Alaska Department of Transportation & Public Facilities
Research & Technology Transfer

ACCIDENT REDUCTION FACTORS RELATING TO MOOSE-VEHICLE COLLISION CRASH TYPES

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May 2018

Prepared for:
Alaska Department of Transportation & Public Facilities
Statewide Research Office
3132 Channel Drive
Juneau, AK 99801-7898

Z586520000/RSA 2558049

REPORT DOCUMENTATION PAGE			Form approved OMB No.
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			
1. AGENCY USE ONLY (LEAVE BLANK)	2. REPORT DATE June 2017	3. REPORT TYPE AND DATES COVERED	
4. TITLE AND SUBTITLE Accident Reduction Factors Relating to Moose-Vehicle Collision Crash Types			5. FUNDING NUMBERS
6. AUTHOR(S) Osama A. Abaza, C.Eng., Ph.D. and Colleen C. Moran, P.E.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Alaska Anchorage College of Engineering 2900 Spirit Drive Anchorage, AK 99508			8. PERFORMING ORGANIZATION REPORT NUMBER N/A
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) State of Alaska, Alaska Dept. of Transportation and Public Facilities Research and Technology Transfer 3132 Channel Drive Juneau, AK 99801-7898			10. SPONSORING/MONITORING AGENCY REPORT NUMBER Z586520000/RSA 2558049
11. SUPPLENMENTARY NOTES Performed in cooperation with Department of Civil Engineering at the College of Engineering, University of Alaska Anchorage, under a contract with the Alaska Department of Transportation and Public Facilities (DOT&PF). Osama Abaza, Professor of Civil Engineering, University of Alaska Anchorage, was the Principal Investigator, Colleen C. Moran, P.E., was the Research Assistant.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT No restrictions			12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

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It has been hypothesized that moose related crash rates are dependent on environmental conditions such as snowfall and daylight conditions. The DOT&PF has performed many studies on moose vehicle collisions on the following corridors; Glenn Highway – Muldoon Road to Artillery Road, Glenn Highway - Hayflats, and the Knik Goose Bay. The Glenn Highway – Muldoon Road to Artillery Road project showed a significant drop in the number of moose-vehicle collisions after the installation of continuous illumination. The Glenn Highway project at the Hayflats, Matanuska River Bridge to the Parks Highway Junction, resulted in a 50% drop in the five-year average of moose-vehicle collisions after the installation of continuous lighting.

This study showed that there is a consistent drop in the number of moose-vehicle collisions following clearing and grubbing, with the exception of one corridor. Similar to the clearing and grubbing projects, the projects with the combination of both clearing and grubbing and continuous lighting showed a consistent drop in the number of moose-vehicle collisions following project completion. The projects with clearing and grubbing as a component had varying trends in moose-vehicle collisions post construction, which may indicate that DOT&PF Maintenance and Operations performed clearing of re-vegetated areas or older growth is less of an attractant for moose.

14- KEYWORDS: Moose vehicle collisions, countermeasures, lighting, clearing and grubbing, crash reduction, crash modification factors			15. NUMBER OF PAGES 74 (including introductory pages and Appendices) 16. PRICE CODE N/A
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT N/A

METRIC (SI*) CONVERSION FACTORS

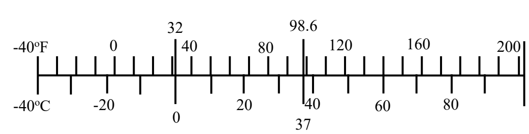
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4		mm
ft	feet	0.3048		m
yd	yards	0.914		m
mi	Miles (statute)	1.61		km
		AREA		
in^2	square inches	645.2	millimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.4046	hectares	ha
		MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g
lb	Pounds (avdp)	0.454	kilograms	kg
T	Short tons (2000 lb)	0.907	megagrams	mg
		VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL
gal	Gallons (liq)	3.785	liters	liters
ft^3	cubic feet	0.0283	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
Note: Volumes greater than 1000 L shall be shown in m^3				
		TEMPERATURE (exact)		
ºF	Fahrenheit temperature	5/9 (ºF-32)	Celsius temperature	ºC
		ILLUMINATION		
fc	Foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

These factors conform to the requirement of FHWA Order 5190.1A *SI is the symbol for the International System of Measurements

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 (statute)	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.471	acres	ac
		MASS (weight)		
g	grams	0.0353	Ounces (avdp)	oz
kg	kilograms	2.205	Pounds (avdp)	lb
mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces (US)	fl oz
liters	liters	0.264	Gallons (liq)	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
ºC	Celsius temperature	9/5 ºC+32	Fahrenheit temperature	ºF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi



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Acknowledgments

The research reported herein was performed under contract with the Alaska Department of Transportation and Public Facilities (DOT&PF) by the Department of Civil Engineering at the University of Alaska Anchorage, College of Engineering. Osama A. Abaza, Ph.D., Professor of Civil Engineering, University of Alaska Anchorage, was the Principal Investigator. The other author of this report is Colleen C. Moran, P.E., Graduate Student and Research Assistant, University of Alaska Anchorage. The work was done under the general supervision of Professor Abaza with the assistance of Colleen Moran and Jesse Crask, Research Assistant. The research team is grateful to the DOT&PF for their sponsorship of this research and cooperation of Alaska Department of Fish and Game (ADF&G). The information, findings, and opinions of the research team presented in this report do not represent the views of the sponsoring agency.

We would like to acknowledge the contributions of the following individuals:

- Anna Bosin, P.E., Research Engineer and Tribal Relations Liaison, DOT&PF
- Scott Thomas, P.E., Regional Traffic and Safety Engineer, DOT&PF
- Jefferson Jeffers, P.E., State Traffic Engineer, DOT&PF
- Matthew Walker, P.E., Assistant State Traffic Engineer, DOT&PF
- Carolyn Morehouse, P.E., Chief of Research, DOT&PF
- Jim Amundsen, P.E., Highway Design Chief, DOT&PF
- David Battle, Wildlife Biologist - Anchorage, ADF&G
- Gino DelFrate, Fish & Game Coordinator – Palmer, ADF&G
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Abstract

This report presents the results of a study of the statistical significance of continuous lighting and/or clearing and grubbing of roadway corridors as measures taken to reduce moose-vehicle collisions. Individual analyses and a combined regression analysis were conducted to investigate moose-vehicle collision rates, given several combinations of variables. The variables included clearing and grubbing, continuous lighting, clearing, moose population, precipitation, snowfall, and maximum snow depth. Ten project corridors were analyzed based on the variables present; each combination of variables was analyzed separately. The results were reviewed to determine the most influential variables, and a combined analysis of all corridors was conducted. Some variables showed stronger influence on moose-vehicle collisions. The findings suggest that more factors contribute to moose-vehicle collisions than the variables considered.

It has been hypothesized that moose related crash rates are dependent on environmental conditions such as snowfall and daylight conditions. The DOT&PF has performed many studies on moose vehicle collisions on the following corridors; Glenn Highway – Muldoon Road to Artillery Road, Glenn Highway - Hayflats, and the Knik Goose Bay. The Glenn Highway – Muldoon Road to Artillery Road project showed a significant drop in the number of moose-vehicle collisions after the installation of continuous illumination. The Glenn Highway project at the Hayflats, Matanuska River Bridge to the Parks Highway Junction, resulted in a 50% drop in the five-year average of moose-vehicle collisions after the installation of continuous lighting.

This study showed that there is a consistent drop in the number of moose-vehicle collisions following clearing and grubbing, with the exception of one corridor. Similar to the clearing and grubbing projects, the clearing and grubbing and continuous lighting projects showed a consistent trend of a drop in the number of moose-vehicle collisions following project completion. The projects with clearing and grubbing as a component had varying trends in moose-vehicle collisions post construction which may indicate that DOT&PF Maintenance and Operations performed clearing of re-vegetated areas or older growth is less of an attractant for moose.

Summary of Findings

Crashes are random and multivariate in nature, therefore, statistical methods are needed to account for natural variation of crashes over time while simultaneously accounting for other factors that are likely to impact crash risk. In this study, the research team analyzed the statistical significance of continuous lighting and/or clearing and grubbing of roadway corridors as measures taken to reduce moose-vehicle collisions (MVCs). Construction improvements, moose population, and weather data were believed to be the influencing factors in MVCs and the data was collected for ten project corridors: Sterling Highway MP 82.0–93.72, Kalifornsky Beach Road MP 16.4–22.4, Glenn Highway MP 4–11, Glenn Highway MP 3.24–11.46, Glenn Highway MP 30.7–33.5, Glenn Highway MP 12.082–16.5, Parks Highway MP 35–37, Parks Highway MP 37–39, Parks Highway MP 72–83, and Knik-Goose Bay Road MP 0.0–19.56. Data were gathered for a 10-year period for each project, spanning from 5 years before to 5 years after the construction completion date. To determine the statistical significance of the variables, regression analysis was performed for every possible combination of variables.

The results of the regression analyses showed different levels of variation in crashes being explained by the data set. The results for four of the projects were inconclusive; therefore, a correlation between the number of reported MVCs and the independent variables could not be determined. This indicates that additional variables not included in the study are influencing MVCs and additional data is needed. The results from the other projects show between 22.0% and 85.9% of the variation in collisions being explained by the independent variables, with differing results on which variables contributed to the number of MVCs. Among the projects, differences in whether the variable contributes to an increase or decrease in the number of MVCs are apparent. These results show that the variables do not capture all the contributing factors related to MVCs.

A combined set of all project corridors was evaluated. The combined set regression analysis resulted in only 12.0% of the variation in collisions being explained by the independent variables. This result also shows that more factors contribute to MVCs than were included as variables in this study.

Once each corridor was analyzed, Crash Modification Factors (CMFs) were developed to be used to estimate the expected average crash frequency of an individual site. The MVC CMFs that were developed are an estimate of the effectiveness of the implementation of continuous lighting and/or clearing and grubbing of roadway corridors. Most corridors showed a drop in MVC based on CMF and five year averages prior to and post construction. Continued study and analysis could assist in the development of more reliable CMFs.

Although this study resulted in low statistical significance, there is evidence of positive results for the mitigation measures, continuous lighting and clearing and grubbing. Continued monitoring of post construction conditions, Maintenance and Operations events, and data collection for continued improvements will increase the accuracy of the data for future re-analysis and improve the developed crash modification factors.

CHAPTER 1 – INTRODUCTION AND RESEARCH APPROACH

The State of Alaska Department of Transportation and Public Facilities (DOT&PF) has used continuous lighting and/or clearing and grubbing of several corridors in the past two decades with apparent, but unquantified, success at reducing moose-vehicle collisions (MVCs). These measures, which pose less of a barrier to moose movement than fencing, are used more often in corridors where adjacent land access precludes fencing systems. However, very few in-depth analyses have been conducted to document the correlation between clearing and lighting and the effects of these measures on MVCs. In order to analyze the effects of past efforts, it was important to accumulate project examples with 3 to 5 years of reportable crash data after project completion. Projects with ground clearing and continuous highway illumination were not funded as Highway Safety Improvement Program (HSIP) projects, so before-and-after analyses were not previously conducted.

The MVC problem has been mainly reported on rural highways surrounding major cities and towns, primarily near Anchorage, Palmer, Wasilla, Soldotna, Kenai, Fairbanks, and North Pole. With large numbers of Alaskans living in proximity to significant moose populations, transportation of people and goods poses challenges that increase risks to both humans and moose.

Table 1 shows the average number of moose–vehicle collisions on an annual basis in Alaska—over 800 MVCs every year (ADF&G, 2017). This rate is one of the highest in the world for this type of animal (Thomas, 1995). A vehicle that collides with a moose has the potential to cause significant injury or death to vehicle occupants. About 1.5% of all MVCs result in serious injuries to vehicle occupants, and 0.25% results in fatalities as well as death to the animal and a hazard for road crew during cleanup. The average cost per moose collision is about $35,000 in vehicle damage and collision response (DOT&PF, 2014).

Table 1 – Average Number of Moose-Vehicle Collisions by Region

Region	Annual Average Number of Moose-Vehicle Collisions
Kenai Peninsula	250
Municipality of Anchorage	120
Mat-Su Valley	280
Fairbanks Area	126

Data taken from ADF&G Give Moose a Brake website (ADF&G, 2017).

Problem Statement and Research Objective

Moose-vehicle collisions increase the risk of injury and damage to humans and moose as well as property. The objective of this study was to investigate the statistical significance of continuous lighting and/or clearing and grubbing of roadway corridors as measures taken to reduce MVCs. The study's findings will help to determine accident reduction factors applicable to MVCs.

Scope of Study

In an effort to reduce the causal factors of MVCs, the DOT&PF proposed research to determine whether improvement projects performed by the agency have been effective at mitigating the number of MVCs on a given corridor. Many studies have been performed to evaluate the effectiveness of mitigation measures on ungulates such as deer, but there has not been a project that evaluated the effectiveness with respect to moose related accidents. These studies have been in locations where MVCs are less common than other wildlife collisions so moose were not the main focus (see Chapter 2). Alaska has a much higher rate of MVCs and the DOT&PF has been focusing on mitigation measures specific for moose for a long time.

This study reviewed and documented the apparent crash mitigation effects of highway lighting and clearing in reducing/preventing MVCs. The results are of value, as moose are difficult to see at night because of their dark bodies which do not reflect light or because they blend into vegetation along the roadway (see Figure 1). Unlike deer, moose seldom look directly at on-coming vehicles, so no eye-shine reflection of headlights can be observed. This study also reviewed the differences in the two mitigation measures for continued use in Alaska, as they are not routinely accepted for ungulates such as deer and elk. Based on the results of studies reviewed, better illumination and clearing methods have been suggested, but further analysis is required.

Photo provided by Colleen Moran, Raspberry Road, Anchorage 3/23/2017.

Figure 1 – Moose Eating Vegetation Alongside Roadway

Project Approach

A literature review of other studies on MVCs was conducted. The literature review was followed by data collection related to the project corridors, information provided by DOT&PF, and additional characteristics considered influential in MVCs. The data were assembled for each corridor and analyzed to determine each variable's statistical significance in MVCs. The resulting correlations between the independent variables studied and their relation to the number of MVCs, were used to develop crash modification factors (CMFs) for each corridor.

LITERATURE REVIEW

The literature reviewed included published research, reports, and articles relevant to the project. Journal databases accessed for articles on animal-vehicle collisions, specifically MVCs, were *Alces, Biological Conservation, International Journal of Geographical Information Science, Journal of Applied Ecology, Journal of Environmental Management, Journal of Safety Research, The Journal of Wildlife Management, Landscape and Urban Planning, Conservation Biology,* and *Wildlife Society Bulletin*.

Also reviewed were publications by Alaska DOT&PF, Alaska Department of Fish and Game (ADF&G), the Washington State Department of Transportation, Highway Safety Information System, and other national and international organizations interested in highway and traffic safety.

Purpose

The literature review focused on the following issues related to clearing and lighting:

- Identification of moose activity patterns
- Identification of moose migration patterns
- Determination of factors that influence moose behavior
- Identification of methodologies for establishing statistical relationships between MVCs and various environmental factors
- Identification of MVC mitigation measures
- Effectiveness of mitigation measures
- Management implications
- Alaska DOT Database and Previous Studies

Moose Behavior

Moose movement has been found to differ between the sexes and be influenced by daily and annual periods. Moose are significantly more active in summer than in winter due to shorter resting periods during summer months compared with winter months. Home-range size is larger in summer than in winter, but the seasonal difference is greater for females than males. Home-range size has been determined to be 42.1 km^2 (16.3 mi^2) in summer and 6.4 km^2 (2.5 mi^2) in winter regardless of sex (Dussault, et al., 2005b). In another study (Sweanor & Sandegren, 1989), winter range was determined to be 11.5 km^2 (4.44 mi^2), the difference in these findings likely due to terrain and forage differences between the study areas. The winter range of moose varies slightly from year to year, showing that moose have a tendency to return to a particular area. The effect of snow depth on winter home-range size is apparent only when snow depth is > 70 cm (27.6 in.). Moose begin fall migration on different dates in different years, and duration varies from year to year, although, size or range does not differ (Sweanor & Sandegren, 1989).

The daily movements of parturient moose increase significantly in the 2 days prior to calving, and are greatly reduced for at least 9 days post-parturition. Female moose also return to successful birth site areas (Testa, Becker, & Lee, 2000). Female moose with calves have a higher preference for areas providing protection from predation, whereas, solitary moose prefer areas that provide moderate food abundance, moderate protection from predation, and substantial shelter against deep snow (Dussault, et al., 2005a).

Moose movement in relation to food availability varies between the summer and winter seasons. In summer, moose movement rates are lower in deciduous and fir habitats than in spruce and other habitat types. In winter, movement rates are lower in fir than in spruce and other habitat types (Dussault, et al., 2005b). Roe deer and moose have low activity levels in winter and early spring, indicating conservation of energy, when the animals make use of patches with relatively dense but low-quality forage. In summer, emphasis shifts toward high-quality plants. More browsing and activity increase (Cederlund, 1989).

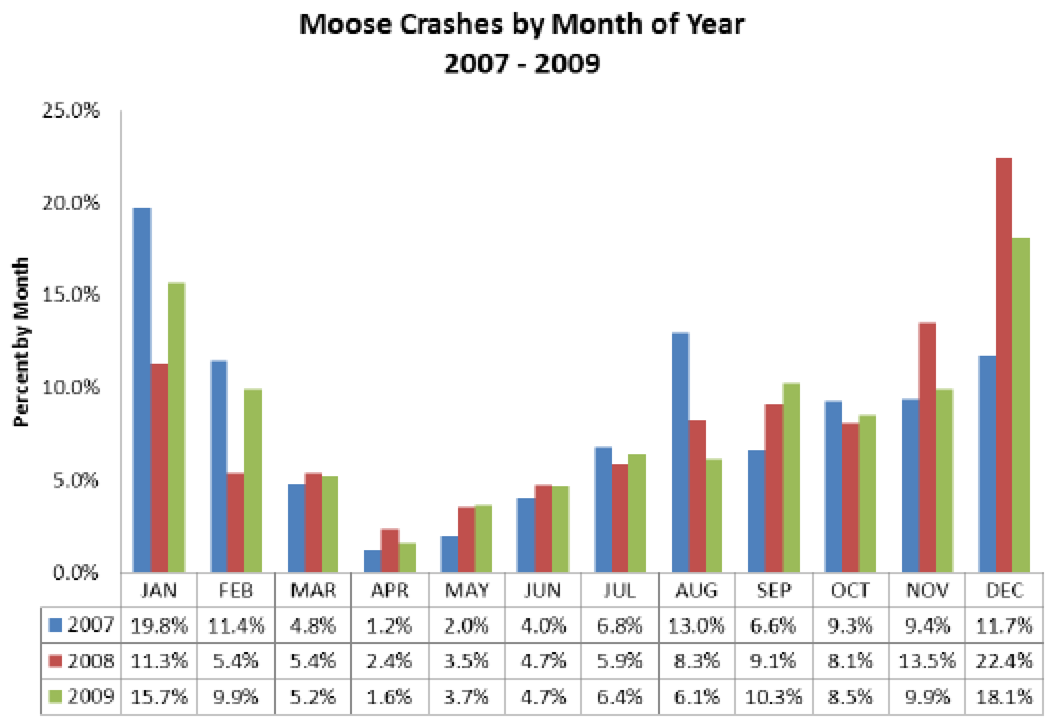
Moose activity in relation to other animal species has been studied. Moose and wolf activity patterns are asynchronous; in general, moose activity peaks at dusk and wolf activity peaks at dawn (Eriksen et al., 2011). Roe deer differ from moose in that their activity is evenly distributed over the day. Generally, in late autumn both roe deer and moose are most active during sunrise and sunset, showing an evident biphasic pattern (Cederlund, 1989).

It has been determined that the greatest number of animal collisions occurs during early morning hours (4:00 to 6:00 a.m.) and the evening hours (6:00 to 11:00 p.m.). Collisions with animal are more frequent at night, with occurrences ranging from 68% to 85% (Highway Safety Information System, 1995). During 2009 in Alaska, 64.7% of moose collisions occurred in darkness or in reduced light conditions (DOT&PF, 2012).In addition to daily peak movements, moose have seasonal migration patterns with spring-peaks, spring-dips, and summer-dips. Moose-vehicle collisions have a seasonal cyclic component, with the majority of collisions occurring from May to October, which is linked to the peak movement times of moose. Figure 2 shows moose crashes on Alaska roadways by month with the lowest number in April and the rates increasing into the winter months. In Alaska, the highest number of moose related crashes occurred in January and December (DOT&PF, 2012). Sweanor and Sandegren found that moose winter range is significantly smaller in winter than summer (1989). With moose movement smaller in range in winter months and moose crashes highest in winter months may reflect that moose are foraging closer to roadways, using roadways for ease of travel, or moose are forced out of other areas due to snow depth changes.

Establishing Methodologies

In an analytical hierarchy process (AHP) used to develop expert-based models to provide a quantitative prediction of MVC risk across a study area, it was found that, overall, habitat-based models are more proficient than driver-based models in predicting MVCs (Hurley, Rapaport, & Johnson, 2009). Logistic regression models and Akaike's information criteria (AIC) were used to develop best-matched models for six subsets related to MVCs: driver visibility, moose evidence, highway design, roadside vegetation, moose habitat, and landscape/GIS. The landscape-scale/GIS model approach shows promise in assessing contributing variables within the process of determining where MVCs occur (Hurley, Rapaport, & Johnson, 2007). The kernel estimation generates comparable distribution maps of density. The Ripley's K-function (or reduced second moment function) measures spatial dependence or clustering of events at multiple scales. This exploratory and multi-scale statistical analysis proved effective in displaying varying and similar spatiotemporal patterns on roads (Mountrakis & Gunson, 2009).

Simple logistic regression analyses used in predicting locations of MVCs in Sweden showed strong support for the combined model. The combined model used the predicted likelihood for MVCs as the independent variable and the actual accident status of the selected road sections as the dependent variable (Seiler, 2005).



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2007	19.8%	11.4%	4.8%	1.2%	2.0%	4.0%	6.8%	13.0%	6.6%	9.3%	9.4%	11.7%
2008	11.3%	5.4%	5.4%	2.4%	3.5%	4.7%	5.9%	8.3%	9.1%	8.1%	13.5%	22.4%
2009	15.7%	9.9%	5.2%	1.6%	3.7%	4.7%	6.4%	6.1%	10.3%	8.5%	9.9%	18.1%

Figure 35 from the 2009 Alaska Traffic Crashes report provided by DOT&PF (DOT&PF, 2012)

Figure 2 - Moose Crashes by Month of Year 2007 – 2009

Mitigation Measures

Reed and Woodard (1981) found that the presence of highway lighting did not significantly affect the crossings-per-accident ratios for deer, and highway lighting did not affect location of deer crossings, in that deer continued crossing at preferred locations. Neither the effects of highway lighting in relation to MVCs nor the relation between clearing, grubbing, and/or roadway illumination and MVCs have been studied.

