

RESEARCH ARTICLE

Analysis of moose-vehicle collisions countermeasures in northern climates

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Abstract

This research investigates the reliability of two measures intended to reduce moose-vehicle collisions (MVCs): continuous lighting and clearing/grubbing of roadway corridors. Individual analyses and a combined regression analysis were conducted to measure the effects of several combinations of variables on MVC rates, including clearing and grubbing, continuous lighting, clearing without grubbing, moose population, precipitation, snowfall, and maximum snow depth. Nine corridor improvement projects were analyzed based on the variables present. In previous studies, it has been hypothesized that MVC rates are influenced by environmental conditions such as snowfall and daylight. The Alaska Department of Transportation and Public Facilities (DOT&PF) has performed many studies on MVCs along several corridors. Some corridors showed a significant drop in the number of MVCs after the installation of continuous lighting. The results show there is a consistent drop in MVCs after clearing and grubbing, with the exception of one corridor. The combined clearing/grubbing and continuous lighting projects also resulted in a consistent drop in MVCs. The projects with clearing and grubbing as a component had varying trends in MVCs, which may indicate that DOT&PF Maintenance and Operations performed clearing of re-vegetated areas, or that older growth is less of an attractant for moose.

Keywords: continuous lighting; clearing; grubbing; moose-vehicle collisions; countermeasures; cold regions; wildlife

1. Introduction

The State of Alaska Department of Transportation and Public Facilities (DOT&PF) has used continuous lighting and/or the clearing/grubbing

of several corridors in the past two decades with apparent, but unquantified, success in reducing moose-vehicle collisions (MVCs). These measures, which pose less of a barrier to moose

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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 MVCs and continuous lighting and/or clearing/grubbing. To analyze the effects of past efforts, it was important to accumulate project examples with three to five years of reportable crash data post-project completion. Prior projects with ground clearing and continuous highway lighting were not funded as Highway Safety Improvement Program (HSIP) projects, so before-and-after analyses were not previously conducted.

Due to their dark coloring, moose are difficult to see at night. The problem is exacerbated because, unlike deer, moose seldom look directly at oncoming vehicles, so the eye-shine reflection of headlights cannot be observed [1]. MVCs occur most often on rural highways surrounding major cities and towns in Alaska, primarily near Anchorage, Palmer, Wasilla, Soldotna, Kenai, Fairbanks, and North Pole, where continuous lighting may not be available. With large numbers of Alaskans living in proximity to substantial moose populations, the transportation of people and goods poses challenges that increase risks to both humans and moose. In fact, there are more than 800 MVCs in Alaska annually [2], which is one of the highest rates in the world [3]. About 1.5% of MVCs result in serious injuries to vehicle occupants, while 0.25% result in human fatalities. MVCs are also a hazard to road crews who are responsible for cleanup. The average cost per MVC is roughly \$35 000, which includes vehicle damage and emergency services response [4].

2. Research significance

MVCs increase the risk of injury to humans and moose, as well as damage to property. The objective of this study was to investigate the statistical effectiveness of continuous lighting and clearing/grubbing of roadway corridors, as measures taken to reduce MVCs. The findings can inform decision-makers and researchers on the effectiveness of accident reduction techniques and crash modification factors applicable to MVCs.

Many studies have evaluated the effectiveness of mitigation measures on deer-vehicle collisions, but no project has evaluated their effectiveness with respect to MVCs. Previous studies were conducted in locations where MVCs are less common than other wildlife collisions, so moose were not a

concern. However, Alaska has a much higher rate of MVCs, and the DOT&PF has focused on MVC mitigation measures for many years. 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 reducing the number of MVCs on a given corridor.

This study reviewed and documented the apparent crash mitigation effects of highway lighting and clearing/grubbing in reducing MVCs. This study also compared the two mitigation measures for possible continued use in Alaska, as they are not routinely accepted for ungulates such as deer and elk. Based on the results and a review of the literature, better lighting and clearing methods are suggested, but further analysis is required.

