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Highway Patrol Investment Levels vs. Crash Outcomes

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13. ABSTRACT (Maximum 200 words)

As a part of an effort to improve safety and evaluate optimal levels of investment in trooper patrols, Alaska's Department of Transportation and Public Facilities (DOT&PF) and Alaska State Troopers (AST) with the coordination of the University of Alaska Anchorage (UAA) College of Engineering commenced a study to develop a relationship between highway investment levels and crash instances in Alaska. The Phase I (Abaza, 2016) of the project is considered as "Proof of Concept" due to fact that scarcity of datasets for analysis to make further conclusions. The current research focuses on developing the correlation between patrol vehicle presence and crash occurrence, considering longer data collection periods for better statistical correlation. Data for an additional 18 months were collected from the appropriate sources and for a total of 2.5 years data were analyzed. Additional data, including pavement surface conditions and weather conditions, were also collected from the Road Weather Information System (RWIS). Binary logistic regression was used to examine the correlation.

The research team determined that a correlation exists between trooper presence (enforcement) and reduction in crashes in the five highway corridors. In addition, analysis of the data revealed some characteristics that might help AST develop enforcement strategies to further reduce crashes. Lastly, a comprehensive benefit-cost analysis was performed, showing that current enforcement levels are economically favorable on all corridors. In some areas, the benefit-cost ratio indicated that Alaska receives benefits that are twice the cost of enforcement. It is recommended to use the findings of this project to improve safety on these corridors and continue ongoing data monitoring with the data for extended periods to demonstrate adjustable enforcement levels as needed to achieve more predictable and desirable outcomes.

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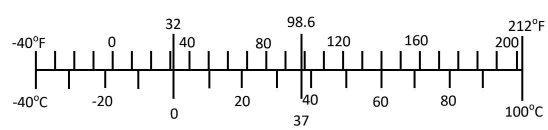
		VOLUME					VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces (US)	fl oz
gal	Gallons (liq)	3.785	liters	liters	liters	liters	0.264	Gallons (liq)	gal
ft^3	cubic feet	0.0283	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
Note: Volumes greater than 1000 L shall be shown in m^3									
		TEMPERATURE (exact)					TEMPERATURE (exact)		
ºF	Fahrenheit temperature	5/9 (ºF-32)	Celsius temperature	ºC	ºC	Celsius temperature	9/5 ºC+32	Fahrenheit temperature	ºF
		ILLUMINATION					ILLUMINATION		
fc	Foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2	cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

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



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- Matthew Murphy, Transportation Planner I, T DOT&PF
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ABSTRACT

As part of an effort to improve safety and evaluate optimal levels of investment in trooper patrols, Alaska's Department of Transportation and Public Facilities (DOT&PF) and Alaska State Troopers (AST) with the coordination of the University of Alaska Anchorage (UAA) College of Engineering commenced a study to develop a relationship between highway investment levels and crash instances in Alaska. Phase I (Abaza, 2016) of the project was considered "Proof of Concept" because of a scarcity of datasets for analysis to make further conclusions. The current research focuses on developing the correlation between patrol vehicle presence and crash occurrence, considering additional data for better statistical correlation. Data for an additional 18 months were collected from appropriate sources. Additional data, including pavement surface conditions and weather conditions, were also collected from the Road Weather Information System (RWIS). Binary logistic regression was used to examine the correlation.

The research team determined that a correlation exists between trooper presence (enforcement) and reduction in crashes in the five highway corridors. In addition, analysis of the data revealed some characteristics that might help AST develop enforcement strategies to further reduce crashes. Lastly, a comprehensive benefit-cost analysis was performed, showing that current enforcement levels are economically favorable on all corridors. In some areas, the benefit-cost ratio indicated that Alaska receives benefits that are twice the cost of enforcement. It is recommended to use the findings of this project to improve safety on these corridors and continue ongoing data monitoring for extended periods to demonstrate adjustable enforcement levels as needed to achieve more predictable and desirable outcomes.

SUMMARY OF FINDINGS

During the first phase of the project "Highway patrol investment levels versus crash outcomes" (Abaza, 2016), macro and intermediate analyses were performed to determine the correlation between trooper presence and crash occurrence in five corridors in Alaska. The results showed the existence of a strong correlation, but there was a lack of statistical significance due to the unavailability of data. Micro analysis was not performed for the same reason. The current phase uses binary logistic regression to perform macro, intermediate, and micro analysis using the data of an extended period of 2.5 years. Data characteristics of the variables considered are provided in depth. Benefit-cost analysis was also utilized following the method described in Phase I (Proof of concept).

It is observed from the data characteristics that trooper enforcement levels are maintained with respect to crash occurrence. In addition, the incidents and citations pattern seems to have a seasonal variation where number of citations and incidents are higher in summer than winter. On the other hand, seasonal variation of crash occurrence is opposite, meaning more crashes occur in winter than summer.

Both macro and intermediate analysis failed to describe the relationship between trooper presence and crash occurrence while also achieving statistical significance at a 95% confidence interval. On the other hand, the micro analysis results indicate that a strong correlation exists between trooper presence and crashes. The correlation is statistically significant for each corridor at a 95% confidence interval. The negative coefficients from analysis results suggest that the higher the presence of troopers, the lower the crash occurrence. Thus, enforcement is effective in reducing crashes in the studied corridors. Several variables in the micro analysis (traffic volume, pavement surface conditions, and weather conditions) have not yielded usable results because of the lack of instantaneous data.

For the purpose of benefit-cost analysis, the benefits were measured as the savings associated with the estimated crash reduction and the costs were determined by the observed troopers' patrol hours. The benefit-cost analysis revealed that current enforcement levels are economical due to the effectiveness of crash reduction on all corridors except Parks Highway reflecting a 0.94 ratio.

Chapter 1 – INTRODUCTION

In Phase I of this project, the research team successfully verified that geospatial data from trooper vehicles, along with crash, citation, and arrest data, could offer valuable correlations for DOT&PF to monitor in the future. Analyses also revealed that inclusion of additional independent contributing factors and at least another 18 months of data collection were needed to achieve statistical significance for meaningful conclusions. Phase II addressed the additional data and variables to arrive at statistically significant conclusions.

Efforts to reduce fatal and severe injury crashes on highways are one of the top priorities of transportation agencies in the United States. In 2015, an estimated 6,296,000 traffic crashes occurred in the United States, resulting in 35,092 fatalities and 2,443,000 serious injuries (NHTSA, 2015). Both monetary and non-monetary costs are associated with crashes, with an economic cost estimated at $242 billion in 2010 (NHTSA, 2015). To compare crash statistics across states, the number of fatalities per 100 million vehicle miles travelled (VMT) within each state is compared with the national average. In 2014, the national fatality rate was 1.08 whereas in Alaska the rate was 1.50 (AHSO, 2016). The Alaska Strategic Highway Safety Plan (SHSP) provides a framework of strategies and actions to reduce the most serious highway crashes by half by 2030.

In 2006, Legislatures, Alaska's Governor, DOT&PF Commissioner, and Public Safety Commissioner, announced an initiative to improve safety on Alaska's highways with the designation of Traffic Safety Corridors (TSC). These corridors, which include portions of the Seward, Parks, and Sterling Highways, as well as a portion of Knik/Goose Bay Road, have the highest rate of serious crashes on rural roads in the state. Most notably, there is a high occurrence of head-on and multi-vehicle collisions. These designations (and associated engineering, enforcement, and education efforts) have reduced the combined number of fatal and major injury crashes on the four TSCs by 45%.

The construction of divided highways with access management is documented in Alaska as the primary way to achieve a 45% or higher reduction in serious injury caused by opposing vehicle crashes. Current Safety Corridor Audits suggest the lasting effect of this crash reduction requires a continued intensive effort that may have diminishing results over time, and that significant highway projects are recommended towards removing Safety Corridor designation. The Safety Corridor Audit Team—consisting of the DOT&PF, the Alaska Highway Safety Office, local EMS officials, and the Bureau of Highway Patrol (BHP)—recommends enforcement in the TSCs to target aggressive, reckless, and improper driving, and to provide continuous evaluation of engineering, enforcement, and education countermeasures.

Problem Statement

The State of Alaska needs to determine optimum levels of law enforcement for minimizing the risks of highway travel. Knowing the relationship between enforcement levels and crash occurrence is a key component of that assessment, which would allow public officials to assign a dollar value to be compared against the cost of other solutions, such as building new roads or redesigning current roads.

Reductions in citations or arrests may falsely indicate that a reduction in enforcement is possible, when enforcement presence may actually prevent dangerous and illegal driving behaviors and therefore reduce serious injury crashes. Presence of troopers may be considered a countermeasure to prevent dangerous driving behavior as well as to reduce citations and incidents. A new performance measure is required to correlate enforcement times within and around high crash locations to find an appropriate balance. This project sought to create a method to link law enforcement presence to crash occurrence, including the impact of citations and arrests on illegal driving behavior.

Collision reports, citations, and incident information from appropriate agencies, such as the DOT&PF and AST, along with time and location information gathered by the installation of sensors on trooper vehicles along targeted highway corridors (including the above mentioned TSCs), were analyzed to assess data characteristics and potential interactions. This information was used to calculate the benefit-cost ratio of enforcement levels.

Chapter 2 - LITERATURE REVIEW

The literature review for Phase I explored published research articles pertaining to the project. This review discussed the idea of how the presence of patrol vehicles and automated enforcement technologies psychologically affect driving behavior, and presented information on the financial effects of vehicle crashes. It was also described how several statistical tools were used to correlate different parameters in various studies. Also discussed were various methodologies, traffic enforcement effectiveness, and cost-benefit analysis. Additionally, some background information related to the impact of pavement surface conditions and AADT on crashes were provided.

This literature was published in several sources, including the Australasian Transport Research Forum, Journal of Advanced Transportation, Transportmetrica A: Transport Science, International Journal of Police Strategies & Management, Journal of Transport & Health, Transportation Research Record: Journal of the Transportation Research Board, Safety Science, Analytic Methods in Accident Research, Accident Analysis & Prevention, Journal of Transportation Engineering, and Journal of Transportation Safety & Security. Details of the literature are attached in Appendix A.

Literature Review Findings

Various studies used binary logistic regression to identify relative importance of the variables considered. Some researchers used Pearson chi-square tests to correlate dependent and independent variables. The project used huge databases, which were extracted from Verizon Networkfleet and the Road Weather Information System (RWIS). Various tools such as SQL, SSIS, and MyMaps were used to process those databases for statistical and economic analysis. There is research demonstrating a methodology to process large data using GIS and SQL to evaluate effectiveness of law enforcement in reducing crashes.

Traffic enforcement effectiveness was also evaluated in many studies considering different enforcement laws, such as handheld cellphone bans, speed limits, speed camera systems, red-light running cameras, police enforcement, and mobile speed cameras. Handheld cellphone bans, red light cameras, and fixed-speed enforcement cameras were the most effective law enforcement tools to reduce crashes. Most countermeasures required law enforcement involvement to implement. Some proposed law enforcement strategies include rewarding safe drivers, defensive driving courses, community service for traffic tickets, and using automatic detection techniques to fine drivers and passengers for various offenses, including failure to wear seat belts, using cell phones while driving, and aggressive behavior.

Chapter 3 – METHODOLOGY

Phase I of the project presented a unique analysis methodology inspired by the DOT&PF, local research team, and the literature review based on the nature of the data retrieved from the field. The analyses were divided into three levels—macro, intermediate, and micro—to observe the interaction between trooper presence and crash occurrence.

The macro analysis of the first phase compared patrol vehicle spatial distributions to the presence of crash events over a 12-month period were not accounted for in the macro analysis. Both binary logistic regression and Poisson regression were applied. In the first trial, patrol vehicle presence, in units of hours, was considered the independent variable, and the binary presence of a crash event was the dependent variable. No statistical significance was found from the macro logistic regression analysis, except on the Richardson Highway. Finally, AADT was used as an additional independent variable in the second trial. This addition led to two of the five study corridors achieving statistical significance between patrol presence and crash events. The study corridors considered in the study were:

1. Glenn Highway
2. Parks Highway
3. Richardson Highway
4. Seward Highway
5. Sterling Highway

The intermediate analysis followed a two-trial methodology similar to the macro analysis, but regressions were based on monthly increments instead of a 12 month period. The results from both trials showed a statistically significant relationship between the presence of troopers and crash events for sections of all highways, except for the Glenn Highway. The coefficients of the logistic regression model were positive for both macro and intermediate analysis. Ultimately, micro analysis was not performed due to a lack of sufficient data for statistical significance.

Phase II also utilized binary logistic regression to correlate trooper presence with crash occurrence based on two and a half years of data (July 2015 to December 2017) along all corridors. AADT volumes were updated. Various pavement conditions and weather data, such as dry, wet, snow, icy, and temperature, were also included in the database.

3D and 2D plots of different data characteristics are used to illustrate the general relationship between trooper presence and crash events along each corridor over the two and a half years. AADT volumes are also shown to indicate the changes along these highways.

Three levels of analysis were performed in a manner that is similar to the analyses for Phase I. The statistical approach is explained in greater detail in Appendix C.

Macro Analysis

Phase II macro analysis of the datasets consisted of patrol vehicle spatial distributions compared to the presence of crash events over a 6-month period for each study corridor. In the first trial of the macro analysis, the independent variable was patrol vehicle presence, in units of hours, and the dependent variable was a binary rendering of crash events ('1' as 'YES' and '0' as 'NO').

Intermediate Analysis

Phase II intermediate analysis of the datasets follows a methodology similar to the macro analysis, but the data are divided into monthly increments.

Micro Analysis

Phase II micro analysis considered the activity details of each patrol vehicle when their location was near a crash event. Activity details are given based on 30 second intervals for vehicles in particular "geofences" (segments) of a corridor. "Geofences" are generally known as virtual geographic areas, either as a radius around a point location or as a predefined set of boundaries. For the purpose of this research, "geofences" are considered as a section of the corridors where data are extracted for trooper presence in and around the corridor for a length of five miles. If there was a crash event within approximately 500 ft. of the patrol vehicle's location, then a '1' ('YES') was assigned corresponding to the nearest time (within 15s). Otherwise, a '0' ('NO') was assigned.

The 500 ft. proximity along the transverse direction of highway is chosen based on discussion with AST and DOT personnel. Since there are no previous studies done to date on the consideration of the downstream effect of seeing an officer, the analysis was performed using a conservative 500 ft. window along the length of the highways, which is proportional to the 3 second data interval retrieved from the GPS units imbedded in the AST vehicles. Besides, the data processing considering that effect would be more complex and require a huge time commitment as it needs to be programed in the domain of the impact for each event separately in addition to dealing with a possible overlap of officers present on the corridor. It is worth noting that the total number of events used in this research are about 5 million covering 2.5 years.

The activity details of around 88 trooper vehicles within five corridors were recorded for the period of July 2015 to December 2017. Pavement conditions and weather data (dry, wet, snow, icy) were also assigned as binary variables, except for AADT and temperature, in order to perform binary logistic regression. Binary logistic regression was applied separately for each corridor. Figure 3.1 highlights the five corridors considered in this study. The freeway sections of Seward and Glenn Highway near Anchorage were not included in the study because there are no crash data available. Only AST crash data were available during the period of the project. These sections are patrolled by the Anchorage Police Department (APD).

Figure 3.1: Google Map highlighting the five corridors considered in the study

Chapter 4 – ANALYSES AND RESULTS

This chapter includes a summary of the data characteristics and their interpretation, followed by the statistical analysis results and outcomes. The descriptions of statistical analysis carried out for this study are presented in Appendix C. Details of the data characteristics are described in Appendix B. The results from economic analysis are also presented in this chapter with details in Appendix D.

Data Characteristics

The data considered in this project covers the time period of July 2015 to December 2017. Behavior changes from year to year, so changes in the variables were considered during data collection. The data characteristics might help AST in developing enforcement strategies. In addition, it will aid in understanding the statistical analyses in the following section.

Generally, patrol hours and number of crashes are found to be higher in the sections of corridors with higher traffic volumes. For example, on the Seward Highway, traffic volumes increase gradually heading northbound toward Anchorage. Average patrol hours follow the same trend, except near the city of Seward (Milepoint 0-25) (Figure 4.1). The AADT to average patrol hours ratio is low for the first 25 miles from Seward, then it begins to escalate. The overall scenario is similar to the Glenn and Richardson Highways. The total collisions are distributed almost uniformly across the highway. Milepoint 71-75 has the greatest number of crashes.

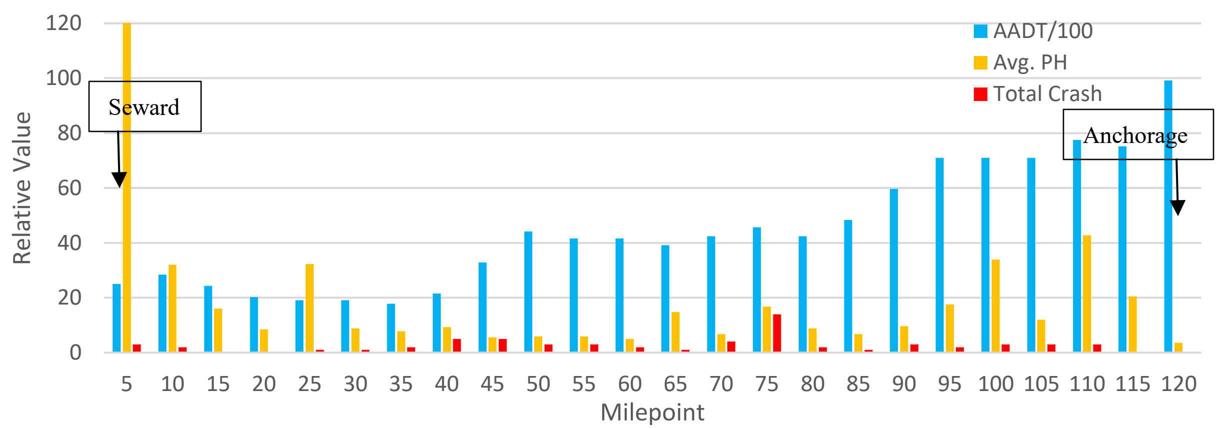

Figure 4.1: Data characteristics on Seward Highway in 2017

Overall, the greatest number of crashes occurred on the Parks Highway, but the most crashes per geofence were observed on the Seward Highway. The fewest number of crashes occurred on the Richardson Highway, which also had the fewest patrol hours. Patrol hours per geofence were greatest on the Sterling Highway, where crashes per geofence were almost equal to those that occurred on the Seward Highway. It is worth noting that the few miles of the Glenn and Seward highway beyond the Anchorage area are generally patrolled by APD. The patrol hours on those sections are very low compared to traffic volumes since the crash and patrol hour data used in this study are from AST. Per earlier discussions, these sections were not analyzed.

The patrol hour and crash distributions along the corridors are not uniform. Figure 4.2 and Figure 4.3 show patrol hours vs crashes on the Glenn Highway. The presence of troopers is substantial in only two locations, Palmer and Glenallen, the most populous towns along the corridor. Clusters of collisions are also visible in the Palmer area, though there is an almost uniform distribution of crashes between Palmer and Glenallen, indicating that additional enforcement might be needed. There are no crashes recorded by AST for the first 25 miles of the highway since the area is patrolled by APD (not shown in the figure).