In their moose tracking study, Becker et al. (2011) found a high probability of moose crossing underneath the highway at bridge locations. The results of their study suggest that preferred moose habitat and landscape features are strong indicating factors in predicting where moose crossings will occur, with preferred habitat and landscape features having a stronger influence on crossing locations than fences. For this reason, fencing projects were not included in the present study, which focused on whether clearing and grubbing along highway corridors has an effect on MVCs by altering preferred moose habitat and improving the visibility of moose for drivers.

Effectiveness of Mitigation Measures

Moose-vehicle collisions have been shown to have a higher probability of occurring in areas of higher speed, at areas that have been human-modified, where higher moose activity is present, and in the dark than in daytime. Additional factors are light conditions, road surface conditions, location of preferred habitat, weather, and traffic volume (Neumann et al., 2012). Given that moose activity is at its highest during dusk or dawn, when moose are almost impossible to see, many past studies have suggested the use of lighting along roads with high moose activity. Clearing, however, has had varying results. Some studies show that roadside clearing increased preferred habitat and MVCs; other studies show that roadside clearing reduced MVCs (see Appendix A, Section A 4). These findings indicate that vegetation management can be an effective means of reducing MVCs if done correctly.

Recently, the Washington State Department of Transportation (WSDOT) evaluated continuous roadway lighting on mainline freeway segments in Washington State and the research team concluded that continuous illumination makes no measureable contribution to nighttime safety performance and that installation for safety performance is not warranted (van Schalkwyk, et al., 2016). Given that roadway lighting targets crashes occurring during darkness, the WSDOT research team decided to develop nighttime safety performance functions and only include nighttime crashes in the analysis. These results contradict the belief that illumination is an effective mitigation measure at reducing crash rates as current guidance in the AASHTO Highway Safety Manual presents (2010). As previously discussed in the Moose Behavior section, several studies have shown that moose activity and animal related accidents peak at dawn and dusk; Eriksen et al. (2011) found that moose activity generally peaks at dusk, the Highway Safety Information System (1995) reported that the greatest number of animal collisions occurs during the early morning hours (4:00 to 6:00 a.m.) and during the evening hours of 6:00 to 11:00 p.m., and Cederlund (1989) reported that both roe deer and moose are most active during sunrise and sunset. Although the WSDOT study showed that illumination may not be effective at reducing general vehicle crashes, continuous lighting is believed to be effective at mitigating moose vehicle related accidents.

DOT&PF Database

The DOT&PF has performed many studies in the past related to MVCs on corridors around the state. Figure 3 is a chart provided by DOT&PF showing the construction improvements performed by milepoint along the Glenn Highway corridor from milepoint 131 to 141 (milepost 2 to 11). From milepoint 135 to about milepoint 138, continuous illumination was installed in 1987. The black marks show the number of MVCs from 1982-1986 and the grey marks show the number of MVCs from 1988-1992. There was a significant drop in the number of MVCs after the installation of continuous illumination. Continuous lighting was also installed in 1989 from about milepoint 138 to 139 and also resulted in a drop in the number of MVCs, although the effects are not fully shown since the installation occurred during the 1988-1992 time period that the MVCs reflect.

The DOT&PF also studied the Glenn Highway at the Hayflats, Matanuska River Bridge to the Parks Highway Junction. Continuous lighting was installed on this corridor in October of 2002. Figure 4 shows the results of the study. The five-year average per year dropped by over 50% after the installation of continuous lighting.

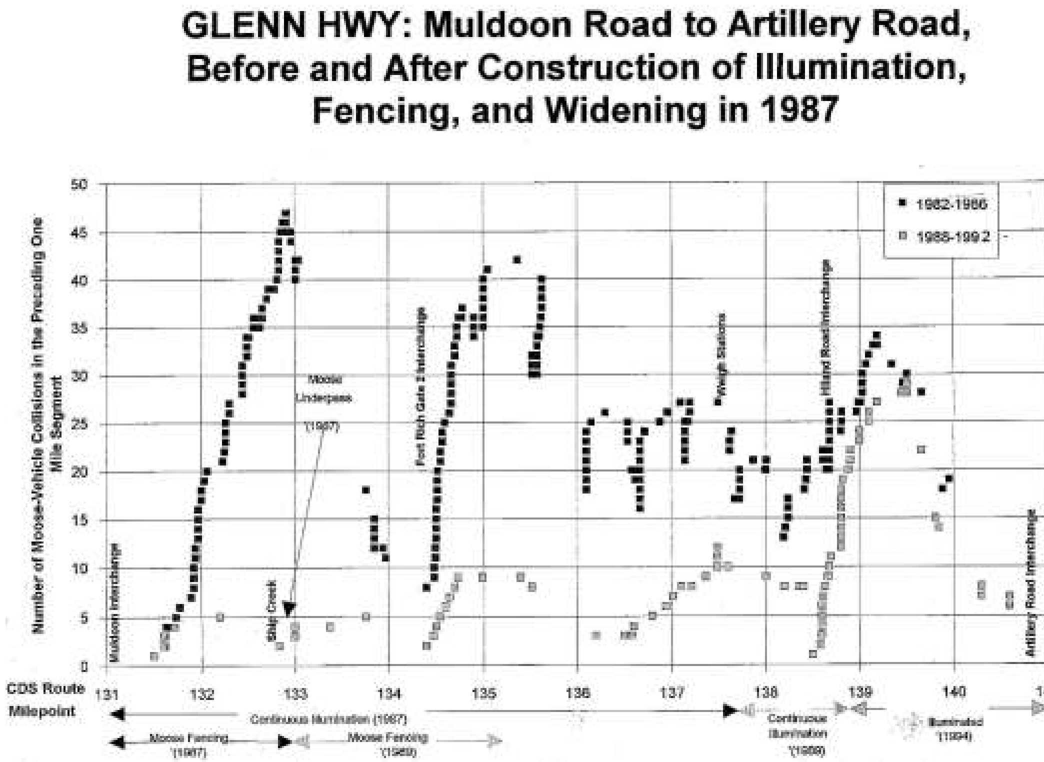


Figure provided by DOT&PF (DOT&PF, Moose-Vehicle Accidents on Alaska's Rural Highways, 1995)

Figure 3 - Glenn Highway Moose-Vehicle Accidents Before and After Construction of Illumination, Fencing and Widening – Muldoon Road to Artillery Road

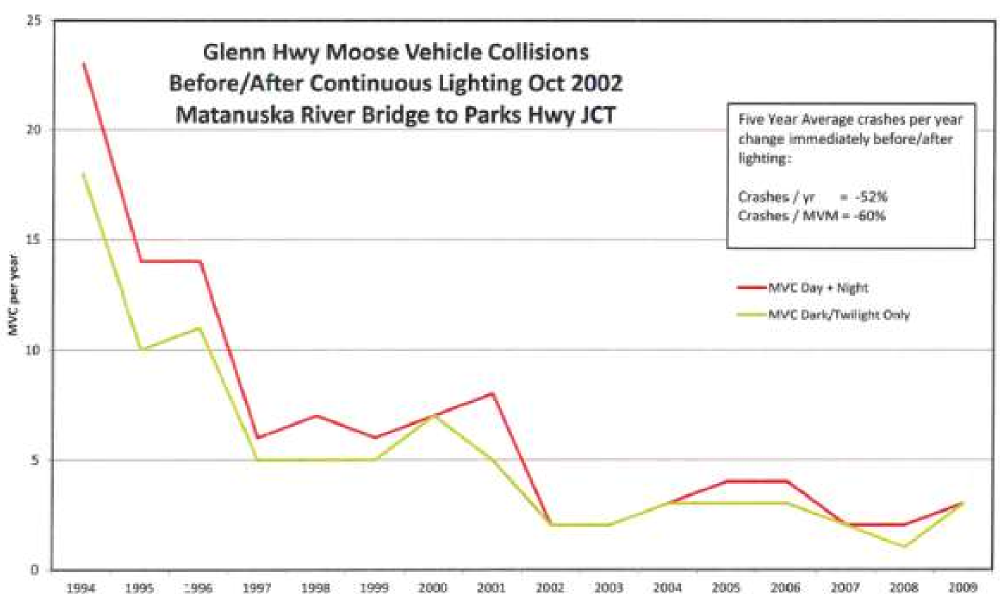


Figure provided by DOT&PF (DOT&PF, 2010)

Figure 4 - Glenn Highway Moose vehicle Collisions Before and After Construction of Continuous Lighting – Matanuska River Bridge to Parks Highway Junction (Hayflats)

Management Implications

Several structural and nonstructural methods have been identified as mitigation measures in wildlife collision reduction. Structural methods include crossing structures that maintain the connectivity of habitat. Nonstructural methods include repellents, ultrasound, road lighting, population control, and habitat modification. Although more expensive, structural methods were thought to reduce collisions better (Glista, DeVault, & DeWoody, 2009).

Moose-vehicle collisions were found to be a product of various environmental factors that are not exclusive and affect the significance of one another. Therefore, determining helpful mitigation measures will need to involve all factors present in a given corridor where MVCs are high.

Summary

Moose behavior is an important aspect to consider in how the study periods of a project are determined. It is important to capture the seasonal patterns in one study period for each year of a project. Moose movement and behavior is influenced by season, weather, and predation. Weather is considered in this study, as is clearing and grubbing, which is thought to possibly remove a food source and improve the visibility of moose on the road for drivers. Illumination projects are included to address the high occurrence of MVCs during periods of low visibility in early morning or dusk when peak movements occur.

Previous studies have used many different modeling and regression analyses to determine the relationship between drivers, MVCs, and the specific movement of moose. Due to several environmental factors thought to influence MVCs, it was determined that a linear regression analysis should be used. Linear regression is used to establish a relationship between dependent and independent variables, which is useful in estimating the resultant dependent variable in case independent variables change. All independent variables in this study varied from study year to study year.

The DOT&PF has performed a few studies on MVCs on the following corridors; Glenn Highway – Muldoon Road to Artillery Road, Glenn Highway - Hayflats, and the Knik Goose Bay Road. The Glenn Highway – Muldoon Road to Artillery Road project showed a significant drop in the number of moose-vehicle collisions after the installation of continuous illumination. The Glenn Highway project at the Hayflats, Matanuska River Bridge to the Parks Highway Junction, resulted in a 50% drop in the five-year average of moose-vehicle collisions after the installation of continuous lighting.

The statistical effects of highway lighting in relation to MVCs have not been studied, and neither has the relation between clearing, grubbing and/or roadway illumination and MVCs. Further study is needed to determine if vegetation management can be an effective means of reducing MVCs. Several structural methods (overpasses and underpasses) and nonstructural methods (repellents, ultrasound, road lighting, population control, and habitat modification) have been identified as mitigation measures in reducing vehicle-wildlife collisions. Although more expensive, structural methods are thought to be helpful means of reducing collisions.

Fencing is another structural method that has been suggested as a mitigation measure for MVCs, but fencing has been found to be a less effective indicating factor in moose crossing locations than preferred moose habitat and landscape features. Fencing sited in previous studies have included bighorn fence, buck-and-rail fence, and barbed wire fence, which are used to control livestock and other wild game and not moose. Moose can cross these types of fencing as seen with 311 fence crossings by 19 of 22 moose during the study period in Wyoming (Becker, Nielson, Brimeyer, & Kauffman, 2011). Electric fencing was also studied in its effectiveness to reduce MVCs and 30% of moose tracks observed were from moose that crossed an operation fence (Leblond, et al., 2007). Moose fencing, which has been frequently used in Alaska, has not been studied in other states. The DOT&PF installed moose fencing and continuous illumination along the Glenn Highway from milepoint 131 to 135 between 1987 and 1989, see Figure 3. These two mitigation measures combined significantly reduced the number of MVCs along this corridor.

This study includes many environmental factors thought to affect the number of MVCs, lighting installation, and clearing and grubbing of vegetation. Although, moose fencing seems to be a promising mitigation measure, it was not included in this study due to limited project study areas.

Appendix A provides detail information about the literature review conducted as part of this project.

Research Approach

The goal of the analysis was to determine if the number of MVCs (number of reported accidents with moose) was reduced based on the measures of clearing and grubbing, continuous lighting, or both improvements along a section of highway. Other factors considered were moose population and weather. The weather component included precipitation, snowfall, and maximum snow depth.

The purpose of a multiple regression analysis is to predict a single variable from one or more independent variables. To determine whether there is a significant relationship between the number of reported MVCs and the independent variables, assume the following null hypothesis (H_0), where H_0: The number of reported MVCs is independent of the dependent variables.

H_0: $\beta_1=\beta_2=\beta_3=\beta_4=\beta_5=\beta_6=0$

H_a: At least one β_i does not equal 0

To determine whether a significant linear relationship could be detected between number of reported collisions, construction improvements, moose population, and weather, a regression analysis was performed. The dependent or predictor variable is the number of reported collisions. The independent or explanatory variables are construction improvements, moose population, and weather. The regression analysis is run, and the regression statistics are evaluated. The closer the r-squared value is to 1, the better the regression function fits the data. To check the results for statistical significance, the significance F is evaluated. Values of F less than 0.05 indicate reliable or statistically significant data. A variable with a high p-

value (greater than 0.05) is an indication of unreliability and consequently is removed from the data set. The regression is rerun until significance *F* drops below 0.05.

The regression function is represented by Equation 1, where α and β are the least-squares solutions to several simultaneous linear equations, x_1 through x_k are independent variables, and y is the dependent variable (or predictor variable) (Dowdy, Wearden, & Chilko, 2004).

$$\boldsymbol{y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \varepsilon}$$ **Equation** 1

The number of variables in each analysis was either five or six. The number of possible combinations of variables is represented by Equation 2, the number of combinations of *n* things taken *r* variables at a time (Dowdy, Wearden, & Chilko, 2004).

$$\binom{\boldsymbol{n}}{\boldsymbol{r}} = \frac{\boldsymbol{n}!}{\boldsymbol{r}!(\boldsymbol{n}-\boldsymbol{r})!}$$ **Equation 2**

Once each corridor was analyzed, Crash Modification Factors (CMFs) were developed to be used in the Highway Safety Manual (HSM) Predictive Method (2010), which is used to estimate the expected average crash frequency of an individual site. The development of the MVC CMFs are important for the use of estimating the anticipated effects of implementing one or both of the MVC mitigation measures, continuous lighting and clearing and grubbing of roadway corridors. The predictive method can be applied to an existing roadway, a design alternative for an existing roadway or a design alternative for a new roadway.

As presented in Part C of the Highway Safety Manual, CMFs are the ratio of the estimated average crash frequency of a site under two different conditions, representing the relative change in estimated average crash frequency due to a change in one specific condition (2010). In this study, the change in condition is the implementation or construction of a mitigation measure, continuous lighting and/or clearing and grubbing of roadway corridors. Equation 3 shows the calculation of a CMF for the estimated average crash frequency from before and after construction of the mitigation measures.

$$CMF = \frac{estimated\ average\ crash\ frequncy\ after\ mitigation}{estimated\ average\ crash\ frequency\ before\ mitigation}$$ **Equation 3**

CMFs are an estimate of the effectiveness of the implementation of a particular treatment, also known as a countermeasure, intervention, action or alternative design (Highway Safety Manual, 2010). Equation 4 shows the relationship between a CMF and the expected percent change in crash frequency.

$$Percent\ Reduction\ in\ MVCs = 100\% \times (1.00 - CMF)$$ **Equation 4**

DATA COLLECTION AND CHARACTERISTICS

Crash data were collected from the Alaska Department of Transportation Statewide Crash Database (DOT&PF, 2016). Crash data, which were sorted only for crashes that involved moose collisions, were grouped by road segment. Once sorted, the data were further refined to eliminate crashes outside the improvement corridor and outside the 10-year analysis period.

Construction as-builts were reviewed to determine improvement corridors by milepost (MP), construction dates, and improvements preformed. The crash data range was selected based on the construction date, taking the completion date as the year the project was built. The crash data range is a 10-year analysis period—5 years before and 5 years after the completion year. Table 2 lists each road segment analyzed, along with corridor MP limits, construction dates, and improvement information.

According to the DOT&PF Standard Specifications for Highway Construction, clearing consists of the cutting and disposal of all trees, down timber, stubs, brush, bushes, and debris from all designated areas. Grubbing is the removal and disposal of all stumps, roots, moss, grass, turf, debris or other objectionable material within designated areas (2017 Edition). These areas are then replanted with grass.

Sweanor and Sandegren (1989) found that long durations of snow depth greater than 27.6 in. affected winter home-range size. For this reason, snow depth was a crucial variable to collect. Precipitation and snow data were obtained from Climate Data Annual Summaries (NOAA, 2016) of weather stations near the road segments studied; this data is available upon request.

Several studies have shown seasonal patterns in moose; many studies were performed during summer (e.g., Leblond et al., 2010) and winter (e.g., Sweanor and Sandegren, 1989). Leblond et al. (2010) found that moose movement differed among annual periods: winter, spring, summer, and fall. For this reason, each year in the study needed to range from the beginning of a season to another, and not by year alone. The annual precipitation data were grouped from fall to summer. This approach corresponds well with the construction season in Alaska, as shown by the as-built review. It was found that October was a common completion date. Since weather data were summarized by month, October was selected as the starting month of the study year, which aligns closely with the start of the fall season that begins on fall equinox, approximately September 22. This approach also groups the full snowfall data for the winter season into one study year.

Moose population information was gathered from the ADF&G Moose Management Reports (Alaska Department of Fish and Game – Division of Wildlife Conservation, 1989–2014). For Game Management Unit (GMU) 14A, population surveys have historically been conducted during fall and winter months, typically November and December, but have ranged from October to February. In GMU 14B, population surveys are conducted in fall, usually in October and November. For GMU 14C, surveys are conducted annually in the fall and early winter. In GMU 15A, moose population surveys are conducted in November and December of each year. For GMU 15B, the surveys are typically conducted in November and December, but 1 year, was conducted in February. For this reason, the yearly moose population estimates were assigned accordingly, matching the same study year as precipitation data.

Table 2 – Study Areas by Corridor and Improvement Information

Route No.	Road Segment	Milepost Est	Milepoint Range	Construction Dates	Year Built	Crash Data Range	Road Type	Continuous Lighting	Clearing and Grubbing	Clearing	GMU
110000	Sterling Highway	82.0-93.72	47.3999-56.5237	8/13/1991-10/24/1991	~1991	1986-1996	2 Ln	No	Yes	N/A	15A
115400	Kalifornsky Beach Road	MP 16.4-22.4	16.4-22.4	7/28/1999 - 8/6/2001	~2001	1996-2006	3 Ln	No	Yes	N/A	15B
135000	Glenn Highway	MP 4 - 11.	4.0-11.9	1/12/1987 - 9/20/1988	~1988	1983-1993	6 Ln Frwy	Yes	Yes	N/A	14C
135000	Glenn Highway	MP 3.24-11.46	3.24-11.46	Unknown	~2000	1995-2005	6 Ln Frwy	Yes	No	No	14C
135000	Glenn Highway	MP 30.7-33.5	30.7827-33.1182	9/5/2001 - 7/18/2002	~2002	1997-2007	4 Ln Frwy	Yes	Yes	N/A	14A
135000	Glenn Highway	MP 12.082-16.5	12.0327-16.5540	6/18/2007 - 9/23/2008	~2008	2003-2013	4 Ln Frwy	Yes	No	No	14C
170000	Parks Highway	MP 35-37	0-1.79	8/30/1999 - 10/31/2000	~2000	1995-2005	4 Ln Frwy	Replaced Existing	Yes	N/A	14A
170000	Parks Highway	MP 37-39	1.79-4.1617	10/12/2001 - 8/2004	~2004	1999-2009	4 Ln Frwy	No	Yes	N/A	14A
170000	Parks Highway	MP 72-83	36.3431-47.7586	10/21/2009 - 8/31/2011	~2011	2006-2016	2 Ln	No	No	Yes	14B
170044	Knik-Goose Bay Road	MP 0.0-19.56	0.0-7.0	8/4/2003 - 6/30/2005	~2005	2000-2010	2 Ln	No	Yes	N/A	14A

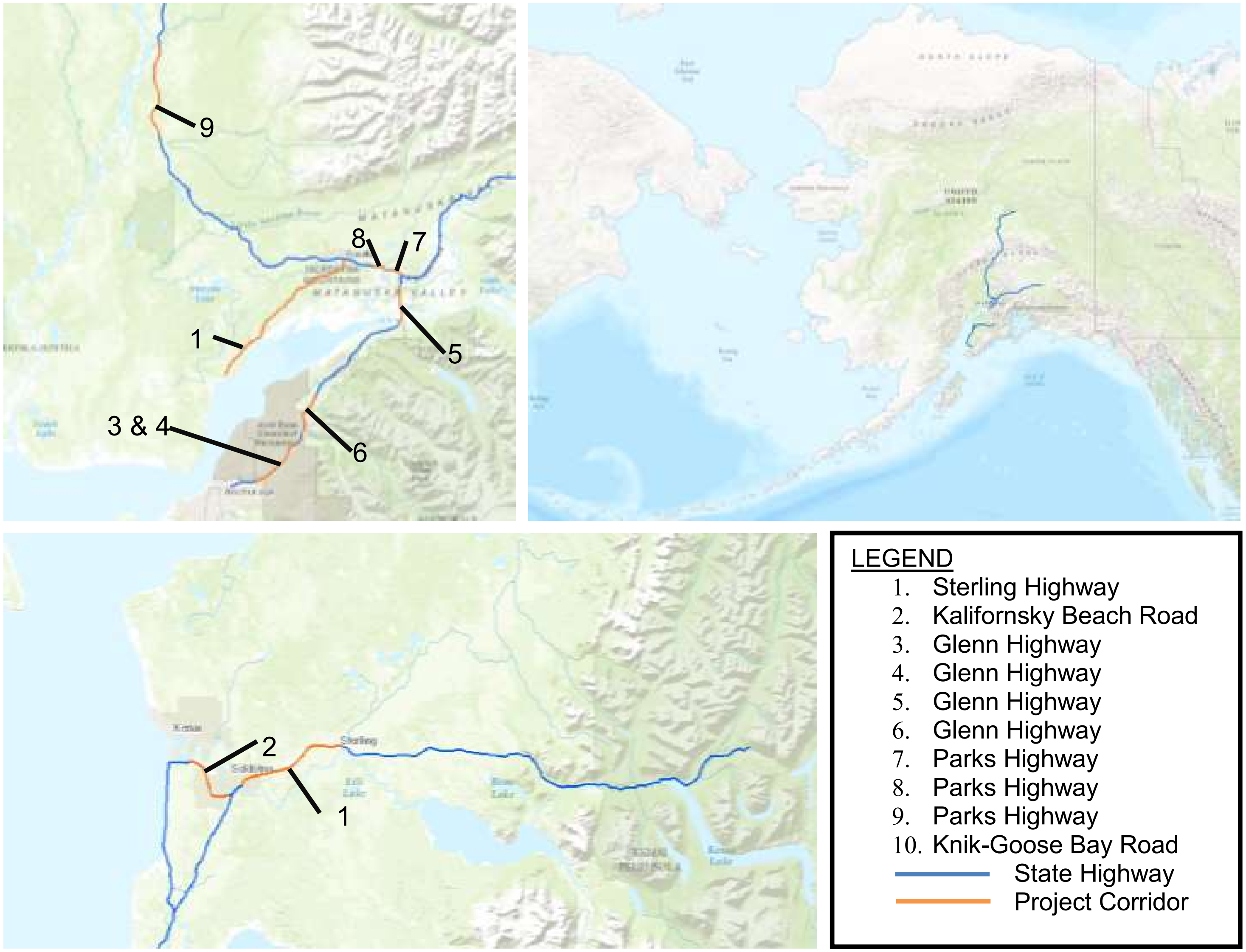


Figure 5 – Project Location Map (DOT&PF TGIS, 2017)

Sterling Highway Milepost (MP) 82.0–93.72

This section provides an overview of the full data collection and characteristics investigation conducted for the Sterling Highway MP 82.0–93.72 project. Detailed information on data collection and characteristics for all projects studied is available upon request.

