practices of spatial analysis in highway safety. Several studies provided viable options for discovering the density of data points and measures to rank road segments.

Puluguthra et al. (2007) analyzed methods for ranking pedestrian crash zones in the state of North Carolina. Three steps in the study were: geocode pedestrian crash data, create a crash concentration map, and identify zones, their shapes, and sizes. Of interest was the method of creating a crash concentration map. Also, the study compared the use of the Simple Ranking method and the Kernel Density estimation technique. Kernel Density produced a smoother mapping of crash concentrations and accurately identified crash locations of high or low density. It was concluded that Kernel Density identifies high pedestrian crash zones better than the Simple Ranking method. Mohaymany et al. (2013) described the usefulness in employing Kernel Density estimation as a tool to detect high-crash-risk road segments. The study indicates that the major value of Kernel Density lies in its visual appeal and easy-to-display results, and suggests that multiple Kernel surfaces be produced over a time period (3 years in this particular study) to determine the stability of hotspots.

The literature proposes many hotspot identification measures. The Highway Safety Manual (AASHTO, 2010) presents the advantages and disadvantages of these hotspot identification measures from the literature. Manepalli and Bham (2016) evaluated most commonly used hotspot identification measures, Crash Rate (CR), Empirical Bayes (EB) (Hauer, 1997), Equivalent Property Damage Only (EPDO) (Pawlovich, 2007), and the Empirical Bayes based on crash severity (EB_{CS}), and based on limitations of existing measures proposed a new measure, the Crash Factor Measure (CFM). CFM takes into account the frequency and the injury severity of crashes in ranking high crash locations or hotspots. The ranking of segments on Interstate, US, and State highways was carried out to evaluate and compare the different measures. It was determined that CFM performed better and was reliable than other severity-based measures (Manepalli and Bham, 2016).

The past studies cited lead this study in integrating the application of Kernel Density Estimation (KDE) and CFM effectively to identify and rank hotspots on the freeways examined in this study.

3.3. METHODOLOGY

This study applies Kernel Density Estimation and CFM with subsequent ranking. Kernel Density was chosen over methods such as a Simple Ranking or a Sliding Window method, as the results reflect the entire segments that are considered hotspots and neglect areas that are not. This procedure is more accurate as the segments that are ranked depend solely on their crash characteristics, and not based on a fixed length or shape before any analysis was conducted.

CFM was selected as a ranking mechanism as it takes into account for a specific highway segment the frequency and the injury severity of crashes, and the Annual Average Daily Traffic (AADT) to present a more realistic view of the nature of the selected segment. This section describes Kernel Density and the CFM, and their application in this study to identify hotspots.

3.3.1 Kernel Density

Kernel Density is a non-parametric method that estimates the probability density function of a random variable. It evaluates the local probability of an occurrence to infer about the population. For a given set of observations (x_1, x_2, …. x_n) from an unknown probability density function, the Kernel estimator can be defined as:

$$\hat{f}(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x-x_i}{h}\right) \tag{3.1}$$

where: h is called the smoothing parameter (or bandwidth), K is called the kernel, and $\hat{f}$ is the estimator of the probability density function f. Thus, the Kernel estimator depends on h and K. An appropriate choice of h is determined by the purpose of the estimate.

The Kernel estimator calculates the density of clustering of data points that can be visualized in different ways. Conceptually, Kernel Density is defined by placing a "surface" over the map divided into a grid, or cells, with data points. This surface follows a Search Radius (bandwidth) algorithm (SRA) that can be expressed as (HKDW, 2016)):

$$SRA = 0.9 \cdot \min(SD, \sqrt{\frac{1}{\ln(2)}} \cdot D_m) \cdot n^{-0.2} \tag{3.2}$$

where:

SD = Standard Distance,
D_m = Median of the distance from the mean center for all points,
n = Number of data points.

SD is a measure of concentration of data points around the mean center of the data. SD is expressed as:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{X})^2}{n} + \frac{\sum_{i=1}^{n}(y_i-\bar{Y})^2}{n} + \frac{\sum_{i=1}^{n}(z_i-\bar{Z})^2}{n}} \tag{3.3}$$

where a data point has location defined in terms of x, y, and z.

The SD is used as the radius of the circle and is plotted around each data point. The circle is used to develop a dome, with the dome being a unit high at the data point and decreasing evenly to zero at the edges of the circle, following the Kernel estimator given in Equation 3.1. The sum of each of the domes, or kernel values, around each data point that overlap in a given cell is used as the value of the density. This gives a value per unit area, which is the cell's value of density. ArcGIS was used to conduct this, in which various volumes were represented by different colors. Figure 3.1 presents an example of results from Kernel Density.

Figure 3.1. Kernel Density used with New Seward Highway data

KDE uses a threshold value to identify significant clusters of data. This is similar to identification of high crash locations. High crash locations are segments on a highway that have crash frequency significantly higher than expected at some threshold level of significance (Hakkert and Mahalel, 1978). KDE in this study used a threshold value of 40/km^2 (or 103.63/mi^2) to identify crash clusters. The value indicates the volume under the kernel density surface. To evaluate the effects of this threshold, a sensitivity analysis was performed. It was found that a value of 40/km^2 and above selects segments with significant clustering. At this value, the insignificant clusters were minimal as well. Higher cutoff values, such as 80 or 100/km^2 (207.25 or 259.07/mi^2), excluded many segments with clusters, while lower values such as 20/km^2 (51.81/mi^2) included too many segments with sparse crashes. The segments that met or exceeded this threshold value were further analyzed to identify high crash locations.

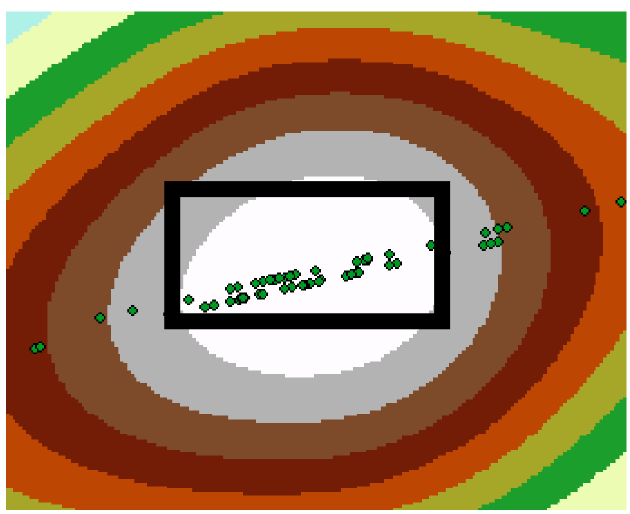

Figure 3.2. Segment Used for Analysis

In Figure 3.1, every segment contained within the dark red (gray in black and white) was selected for analysis. Within these chosen segments, only the segment(s) with the highest kernel density value was further analyzed as a hotspot. For instance, in Figure 3.1, the segment within the white surface was considered, but not within the entire dark red circle. Figure 3.2 shows this segment in more clarity, with the black outlined segment to be further analyzed. Similar segments were analyzed on the four freeways to ensure that the resulting segments were the most high risk segments, not segments that contained some high risk and other less risk segments.

3.3.2. CFM and Ranking

After all qualifying segments were identified using KDE, the CFM of each identified segment was calculated. The CFM is calculated as:

$$CFM = \frac{CSI \cdot AADT}{Segment\ Length \cdot T} \tag{3.4}$$

where:

AADT = Average Annual Daily Traffic
CSI = Crash Severity Index (see Equation 3.5)
T = number of days for the time period analyzed.

The AADT values were obtained for each crash, based on its location and year of the crash. The CSI in the above equation is computed as:

$$CSI = C_K{*}W_K + C_A{*}W_A + C_{B/C}{*}W_{B/C} + C_O{*}W_O \tag{3.5}$$

where:

C_I = frequency of crashes, I indicates the levels of crash injury severity, varies from K to O,
K = fatal injury crashes,
A = incapacitating injury crashes,
B/C = moderate injury crashes/complaint of pain and possible injury crashes,
O = property damage only (PDO) crashes,
W_I = weights assigned to crash injury severity levels, I indicates the levels of crash injury severity.

The levels of injury severity can be weighted based on crash costs (Council et al., 2005) to represent equivalent levels of PDO crashes. In Alaska, the DOT&PF uses a four level scale of injury severity i.e., B and C are combined. For 2016, the crash costs in Alaska were: $9,500,000, $660,000, $100,000, and $7,300 for K, A, B/C, and O crashes, respectively. The weights (W_I) were therefore found to be 1301.37, 90.41, 13.7, and 1, respectively. The weights are computed by dividing the estimated crash costs by the estimated cost of a PDO crash.

From Equation 3.4, a higher value of CFM will indicate a segment with both a higher frequency and higher severity of crashes. After CFM was calculated for every segment considered to have significant clustering, the segments were ranked based on these values. In this study, the CFM value computed for the segments were divided by 1000 for easy comparison. As the CFM was used as a mechanism to rank the various segments, this division did not affect the results. The selected highways segments were also analyzed with a simple measure i.e., Crash Density (CD). The CD of a segment is calculated as:

$$CD = \frac{Crash\ Frequency}{Segment\ Length} \tag{3.6}$$

Table 3.2, and Tables 3.4 to 3.8 present the segment ranks based on CFM for the four freeways analyzed. The methodology presented above was used to identify the hotspot locations on the freeways with regards to all crashes. Further, it was applied to identify the hotspot segments with regards to median crashes on these freeways. The hotspot ranking of freeways segments is separated by direction.

3.4. DATA DESCRIPTION

This chapter uses four years of data, 2009 to 2012, provided by the DOT&PF to identify freeway segments identified as hotspots. This timespan was short enough to minimize the effect of year-to-year random fluctuations, and not affected by major roadway changes and traffic conditions. Data from the four freeways were used. Table 3.1 presents the details of the routes and the frequency of crashes at various severity levels.

Table 3.1. Highway Crash Frequency at Levels of Injury Severity

Freeways	Fatal (K)	Incapacitating Injury (A)	Non-incapacitating/ Possible Injury (B/C)	PDO (O)	Total
Glenn	9	56	352	802	1219
Minnesota Drive	0	6	56	122	184
New Seward	1	11	103	233	348
Parks	0	3	21	63	87
Total	10	76	532	1220	1838

Analysis of crash data was performed with under-reporting of PDO crashes as an issue duly noted. The crash under-reporting should be appreciably high to impact scores generated by crash severity measures, as the weights vary from 1 to 1301 for the different levels of crash severity. Hence, 1301 PDO crashes should be under-reported to have an impact of one fatal crash. Under reporting, therefore, should not appreciably affect crash severity measures when the KABCO-based weights are used. Truong et al. (2011) evaluated the influence of under-reporting of crashes at different levels and found that the impact was not significant for a hotspot identification performance measure. Further, under-reporting is highest mainly for PDO crashes, minimal in injury crashes, and zero for fatal crashes. Ye and Lord (2011) indicated that the analysis will not be affected when a severity weight of 1 is used and the under-reporting for PDO crashes is not more than 40%. Another study, Oh et al. (2010), also reached the same conclusion. Therefore, it was believed that the impact of under-reporting of crashes will be minimal on the identification of freeway hotspot locations, and hence, were not further explored. The identification of location of median intrusions which may be impacted by under-reporting of PDO crashes is addressed in Chapter 4.

3.5. RESULTS AND DISCUSSION

The four freeways were analyzed individually by direction to identify high crash segments. The combined results are presented to identify the top ranked segments on these freeways. Further, the crash data were analyzed to identify locations of cross-median crashes (both rollover and non-rollover) and in-median crashes that were rollover. Due to the risk of a crash with vehicles traveling in the opposite direction, all cross-median crashes were analyzed, instead of separating into rollover versus non-rollover. As presented in Table 1.2, due to the high frequency and injury severity of in-median rollover crashes, their locations were important to identify any hotspots and were therefore analyzed separately. These results are presented below.

3.5.1. Glenn Highway

Figure F2 in the appendix shows the results of Kernel Density when applied to Glenn Highway crash data to provide an example of the output examined for this study. The darker areas in the figures indicate the high crash locations, whereas the lighter areas indicate locations with comparatively fewer crashes. The high crash locations identified were ranked separately for both Northbound and Southbound directions. Table 3.2 summarizes the data from these analyses by milepoints. Figures 3.3-3.6 show an approximate location for the top four hotspot locations on the Glenn Highway. For Northbound and Southbound travel, an overlap between hotspot locations is observed, and this is reflected in the images. The solid box indicates a hotspot in the Northbound, and the dashed box indicates a hotspot in the southbound direction. This overlap indicates freeway segments in both directions of travel with high frequency and injury severity crashes, indicating that the crash causes are not unique to one direction of the freeway.

Table 3.2. Glenn Highway, High Crash Locations

Location (MP#)	CFM	CD	Rank*	Location (MP)	CFM	CD	Rank*
Northbound				Southbound			
2.60-3.82	8.02	44.12	4	3.07-3.43	45.44	119.44	1
4.70-6.10	12.63	47.86	3	5.78-6.32	19.20	69.16	2
9.57-10.66	53.11	54.95	1	10.17-10.90	16.35	40.82	3
24.46-24.86	20.32	84.44	2	24.47-25.19	11.93	40.00	4

MP = milepoint; * Rank based on CFM

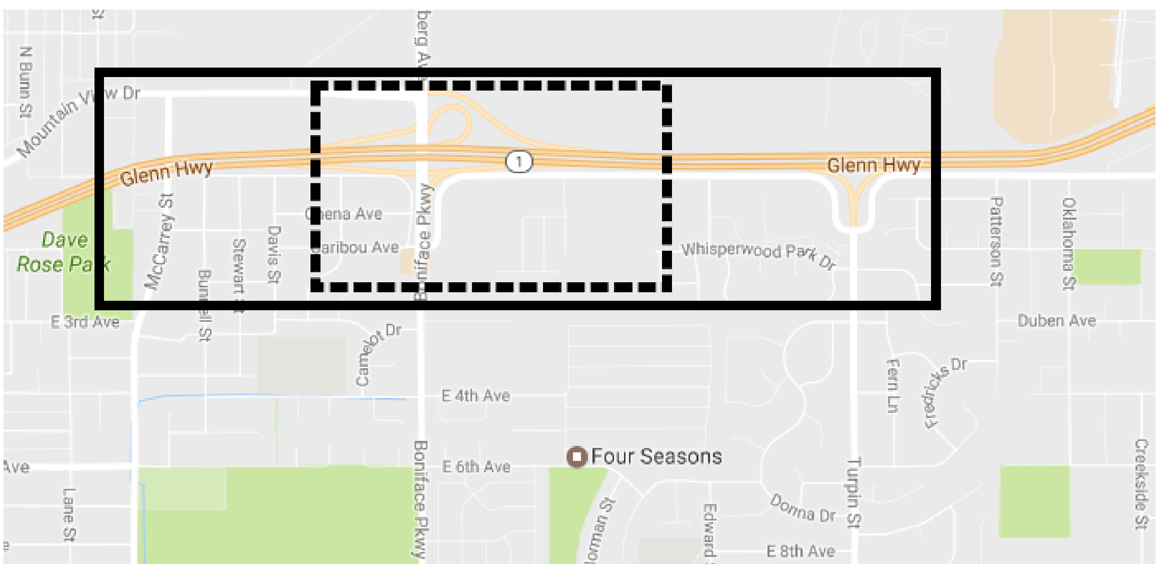

Figure 3.3. Glenn Highway: #4 Northbound Hotspot (solid box), MP 2.60-3.82, and #1 Southbound Hotspot (dashed box), MP 3.07-3.43

In Figure 3.3, MP 3.07-3.43 contains the most severe hotspot in the Southbound direction on the Glenn Highway. This segment starts just before and extends beyond the interchange, indicating the exit and interchange itself are at risk of serious injury crashes.

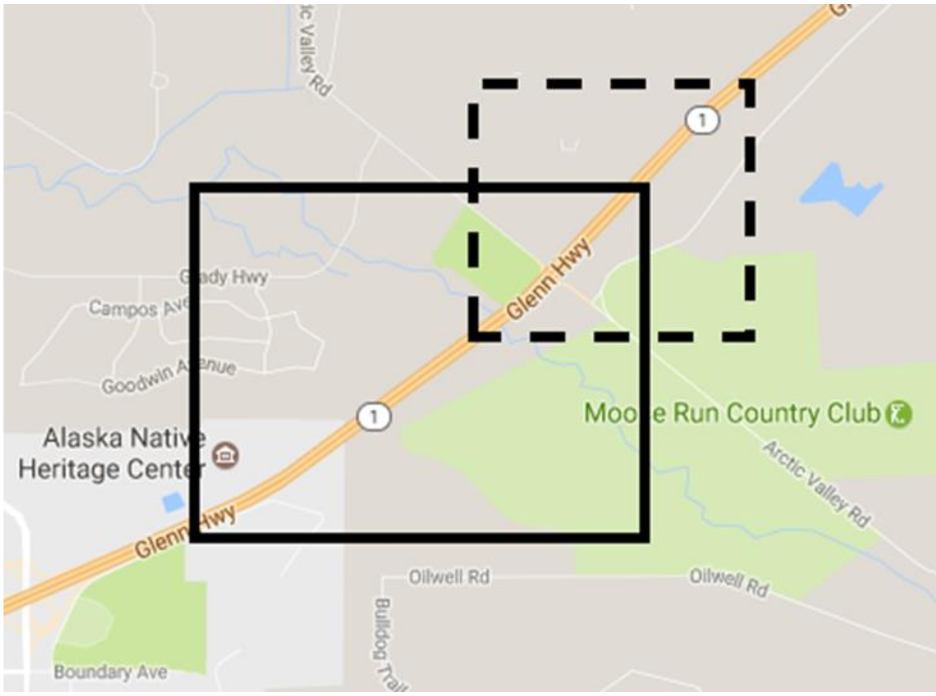

Figure 3.4. Glenn Highway: #3 Northbound Hotspot (solid box), MP 4.70-6.10, and #2 Southbound Hotspot (dashed box), MP 5.78-6.32

Figure 3.4 presents the third ranked hotspot on the Northbound segment, MP 4.70-6.10, around an interchange. This indicates that the interchange and exit at Muldoon Road are at risk for crashes. This interchange, however, is being reconstructed as a diverging diamond interchange. And is planned to be completed in the summer of 2018.