3. Literature review

3.1 Moose behavior

It is crucial to understand moose behavior to track their migration and habitat routes more efficiently as they cross major roadways. Moose movement has been found to differ between the sexes, varying both daily and annually. Moose are significantly more active in summer than in winter due to shorter necessary resting periods during summer months compared to winter months. Home-range size is larger in summer than in winter, but the seasonal difference is greater for females than for males. One study determined that home-range size is 16.3 mi² (42.1 km²) in summer and 2.5 mi² (6.4 km²) in winter regardless of sex [5]. Another study determined that winter range size is 4.44 mi² (11.5 km²) [6]. The discrepancy in these findings is likely due to terrain and foraging provision differences between the areas studied. The winter range of moose varies only slightly from year to year, showing that moose tend to return to particular areas. The effect of snow depth on winter home-range size is apparent only when snow depth is greater than 27.6 in. (70 cm). Moose begin fall migration on different dates each year, and while duration varies from year to year, size and range do not change [6].

The daily movements of parturient moose increase significantly in the two days prior to calving, but are greatly reduced for at least nine days post-parturition. Female moose typically return to successful birth sites [7]. Female moose with calves have a higher preference for areas providing protection from predation, whereas solitary

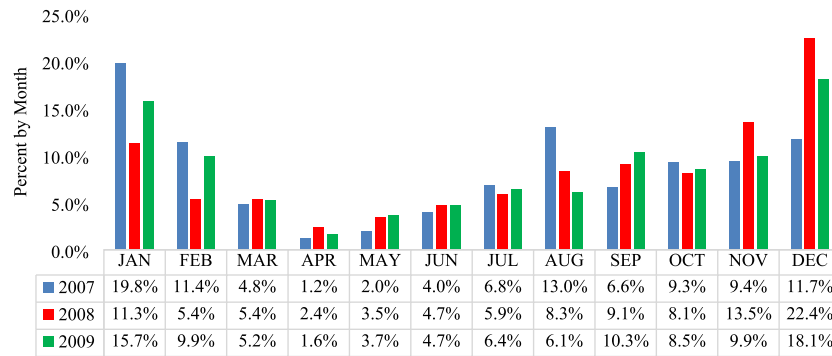


Fig. 1. Moose Crashes by Month for 2007–2009 [12]

moose prefer areas that provide moderate food abundance, moderate protection from predation, and substantial shelter from deep snow [8].

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 [5]. Roe deer and moose have low activity levels in winter and early spring, indicating conservation of energy, so the animals make use of areas with relatively dense but low-quality forage. In summer, their browsing activity increases and shifts toward searching for high-quality plants [9].

Moose activity also relates to other species. Moose and wolf activity patterns are asynchronous; in general, moose activity peaks at dusk and wolf activity peaks at dawn [10]. 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 [9].

In relation to this pattern, it has been determined that the greatest number of animal collisions occur during early morning hours (4:00 a.m. to 6:00 a.m.) and evening hours (6:00 p.m. to 11:00 p.m.) [2]. Collisions with animals are more frequent at night than during the day, with occurrences ranging from 68% to 85% [11]. During the year 2009 in Alaska, 64.7% of MVCs occurred in darkness or in reduced-light conditions [12]. In addition to daily peak movement, moose have seasonal migration patterns with spring peaks, spring lulls, and summer lulls. Thus, MVCs have a seasonal cyclical component, with most occurring from May to October. In Alaska, the fewest MVCs occur in April and then rates increase in the winter months (Fig. 1); the highest number of MVCs occur

in January and December [11]. The fact that moose home-range decreases during winter while MVCs increase may reflect that moose forage closer to roadways, use them for ease of travel, or are forced out of other areas due to snow-depth changes.

3.2 Establishing methodologies

Utilizing an analytical hierarchy process (AHP) to develop an expert-based model 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 [13]. Logistic regression models and Akaike's information criteria (AIC) were employed to develop best-matched models for six subsets related to MVCs: driver visibility, evidence of moose presence, highway design, roadside vegetation, moose habitat, and landscape/GIS. The landscape-scale/GIS approach allows one to assess variables that contributed to where MVCs occur [13]. 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 on multiple scales. This exploratory and multi-scale statistical analysis proved effective in displaying varying and similar spatiotemporal patterns on roads [14].