The Sterling Highway MP 82.0–93.72 project is located in GMU 15A. Moose population information for GMU 15A was gathered from ADF&G Moose Management Reports; additional information was provided by ADF&G. Linear population interpolations were conducted to estimate moose population for years when population surveys were not conducted, as shown in Figure 6.

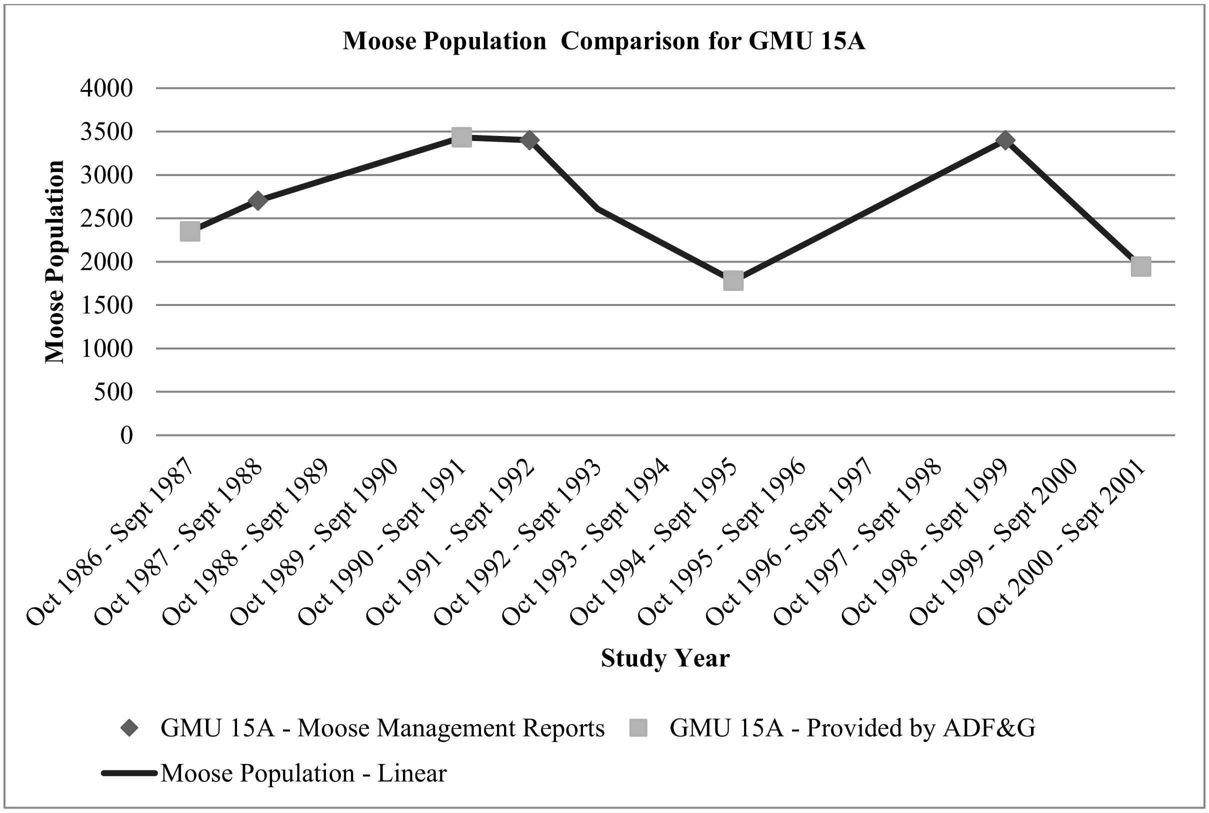


Figure 6 – Moose-Population Comparison for GMU 15A

Weather information was gathered from weather station KENAI MUNICIPAL AIRPORT, AK US COOP: 504546, the closest weather station to the project corridor with complete precipitation data (NOAA, 2016). The linear moose population estimate and the precipitation data were charted to compare data trends (see Figure 7–Figure 9). It can be seen from Figure 7 that the number of reported MVCs shows a trend similar to recorded precipitation information, both dipping and rising the same years. Moose-vehicle collisions closely follow the same trend per year as maximum snow depth and snowfall, as depicted in Figure 8 and

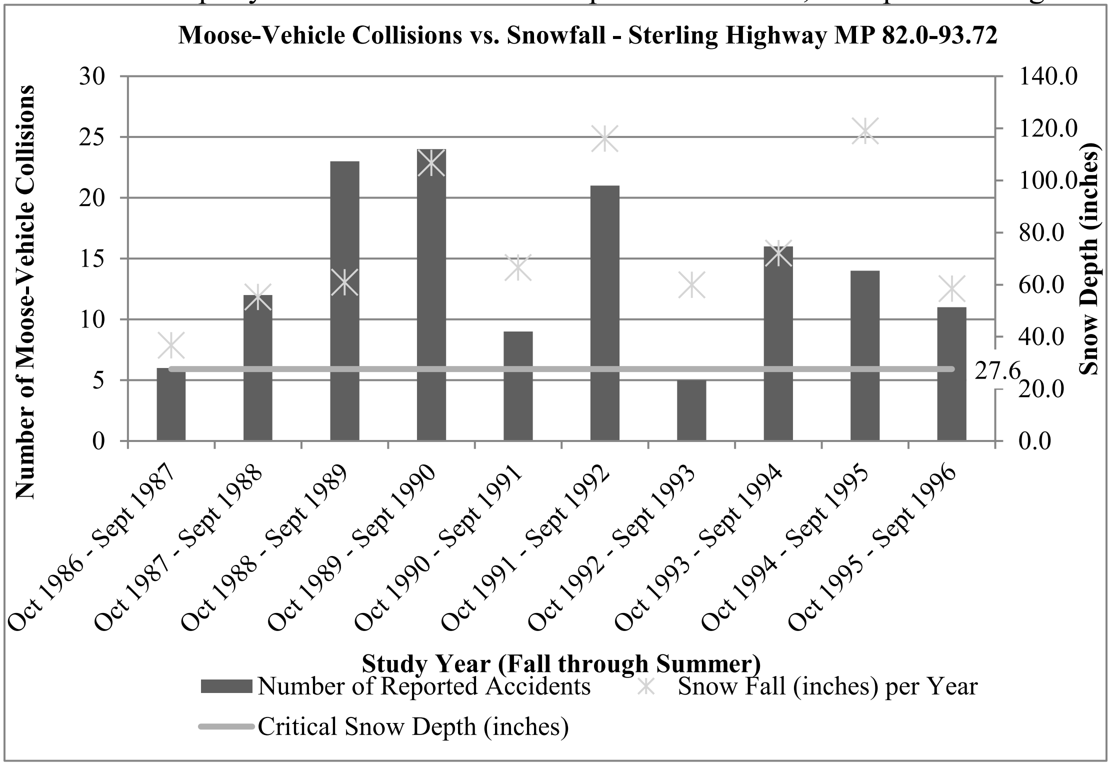


Figure 9. Precipitation and snow depth are in harmony, since years of high precipitation yield high snowfall and snow depth, and therefore have a similar relationship with MVCs. Figure 6 and Figure 8 are graphs of the same data in ascending order, from lowest number to highest number of MVCs. Although the overall rising trend is similar between snow depth and MVCs and between snowfall and MVCs, these graphs indicate no direct connection between the two. The highest collision years were not the highest snowfall or maximum snow depth years, so other factors are contributing to MVCs. The lowest dip in MVCs occurred the second year of post-project completion.

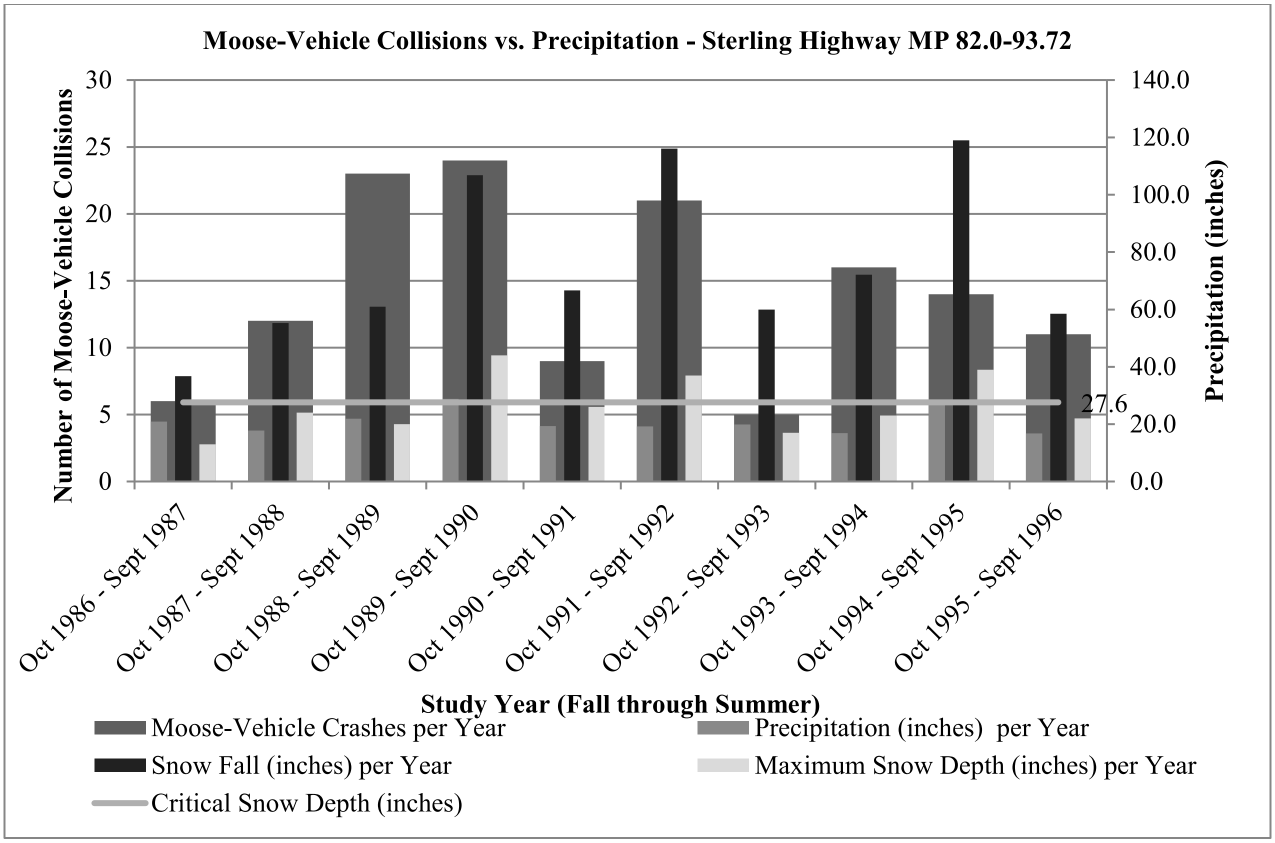


Figure 7 – Moose-Vehicle Collisions vs. Precipitation

Moose population information was gathered from ADF&G Moose Management Reports and provided by ADF&G for the remaining nine projects in the study. Linear interpolations were conducted to estimate moose population for years when population surveys were not conducted. Weather information was gathered from weather stations reported in the climate summaries on the NOAA website (2016). The linear moose population estimates and the precipitation data were charted to compare data trends.

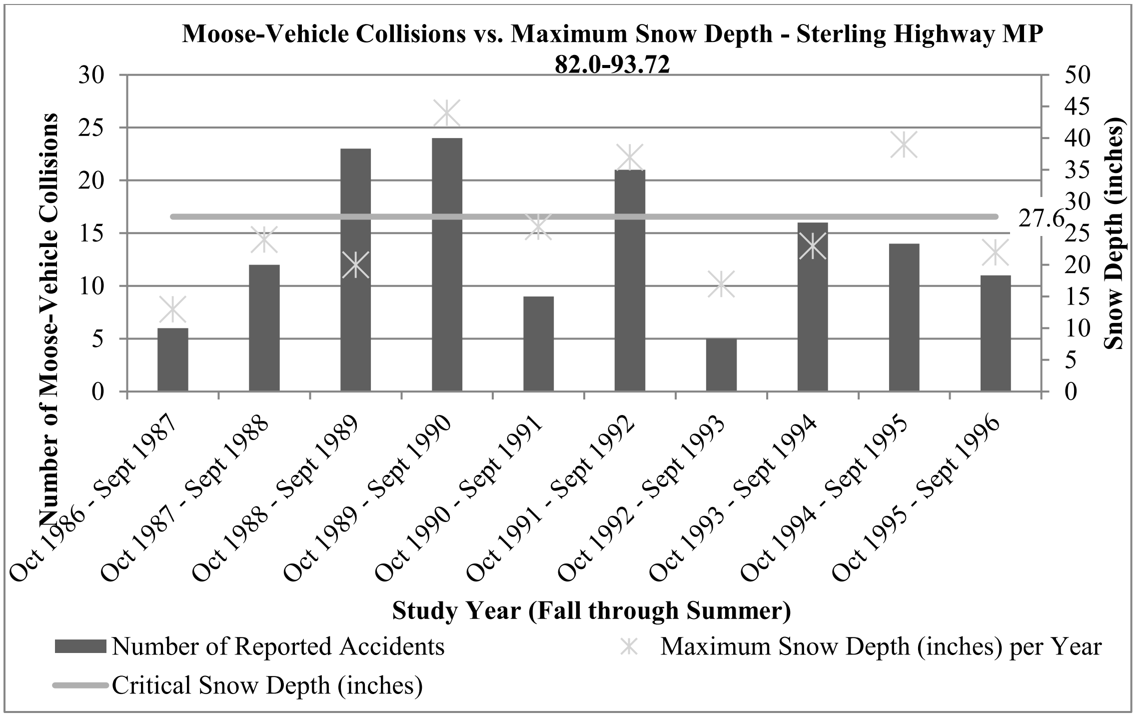


Figure 8 – Moose-Vehicle Collisions vs. Maximum Snow Depth

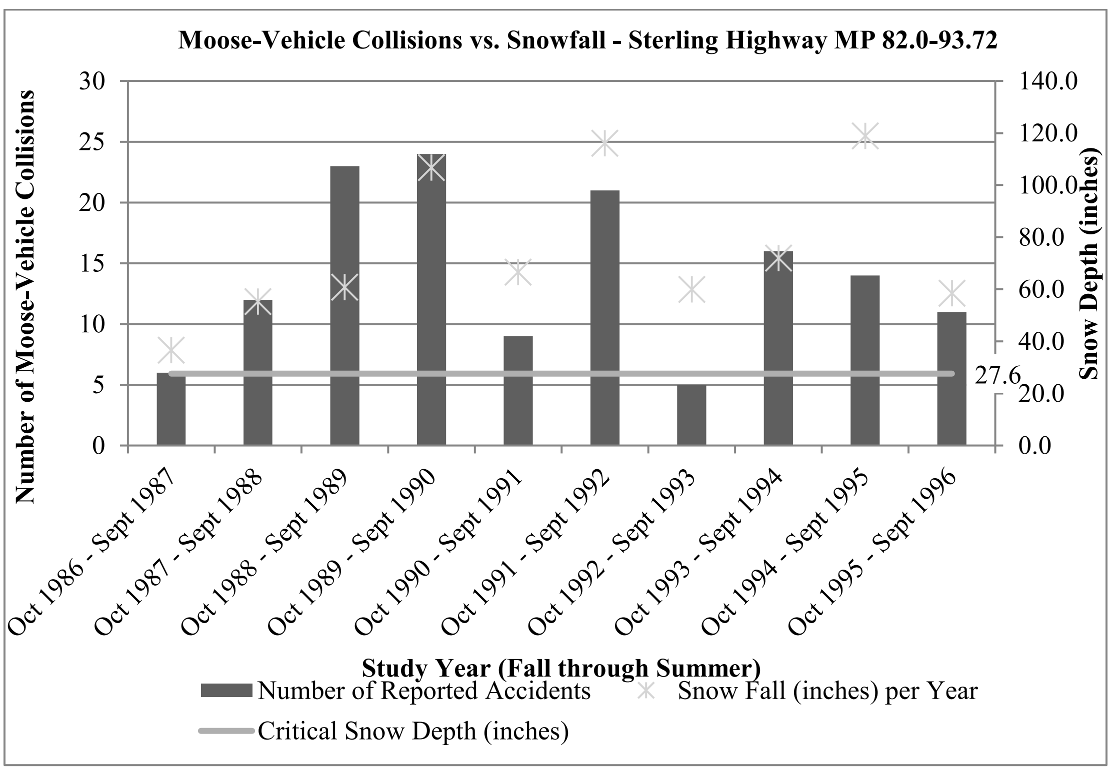


Figure 9 – Moose-Vehicle Collisions vs. Snowfall

Glenn Highway MP 12.082–16.5

This section provides an overview of the full data collection and characteristics investigation conducted for the Glenn Highway MP 12.082–16.5 project. Detailed information on data collection and characteristics for all projects studied is available upon request.

The Glenn Highway MP 12.082–16.5 project is located in GMU 14C. Moose population information for GMU 14C was gathered from ADF&G Moose Management Reports, and additional information was provided by ADF&G. Moose population trends from GMU 14A provided by ADF&G were used to estimate moose population for years when population surveys were not conducted using linear interpolation, as shown in Figure 10.

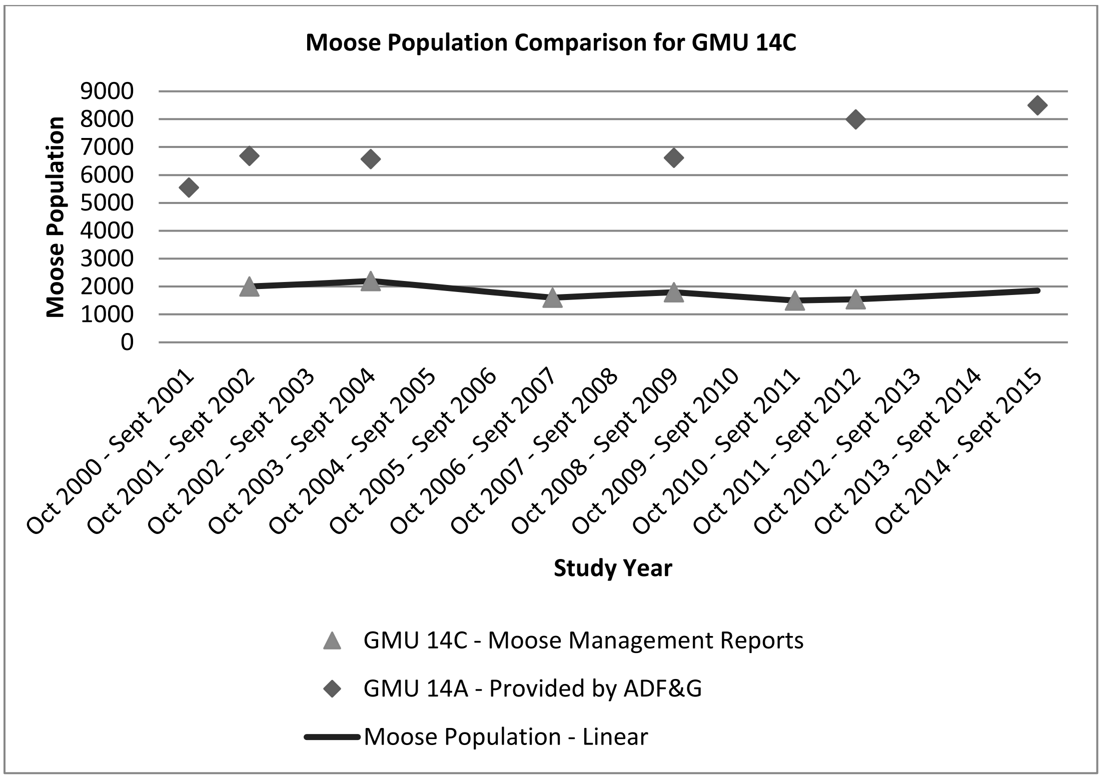


Figure 10 – Moose Population Comparison for GMU 14C

Weather information was gathered from weather stations ANCHORAGE TED STEVENS INTERNATIONAL AIRPORT, AK US COOP: 500280 and PALMER JOB CORPS, AK US COOP: 506870. The weather station PALMER JOB CORPS, AK US COOP: 506870, which is located closer to the project corridor, did not have complete precipitation data for the entire study period, so a comparison of data from both weather stations was made. There were only 3 years of complete precipitation data for PALMER JOB CORPS, AK US COOP: 506870 during the study period: October 2006–September 2007, October 2008–September 2009, and October 2009–September 2010. For this reason, data from weather station ANCHORAGE TED STEVENS INTERNATIONAL AIRPORT, AK US COOP: 500280 were used to estimate full precipitation for the project corridor.