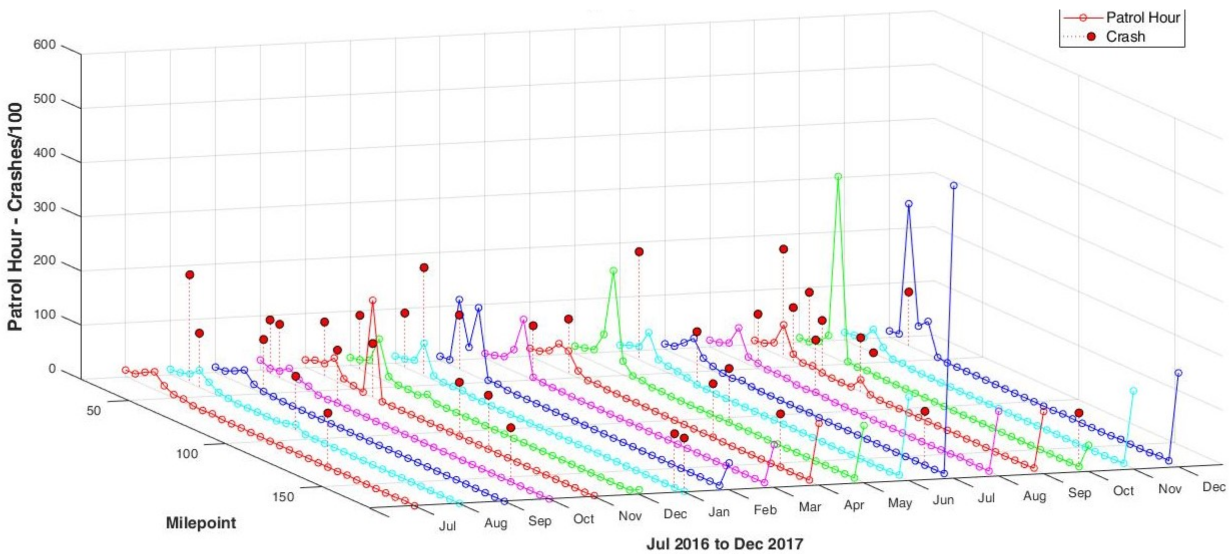

Figure 4.2: Glenn Highway patrol hours vs crashes (3D)

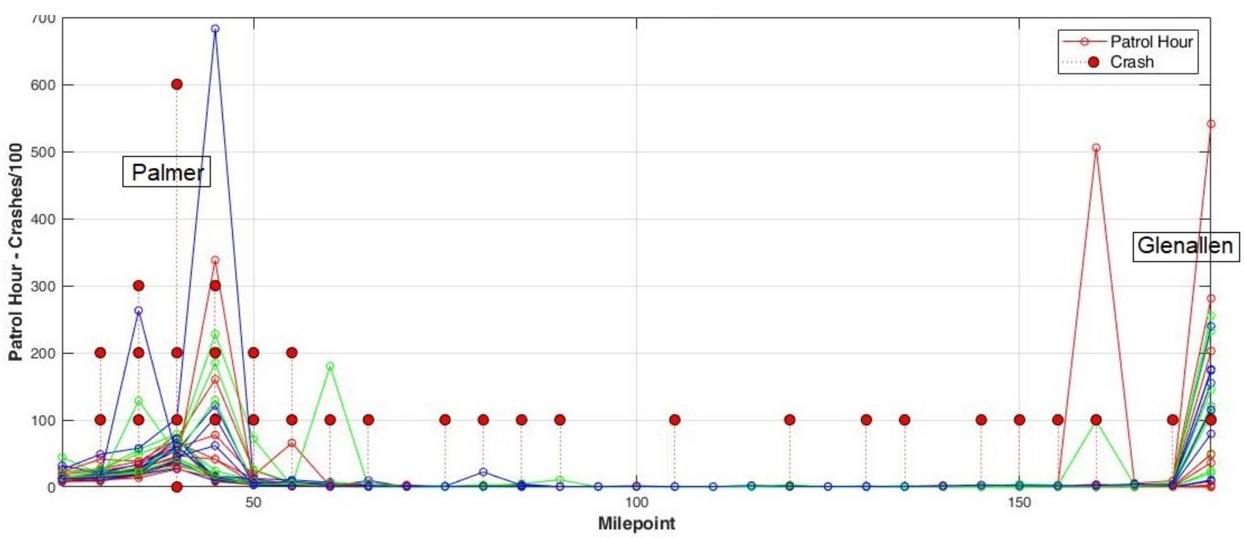

Figure 4.3: Glenn Highway patrol hours vs crashes (2D) (July 2016 to December 2017)

Considering total patrol hours and total crashes, trooper presence was not consistent throughout some areas. For example, Figure 4.4 shows patrol hours vs total crashes on the Parks Highway during the study period. Patrol hours are proportional to total crashes in the areas around Wasilla, Cantwell, and Fairbanks, but they are not proportional in the region between Wasilla and Cantwell (Milepoint 70 to 150). This is partly explained by the fact that some trooper headquarters are located within the urban areas near these corridors, which could result in a measure of patrol hours in excess of the actual number used for enforcement purposes

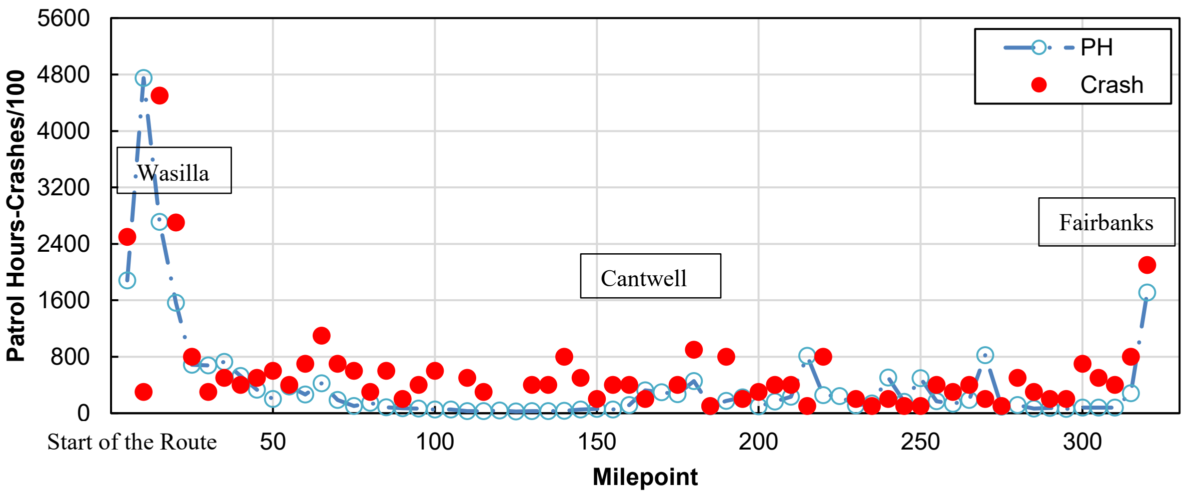

Figure 4.4: Total patrol hours vs total crashes along milepoint of the Parks Highway

The overall number of crashes for each individual corridor decreased in 2017 without exhibiting seasonal similarities (Figure 4.5). The greatest crash frequency occurred between July of 2015 and March of 2016, whereas the lowest crash frequency occurred in April and May of 2017. However, the combined data for all corridors offers variation that is clearly seasonal (Figure 4.7). Generally, November to January is when total crashes are at their highest. The months of April and September, on the other hand, have the fewest crashes.

As mentioned earlier, the distribution of patrol hours are not uniform throughout the study period. Patrol hours increased on the Seward Highway over the study period but decreased along all other corridors. However, the combined patrol hours displayed a greater degree of uniformity from month to month (Figure 4.7). The fewest patrol hours were logged in August to October of 2016 and 2017.

Figure 4.5: Monthly total crashes along all corridors (July 2015 to December 2017)

Figure 4.6: Monthly total patrol hours along each corridor (July 2015 to December 2017)

The ratio of total patrol hours to total crashes for all corridors together were greater in 2015 and 2016 than in 2017.

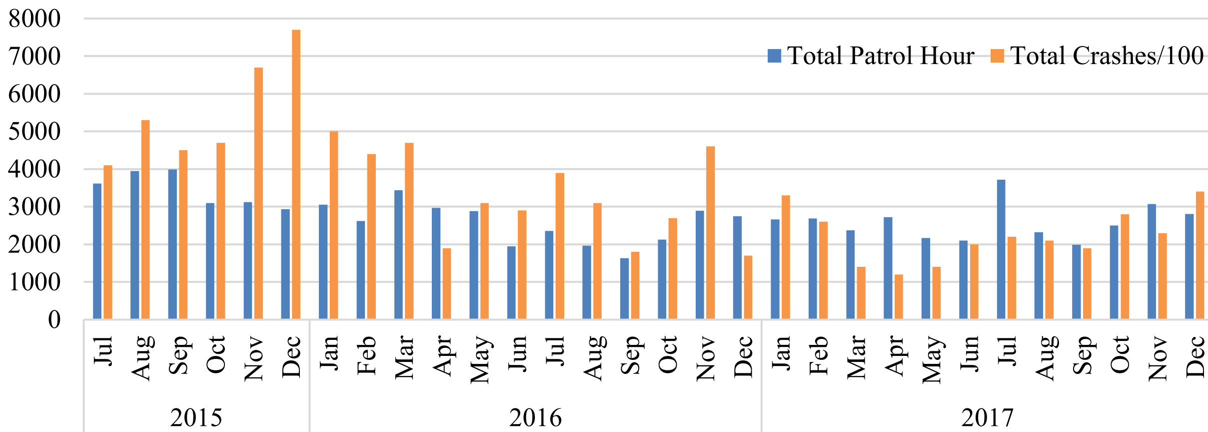

Figure 4.7: Combined monthly total patrol hours vs total crashes along all corridors

The monthly patterns of citations and incidents suggest a seasonal trend that opposes the seasonal trend for crashes (Figure 4.8 and 4.9). The categories and definitions considered for citations and incidents are given in Appendix B. The greatest number of citations and incidents occur in summer, while the fewest occur in winter. That this pattern is opposite the crash trend may indicate that drivers try to drive more safely when the level of enforcement is greater.

Figure 4.8: Monthly total citations along the corridors (July 2015 to December 2017)

Figure 4.9: Monthly total incidents along the corridors (July 2015 to December 2017)

Overall, patrol hours were higher and number of crashes lower on the Parks, Seward, and Sterling Highways, as compared to the Glenn and Richardson Highways. However, there are several sections along each corridor where trooper presence is much higher than on other sections of the corridor, despite the fact that number of crashes are higher in some of those other sections. Reallocating patrol hours to sections with a higher number of crashes may be a way to decrease the number of crashes. More insights of probable percent reduction in crashes with percentage of trooper's presence are presented later in this chapter. Moreover, as there is some inconsistency in patrol hours from month to month and season to season, it may reduce the number of crashes to increase patrol hours in periods that had lower patrol hours during the study period.

Statistical Analysis and Results

Statistical analyses were performed based on the methodology discussed earlier. There were three levels of statistical analysis: macro analysis of each study corridor for the full period (2.5 years) and 6-month periods, intermediate analysis of monthly data along all highways, and micro analysis for the full period. A detailed explanation of the statistical analyses and corresponding results are presented in Appendix C.

Macro Analysis

The macro analysis results from the full study period achieved statistical significance for all corridors except for the Seward Highway, which was also true of the Poisson regression analysis from Phase I. However, the positive coefficients suggest a positive correlation between trooper presence and crash occurrence, meaning that the probability of a crash increases with an increase in the presence of troopers—which is an improbable conclusion.

This may be because of the unusual characteristics of the data. For example, the distribution of trooper presence and crash frequency is much higher along certain sections of the corridors for certain periods. The likely explanation for the false positive correlation is that trooper presence increases because troopers are responding to crash events. Because this level of analysis did not provide realistic results, it will not be considered any further for this project.

Intermediate Analysis

The intermediate analysis results did not achieve statistical significance for the correlation between patrol hours and crashes on most highways in most months. There is no statistical significance for the Seward Highway at all. These results were expected due to the small number of crashes in many cases, or no crashes in some cases. Therefore, the use of intermediate analysis to build the correlation between trooper presence and crash occurrence does not suffice because instantaneous time occurrence and alignment of the variables are important in establishing the relationship. No further actions were taken on this level of analysis.

Micro Analysis

The results from the micro analysis suggest that a strong correlation exists between trooper presence and crashes. The correlation is statistically significant for each highway at a 95% confidence interval (Table 4.1). The coefficients of the independent variable for every highway are negative, suggesting that the number of crashes decrease in the presence of troopers.

Estimated probabilities of crashes also suggest that trooper enforcement is effective in reducing crashes.

Table 4.1: Results of micro analysis

Highway	P-value	Coefficient	Constant	Odd Ratio	Probability of crashes without presence of troopers per 30 s	Probability of crashes with presence of troopers per 30 s	Probable number of crashes without presence of troopers per year	Probable number of crashes with full presence of troopers per year
Glenn	<0.0001	-2.215	-8.527	0.109	0.019801	0.002162	208.15	22.72
Parks	<0.0001	-1.759	-8.694	0.172	0.016756	0.002886	176.14	30.34
Richardson	<0.0001	-2.766	-8.002	0.063	0.033468	0.002106	351.82	22.14
Seward	<0.0001	-1.912	-8.308	0.148	0.024648	0.003643	259.10	38.30
Sterling	<0.0001	-2.045	-8.591	0.129	0.018574	0.002403	195.25	25.26

Trooper presence was most effective in reducing the number of crashes on the Richardson Highway, while trooper presence was least effective on the Parks Highway. Overall, the crash occurrence would be decreased to an average of 28 crashes per year with full trooper presence through all corridors. Here, full trooper presence indicates the steady presence of trooper in a geofence at each 30s interval. While this is not a practical solution, since troopers cannot be stationed every 500 ft., the knowledge will help to optimize patrol hours and patrol locations for both crash reduction and expense reduction.

Figure 4.10 describes the best scenario for possible crash reduction rates by showing the probability of crashes per geofence per year with respect to trooper presence. The steep negative slope of the Seward Highway indicates that the potential reduction of crashes in the presence of troopers is the highest of any corridor, which resembles the observed crashes per geofence given in Table 4.2. The probability of crash occurrence without the presence of troopers is also the highest in this corridor (about 11 crashes per year per geofence). The probability of crashes per geofence for the Richardson, Glenn, and Sterling Highways agree with the observed crashes per geofence shown in Table 4.2. However, the Parks Highway's predicted crashes per geofence, which are very low, do not reflect the reality of observed crashes. The presence of troopers in the x axis represents the ratio of trooper presence (in patrol hours) to the total number of hours in a year. For example, a value of 20% is equivalent to 1752 patrol hours (0.2*365*24 = 1752, where 365*24 = 8760 is the total numbers of hours in a year). In the sterling highway, for example, the total patrol time of 21(average) trooper vehicles within 2.5 years is about 19,390 hours. Therefore, the presence of troopers = 19,390/ (2.5*365*24)/ 21 = 0.042. The predicted number of crashes from the micro analysis model for this enforcement level (troopers presence = 0.042) is 6.63 crashes per year per geofence.

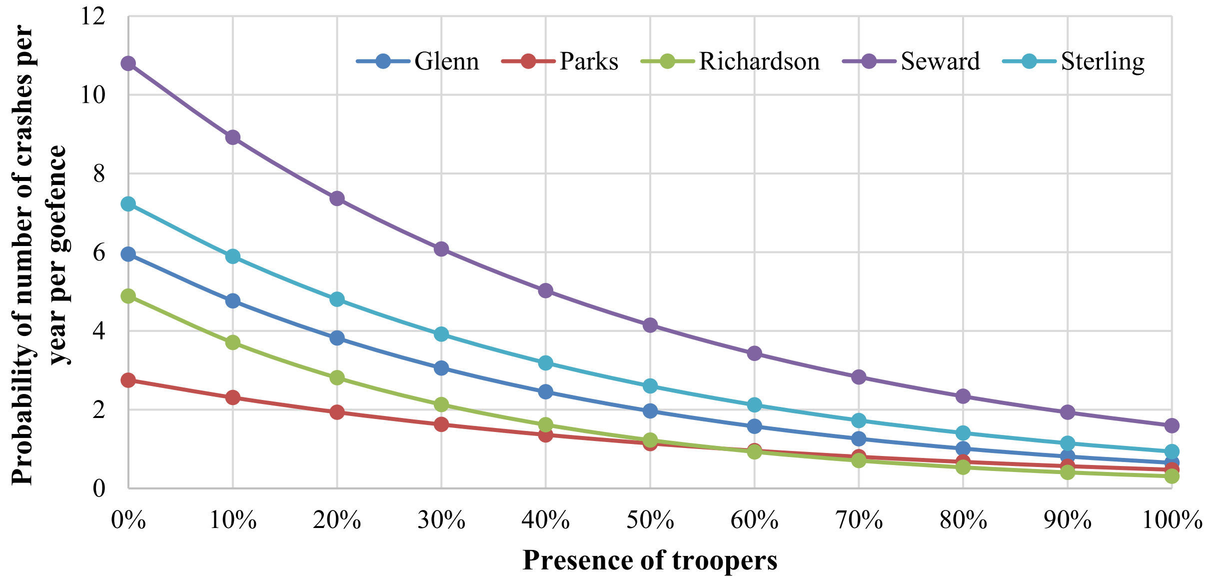

Figure 4.10: Probable number of crashes per geofence along each corridor with respect to patrol presence

Table 4.2: Total patrol hours and crashes per geofence for study corridors based on current rate of enforcement

Highway	Total Patrol Hour	Patrol hours per geofence per year	Total observed crashes (Jul 2015 to Dec 2017)	Observed crashes per geofence per year
Glenn	12706.36	145.22	122	1.39
Parks	25398.36	158.74	388	2.43
Richardson	6798.21	37.77	169	0.94
Seward	14511.02	241.85	202	3.37
Sterling	19387.78	287.23	227	3.36

Binary logistic regression results for combined corridor data are reflected in Figure 4.11. The use of this function should be limited to the planning level only as the differences between corridors probable number of crashes per geofence are significant.

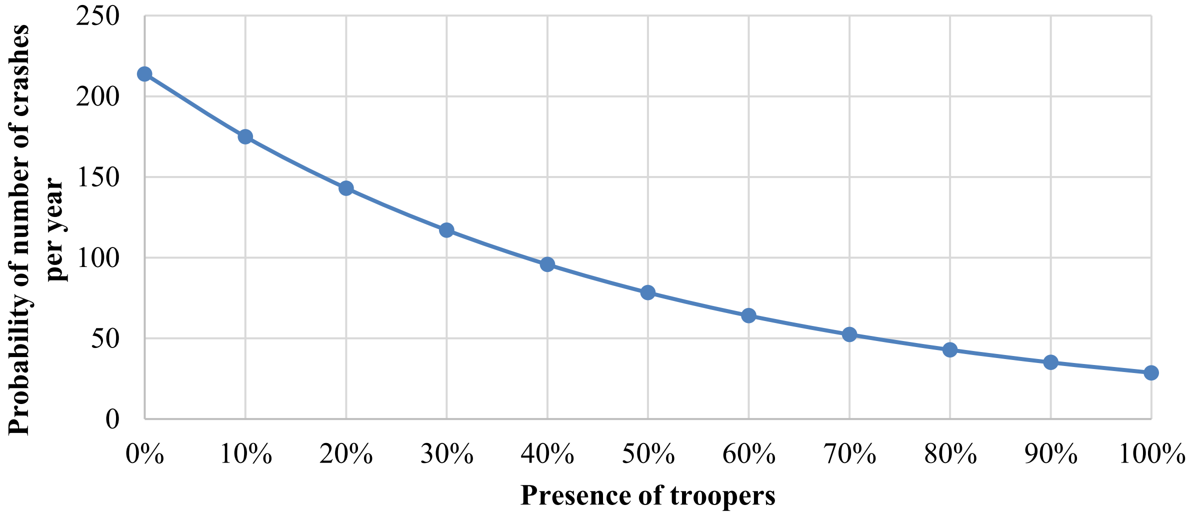

Figure 4.11: Probability of number of crashes per geofence along all corridors together

The list of regression equations from the micro analysis models of each corridor and of all corridors combined are given in Table 4.3. The p values in the regression equations denote the probability of a crash occurrence while the x value is the presence of troopers.

Table 4.3: List of regression equations for estimating probability of crashes

Highway	Coefficient	Constant	Regression Equation
Glenn	-2.215	-8.527	$ln\frac{p}{1-p} = -8.527 - 2.215x$
Parks	-1.759	-8.694	$ln\frac{p}{1-p} = -8.694 - 1.759x$
Richardson	-2.766	-8.002	$ln\frac{p}{1-p} = -8.002 - 2.766x$
Seward	-1.912	-8.308	$ln\frac{p}{1-p} = -8.308 - 1.912x$
Sterling	-2.045	-8.591	$ln\frac{p}{1-p} = -8.591 - 2.045x$
All Corridors	-2.009	-8.500	$ln\frac{p}{1-p} = -8.500 - 2.009x$

The following figures represents the percentage of crash reduction with different levels of trooper presence for individual highways (Figure 4.12) as well as for all corridors combined (Figure 4.13). The figures suggest that trooper enforcement is most efficient on the Richardson Highway whereas it is least efficient on the Parks Highway. A 100% level of trooper enforcement on the Richardson Highway could reduce motor vehicle collisions by about 94%. Here, a 100% level of trooper enforcement means that one trooper is present during every 30 second interval on all 500 ft. sections of the corridor. This value represents an impractical extreme and is considered only theoretically, providing a sense of the relationship between the variables. For example, to achieve a specific crash reduction percentage (y), enforcement levels should reach the corresponding percentage (x).