In Figure 3.5 for Northbound travel, the segment, MP 9.57-10.66, contains the highest ranked hotspot. This is most likely due to the geometry of the road—three horizontal curves all in close proximity to one another (within a mile), including an ‘S’ curve. When traveling at high speeds, during the winter, during low visibility, or during a combination of these conditions, vehicles may lose control while traversing these curves, resulting in a higher frequency and severity of crashes.

One of these horizontal curves in Figure 3.5, outlined within the dashed box, is a Southbound hotspot, MP 10.17-10.90, as well. This indicates that this horizontal curve may be harder to traverse than the other two that proceed it, as it is considered a hotspot for both Northbound and Southbound travel. This may be due to the high volume of traffic merging at this location. Further evaluation is therefore recommended at this location.

Figure 3.6 also shows overlap between North and Southbound hotspot locations. This identifies another location between the two interchanges that is a high crash location. Further examination is recommended to identify the major crash contributing factors at this location.

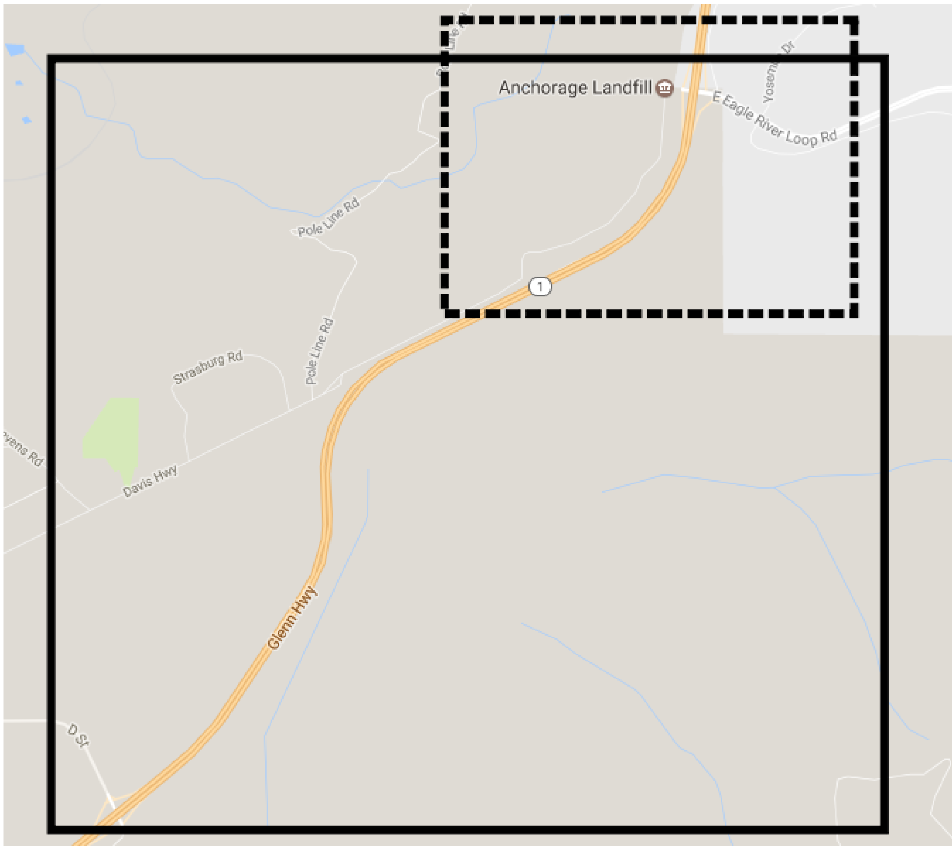

Figure 3.5. Glenn Highway: #1 Northbound Hotspot (solid box), MP 9.57-10.66, and #3 Southbound Hotspot (dashed box), MP 10.17-10.90

3.5.1.1. Median Crashes

Glenn Highway was analyzed to determine the locations for cross-median crashes and in-median rollover crashes. Both rollover and cross-median crashes are of concern. Cross-median crashes are of major concern when considering safety on a highway. As shown in Table 3.3, cross-median crashes have a much higher percentage of at least one fatality or incapacitating injury than other crash types. In the table, "severe injury crashes" refers to a crash that results in at least one fatality or incapacitating injury.

Table 3.3. Severe Injury Crashes, All Crash Types on Glenn Highway

Crash Types	Total Crashes	Severe Injury Crashes	Severe Injury Crashes (%)
Cross-Median Crashes	28	9	32.1%
In-Median Crashes	144	11	7.6%
All Non-Median Crashes	1047	45	4.3%
Total	1219	65	5.3%

Since cross-median crashes have a much higher percentage of a severe injury or a fatality, reducing these crash types is desired. Thus, cross-median crashes on the Glenn Highway were analyzed to determine locations that are conducive to these types of crashes.

Figures 3.7 and 3.8 identify the hotspot locations by milepoints for in-median rollover crashes. Table 3.4 presents these locations and their ranks based on the CFM. In Figure 3.7, the segment MP 19.37-21.11 includes the Birchwood Loop Road interchanges. This indicates that interchanges may be a factor in the higher crash frequency on this section of the freeway.

Figure 3.6. Glenn Highway: #2 Northbound Hotspot (solid box), MP 24.46-24.86, and #4 Southbound Hotspot (dashed box), MP 24.47-25.19.

Table 3.4. Glenn Highway: In-Median Rollover Crashes, High Crash Locations

Location (MP)	CFM	CD	Rank*
19.37-21.11	18.26	6.31	1
2.29-4.5	2.97	6.32	2

Figure 3.7. Glenn Highway: #1 In-Median Rollover Hotspot MP 19.37-21.11.

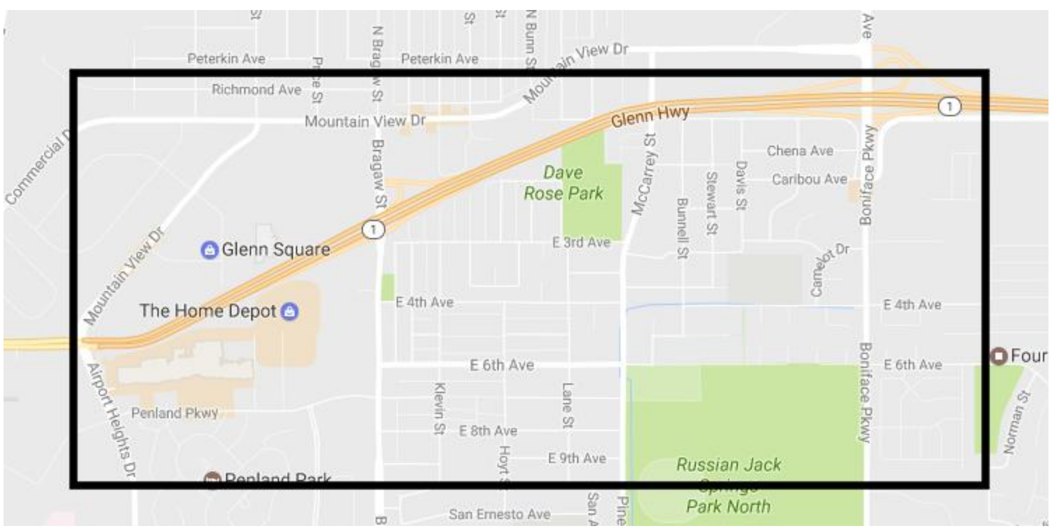

Figure 3.8. Glenn Highway: #2 In-Median Rollover Hotspots, MP 2.29-4.5.

This segment, MP 2.29-4.5 as presented in Figure 3.8, is located entirely within Anchorage, Alaska’s largest and most populated city. This segment also has a higher AADT of 54,000 vehicles/day compared to other locations. Higher volume of traffic, narrow median width, and location of entrance and exit ramps, combined with aggressive driving to leave and enter city during peak periods, especially during winter weather conditions, may be a factor in a greater number of median intrusions in this area.

From Figure F3 in the appendix, it is clear that cross-median crashes are spread sparsely over the entire length of Glenn Highway, indicating random occurrence. Significant clusters were also not observed. So, while cross-median crashes are of major concern, no specific location on Glenn Highway with a significantly high frequency of these crash types were therefore found. Thus, no further analysis was performed on this category of crashes.

To determine prominence of median intrusion in general, both in-median and cross-median crashes were combined and analysis was performed. This proved that there are several segments of the Glenn Highway where median intrusion is common. Table 3.5 summarizes this data. Figures 3.9-3.12 identify these segments on Glenn Highway.

Table 3.5. Glenn Highway Median Intrusion, High Crash Locations

Location (MP)	CFM	CD	Rank*
9.4-10.8	35.92	7.86	1
19.07-20.1	31.56	15.47	2
2.60-4.63	7.77	13.31	3
23.6-25.6	2.64	7.5	4

*Rank based on CFM

Figure 3.9. Glenn Highway: #1 Hotspot Location for Median Intrusions, MP 9.4-10.8.

In Figure 3.9, the location (MP 9.4-10.8) includes two interchanges and a stretch of freeway between them. This once again shows that the presence of interchanges and their surrounding road plays a part in increasing crash frequency and severity.

In Figure 3.10, the freeway segment, MP 19.07-20.1, is centered between two interchanges, again indicating that interchanges increase both the likelihood of a crash and the severity of that crash.

Figure 3.10. Glenn Highway: #2 Hotspot Location for Median Intrusions, MP 19.07-20.1

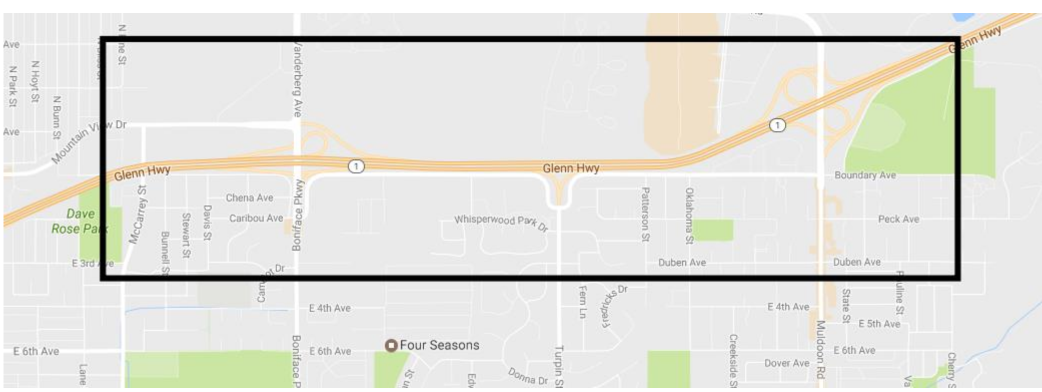

Figure 3.11. Glenn Highway: #3 Hotspot Location for Median Intrusions, MP 2.6-4.63

In Figure 3.11, MP 2.6-4.63 contains two interchanges (Boniface Parkway and Muldoon Road) and a stretch of freeway between them, again illustrating the prominence of interchanges on Alaskan highway crashes.

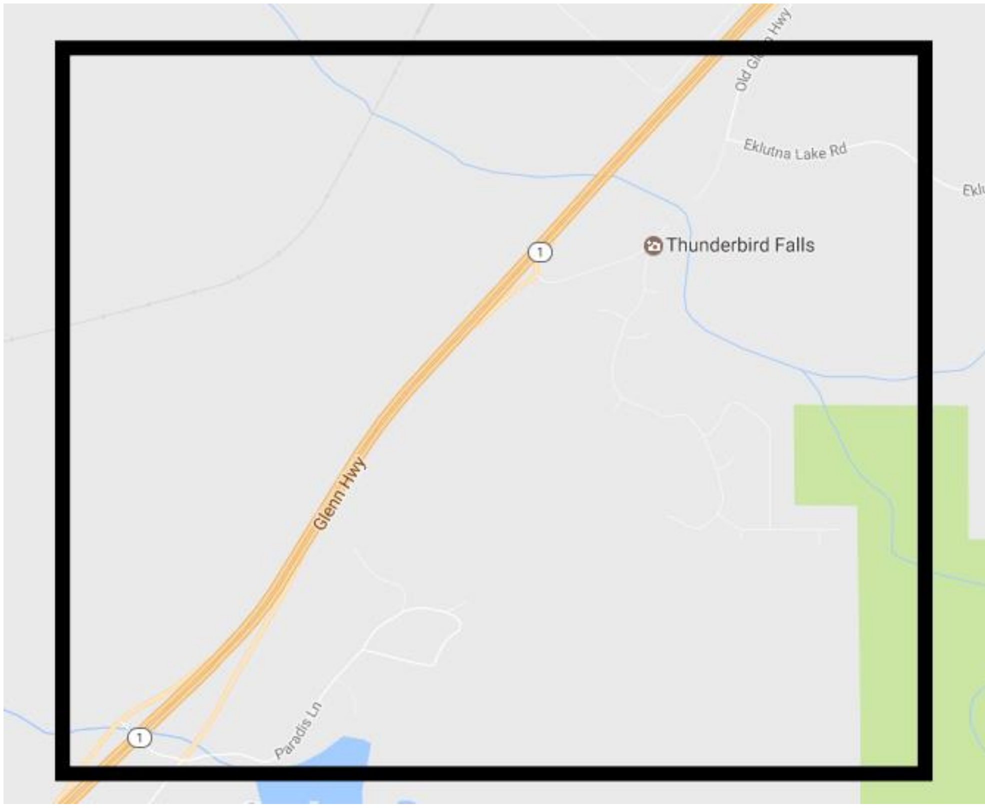

Figure 3.12. Glenn Highway: #4 Hotspot Location for Median Intrusions, MP 23.6-25.6.

Many of the median crash hotspot locations have overlap with the overall Glenn Highway hotspot locations. These segments include a section of Glenn Highway between Bragaw Street and Muldoon Road (MP 2.6-4.6) as shown in Figure 3.11, a segment of Glenn Highway near Joint Base Elmendorf-Richardson (MP 9.4-10.8) as shown in Figure 3.9, and a section of freeway near Thunderbird Falls (MP 23.6-25.6) as shown in Figure 3.12. The fact that the same hotspot locations were identified for Northbound, Southbound, and for median intrusions indicates that crash-reduction measures implemented on these locations would have a significant effect in the reduction of crash frequency and severity on these segments.

The only crash type with segments that did not exhibit a higher tendency to produce crashes were cross-median crashes. These were found to be random events.

3.5.2. Minnesota Drive

Minnesota Drive data was analyzed for both Northbound and Southbound travel. From the results, it was determined that there were no Southbound segments that met the required threshold to be considered significant, and only one Northbound segment. Table 3.6 summarizes the details of the Northbound hotspot. Figures 3.13 shows the Northbound hotspot location along the Minnesota Drive. This Minnesota Drive hotspot centers around an interchange, which shows that interchanges and diverging and merging vehicles have a significant negative impact on the safety of this road.