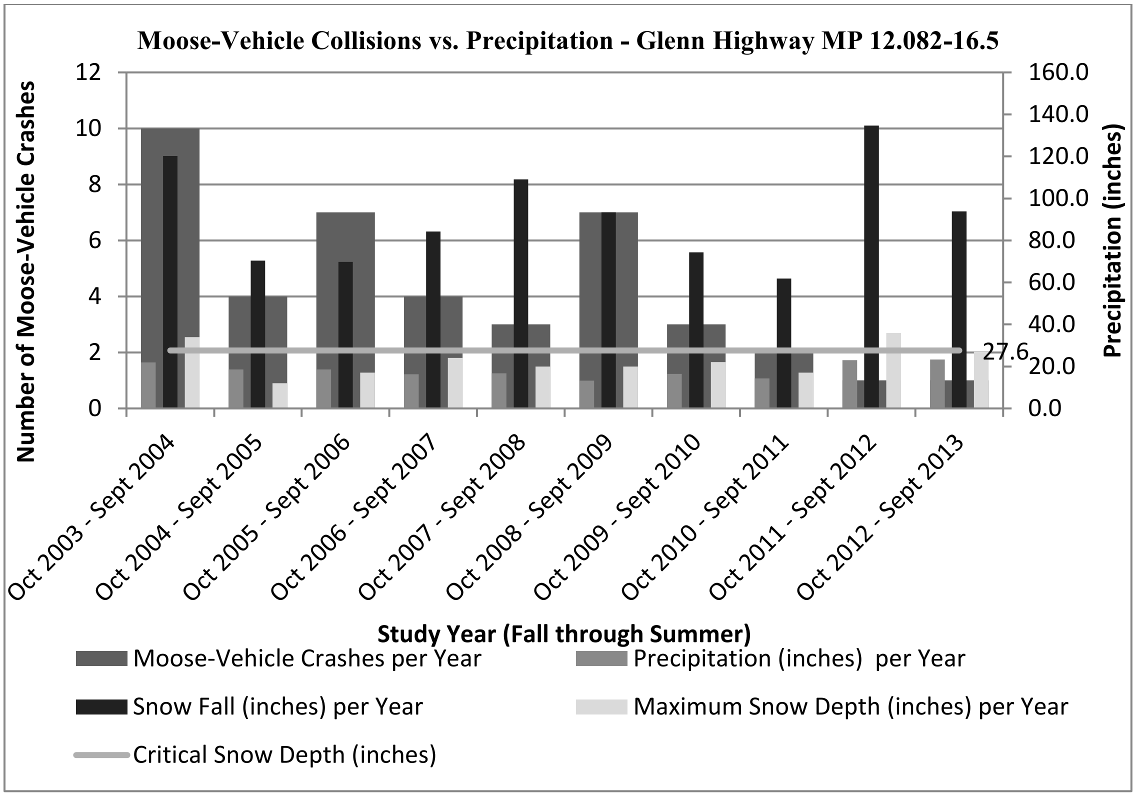


Figure 11 – Moose-Vehicle Collisions vs. Precipitation

The linear moose population estimate and the precipitation data were charted to compare data trends (see Figure 11–13). Figure 11 shows that the number of reported MVCs does not appear to have any sort of pattern related to the recorded precipitation information. The study years with the highest snowfall and maximum snow depth are paired with years of high and low reported MVCs, as depicted in Figure 13. A peak in MVCs occurred the first year after construction completion, although there appears to be a trend of reduced MVCs after construction, with the lowest dip in MVCs occurring 4 and 5 years post-project completion.

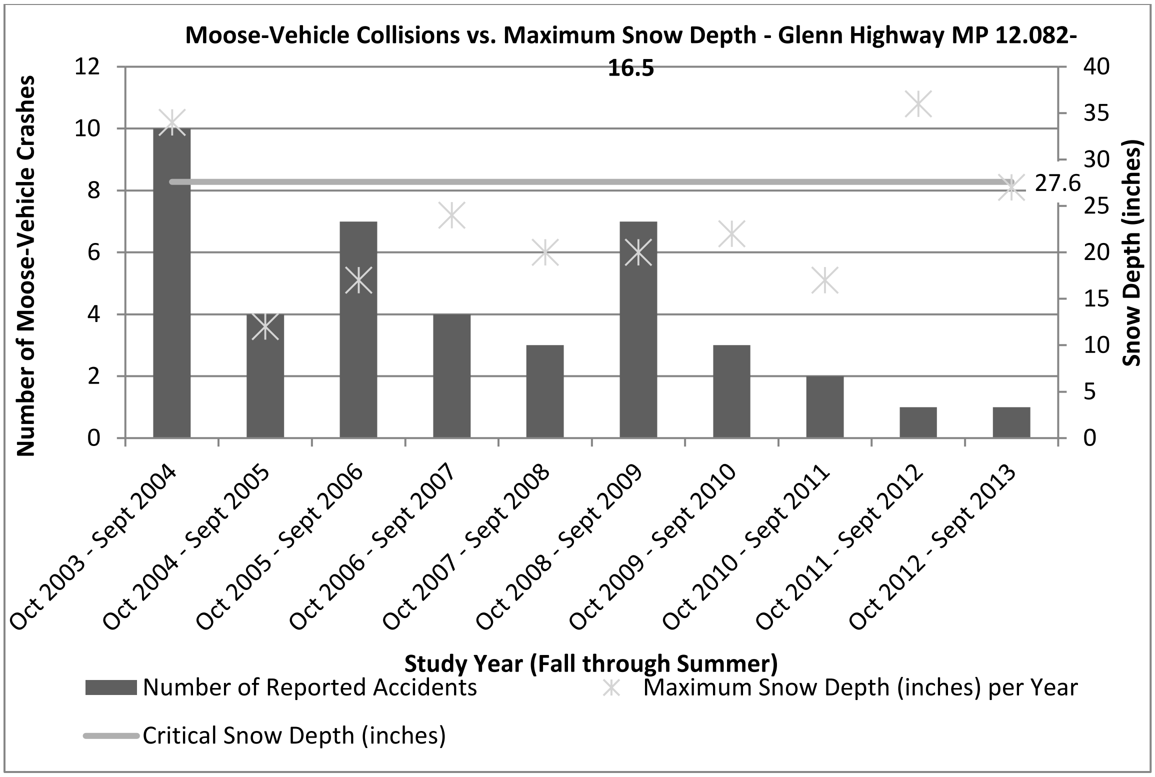


Figure 12 – Moose-Vehicle Collisions vs. Maximum Snow Depth

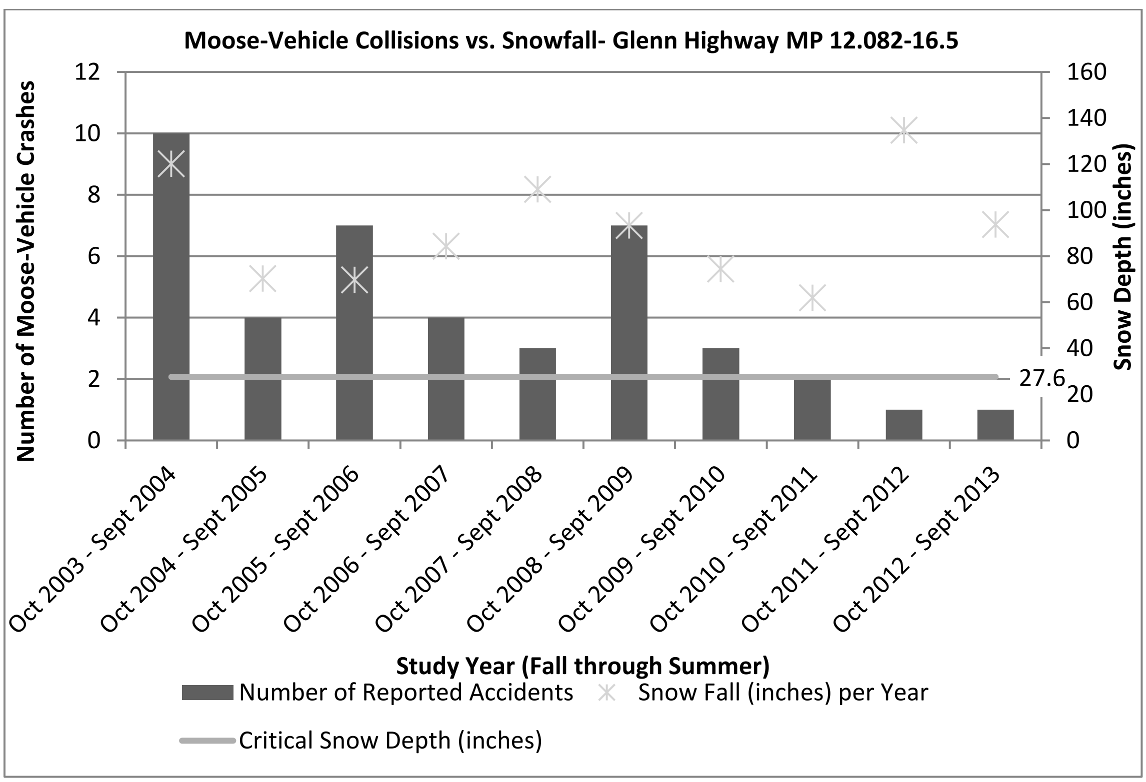


Figure 13 – Moose-Vehicle Collisions vs. Snowfall

Additional Project Corridors

As with the Sterling Highway MP 82.0–93.72 project, data collection and characteristics investigation were conducted for eight additional project corridors. Moose population information was gathered from ADF&G Moose Management Reports and information provided by ADF&G. Linear population interpolations were conducted to estimate moose population for years when moose were not surveyed, and weather information was gathered from the nearest available weather station with complete precipitation data (NOAA, 2016). The linear moose population estimate and the precipitation data were charted to compare data trends. Additional project corridor data collection and characteristic information is available upon request.

CHAPTER 2 – FINDINGS

Moose-Vehicle Collision Analysis Summary

Based on the analysis provided in Appendix B, the results of the regression analyses are summarized in Table B5. Four project results were inconclusive; thus, a relationship between the number of reported MVCs and the independent variables was not determined. The results from the other projects show between 22.0% and 85.9% of the variation in crashes being explained by the independent variables, with differing results on which variables contributed to the number of MVCs. There was also variation among the projects in whether a variable contributed to an increase or decrease in the number of MVCs (i.e., moose population contributed to a decrease in MVCs for Parks Highway MP 37–39 and an increase in MVCs for Kalifornsky Beach Road MP 16.4–22.4). These results show that the variables do not capture all the contributing factors related to MVCs.

For the combined set, regression analysis resulted in only 12.0% of the variation in crashes being explained by the independent variables. This result also shows that more contributing factors affect MVCs than were included in this study.

General Recommendations

Continued data collection is recommended for corridors where mitigation methods are being implemented. Additionally, systematic data collection for analyzing MVCs should be pursued: crash data, moose population data, and current project information. This effort could contribute to higher reliability of data and better results. Ensuring that moose population surveys are conducted every year could eliminate the unreliability of linear interpolation between population study years.

Additional studies, including mitigation methods not covered in this study (e.g., overpasses, underpasses, and fencing) are recommended.

Table 3 – Regression Analysis Summary

Corridor improvement	Project	Percentage of the variation in crashes being explained by the independent variables	Variables included	Contribution to the number of MVCs
Clearing and Grubbing	Sterling Highway MP 82.0–93.72	40.9%	• Maximum Snow Depth, x_5	Increase
	Kalifornsky Beach Road MP 16.4–22.4	26.2% (No Correlation)	• Moose Population, x_2	Increase
	Parks Highway MP 37–39	16.7% (No Correlation)	• Moose Population, x_2 • Snowfall, x_4,	Decrease Increase
	Knik-Goose Bay Road MP 0.0–19.56	15.0% (No Correlation)	• Maximum Snow Depth, x_5	Increase
Clearing and Grubbing and Continuous Lighting	Glenn Highway MP 4–11	22.0%	• Clearing and Grubbing, x_1 or Continuous Lighting, x_2	Decrease
	Glenn Highway MP 30.7–33.5	85.9%	• Clearing and Grubbing, x_1 or Continuous Lighting, x_2 • Precipitation, x_4 • Maximum Snow Depth, x_6	Decrease Increase Decrease
	Parks Highway MP 35–37	79.5%	• Moose Population, x_3, • Snowfall, x_5, • Maximum Snow Depth, x_6	Increase Increase Decrease
Continuous Lighting	Glenn Highway MP 3.24–11.46	52.3%	• Continuous Lighting, x_1 • Snowfall, x_4	Increase Decrease
	Glenn Highway MP 12.082–16.5	65.2%	• Moose Population, x_2	Increase
Clearing	Parks Highway MP 72–83	35.8% (No Correlation)	• Precipitation, x_3 • Maximum Snow Depth, x_5	Decrease Increase
Combined	All Project Corridors	12.0%	• Continuous Lighting, x_2 • Moose Population, x_4 •	Decrease Decrease

CHAPTER 3 – CONCLUSIONS AND SUGGESTED RESEARCH

Conclusions

In previous studies, MVCs were found to be a product of several environmental factors: landscape, road and traffic characteristics, moose migration and behavior, moose density, vehicle speed, traffic volume, visibility in relation to lighting, and the amount of and proximity to preferred habitat. The factors considered in this study included clearing and grubbing and/or lighting (visibility, landscape, and moose grazing components), moose population (moose density), and weather (affects road and traffic characteristics). The results suggest that several factors not considered are likely needed to achieve the required significance in data to accurately predict the number of MVCs, given construction improvements and the environmental factors present in a corridor. Further studies involving vehicle speed and traffic volume are recommended.

Reported effective mitigation measures identified in previous studies are fencing, wildlife passages, reduced driving speeds at night, moose population control, and roadside illumination. This study included illumination, although the results were inconclusive. Of the effective mitigation measures identified, fencing is a more common method used in Alaska. Therefore, it is recommended that corridors with fencing improvements also be analyzed to determine the significance of fencing in reducing the number of MVCs.

Past DOT&PF studies on MVCs have shown significant drops in MVCs. The Glenn Highway – Muldoon Road to Artillery Road project showed a significant drop in the number of moose-vehicle collisions after the installation of continuous illumination. The Glenn Highway project at the Hayflats, Matanuska River Bridge to the Parks Highway Junction, resulted in a 50% drop in the five-year average of moose-vehicle collisions after the installation of continuous lighting.

This study showed that there is a consistent drop in the number of moose-vehicle collisions following clearing and grubbing, with the exception of one corridor. Similar to the clearing and grubbing projects, the clearing and grubbing and continuous lighting projects showed a consistent trend of a drop in the number of moose-vehicle collisions following project completion. The projects with clearing and grubbing as a component had varying trends in MVCs post construction, which may indicate that DOT&PF Maintenance and Operations performed clearing of re-vegetated areas or older growth is less of an attractant for moose. Tracking Maintenance and Operations activities and regrowth post construction could continue to improve data for future re-evaluation. The projects with only continuous lighting as a corridor improvement varied, one indicated that the improvement increased the number of MVCs and the other showed a drop in MVCs. This increase could be attributed to higher driving speeds on the newly lighted roadway, and increase in moose population, or other factors not included in this study.

Based on statistical analysis and project specific results, Crash Modification Factors (CMFs) were developed ranging from 0.34 to 0.78 depending on the type of countermeasure and project location. Table 4 summarizes each CMF with each corridor CMF grouped by mitigation measure. The five-year average comparison is also included for each corridor. In general, a combination of continuous lighting and Clearing and Grubbing showed lower CMF's or resulted in lower MVC.

Crash reduction factors (CRF) were also developed using the average number of MVCs prior to and post construction. Table 5 summarizes the CRF for each corridor and are grouped by mitigation measure. The resulting combined CRF is very similar to the developed combined CMFs for each mitigation measure type. The CMF for each corridor may vary from the CRF in whether the mitigation measure reflects an increase or a decrease in MVCs because the CMF is determined using the developed correlation equation which determines a predicted MVC whereas the CRF is determined based on the actual MVCs observed.

The CMFs and CRFs shown in Table 4 and Table 5, respectively, are for reference only. The use of these values is not recommended due to the limitations of this study. Further information is needed in the development of more reliable values and additional study is recommended.

Table 4 - Crash Modification Factor Summary by Mitigation Measure

	Clearing and Grubbing	Continuous Lighting	Clearing	Five Year Average Comparison	Crash Modification Factor	Combined Crash Modification Factor
Sterling Highway MP 82.0-93.72	■			9.5% drop	1.07	0.78
Kalifornsky Beach Rd. MP 16.4–22.4	■			41.7% drop	0.54	
Parks Highway MP 37–39	■			36.4% drop	0.81	
Knik-Goose Bay Rd. MP 0.0-19.56	■			19.0% rise	0.98	
Glenn Highway MP 4–11	■	■		55.8% drop	0.44	0.48
Glenn Highway MP 30.7–33.5	■	■		47.8% drop	0.52	
Parks Highway MP 35–37	■	■		100% rise	3.01	
Glenn Highway MP 3.24–11.46		■		43.3% rise	1.43	0.53
Glenn Highway MP 12.082–16.5		■		50.0% drop	0.53	
Parks Highway MP 72–83			■	61.5% drop	0.34	0.34

Variable included in the regression analysis (Clearing and Grubbing project)
Variable included in the regression analysis (Continuous Lighting project)
Variable included in the regression analysis (Clearing project)
#.## Crash Modification Factor outlier not included in the combined CMF calculation

Table 5 - Crash Reduction Factor Summary by Mitigation Measure

	Clearing and Grubbing	Continuous Lighting	Clearing	Crash Reduction Factor	Combined Crash Modification Factor
Sterling Highway MP 82.0-93.72				0.91	0.83
Kalifornsky Beach Rd. MP 16.4–22.4				0.58	
Parks Highway MP 37–39				0.64	
Knik-Goose Bay Road MP 0.0-19.56				1.19	
Glenn Highway MP 4–11				0.44	0.48
Glenn Highway MP 30.7–33.5				0.52	
Parks Highway MP 35–37				2.00	
Glenn Highway MP 3.24–11.46				1.43	0.50
Glenn Highway MP 12.082–16.5				0.50	
Parks Highway MP 72–83				0.38	0.38

	Variable included in the regression analysis (Clearing & Grubbing project)
	Variable included in the regression analysis (Continuous Lighting project)
	Variable included in the regression analysis (Clearing project)
#.##	Crash Reduction Factor outlier not included in the combined CRF calculation

Although this study resulted in low statistical significance, there is evidence of positive results for the mitigation measures, continuous lighting and clearing and grubbing. Continued monitoring of post construction conditions, Maintenance and Operations events, and data collection for continued improvements will increase the accuracy of the data for future re-analysis and the development of crash modification factors.

Suggested Research

Future research should include more reliable data, mitigation measures not previously studied such as fencing, and additional variables such as traffic volume.

CHAPTER 4 – REFERENCES (including appendixes)

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APPENDIX A - Literature Review

Moose Behavior

Testa et al. (2000) studied the daily movements of parturient female moose from 1994 to 1997 in southcentral Alaska and found that movements increased significantly in the 2 days prior to parturition and decreased for at least 9 days post-parturition. They also found that levels of pre-parturition movement were not resumed until the calf reached about 26 days old. The study revealed that the daily movements of females that eventually lost a calf exceeded the movements of females with surviving calves by 12%. Distances between birth sites in successive years were greater among females that lost their calves the first year, regardless of age at which the calf died, which suggests that female moose return to successful birth site areas.

In a study reported in the article "Winter-Range Philopatry of Seasonally Migratory Moose" (Sweanor and Sandegren, 1989), a seasonally migratory population of moose was monitored in central Sweden to study the winter-range distribution of individual nonbreeding moose in areas with differing population density, snow conditions, and forest damage. Sweanor and Sandegren found the following:

- The average winter range is 11.5 km^2 (4.44 mi^2), with no difference between age or gender.
- Winter home-range size is affected by long durations of snow > 70 cm (27.6 in.) deep, but not by snow depths of 25 or 40 cm (9.8 or 15.7 in.). Moose begin fall migration on different dates in different years, and duration varies from year to year, although size or range does not differ.
- Consecutive winter ranges have mean midpoint separation distances less than the approximate diameter of the average winter home range, but there are no differences between nonconsecutive winter ranges, indicating that moose do not disperse gradually.

In a case study of fine-scale movements of moose, Leblond et al. (2010) found that moose movement differs between sexes and within daily and annual periods. Their study, as reported in the article "What Drives Fine-Scale Movements of Large Herbivores? A Case Study Using Moose," revealed that moose select steeper uphill slopes and avoid downhill slopes during late winter, and select gentle slopes and intermediate elevation variation from spring to early winter.

In the article "Linking Moose Habitat Selection to Limiting Factors," Dussault et al. (2005a) discuss their investigation of moose habitat selection, where the main factors limiting moose numbers were likely predation risk, food availability, and snow. They used GPS telemetry to track moose in the Jacques Cartier Park and part of the adjacent Laurentides Wildlife Reserve in Quebec, Canada. The researchers found that, at the landscape scale, moose segregate themselves from predators by avoiding areas that receive the lowest snowfall, but moose also establish home ranges in areas of shelter from snow, bordered by habitat providing abundant food. At the home-range scale, moose display a preference for food abundance, but not protection from predation or snow. The researchers also found that female moose with calves had a higher preference for areas providing protection from predation, whereas solitary moose prefer areas providing moderate food abundance, moderate protection from predation, and substantial shelter from deep snow).

In their article “Space Use of Moose in Relation to Food Availability,” Dussault et al. (2005b) assessed the influence of temporal and spatial changes in food availability on home-range size and movements of moose. They found that home-range size is 42.1 km^2 (16.3 mi^2) in summer and 6.4 km^2 (2.5 mi^2) in winter, regardless of sex. Though home-range size is larger in summer than in winter, the seasonal difference is greater for females than males. Movement rates of moose are twice as high in summer than in winter, and as with home-range size, the seasonal difference is more pronounced for females than for males. The researchers found the following in relation to food availability:

- In summer, moose movement rates are lower in deciduous and fir than in spruce and other habitat types.
- In winter, movement rates are lowest in fir than in spruce and other habitat types.

In a study of seasonal activity patterns of moose, Bevins et al. (1990) obtained monthly estimates of 24-hour activity patterns of moose on the Kenai Peninsula, Alaska, during winter and summer. They found the following:

- Mean time spent active in a 24-hour period during a winter month ranges from 349 to 587 minutes and during a summer month ranges from 427–838 minutes, which shows that moose are significantly more active in summer than in winter.
- Shorter resting periods during summer months compared with winter months, resulting in increased activity from winter to summer.
- No difference in active period length between summer and winter (80 and 81 minutes, respectively).

Del Frate and Spraker (1991) used collected information from moose-vehicle collisions (MVCs) on the Kenai Peninsula, Alaska, to assess roadkills and initiate a public awareness program that potentially would reduce moose roadkills. Their analysis revealed that improved winter road maintenance and the severe winter of 1989–90 led to a significant increase in roadkills.

In the article “Activity Patterns of Predator and Prey: A Simultaneous Study of GPS-Collared Wolves and Moose,” Eriksen et al. (2011) summarized their study of the simultaneous activity of a breeding wolf pair and five adult moose cows from April to November 2004 in southeastern Norway. They found that moose activity generally peaks at dusk, whereas wolf activity peaks at dawn. Travel speed varies significantly between species and months. The distance that wolves travel per time unit is highest in September and lowest in June; for moose, the highest is in May and August. The results of the study did not support the hypothesis that moose have adopted an activity pattern asynchronous with that of wolves in order to avoid them.