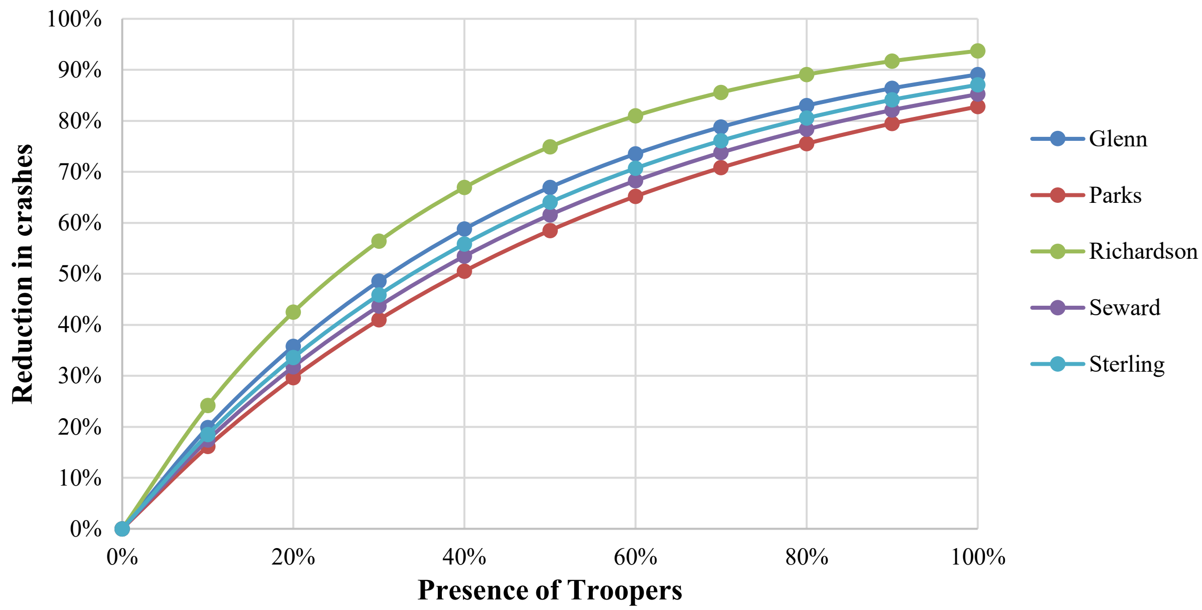

Figure 4.12: Reduction in crashes with presence of troopers for individual highway corridors

On average, using the overall model, the greatest possible crash reduction percentage is 86%. Again, this level of enforcement is purely theoretical. However, if the target crash reduction is 55% and the current enforcement level is at 20%, then this model could be used to recommend a doubling of the enforcement level to 40%.

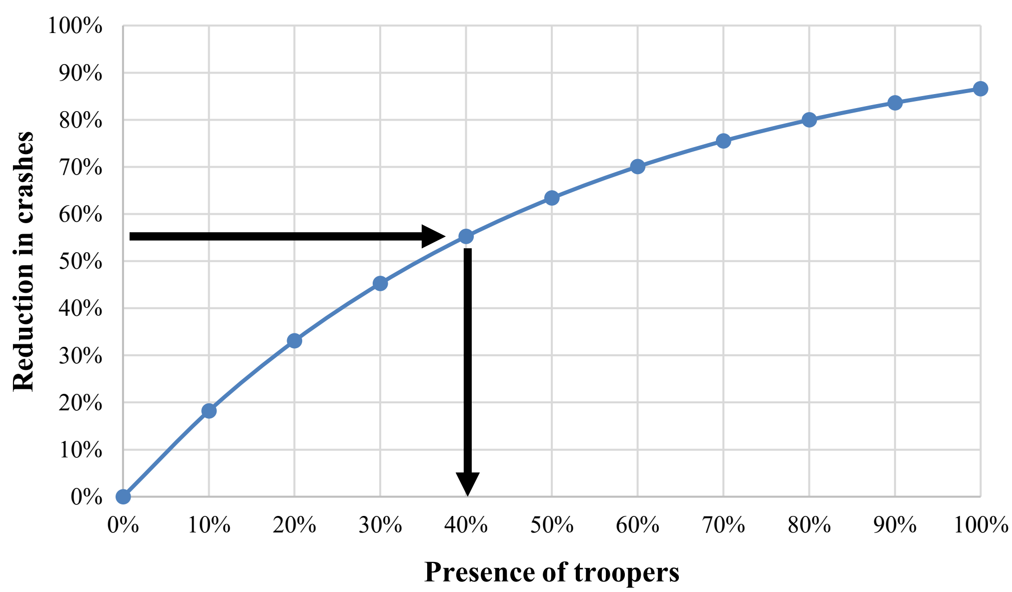

Figure 4.13: Reduction in crashes with presence of troopers for all corridors together

Micro Analysis Using Other Variables

Micro analysis was performed at a 95% confidence interval using three new variable types: traffic volume (AADT), pavement surface conditions (surface temperature, dry, wet, and icy), and weather conditions (snow only). The pavement surface conditions and the weather condition data were collected via Alaska's Road Weather Information System (RWIS) where data are recorded at fixed stations along the five highways (Figure 4.14). The correlation between surface temperature and crashes is found to be significant only on the Glenn Highway, and the effect of temperature was different on different corridors. The results for traffic volume depict statistical significance for the relationship between crashes and pavement surface temperature except on the Seward and Sterling Highways. However, the odd ratios for each highway are close to 1, which indicates that AADT has very little effect on crash occurrence when considered with trooper presence.

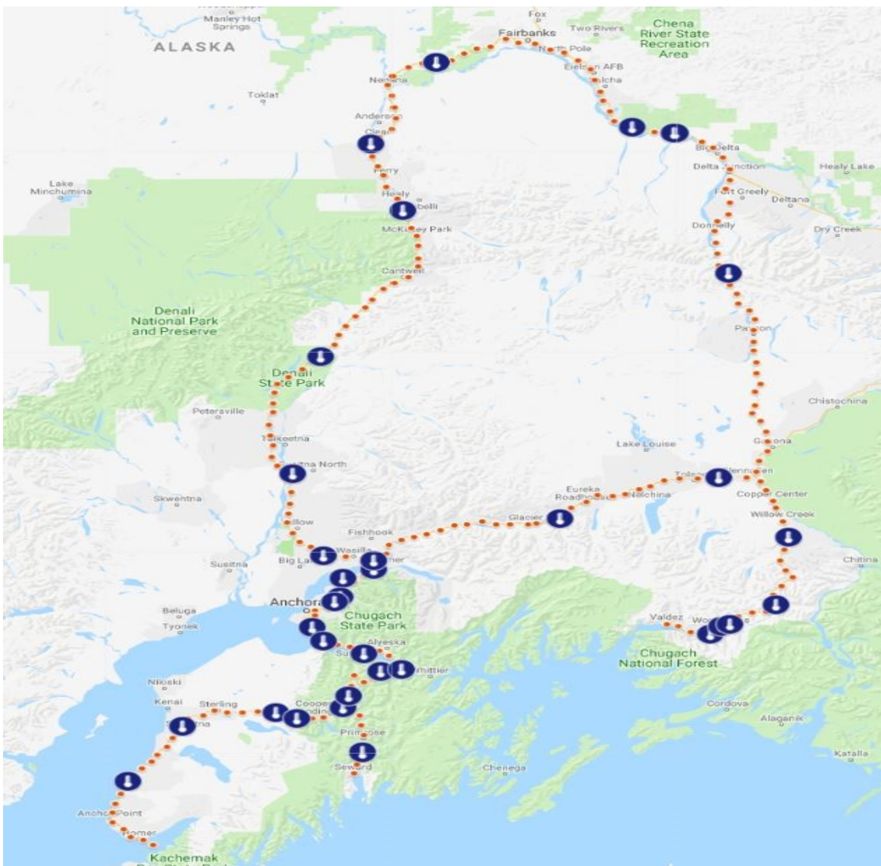

Figure 4.14: RWIS stations along the highways

The different pavement surface conditions had differing effects. Icy surface conditions did not have any influence on crashes, whereas both dry and wet surfaces had some effect on the Parks, Richardson, and Seward Highways, though the relationship was not statistically significant. On the Parks Highway, the probability of a crash increased in dry surface conditions and decreased in wet surface conditions. The probable number of crashes in dry surface conditions on both the Richardson and Seward Highways is unrealistically high.

Finally, the results for presence of snow show a positive effect on the number of crashes on the Glenn, Seward, and Sterling Highways, though the relationships are not statistically significant. The odd ratios and coefficients for snowy conditions indicate a low probability of crashes in snowy weather condition.

The results for traffic volumes are unusual since AADT is measured annually, while crash occurrence is measured in 30 second intervals. For AADT to be a viable measure for analysis, traffic volume would need to be measured at the time of the crash, which is not currently possible. Similarly, the overall results for both pavement conditions and weather conditions are not significant because the data collected from RWIS were measured in 10 minute intervals, not 30 second intervals. Additionally, some of the pavement condition data were recorded as 'Error', 'Other', and '?', which were considered as dry in the analysis. Moreover, the data collected from RWIS were based on 34 fixed stations in the study corridors (Figure 4.14), which does not necessarily represent the actual conditions in each geofence.

In summary, the additional variables collected to improve the crash prediction model will not be considered because they may not reflect the actual conditions during crash events and were not statistically significant. This will lead to a simplified model that considers only trooper presence as a predictor of crash occurrence.

Economic Analysis

Benefit-cost analysis was performed based on the method described in the first phase of the project. The analysis will enable decision-makers to compare the benefit of crash reduction to the cost of trooper enforcement on each of the five studied corridors. Results from the micro analysis were used to carry out the benefit-cost analysis.

Benefit-cost ratios were calculated using a given set of data and values for benefits versus costs. Benefits were determined by the direct and indirect costs associated with the estimated crash reduction. The KABCO scale representing national crash values was used to estimate the direct costs associated with each crash severity type. This scale was developed by the National Safety Council (NSC) and is frequently used by law enforcement for classifying injuries:

- K – Fatal;
- A – Incapacitating injury;
- B – Non-incapacitating injury;
- C – Possible injury; and
- O – No injury.

Costs were determined by the actual total patrol hours of each corridor within the study period. The benefit-cost ratios for each study corridor are presented in Table 4.4. Details of the benefit-cost analysis are described in Appendix D.

Table 4.4: Benefit/Cost Value

Highways	Total Benefits	Total Cost	Benefit/Cost
Glenn	$ 1,921,708	$ 1,905,932	1.01
Parks	$ 3,656,879	$ 3,872,988	0.94
Richardson	$ 1,688,999	$ 1,029,576	1.64
Seward	$ 5,103,405	$ 2,223,487	2.30
Sterling	$ 3,493,715	$ 2,934,641	1.19

The benefit-cost ratios indicate that the current trooper presence on the Glenn, Richardson, Seward, and Sterling Highways is economically justifiable. However, the ratio on the Parks Highway is slightly less than 1, which indicates that the trooper presence on that highway could become economically justifiable with either an increase in benefits or reduction in costs. This could likely be accomplished without a reduction in patrol hours by redistributing trooper presence along these corridors to areas with a higher number of crashes, thereby reducing the number of crashes. The total breakeven cost for the combined corridors is about 8.5 million.

Chapter 5 – CONCLUSION

As a continuation of the previous phase of this research, the primary objective of this project was to develop a correlation between highway patrol investment and crash instances along the five major corridors in Alaska. Data characteristics and their variation along the highways were explained in detail to visualize the situation that generally exists in the corridors. Benefit-cost analysis was also addressed, which will help the authorities to compare the benefits of crash reduction to the cost of trooper enforcement on each of the five highways.

Findings/Interpretations of Analyses

The results from the statistical analysis suggest that there is a correlation, statistically significant at a 95% confidence interval, between reductions in crashes with trooper presence for all the corridors studied. The relationship indicates that the presence of troopers has a major effect on the number of crashes. The coefficients for trooper presence from the binary logistic regression were negative, meaning that the higher the trooper presence, the lower the crash occurrence. Therefore, future strategies to reduce the number of crashes in Alaska should include a careful examination of the level of enforcement.

The results of analyzing crashes with additional variables, such as traffic volumes, weather conditions, and pavement surface conditions, failed to yield any significant correlation due to a lack of appropriate data. While these variables did not show any significant influence on crashes in these analyses, it is unlikely that the results are valid.

Based on the data characteristics, there are some sections along each corridor where the enforcement level is too low. There are also several sections where the trooper presence is higher than necessary, at least in relation to the number of crashes. Therefore, the redistribution or increase of trooper presence may play an essential role in reducing collisions. The incidents and citations pattern over the study period has a seasonal trend that is opposite of the crash trend. This indicates that higher rates of citations and incidents tend to reduce the number of crashes.

The economic analysis shows that investment in enforcement is economically justifiable due to the benefit of crash reduction. Thus, funding for enforcement is crucial for safety along those five corridors.

Recommendations for Future Research

Though the findings from this research suggest a correlation between reduction of crashes and trooper presence, it would be possible to refine the model by further extending the study period and as data improves in quality and quantity. The data for trooper patrol hours and crashes need to be continuously recorded and the database should be upgraded to examine the findings more precisely. The traffic volumes and weather data would become more meaningful if it was captured in 30 sec. intervals, thereby matching the 30 sec. intervals of trooper location data. In addition, the proximity for crashes should be increased to address the downstream effect of seeing a trooper on drivers. Moreover, it might be more realistic if the analysis used data on the segment based on similar vehicle miles traveled (VMT) instead of geofence. The findings from this report may be used to optimize enforcement strategies to reduce crashes for the AST. Other variables, such as driver behavior and geometric features of the highways, may also be considered.

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Appendix A – Literature Review

The research literature pertaining to this project was addressed in Phase I. As part of Phase II, the literature review was updated to include methodologies being considered for the study of traffic enforcement effectiveness, crash cost estimation and safety investment, and impact of pavement surface condition and AADT on crashes.

Methodologies

A study was done on enforcement investment by DOT&PF. In the study, a 2007 review of the Anchorage Police Department (APD) Traffic Unit was presented. The APD had taken measures to make roads safer, including transferring officers from patrol units to traffic units within the period of 2003 to 2007. The collisions and fatalities in the Municipality of Anchorage were decreased significantly during this period, which suggests a correlation between enforcement investment and reduction in crashes.

Al-Taweel et al. (2016) used binary logistic regression to determine the factors affecting avoidance maneuvers of two-passenger vehicle crashes. A Pearson Chi-square test was applied using the National Automotive Sampling System-Crashworthiness Data System to evaluate significance of the variables considered. To find the relative importance of the variables, a binary logistic regression model was also introduced.

Simandl et al. (2016) evaluated the effectiveness of selective enforcement. A large dataset was processed by using structured query language (SQL) and geographic information system (GIS) technology. The varied data—such as police patrol patterns, citations issued, crash occurrences, and selective enforcement periods—were integrated by that approach. 1.3 million datasets of selective enforcement location information were gathered from 37 million points of GPS data using SQL. 72.6% of electronic citations were enabled with geolocation data and 21 selective enforcement areas were identified using the same technique. After performing analysis, crash frequency was found to be reduced with an 85% confidence level and 254% increase in citations, as well.

Traffic Enforcement Effectiveness

Dong et al. (2017) conducted research on the effectiveness of highway safety laws for improving traffic safety across the U.S. The effects of highway safety laws on fatal crashes were analyzed for their variation across the states. Random-parameter zero truncated negative binomial (RZTNB) models were used to examine the effectiveness and performance of those laws. The models were found to be useful in describing relationships among the variables considered. Handheld cellphone bans and speed limits were indicated as effective and safe. Speed camera systems and ignition interlocks showed weak performance. It was suggested in the study to consider other methods when updating laws and regulations.

Shabaan (2017) conducted research on drivers' perceptions of various police enforcement strategies in Qatar. Face-to-face surveys were conducted to examine drivers' perceptions towards existing and proposed police traffic enforcement strategies and associated penalties and rewards.

The existing police enforcement strategies included red light running cameras, fixed-speed enforcement cameras, police enforcement, and mobile speed cameras. Among these existing strategies, red-light running cameras were perceived to be the most successful due to high violation fines and automation of the system. A reward for safe driving was selected by participants to be the most successful proposed strategy. Other proposed strategies considered were defensive driving courses, community service for traffic tickets, and additional automated enforcement methods, such as detecting and fining drivers and passengers who do not wear seat belts, drivers who use their cell phone while driving, and drivers who display aggressive behavior.

Wu and Lou (2014) developed a patrol beat scheduling model to improve highway accident management in Taiwan. The model is formulated as a chance-constrained optimization model and its objective was to decrease officer work hours. Historical accident data were used for the model to create beat schedules and to determine their effectiveness. It was found from the study that total daily work hours generated by the model were 21 hours less than the average work hours in 2006 at a confidence level of 100%, which is a 24 percent reduction in work hours, leading to a large cut in costs, too. A simulation program was also introduced to determine effectiveness of beat schedules extracted from the model.

Sung et al. (2015) studied law enforcement involvement and traffic safety effectiveness. The U.S. National Highway Traffic Safety Administration's (NHTSA) 2013 data were used to evaluate law enforcement effectiveness as a countermeasure. NHTSA rated those countermeasures in terms of effectiveness and expert reviewers coded countermeasures as a means of requirement of law enforcement. After performing cross tabulation of rated countermeasure and involvement of law enforcement, Spearman’s rho was calculated and assessed effectiveness of countermeasures and relation with law enforcement. It was found from the assessment that 43% of the countermeasures required law enforcement involvement, whereas only 19% did not require law enforcement. The study suggested that countermeasures that involve law enforcement tend to be more effective than those that do not.

Crash Cost Estimation and Safety Investment

Mangones et al. (2017) compared safety-related risk and benefit-cost analysis of crash avoidance systems applied to transit buses between New York City and Bogota, Colombia. The safety benefits of using forward- and side-collision warning systems and active collision avoidance systems in transit buses for each city were observed. A transportation risk profile was also developed using historical data from crashes, including driver, passenger, pedestrian, bicyclist, and crash severity. The assessment of potential reduction in injuries and fatalities in road crashes that involve buses was done by analyzing the judgment of 12 experts. A benefit-cost analysis was also performed and distributions of benefit-cost ratios were computed using a Monte Carlo simulation. Risk analysis showed that the fatality and injury risk of the crashes in Bogota is higher than in NYC. However, according to experts, expected reduction of fatalities is higher in Bogota compared to NYC. It was found from the economic analysis that implementing any of the technologies in NYC is nonetheless economically justifiable.

Impact of Pavement Surface Condition on Crashes

Chen et al. (2017) examined the safety effects of pavement conditions on rural roads. The hypotheses that the pavement surface condition (pavement roughness) has a varying non-trivial residual impact on safety outcomes was tested. Different models were developed considering three levels of crash severity and five different road surface conditions using the multivariate random parameters negative binomial specification. It was found that surface condition has fixed effects on crash frequency. A normally distributed significant random parameter suggests that poor pavement conditions (higher pavement roughness) increases the expected crash frequency.

Li et al. (2013) analyzed the impact of pavement conditions on crash severity in Texas. Data from the Texas Department of Transportation crash record information system (CRIS) and pavement management information system (PMIS) were linked using GIS. Crash data between 2008 and 2009 were analyzed to determine the correlation between different pavement conditions and crash severity. The results revealed that poor pavement conditions tend to increase the severity of crashes when compared to fair and very poor pavement conditions. It was also found that the effects of pavement conditions on crash severity were more evident for passenger cars than commercial vehicles.

Lee et al. (2015) studied the effects of pavement conditions on crash severity levels using a discrete model that handled ordered data. The aim of the study was to develop a correlation between poor pavement conditions and crash severity levels. A series of Bayesian ordered logistic models were analyzed for different speeds of road (low/medium/high) and collision type (single/multiple vehicle) combinations. The result from the models showed that the severity of the single vehicle collisions were decreased on low speed roads compared to high speed roads. Considering multiple vehicle crashes, however, the severity level was increased for all road types (low/medium/high speed).

Chan et al. (2009) researched the relationship between highway pavement condition, crash frequency, and crash type. In this study, 20 negative binomial regression models were developed using the state of Tennessee's pavement management system (PMS) and accident history database (AHD). Variables considered for the models include AADT, right shoulder, left clearance, Present Serviceability Index (PSI), International Roughness Index (IRI) and rut depth. Present Serviceability Index (PSI) and International Roughness Index (IRI) were found to be the most significant pavement variables to predict crash frequency.

Effects of AADT on Collisions

Chen and Xie (2016) examined the effects of AADT on predicting multiple vehicle crashes in signalized intersections. Generalized Additive Models (GAMs) and Piecewise Linear Negative Binomial (PLNB) regression models were used to fit the crash data. Crash data and AADT of 48 three-approach signalized (3SG) intersections and 52 four-approach signalized (4SG) intersections were used for the analysis. Three dependent variables were considered for the models: total multiple-vehicle crashes, rear-end crashes, and angle crashes. The results of the models showed that there is a non-linear functional form to describe the relationship between the natural logarithm of expected crash frequency and covariates derived from AADTs. The results also found that the ratio of minor to major-approach AADT has an inconstant influence on intersection safety.

Appendix B – Data Characteristics

Introduction

This appendix gives an overall description of the data collected over the two and a half year period of the project, focusing on data that serves the project's purpose. Descriptions of various data that were considered for analysis, such as patrol hours, crash events, citations, incidents, and AADT along all five corridors, are provided, including in visual formats. Seasonal variations of these variables are also described. A better understanding of the data will also improve understanding of the statistical analyses, the conclusion, and recommendations.

Data Characteristics

The data considered in this project covers the time period of July 2015 to December 2017. Behavior changes from year to year, so changes in the variables were considered during data collection. This section addresses changes within the first year and then describes the full study period.

Figure B-1 gives an overall view of the five corridors considered in this study. Figure B-2 to B-6 represents the different data characteristics along each highway for 2017. AADT volume, average patrol hours of the corresponding year, and total crashes are shown on those figures. The outcomes from the first year of analysis will be incorporated into the full study period to monitor trends in trooper enforcement hours, locations, and the associated crashes, as well as rates of crashes per geofence of five mile sections as addressed in the methodology. It is noteworthy to state that the few miles of the Glenn and Seward highway beyond the Anchorage area are generally patrolled by the Anchorage Police Deportment (APD). Because of this overlap, the AST patrol hours on those sections seem low compared to traffic volumes.