Table 3.6. Northbound Results, Minnesota Drive

Location (MP)	CFM	CD
3.78-4.09	33.81	73.22

*Rank based on CFM

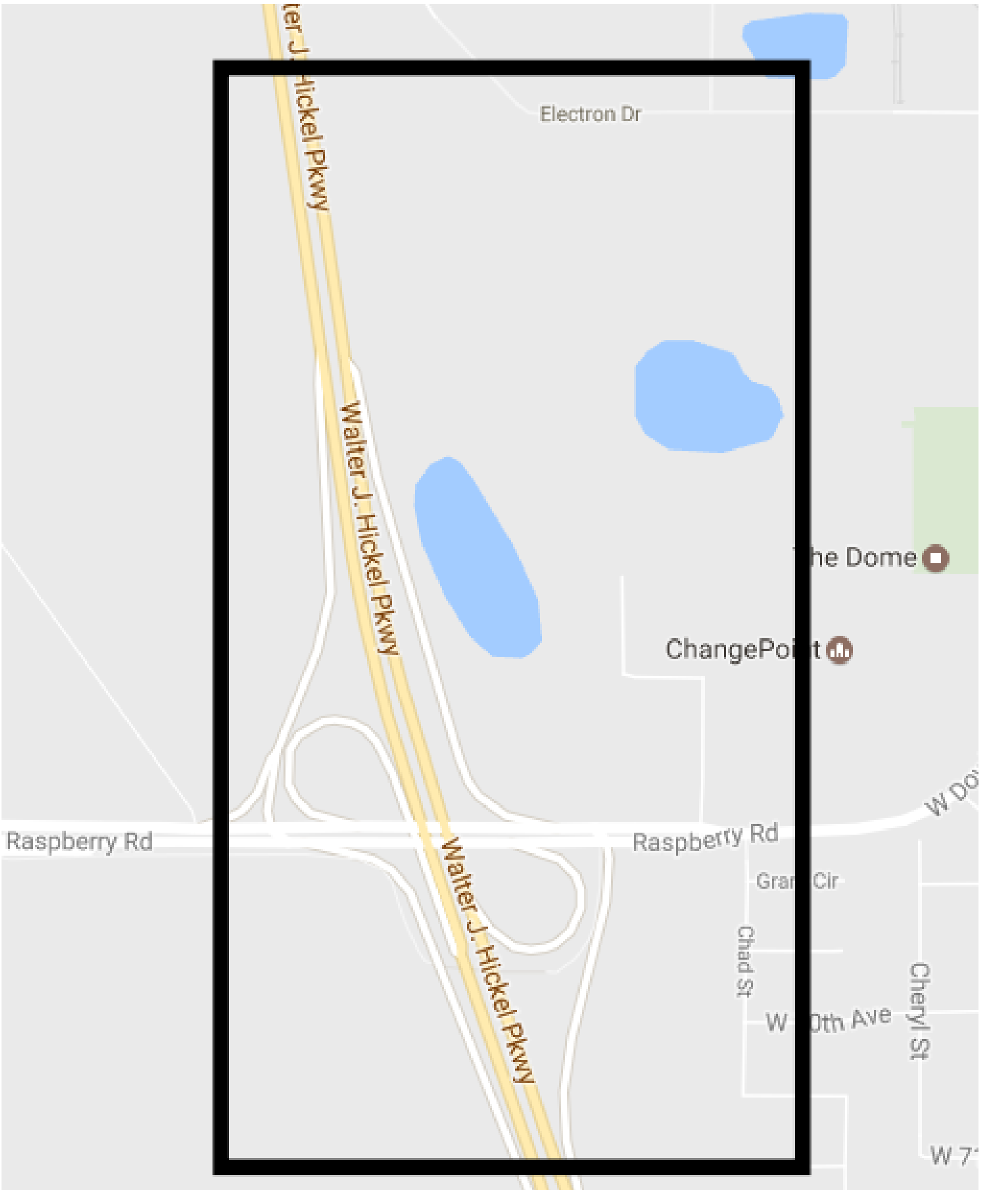

Figure 3.13. Minnesota Drive: Northbound Hotspot, MP 3.78-4.09

3.5.2.1. Median Crashes

Minnesota Drive was analyzed using KDE to determine areas of the freeway that have significant clustering of median intrusion crashes. However, it was determined that no segments of this freeway had significant clustering, as none met the required KDE value threshold of 40/km^2.

3.5.3. Seward Highway

Seward Highway data was divided and analyzed by direction of travel. Table 3.7 summarizes the results of this analysis. Figures 3.14 to 3.17 show the Northbound hotspot locations, and Figures 3.18 and 3.19 show the Southbound hotspot locations along the Seward Highway.

Table 3.7. Seward Highway, High Crash Locations

Location (MP)	CFM	CD	Rank*
Northbound			
122.69-122.92	497.85	222.73	1
124.25-124.36	162.39	772.73	2
121.31-121.48	40.79	147.06	3
119.77-120.08	21.14	74.19	4
Southbound			
123.82-124.01	307.87	172.97	1
122.11-122.79	3.97	29.15	2

*Rank based on CFM

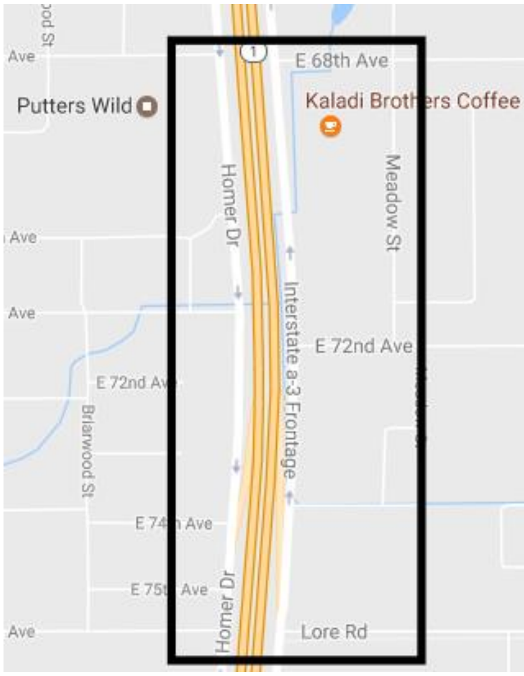

Figure 3.14. Seward Highway: #1 Northbound Hotspot, MP 122.69-122.92

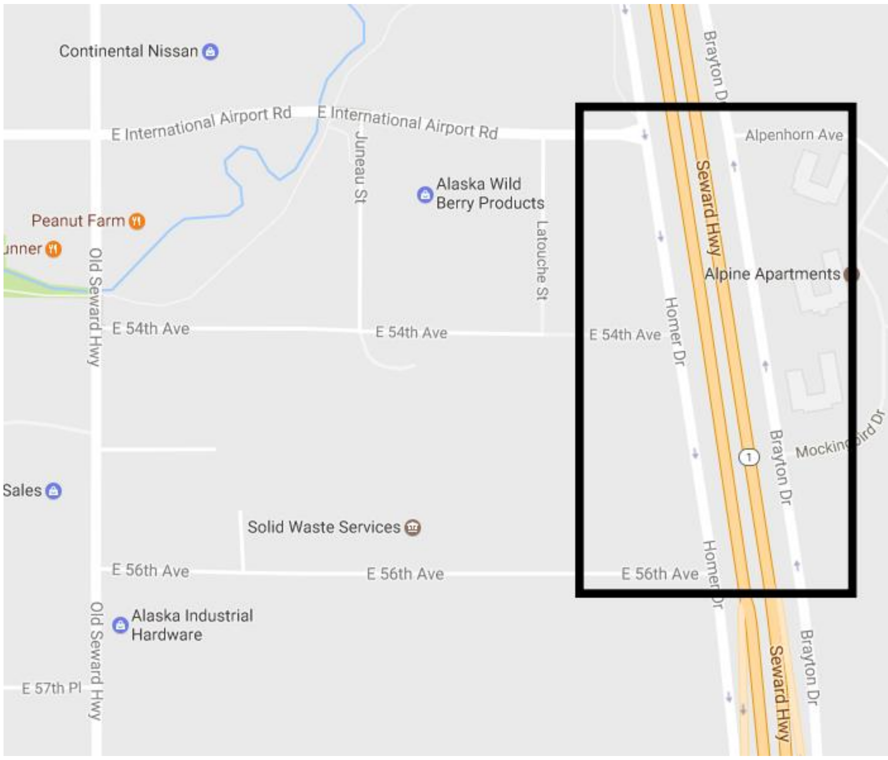

Figure 3.15. Seward Highway: #2 Northbound Hotspot, MP 124.25-124.36

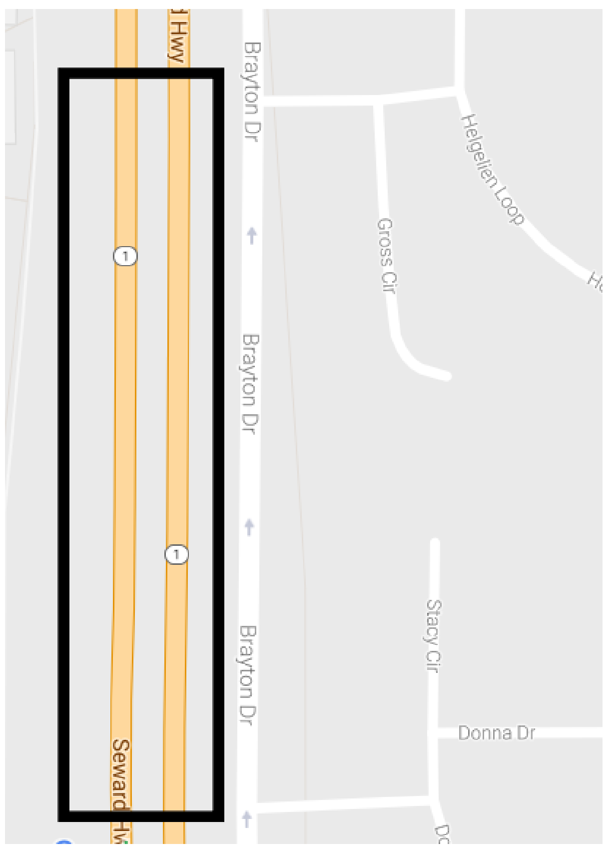

Figure 3.16 Seward Highway: #3 Northbound Hotspot, MP 121.31-121.48

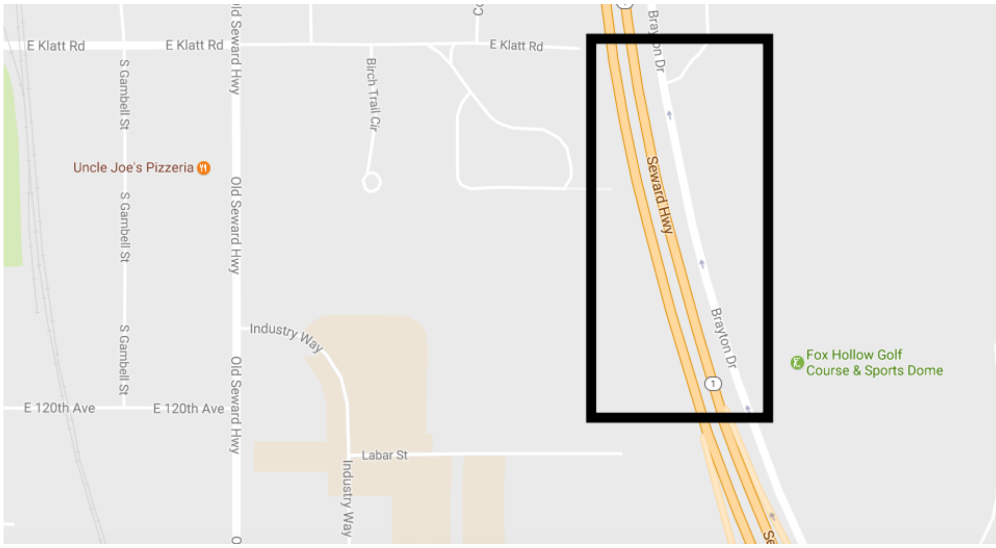

Figure 3.17 Seward Highway: #4 Northbound Hotspot, MP 119.77-120.08

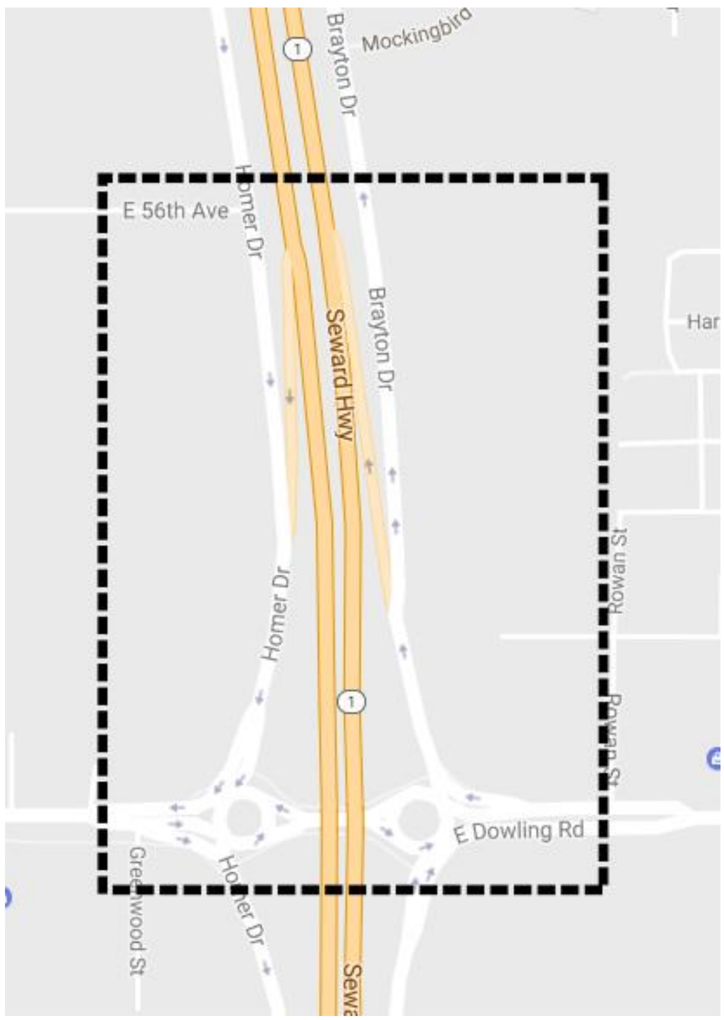

Figure 3.18. Seward Highway: #1 Southbound Hotspot, MP 123.82-124.01

In Figure 3.18, the segment of Seward Highway, MP 123.82-124.01, is located directly after vehicles have a chance to exit the freeway. These exiting vehicles decelerate and change lanes, therefore slowing traffic and causing other drivers to decelerate or change lanes. Merging, diverging, weaving, slowing down, and accelerating may be the main causes of crashes on this segment of the freeway. A detailed study is required to ascertain the crash contributing factors and subsequent deployment of measures to reduce the frequency and severity of crashes.

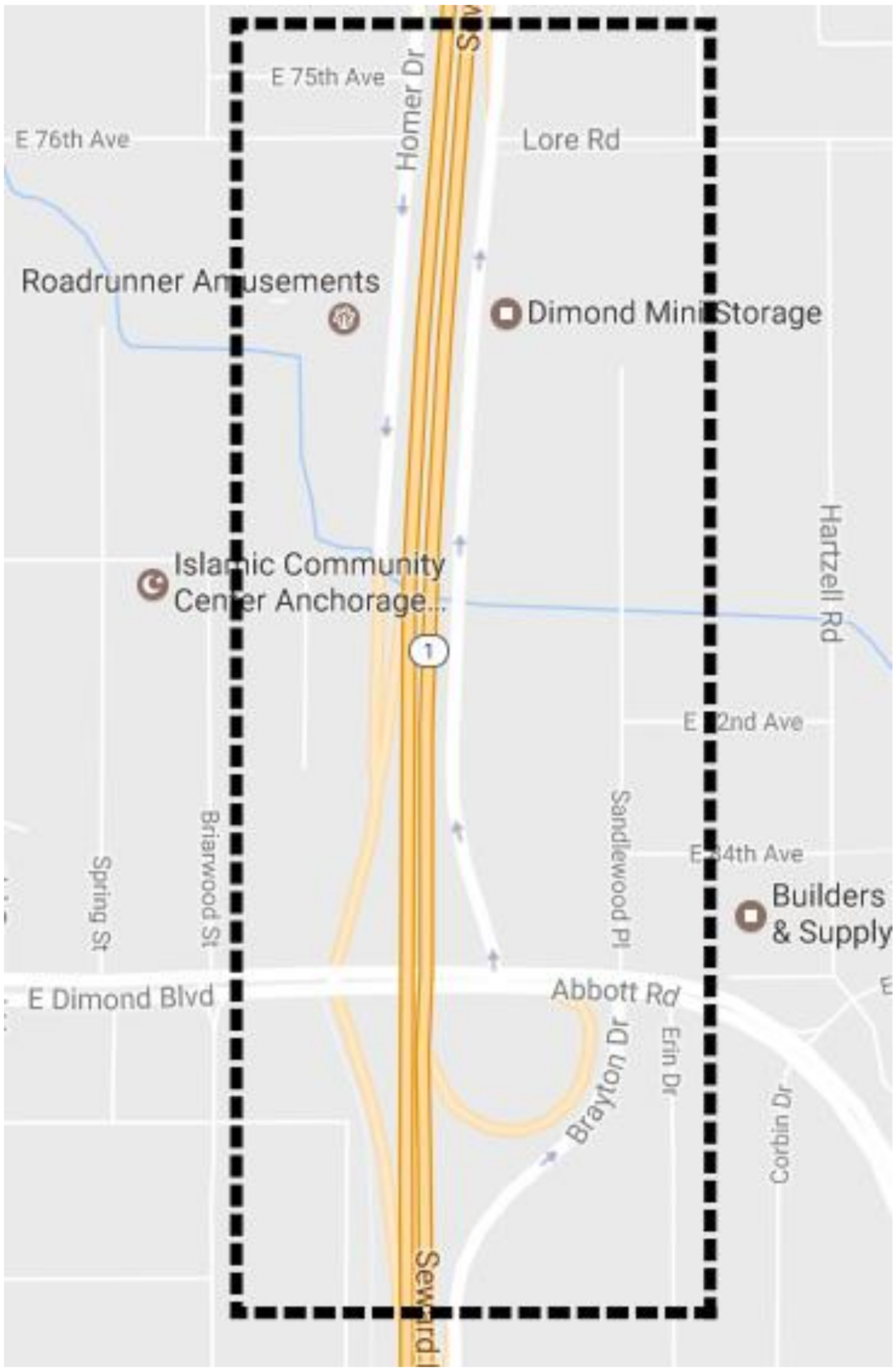

Figure 3.19 Seward Highway: #2 Southbound Hotspot, MP 122.11-122.79

In Figure 3.19, the segment, MP 122.11-122.79, includes an interchange, and is a factor that requires a detailed study to identify crash contributing factors.