Simple logistic regression analyses used in predicting locations of MVCs in Sweden showed strong support for the combined model, which used the predicted likelihood for MVCs as the independent variable and the actual accident total of the selected road sections as the dependent variable [15].

3.3 Effectiveness of mitigation measures

MVCs are more likely to occur in areas with higher speed limits, areas that have been modified by

humans, areas where higher moose activity is present, and at night. Additional factors include light conditions, road surface conditions, location of preferred habitat, weather, and traffic volume [16]. Given that moose activity is at its highest during dusk and dawn, when moose are more difficult to see, many past studies have suggested the use of lighting along roads with high moose activity. When it comes to roadside clearing, past studies offer contradictory results: some studies show it increased preferred habitats and MVCs, while other studies show it reduced MVCs. These findings may indicate that vegetation management may be an effective means of reducing MVCs, but only under certain circumstances.

Recently, the Washington State Department of Transportation (WSDOT) evaluated continuous roadway lighting on mainline freeway segments in Washington State. The research team concluded that continuous lighting makes no measurable contribution to nighttime safety performance, and that its installation for safety performance is not warranted [17]. 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 lighting is an effective mitigation measure for reducing crash rates, as current guidance in the AASHTO Highway Safety Manual suggests [18].

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.* found that moose activity generally peaks at dusk [10]; the Highway Safety Information System (1995) reported that the greatest number of vehicle-animal collisions occur during the early morning hours (4:00 a.m. to 6:00 a.m.) and during evening hours (6:00 p.m. to 11:00 p.m.); Cederlund reported that both roe deer and moose are most active during sunrise and sunset [9]. Although the WSDOT study showed that lighting may not be effective at reducing general vehicle crashes, continuous lighting is believed to be effective at mitigating MVCs.

3.4 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 a habitat. Nonstructural

methods include repellents, ultrasound, road lighting, population control, and habitat modification. Although more expensive, structural methods were thought to be more effective in reducing collisions [19].

MVCs were found to be a product of various environmental factors that are not exclusive and tend to affect the significance of one another. Therefore, the determination of helpful mitigation measures needed to involve all factors present in a given corridor where MVCs are frequent.

4. Methodology

The goal of the analysis was to determine if the number of MVCs (defined as the number of reported accidents involving moose) was reduced based on the measures of clearing and grubbing, continuous lighting, or a combination of these improvements along a given 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 apart 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): The number of reported MVCs is independent of the dependent variables.

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

$$H_a : \text{At least one } \beta_i \text{ does not equal zero}$$

To determine whether a significant linear relationship exists between the 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. To check the results for statistical significance, the significance, F , was evaluated. A variable with a high p -value (greater than 0.05) is an indication of unreliability and was consequently removed from the data set. The regression was rerun until F dropped 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