Figure B-1: Google Map highlighting the five corridors considered in the study

The Glenn Highway's average traffic volume is about 40,000 vehicles per day (vpd) for the first 45 miles northbound and then drops to less than 20,000 vpd where the highway turns into a two-lane two-way road as it passes the Palmer area (figure B-2(a)). The average patrol hours are higher at the area between Milepoint 35 to 45, where total crashes are relatively high compared to other segments of the road. The average patrol hours are highest (close to 140 hours) at the end of the corridor (Glenallen area), though volume of traffic is significantly lower as the corridor turns into a two-lane two-way rural arterial. Overall, the ratio of AADT volumes to average patrol hours along the Glenn highway is about 759, the highest among all corridors considered in this study. Moreover, there is a clear lack of balance in allocating trooper hours based on AADT. It is worth noting that some of the graphical representations of the data do not show full-scale values of AADT and average patrol hours so that crash events can be emphasized.

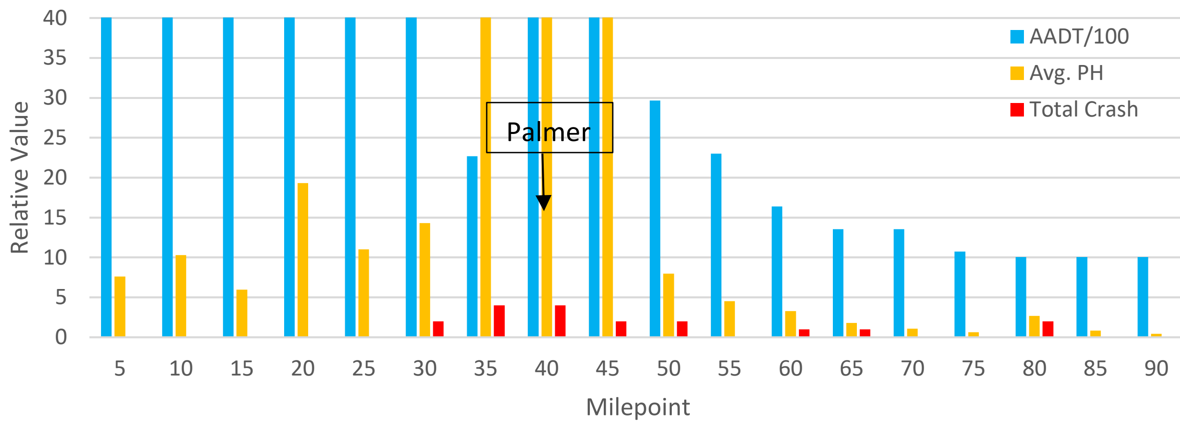

Figure B-2(a): Data characteristics on Glenn Highway in 2017 (1-90)

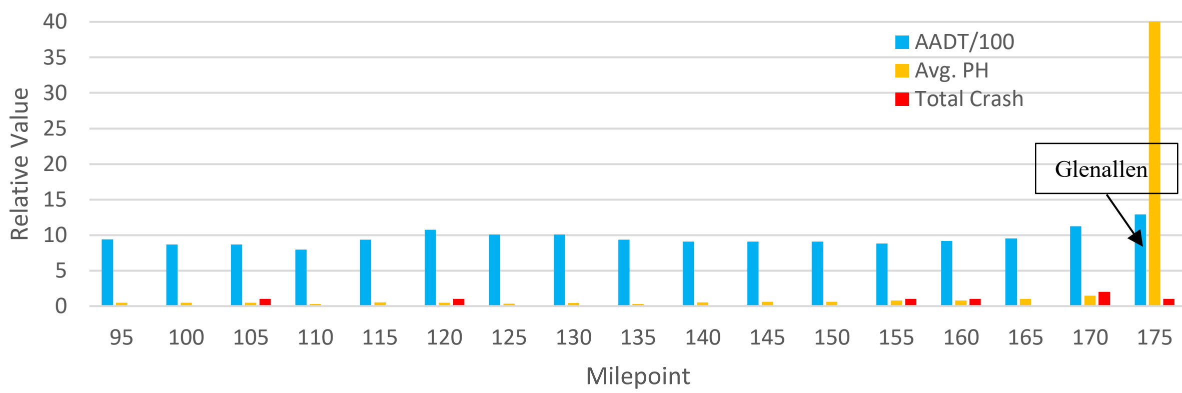

Figure B-2(b): Data characteristics on Glenn Highway in 2017 (91-175)

The Richardson Highway's AADT volumes remain mostly constant, except between Milepoint 350-360 in the Fairbanks area (Figure B-3). Troopers spend a majority of their time patrolling this location, which is proportional to crash occurrence. The overall ratio for average patrol hours to total crashes is near 4, which is the lowest among all corridors, but the ratio of AADT to average patrol hours is about 568, which is slightly less than Glenn Highway. The proportion of patrol hours to traffic volume are in agreement, except for the first 45 milepoints. In addition, crashes follow the same trend except in some spots, like Milepoint 50, 60, 85, and 166-175, where a greater number of crashes occurred without a corresponding increase in patrol hours.

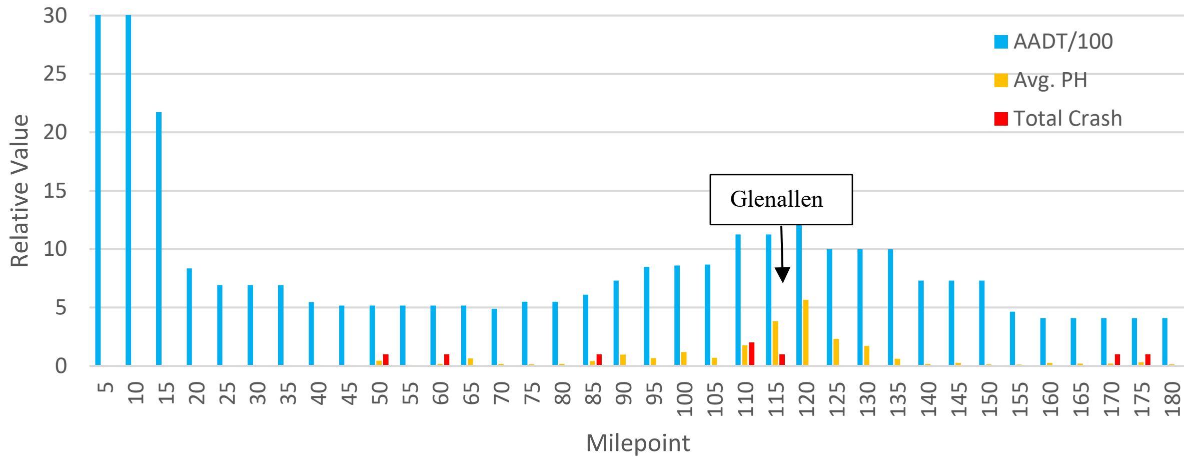

Figure B-3(a): Data characteristics on Richardson Highway in 2017 (Milepoint 1-180)

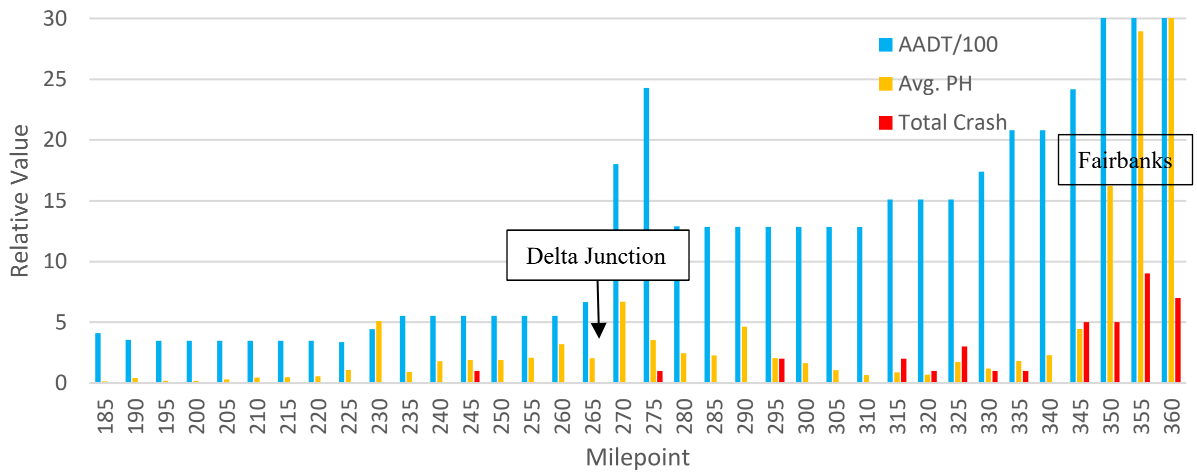

Figure B-3(b): Data characteristics on Richardson Highway in 2017 (181-360)

On the Parks Highway, the annual traffic volumes is highest near Wasilla (Milepoint 0-20) and Fairbanks (Milepoint 315-320) (Figure B-4). Patrol hours are also distributed consistently with traffic volumes throughout most of the corridor. The overall ratio of average patrol hours to AADT is approximately 35, which is the lowest among all corridors considered in this study. Moreover, the overall ratio of average patrol hours to crashes is the highest (about 26) for this highway. Despite lower traffic volumes, there are many crashes that took place between Milepoint 61 and 95. In general, no significant crashes were recorded between Cantwell and Fairbanks, though there was a noticeable presence of troopers.

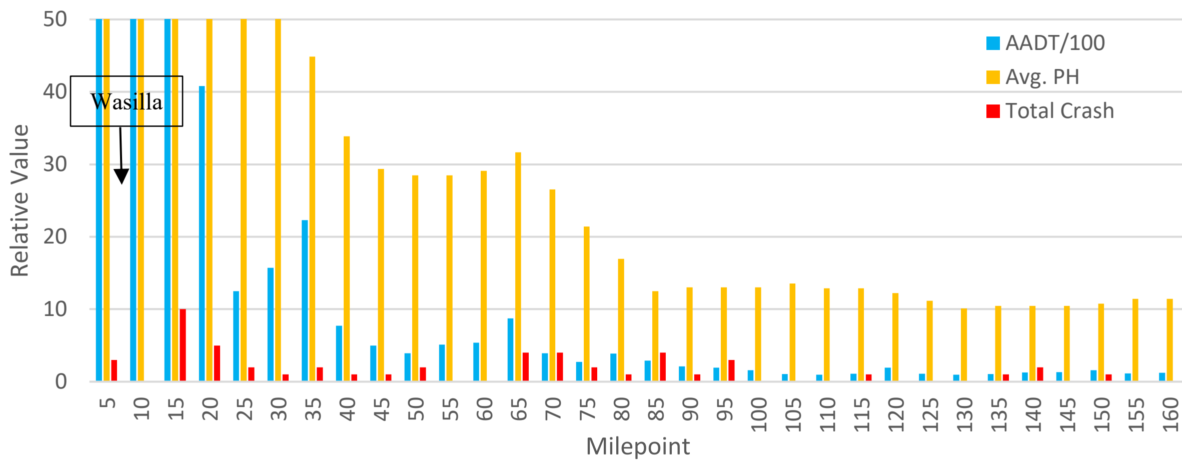

Figure B-4(a): Data characteristics on Parks Highway in 2017 (Milepoint 1-160)

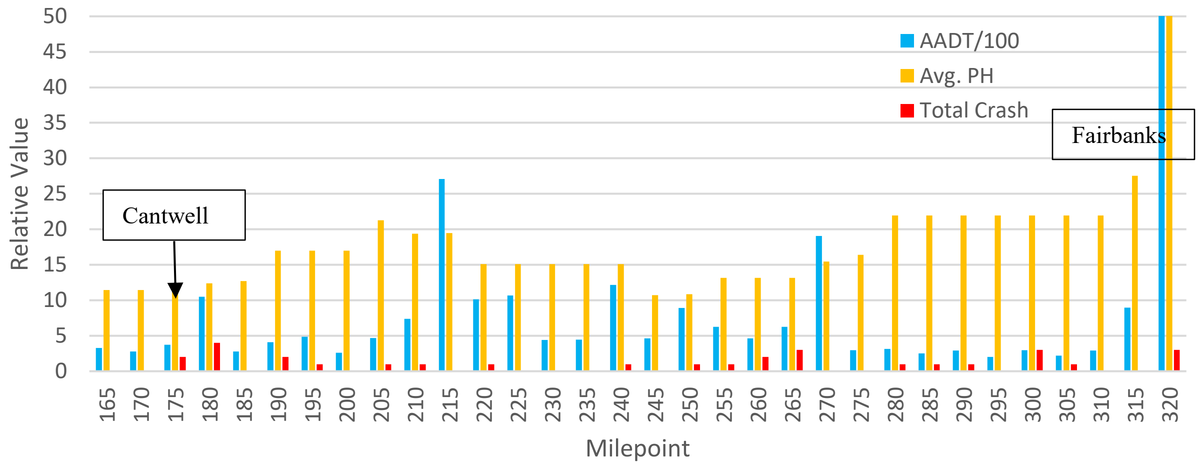

Figure B-4(b): Data characteristics on Parks Highway in 2017 (Milepoint 161-320)

On the Seward Highway, traffic volumes increase gradually heading northbound toward Anchorage. Average patrol hours follow the same trend, except near the city of Seward (Milepoint 0-25) (Figure B-5). The AADT to average patrol hours ratio is low for the first 25 miles from Seward, and starts to increase passing Milepoint 35. The overall scenario is similar to the Glenn and Richardson Highways. The total collisions are distributed almost uniformly across the highway. It is worth mentioning that Milepoint 71-75 has the greatest number of crashes.

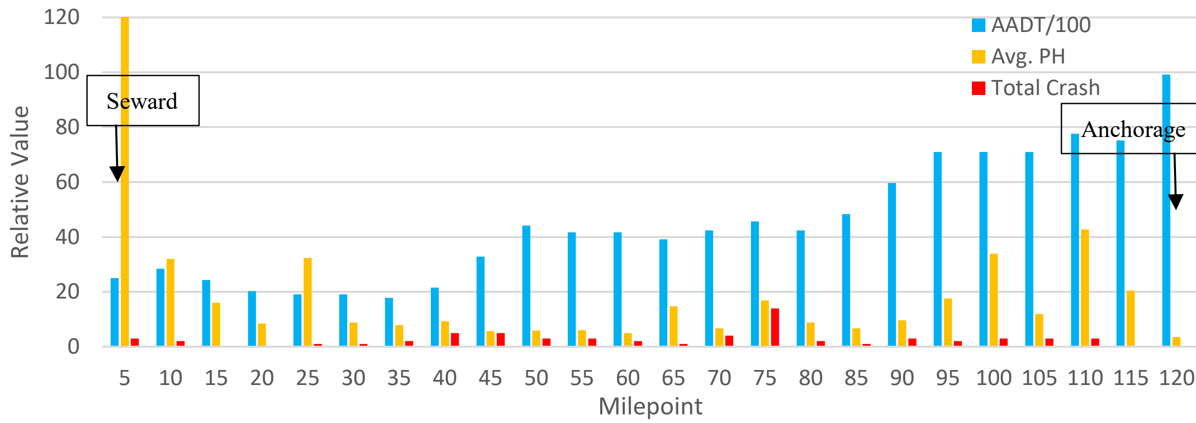

Figure B-5: Data characteristics on Seward Highway in 2017

Lastly, the Sterling Highway's ratio of average patrol hours to AADT are consistent with other corridors, especially the Seward, Glenn, and Richardson Highways, though Milepoint 11-15 and 21-25 (near the city of Homer) exhibit a different pattern (Figure B-6). Both patrol hours and traffic values peaked at Milepoint 76-80. Crash patterns are distributed almost evenly on this corridor.

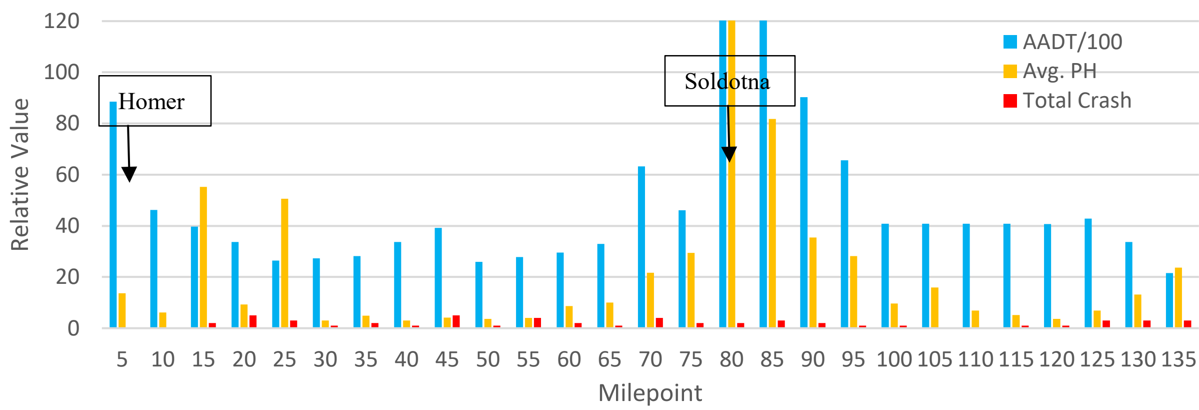

Figure B-6: Data characteristics on Sterling Highway in 2017

Patrol Hours vs Crashes Monthly Timeframe

To get an overall picture of the trends, this section addresses monthly patrol hour distribution and crash events along each corridor for the period of July 2016 to December 2017 (Figures B-7 through B-16). Figures are offered in 3D and 2D formats to better illustrate the trends. Total patrol hours, monthly average patrol hours, average patrol hours per geofence, patrol hours per crash, and total crashes are shown in Table B-1.

Table B-1: Average patrol hours and crashes on each corridor (July 2015 to December 2017)

Highway	Number of Geofences	Total Patrol Hour	Monthly Average Patrol Hour	Monthly average PH/Geofence	Patrol hour per Crash	Total Crashes	Crashes per geofence
Glenn	35	12706.36	423.55	12.1	114.5	122	3.49
Parks	64	25398.36	846.61	13.23	72.6	388	6.06
Richardson	72	6798.21	226.61	3.15	51.5	169	2.35
Seward	24	14511.02	483.7	20.15	77.2	202	8.42
Sterling	27	19387.78	646.26	23.94	94.6	227	8.41

Figure B-7 and Figure B-8 show patrol hours vs crashes on the Glenn Highway. The presence of troopers is substantial in only two locations, Palmer and Glenallen, the most populous towns along the corridor. Clusters of collisions are also visible in the Palmer area, though there is an almost uniform distribution of crashes between Palmer and Glenallen, indicating that additional enforcement might be needed. There are no crashes recorded by AST for the first 25 miles of the highway since the area is patrolled by APD (not shown in the figure).