3.5.3.1. Median Crashes

Seward Highway was analyzed using KDE to determine areas of the freeway that have significant clustering of median intrusion crashes. However, it was determined that no segments on this freeway had significant clustering, as none met the required KDE value threshold of 40/km^2.

3.5.4. Parks Highway

Parks Highway data were analyzed for both Northbound and Southbound directions to determine the location of hotspots. Table 3.8 presents the results of this analysis. Figures 3.20 and 3.21 show these locations along the Parks Highway.

Table 3.8. Parks Highway, High Crash Locations

Location (MP)	CFM	CD	Rank*
37.61-37.9	5.17	30.84	1
35.74-36.86	1.41	18.76	2

*Rank based on CFM

It is notable that the CFM values for Parks Highway hotspots are considerably lower than the values for the other freeways, and while still considered to be significant where crash clustering is concerned, these segments may not be as high risk sites as the segments identified on other freeways with higher CFMs.

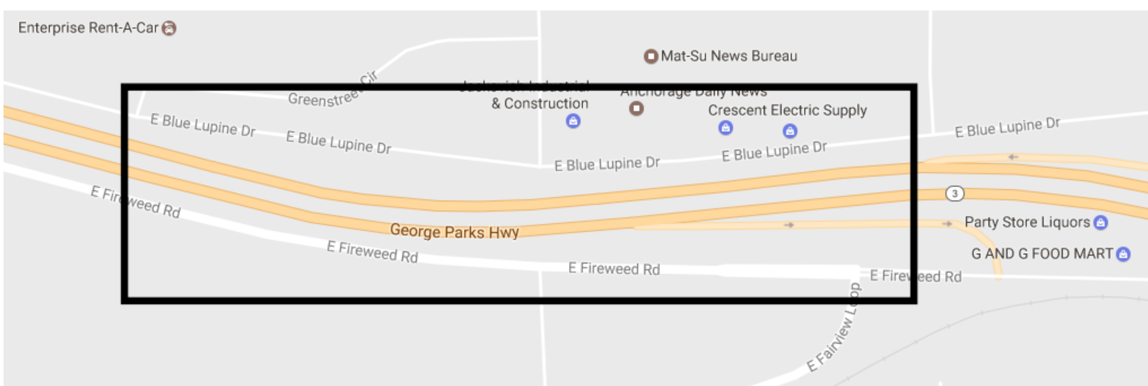

Figure 3.20. Parks Highway: #1 Hotspot Location, MP 37.61-37.9

3.5.4.1. Median Crashes

No segments on the Parks Highway were found to have significant clustering, therefore further analysis was not performed.

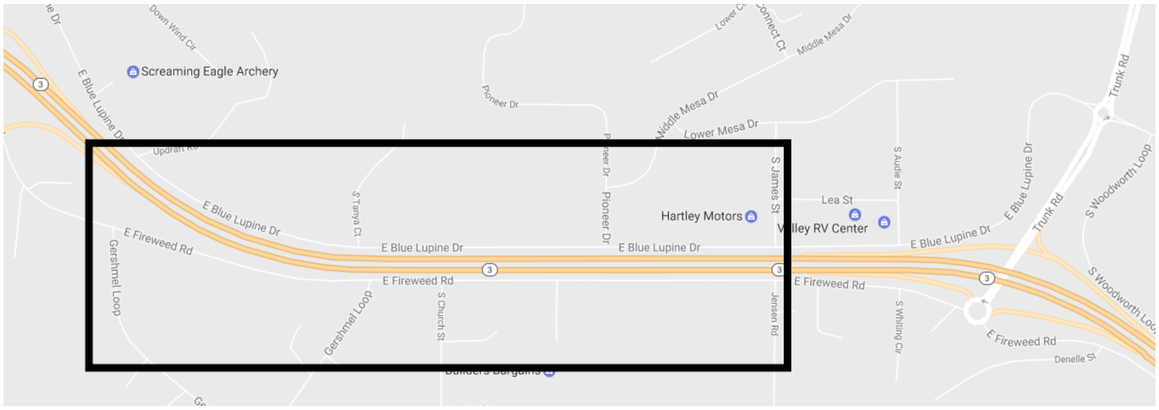

Figure 3.21. Parks Highway: #2 Hotspot Location, MP 35.74-36.86

3.5.5. Overall Results: Ranking of Hotspots

To tabulate the results of the analysis and summarize the identification of hotspots, the high crash locations on all four freeways were ranked. Table 3.9 presents the top hotspots across the Glenn Highway, Seward Highway, Minnesota Drive, and Parks Highway.

Table 3.9. Top Hotspots

Rank	Freeways	MP	Direction of Travel	CFM*	Median Crashes?
1	Seward	122.69-122.92	Northbound	497.85	-
2	Seward	123.82-124.01	Southbound	307.87	-
3	Seward	124.25-124.36	Northbound	162.39	-
4	Glenn	9.57-10.66	Northbound	53.11	Yes
5	Glenn	3.07-3.43	Southbound	45.44	Yes
6	Seward	121.31-121.48	Northbound	40.79	-
7	Minnesota Drive	3.78-4.09	Northbound	33.81	-
8	Seward	119.77-120.08	Northbound	21.14	-
9	Glenn	24.461-24.866	Northbound	20.32	Yes

* CFM used for ranking of segments: CFM value divided by 1000.

As shown in Table 3.9, the most number of segments was identified on Seward Highway. Further, the top ranked segments were also identified on the Seward Highway. Seward Highway has a high AADT during much of the year, as this freeway leads to popular recreational activities (Alyeska for skiing, Seward for fishing, etc.) and is used for commuting to work. Other characteristics of the Seward Highway may also contribute to crashes compared to freeways in Southcentral Alaska. Various hotspots also have significant median crashes. These are also indicated in Table 3.9.

3.6. SUMMARY

Identification of high crash locations, or “hotspots," on freeways is essential for implementation of crash countermeasures in order to reduce both the frequency and severity of crashes. This chapter identified these hotspots for overall crashes, and for crashes that intrude the medians on depressed divided freeways in Southcentral Alaska.

Kernel Density Estimation (KDE), an approach to identify clustering patterns within a data set, was used to effectively identify hotspots. Segments determined to have statistically significant clustering were ranked using the Crash Factor Measure (CFM), which takes into account both the frequency and severity of crashes on a freeway segment. By effectively combining these measures, an accurate account of the nature of a hotspot—both length and frequency/severity of crashes—was portrayed.

The highest frequency of hotspots was identified on the Seward Highway compared to the four freeways studied. This shows that various characteristics of Seward Highway, such as high AADT, contribute to a higher frequency and severity of crashes. A detailed study is required to evaluate, identify, and propose countermeasures.

Cross-median crashes were found to be random events. On Glenn Highway, however, other median intrusions were found to have significant clustering. The analysis conducted in this chapter identified that close proximity to interchanges increases both the likelihood of a median intrusion and the likelihood of a crash in general. This finding supplements the findings of the previous chapter. This may be due to the design of on-ramps and off-ramps on freeways considered. The on-ramps and off-ramps on Glenn Highway were not built to handle the type of traffic they now experience. Updating these ramps to the needs of current traffic and vehicle characteristics may significantly reduce both crash frequency and severity on these freeway segments. Freeway segments upstream and downstream of interchanges require detailed evaluation to study the crash characteristics and the crash contributing factors. Driver behavior near interchanges is also of concern and requires further evaluation.

The reduction of median crashes is of major concern. On the Glenn Highway from 2009 to 2012, 1047 crashes were non-median crashes. Of these, 45 resulted in a fatality or incapacitating injury, a rate of 4.3%. In contrast, for the same data set, 172 crashes were median intrusions (either cross-median crashes or in-median crashes). Of these 172 crashes, 20 resulted in a fatality or incapacitating injury, a rate of 11.6%. When only considering cross-median crashes, 9 out of 28 crashes, or 32.1% of all crashes, caused either a fatality or incapacitating injury. These numbers indicate that median intrusions are almost three times as likely to result in a serious injury compared to a non-median crash, while cross-median crashes are 7.5 times more likely than a non-median crash to cause a crash with a serious injury. Thus, reducing all median crashes is of concern with respect to safety of travelers.

Many crashes occurred near the interchanges. Various countermeasures may be implemented to reduce these crashes, and a study is proposed to identify the countermeasures that will have a significant impact on the reduction of both crash frequency and severity on these segments of freeways. The interchanges with freeway segments identified as hotspots either upstream, downstream, or both are:

- Glenn Highway and Muldoon Road
- Glenn Highway and Boniface Parkway
- Glenn Highway and Birchwood Loop Road
- Glenn Highway and Eagle River Loop Road
- Minnesota Drive and Raspberry Road
- Seward Highway and Abbott Road.

4. ANALYSIS OF VIDEO DATA COLLECTED

4.1. INTRODUCTION

Median intrusion crashes were examined on four freeways in Southcentral Alaska. During the winters (November – April), drive through video data were collected from 2013 to 2016 to identify the location and frequency of these crashes in the median. The identification of location of median intrusions, including rollover crashes, will allow for better recommendations for treatments to mitigate these crashes.

This chapter presents the analysis of video data collected on the four freeways considered in this study. During the winter, many vehicles lose control and crash into the depressed median. According to the Alaska Statue (28.35.080), a driver in an accident resulting in a bodily injury or death or property damage to an extent of $2000 or more is required to give immediate notice to the local police department or the Department of Public Safety (Alaska Statues, 2016). A self-report can be mailed or faxed to report a crash as well. Property damage only (PDO) crashes that may cost less than $2000, therefore, may not be reported, resulting in underreporting of PDO crashes. Median crashes during the (short) summers in Alaska lack clear evidence of high frequency of intrusions and therefore were not studied. Video data collected during the winters was used to arrive at an estimate of the frequency of vehicles that enter the depressed medians and the most vulnerable locations. The crashes observed from video data were analyzed independently of archived crash data provided by the DOT&PF.

4.2. DATA COLLECTION

Median crash data were collected with Garmin VIRB Elite video cameras attached to vehicles while driving at the freeway speed. The video cameras can record at 1080 pixels and can collect Global Positioning System (GPS) data. The GPS data provides approximate location of a crash in the median. Figure F4 shows one of the vehicles used in data collection with two video cameras attached. Two cameras provided better coverage, from two different angles and added redundancy to video data recording. The video cameras are capable of data collection at temperatures of -5F.

Table 4.1 Snowfall Comparison of Observed Winter Seasons and Average Data (NOAA, 2016)

Winters	Snowfall (inches)	Number of Observed Crashes	Days with Snow Fall
2013-2014	64.6	90	42
2014-2015	25.2	64	23
2015-2016	38.3	40	26

Vehicles equipped with a video camera(s) drove sections of all four freeways in Southcentral Alaska with depressed medians. The observed freeways were the divided sections of Glenn Highway, New Seward Highway, Minnesota Drive and the Parks Highway. Video drive through data were collected over the three winters.

Table 4.1 presents the total snowfall during these winters and the number of days with snowfall. These winters were the 11th, 5th, and 2nd warmest on record (Di Liberto, 2016). The 30-year average winter snow fall is 74 in. From comparison with the average 30-year snowfall, it is clear that these winters had almost 10 to 50 inch less snowfall; 2014-15 and 2015-16 winters had uncharacteristic low snowfall.

Data was collected throughout each winter season starting in November 2013. As much as possible, the freeways were driven after snow events for two reasons: 1) crashes are most likely to occur within the first hour or so of a snow event (Usman et al., 2012) and it is important to collect as much data as possible, and 2) main freeways in Southcentral Alaska have maintenance priority and the snow displaced from the freeways by plows obscures the tracks of vehicles that entered the median. Table 4.2 presents the number of times each freeway was traversed with video camera equipped vehicles over the three winters.

Table 4.2 Frequency of Drive Through Data Collected Per Year and By Freeway

Freeways	Length (miles)	2013-2014	2014-2015	2015-2016	Total
Glenn Highway	34.00	12	6	1	19
New Seward Highway	9.87	2	4	2	8
Minnesota Drive	5.36	2	6	2	10
Parks Highway	4.16	10	6	1	17
Total	53.39	26	22	6	54

From Table 4.2, it can be observed that Glenn and Parks Highways were traversed the most number of times. Also, the most number of drive-through were conducted the first year and the least number during the last year, indicating the impact of decrease in snow events over the years. As much as possible, drive-through were executed after a snowfall. However, due to logistical challenges and the short duration of available daylight during the winter months, video data on median crashes after every snow fall could not be collected.

4.3. DATA ANALYSIS

Videos of the drive through were analyzed, and multiple still shots near crashes were obtained. The still shots were taken with a GOM Player, a media player that allows shots to be extracted at predefined intervals of time. Ten shots per second were used in the study. From multiple still shots, the best shots were selected to study these crashes. The shots were then examined for details of vehicle tire tracks to study the angle of entry, locations where the vehicle stopped and exited from the median, frequency of crashes, etc. Software developed by Garmin, VIRB Edit, was used to integrate the video data with the coordinates obtained from the GPS data.

Crashes analyzed included ones with evidence that vehicles entered and exited the median. For example in Figure 4.1, it can be observed that by the time the drive-through data were collected, tire tracks of vehicle entrance, exit, or both became unclear due to effects of time, weather, and maintenance. When either the intrusion entrance, exit, or both became unclear, the intrusion was not included in analysis. On the contrary, Figure 4.2 shows a set of vehicle tracks that appear intentional. To have reliable crash results to analyze, these types of observations were not included in the analysis or crash count.

To be identified as a cross-median crash from drive-through video data, a clear entrance point and a clear exit point need to be observed, without evidence of the vehicle stopping in the median. Both in-median and cross-median crashes can result in a rollover. Figures 4.3 and 4.4 shows the tire tracks of non-rollover cross-median crashes.

Figure 4.1 Example of a Crash that was Not Counted

Figure 4.2 Example of an Intentional Drive Crossing the Median

Figure 4.3 A Cross-Median Crash on Glenn Highway

Figure 4.4 A Cross-Median Crash on the Parks Highway

Figure 4.3 shows a cross-median crash that is ambiguous from which direction the vehicle entered the median, but it is clear that the vehicle traveled all the way through the median. The trajectory of the tire tracks suggest the vehicle was traveling at a high speed and the driver did not have enough time to take corrective action while in the median. In Figure 4.4, the crash exhibits a clear entrance point in the same direction of travel as the camera. The vehicle appears to have turned to its left, but still exits the far side of the median without coming to a stop. It is clear from Figures 4.1 to 4.4 that the median width and slope are such that it is relatively easy for vehicles to traverse the depressed median. It should be noted that tire tracks could be from law enforcement vehicles albeit rare, however, challenging to distinguish the differences in tire tracks from the photos.

On repeated reviewing of the drive-through videos, median intrusion crashes were further categorized by two variables; a) angle at which the median was entered, and b) how far into the median the vehicle traveled. Figure 4.5 resents the sub-categories for angles of entry and Figure 4.6 shows specific median locations where the vehicles presumably came to a stop or went through the median. For the purpose of exploratory analysis, entry angles were divided into multiples of 30 degrees. The positioning of the cameras varied from drive-through to drive-through and the exact angle of entry was not obtainable. Measurement of angle of entry was carried out visually. The thirty degree intervals provided adequate accuracy to estimate the angle of entry of vehicle in the median from the edge of the roadway.

Figure 4.6 shows the three categories assigned to crashes based on evidence of where they stopped or traversed the median. The first two categories are in-median crashes, i.e., the first area (I) is the closest half of the median, the second area (II) is past the half way point of the median, and the third area (III) is in the roadway across the median, with traffic moving in the opposite direction. In the third case, the crash was classified as a cross-median crash.