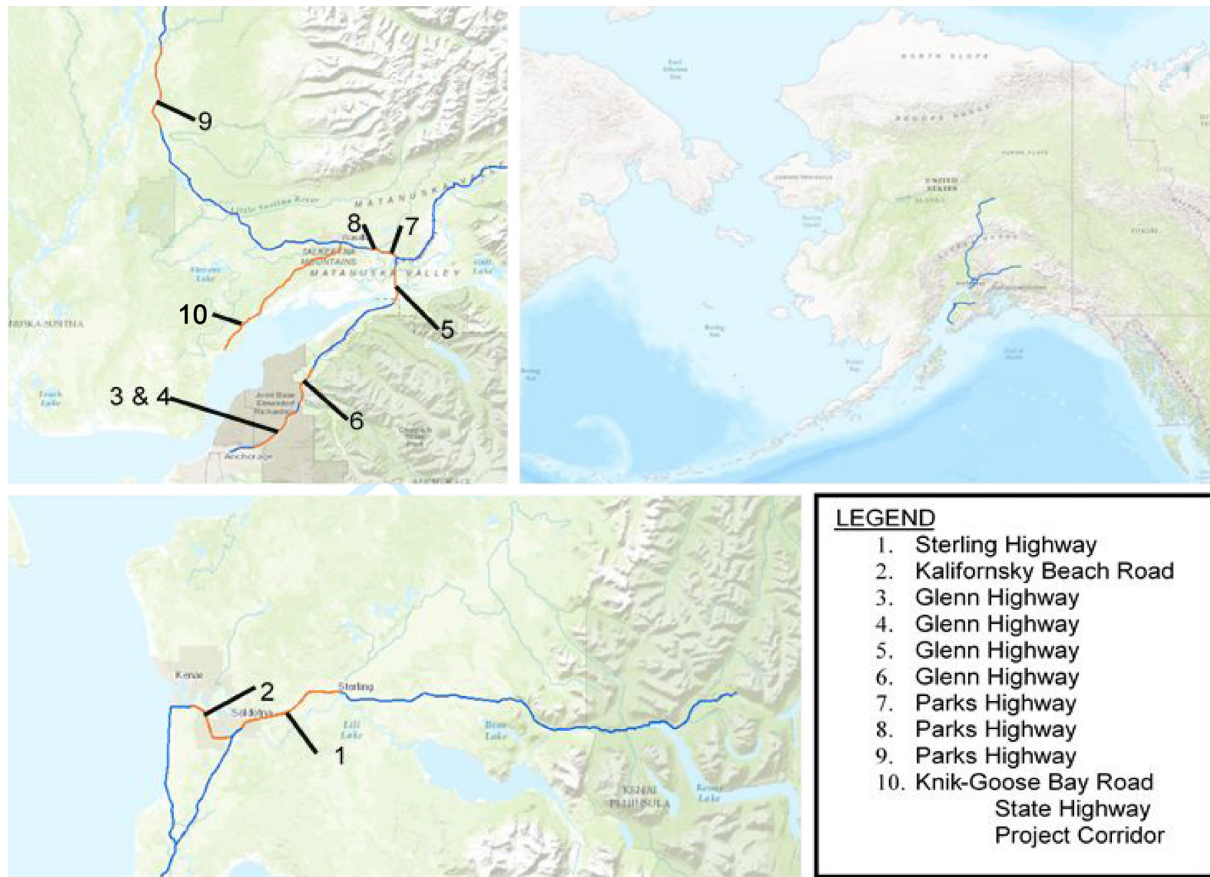


Fig. 2. Project Location Map (DOT&PF TGIS, 2017)

dependent variable, or predictor variable [20].

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k + \varepsilon \quad (1)$$

The number of variables included 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 [20].

$$\binom{n}{r} = \frac{n!}{r!(n-r)!} \quad (2)$$

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 is important for the use of estimating the anticipated effects of implementing one or both MVC mitigation measures: continuous lighting and clearing/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.

5. Data characteristics and discussion

Crash data were collected from the Alaska DOT&PF Statewide Crash Database. The data were sorted to include only crashes that involved MVCs and were then 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-built drawings were reviewed to determine improvement corridors by milepost (MP), construction date, and improvements performed. The crash data range includes a 10-year analysis period—five years before and five years after the project completion year. For each of the 10 projects (Fig. 2), the road segments analyzed were identified along with corridor MP limits, construction date, 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