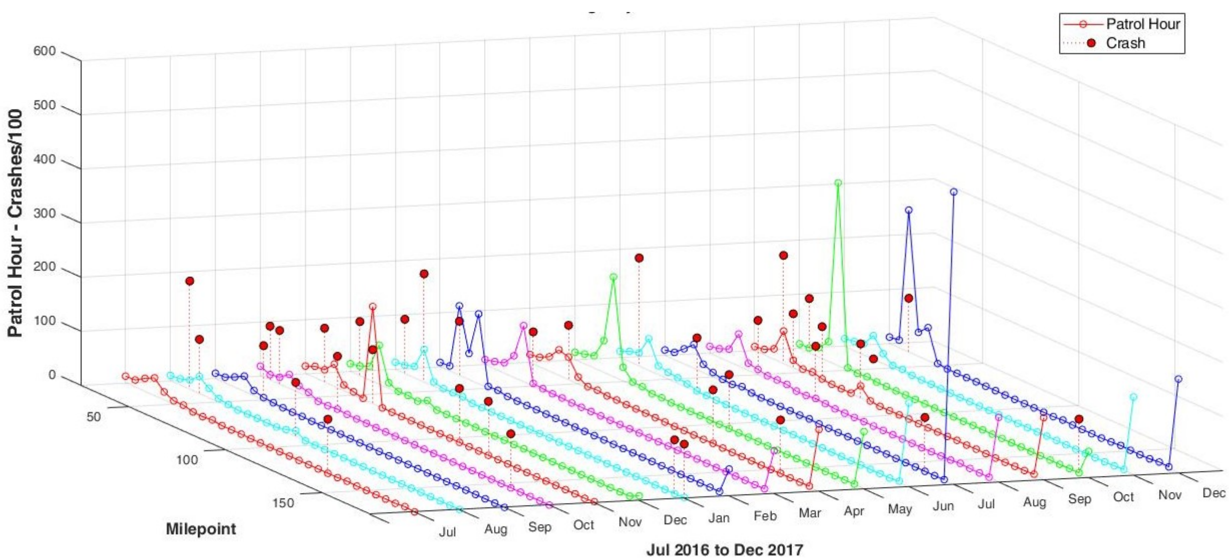

Figure B-7: Glenn Highway patrol hours vs crashes (3D)

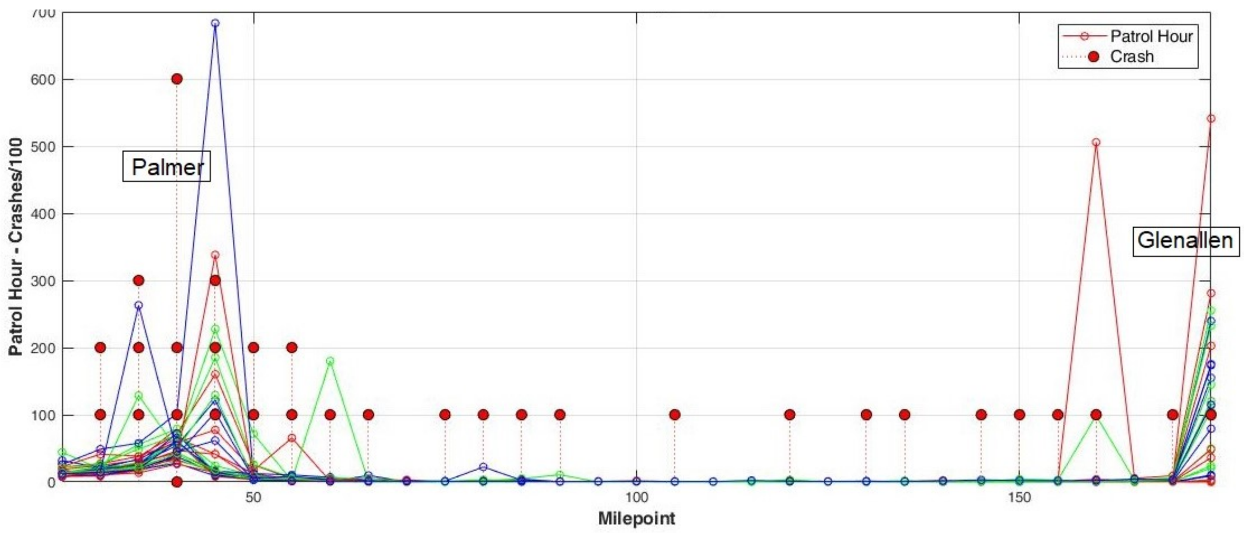

Figure B-8: Glenn Highway patrol hours vs crashes (2D)

Among the five highways, the most crashes occurred on the Parks Highway. The crashes are almost uniformly distributed along the corridor, except for some concentration visible in Wasilla, Cantwell, and Fairbanks (Figure B-9 and Figure B-10). The trooper presence is greatest in the Wasilla region, though there is also a substantial number of patrol hours between Cantwell and Fairbanks. Still, more patrol hours might be needed between these urban areas to address the occurrence and distribution of crashes on these segments. The monthly average patrol hours are 13.23 per geofence, which is slightly higher than the monthly average patrol hours of 12.1 per geofence on the Glenn Highway. Likewise, the number of crashes on the Parks Highway (6.06 crashes per geofence) is significantly higher than the number of crashes on the Glenn Highway (3.49 crashes per geofence).

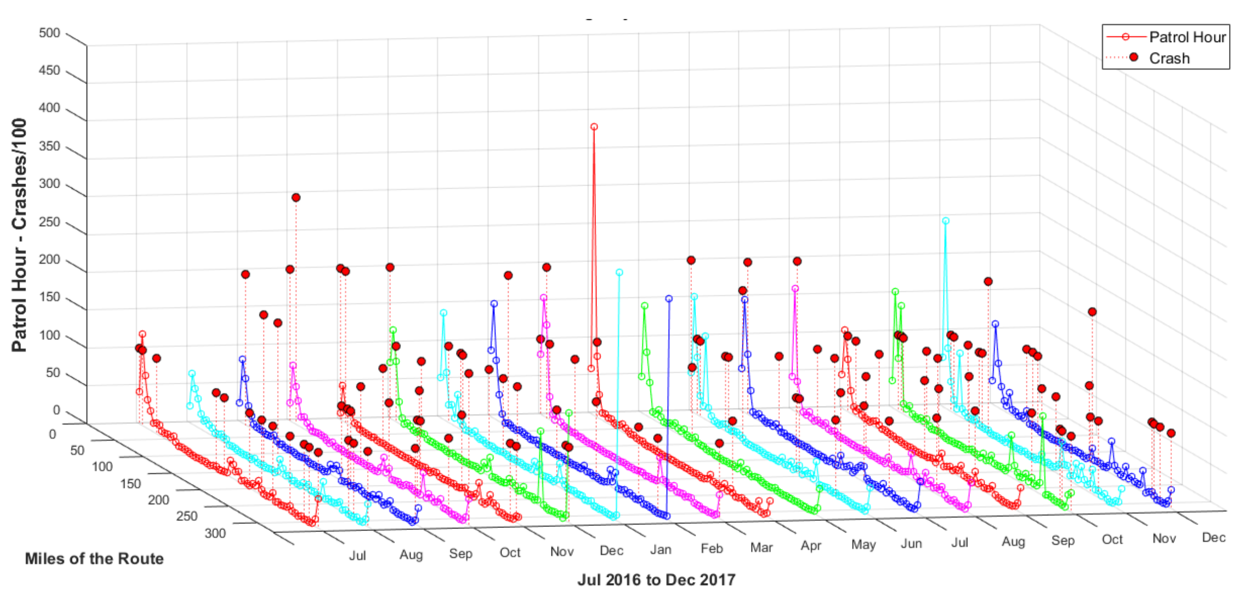

Figure B-9: Parks Highway patrol hours vs crashes (3D)

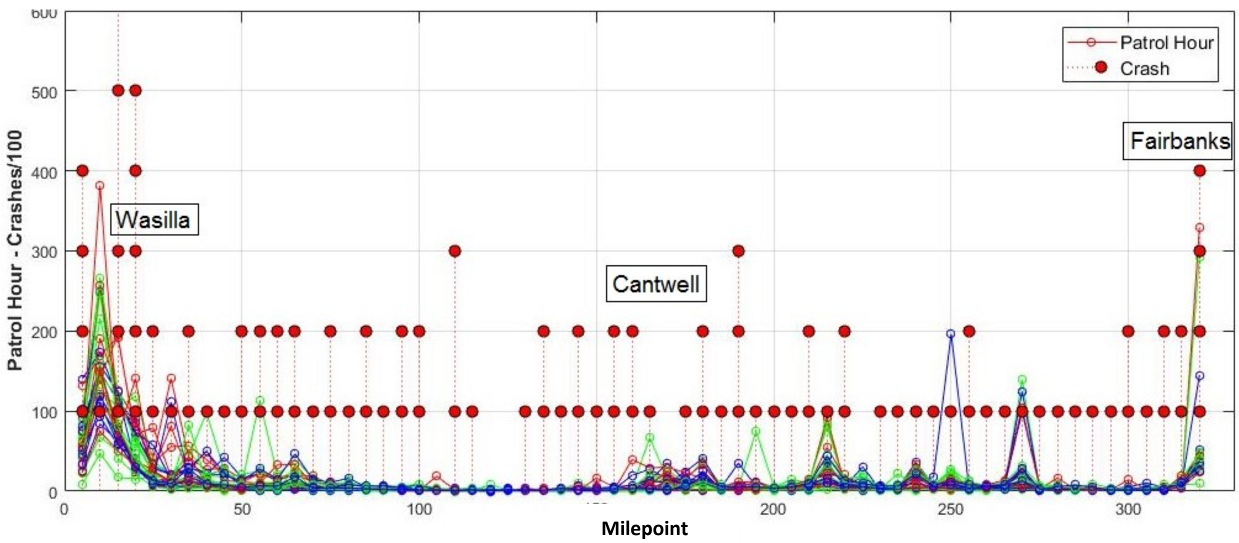

Figure B-10: Parks Highway patrol hours vs crashes (2D)

The lowest trooper presence among all corridors, with a monthly average of 226.61 hours, was recorded on the Richardson Highway (figure B-11 and figure B-12). However, there were only 132 crashes on this corridor and the number of crashes per geofence was 2.35, which is lower than all other corridors. Patrol hours are concentrated near Glenallen (Milepoint 100-140) and between Delta Junction and Faibanks (Milepoint 260-360). As most crashes occurred in these regions, the concentration of patrol hours is appropriate.

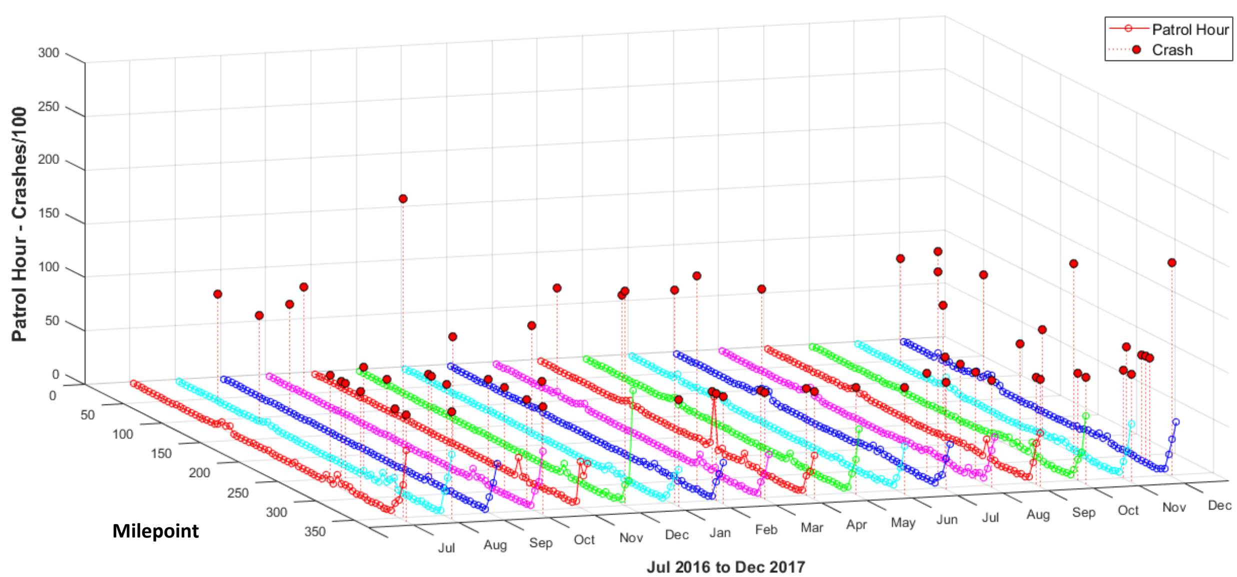

Figure B-11: Richardson Highway patrol hours vs crashes (3D)

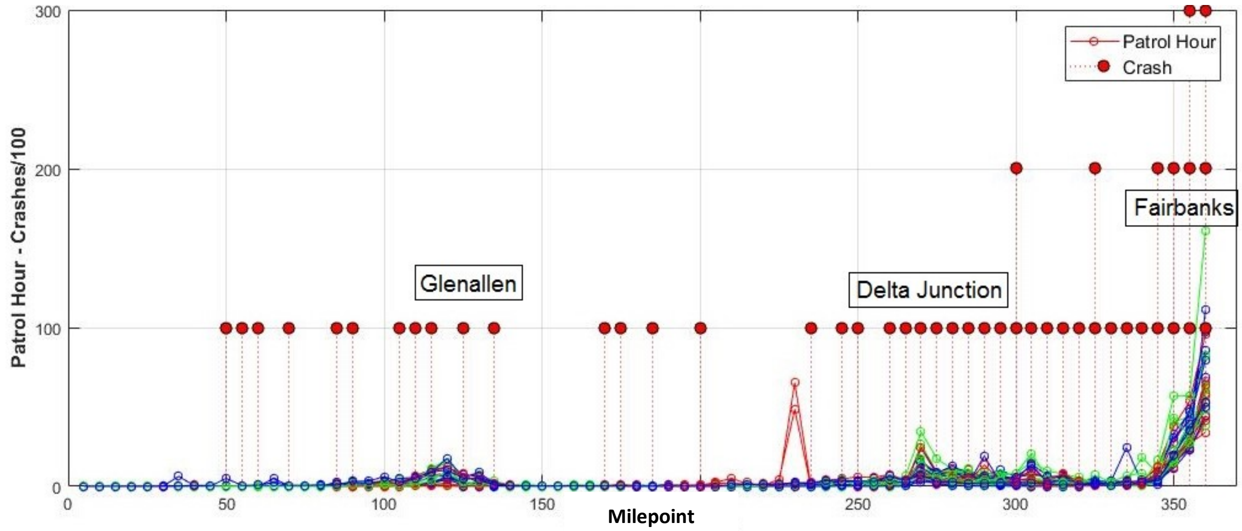

Figure B-12: Richardson Highway patrol hours vs crashes (2D)

On the Seward Highway, there are some regions where patrol hours are comparatively lower, even though there are more crashes in these areas (Figure B-13 and Figure B-14). The number of collisions per geofence is roughly 8.42, which is highest among all corridors. The number of collisions is much higher between Tern Lake and Girdwood (Milepoint 40-80) and near Beluga Point (Milepoint 95–110) than on other sections of the highway. The large number of crashes in that area is countered with only 20.15 hours per geofence per month. A greater patrol presence might reduce the number of crashes in this region.

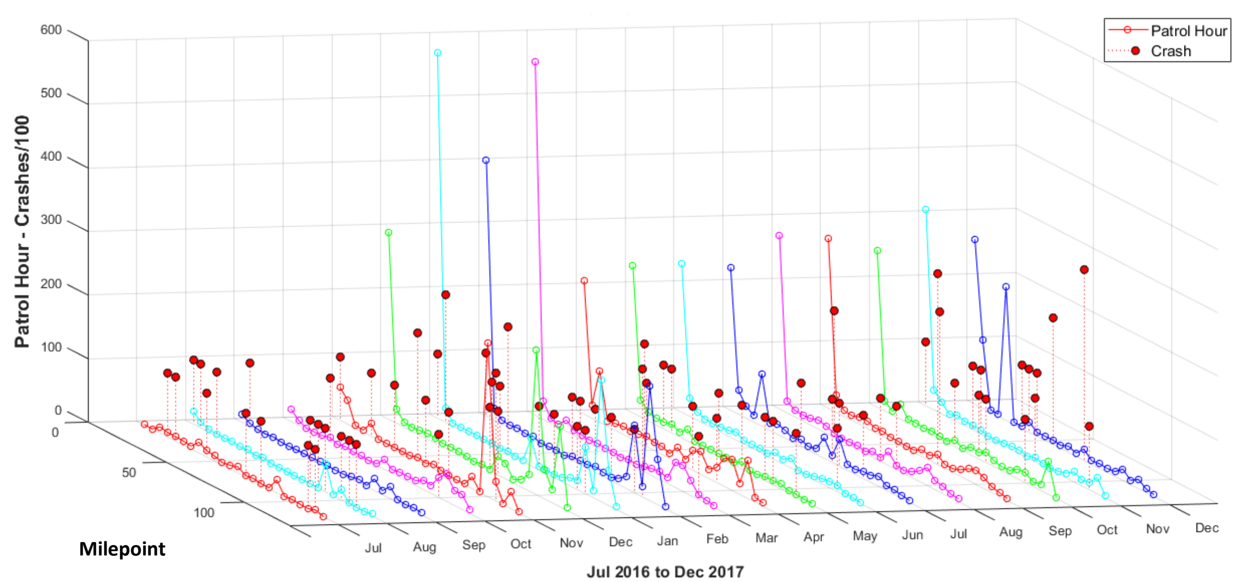

Figure B-13: Seward Highway patrol hours vs crashes (3D)

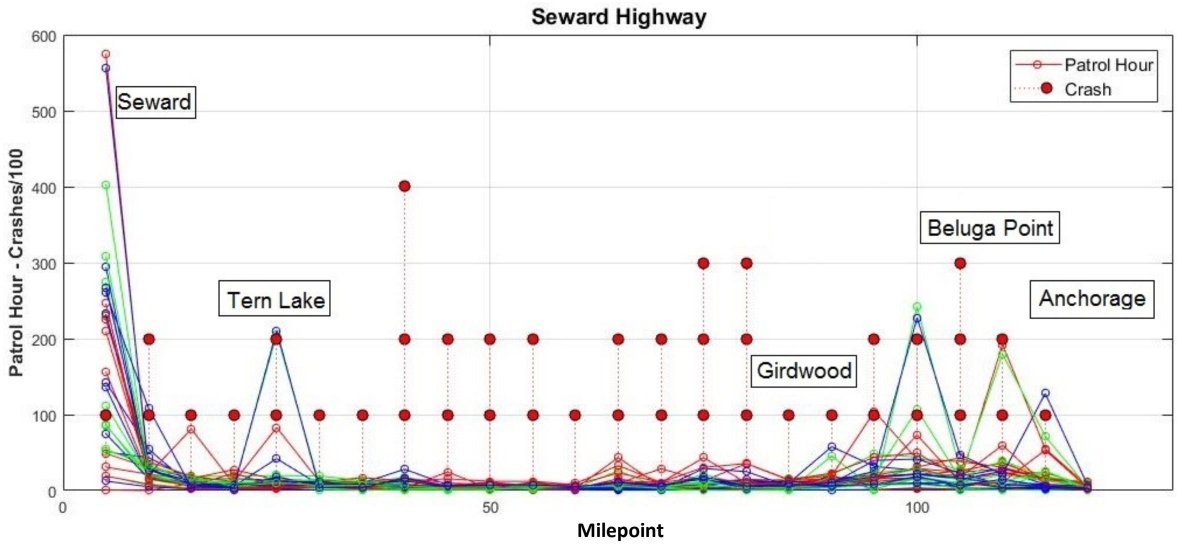

Figure B-14: Seward Highway patrol hours vs crashes (2D)

The greatest number of patrol hours per geofence occurred on the Sterling Highway (23.94 hours) and the highway also had one of the highest number of crashes (8.41 crashes per geofence). Patrol hours and number of crashes were highest near Homer and Soldotna (Figure B-15 and B-16). Patrol hours totaled between 500 and 700 hours per month at these two locations. Crash distribution for the remaining part of the route was relatively uniform. At Milepoint 30-70 and Milepoint 110-125, both the number of crashes and patrol hours follow similar orientation as Milepoint 40-80 of the Seward highway. Thus, spreading troopers from concentrated sections to other locations might reduce collisions.

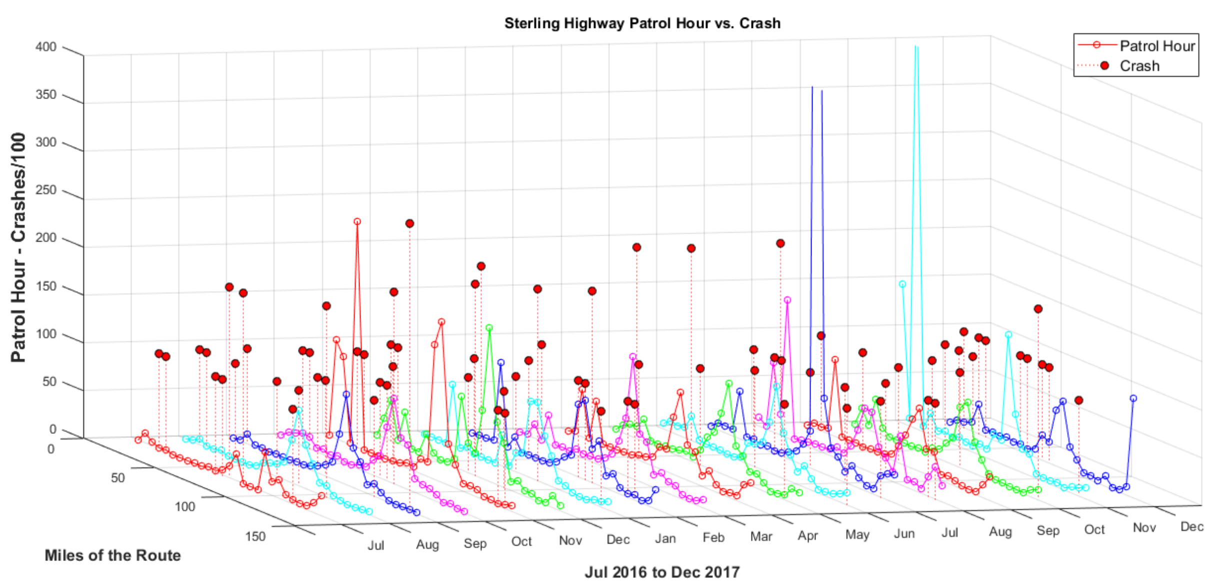

Figure B-15: Sterling Highway patrol hours vs crashes (3D)

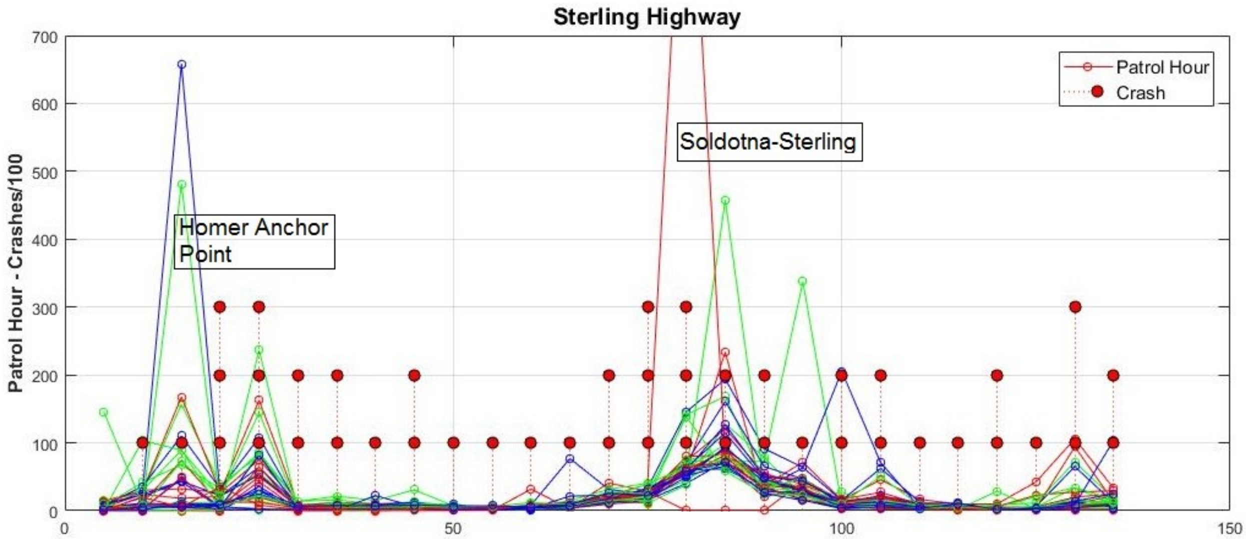

Figure B-16: Sterling Highway patrol hours vs crashes (2D)

Total Patrol Hours vs Total Crashes

On the planning level, Figures B-17 through B-21 depict total patrol hours and total crashes for the period of July 2015 to December 2017 along each corridor. The analysis from these figures help to understand the overall variation of the trooper presence and the crash patterns along each of Milepoint of each corridor for the full period of analysis. It will also be useful for identifying inconsistences, if any, in the distribution of trooper patrol hours relative to crash occurrence.