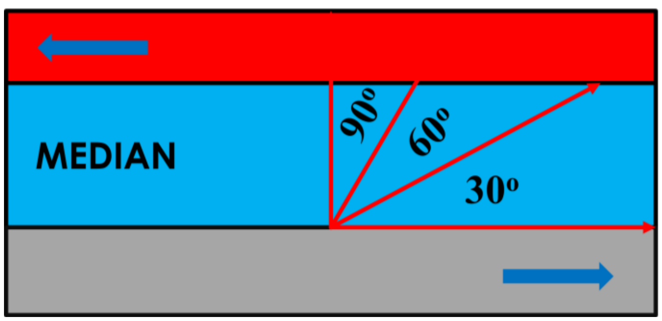

Figure 4.5 Categories Describing Angles at which Vehicles Left the Roadway

Figure 4.6 Location of Vehicle after Crash, Relative to Median

Figure 4.7 shows an example of a crash involving a vehicle that entered the median at a shallow angle and traveled less than half-way through the median. Figure 4.8 shows a crash that occurred between 30 and 60 degrees. From the tire tracks it can be observed that the vehicle traveled over half-way through the median and was able to exit on its own. Figure 4.9 shows a crash that occurred almost perpendicular (60 to 90 degrees) to the freeway. The vehicle did not travel very far into the median.

Figure 4.7 Median Crash on Minnesota Drive

Figure 4.8 A 30-60 Degree Entrance, Vehicle was Able to Exit Median on its Own

Figure 4.9 Crash Occurred Almost Perpendicular to the Freeway

The vehicles that intruded the median were able to exit the median on their own or they required assistance such as towing. Figure 4.10 shows an abrupt change in the direction of the crash. Such features were interpreted as an assisted exit.

Figure 4.10 Crash that Resulted in an Assisted Exit

The GPS-enabled video data provided the necessary information to identify the approximate location of median crashes and visualize it on a map; Google Earth was used for this purpose. The crash locations were moved to Google Maps for better display and clarity of presentation. For better display, the crashes were classified as: a) in-median half-way, b) in-median over half-way, and c) cross-median crashes.

4.4. RESULTS

4.4.1. Median Intrusion Crashes

Table 4.3 shows the frequency of crashes tabulated by freeways and the winter season. Based on the analysis of three winters, little snow was observed in the median on the Parks Highway. Therefore, data for Parks Highway and Glenn Highway were combined. By far, the most intrusions were observed on the Glenn Highway, mainly due to its longer length of 34 miles compared to a length of 19.39 miles for the remaining three freeways. Most crashes were observed during the winter of 2013-2014, likely due to the greater snowfall as presented in Table 4.1.

For 2013-2014, in Table 4.3, two data collection trips on the New Seward Highway were made. This resulted in observation of two encroachments in the median. GPS coordinates, however, were not available for these crashes. Further analysis of these crashes, therefore, was not carried out. Moreover, drive-through on Minnesota Drive and Seward Highway were limited during the 2013-14 winter. The frequency of crashes during that period is therefore non-representative of real conditions.

Table 4.3 Frequency of Crash Data by Year and Freeway

Winters	Glenn Highway and Parks Highway	Minnesota Drive	New Seward Highway	Total
2013-2014	88	2	2*	90
2014-2015	28	16	13	57
2015-2016	26	13	8	47
Total	142	31	21	194

* No GPS data available for these trips

Figure 4.11 shows a summary of the observed crashes from the video recordings on all four freeways in Southcentral Alaska over the last three years. Overall, 194 crashes were observed over the three winters; 97 (50%) were in-median halfway crashes, 61 (31.4%) were in-median over halfway crashes, and 36 (18.5%) were cross-median crashes.

Of the 194 crashes, 135 (70%) departed the road at an angle between 0 and 30 degrees. Out of the 135 crashes, 83 (61%) were in-median halfway crashes. Thirty-eight (38, 28%) were in-median over halfway crashes, but did not cross the median and 14 (10%) were cross-median crashes. The large proportion of vehicles which entered the median at a shallow angle and did not travel more than half-way through the median may indicate inattentive drivers or drivers losing sight of the edge of the road. It may also indicate driving at unsafe speed during the winter weather conditions.

Between 30 and 60 degrees, forty-four (44) median encroachments were observed. Nineteen encroachments, about 43%, were cross-median crashes. Both proportionally and volume-wise, vehicles departing the road between 30 and 60 degrees crossed-the-median were more than the vehicles departing the roadway at both lesser and greater angles. In addition, vehicles entering-the-median between 30 and 60 degrees seem less likely to stop or recover within the first-half of the median. The proportion of vehicles intruding the median between 30 and 60 degrees and traveling over halfway in-the-median could be indicative of drivers making evasive maneuvers at high speeds, losing control of the vehicles, and entering the median.

At an angle greater than 60 degrees, a pattern for vehicles intruding the median does not emerge. Fifteen encroachments were observed. Of the 15 encroachments, 20% of vehicles crossed-the-median, 80% of errant vehicles did not cross the median, and half of the 80% traversed over halfway in-the-median. No vehicles were identified entering the median with an angle greater than 90 degrees.

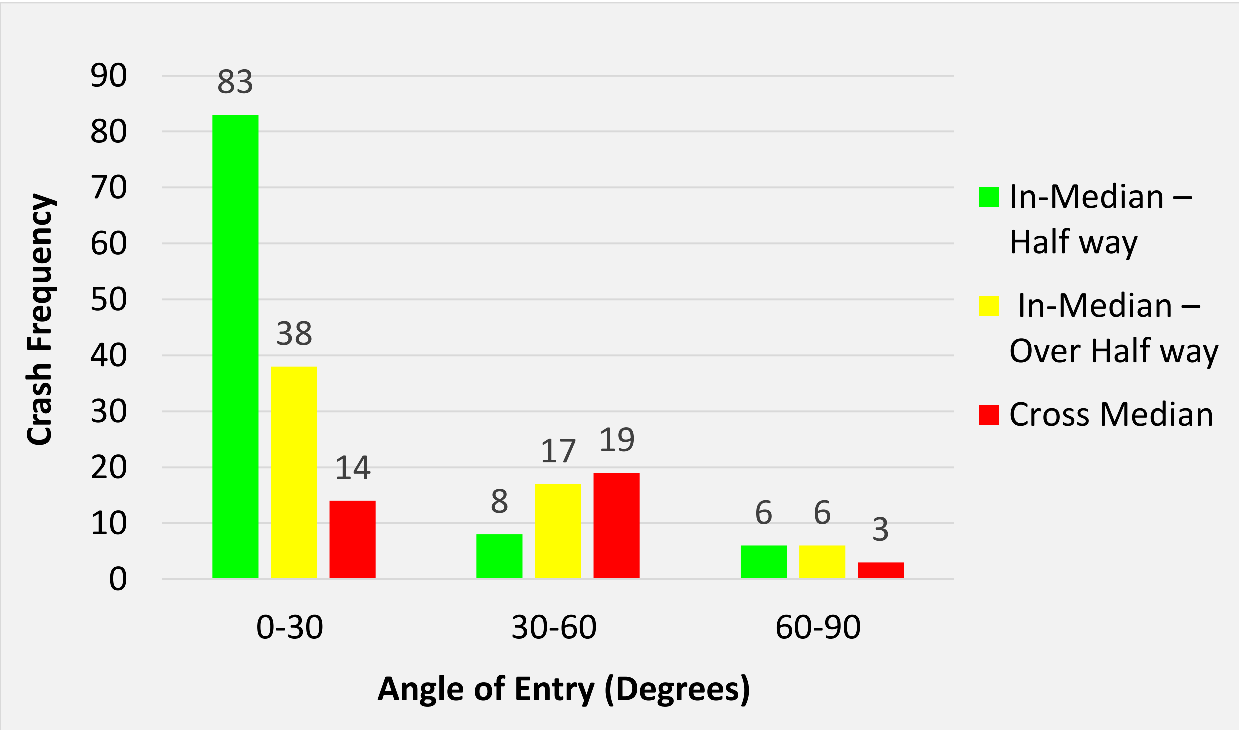

Figure 4.11 Summary of Median Intrusions, 2013-2016

Early median studies examined angles and lateral distance as a result of median crashes. Hutchinson and Kennedy (1967) analyzed crashes on Illinois Interstate highways. They found that as traffic volumes increased, the degree of angle encroachment also increased. Additionally, as traffic volume increased, the percentage of vehicles intruding the median increased. The lateral distance traveled into the median by encroaching vehicles also increased as traffic volume increased. Further, as median width increased, crash data clearly shows that the number of cross-median crashes decreased and the number of rollovers increased (Stine et al., 2010).

4.4.2. High Crash Locations

Median width and horizontal curvature are a few of the most important design factors in freeway safety as agreed by a panel of experts (Kim et al. 2008). Factors that contribute to median encroachments and cross-median crashes, among other factors, are the presence of on-ramps, off-ramps, and sharp horizontal curves (radii less than 3,000 feet) (NCHRP 790). Figure 5 shows the location of the overall highest frequency of in-median and cross-median crashes observed on Minnesota Drive just north of the Strawberry Road off-ramp near MP 3.3. Most of these crashes, 13 out of 15, involved vehicles traveling in the northbound direction. Figure F6 shows crashes on Minnesota Drive and New Seward Highway. The figure also shows median crashes on horizontal curves, on- and off-ramps. The radii of the curves are greater than 3,000 feet. This finding supplements the results presented in the determination of crash contributing factors, which found horizontal curves with vertical grades as a statistically significant factor that contributes toward crashes. Overall, fewer crashes can be observed on the New Seward Highway and are not as clustered as Minnesota Drive. Clustering of median crashes can be observed near ramps, however, and a number of crashes occurred on straight segments of the freeway as well.

On the Glenn Highway, Figure F7 shows higher occurrence (11 southbound vehicles and 6 northbound vehicles) of cross-median crashes observed between the Turpin Street and Muldoon Road interchanges, MP 2.375 to MP 3.243, possibly due to the median width of 32 feet. Clustering of median crashes near ramps and horizontal curves, despite the curve radii being greater than 3,000 feet, can be observed. Near the Peter’s Creek interchange, a higher occurrence of vehicles traveling half way or more in-the-median can be observed as well. Three cross-median crashes were noted north of the South Birchwood interchange on a straight segment, MP 16.5 to 17.5, Figure F8. North of the Fort Richardson interchange where in-bound traffic travels out of a curve, about MP 7.0 to 7.5 (Figure F9), clustering of intrusions traveling more than half way in-the-median can be observed. From about MP 10.0 to 10.6, surrounding the Eagle River interchange, a higher frequency of cross-median crashes and intrusions traveling more than halfway in-the-median were witnessed (Figure F10). A higher occurrence of vehicles traveling halfway in-the-median near MP 25 through MP27 can also be noticed. Figure F11 shows all observed median intrusions on Glenn Highway and Parks Highway.

4.4.3. Median Slope

Two important variables that can influence cross-median crashes and rollovers are median width and median slopes. Median slopes and median widths were obtained from typical freeway cross-section drawings provided by the DOT&PF. Approximate locations of where the median design changed were found using Google Earth. Table 4.4 shows intrusions that traveled more than half-way in-the-median and cross-median crashes for all four freeways considered. Of all 194 observed intrusions, 139 (72%) occurred where the median is 32 feet wide. As appreciable number of intrusions occurred on segments with similar widths (32 feet), and median slope was found to be statistically significantly associated with different crash types as presented in Chapter 2, crashes were compared with respect to median slopes. Table 4.4 shows that over half of cross-median crashes (55.6%) occur when the slope is the shallowest, 6:1 (H:V). Similar results were also observed from archived data for 2007-2012 for the four freeways considered.

On the other hand, the largest proportion of encroachments traveling over half-way in-median occurred with the median slope at the steeper grade, 4:1 (H:V). This indicates that a flatter median permits cross-median crashes while a steep median slope helps prevent them. This agrees with findings from a study which found that as the median slope was flatter, the crash data verified that the number of cross-median crashes increased and the number of rollover crashes decreased (Stine et al, 2010). Intuitively, the steeper the slopes of the median the harder it is for a vehicle to traverse the median. This is beneficial for preventing cross-median crashes. However, it contributes to rollover crashes. For every unit increase in slope, 4.8% increase in median rollover crashes was reported (NCHRP 794, 2014).

Table 4.4 Median Slope and Crash Types*

Slope (H:V)	Length (miles)	Crashes			Crash Rate (Crashes/mile)
		In-Median Over Half Way	Cross Median	Total	
4:1	25.73	33 (54.1%)	14 (38.9%)	47	1.83
5:1	1.54	4 (6.6%)	2 (5.6%)	6	3.89
6:1	26.12	23 (39.3%)	21 (55.6%)	44	1.69
Total	53.39	60 (100%)	37 (100%)	97	1.82

* Combined data for the four freeways

Rollover crashes could not be identified from the tire tracks observed in the video data. Rollover crashes were also not found in the video data recorded over the three winters. The occurrence of rollover crashes during those winters, however, continued. Figure 4.12 shows a rollover crash observed on New Seward Highway after a snowfall. Further details of the crash were unavailable.

Figure 4.12 Median Rollover Crash on the New Seward Highway (Abaza, 2015)

4.5. SUMMARY

The three winter seasons between 2013 and 2016 saw unseasonably warm weather and uncharacteristically low snow falls in the Anchorage area. Using drive-through video data to analyze median intrusions, 194 median intrusions were identified and analyzed. Almost half of all intrusions, 83 (43%) were at an angle less than 30 degrees and the vehicle stayed on the side of the road from which the vehicle entered. Although many vehicles entering the median at an angle less than 30 degrees did not cross over halfway in-the-median, 38 (45.8%) encroachments were observed traversing over halfway in-the-median, and 14 (16.9%) vehicles crossed the median. Vehicles entering the median between 30 and 60 (81.81%) degrees were found to be prone to travel further in-the-median and cross the median when compared to vehicles entering at lesser (38.5%) and greater angles (60.0%). These vehicles can be most hazardous as the aberrant vehicle can hit vehicles traveling in the opposite direction. In terms of total number of median intrusions observed, out of 194, 36 (18.6%) cross-median crashes were observed.

The median slope is a factor in preventing cross-median crashes, although the relationship between median slopes and rollover crashes was unobservable from this analysis.

During the three winters, little snow and winter-related median crashes were observed along the Parks Highway, although there is evidence of median intrusions along the Parks Highway, which warrants further investigation in the future.

Analysis of recorded video data provided useful information to identify crash clusters and supplement archived data. The high crash locations observed from video data were compared to high crash locations identified by archived data to examine any differences in these locations. These results are presented in the next chapter. The locations of cross-median crashes were found to be random events, similar to the results found from analysis of archived data. Cross-median crashes appear to have uncharacteristic occurrence and therefore require very detailed evaluation.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. CRASH COST AND MEDIAN DESIGN

Additional analysis was conducted to evaluate the median slope and median width. Crash costs were also determined to compare the associated costs with different crash types. For 2007-2012 crash data, Table 5.1 shows the crash frequency and crash cost by median slopes separated by levels of crash injury severity, (crash injury cost based on Section 3.3.2). The table further presents the computed total crash cost, cost per crash, and crashes per mile per year by median slope.

Table 5.1. Crash Frequency* by Median Foreslope

Fore-slope	K	A	B/C	O	Crashes (%)	Total Crash Cost ($)	Cost ($)/ Crash	Crash/ mi/yr (All)	Crash/ mi/yr (Fatal)
4:1	4	8	48	94	154 (43.1%)	$48,766,200	$316,664	1.00	0.026
5:1	0	5	1	10	16 (4.5%)	$3,473,000	$217,063	1.73	-
6:1	3	9	79	96	187 (52.4%)	$43,040,800	$230,165	1.19	0.019
Total	7	22	128	200	357 (100%)	$95,280,000	$266,891	1.11	0.022

* All median crashes, include (17) crashes that lacked rollover information

In Table 5.1, equal number of severe crashes (K&A) are observed on median slopes of 4:1 and 6:1, i.e. 12 crashes over the six years of data. The most number of crashes occur on a slope of 6:1, i.e. 187 (52.4%). The crash per year and crash per mile are also higher, i.e., 31.17 crash/year, and 7.16 crash/mile, respectively compared to a median foreslope of 4:1.

On a foreslope of 4:1, however, the total crash cost is higher, $48.7 million versus $43.0 million for 6:1 crashes, and the cost per crash is also higher, $316k versus $230k for 6:1 crashes. These differences in cost are primarily due to the difference in the number of fatal crashes for median foreslopes of 4:1 and 6:1. This indicates that the median foreslope of 6:1 contributed to higher frequency of crashes, especially in terms of B/C crashes, and crashes in terms of per year and per mile compared to a slope of 4:1.

Table 5.2 is presented to further differentiate crash frequency by median slope and crash type, and present the crash costs. It can be observed that higher frequency of non-rollover crashes occurs on a median foreslope of 6:1 compared to 4:1, 56 versus 28 crashes. And the frequency of rollover crashes by foreslopes of 6:1 and 4:1 is similar, i.e. 121 versus 119 crashes. This indicates that a median foreslope of 6:1 is associated with higher frequency of non-rollover crashes than a foreslope of 4:1. Conversely, this indicates that if the foreslope was 4:1 instead, these crashes could be a rollover crash with higher level of crash injury severity.

A major concern for any agency is high frequency of median crashes and as a result the associated crash cost. Table 5.2 indicates the high frequency of in-median (versus cross-median) crashes. The cost per crash per year is highest and second highest for cross-median rollover and non-rollover crashes, respectively. This reflects, as indicated (previously) in Table 1.2 and (reiterated in) Table 3.3, that the percentage of severe crashes (K&A) for cross-median crashes is much higher (11/66, 16.7%) compared to in-median crashes (18/274, 6.6%) and this is reflected in the crash cost.