According to the summary report by the Highway Safety Information System (1995) "Investigation of Crashes with Animals," the greatest number of animal collisions occurs during the early morning hours (4:00 to 6:00 a.m.) and during the evening hours of 6:00 to 11:00 p.m. Based on the five Highway Safety Information System statistics used in the study, 66% of all reported animal collisions occurs on two-lane rural roads, and animal crashes are more frequent at night, with occurrences ranging from 68% to 85%.

In the article, "Activity Patterns in Moose and Roe Deer in a North Boreal Forest," Cederlund (1989) reported that roe deer differ from moose in having activity bouts more evenly distributed over the day. In this study, conducted in a north boreal forest in central Sweden, the following was determined:

- Generally, both species are most active during sunrise and sunset, showing an evident biphasic pattern in late autumn.
- Average length of active bouts does not differ significantly between the species, but changes with season.
- Low activity level in winter and early spring indicates conservation of energy, when animals make use of patches with relatively dense but low-quality forage.
- In summer, emphasis shifts toward high-quality plants. More browsing and activity increase.

Establishing Methodologies

In the article "Utility of Expert-Based Knowledge for Predicting Wildlife-Vehicle Collisions" (Hurley et al., 2009), an Analytical Hierarchy Process (AHP) was used to better understand why and where wildlife-vehicle collisions occur. Using the AHP, expert-based models were developed to test the hypothesis that collisions are either a product of habitat- or driver-related factors. Spatially overlaid expert-based weightings for all criteria were used to provide a quantitative prediction of MVC risk across the study area, and it was found that, overall, habitat-based models are more proficient than driver-based models in predicting MVCs. The data from this study suggest that MVCs and highway attractants related to habitat are strongly related, indicating that MVCs can be reduced through vegetation management or alternative routing.

Hurley et al. (2007) used six subsets of logistic regression models and Akaike's Information Criteria (AIC) to determine the best matched model within each subset. In their study published in the article "A Spatial Analysis of Moose-Vehicle Collisions in Mount Revelstoke and Glacier National Parks," five of the six subsets modeled local-scale/field-based hypotheses, while the sixth examined landscape-scale hypotheses with the use of a Geographic Information System (GIS). The six subsets included driver visibility, moose evidence, highway design, roadside vegetation, moose habitat, and landscape/GIS. The driver visibility model showed a significant relationship between speed and MVCs. In the GIS model, the landscape slope variable was observed to have a negative influence on MVC probability, indicating that moose prefer to cross on a relatively flat slope. Distance to wetland showed high correlation with MVCs, and distance to water showed low correlation with MVCs. Low prediction ability was found between roadside vegetation and MVCs, which can be attributed to the uniform corridor throughout the study area. The landscape-scale/GIS model approach shows promise in assessing contributing variables within the process of determining where MVCs occur.

An adapted kernel density estimator and Ripley's *K*-function was used to test the hypothesis that MVC clustering occurs at multiple scales in space, in time, and in space-time combined as reported in "Multi-scale Spatiotemporal Analyses of Moose-Vehicle Collisions: A Case Study in Northern Vermont" (Mountrakis and Gunson, 2009). This exploratory and multi-scale statistical analysis proved effective in displaying varying and similar spatiotemporal patterns on roads. The kernel estimation generates comparable distribution maps of density. Ripley's *K*-function or reduced second moment function measures spatial dependence or clustering of events at multiple scales. The researchers noted that the analyses were based on recorded incidents and did not include unreported cases or when animals die away from the road.

Simple logistic regression analyses were used in predicting locations of MVCs in Sweden (Seiler, 2005). The data in Seiler's study, "Predicting Locations of Moose Vehicle Collisions in Sweden," included the spatial distribution of moose-vehicle collisions reported to the police in two regions with similar habitat conditions, moose populations, and road networks. Additional data for the two study areas were collected; they included landscape, road and traffic, MVCs, and moose abundance and harvest. Multiple logistic regression analyses were used to identify 25 different road traffic and landscape parameters that are assumed to influence MVCs. Unpaired *t*-tests and univariate logistic regression models were used to identify variables that significantly differed between accident sites and control sites. The variables were then grouped into three priori models: road-traffic model, landscape model, and a combined model. The results of this study showed that simple logistic regression analyses give strong support for the combined model.

Mitigation Measures

In an article "Difference in Spatiotemporal Patterns of Wildlife Road-Crossings and Wildlife-Vehicle Collisions," Neumann et al. (2012) reported that moose show a bimodal activity pattern with a strong seasonal pattern. Moose are most active in the morning and afternoon for about 3 hours. In addition to determining daily peak movements of moose, the study found that moose road crossings peak in spring between the end of April and end of June, and peak in winter between mid-November and the beginning of January. Crossings were found to dip in spring between the beginning of March and beginning of April, and dip in summer between the end of June and mid-August. Additional results showed higher probability of collision at higher speed areas and areas that have been human-modified. The findings of this study suggest that, although risk of collision increases with higher moose activity, poor light and road surface conditions may be the greatest factors in increasing the risk of collision.

In a study by Garrett and Conway (1999) of MVCs in Anchorage, Alaska, between 1991 and 1995, it was found that collisions are 2.6 times more likely to occur in the dark than during daytime, with 61% of the collisions occurring in the dark on unlit roadways. The researchers suggested that streetlights be placed in known areas of high moose activity. Garrett and Conway found that weather was a factor in many MVCs, that roads were slick in 54% of all

MVCs, and that in 18% of the collisions, visibility was reduced due to weather. However, the study showed that injury was twice as likely to occur on a dry road as on a slick road. During the years with the highest reported MVCs, 1994 and 1995, snow depths varied significantly, with snow depth higher than average in 1994 and lower than average in 1995. This suggests that snow depths may not be directly linked to the number of MVCs, but could adversely affect moose migration and moose populations in a given year or season.

Through their analysis reported in "Multi-scale Spatiotemporal Analyses of Moose-Vehicle Collisions: A Case Study in Northern Vermont," Mountrakis and Gunson (2009) verified that MVCs are clustered in space, time, and space-time. Their analysis results showed that MVCs recur at regular intervals and have a seasonal cyclic component, the majority of collisions occurring from May to October.

In "Spatial and Temporal Characteristics of Moose Highway Crossings During Winter in the Buffalo Fork Valley, Wyoming," Becker et al. (2011) tracked adult female moose in the Buffalo Fork Valley and collected hourly locations during the winter from 2005 to 2007. This information was mapped to estimate the number of highway crossing events within the study area. Becker et al. found that moose cross the highway more frequently during early to mid-evening and less frequently during midday; that moose crossings can be predicted by estimating winter habitat selection characteristics; and that moose crossings accumulate where preferred habitat and landscape features are present on both sides of the highway. The researchers' moose tracking showed a high probability of moose crossing underneath the highway at bridge locations. The results of this study suggest that preferred moose habitat and landscape features are strong indicators in predicting where moose crossings will occur, and that preferred habitat and landscape features have a stronger influence on crossing location than fences.

In their analysis of MVCs in western Maine, Danks and Porter (2010) showed that the proportion of cutover forest within 2.5 km (1.55 mi) of the road is positively correlated with probability of MVCs. They found that traffic amount and speed are the first and third, respectively, most important landscape characteristics related to MVCs. The study results showed that the effect of traffic volume is dependent on speed limit, indicating varying probabilities of MVC for different types of roads. For example, on a local road with a lower speed limit, greater traffic flow increases MVC probability. The opposite is shown for interstate and major arterials with higher speed limits, where MVC probability decreases at higher traffic volumes.

In their study, "Spatial and Temporal Distribution of Moose-Vehicle Collisions in Newfoundland," Joyce and Mahoney (2001) found that, spatially, MVCs are dependent on both moose density and traffic volume. Joyce and Mahoney found that there is a greater probability of MVCs in areas of high or low (but not moderate) moose densities and high traffic flow, and that 75% of all accidents occur between sunset and sunrise.

Effectiveness of Mitigation Measures

In a review of European, North American, and Japanese literature on ungulate traffic collisions, Bruinderink and Hazebroek (1996) found a lack of strong evidence for the number of kills per crossing being affected by the use of permanent warning signs, 90° light mirrors, scent, or acoustic fencing. In their article "Ungulate Traffic Collisons in Europe," the researchers recommend a combination of fencing and wildlife passages.

Nighttime detection distances on highways were tested by using a life-sized bull moose decoy. As reported by Rodgers and Robins (2006), overall, the mean detection distance was found to be 105 m (344 ft). The researchers' study found that headlamp setting, low beam or high beam, was a significant factor in detection distance. The mean detection with use of a low beam setting was found to be 74 m (243 ft); the mean detection with use of a high beam setting was found to be 137 m (449 ft). This study by Rodgers and Robins determined that drivers travelling at night in excess of 70 km/h (approximately 45 mph) are very likely to be overdriving the illumination capabilities of their headlamps for moose encounters. They determined the safe speed for low beam setting was 60 km/h (approximately 40 mph); the safe speed for high beam setting was 80–90 km/h (approximately 50–55 mph). The results of this study suggest that night speeds should be no higher than 70 km/h in areas where MVCs are a high risk. A possible mitigation measure would be reduced night-driving speeds in high MVC corridors along highways.

In their study, "Effectiveness of Highway Lighting in Reducing Deer-Vehicle Accidents," Reed and Woodard (1981) found that the crossings-per-accident ratios of deer are not significantly different with lighting off and with lighting on. The researchers determined that highway lighting did not affect location of deer crossings, in that deer continue crossing at preferred locations. Reed and Woodard found that winter severity, as indicated by snow and temperature, likely is causally related to numbers of deer and accidents in the study area.

Leblond et al. (2007), as reported in the article "Electric Fencing as a Measure to Reduce Moose-Vehicle Collisions," tested the effectiveness of electric fences in reducing MVCs. The results of their tests showed an 80% reduction in observed moose tracks along highways; only 30% of moose tracks observed were from moose that crossed an operational fence. The researchers found that moose mostly cross the highway at openings where roads intersect or at fence limits. In order for electric fencing to be effective, Leblond, et al. recommend that electric fences be continuous, circuit breakers be used to prevent power failures, breaks in fence line occur only where anti-ungulate structures are used, unpowered cables be used next to lakes, fences be equipped with a failure-detection system, and frequent physical checks be required. Although electric fences may be less expensive and have a lower visual impact than conventional metal fences, this type of mitigation promised to be extremely cumbersome.

Seiler (2005) used a MVC predictive model to show that the amount and proximity of forest habitat that provides cover and forage significantly affects the risk of MVC, with a 15% reduction in risk of collision with an increase of 100 m (328 ft) distance between forest cover and the road. The results of this study, "Predicting Locations of Moose-Vehicle Collisions in Sweden," showed that if vehicle speed and moose density are simultaneously increased, the effect of forest proximity is weaker. For sections of Alaska's highway system where traffic and speed limits are highest, clearing would be a less effective mitigation measure than on low-volume low-speed roads. Seiler's results showed a nonlinear relation between traffic volume and vehicle speed that peaked at intermediate speed limits and intermediate traffic volumes, suggesting that intensive traffic may repel wildlife from approaching roads and thereby reduce the likelihood of accidents. Seiler found that MVCs were most likely to occur on unfenced roads with intermediate traffic volumes and intermediate speed limits.

It is common for roadway lighting to be installed with the goal of nighttime crash reduction. The AASHTO Highway Safety Manual (2010) presents illumination as an effective mitigation measure at reducing crash rates. Recently, the Washington State Department of Transportation (WSDOT) evaluated continuous roadway lighting on mainline freeway segments in Washington State and the research team concluded that continuous illumination makes no measureable contribution to nighttime safety performance. Also, that the installation of continuous mainline lighting on freeways for safety performance is not warranted (van Schalkwyk, et al., 2016). The WSDOT research team specifically excluded daytime crashes from their study because the inclusion of daytime crashes into the evaluation of the safety performance of illumination is problematic since the lighting system is off during daylight hours. Given that roadway lighting targets crashes occurring during darkness, the research team decided to develop nighttime safety performance functions and only include nighttime crashes in the analysis.

The results of the WSDOT study contradict the belief that illumination is an effective mitigation measure at reducing crash rates as current guidance in the AASHTO Highway Safety Manual presents (2010). As previously discussed in the Moose Behavior section, several studies have shown that moose activity and animal related accidents peak at dawn and dusk; Eriksen et al. (2011) found that moose activity generally peaks at dusk, the Highway Safety Information System (1995) reported that the greatest number of animal collisions occurs during the early morning hours (4:00 to 6:00 a.m.) and during the evening hours of 6:00 to 11:00 p.m., and Cederlund (1989) reported that both roe deer and moose are most active during sunrise and sunset. As identified in previous studies, moose are more active during dawn and dusk, a crucial time for illumination to be present to increase the visibility of the moose crossing roadways. Although illumination may not be effective at reducing general vehicle crashes, continuous lighting is believed to be effective at mitigating moose vehicle related accidents.

No body of knowledge was found specifically on the relation between clearing, grubbing and/or roadway illumination and MVC. Glista et al. (2009) reported in their literature review that very few before-and-after studies have been done to evalute mitigation effectiveness.

DOT&PF Database

The DOT&PF has performed many studies in the past related to MVCs on corridors around the state. Figure A14 is a chart provided by DOT&PF showing the construction improvements performed by milepoint along the Glenn Highway corridor from milepoint 131 to 141. From milepoint 135 to about milepoint 138, continuous illumination was installed in 1987. The black marks shows the number of MVCs from 1982-1986 and the grey marks show the number of MVCs from 1988-1992. There was a significant drop in the number of MVCs after the installation of continuous illumination.

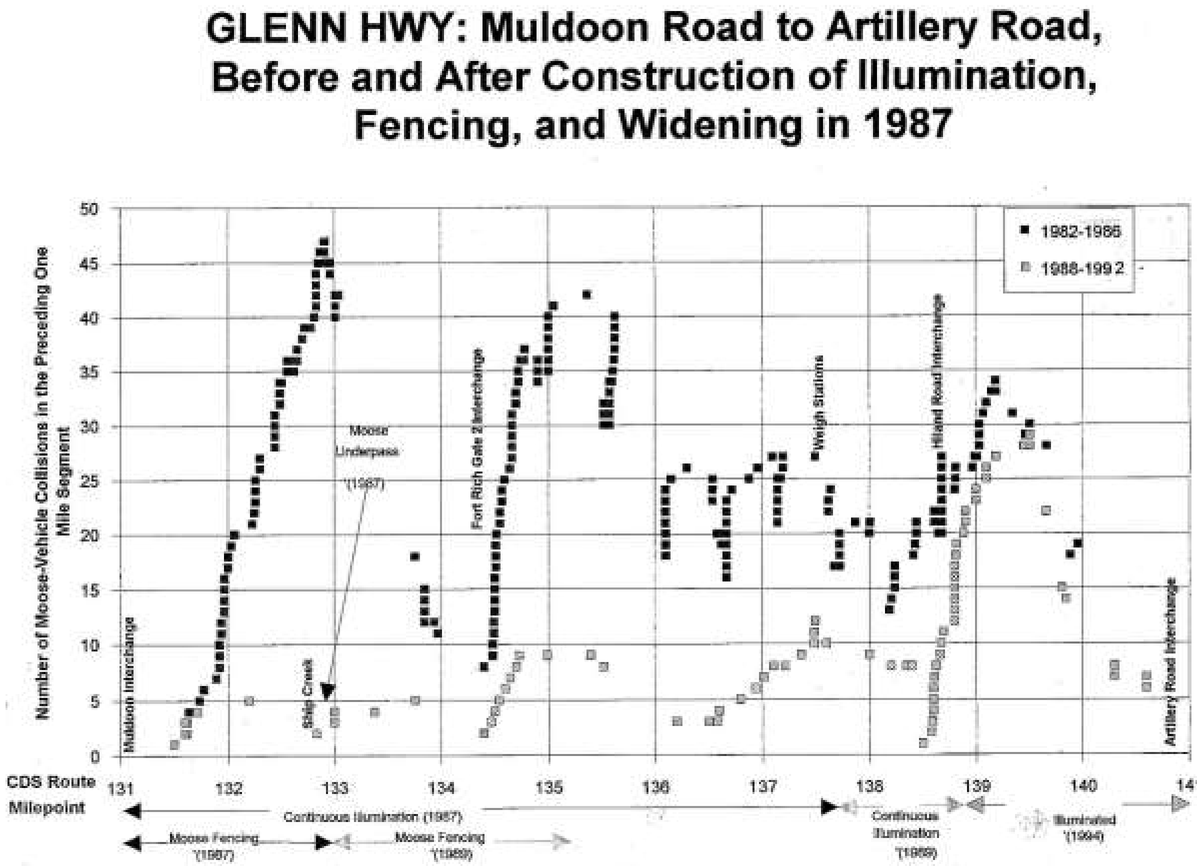

Figure provided by DOT&PF (DOT&PF, Moose-Vehicle Accidents on Alaska's Rural Highways, 1995)

Figure A14– Glenn Highway Moose-Vehicle Accidents Before and After Construction of Illumination, Fencing and Widening – Muldoon Road to Artillery Road

The DOT&PF also studied the Glenn Highway at the Hayflats, Matanuska River Bridge to the Parks Highway Junction. Continuous lighting was installed on this corridor in October of 2002. Figure A15 shows the results of the study. The five year average per year dropped by over 50% after the installation of continuous lighting.

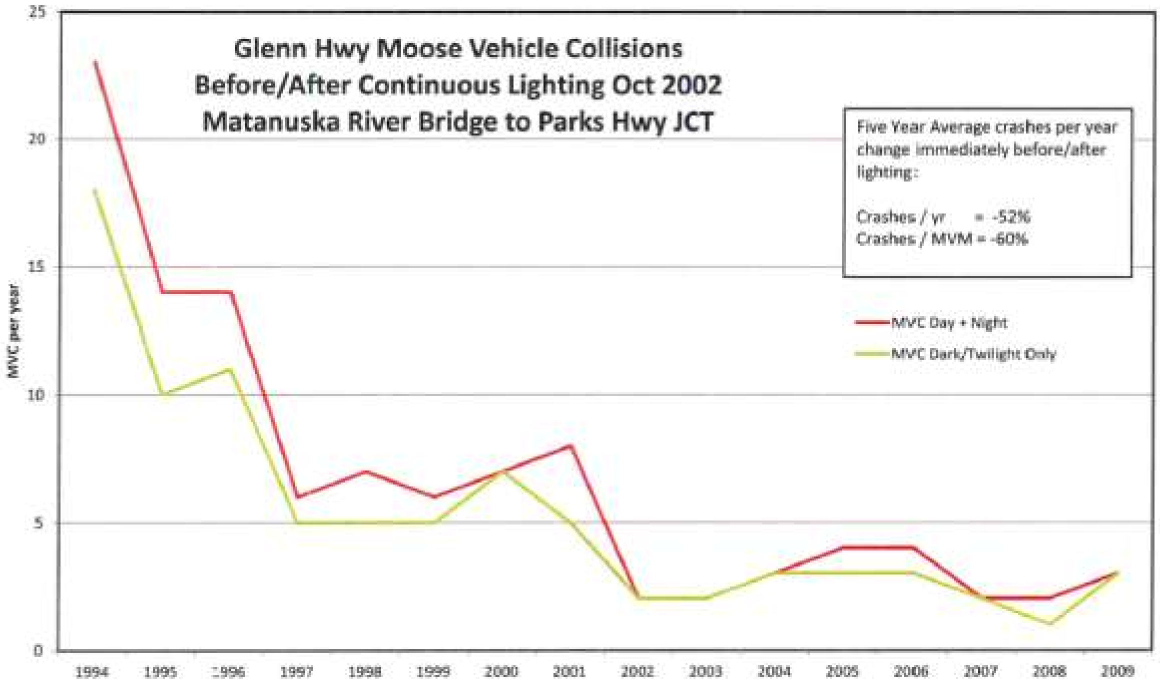

Figure provided by DOT&PF (DOT&PF, 2010)

Figure A15 - Glenn Highway Moose vehicle Collisions Before and After Construction of Continuous Lighting – Matanuska River Bridge to Parks Highway Junction (Hayflats)

Management Implications

As reported in "A Review of Mitigation Measures for Reducing Wildlife Mortality of Roadways," Glista et al. (2009) recommend that preconstruction planning, connectivity of habitat and permeability of road systems, financial considerations, and efficiency all be included in wildlife collison reduction. They reported that structural methods, although more expensive, are probably more effective at reducing collisions. The structural mitigation measures identified were crossing structures, that is, which overpasses and uderpasses would be applicable to moose. The nonstructural methods identified were repellents, ultrasound, road lighting, population control, and habitat modification.

Moose-vehicle collisions were found to be a product of various environmental factors including landscape, road and traffic characteristics, moose migration and behavior, moose density, vehicle speed, traffic volume, visibility in relation to lighting, and the amount of and proximity to preferred habitat. These factors are not exclusive and affect the significance of one another. Therefore, determining effective mitigation measures will need to include all elements present in a given corridor where MVCs are high. Less effective mitigation measures for reducing MVCs have been identified as permanent warning signs, 90° light mirrors, scent, or acoustic fencing. Reported effective mitigation measures include fencing, wildlife passages, reduced night-driving speeds, population control, and roadside illumination.

APPENDIX B - Data Analysis

Introduction

Based on data collected, each project corridor had a different number of variables due to the types of improvements performed during construction. To determine how each variable interacts with the others in influencing the number of MVCs, numerous analyses were performed for each project to capture each variable combination.

Sterling Highway Milepost (MP) 82.0–93.72

This section provides an overview of the full data analysis conducted for the Sterling Highway MP 82.0–93.72 project. Detailed information on data analysis for all projects in this study is available upon request.

The Sterling Highway MP 82.0 to 93.72 improvement project included clearing and grubbing. Additional factors analyzed were moose populations, precipitation, snowfall, and maximum snow depth. Therefore, five independent variables were analyzed to determine whether there is a significant relationship between the number of reported MVCs and the independent variables. With five independent variables, *n,* the number of combinations of independent variables to analyze can be determined using Equation 2, given in Section 3.1.

Thirty-one different analyses were conducted, and the results of those analyses are summarized in Table B1, to test the null hypotheses:

> H_0: The number of reported MVCs is independent of the dependent variables.

H_0 is accepted if significance F is greater than 0.05, and rejected if significance F is less than 0.05. If the null hypothesis is rejected, it can be assumed that there is a significant relationship between the number of reported MVCs and the independent variables. Table B2 shows the results with significance F less than 0.05. The analysis with the highest correlation can be determined by looking at the adjusted r-squared (used when there is more than one independent variable) or r-squared (there is only one independent variable) value. The higher the adjusted r-squared or r-squared, the better the correlation. Set 31 has the highest correlation, where 40.9% of the variation in crashes is explained by the independent variables. The resulting linear regression coefficients are provided in Table B3. Therefore, the relationship between the number of reported MVCs, y, and the independent variable: and maximum snow depth, x_5 (clearing and grubbing, x_1, moose population, x_2, precipitation, x_3, and snowfall, x_4, were not included in the set)—is as follows:

$$\boldsymbol{y} = 2.7306 + (-0.4290)\boldsymbol{x}_5$$

The remaining nine projects were analyzed in the same manner as Sterling Highway MP 82.0 to 93.72. Table B4 summarizes the number of analyses performed per project, whether the null hypothesis was rejected or accepted, and the resulting linear regression coefficients in the event of a rejected null hypothesis. Detailed information from Table B4 is available upon request.