On the Glenn Highway, the general trend of the total number of crashes is consistent with patrol hours (Figure B-17). The location with the highest enforcement (maximum hours patrolled by troopers) is in Glenallen, reaching about 3200 hrs. The fewest number of crashes occurred in this section. The greatest number of crashes occurred in the Palmer area and a considerable number of patrol hours were also recorded there. In addition, an average of 300-400 troopers' patrolling hours in a location just before Palmer urban area (Milepoint 0 to 25) were registered no crashes. Further consideration of trooper distribution can be incorporated on this route based on the data collected.

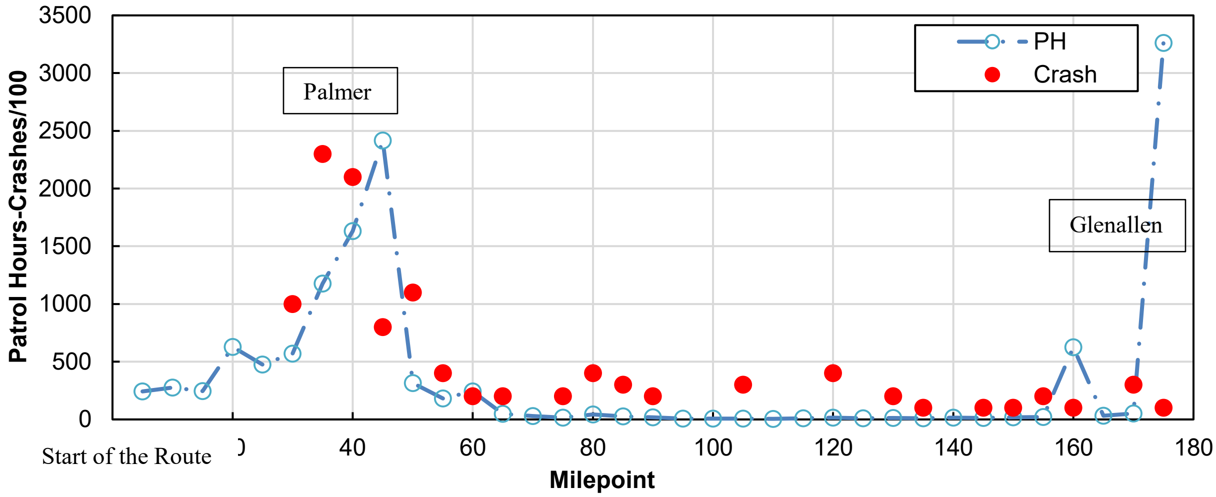

Figure B-17: Total patrol hours vs total crashes along milepoint of the Glenn Highway

Total patrol hours and total crashes in the period of July 2015 to December 2017 along Parks Highway are shown in Figure B-18. Patrol hours are proportional to total crashes in the areas around Wasilla, Cantwell, and Fairbanks, but they are not proportional in the region between Wasilla and Cantwell (Milepoint 70 to 150). This is partly explained by the fact that trooper headquarters are located within the urban areas near these corridors, which could result in a measure of patrol hours in excess of the actual number used for enforcement purposes

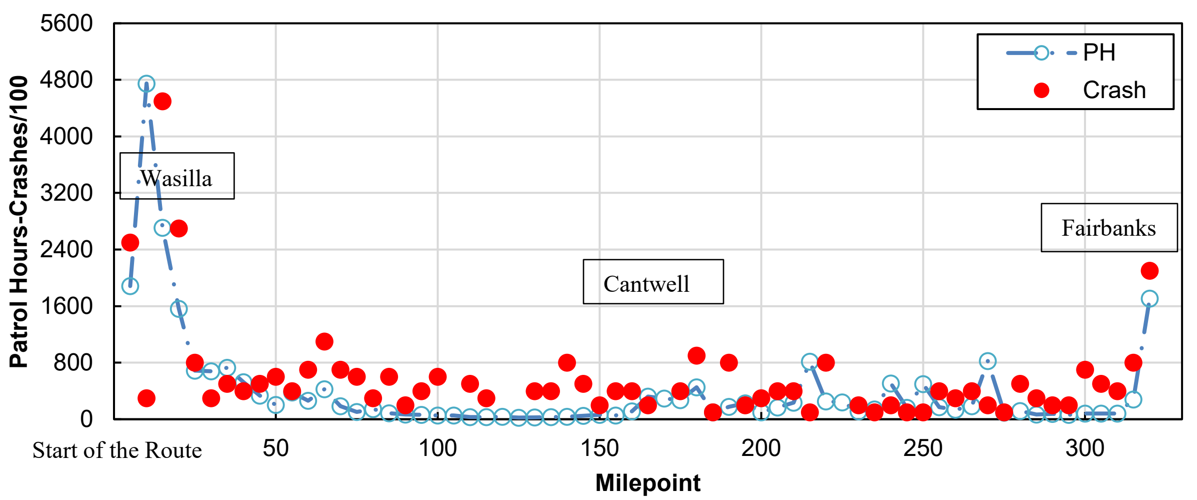

Figure B-18: Total patrol hours vs total crashes along milepoint of the Parks Highway

On the Richardson highway (Figure B-19), there are some locations with consistency between patrol hours and number of crashes, such as Glenallen, Delta Junction, and Fairbanks. However, there appears to be inadequate patrol hours in some sections with a substantial number of crashes (Milepoint 50-100, Milepoint 160-200 and Milepoint 290-340).

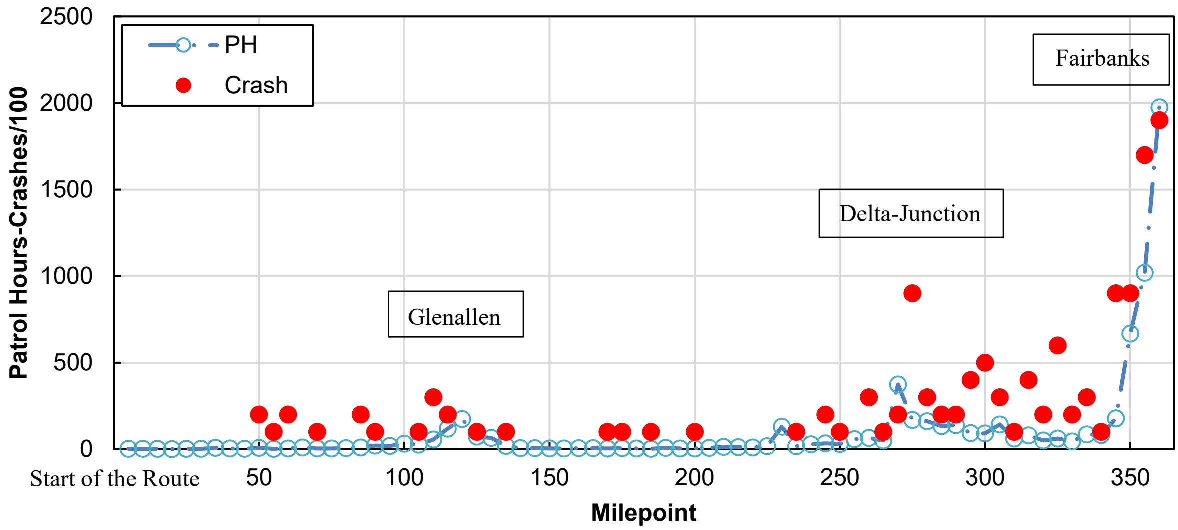

Figure B-19: Total patrol hours vs total crashes along milepoint of the Richardson Highway

A higher patrol hour to number of crashes ratio exists on the Seward Highway between Girdwood and Anchorage (Figure B-20). However, a lower ratio exists at Milepoint 70-80, signifying that a greater trooper presence may be necessary to reduce the number of crashes.

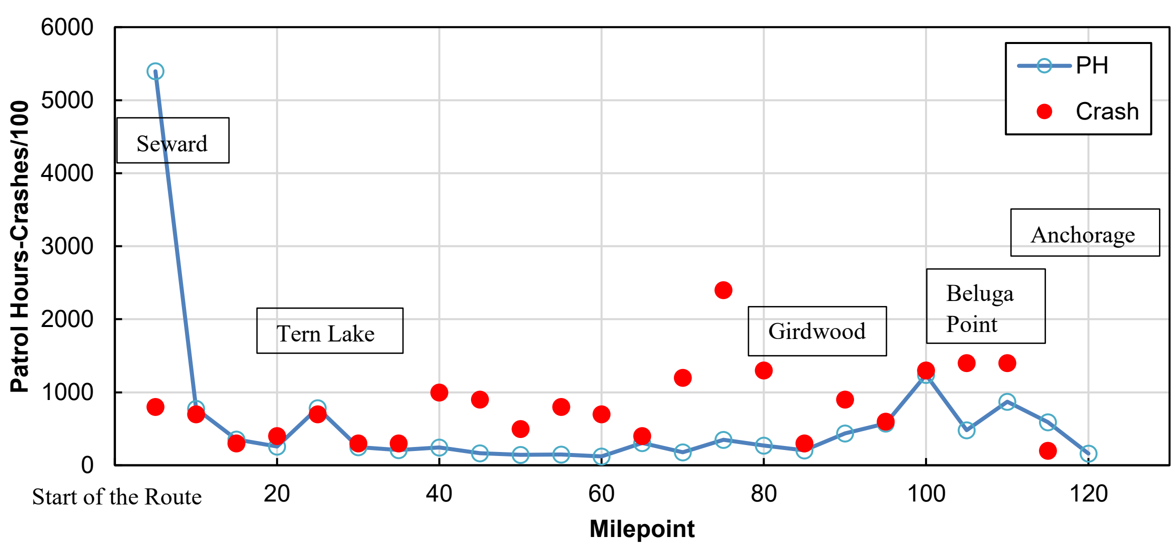

Figure B-20: Total patrol hours vs total crashes along milepoint of the Seward Highway

On Sterling Highway (Figure B-21), the Homer and Soldotna areas experienced a high number of crashes and troopers patrolled these locations at higher rates. Milepoint 30 to 65 of the highway has the fewest patrol hours, suggesting that patrol hours could be dispersed from Homer and Soldotna in order to reduce crashes in that region.

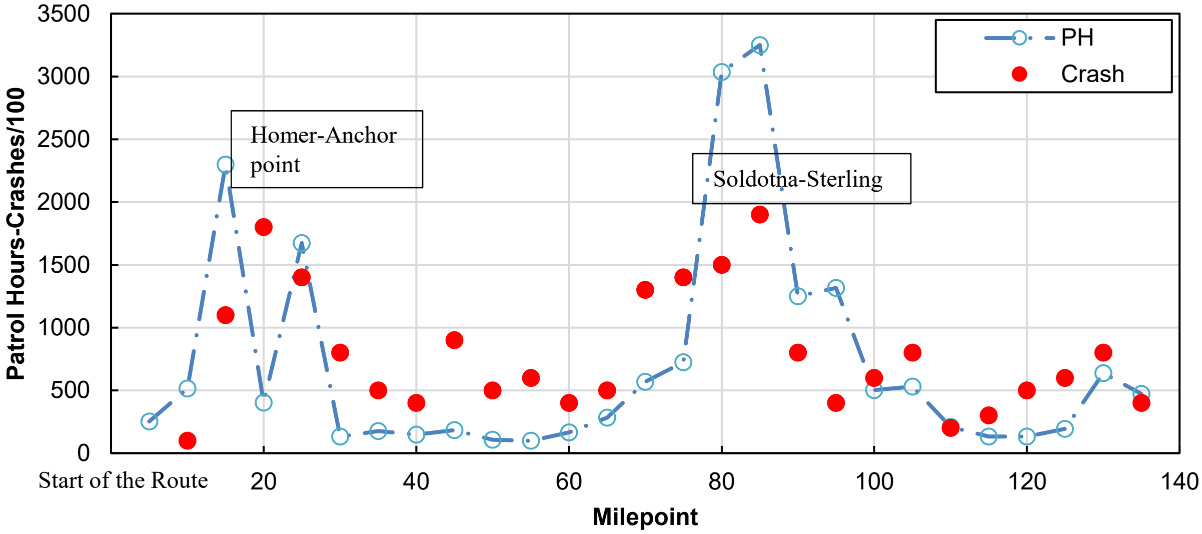

Figure B-21: Total patrol hours vs total crashes along milepoint of the Sterling Highway

Monthly Data Analysis

Per month distribution of total patrol hours and total crash events are shown in figures B-22 through B-26. Monthly analysis of data is beneficial to observe seasonal similarities (or dissimilarities) and to identify periods of increased patrol hours or crash events. Overall, there is no consistency in the distribution of patrol hours throughout the project period (July 2015 to December 2017), indicating that the allocation of patrol hours for each month for different corridors is somewhat random. Generally, increased patrol hours are associated with decreased crash occurrence.

For the Glenn highway (Figure B-22), the greatest number of patrol hours (about 1000 hours) occurred in July 2015 and March of 2016, whereas the fewest number of patrol hours (roughly 100 hours) occurred in September of 2016. Overall, the presence of troopers in this corridor was lower in 2016, though the collisions on the Glenn highway were highest between July 2015 and June 2016. There is no consistency in patrol hours from month to month and year to year, as well as the ratio of patrol hours to crash events.

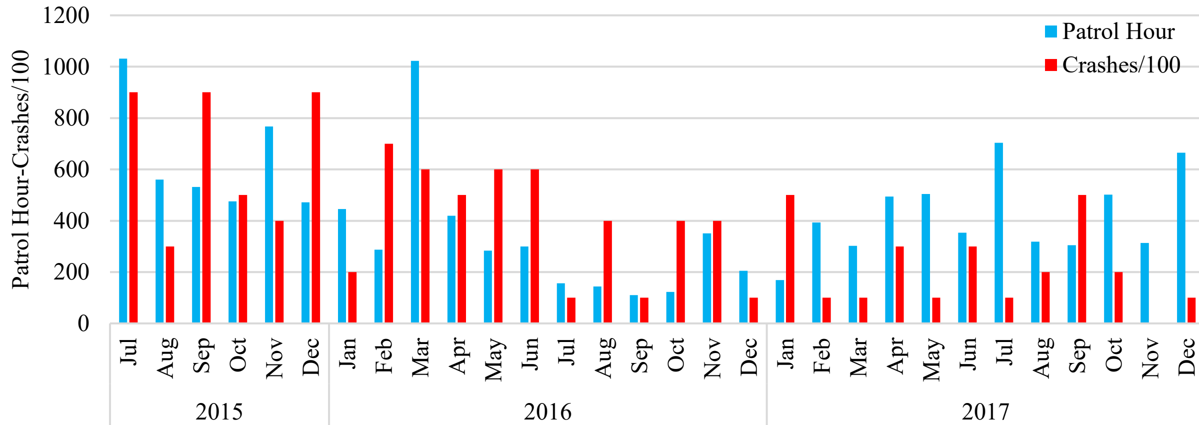

Figure B-22: Monthly total patrol hours vs total crashes on the Glenn Highway

A similar pattern was observed on the Parks Highway, as shown in Figure B-23. The patrol hours varied substantially within a relatively short range. The ratio of crashes to patrol hours is significantly higher on this corridor as compared to the Glenn Highway for the period of August 2015 to March 2016.

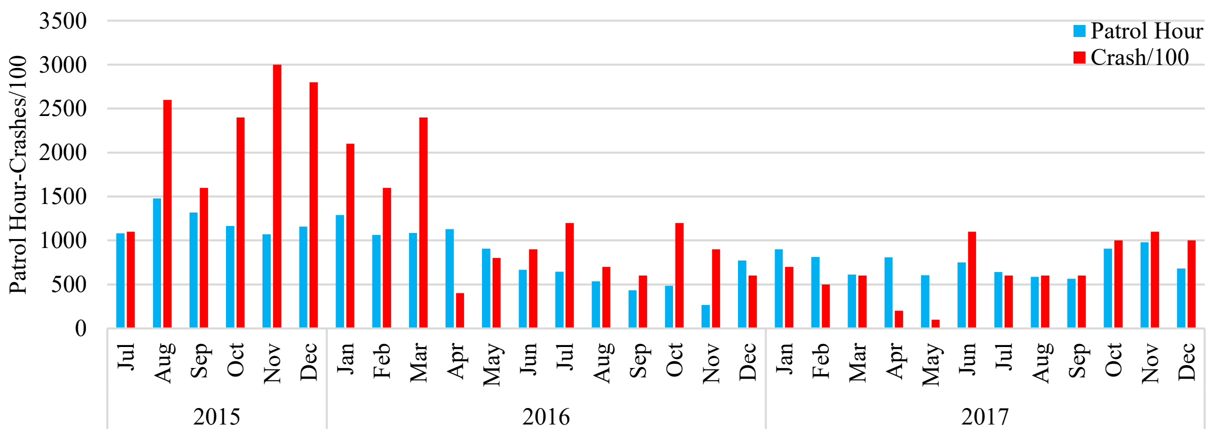

Figure B-23: Monthly total patrol hours vs total crashes on the Parks Highway

The distribution of patrol hours on the Richardson Highway throughout the period resembled that of the Parks Highway as shown in Figure B-24. The distribution of total crashes per year suggests that the crash occurrence has not decreased over time. Rather, crashes are distributed more evenly in some periods.

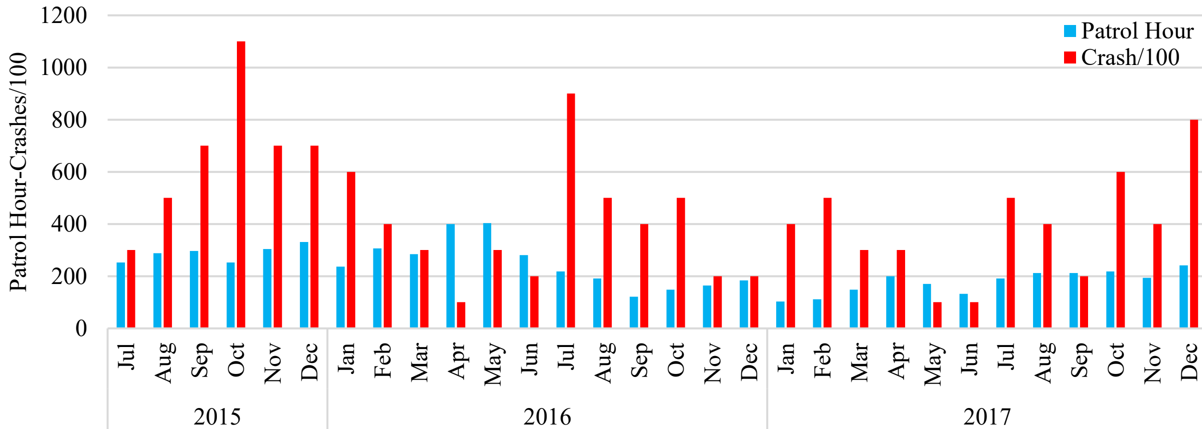

Figure B-24: Monthly total patrol hours vs total crashes on the Richardson Highway

The ratios of crashes to patrol hours in 2015 and 2016 along the Seward Highway are opposite of the ratio in 2017, as shown in Figure B-25. Total crashes decreased in 2017 and patrol hours increased. This is one piece of evidence that an increase in patrol hours may significantly decrease the total number of crashes.