Further, Table 5.2 presents crashes per year, the expected crashes per year, and the expected crash cost for the next 10 years. The crash cost was based on Alaska 2016 crash injury cost. The expected crashes were computed based on extrapolation of last six years of crash data. The expected crash cost was highest for in-median rollover crashes, followed by cross-median rollover crashes. Therefore, the occurrence of rollover crashes (in-median and cross-median) is the main reason for the high frequency and injury severity of median crashes. Any reduction in crash frequency and injury severity and subsequent cost savings can be achieved by measures to reduce these crash types. The cross-median non-rollover crashes were found to be associated with 21.2% of K&A crashes, and indicate high expected crash cost.

Table 5.2 Crash Frequency and Cost Summary by Crash Types and Foreslopes

Crash Type		Fore-Slope	Crash.	Total Crash.	Total Cost ($)	$/Crash /Year	Expected Crashes/ 10-Years	Expected Crash Cost (10-Year Period)
CROSS-MEDIAN	Rollover	4:1	13	33	$22,014,900	$111,186	55	366,915,000
		5:1	6					
		6:1	14					
	Non-Rollover	4:1	9	33	$14,669,500	$74,088	55	244,491,667
		5:1	5					
		6:1	19					
IN-MEDIAN	Rollover	4:1	106	215	$55,626,800	$43,122	358.33	927,113,333
		5:1	2					
		6:1	107					
	Non-Rollover	4:1	19	59	$2,473,900	$6,988	98.33	41,231,667
		5:1	3					
		6:1	37					

Table 5.3 Median Crash Frequency by Crash Types and Median Width

*Wid (ft)	^Len (mi)	Cross-Median					In-Median					Total Crash	PER	Total Cr. /mi/yr
		!NRO	+RO	@TOT	#PER	&Cr. /mi/yr	NRO	RO	TOT	PER	Cr. /mi/yr			
<30	8.9	-	-	-	-	-	3	2	5	1.8	0.09	5	1.5	0.09
30-40	19.6	22	22	44	**66.7**	0.37	37	170	207	**75.5**	1.76	251	**73.8**	**2.14**
56-64	24.9	11	11	22	33.3	0.15	19	43	62	22.6	0.41	84	24.7	0.56
Total	53.39	33	33	66	100	0.21	59	215	274	100	0.86	340	100	1.06

* Wid = Median width (excludes inner shoulder), ^Len = length, !NRO = Non-rollover crashes, +RO = Rollover crashes

@TOT = Total, #PER = Percent, &Cr./mi/yr = Crashes/mile/year, represents all crashes.

Table 5.3 presents the summary of results by median width, and the frequency of different crash types (rollover and non-rollover crashes) for the four freeways. The median width did not include the inner shoulder width. In general, as the median width increased, the frequency of median crashes decreased. Seventy percent of crashes occurred with a median width less than or equal to 36 ft. The highest frequency of crashes (186/340, 54.7%) was observed with a median width of 32 ft. Further, 65% of cross-median crashes occurred on a median width of 32 – 36 ft.

Table 5.4 analyzes the combined effects of median width and slope on severe crashes (K&A). The results are summarized by cross-median and in-median crashes and separated by rollover and non-rollover crashes. Nearly 73% (8/11) of cross-median K&A crashes occurred with a median slope of 6:1. Equal number (9) of in-median K&A crashes occurred on medians slopes of 4:1 and 6:1. Four (57.1%) fatal crashes occurred on a median slope of 4:1.

Table 5.5, further, simplifies the combined effects of median width and slope: 34.5% (10) of K&A crashes occurred with a median width of 56 ft and a slope of 6:1. With a median width of 32 ft, 31% (9) and 24.1% (7) of K&A crashes occurred on slopes of 4:1 and 6:1, respectively. Highest frequency of K&A crashes (55.2%) occurred with a median width of 32 ft, all on the Glenn Highway. Further, most fatal (5/7, 71.4%) crashes were associated with a median width of 32 ft, again all on the Glenn Highway. Highway sections with these K&A crashes need careful consideration and this is recommended as a future study.

Table 5.4 Median K&A Crashes: Median Width and Slope

Width (ft)	Cross-Median			In-Median			Total Percent by Width
	Slope/Rollover			Slope/Rollover			
	4	6	Total	4	6	Total	
32	-	***2******	2	***7***	***4***	11	61.9%
36	***1***	-	1	2	-	2	14.3%
56	-	1	1	-	***4***	4	23.8%
Total	1	3	4	9	8	17	100.0%
Width (ft)	Slopes/Non-Rollover			Slopes/Non-Rollover			Percent Total
	4	6	Total	4	6	Total	
32	***2***	1	3	-	-	0	37.5%
56	-	4	4	-	1	1	62.5%
Total	2	5	7	0	1	1	100.0%
T. Percent by Slope	27.3%	72.7%	100.0%	50.0%	50.0%	100.0%	-

* Bold and italicized text indicates cell with a fatal crash

Table 5.5 Median K&A Crashes by Percentage: Median Width and Slope

Width(ft)/Slope	4	6	Total
32	31.0%	24.1%	55.2%
36	10.3%	-	10.3%
56	-	34.5%	34.5%
Total	41.4%	58.6%	100.0%

In terms of the shape of the median, only Minnesota Drive has a flat-bottom median, and rest of the three freeways have a vee-shaped median. From a total of 340 median crashes, only 24 (7.1%) crashes occurred on Minnesota Drive. Therefore, due to the availability of very limited crash data by median shape, specific conclusions could not be made.

5.2. CONCLUSIONS

This study analyzed archived crash data and relevant information from crash reports on freeways with depressed medians in Southcentral Alaska. Drive-through video data was collected on these freeways for three consecutive winters. Based on the data analyzed, crash-contributing factors were identified based on two multinomial regression models developed. Hotspots on these freeways as well segments for median intrusion crashes were also identified. Further, video data analysis identified sections of freeway where median intrusions were evidenced.

5.2.1. Crash Causality

Multinomial regression models were developed for median crashes and rollover crashes. As a result, crash contributing factors were identified. They are presented as follows, divided by different categories of crashes.

5.2.1.1 Median Rollover Crashes

Median (both cross-over and in-median) rollover crashes were found to be at higher risk on horizontal curves with level vertical alignment, on a grade, or on a hill crest. A tangent with a hill crest and a grade was also found to be vulnerable. Risk of severe and non-severe injury was evident for rollover crashes. Driver inexperience, no improper driving, icy surface conditions, median width between 26 and 40 feet, and hours with low volume of traffic were found to be at risk of median rollover crashes. Cross-median rollover crashes were associated with light trucks.

5.2.1.2 Median Non-Rollover Crashes

Cross median non-rollover crashes were found to be associated with risk of severe injury crashes. Variables such as lighted freeways (dark but lighted), ice and dry surface conditions, median slope of 6:1, and multiple vehicles were positively associated with the risk of median non-rollover crashes.

5.2.1.3 Roadside Rollover crashes

Roadside rollover crashes were associated with non-severe injury, horizontal curves with vertical alignment at level, at grade or on a hill crest, different driver behaviors including unsafe speed, driver inexperience, no improper driving, icy, snow and slush pavement surface conditions, females between the ages of 21 and 25 years, early morning, and morning peak periods.

Medians in addition to acting as a buffer to separate vehicles traveling in the opposite directions, serve as a space for errant vehicles to regain control. Medians may also act as an escape area for vehicles that are avoiding possible crashes with leading vehicles in their own lanes (Knuiman et al., 1993). This may be a cause of higher frequency of single-vehicle crashes compared to multi-vehicle crashes. Median width therefore impacts safety. A wider median provides space for errant vehicles to regain control and a perception of safety to drivers (Knuiman et al., 1993).

The crash/mile/year calculated in Table 5.3 was compared to the results with warrants for median barriers from California (Borden, 1997) and Kentucky (Agent and Pigman, 2008). California uses a crash study warrant to identify sections of freeways that may need installation of a median barrier. The warrant requires a minimum of 0.5 cross-median crashes per mile per year of any severity, or 0.12 fatal crashes per mile per year. This warrant example is summarized in the

AASHTO Roadside Design Guide (2011). Similarly, Kentucky recommends 0.35 cross-median crashes per mile per year of any severity, or 0.2 fatal crashes per mile per year.

From the results of Table 5.3, 0.37 and 0.15 cross-median crashes per mile per year of any severity were found for median widths of 30-40 and 56-64 ft, respectively. Further, 0.026 fatal crashes per mile per year for median widths of 30-40 ft were found. Therefore, of Alaska's freeways considered, only the Glenn Highway is at or near these guidelines when compared to research from Kentucky, but fall below California's research guidelines. For these reasons, the Glenn Highway median width of 30-40 ft requires careful consideration as the crashes/mile/year slightly exceeds 0.35 cross-median crashes per mile per year.

From the analysis of Alaska's freeway data, it can be inferred that median widths of 32 – 36 ft should be selected with consideration of crash history, traffic volumes, and speeds in Alaska. This is consistent with AASHTO's Roadside Design Guide Figure 6-1 (2011), which recommends a barrier is optional at median widths greater than 30 ft (includes width of inner shoulders), but should be considered at higher speeds and higher volumes (>30,000 vehicles per day). In Alaska, higher speeds and higher frequency of crashes have been noted with freeways operating speeds at or above 65 mph.

5.2.2 Hotspots

Each freeway had segments that produced higher frequency and severity of crashes than others, and crash-reduction measures implemented at these segments will have the highest impact on lessening the frequency and severity of crashes. The following sections of the freeway were found to be most vulnerable to crashes including median intrusions.

5.2.2.1 Glenn Highway

Segments from milepoints, MP 2.29 to 4.63 (between interchanges at Mountain View and Muldoon), 19.07 to 21.11 (between interchanges at S. Birchwood Loop and Birchwood Loop), and 23.6 to 25.6 (1.5 miles before Thunderbird Falls to 0.5 miles after Thunderbird Falls) were found to be hotspots and also evidenced in-median rollover crashes. The figures in Chapter 3 provide the detailed locations by MPs with respect to all hotspots identified.

Segments from MP 4.70 to 6.32, 9.4 to 10.90, and 25.0 to 27.0 evidenced median intrusions. Therefore, segments between MP 2.60 to 6.32 require detailed evaluation and countermeasures to reduce crashes related to the median. MP 7.0 to 7.5, near Fort Richardson interchange and MP 10.0 to 10.6, surrounding the Eagle River interchange were also vulnerable to median crashes as evidenced by crashes captured from the video recordings.

5.2.2.2 Seward Highway

The segments found to be top hotspots were MP 122.69 to 122.92 Northbound (NB) and specific segments, MP 123.82 to 124.01 Southbound (SB) near an interchange, and MP 124.25 to 124.36 NB. Segments MP 121.31 to 121.48 NB and MP 119.77 to 120.08 NB were also found to be hotspots.

5.2.2.3 Minnesota Drive

High frequency of in-median and cross-median crashes occurrence were found just north of the Strawberry Road off-ramp, near MP 3.3. Segments near Raspberry Road (MP 3.78 to 4.09 NB) and International Drive (MP 5.25 to 5.43 NB) interchanges were also found to be vulnerable to crashes.

From the above presentation of crash causality i.e., what causes crashes, and from identification of hotspot locations i.e., where crashes occur, freeway segments with ‘S’ curves require further evaluations as those segments were found to be crash hotspots.

5.3. RECOMMENDATIONS

Changes in winter weather conditions, especially the deposition of frost on the pavement surface combined with varying levels of snowfall, can create difficult driving conditions. Out of 340 median crashes (Table T2), 180 (52.6%) crashes were associated with ice as the surface condition. Further, 226 (66.1%) (including 180 crashes as mentioned) were associated with ice, snow, and slush, as the surface condition i.e., representing winter weather conditions. Skidding and out-of-control vehicles contributed to 71.2% (242/340) of median crashes. The presence of rutting compounds the challenge as controlling vehicles driving at or above the posted speed limit can be difficult. Timely information of hazardous road conditions, mainly due to winter weather, is of utmost importance to drivers. This information is currently available via multiple sources: TV (news), radio (511), 511 website based on Road Weather Information System (RWIS) with weather cameras available online, etc. In the following, further studies are recommended to reduce the frequency and severity of crashes.

The highest frequency of cross-median crashes occurs between the months of September and December (Minturn et al., 2015). Due to lack of snow within the median during these months, vehicles are able to traverse through the median. The late fall/early winter months may have enough ice and/or snow on the roads for vehicles to lose control, but not enough snow in the median to slow down the vehicle from traversing the median. This challenge can be overcome by a) median barriers, and/or b) improved plowing by moving most of the snow in the median during the fall and early winter months. A study to propose countermeasures to minimize cross-median crashes is therefore recommended.

From the analysis of Alaska’s freeway data, it can be inferred that median widths of 32 – 36 ft should be selected with consideration of crash history, traffic volumes, and speeds in Alaska. This is consistent with AASHTO’s Roadside Design Guide Figure 6-1 (2011), which recommends a barrier is optional at median widths greater than 30 ft (includes width of inner shoulders), but should be considered at higher speeds and higher volumes (>30,000 vehicles per day). In Alaska, higher speeds and higher frequency of crashes have been noted with freeways operating speeds at or above 65 mph.

A study to perform safety analysis based on different attributes of freeway cross-section is proposed. Different crash models based on Alaskan conditions can be developed. The study will be able to recommend a combination of median slope, shape, width, etc. that will help reduce the frequency of cross-median and rollover crashes. Further, a study to evaluate median cross-section design that will minimize the risk of cross-median and rollover crashes with and without the presence of snow in the median is recommended. Three winters from 2013 to 2016 had uncharacteristically low snowfall events. As a result, due to lack of snow berms in the median, the effect of snow berms as a contributing factor in rollover crashes could not be studied. From Figure 5.1, it can be observed that a vehicle collision with a snow berm can cause a multiple vehicle crash in either direction of traffic. A study on the effect of snow berms on crashes is therefore proposed.

In terms of further examination of crash data, development of models for levels of injury severity is recommended. Moreover, the development of models of crash-contributing factors based on advanced statistical techniques that further examines the structure of the data is recommended. A detailed study is proposed for severe crashes and their relation to different crash types. To help develop better crash prediction models, the quality of crash data can be further improved with additional information on rollover crashes from crash reports.

Detailed examination of freeway segments with rutting is proposed. From the results of this study, it is evident that rutting is associated with cross-median crashes. A future study is proposed that can associate levels of crash injury severity with different levels of rutting.

Detailed review of on- and off-ramps on Glenn Highway is proposed. The current study did not review their design, but from the statistical analysis of crash data it was found that roadway crashes are at higher risk of occurrence near the interchanges. Further, the on- and off-ramp design on Glenn Highway is different from other freeways, and may not provide adequate length for vehicles to accelerate and decelerate to merge and diverge with/from vehicles on the main freeway. The crashes near the various interchanges on Glenn Highway can possibly be reduced from a detailed review of these on- and off-ramps, weaving sections, etc. Further, detailed review of higher frequency of crashes near many interchanges identified in Chapter 3 is also proposed to reduce their occurrence as observed from crash data in this study.

Figure 5.1. Median Snow Berm on Seward Highway

Several issues were observed with crash reports. Information on specific crash types for median crashes, both in-median and cross-median, and rollover versus non-rollover will be very helpful for future safety programs, policies, standards, and studies. Further, information related to tires, e.g. winter, summer, all-season, studded, non-studded, and any indication of tire tread when collected could be helpful in ascertaining the causality of a crash. Moreover, 'event type' had many categories, which made data aggregation into manageable categories for use in statistical analysis challenging. The archived data combine different restraint types, helmet use, and airbag deployment into one category. It is highly recommended to separate them out to help improve crash severity models and address crash injuries associated with lack of restraint, helmet use, and airbag deployment.

As Alaska has one of the longest winter seasons in the United States, additional education and driver training can help in reducing ice/snow related crashes. This can be very helpful for drivers new to winter road conditions specific to Alaska.

REFERENCES

Abaza, O. (2015). Seward Highway.

Agent, K. R. and Pigman, J. G. (2008). Evaluation of median barrier safety issues, Research Report KTC-08-14/SPR329-06-IF, Kentucky Transportation Center and Federal Highway Administration, Lexington, KY.

Alaska Motor Vehicle Crash Report Form 12-209, Accessed October 18, 2016. http://www.muni.org/Departments/police/forms/Pages/AccRptInfo.aspx.

AMVCR, Alaska Motor Vehicle Collision Report (12-200) Instruction Manual, Nov. 2014.

American Association of State Highway and Transportation Officials. (2010). Highway Safety Manual, Washington, DC: American Association of State Highway and Transportation Officials.

Alaska Statues, Sec. 28.35.080. Immediate notice of accident. (a), Accessed April 4, 2017. http://www.legis.state.ak.us/basis/statutes.asp#28.35.080.

Bham, G. H., B. S. Javvadi and U. R. R. Manepalli, Multinomial logistic regression model for single- and multi-vehicle collisions for urban U.S. highways in Arkansas, ASCE Journal of Transportation Engineering, Vol. 138, No. 6, 2012, pp. 786-797.