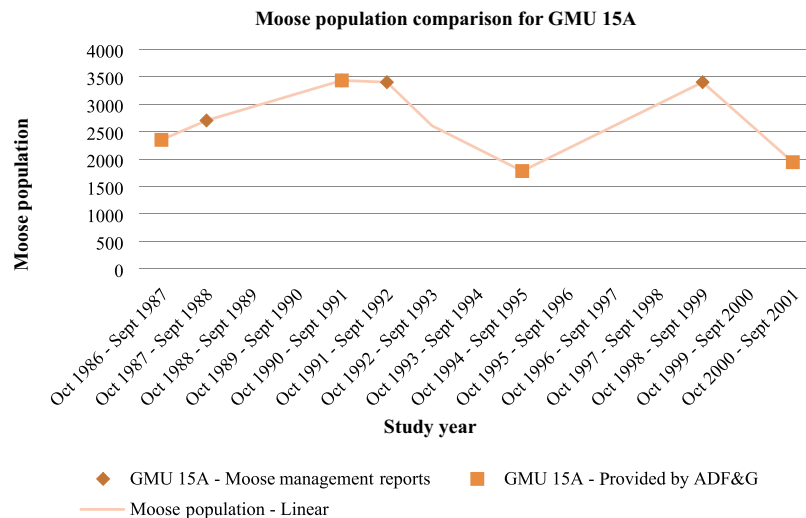


Fig. 3. Moose population comparison for GMU 15A

designated areas. Grubbing is the removal and disposal of all stumps, roots, moss, grass, turf, debris, or other objectionable material within designated areas [2]. These areas are then replanted with grass.

Sweanor and Sandegren found that lengthy durations of snow depth greater than 27.6 in. (70.1 cm) affected winter home-range size [6]. For this reason, snow depth was a crucial datapoint. Precipitation and snow data were obtained from Climate Data Annual Summaries for weather stations near the road segments studied.

Several studies have shown seasonal patterns in moose migration during summer [24] and winter [6]. Leblond *et al.* found that moose movement differed between annual periods: winter, spring, summer, and fall [24]. For this reason, each year of the study needed to range from the beginning of one season to the start of another, and not by calendar year alone. The annual precipitation data were grouped from fall to summer. This approach corresponds with construction season in Alaska, as shown in 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. This aligns closely with the start of the fall season beginning on fall equinox, which is approximately September 22nd. This approach also groups the full snowfall data for the winter season into one study year.

Moose population information was gathered from Alaska Department of Fish and Game (ADF&G) Moose Management Reports [25]. For Game Management Unit (GMU) 14A, population

surveys have historically been conducted during fall and winter months, typically November and December, but have also ranged from October to February. GMU 14B population surveys are conducted in fall, usually in October and November. GMU 14C surveys are conducted annually in the fall and early winter. GMU 15A moose population surveys are conducted in November and December of each year. GMU 15B surveys are typically conducted in November and December, but for one year the survey was conducted in February instead [25]. Due to these variations, yearly moose population estimates were assigned to match the same study year as precipitation data.

6. Results and discussion

This section provides an overview of the data collection and characteristics investigation conducted for the Sterling Highway MP 82.0–93.72 project as an example corridor. The project is 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 (Fig. 3).

6.1 Snow depth and snowfall

Weather information was gathered from KENAI MUNICIPAL AIRPORT, AK US COOP: 504 546, the closest weather station to the project corridor with complete precipitation data [23]. The linear moose