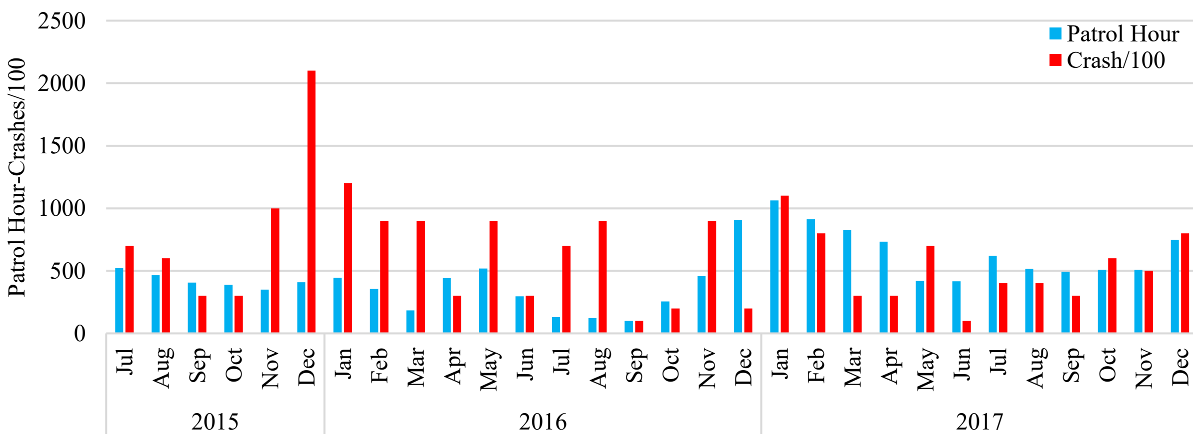

Figure B-25: Monthly total patrol hours vs total crashes on the Seward Highway

On the Sterling Highway, the total patrol hours are almost constant throughout the study period, as shown in Figure B-26. The total number of crashes decreased in 2017.

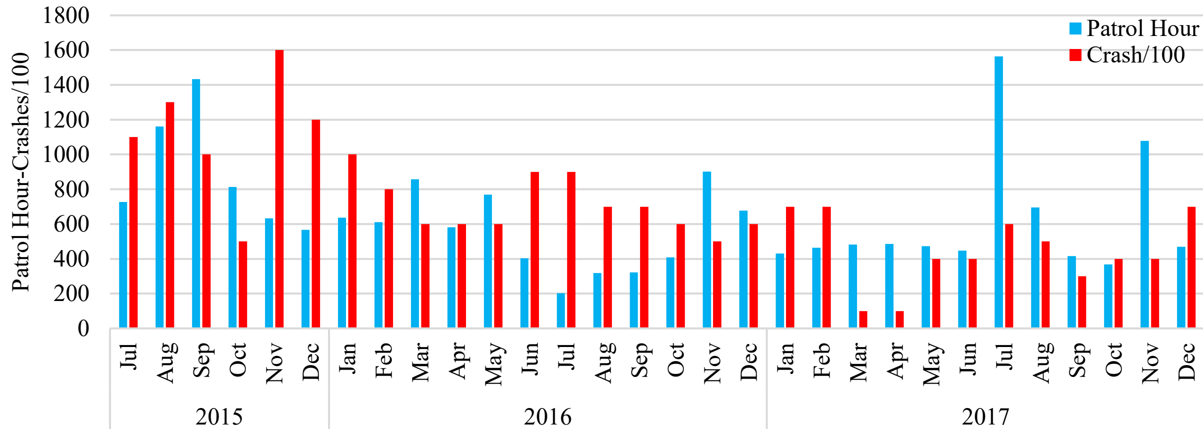

Figure B-26: Monthly total patrol hours vs total crashes on the Sterling Highway

Figure B-27 shows the monthly total crashes for each corridor within the study period. The combined total patrol hours and crash data for all corridors are displayed in Figure B-29. Figure B-27 shows that the overall number of crashes decreased in 2017. The greatest crash frequency occurred between July 2015 and March 2016. The lowest crash frequency occurred in April and May 2017. On individual corridors, there is no visible pattern throughout the year, suggesting that there is no seasonal variation. However, the combined crash data offers variation that is clearly seasonal (Figure B-29). Generally, November to January is when total crashes are at their highest. The months of April and September, on the other hand, have the least number of crashes.

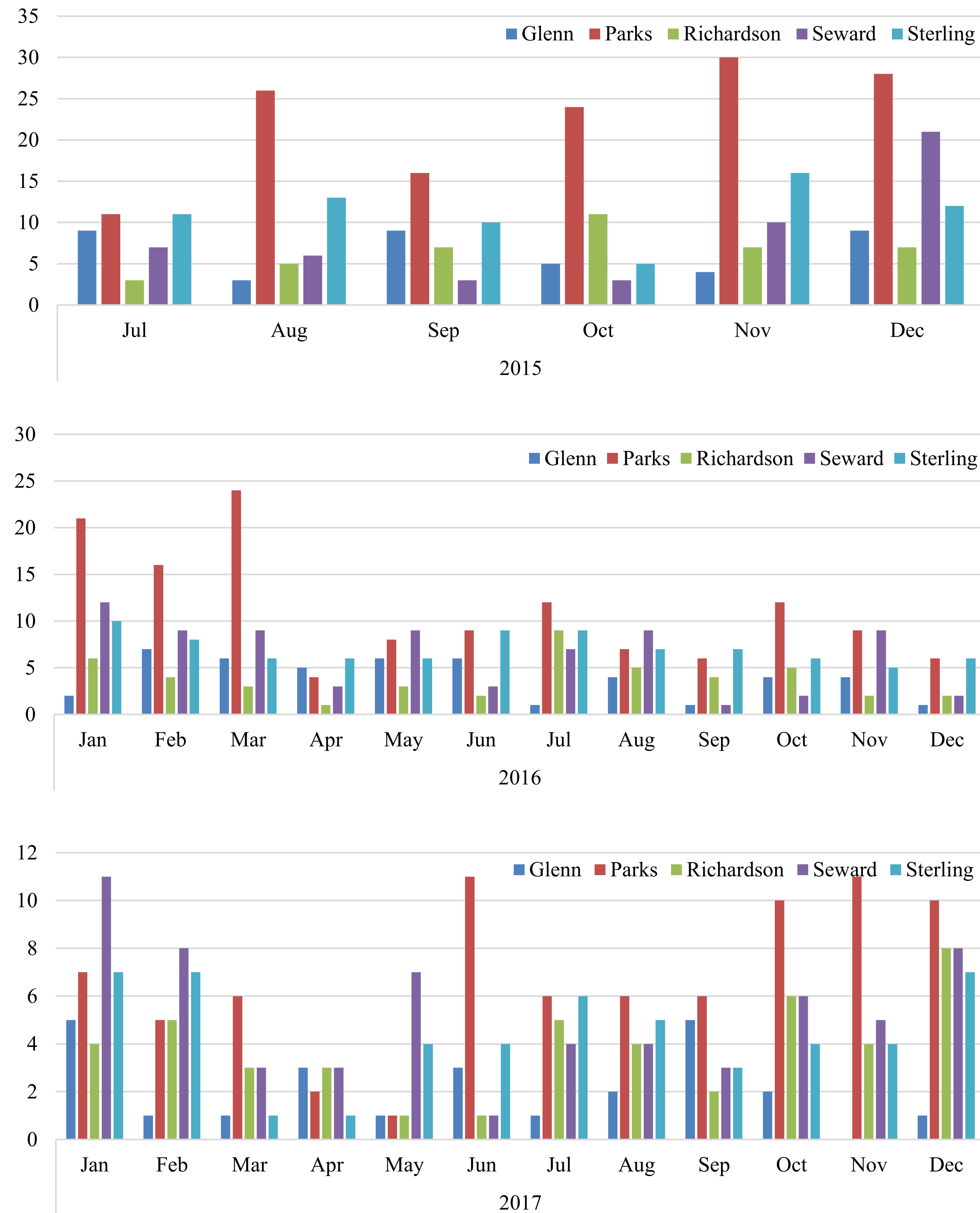

Figure B-27: Monthly total crashes along all corridors (July 2015 to December 2017)

Monthly total patrol hours for the study period along each corridor are shown in Figure B-28. The combined patrol hours are shown in Figure B-29. Generally, the distribution of patrol hours are not uniform throughout the study period. Patrol hours increased on the Seward Highway over the period but decreased along all other corridoes. However, the combined patrol hours displayed a greater degree of uniformity from month to month (Figure B-29). The fewest patrol hours were logged in August to October of 2016 and 2017.

Figure B-28: Monthly total patrol hours along each corridor (July 2015 to December 2017)

The ratio of total patrol hours to total crashes for all corridors together were greater in 2015 and 2016 than in 2017.

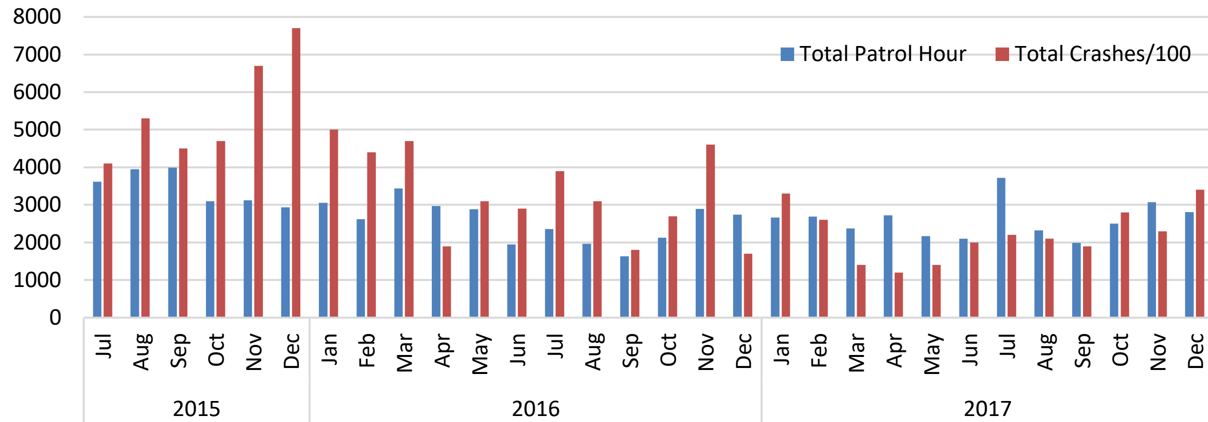

Figure B-29: Combined monthly total patrol hours vs total crashes along all corridors

Citation and incident data are also helpful to infer trooper presence on the highways. The categories considered for citations and incidents are given in Table B-2. Monthly variations of citation data are presented in Figure B-30. The number of citations over different time periods from year to year are comparable along most corridors. The pattern of citations suggests some seasonal variation. For example, summer of each year experiences the greatest number of citations, while winter of each year experiences the lowest. This pattern means that the citation distribution is opposite the crash distribution over the study period.

Table B-2: List of incident and citation categories

Incident Categories	Citation Categories
Driving with Suspended License	Not Wearing Seatbelt
Driving Under the Influence	No Proof of Insurance
Reckless Driving	Follow too closely
Leaving Scene	Equipment Violation
Negligent Driving	Speeding
	Stop Sign
	Distracted Driving
	Aggressive Driving
	Fail to Restrain Child
	Red Light
	License Violation

Figure B-30: Monthly total citations along the corridors (July 2015 to December 2017)

Figure B-31 depicts monthly variations of incidents along each corridor. Like citations, incident data have seasonal trends, but the overall number of incidents decreased over the study period in a way that resembles the crash trend. On average, there are fewer incidents from November to

January than in other months. This means that incidents, much like citations, have a seasonal trend that is opposite the crash trend. This may suggest that when there are high rates of citations and incidents that drivers try to drive more safely.

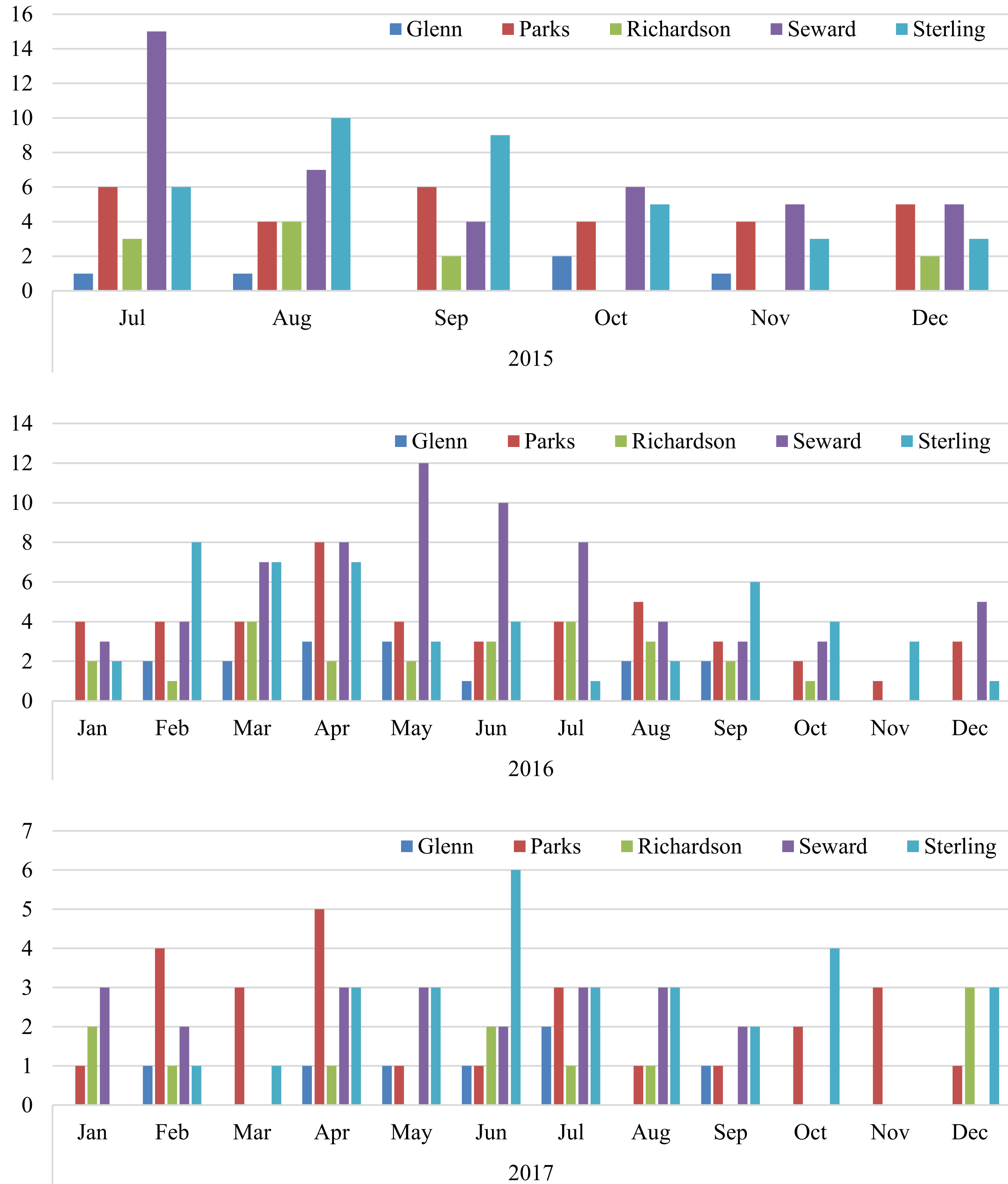

Figure B-31: Monthly total incidents along the corridors (July 2015 to December 2017)

In summary, patrol hours were higher and the number of crashes lower on the Parks, Seward, and Sterling Highways, as compared to the Glenn and Richardson Highways. However, there are several sections along each corridor where trooper presence is much higher than on other sections, even if the number of crashes are higher in the relatively unpatrolled sections. Reallocating patrol hours to corridor sections with a higher number of crashes may be a way to decrease the number of crashes. Moreover, as there is some inconsistency in patrol hours from month to month and season to season, it may reduce the number of crashes to increase patrol hours in periods that had lower patrol hours during the study period.

Appendix C – Data Analysis

Introduction

The methodology for Phase II is based on the literature review and the methodology of Phase I, and it is discussed in the body of the report. Three levels of statistical analysis are taken into consideration to determine the relation between crash instances and trooper presence. Macro analysis was performed using logistic regression of the whole period (2.5 years) and 6-month periods for each study corridor. Intermediate analysis included regression analysis of monthly crash and patrol hour data, similar to the analysis done in Phase I. Finally, micro analysis was performed by analyzing 30 second intervals from the troopers' activity details.

This section provides an in-depth explanation of the statistical analysis and corresponding results with discussion. The outcome of this analysis shapes the relationship between trooper presence and number of crashes. In addition, it addresses the influence of other variables that were considered in Phase II to further explain the relationship.

Macro Analysis

For macro analysis, the patrol vehicle presence, in units of hours, is the independent variable, while the binary presence of a crash event ("1" as "Yes" and "0" as "No") is the dependent variable. The results of the binary logistic regression analysis for each highway are given in Table C-1. The second column of the table represents the raw significance value (generally known as p-value) from the logistic regression analysis. The p-value determines the significance of the relationship between two variables that originates from hypothesis testing. A p-value of less than 0.05 indicates a statistically significant correlation at a 95% confidence interval. For ease of interpretation, the third column indicates whether or not a 95% confidence interval was achieved. The correlation coefficient given in the fourth column represents the type of correlation and strength of the correlation between the dependent and independent variables. The values are either positive or negative, with a positive value indicating a positive correlation and a negative value indicating a negative correlation. If the resulting statistical value is "Error," it indicates no crashes occurred along any part of the study corridor within that particular period.

Table C-1: Results of macro analysis of full study period (July 2015-December 2017)

Highway	Raw Value of Significance (P-value)	95% Confidence Interval Achieved?	Coefficient for Patrol Presence
Glenn	0.015	Yes	0.004
Parks	0.000	Yes	0.013
Richardson	0.000	Yes	0.042
Seward	0.340	No	N/A
Sterling	0.039	Yes	0.003

Results of the macro analysis indicate that four study corridors out of five achieved significance between patrol presence and crash instances, therefore a strong statistical correlation between presence of patrol and crashes exists. Only the Seward highway did not achieve significance, reaching the same results from the Poisson regression analysis from Phase I. However, the positive coefficients of presence of patrol from the analysis suggest a positive correlation between trooper presence and crash instances, meaning that as trooper presence increases so too does the probability of a crash occurrence, which is a highly unlikely conclusion. Therefore, though macro analysis results showed a correlation, it does not reflect a realistic outcome.

Another form of macro analysis was conducted with binary logistic regression, but considering six month periods. The results of the analysis are shown in Table C-2. It shows most of the six month periods for different corridors are not statistically significant at a 95% confidence interval. The results for the Glenn Highway are insignificant throughout the whole study period. For the Parks Highway, the results are significant except in 2017 and the coefficients suggest a positive correlation between trooper presence and crash occurrence. The results for the Richardson Highway indicate statistical significance for almost the entire period, except January 2016 to June 2016. For the Sterling and Seward Highways, there were very few statistically significant relationships.

The results of the second form of macro analysis suggest that statistical significance cannot be achieved from this model based on six month periods. This is because of the unusual characteristics described in Appendix B. For example, the distribution of trooper presence and crash frequency is much higher along certain sections of the corridors for certain periods. Besides, a greater number of crash instances that were accompanied by higher patrol hours may result in unrealistic positive correlations.

Table C-2: Results of macro analysis of six months period

Highway		Jul 2015 - Dec 2015	Jan 2016 - Jun 2016	Jul 2016 - Dec 2016	Jan 2017 - Jun 2017	Jul 2017 - Dec 2017
Glenn	P-value	0.892	0.202	0.066	0.165	0.176
	95% Confidence Interval	No	No	No	No	No
	Coefficient	N/A	N/A	N/A	N/A	N/A
Parks	P-value	0.000	0.000	0.000	0.144	0.097
	95% Confidence Interval	Yes	Yes	Yes	No	No
	Coefficient	0.014	0.015	0.029	N/A	N/A
Richardson	P-value	0.000	0.48	0.009	0.000	0.000
	95% Confidence Interval	Yes	No	Yes	Yes	Yes
	Coefficient	0.067	N/A	0.034	0.109	0.087
Seward	P-value	0.048	0.873	0.526	0.201	0.927
	95% Confidence Interval	Yes	No	No	No	No
	Coefficient	0.021	N/A	N/A	N/A	N/A
Sterling	P-value	0.096	0.015	0.279	0.487	0.468
	95% Confidence Interval	No	Yes	No	No	No
	Coefficient	N/A	0.012	N/A	N/A	N/A

This level of analysis failed to describe the relationship between trooper presence and crash occurrence. Further analysis on the intermediate level as well as micro level better described the relationship. It is worth noting that the overall trooper presence and total crashes were considered without instantaneous time occurrence, meaning the trooper and crashes do not coincide in the prescribed 30 second periods. Time alignment of the variables is important in establishing the relationship. No further actions were taken on this level of analysis in building the relationship.