Table B1 – Summary of Regression Analysis, Sterling Highway Milepost (MP) 82.0–93.72

			Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Regression Results		
Number of Variables	Analysis Set Number	Number of Reported Accidents	Clearing and Grubbing	Moose Population - Linear	Precipitation (inches)	Snowfall (inches)	Max Snow Depth (inches)	Significance *F*	Adjusted *r*-squared	*r*-squared
5	Set 1	■	■	■	■	■	■	0.5764	-0.0876	N/A
4	Set 2	■	■	■	■	■		0.3769	0.1245	N/A
4	Set 3	■	■	■	■		■	0.4538	0.0358	N/A
4	Set 4	■	■	■		■	■	0.3987	0.0989	N/A
4	Set 5	■	■		■	■	■	0.3723	0.1299	N/A
4	Set 6	■		■	■	■	■	0.4543	0.0352	N/A
3	Set 7	■	■	■	■			0.4571	-0.0021	N/A
3	Set 8	■	■	■		■		0.2172	0.2479	N/A
3	Set 9	■	■	■			■	0.2593	0.1963	N/A
3	Set 10	■	■		■	■		0.2002	0.2702	N/A
3	Set 11	■	■		■		■	0.2783	0.1745	N/A
3	Set 12	■	■			■	■	0.2296	0.2322	N/A
3	Set 13	■		■	■	■		0.2735	0.1800	N/A
3	Set 14	■		■	■		■	0.2662	0.1883	N/A
3	Set 15	■		■		■	■	0.2625	0.1925	N/A
3	Set 16	■			■	■	■	0.3350	0.1138	N/A
2	Set 17	■	■	■				0.5939	-0.1079	N/A
2	Set 18	■	■		■			0.5249	-0.0695	N/A
2	Set 19	■	■			■		0.0970	0.3398	N/A
2	Set 20	■	■				■	0.1294	0.2831	N/A
2	Set 21	■		■	■			0.2836	0.1031	N/A
2	Set 22	■		■		■		0.1284	0.2847	N/A
2	Set 23	■		■			■	0.1177	0.3023	N/A
2	Set 24	■			■	■		0.2038	0.1839	N/A
2	Set 25	■			■		■	0.1585	0.2403	N/A
2	Set 26	■				■	■	0.1586	0.2403	N/A
1	Set 27	■	■					0.7656	N/A	0.0118
1	Set 28	■		■				0.2988	N/A	0.1337
1	Set 29	■			■			0.2399	N/A	0.1677
1	Set 30	■				■		0.0664	N/A	0.3606
1	Set 31	■					■	0.0464	N/A	0.4091

■	Variable included in the regression analysis
#.###	Low statistical significance, significance *F* > 0.05

Table B2 – Regression Analyses with Statistical Significance, Sterling Highway Milepost (MP) 82.0–93.72

			Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Regression Results		
Number of Variables	Analysis Set Number	Number of Reported Accidents	Clearing and Grubbing	Moose Population - Linear	Precipitation (inches)	Snowfall (inches)	Max Snow Depth (inches)	Significance *F*	Adjusted *r*-squared	*r*-squared
1	Set 31	■					■	0.0464	N/A	0.4091
1	Set 30	■				■		0.0664	N/A	0.3606
2	Set 19	■	■			■		0.0970	0.3398	N/A
2	Set 23	■		■			■	0.1177	0.3023	N/A
2	Set 22	■		■		■		0.1284	0.2847	N/A
2	Set 20	■	■				■	0.1294	0.2831	N/A
2	Set 25	■			■		■	0.1585	0.2403	N/A
2	Set 26	■				■	■	0.1586	0.2403	N/A

■ Variable included in the regression analysis

#.### Low statistical significance, significance *F* > 0.05

Table B3 – Set 31 Linear Regression Coefficients, Sterling Highway Milepost (MP) 82.0–93.72

	Coefficients
Intercept	2.7306
Max Snow Depth (inches)	0.4290

Table B4 – Data Analysis Summary, Individual Analysis

Road Segment	Milepost (MP) Est	Number of Independent Variables	Number of Analyses Performed	Reject or Accept Null Hypothesis	Constant	Continuous Lighting	Clearing and Grubbing	Moose Population	Precipitation	Snowfall	Maximum Snow Depth
Sterling Highway	MP 82.0–93.72	5	31	Rejected	2.7306						0.4290
Kalifornsky Beach Road	MP 16.4–22.4	5	31	Accepted							
Glenn Highway	MP 4–11.	6	63	Rejected	30.8	-17.2	Or -17.2				
Glenn Highway	MP 3.24–11.46	5	31	Rejected	24.3006	5.9046				- 0.1753	
Glenn Highway	MP 30.7–33.5	6	63	Rejected	1.3096	-3.8894	Or -3.8894		0.4548		-0.1624
Glenn Highway	MP 12.082–16.5	5	31	Rejected	-14.8503			0.0109			
Parks Highway	MP 35–37	6	63	Rejected	-3.4721			0.0004		0.0457	-0.0768
Parks Highway	MP 37–39	5	31	Accepted							
Parks Highway	MP 72–83	5	31	Accepted							
Knik-Goose Bay Road	MP 0.0–19.56	5	31	Accepted							

Combined Analysis

The results from the individual analyses varied substantially. This could be due to small corridor segments (the shortest corridors were 2 miles long), as well as to limited data. According to the report “2009 Alaska Traffic Crashes” (DOT&PF, 2012), law enforcement agencies may not perform a formal crash investigation when no injuries are apparent, the crash does not involve collision with wildlife, and all vehicles can be driven away from the crash scene. If police decline to investigate, some drivers may not understand their obligation to report a collision, or may choose not to report the crash to the Alaska Division of Motor Vehicles (DOT&PF, 2012). Thus, data used in this study only capture reported crashes. It is very likely that MVCs are often not reported when the impact does not injure the moose or if the moose wanders away from the scene of the collision. To determine an overall trend, a combined analysis was run.

Table B5 the three most statistically significant data sets from each project. This comparison shows which variable in each data set had the most influence on the number of reported MVC accidents.

Looking at the projects that had a continuous lighting component, most had a negative coefficient, showing that this component leads to a reduction in reported MVCs. The Parks Highway MP 35–37 project had a continuous lighting component, although continuous lighting already existed in this corridor before the project. This resulted in a zero coefficient because no change was associated with replacing the lighting system.

For the projects that had a clearing and grubbing component, clearing and grubbing had a wide variety of coefficients for each data set, most of which were negative, showing that this component leads to a reduction in reported MVCs. It would be beneficial to analyze a combined set of all project data to determine the significance of clearing and grubbing.

Looking at the project that had only a clearing component, the clearing variable was only included in one of the top three most statistically significant data sets and had a large, positive coefficient. This could mean that clearing alone does not influence the number of reported MVCs or that it increases the number of reported MVCs. The data for this project, Parks Highway MP 72–83, were shown to have low statistical significance, possibly due to less data since these project data were available only for 2 years past the construction date.

The following gives all the variables from highest influence to lowest influence, based on inclusion in the data sets: continuous lighting (7/15 or 46.7%), moose population (12/30 or 30.0%), maximum snow depth (12/30 or 40.0%), clearing and grubbing (8/21 or 38.1%), clearing (1/3 or 33.3%), snowfall (10/30 or 33.3%), and precipitation (8/30 or 26.7%).

Table B5 – Linear Regression Coefficients Comparison

				Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Variable 6	Variable 7	Regression Results		
	Number of Variables	Analysis Set Number	Number of Reported Accidents	Clearing and Grubbing	Continuous Lighting	Clearing	Moose Population - Linear	Precipitation (inches)	Snow Fall (inches)	Max Snow Depth (inches)	Significance *F*	Adjusted *r*-squared	*r*-squared
Sterling Hwy MP 82.0-93.72	1	Set 31	2.7306							0.4290	0.0464	N/A	0.4091
	1	Set 30	3.2838						0.1438		0.0664	N/A	0.3606
	2	Set 19	3.2129	-4.9297					0.1776		0.0970	0.3398	N/A
Kalifornsky Beach Rd MP 16.4-22.4	1	Set 28	-21.6329				0.0313				0.1306	N/A	0.2618
	1	Set 27	9.6000	-4.0000							0.2242	N/A	0.1783
	2	Set 24	-26.6469				0.0332			0.1474	0.2278	0.1575	N/A
Glenn Hwy MP 4 - 11	2	Set 43	30.8	0	-17.2						0.0334	0.2202	N/A
	1	Set 58	30.8	-17.2							0.0434	N/A	0.4179
	1	Set 59	30.8		-17.2						0.0434	N/A	0.4179
Glenn Hwy MP 3.24 – 11.46	2	Set 19	24.3006		5.9046				-0.1753		0.0312	0.5226	N/A
	3	Set 10	17.9577		5.3296			0.6810	-0.2345		0.0446	0.5733	N/A
	2	Set 20	19.6524		5.2696					-0.3478	0.0598	0.4250	N/A
Glenn Hwy MP 30.7-33.5	3	Set 31	1.3096	-3.8894				0.4548		-0.1624	0.0018	0.8585	N/A
	3	Set 37	1.3096		-3.8894			0.4548		-0.1624	0.0018	0.8585	N/A
	4	Set 12	1.3096	0.0000	-3.8894			0.4548		-0.1624	0.0031	0.6919	N/A
Glenn Hwy MP 12.082-16.5	1	Set 28	-14.8503				0.0109				0.0047	N/A	0.6524
	2	Set 21	-11.8687				0.0118	-0.2452			0.0095	0.6599	N/A
	3	Set 14	-12.4725				0.0125	-0.4699		0.1501	0.0126	0.7245	N/A
Parks Hwy MP 35-37	3	Set 41	-3.4721				0.0004		0.0457	-0.0768	0.0053	0.7949	N/A
	4	Set 16	-5.7369	-0.6753			0.0009		0.0503	-0.0921	0.0066	0.8496	N/A
	2	Set 57	-1.1198						0.0438	-0.0652	0.0074	0.6834	N/A
Parks Hwy MP 37-39	2	Set 22	9.0601				-0.0015		0.0281		0.2191	0.1668	N/A
	1	Set 28	9.4385				-0.0012				0.2548	N/A	0.1583
	1	Set 27	2.2	-0.8							0.4236	N/A	0.1187
Parks Hwy MP 72-83	2	Set 25	12.8091					-1.3763		0.6640	0.1833	0.3577	N/A
	1	Set 28	14.8405				-0.0058				0.2067	N/A	0.2961
	4	Set 2	108.7656			41.7785	-0.0328	-2.3136	-0.1663		0.2494	0.5991	N/A
Knik-Goose Bay Rd MP 0.0-19.56	1	Set 31	6.1680							0.1417	0.2692	N/A	0.1498
	1	Set 28	-12.3412				0.0033				0.2787	N/A	0.1444
	1	Set 30	5.1231						0.0508		0.2975	N/A	0.1344
Linear Regression Coefficients Comparison Legend for Table B5				38.1%	46.7%	33.3%	40.0%	26.7%	33.3%	40.0%			

Legend:
- Variable included in the regression analysis (Clearing and Grubbing project)
- Variable included in the regression analysis (Clearing and Grubbing and/or Continuous Lighting project)
- Variable included in the regression analysis (Clearing project)
- Variable not included in the regression analysis
- #.### Low statistical significance, significance *F* > 0.05

All project corridors with a clearing and grubbing, clearing, and continuous lighting component were included in a combined data set. Additional factors analyzed were moose populations, precipitation, snowfall, and maximum snow depth. Therefore, seven independent variables were analyzed to determine whether there is a significant relationship between the number of reported MVCs and the independent variables. With seven independent variables, *n,* the number of combinations of independent variables to analyze can be determined using Equation 2 given in Section 3.1.

In total, 127 different analyses are possible based on the number of variable combinations. From the information in Table B5 and the results shown in Table B6 through B12, the data set can be adjusted by looking at the *p*-values for each variable. In Table B6, Clearing and Grubbing has the highest *p*-value of 0.5563. This is the *p*-value of the hypothesis test H_0: $\beta_1 = 0$. To reject it is to conclude that there is a significant relationship between x and y. A *p*-value over 0.05 shows low statistical significance and can, therefore, be removed from the data set. The variable with the highest *p*-value was removed, and the set was re-analyzed until all remaining variables had a resulting *p*-value less than 0.05.

The results of the analyses are shown in Table B7 through Table B12. To test the null hypotheses:

H_0: The number of reported MVCs is independent of the dependent variables.

H_0 is accepted if significance F is greater than 0.05, and rejected if significance F is less than 0.05. If the null hypothesis is rejected, it can be assumed that there is a significant relationship between the number of reported MVCs and the independent variables. Table B12 shows the results of the final analysis where each variable *p*-value was less than 0.05. This data set resulted in a significance F of 0.0009. Since multiple variables were included in the analysis, the relationship can be determined by looking at the adjusted *r*-squared (used when there is more than one independent variable) value. The higher the adjusted *r*-squared, the better the correlation. For the combined set, 12.0% of the variation in crashes is explained by the independent variables. The resulting linear regression coefficients are provided in Table B12. Therefore, the relationship between the number of reported MVCs, y, and the independent variables—continuous lighting, x_2, and moose population, x_4, (clearing and grubbing, x_1, clearing, x_3 , precipitation, x_5, snowfall, x_6, maximum snow depth, x_7 were not included in the set)—is as follows:

$$\boldsymbol{y} = 12.9940 + (-4.9172)\boldsymbol{x_2} + (-0.0009)\boldsymbol{x_4}$$

Summaries of the combined analysis are provided in Table B13 and Table B14. The analysis shows that continuous lighting contributes to a decrease in MVCs; and moose population contributes slightly to a decrease in MVCs. An adjusted *r*-squared value of 12.0% is very low, likely meaning there are more contributing factors that affect MVCs.

Table B6 – Combined Linear Regression Coefficients and *p*-values, Full Set

	Coefficients	*P-value*
Intercept	11.7358	0.0205
Clearing and Grubbing	1.0496	0.5563
Continuous Lighting	-5.3104	0.0086
Clearing	-8.6803	0.1620
Moose Population - Linear	-0.0009	0.0240
Precipitation (inches)	0.1950	0.4847
Snowfall (inches)	-0.0572	0.2007
Max Snow Depth (inches)	0.0976	0.4190

Table B7 – Combined Linear Regression Coefficients and *p*-values-without Clearing and Grubbing

	Coefficients	*P-value*
Intercept	11.5884	0.0215
Continuous Lighting	-5.1043	0.0099
Clearing	-9.1354	0.1368
Moose Population - Linear	-0.0009	0.0279
Precipitation (inches)	0.2189	0.4262
Snowfall (inches)	-0.0570	0.2006
Max Snow Depth (inches)	0.0954	0.4279

Table B8 – Combined Linear Regression Coefficients and *p*-values-without Clearing and Grubbing and Max Snow Depth

	Coefficients	*P-value*
Intercept	11.7867	0.0190
Continuous Lighting	-5.1596	0.0090
Clearing	-9.1298	0.1362
Moose Population - Linear	-0.0009	0.0266
Precipitation (inches)	0.2545	0.3478
Snowfall (inches)	-0.0395	0.3047

Table B9 – Combined Linear Regression Coefficients and *p*-values-without Clearing and Grubbing, Max Snow Depth, and Precipitation

	Coefficients	*p-value*
Intercept	43.87226	0.00014
Clearing and Grubbing	9.25148	0.02552
Continuous Lighting	-11.45146	0.01374
Moose Population – Linear	-0.00271	0.00413
Precipitation (inches)	-1.19143	0.03903

Table B10 - Combined Linear Regression Coefficients and P-values-without Clearing and Grubbing, Max Snow Depth, and Precipitation

	Coefficients	*P-value*
Intercept	15.3723	0.0000
Continuous Lighting	-5.0507	0.0103
Clearing	-8.2074	0.1740
Moose Population - Linear	-0.0010	0.0152
Snowfall (inches)	-0.0259	0.4664

Table B11 - Combined Linear Regression Coefficients and P-values-without Clearing and Grubbing, Max Snow Depth, Precipitation, and Snowfall

	Coefficients	*P-value*
Intercept	13.4184	0.0000
Continuous Lighting	-5.1242	0.0090
Clearing	-9.2104	0.1167
Moose Population - Linear	-0.0010	0.0146

Table B12 - Combined Linear Regression Coefficients and P-values-without Clearing and Grubbing, Max Snow Depth, Precipitation, Snowfall, and Clearing

	Coefficients	*P-value*
Intercept	12.9940	0.0000
Continuous Lighting	-4.9172	0.0125
Moose Population - Linear	-0.0009	0.0207

Table B13 – Summary of Regression Analysis with *P*-Values, Combined

			Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Variable 6	Variable 7	Regression Results		
No. of Variables	Analysis Set Number	No. of Reported Accidents	Clearing and Grubbing	Continuous Lighting	Clearing	Moose Population - Linear	Precipitation (inches)	Snowfall (inches)	Max Snow Depth (inches)	Signifi-cance *F*	Adjusted *r*-squared	*r*-squared
7	1	0.0205	0.5563	0.0086	0.1620	0.0240	0.4847	0.2007	0.4190	0.0102	0.1182	N/A
6	8	0.0215		0.0099	0.1368	0.0279	0.4262	0.2006	0.4279	0.0058	0.1246	N/A
5	24	0.0190		0.0090	0.1362	0.0266	0.3478	0.3047		0.0035	0.1281	N/A
4	51	4.3623E-06		0.0103	0.1740	0.0152		0.4664		0.0021	0.1292	N/A
3	80	2.2758E-12		0.0090	0.1167	0.0146				0.0010	0.1335	N/A
2	107	6.0272E-12		0.0125		0.0207				0.0009	0.1196	N/A

	Variable included in the regression analysis and *p*-value for each variable
#.####	Low statistical significance, Significance *p*-value > 0.05
#.####	Low statistical significance, Significance *F* > 0.05

Table B14 –Regression Analyses with Statistical Significance with Linear Regression Coefficients, Combined

			Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Variable 6	Variable 7	Regression Results		
No. of Variables	Analysis Set No.	No. of Reported Accidents	Clearing and Grubbing	Continuous Lighting	Clearing	Moose Population - Linear	Precipi-tation (inches)	Snowfall (inches)	Max Snow Depth (inches)	Signifi-cance *F*	Adjusted *r*-squared	*r*-squared
2	107	12.9940		-4.9172		-0.0009				0.0009	0.1196	N/A
3	80	13.4184		-5.1242	-9.2104	-0.0010				0.0010	0.1335	N/A
4	51	15.3723		-5.0507	-8.2074	-0.0010		-0.0259		0.0021	0.1292	N/A
1	122	9.8333		-5.8333						0.0033	N/A	0.0872
5	24	11.7867		-5.1596	-9.1298	-0.0009	0.2545	-0.0395		0.0035	0.1281	N/A
1	124	12.4678				-0.0011				0.0054	N/A	0.0785
6	8	11.5884		-5.1043	-9.1354	-0.0009	0.2189	-0.0570	0.0954	0.0058	0.1246	N/A
7	1	11.7358	1.0496	-5.3104	-8.6803	-0.0009	0.1950	-0.0572	0.0976	0.0102	0.1182	N/A

	Variable included in the regression analysis

Clearing and Grubbing

The Sterling Highway MP 82.0–93.72 improvement project included clearing and grubbing. The project data show that the number of reported MVCs follows a trend similar to that of recorded precipitation information, dipping and rising the same years. Moose-vehicle collisions closely followed the same trends per year as maximum snow depth and snowfall, although the highest collision years were not the highest snowfall or maximum snow depth years. This indicates that other factors likely contribute to MVCs. The lowest dip in MVCs occurred the second year post-project completion. Regression analysis of the data resulted in 40.9% of the variation in crashes being explained by the independent variable: maximum snow depth, x_5. Maximum snow depth contributed to a gain in MVCs, which can be expected since the number of MVCs followed a similar trend during the study period so a rise in maximum snow depth would be linked to a rise in MVCs (see Figure 6-Figure 9). The five year average prior to construction was 14.8 MVCs/year and the five year average post construction was 13.4 MVCs/year, a 9.5% drop.

The Kalifornsky Beach Road MP 16.4–22.4 improvement project included clearing and grubbing. The project data show that the number of reported MVCs follows a trend similar to recorded precipitation information, except in years of high precipitation, which is associated with a drop in MVCs. The same trend can be seen with maximum snow depth and snowfall. The lowest number of MVCs occurred during the construction year and the year following project completion. Regression analysis of the data resulted in acceptance of the null hypothesis, concluding that a relationship between the number of reported MVCs and the independent variables does not exist. This variable contributed to an increase in MVCs, with increased moose population. The five-year average prior to construction was 9.6 MVCs/year and the five-year average post construction was 5.6 MVCs/year, a nearly 41.7% drop.

The Parks Highway MP 37–39 improvement project included clearing and grubbing. Project data indicate that the number of reported MVCs is not related to the recorded precipitation information. During the study years, highest snowfall and maximum snow depth are paired with years of high and low reported MVCs. There does not appear to be a trend of reduced MVCs after construction. The lowest dip in MVCs occurred 1 and 3 years after construction completion. Regression analysis of the data resulted in acceptance of the null hypothesis, concluding that a relationship between the number of reported MVCs and the independent variables does not exist. The five-year average prior to construction was 2.2 MVCs/year and the five-year average post construction was 1.4 MVCs/year, a nearly 36.4 % drop.

The Knik-Goose Bay Road MP 0.0–19.56 improvement project included clearing and grubbing. The project data show that the number of reported MVCs does not follow the same trend as recorded precipitation information exactly, but does rise and fall similarly most years. The study years with highest snowfall and maximum snow depth are paired with years of high and moderate reported MVCs. The lowest recorded MVC year occurred 3 years prior to project completion. Regression analysis of the data resulted in acceptance of the null hypothesis, concluding that a relationship between the number of reported MVCs and the independent variables does not exist. The five-year average prior to construction was 8.4 MVCs/year and the five-year average post construction was 10.0 MVCs/year, a 19.0% rise.

Although the clearing and grubbing projects weren't all shown to be statistically significant, there was a consistent trend of a drop in the number of moose-vehicle collisions following clearing and grubbing based on the five year averages, with the exception of the Knik-Goose Bay Road MP 0.0–19.56 project that had a large spike in MVCs five years post construction. This increase may be linked to regrowth of vegetation surrounding the project corridor, possibly grass replanted during construction or regrowth along the boundary of the project. The remaining projects had varying increases and decreases in moose-vehicle collisions throughout the five years post construction, which may indicate that DOT&PF Maintenance and Operations performed clearing of re-vegetated areas or older growth is less of an attractant for moose. Tracking Maintenance and Operations activities and regrowth post construction could continue to improve data for future re-evaluation.