Borden, J.B. (1997). Median barrier study warrant review, California Department of Transportation.

Brorsson, B., Ifver, J., and Rydgren, H. (1988). Injuries from single-vehicle crashes and snow depth. *Accident Analysis and Prevention*, 20, pp. 367-377.

Council, F. M., Zaloshnja, E., Miller, T., and Persaud, B. (2005). Crash cost estimates by maximum police reported injury severity within selected crash geometries. FHWA-HRT-05-051. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

Di Liberto, T. (2016) Winter in Alaska. Climate Watch Magazine.

Donnell, E. T., and Mason Jr., J. M. (2006). Predicting the frequency of median barrier crashes on the Pennsylvania interstate highways. *Accident Analysis and Prevention*, 38, pp. 590-599.

Federal Highway Administration (FHWA), (2014). Roadway Departure Safety. Washington, DC.

Gattis, J. L., Balakumar, R., and Duncan, L. K. (2005). Effects of rural highway median treatments and access. *Transportation Research Record: Journal of the Transportation Research Board*, 1931, pp. 99-107.

GOM Player. Accessed February 16, 2017. https://www.gomlab.com/.

Google Earth. Accessed November, 27, 2016. https://www.google.com/earth/.

Google Maps. Accessed February 16, 2017. https://maps.google.com/.

Graham, J.L., Harwood, D.W., Richard, K.R., O'Laughlin, M.K., Donnell, E.T., and Brennan, S.N. (2014). NCHRP Report 794: Median cross-section design for rural divided highways. *Transportation Research Board of the National Academies.*

Hakkert, A. S., and Mahalel. D. (1978). Estimating the number of accidents at intersections from a knowledge of the traffic flow on the approaches. *Accident Analysis and Prevention*, 10, pp. 69-79.

Harwood, D. W., Gilmore, D .K., Graham, J. L., O'Laughlin, M. K., Smiley, A. M., and Smahel, T. P. (2014). NCHRP Report 790: Factors contributing to median encroachments and cross-median crashes. *Transportation Research Board of the National Academies.*

Hauer, E. (1997). Observational before–after studies in road safety: Estimating the effect of highway and traffic engineering measures on road safety. Oxford, England: Pergamon Press Elsevier Science.

Hall, J.W. (1980). Crash characteristics in which a vehicle overturns. *Transportation Research Record: Journal of the Transportation Research Board*, 757, pp. 41-45.

Hosseinpour, M., Yahaya, A. S., and Sadullah, A. F. (2013). Exploring the effects if roadway characteristics on the frequency and severity of head-on crashes: Case studies from Malaysian federal roads. *Accident Analysis and Prevention*, 62, pp. 209-222.

How Kernel Density Works (HKDW). *ArcGIS Desktop*, Accessed December 26, 2017. http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/how-kernel-density-works.htm.

Hu, W., and Donnell, E. T. (2010). Median barrier crash severity: Some new insights. *Accident Analysis and Prevention,* 42, pp. 1697-1704.

Hu, W., and Donnell, E. T. (2011). Severity models of cross-median and rollover crashes on rural divided highways in Pennsylvania. *Journal of Safety Research,* 42, pp. 375-382.

Hutchinson, J. W., and Kennedy, T. W. (1967). Safety considerations in median design. *Highway Research Record*, 162, pp. 1-29.

Jehle D., Kuebler J., and Auinger P. (2007). Risk of injury and fatality in single vehicle rollover crashes: danger for the front seat occupant in the "outside arc", *Academic Emergency Medicine*, 14(10), pp. 899-902.

Jonsson, T., Lyon, C., Ivan, J. N., Washington, S., Schalkwyk, I. D. and Lord, D. (2009). Investigating differences in the performance of safety performance functions estimated for total crash count and for crash count by crash type. CD-ROM, Proceedings of the Annual Meeting of the Transportation Research Board.

Kim. T. G., Donnell, E. T., and Lee, D. (2008). Use of cultural consensus analysis to evaluate expert feedback of median safety. *Accident Analysis and Prevention*, 40, pp. 1458-1467.

Knuiman, M. W., Council, F. M., and Reinfurt, D. W. (1993). Association of median width and highway accident rates. *Transportation Research Record: Journal of the Transportation Research Board*, 1401, pp. 70-80.

Kutner, M., Nachtsheim, C., and Neter, J. (2004). Applied Linear Regression Models, 4th Edition, McGraw Hill/Irwin series.

Lane, P. l., McClafferty, K. J., Green, R. N., and Nowak, E. S. (1995). A study of injury producing crashes on median divided highways in southwestern Ontario. *Accident Analysis and Prevention*, 27(2), pp. 175-184.

Lu, G., Chitturi, M. V., Ooms, A. W., and Noyce, D. A. (2010). Ordinal discrete choice analyses of Wisconsin cross-median crash severities. *Transportation Research Record: Journal of the Transportation Research Board*, 2148, pp. 47-58.

Manepalli, U. R. R., and Bham, G. H. (2016). An evaluation of performance measures for hotspot identification. *Journal of Transportation Safety and Security*, 8(4), pp. 327-345.

Minturn, J., B. Hafele, and G. H. Bham, Preliminary crash causality study of divided highways with depressed medians in Alaska, 5th International Conference on Road Safety and Simulation, Orlando, Oct. 2015.

Mohaymany, A. S., Shahri, M., and Mirbagheri, B. (2013). GIS-based method for detecting high-crash risk road segments using network kernel density estimation. *Geo-spatial Information Science*, 16(2), pp. 113-119.

National Highway Traffic Safety Administration (NHTSA), (2015). Fatality Analysis Reporting System. Washington, D. C. Accessed December 26, 2017. www.nhtsa.gov/FARS.

National Oceanic and Atmospheric Administration. Accessed November 27, 2016. https://gis.ncdc.noaa.gov/maps/ncei/indices.

Neuman, T.R., Pfefer, R., Slack, K.L., Hardy, K.K., McGee, H., Prothe, L., Eccles, K., and Council, F., (2003). A guide for addressing head-on collisions. NCHRP Report 500, 4. Transportation Research Board, Washington, D.C.

Oh, J., Washington, S., and Lee, D., (2010). Property damage crash equivalency factors for solving the crash frequency-severity dilemma: Case study on South Korean rural roads. Paper No. 10-1867, Transportation Research Board 89th Annual Meeting, Washington, D.C.

Pande, A. and Abdel-Aty, M. (2009). A novel approach for analyzing severe crash patterns on multilane highways. *Accident Analysis and Prevention*, 41 (5), pp. 985-994.

Pawlovich, M. D. (2007). Safety improvement candidate location method. IA: Iowa Department of Transportation, Office of Traffic and Safety. Accessed November 27, 2016. http://www.iowadot.gov/crashanalysis/pdfs/sicl_methodologies.pdf.

Puluguthra, S. S., Krishnakumar, V. K., and Nambisan, S. S. (2007). New methods to identify and rank high pedestrian crash zones: An illustration. *Accident Analysis and Prevention*, 39, pp. 800-811.

Roadside Design Guide (2011). American Association of Safety and Highway Transportation Officials.

Shankar, V. N., Albin, R. B., Milton, J. C., and Mannering, F. L. (1998). Evaluating median crossover likelihoods with clustered accident counts: An empirical inquiry using the random effects negative binomial model. *Transportation Research Record: Journal of the Transportation Research Board*, 1635, Washington, D.C., pp. 44-48.

Stine, J. S., Hamblin, B. C., Brennan, S. N., and Donnell, E. T. (2010). Analyzing the influence of median cross-section design of highway safety using vehicle dynamics simulations, *Accident Analysis and Prevention*, 42, pp. 1769-1777.

Truong, A., Bryden Jr., G., Cheng, W., Jia, X., and Washington, S. (2011). The influence of underreported crashes on hotspot identification. *Journal of Transportation of the Institute of Transportation Engineers,* 1 (1), pp. 19-38.

U.S. Department of Transportation. (2014). Saving lives and reducing injuries from cross median crashes. University Transportation Centers Program.

USCB, (2017). United States Census Bureau, Accessed February 28, 2017, https://www.census.gov/quickfacts.

Usman, T., Fu, L., and Miranda-Moreno, L. F. (2012). A disaggregate model for quantifying the safety effects of winter road maintenance activities at an operation level. *Accident Analysis and Prevention,* 48, pp. 368-378.

Viner, J. G. (1995). Rollovers on sideslopes and ditches. *Accident Analysis and Prevention*, 26, pp. 483-491.

Weaver, G. D., Marquis, E. L., and Olson, R. M. (1975). NCHRP Report 158: *Selection of Safe Roadside Cross Sections,* Transportation Research Board, Washington, DC.

Ye, F., and Lord, D. (2011). Investigating the effects of underreporting of crash data on three commonly used traffic crash severity models: Multinomial Logit, Ordered Probit and Mixed Logit Models. *Transportation Research Record: Journal of the Transportation Research Board*, 2241, Washington, D.C., pp. 51-58.

APPENDIX

Table T.1. Rollover Crashes: Summary of Crash Statistics and Variables with Categories

Variables and Sub-Categories		N	Percentage
ROLLOVER CRASH TYPES	Median Rollover	248	18.4%
	Roadway Non-Rollover	885	65.7%
	Roadside Rollover	214	15.9%
AADT (vehicles/day)	8000-32000 - Low	348	25.8%
	>32000-48000 - Med	490	36.4%
	>48000-63000 - High	509	37.8%
AGE GROUPS (years)	16-20	253	18.8%
	21-25	253	18.8%
	36-50	300	22.3%
	51-65, 66-110	227	16.9%
	26-35	314	23.3%
ALCOHOL	Yes	90	6.7%
	No	1257	93.3%
CRASH SEVERITY	Fatality/Incapacitating Injury	66	4.9%
	Non-capacitating injury/possible injury	430	31.9%
	Property damage only	851	63.2%
GENDER	Female	510	37.9%
	Male	837	62.1%
HOURS	0-6 – Night/Early Morning	139	10.3%
	19-24 – Late Evening	210	15.6%
	6-10 - Morning	326	24.2%
	15-19 - Afternoon	335	24.9%
	10-15 - Morning/Afternoon	337	25.0%
HUMAN CIRCUMSTANCES	Ill, Fell Asleep, Improper Driving, Emotional, Lane Change, Drove Off Road, Following Too Closely	223	16.6%
	Driver Inexperience	70	5.2%
	Distracted	264	19.6%
	Unsafe Speed	267	19.8%
	Unknown	233	17.3%
	No Improper Driving	290	21.5%
MEDIAN SLOPE (H:V)	4:1, 5:1	625	46.4%
	6:1	722	53.6%
MEDIAN WIDTH (FT)	>32-40	275	20.4%
	>40-64	304	22.6%
	26-32	768	57.0%
NEAR OVERPASS	>.75-2.5	194	14.4%
	>.25-.75	421	31.3%
	0-.25	732	54.3%
ROAD CHARACTERISTICS	Curve/Hill Crest/Grade	175	13.0%
	Curve/Level	145	10.8%
	Straight/Hill Crest/Grade	264	19.6%
	Straight/Level, Unknown	763	56.6%
RUTTING (inches)	0-.125 - Lowest	176	13.1%

	>.362-.6 - Medium Low	181	13.4%
	>.6-.836 - Medium High	226	16.8%
	>.836-1.31 - Highest	219	16.3%
	>.125-.362 - Low	545	40.5%
SPEED LIMIT (MPH)	60	111	8.2%
	65	1236	91.8%
SURFACE TYPES	Ice	501	37.2%
	Snow, Slush	151	11.2%
	Other, Missing, Wet, Water	147	10.9%
	Dry	548	40.7%
VEHICLE ACTION	Vehicle Movements, Avoiding Objects in Road, Unknown,	253	18.8%
	Passing, Merging, Changing Lanes	127	9.4%
	Skidding/Out of Control	444	33.0%
	Straight Ahead	523	38.8%
VEHICLE TYPES	Motorcycle, Misc., Passenger Cars	632	46.9%
	Light Trucks, Bus, SU, Semi	715	53.1%
TOTAL		1347	100%

Table T.2. Median Crash Types: Summary of Crash Statistics and Variables with Categories

Variables and Sub-Categories		N	Percentage
MEDIAN CRASH TYPES	In-Median Rollover	215	63.2%
	In-Median Non-Rollover	59	17.4%
	Cross-Median Rollover	33	9.7%
	Cross-Median Non-Rollover	33	9.7%
AADT (vehicles/day)	8000-32000 - Low	102	30.0%
	>48000-63000 – High	117	34.4%
	>32000-48000 - Med	121	35.6%
AGE (years)	16-20	77	22.6%
	21-25	66	19.4%
	36-50	79	23.2%
	51-65, 66-110	40	11.8%
	26-35	78	22.9%
ALCOHOL	Yes	40	11.8%
	No	300	88.2%
CRASH SEVERITY	Fatality/Incapacitating Injury	29	8.5%
	Non-incapacitating injury/possible injury	124	36.5%
	Property damage only	187	55.0%
COLLISION TYPE	Multiple Vehicles	41	12.1%
	Single Vehicle	299	87.9%
GENDER	Female	141	41.5%
	Male	199	58.5%
HUMAN CIRCUMSTANCES	Emotional, Fell Asleep, Following Too Closely, Ill, Improper Driving, Lane Change, Drove Off Road	48	14.1%
	Driver Inexperience	36	10.6%
	Distracted	33	9.7%
	Unknown	59	17.4%
	No Improper Driving	83	24.4%
	Unsafe Speed	81	23.8%
LIGHT	Dark - Roadway Not Lighted, Twilight	58	17.1%
	Dark-lighted	108	31.8%
	Daylight	174	51.2%
MEDIAN SLOPE (H:V)	4:1, 5:1	152	44.7%
	6:1	188	55.3%
MEDIAN WIDTH (ft)	>32-40	65	19.1%
	>40-64	84	24.7%
	26-32	191	56.2%
ROAD CHARACTERISTICS	Curve/Hill Crest/Grade	62	18.2%
	Curve/Level	45	13.2%
	Straight/Hill Crest/Grade	80	23.5%
	Straight/Level, Unknown	153	45.0%
RUTTING (inches)	0-.125 - Lowest	40	11.8%
	>.362-.6 - Medium Low	39	11.5%
	>.6-.836 - Medium High	69	20.3%
	>.836-1.31 - Highest	72	21.2%

	>.125-.362 - Low	120	35.3%
SURFACE TYPES	Other, Missing, Wet, Water	33	9.7%
	Snow, Slush	46	13.5%
	Dry	81	23.8%
	Ice	180	52.9%
VEHICLE ACTION	Vehicle Movements, Avoiding Objects in Road, Unknown, Slowing, Stopped	33	9.7%
	Passing, Merging, Changing Lanes	27	7.9%
	Skidding/Out of Control	129	37.9%
	Straight Ahead	151	44.4%
VEHICLE TYPES	Light Trucks, Bus, SU, Semi	189	55.6%
	Passenger Cars, Motorcycle, Misc.	151	44.4%
TOTAL		340	100.0%

Figure F.1. Median Intrusion on Seward Highway

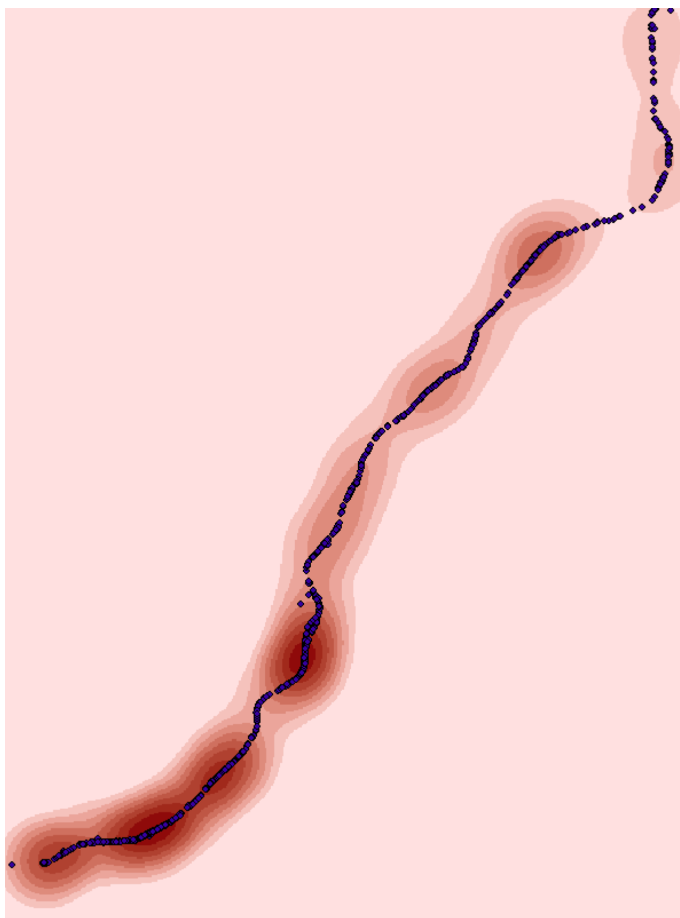

Figure F.2. Results of Kernel Density Estimation on Glenn Highway

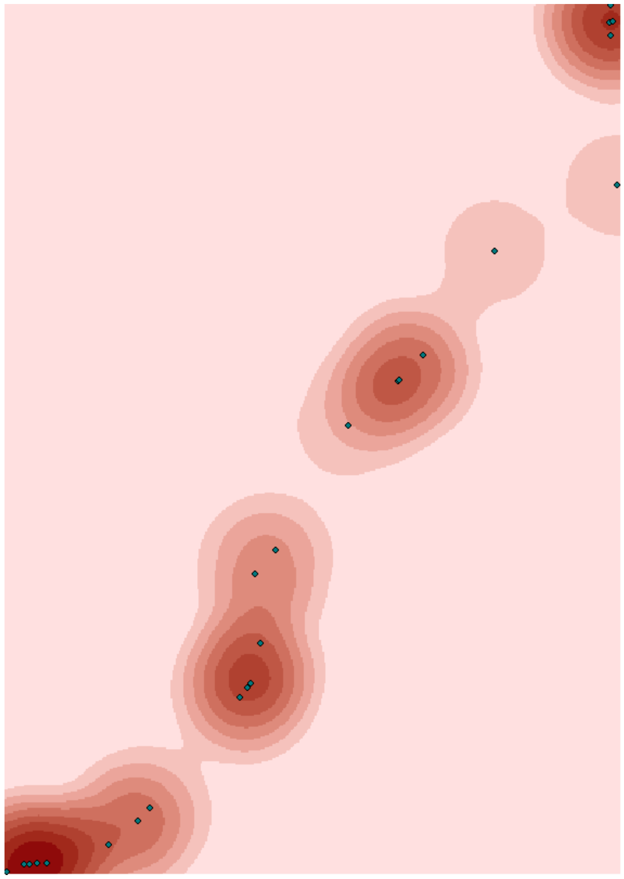

Figure F.3. Kernel Density Estimation Results on Glenn Highway, Cross-Median Crashes