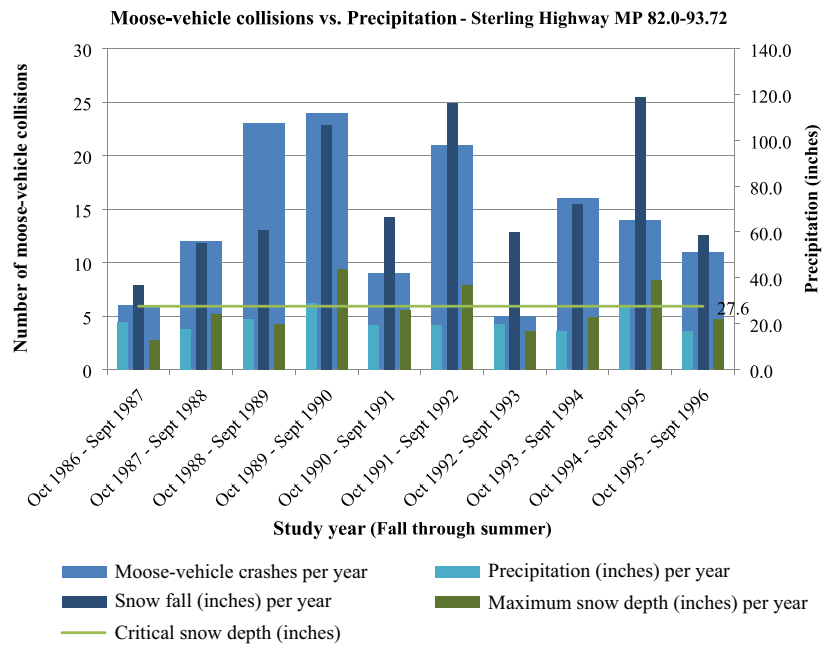


Fig. 4. Moose-vehicle collisions vs. Precipitation

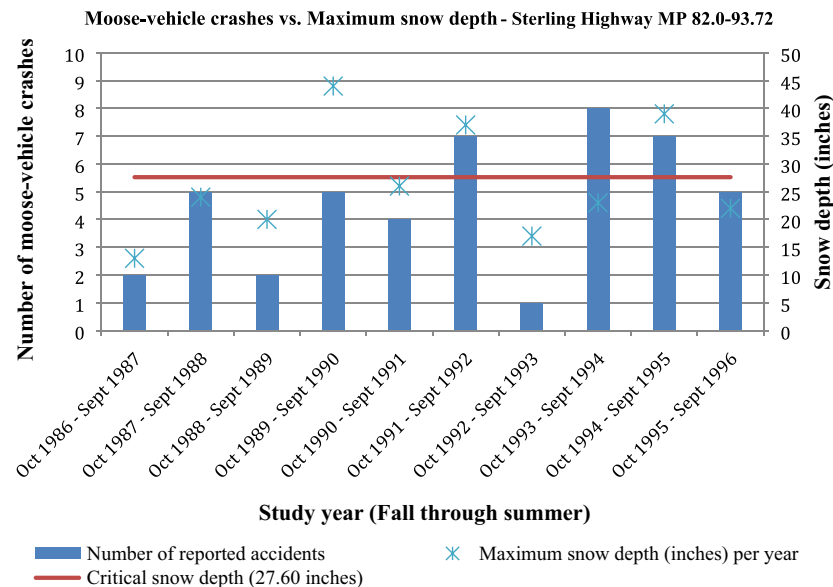


Fig. 5. Moose-vehicle collisions vs. Maximum snow depth

population estimate and the precipitation data were charted to compare data trends (Figs. 4–6). The number of reported MVCs shows a trend similar to recorded precipitation information, with both statistics decreasing and increasing during the same years (Fig. 4).

MVCs closely follow the same annual trend as maximum snow depth and snowfall (Figs. 5 and 6). Precipitation and snow depth are synchronized, since years of high precipitation yield high

snowfall and snow depth, and therefore have a similar relationship with 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 appear to contribute to MVCs. The largest decrease in MVCs occurred during the second year of post-project completion.

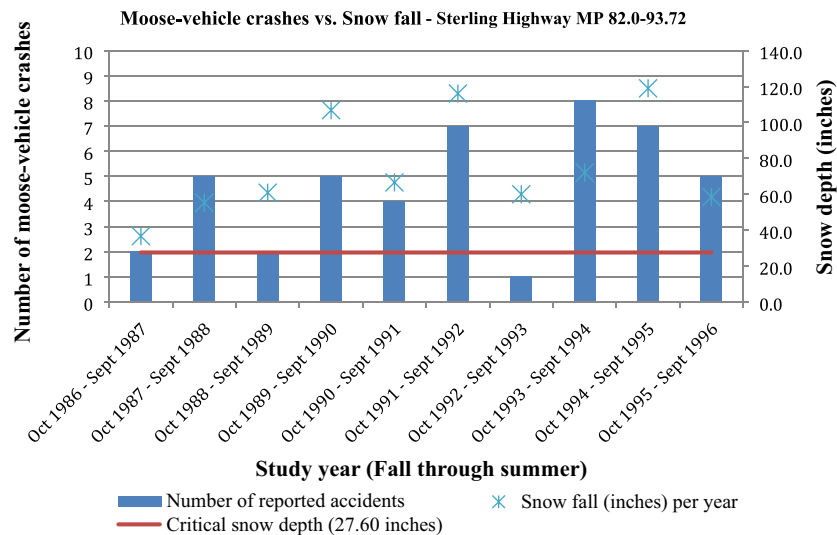


Fig. 6. Moose-vehicle collisions vs. Snowfall

6.2 Clearing, grubbing, and continuous lighting

As with the Sterling Highway MP 82.0–93.72 project, data collection and characteristic investigations were conducted for eight additional project corridors. The results of the regression analyses are summarized in Table 1. Four project results were inconclusive, thus a relationship between the number of reported MVCs and the independent variables was indeterminable. Results from the other projects show between 22.0% and 85.9% of the variation in crashes linked to the independent variables, with differing results on which variables contributed to the number of MVCs. There was also a discrepancy 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).