Clearing and Grubbing and Continuous Lighting

The Glenn Highway MP 4–11 improvement project included clearing and grubbing and continuous lighting. Project data show that the number of reported MVCs does not follow the same trend as recorded precipitation information. Moose-vehicle collisions seem to rise and fall independent of precipitation, maximum snow depth, and snowfall during the first five years of the study. Then in the last five years, the number of MVCs follows a similar trend as recorded precipitation information, dipping and rising the same years. The lowest number of MVCs occurred during the first year following project completion, as well as 5 years after the completion date. Regression analysis resulted in 41.8% of the variation in crashes being explained by the independent variables: clearing and grubbing, x_1, or continuous lighting, x_2. Both variables contributed to a reduction of MVCs. From this set of data, it cannot be determined whether clearing or grubbing or continuous lighting has a greater or equal effect on the outcome of MVCs. The five-year average prior to construction was 30.8 MVCs/year and the five-year average post construction was 13.6 MVCs/year, a nearly 55.8% drop.

The Glenn Highway MP 30.7–33.5 improvement project included clearing and grubbing and continuous lighting. The project data indicate that the number of reported MVCs follows a trend similar to recorded precipitation information, dipping and rising the same years, except for the study years with highest snowfall and maximum snow depth. This indicates that years of significant snowfall and maximum snow depth lead to a reduced number of reported MVCs in the study area. The lowest dip in MVCs occurred the second year post-project completion as well as 5 years post-project completion. Regression analysis of the data resulted in 85.9% of the variation in crashes being explained by the independent variables: clearing and grubbing, x_1, or continuous lighting, x_2, precipitation, x_4, and maximum snow depth, x_6. Clearing and grubbing or lighting contributed to a reduction in MVCs where precipitation contributed to a rise in MVCs with increased precipitation. The five-year average prior to construction was 4.6 MVCs/year and the five-year average post construction was 2.4 MVCs/year, a 47.8% drop.

The Parks Highway MP 35–37 improvement project included clearing and grubbing and partial interchange lighting. The project data show that the number of reported MVCs is not related to recorded precipitation information. Most years in the study period did not experience any MVCs and is likely due to a short study corridor. There does not appear to be a trend of reduced MVCs after construction, but rather an increase. The highest MVCs occurred 4 and 5 years' post-project completion. Regression analysis of the data resulted in 79.5% of the variation in collisions explained by the independent variables: moose population, x_3, snowfall, x_5, and maximum snow depth, x_6. The five-year average prior to construction was 0.4 MVCs/year and the five-year average post construction was 0.8 MVCs/year, a 100% rise in average.

Similar to the clearing and grubbing projects, the clearing and grubbing and continuous lighting projects showed a consistent trend of a drop in the number of moose-vehicle collisions following project completion, then an increase in the three to five years post construction. Two of the projects had an increase in the three to four years post construction followed by a drop in MVCs at five years post construction, which may indicate that DOT&PF Maintenance and Operations performed clearing of re-vegetated areas or older growth is less of an attractant for moose. Tracking Maintenance and Operations activities and regrowth post construction could continue to improve data for future re-evaluation.

Continuous Lighting

The Glenn Highway MP 3.24–11.46 improvement project included continuous lighting. Project data indicate that the number of reported MVCs does not follow the same trend as recorded precipitation information; reported MVCs dip and rise independently of precipitation, maximum snow depth, and snowfall. The highest collision years were not the highest snowfall or maximum snow depth years, showing that other factors contribute to MVCs. The lowest dip in MVCs occurred 5 years prior to project completion and four years post project completion. Regression analysis of the data resulted in 52.3% of the variation in crashes being explained by the independent variables: continuous lighting, x_1 and Snowfall, x_4. This continuous lighting contributed to an increase in MVCs for this data set and snowfall contributed to a decrease. The five-year average prior to construction was 12.0 MVCs/year and the five-year average post construction was 17.2 MVCs/year, a 43.3% rise.

The Glenn Highway MP 12.082–16.5 improvement project included continuous lighting. Project data indicate that the number of reported MVCs is not related to recorded precipitation information. During the study years, highest snowfall and maximum snow depth are paired with years of high and low reported MVCs. There was a peak in MVCs the first year after construction completion, although a trend of reduced MVCs is apparent after construction, with the lowest dip in MVCs occurring 4 and 5 years after project completion. Regression analysis of the data resulted in 65.2% of the variation in crashes being explained by the independent variable: moose population, x_2. This variable contributed to an increase in MVCs, indicating that MVCs rise and fall with changes in moose population. The five-year average prior to construction was 5.6 MVCs/year and the five-year average post construction was 2.8 MVCs/year, a 50.0% drop.

As for the three projects that involved clearing and grubbing and continuous lighting, the results of two of these projects indicated no determination as to whether clearing or grubbing or continuous lighting has a greater or equal effect on the outcome of MVCs. Findings from the third project were inconclusive. The results of two projects with only continuous lighting improvements varied, one indicated that the improvement increased the number of MVCs and the other showed a drop in MVCs. Similarly, Reed and Woodard (1981) found that the presence of highway lighting did not significantly affect the crossings-per-accident ratios of deer.

Clearing

The Parks Highway MP 72–83 improvement project included clearing. The project data show that the number of reported MVCs does not appear to have any relation to the recorded precipitation information. During the study years, the highest snowfall and maximum snow depth are paired with years of high and low reported MVCs. There does appear to be a trend of reduced MVCs after construction. The lowest dip in MVCs occurred 2 years post-project completion, as well as 5 and 3 years prior to construction completion. Regression analysis of the data resulted in acceptance of the null hypothesis, concluding that a relationship between the number of reported MVCs and the independent variables does not exist. The five year average prior to construction was 5.2 MVCs/year and the two year average post construction was 2.0 MVCs/year, a 61.5% drop. Since the study period post construction was limited to two years, the 61.5% drop may not reflect regrowth of the corridor or the long term effects of the mitigation measure.

Combined Analysis

All project corridors with a clearing and grubbing, continuous lighting, and clearing component were included in a combined data set. Additional factors analyzed included moose populations, precipitation, snowfall, and maximum snow depth.

For the combined set, regression analysis resulted in 12.0% of the variation in crashes being explained by the independent variables: continuous lighting, x_2, and moose population. The resulting adjusted r-squared value for the combined set of 12.0% is very low. This likely means that more factors contribute to MVCs.

Crash Modification Factors (CMFs)

Based on statistical analysis and project specific results, Crash Modification Factors (CMFs) were developed using the correlation equations and Equation 3. Table B15 summarizes each CMF with each corridor CMF grouped by mitigation measure. The five-year average comparison is also included for each corridor.

Some project corridor results showed good correlation and most showed a drop in MVC based on CMF and five year averages prior to and post construction. Outliers were removed based on best engineering judgment of CMF for mitigation measures. Continued study and analysis could assist in the development of more reliable CMFs.

Table B15 – Crash Modification Factor Summary by Mitigation Measure

	Clearing and Grubbing	Continuous Lighting	Clearing	Five Year Average Comparison	Crash Modification Factor	Combined Crash Modification Factor
Sterling Highway MP 82.0-93.72				9.5% drop	1.07	0.78
Kalifornsky Beach Rd. MP 16.4–22.4				41.7% drop	0.54	
Parks Highway MP 37–39				36.4% drop	0.81	
Knik-Goose Bay Rd. MP 0.0-19.56				19.0% rise	0.98	
Glenn Highway MP 4–11				55.8% drop	0.44	0.48
Glenn Highway MP 30.7–33.5				47.8% drop	0.52	
Parks Highway MP 35–37				100% rise	3.01	
Glenn Highway MP 3.24–11.46				43.3% rise	1.43	0.53
Glenn Highway MP 12.082–16.5				50.0% drop	0.53	
Parks Highway MP 72–83				61.5% drop	0.34	0.34

	Variable included in the regression analysis (Clearing and Grubbing project)
	Variable included in the regression analysis (Continuous Lighting project)
	Variable included in the regression analysis (Clearing project)
#.##	Crash Modification Factor outlier not included in the combined CMF calculation

APPENDIX C - Moose-Vehicle Collision Charts

The following figures, Figure C1 through C10, show the number of moose-vehicle collisions reported for each study year by project. Also shown are the construction dates and five year averages before and after the mitigation measure was constructed.