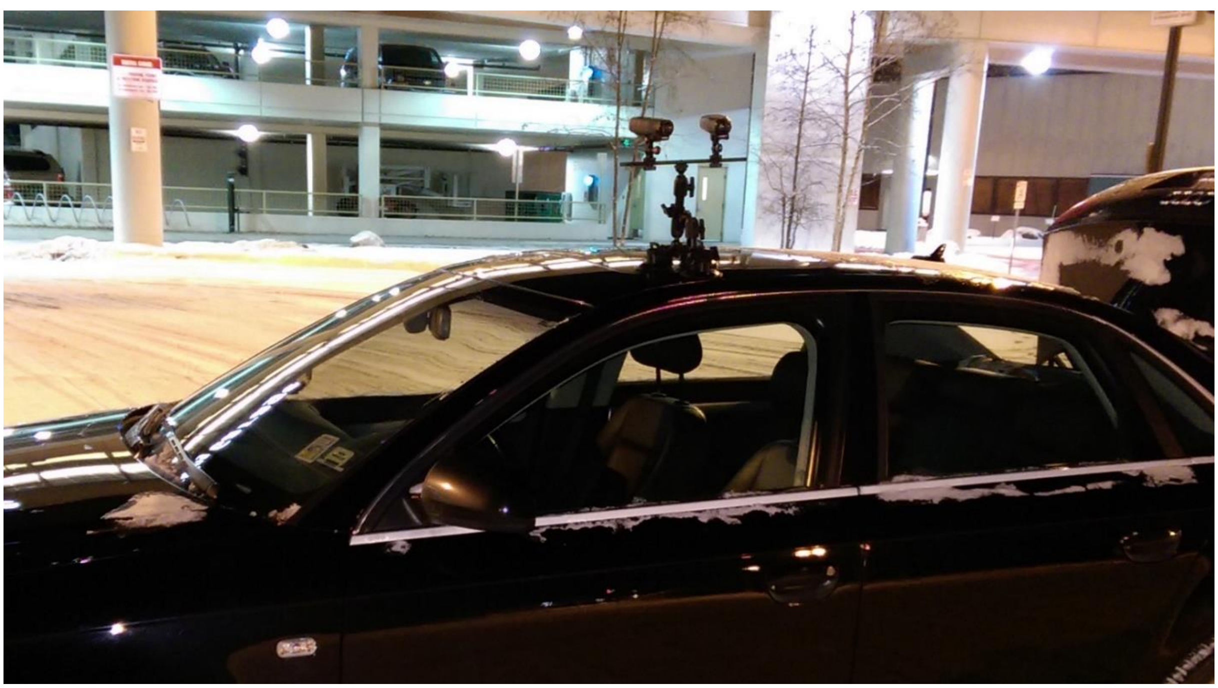

Figure F.4. Vehicle Mounted with Cameras

Figure F.5. Median Crashes on Minnesota Drive in Proximity to the Strawberry Off-Ramp

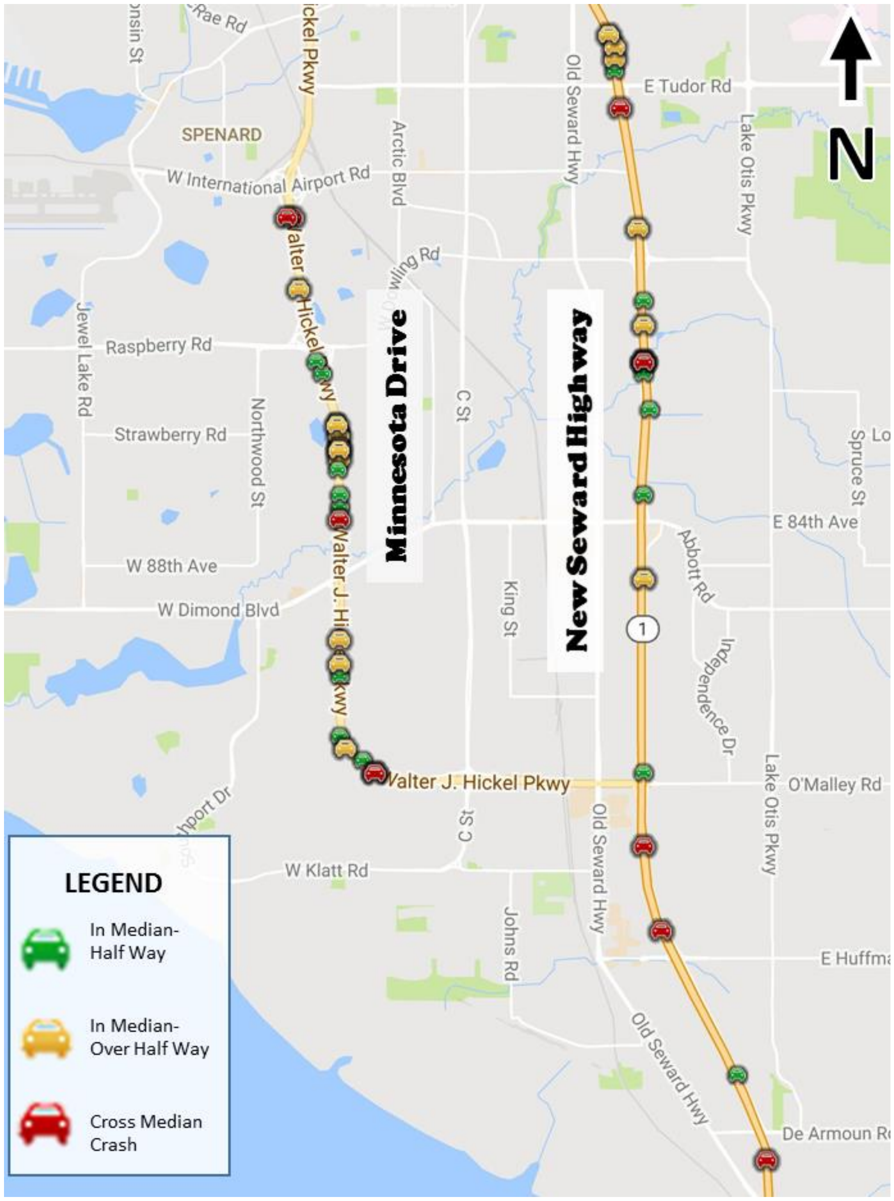

Figure F.6. Median Intrusions on Minnesota Drive and New Seward Highway

Figure F.7. Median Crashes along the Glenn Highway between Turpin Street and Muldoon Road

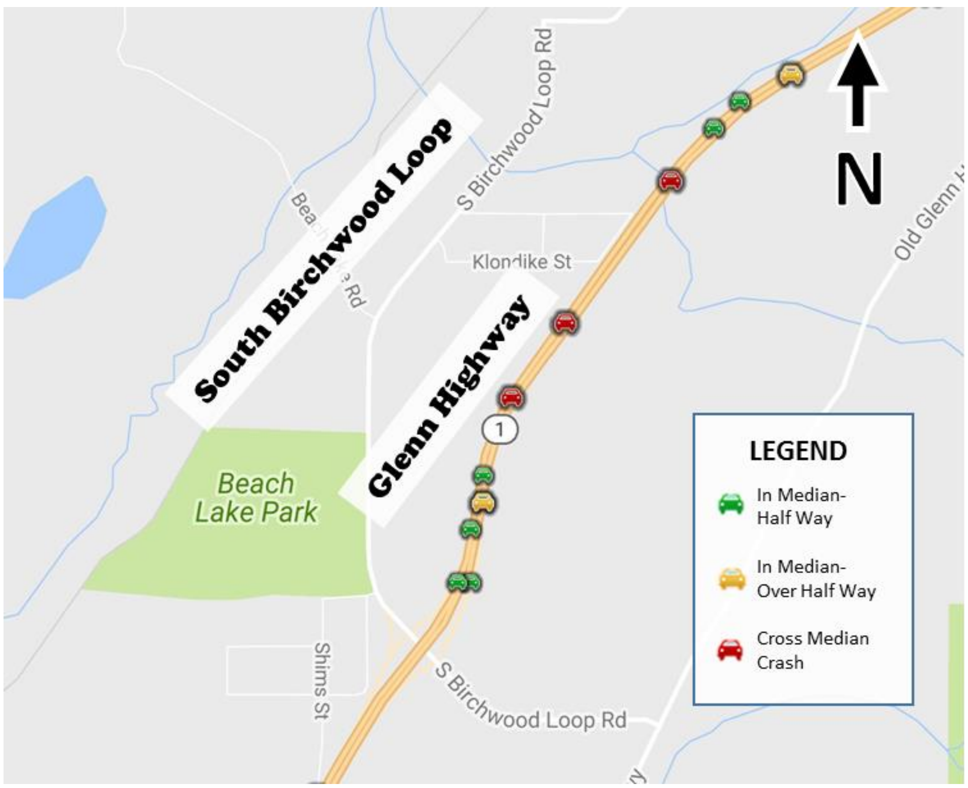

Figure F.8. Observed Median Crashes North of the South Birchwood Interchange

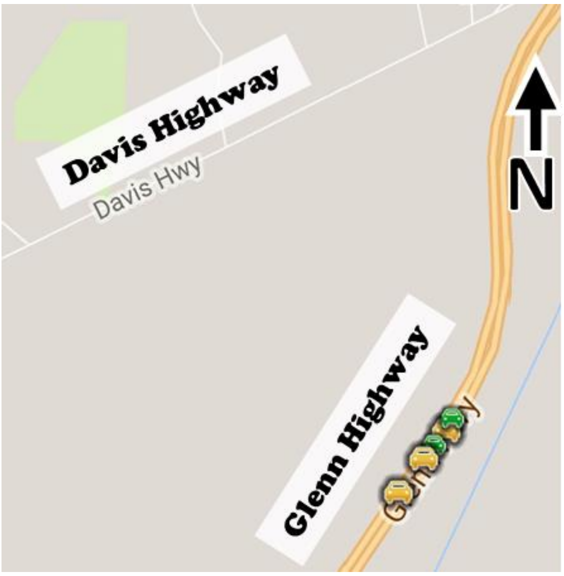

Figure F.9. Crashes near a Curve on the Glenn Highway, about MP 7.0 to 7.5

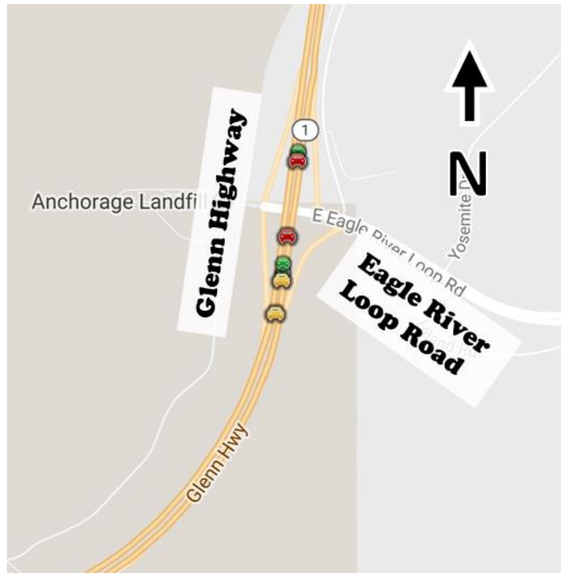

Figure F.10. Crashes near the Eagle River Interchange

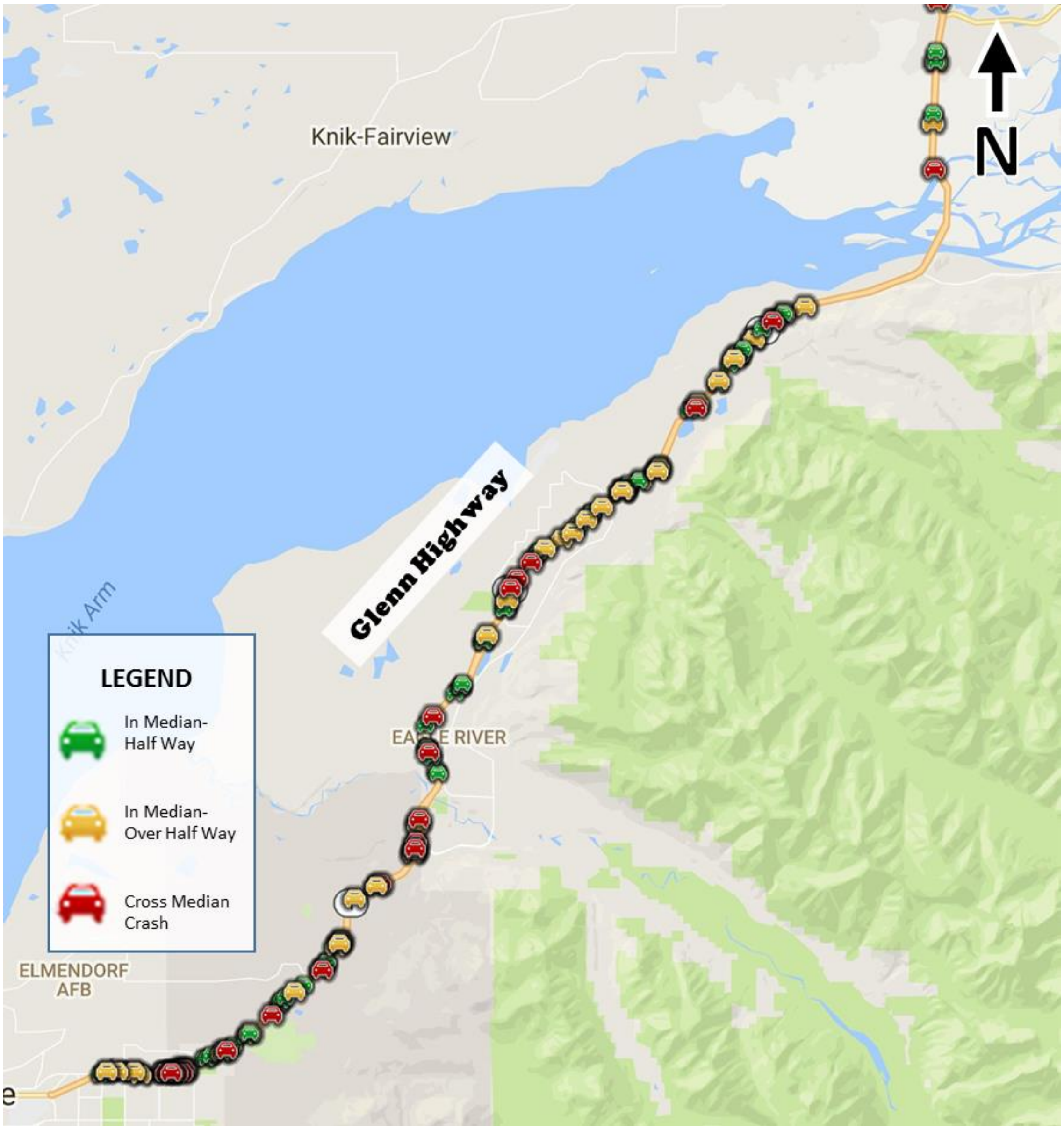

Figure F.11. Median Intrusions on the Glenn Highway