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 (effects on road and traffic characteristics). The results suggest that several factors not considered in this study should be included to achieve the required significance in data to

accurately predict the number of MVCs, such as 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 lighting. This study included lighting, 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 identified the trend of a significant decrease in MVCs due to corridor improvement projects. The Glenn Highway—Muldoon Road to Artillery Road project showed a significant drop in the number of MVCs after the installation of continuous lighting. The Glenn Highway—Hayflats (Matanuska River Bridge to the Parks Highway Junction) project resulted in a 50% drop in the five-year average of MVCs after the installation of continuous lighting.

The results show there is a consistent drop in MVCs following clearing and grubbing, except for one corridor. Like the clearing and grubbing projects, the clearing and grubbing combined with continuous lighting projects showed a consistent trend of a drop in the number of MVCs following project completion. The projects with clearing and grubbing as a component had varying trends

Table 1. Regression Analysis Summary

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

in MVCs post construction, which may indicate that DOT&PF Maintenance and Operations performed clearing of re-vegetated areas, or that older growth is less of an attractant for moose. The tracking of Maintenance and Operations activities and regrowth post construction could continue, in order 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, an increase in moose population, and/or other factors not included in this study.

6.3 Crash modification factors & crash reduction factors

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 2 summarizes each CMF, grouping each corridor by mitigation measure. The five-year average comparison is also included for each corridor. In general, a combination of continuous lighting and clearing/grubbing showed lower CMFs or resulted in lower MVCs.

Crash reduction factors (CRFs) were also developed using the average number of MVCs prior to and post construction. Table 3 summarizes the CRF for the corridors, which 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 produces a predicted MVC, whereas the CRF is determined based on the actual MVCs observed. The use of these values should consider the limitations of this study. Further information is needed in the development of more reliable values and additional study is recommended.

7. Conclusions

Although this study resulted in low statistical significance, there is evidence of positive results for the mitigation measures of continuous lighting and clearing/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.

Table 2. Crash Modification Factor Summary by Mitigation Measure

Project corridor	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	
Kalifornsky Beach Rd. MP 16.4–22.4	*			41.7% drop	0.54	0.78
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	
Glenn Highway MP 30.7–33.5	*	**		47.8% drop	0.52	0.48
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

Note: *Variable included in the regression analysis; **Variable included in the regression analysis; ***Variable included in the regression analysis; [†]Outlier not included in the combined CMF calculation.

Table 3. Crash Reduction Factor Summary by Mitigation Measure

Project corridor	Clearing and grubbing	Continuous lighting	Clearing	Crash reduction factor	Combined crash modification factor
Sterling Highway MP 82.0–93.72	*			0.91	
Kalifornsky Beach Rd. MP 16.4–22.4	*			0.58	
Parks Highway MP 37–39	*			0.64	0.83
Knik-Goose Bay Road MP 0.0–19.56	*			1.19	
Glenn Highway MP 4–11	*	**		0.44	
Glenn Highway MP 30.7–33.5	*	**		0.52	0.48
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

Note: *Variable included in the regression analysis; **Variable included in the regression analysis; ***Variable included in the regression analysis; [†]Outlier not included in the combined CRF calculation.

CMFs were developed in order 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 CMFs and five-year averages prior to and post construction. Continued study and analysis could assist in the development of more reliable CMFs.

8. Recommendations

Continued data collection is recommended for corridors where mitigation methods are being implemented. Additionally, systematic data collection for analyzing MVCs should be pursued

including 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.

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Data availability statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest statement

None declared.

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