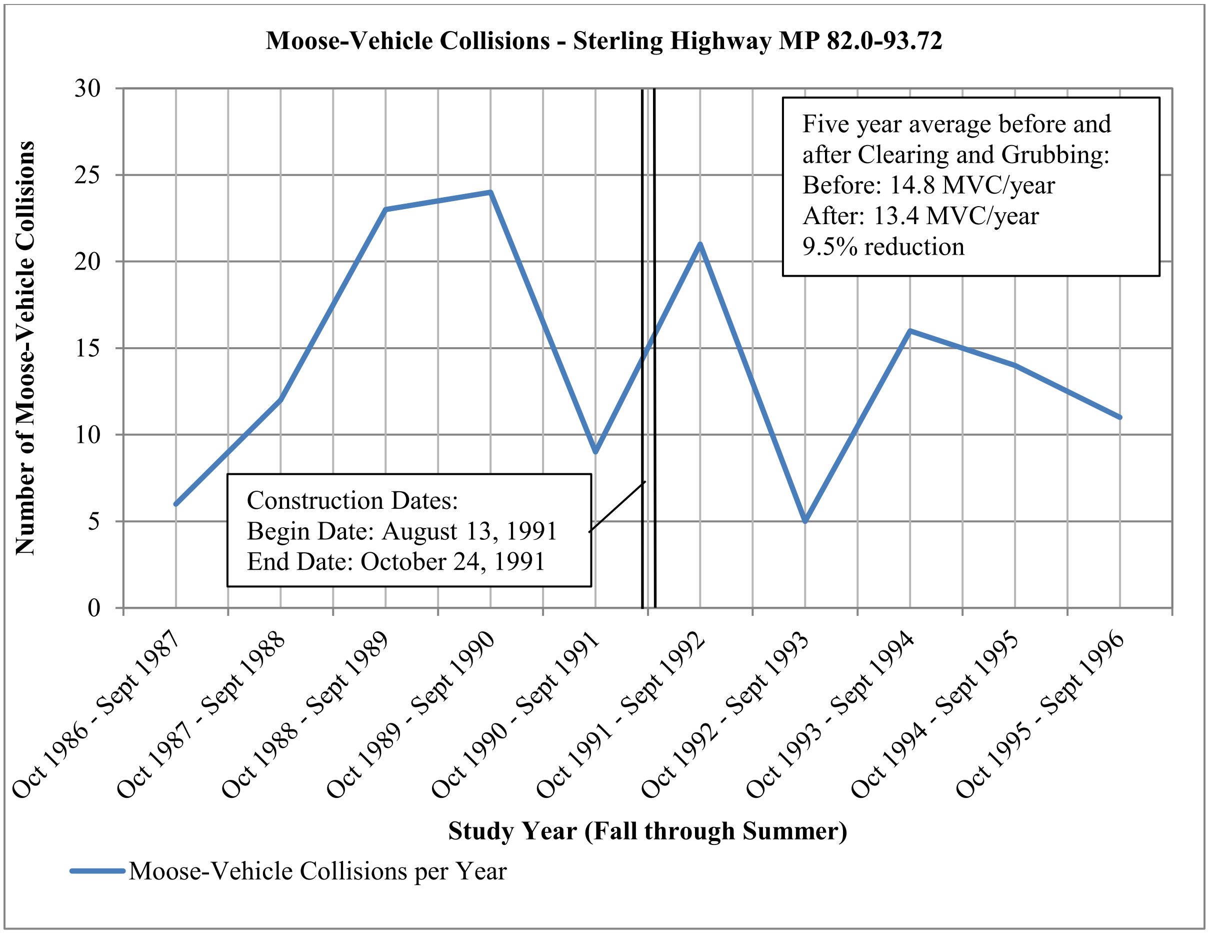

Figure C1 – Moose-Vehicle Collisions - Sterling Highway MP 82.0-93.72

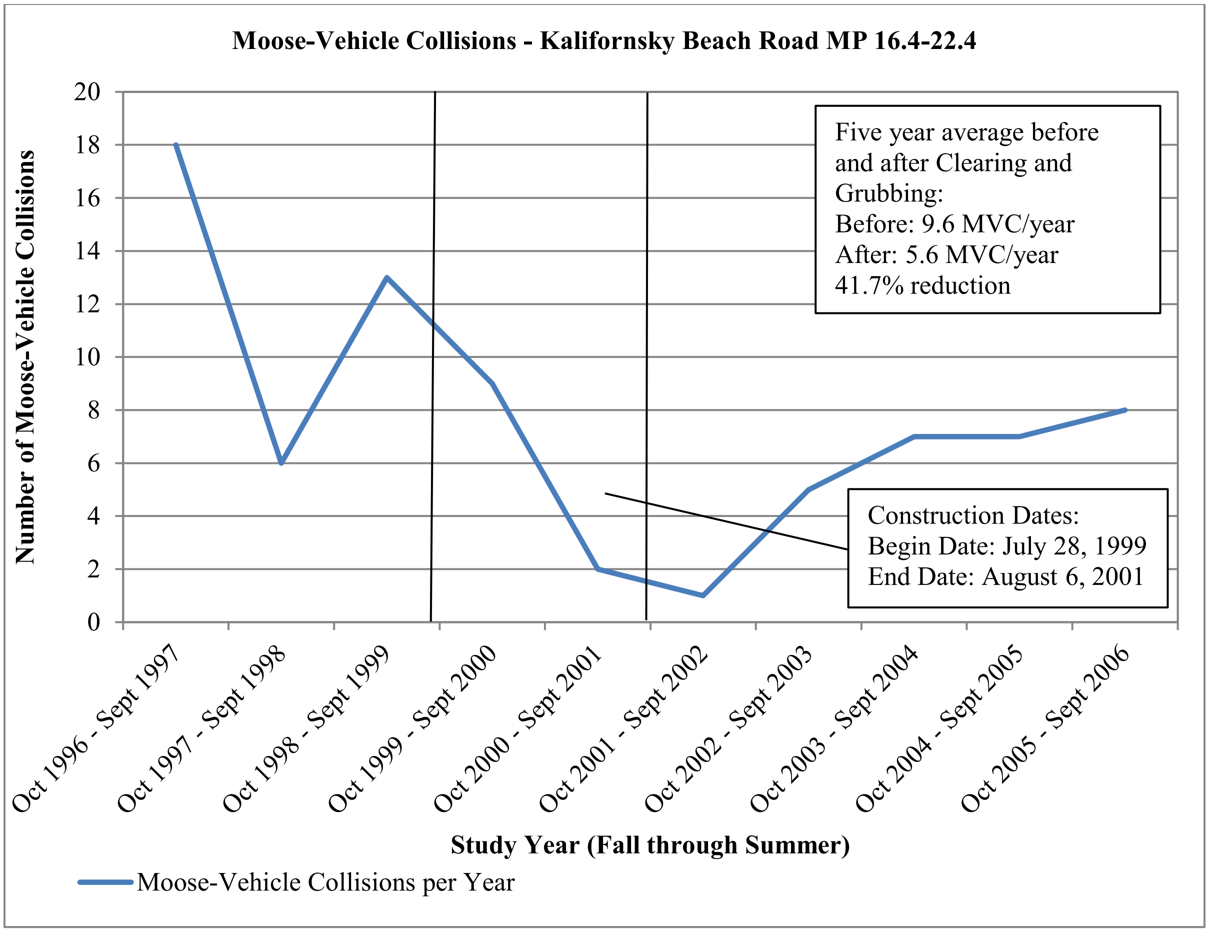

Figure C2 – Moose-Vehicle Collisions - Kalifornsky Beach Road MP 16.4-22.4

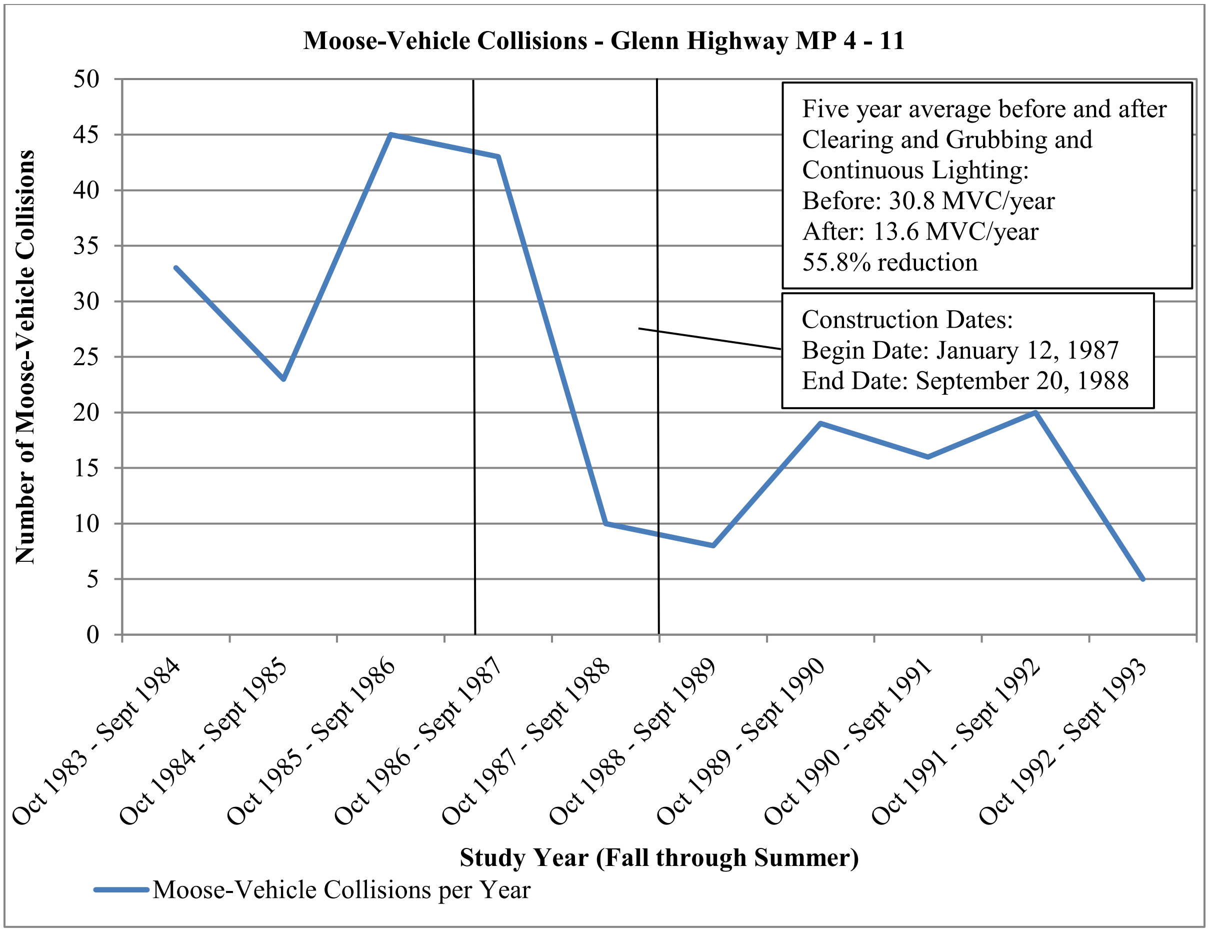

Figure C3 – Moose-Vehicle Collisions - Glenn Highway MP 4 - 11

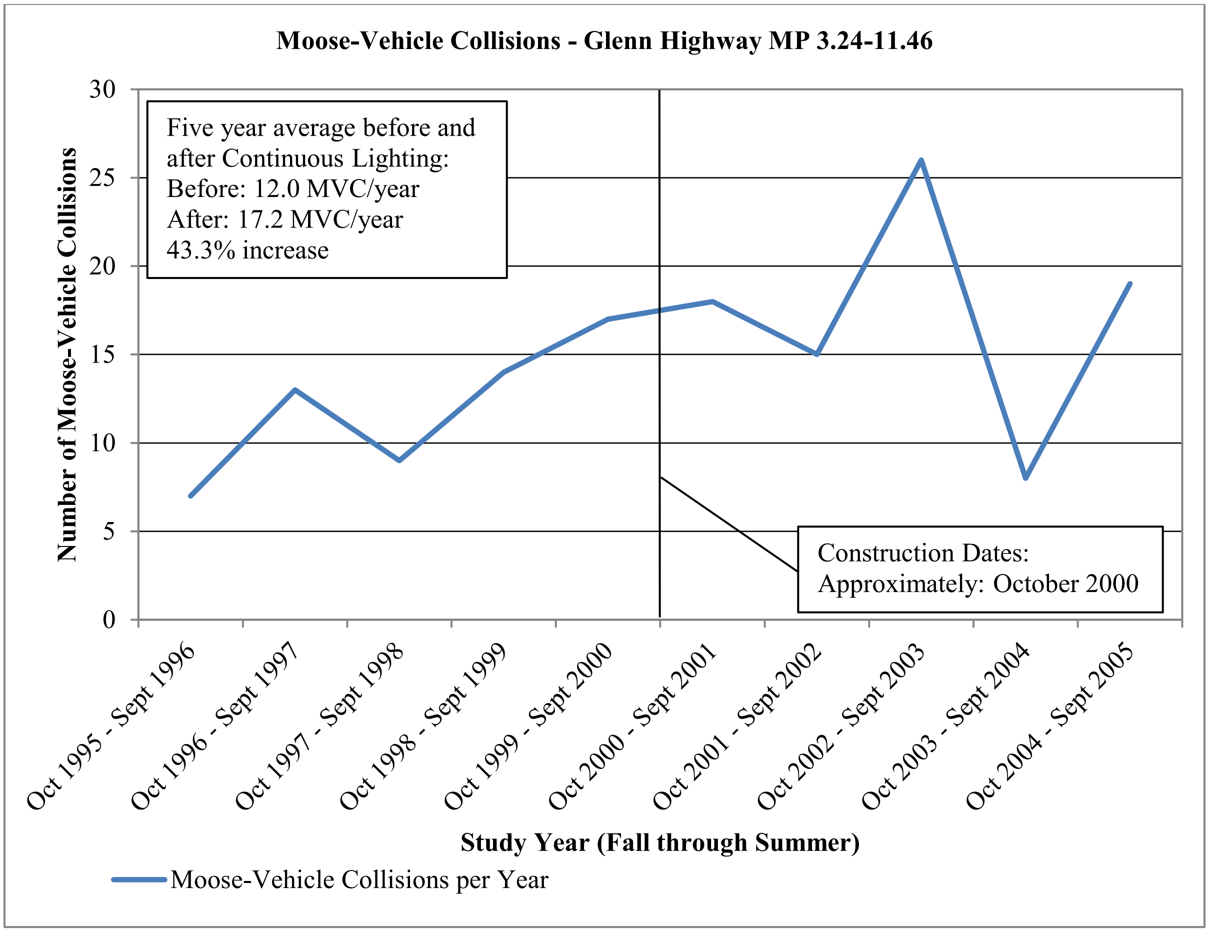

Figure C4 – Moose-Vehicle Collisions - Glenn Highway MP 3.24-11.46

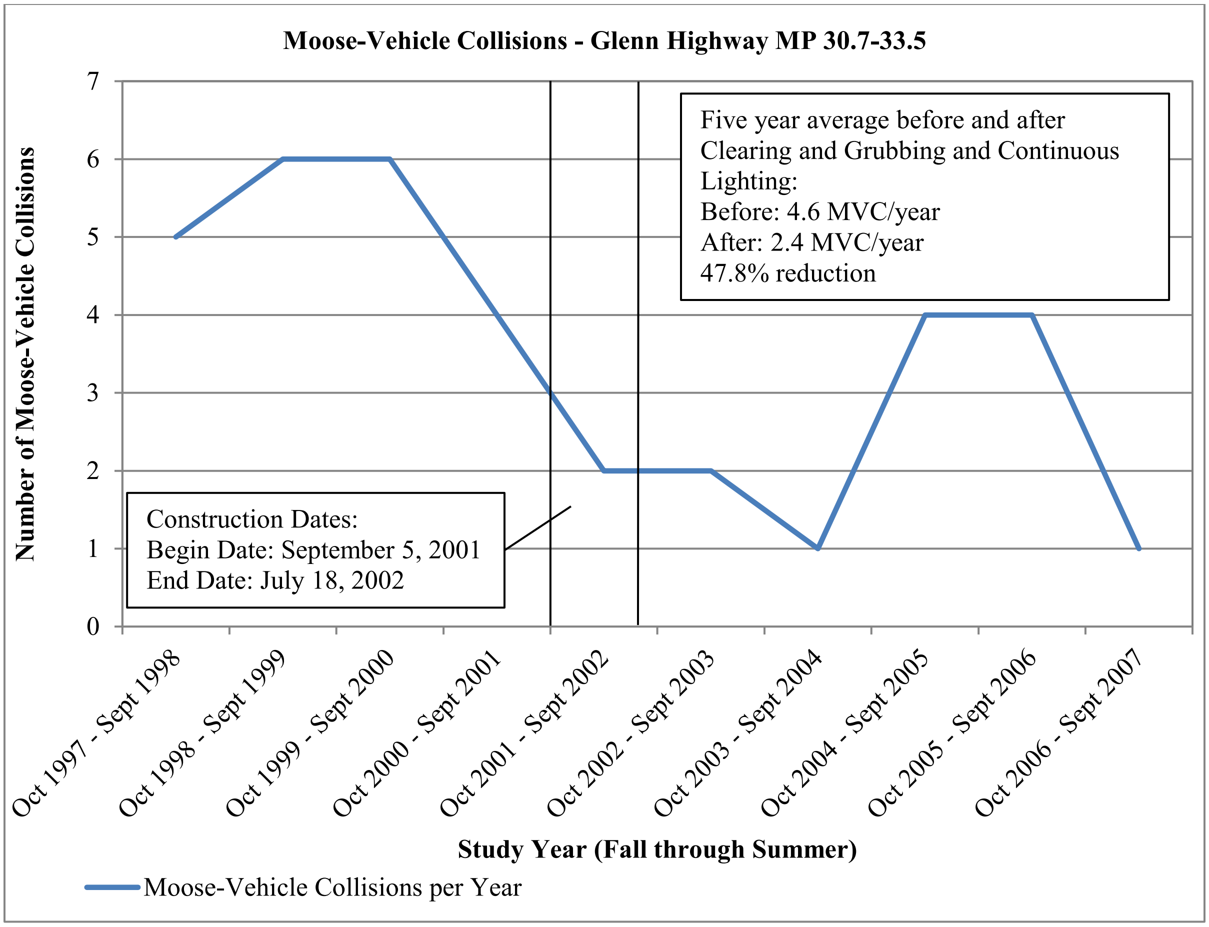

Figure C5 – Moose-Vehicle Collisions - Glenn Highway MP 30.7-33.5

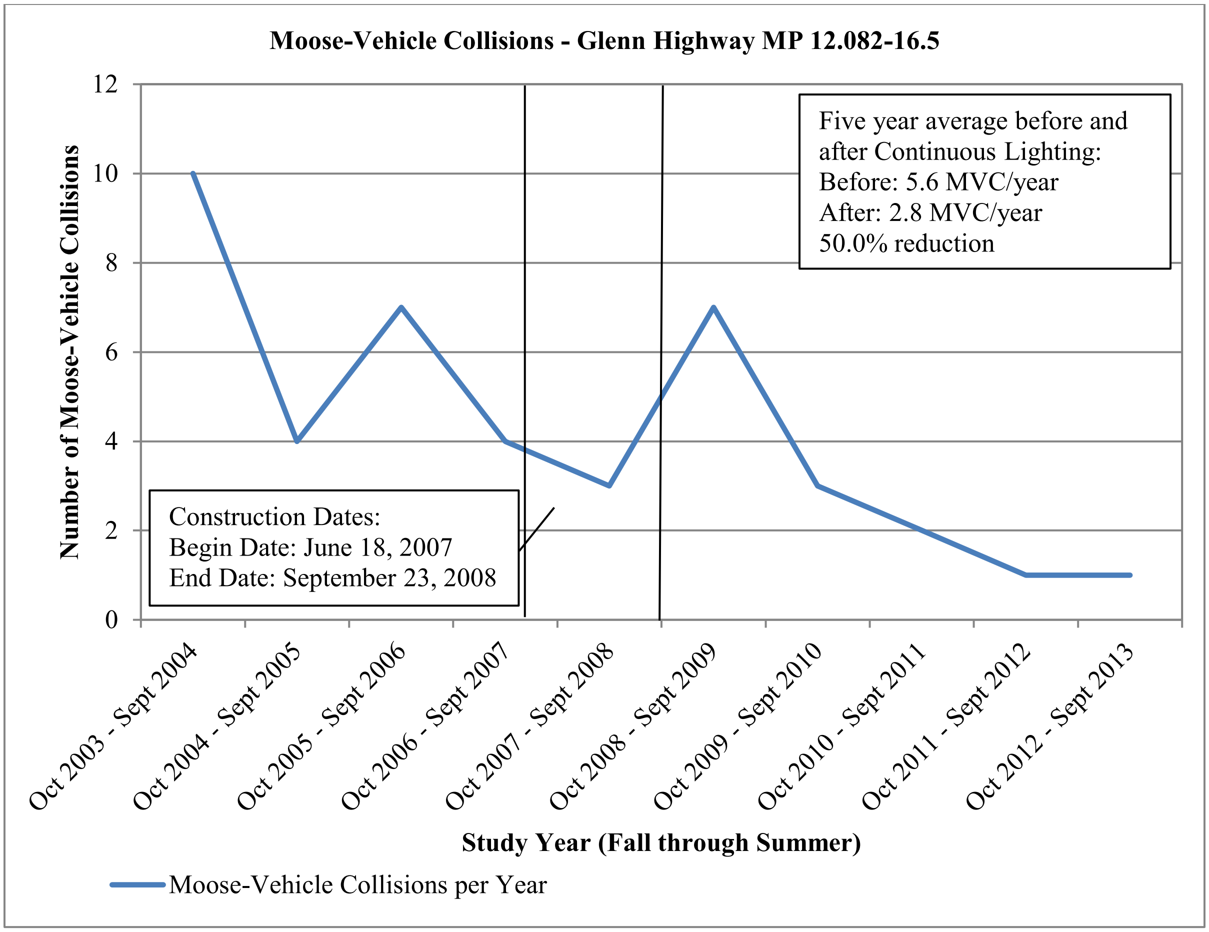

Figure C6 – Moose-Vehicle Collisions - Glenn Highway MP 12.082-16.5

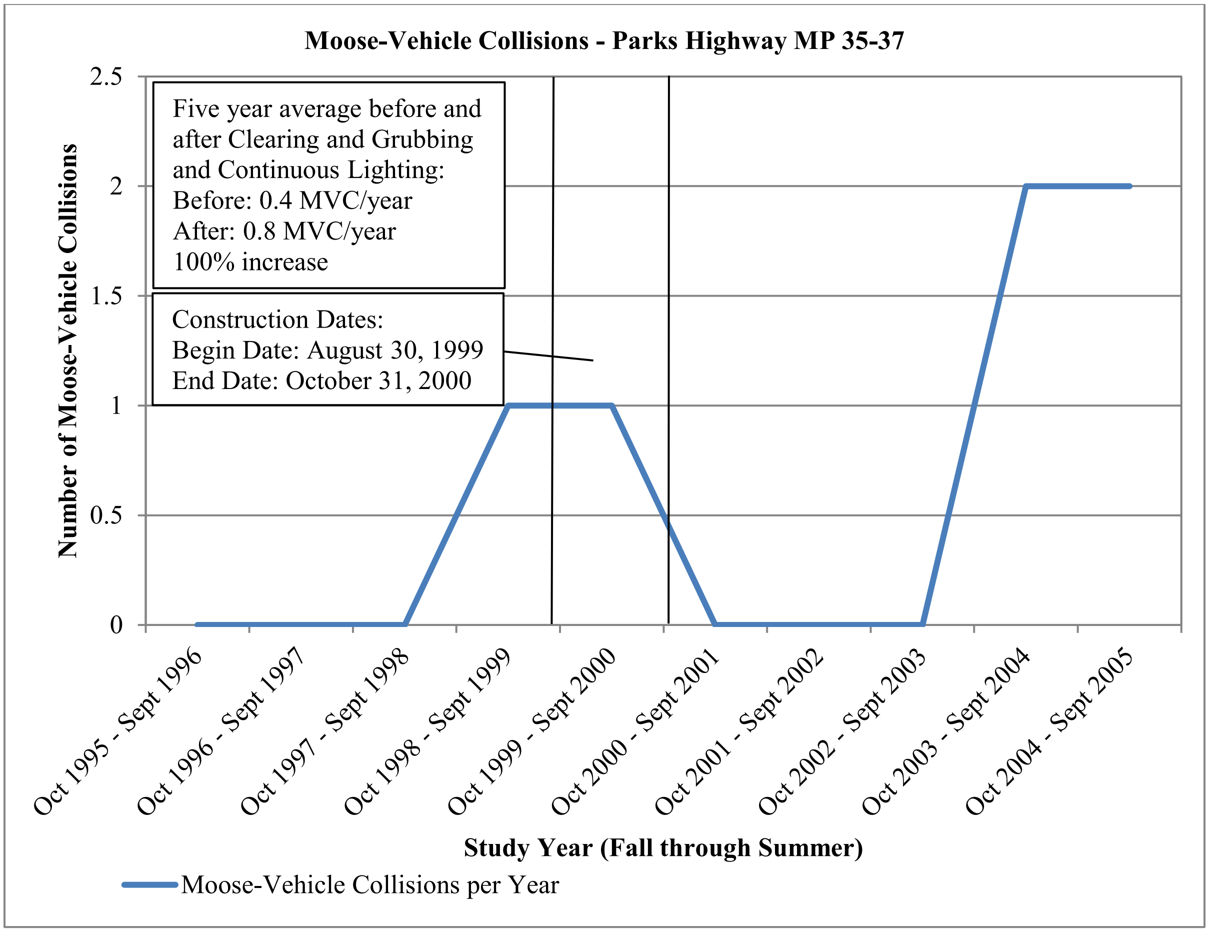

Figure C7 – Moose-Vehicle Collisions - Parks Highway MP 35-37

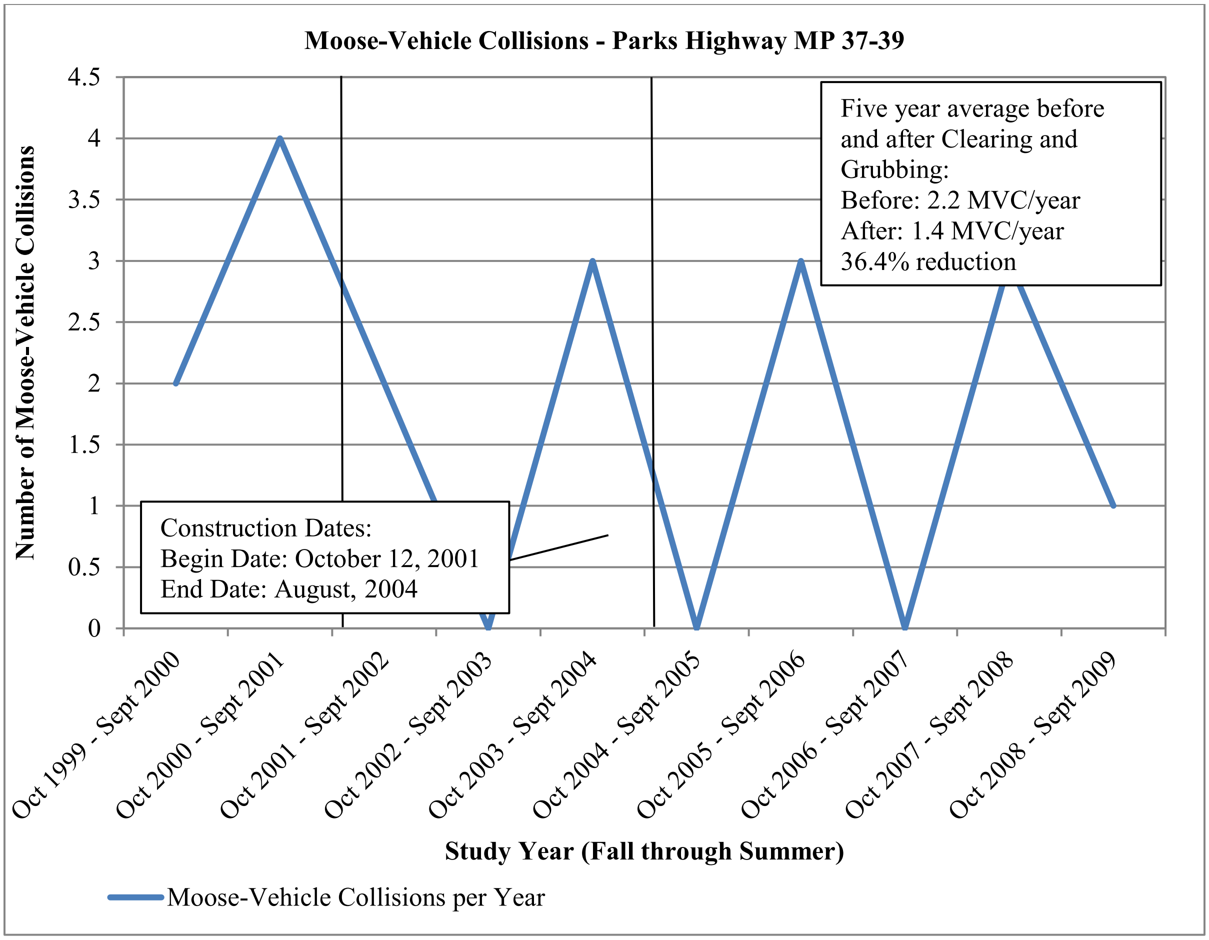

Figure C8 – Moose-Vehicle Collisions - Parks Highway MP 37-39

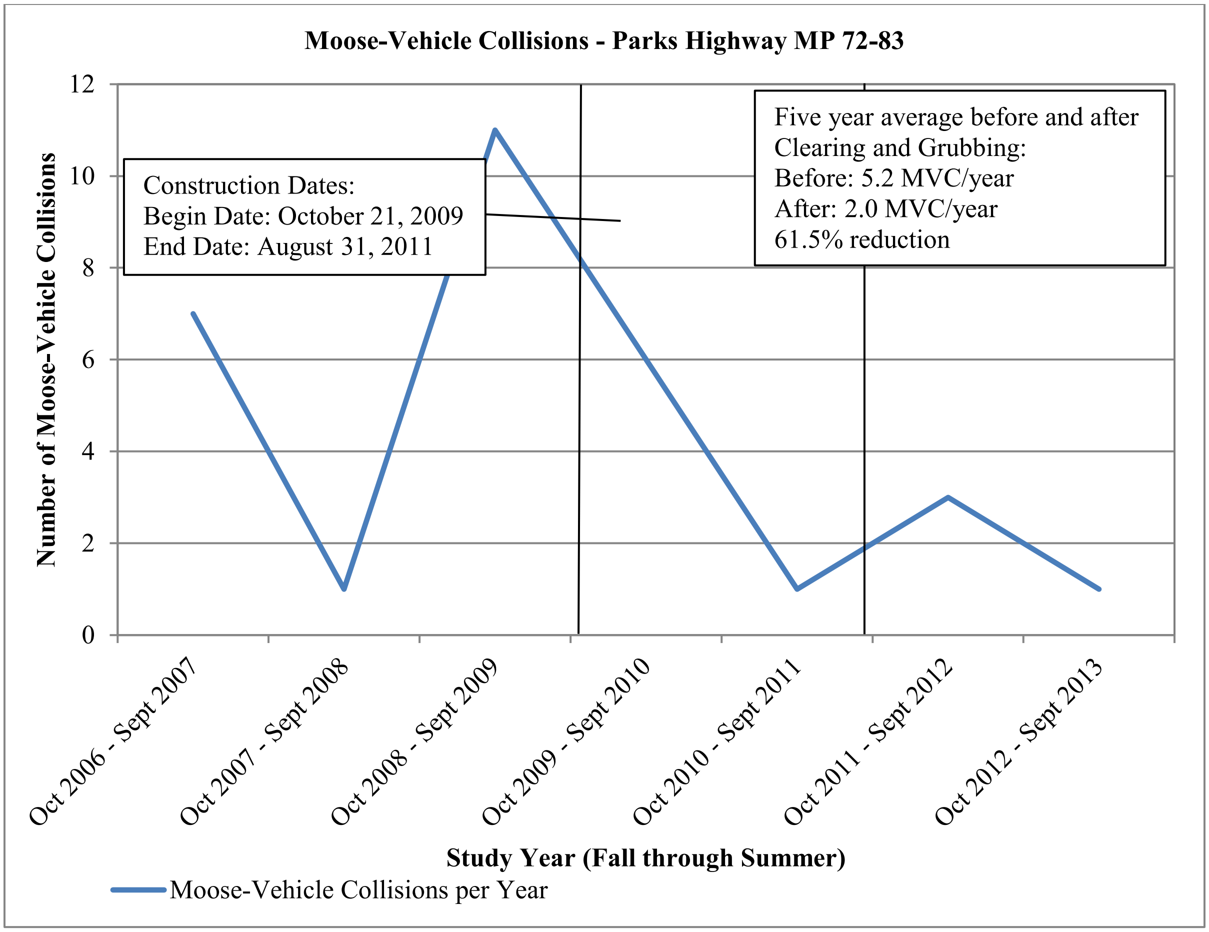

Figure C9 – Moose-Vehicle Collisions - Parks Highway MP 72-83

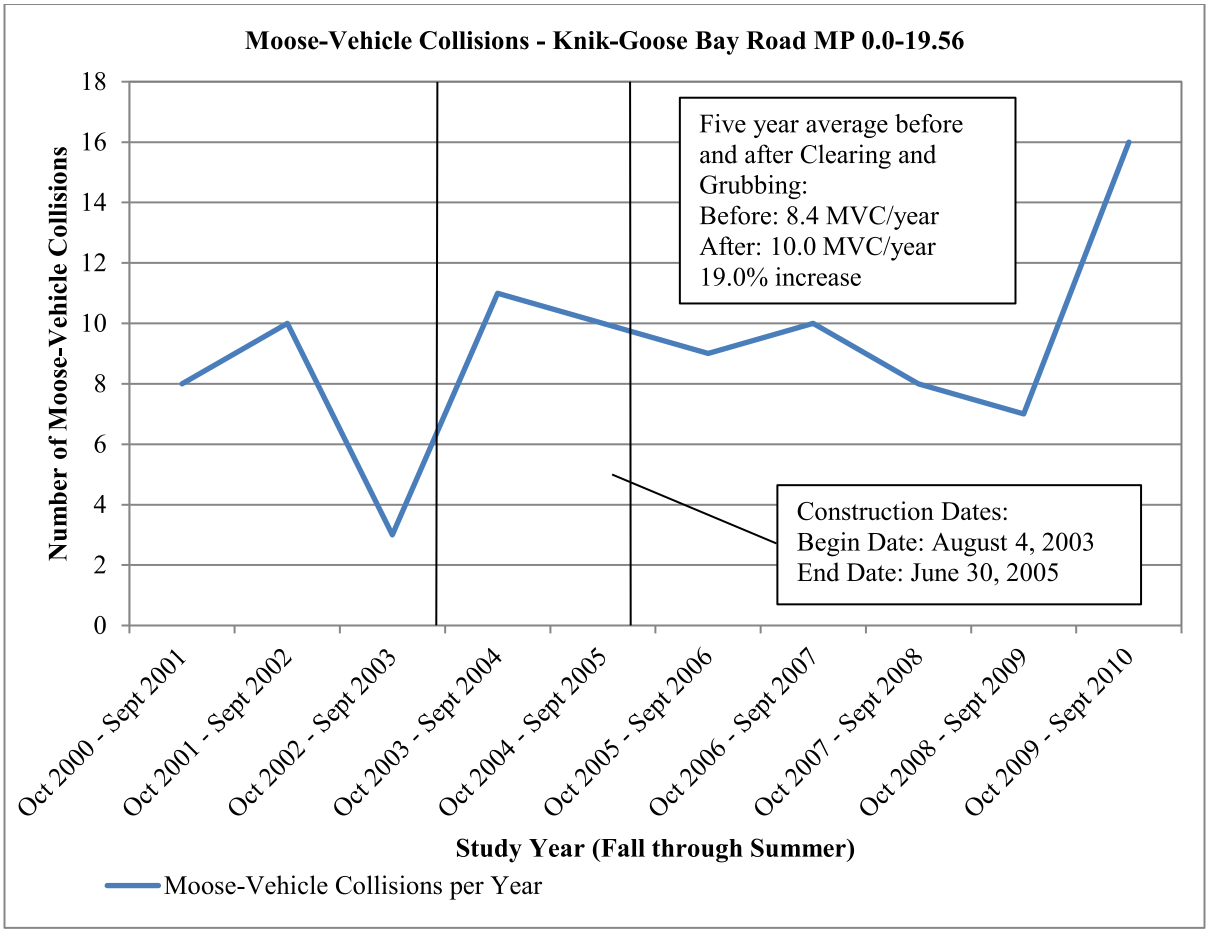

Figure C10 – Moose-Vehicle Collisions - Knik-Goose Bay Road MP 0.0-19.56