Intermediate Analysis

The intermediate analysis is a logistic regression analysis of crash instances and patrol hours on a monthly basis. A summary of total crashes and patrol hours are shown in Table C-3.

Table C-3: Summary of monthly total crashes and patrol hours along all highways

Year	Month	Glenn		Parks		Richardson		Seward		Sterling	
		PH	C	PH	C	PH	C	PH	C	PH	C
2015	Jul	1030.90	10	1082.29	12	252.76	7	521.59	7	727.21	14
	Aug	560.71	3	1476.85	28	288.55	7	464.72	6	1160.32	13
	Sep	531.80	12	1318.51	17	296.61	9	406.46	3	1433.54	10
	Oct	474.99	5	1164.71	26	252.36	11	388.02	3	813.43	5
	Nov	766.76	5	1069.29	32	303.83	9	348.58	10	632.33	16
	Dec	472.05	9	1159.57	28	331.37	7	407.87	21	567.17	12
2016	Jan	445.16	2	1288.78	23	237.03	10	443.59	12	637.38	11
	Feb	286.93	7	1064.06	17	306.19	8	353.83	9	610.43	8
	Mar	1022.23	6	1085.46	24	284.45	5	184.87	9	856.54	7
	Apr	419.67	5	1127.30	5	399.70	1	443.00	3	580.49	6
	May	283.97	7	908.17	9	403.95	3	518.37	9	768.45	6
	Jun	299.57	6	668.11	9	280.87	2	295.97	4	403.54	11
	Jul	156.21	3	644.27	14	218.91	9	174.75	7	378.81	10
	Aug	144.24	4	536.35	7	191.38	8	123.32	9	317.35	8
	Sep	110.18	1	433.68	8	120.96	5	100.14	1	321.21	8
	Oct	123.01	5	484.24	12	148.01	5	254.37	2	409.16	7
	Nov	351.13	4	688.16	9	229.72	5	723.82	9	901.88	5
	Dec	204.90	1	771.52	6	183.50	3	907.11	2	676.65	7
2017	Jan	168.47	4	901.50	8	102.88	4	1062.08	11	429.78	7
	Feb	393.32	1	811.50	5	111.40	6	911.99	9	463.00	8
	Mar	302.12	1	613.20	8	148.12	3	824.96	3	481.56	1
	Apr	494.25	3	807.21	2	200.34	4	733.43	3	485.14	1
	May	503.71	1	604.24	1	169.93	1	418.21	7	472.76	4
	Jun	353.87	4	750.79	11	132.47	2	416.68	1	447.49	4
	Jul	703.58	2	641.64	6	191.22	5	621.06	4	1563.55	6
	Aug	318.01	2	585.61	6	212.30	6	514.63	4	695.55	6
	Sep	304.10	5	565.80	7	212.60	2	492.59	3	416.25	3
	Oct	501.61	2	905.89	10	217.73	6	509.23	6	367.04	5
	Nov	313.56	0	981.44	11	193.24	4	508.55	5	1078.04	6
	Dec	665.22	1	679.78	11	241.47	10	749.48	8	468.23	7

Crashes and patrol presence are the dependent and independent variables, respectively, for this analysis. Similar to the intermediate analysis considered in Phase I, the results are not statistically significant for most cases. The summary of results are represented in Tables C-4 through C-6. Table C-4 presents the raw values of significance for each sample dataset. Whether or not a statistical significance at a 95% confidence interval was achieved is presented in table C-5. Table C-6 provides the correlation coefficient, which represents the nature of the relationship. Since intermediate analysis results for July 2015 to June 2016 are presented in the Phase I project report, only the remaining months of the study period are provided here.

The results from binary logistic regression indicate that statistical significance of the correlation between patrol hours and crashes does not exist on most highways in most months. There is no statistical significance present for Seward Highway at all. The nature of the results are expected due to the small number of crashes in many cases.

In summary, the use of intermediate analysis to build the correlation between trooper presence and crashes does not suffice for the same reason addressed in the macro analysis. Instantaneous time occurrence and alignment of the variables are important in establishing the relationship. No further actions were taken on the intermediate level of analysis.

Table C-4: Results of intermediate analysis (Raw value of significance, P-value)

Year	Month	Glenn	Parks	Richardson	Seward	Sterling
2016	Jul	0.451	0.085	0.018	0.674	0.564
	Aug	0.038	0.98	0.056	0.124	0.427
	Sep	0.895	0.168	0.904	0.867	0.565
	Oct	0.175	0.078	0.045	0.287	0.032
	Nov	0.288	0.196	0.52	0.571	0.526
	Dec	0.415	0.004	0.448	0.695	0.093
2017	Jan	0.135	0.697	0.78	0.355	0.785
	Feb	0.631	0.685	0.048	0.273	0.187
	Mar	0.86	0.02	0.044	0.59	0.377
	Apr	0.975	0.435	0.022	0.744	0.564
	May	0.769	0.88	0.049	0.649	0.568
	Jun	0.941	0.236	0.044	0.882	0.763
	Jul	0.527	0.153	0.046	0.75	0.626
	Aug	0.783	0.755	0.117	0.277	0.831
	Sep	0.174	0.103	0.995	0.913	0.539
	Oct	0.842	0.131	0.031	0.681	0.197
	Nov	**Error**	0.654	0.035	0.421	0.888
	Dec	0.994	0.871	0.249	0.536	0.751

Table C-5: Results of intermediate analysis (95% confidence interval)

Year	Month	Glenn	Parks	Richardson	Seward	Sterling
2016	Jul	No	No	Yes	No	No
	Aug	Yes	No	No	No	No
	Sep	No	No	No	No	No
	Oct	No	No	Yes	No	Yes
	Nov	No	No	No	No	No
	Dec	No	Yes	No	No	No
2017	Jan	No	No	No	No	No
	Feb	No	No	Yes	No	No
	Mar	No	Yes	Yes	No	No
	Apr	No	No	Yes	No	No
	May	No	No	Yes	No	No
	Jun	No	No	Yes	No	No
	Jul	No	No	Yes	No	No
	Aug	No	No	No	No	No
	Sep	No	No	No	No	No
	Oct	No	No	Yes	No	No
	Nov	**Error**	No	Yes	No	No
	Dec	No	No	No	No	No

Table C-5: Results of intermediate analysis (Coefficient for independent variable)

Year	Month	Glenn	Parks	Richardson	Seward	Sterling
2016	Jul	N/A	N/A	0.241	N/A	N/A
	Aug	0.359	N/A	N/A	N/A	N/A
	Sep	N/A	N/A	N/A	N/A	N/A
	Oct	N/A	N/A	0.086	N/A	0.057
	Nov	N/A	N/A	N/A	N/A	N/A
	Dec	N/A	0.034	N/A	N/A	N/A
2017	Jan	N/A	N/A	N/A	N/A	N/A
	Feb	N/A	N/A	0.113	N/A	N/A
	Mar	N/A	0.028	0.1	N/A	N/A
	Apr	N/A	N/A	0.084	N/A	N/A
	May	N/A	N/A	0.079	N/A	N/A
	Jun	N/A	N/A	0.124	N/A	N/A
	Jul	N/A	N/A	0.089	N/A	N/A
	Aug	N/A	N/A	N/A	N/A	N/A
	Sep	N/A	N/A	N/A	N/A	N/A
	Oct	N/A	N/A	0.142	N/A	N/A
	Nov	**Error**	N/A	0.161	N/A	N/A
	Dec	N/A	N/A	N/A	N/A	N/A

Micro Analysis

Micro analysis examined the physical presence of trooper vehicles at the location of crash events, aligning the two variables in space and time. This is perhaps the best indicator of whether or not a relationship exists.

Activity details were gathered in increments of 30 seconds to perform micro analysis, as explained in the methodology. Crash instances are matched within the 30 second interval to the presence of a trooper. For a case to be considered for analysis, the trooper must have entered within a 500 ft. radius of the crash event within 15 seconds of the event. The dependent variable (the crash) is preserved in binary form and coded as '1' for crash occurrence and '0' as the absence of a crash occurrence. The independent variable (trooper presence) is also set in binary form and coded as '1' for trooper presence and '0' for trooper absence.

The results are presented in Table C-6. The raw value of significance is shown in the second column. The third column denotes the regression coefficient for the independent variable. The constant term in the fourth column represents the intercept of the regression equation, which indicates the predicted value when the independent variable is zero. The fifth column displays the odd ratio for each model, which is the exponentiation of the coefficient. This represents a percentage increase or decrease in the number of crashes due to trooper presence. The remaining columns represent the estimated probability of a crash occurrence with or without trooper presence, first per 30 second interval and second per yearly interval.

Table C-6: Results of micro analysis

Highway	P-value	Coefficient	Constant	Odd Ratio	Probability of crashes without presence of troopers per 30 s	Probability of crashes with presence of troopers per 30 s	Probability of crashes without presence of troopers per year	Probability of crashes with full presence of troopers per year
Glenn	<0.0001	-2.215	-8.527	0.109	0.019801	0.002162	208.2	22.82
Parks	<0.0001	-1.759	-8.694	0.172	0.016756	0.002886	176.1	30.3
Richardson	<0.0001	-2.766	-8.002	0.063	0.033468	0.002106	351.8	22.1
Seward	<0.0001	-1.912	-8.308	0.148	0.024648	0.003643	259.1	38.3
Sterling	<0.0001	-2.045	-8.591	0.129	0.018574	0.002403	195.3	25.3

The results suggest that a strong correlation exists between trooper presence and crashes. The correlation is statistically significant for each highway at a 95% confidence interval. The coefficients of the independent variable for every highway are negative, suggesting that the number of crashes decrease in the presence of a trooper. This supports the idea that the higher the presence of troopers, the lower the crash occurrence. The estimated probabilities also support this idea.

Trooper presence was most effective in reducing the number of crashes on the Richardson Highway, which had an Odd ratio of 0.063, while trooper presence was least effective on the Parks Highway, which had an Odd ratio of 0.172. Overall, the crash occurrence would be decreased to an average of 28 crashes per year with full trooper presence through all corridors. Here full troopers presence indicates the steady presence of trooper in a geofence at each 30s interval. Though this is not practical a solution, since troopers cannot be stationed every 500 ft., the knowledge will help to optimize patrol hours and patrol locations for both crash reduction and expense reduction. Further discussion of economic analysis is provided in Appendix D.

The probability of crashes along each corridor with respect to the presence of troopers is shown in Figure C-1. The presence of troopers in the x axis represents the ratio of actual trooper presence per trooper vehicle to the total number of hours in a year. For example, presence of troopers = 20% means that a total 0.2*365*24 = 1732 hours of patrolling by a single vehicle in a geofence per year, where 365*24 = 8760 is the total number of hours in a year. The curve function indicates the rate of reduction in crashes due to the presence of troopers. The Richardson Highway has the highest crash reduction potential among all corridors, whereas the lowest potential is on the Parks Highway. This suggests that trooper presence is most effective on the Richardson Highway in reducing crashes. Since the Parks Highway experienced more crashes as well as more patrol hours, there may be other factors that influence the number of crashes more significantly in this corridor. This indicates that the effectiveness of enforcement may be corridor-specific.

In addition, the observed crashes for different years for these corridors were compared to predicted crashes. The comparisons showed mixed results, but the predicted crashes often overshot observed crashes. This prediction model can be applied to the current allocation of patrol hours. As trooper presence increases, the difference between predicted crashes and actual crashes will be reduced. The rate of reduction of crashes will not be affected by these differences, indicating that the use of this model will be effective in measuring required enforcement.

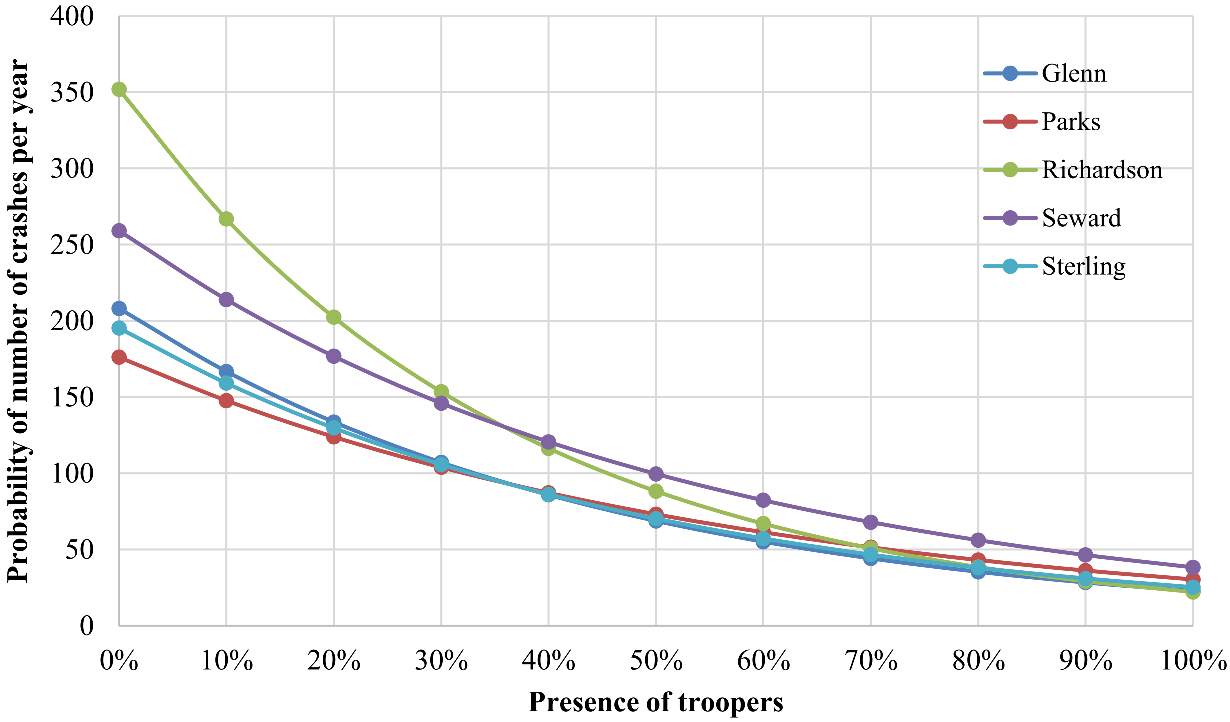

Figure C-1: Probability of crashes along the corridors with respect to presence of patrol

The probability of crashes per geofence per year with respect to trooper presence is shown in Figure C-2. This gives a clearer picture of the possible crash reduction rates. The steep negative slope of the Seward Highway indicates that the potential reduction of crashes in the presence of troopers is the highest of any corridor, which resembles the observed crashes per geofence given in Table C-7. The probability of crash occurrence without presence of troopers is also the highest in this corridor (about 11 crashes per year per geofence). The probability of crashes per geofence on the Richardson, Glenn, and Sterling Highways are in agreement with the observed crashes per geofence shown in Table C-7. However, the Parks Highway's predicted crashes per geofence, which are very low, do not reflect the reality of observed crashes.

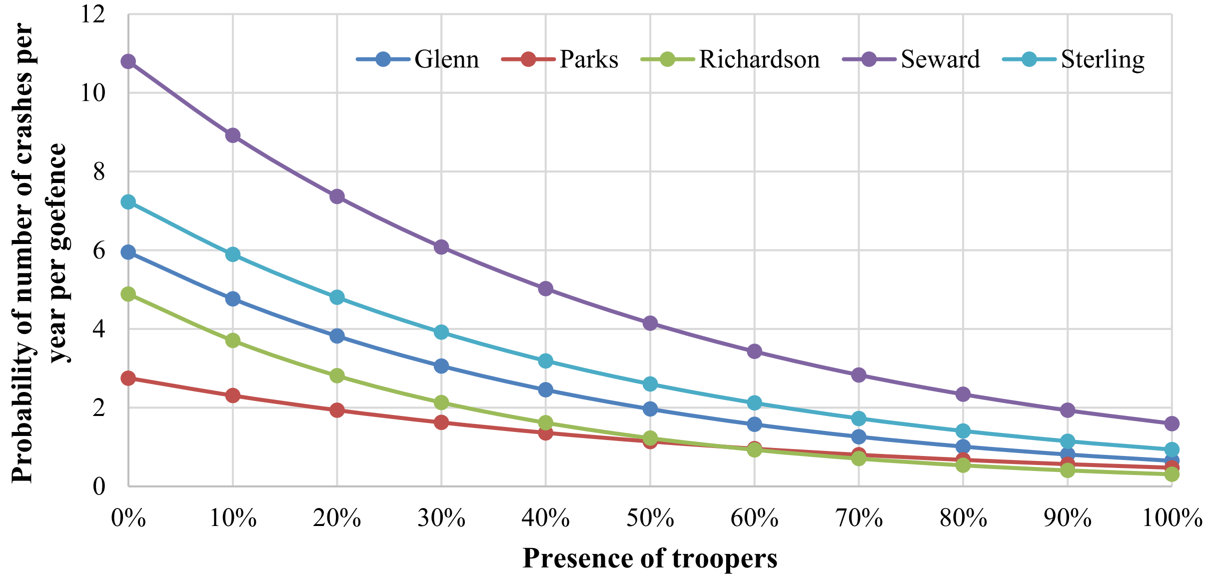

Figure C-2: Probability of crashes per geofence along each corridor with respect to patrol presence

Table C-7: Total patrol hours and crashes per geofence for study corridors based on current rate of enforcement

Highway	Total Patrol Hour	Patrol hours per geofence per year	Total observed crashes (Jul 2015 to Dec 2017)	Observed crashes per geofence per year
Glenn	12706.36	145.22	122	1.39
Parks	25398.36	158.74	388	2.43
Richardson	6798.21	37.77	169	0.94
Seward	14511.02	241.85	202	3.37
Sterling	19387.78	287.23	227	3.36

Binary logistic regression was also performed on the combined corridor data to examine the general correlation of crashes to patrol presence. Figure C-3 shows the probability of number of crashes along all highways together.

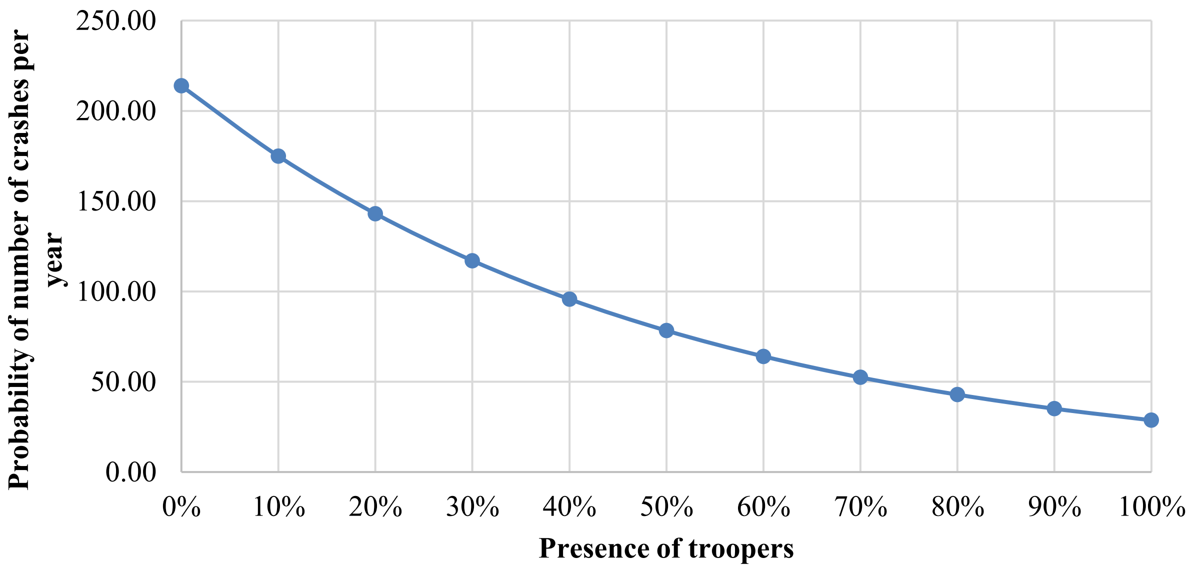

Figure C-3: Probability of number of crashes per geofence along all corridors together

In Table C-8, the probability of crashes based on the micro analysis models are put in the form of an equation for each corridor and for all corridors combined. The second and third columns represent the function coefficient and the constant term, respectively. The p values in the regression equations were given in Table C-6, which denotes the probability of a crash occurrence. The x value is the presence of troopers in a 30 second window within 500 ft.

Table C-8: List of regression equations for estimating probability of crashes

Highway	Coefficient	Constant	Regression Equation
Glenn	-2.215	-8.527	$ln\frac{p}{1-p} = -8.527 - 2.215x$
Parks	-1.759	-8.694	$ln\frac{p}{1-p} = -8.694 - 1.759x$
Richardson	-2.766	-8.002	$ln\frac{p}{1-p} = -8.002 - 2.766x$
Seward	-1.912	-8.308	$ln\frac{p}{1-p} = -8.308 - 1.912x$
Sterling	-2.045	-8.591	$ln\frac{p}{1-p} = -8.591 - 2.045x$
All Corridors	-2.009	-8.500	$ln\frac{p}{1-p} = -8.500 - 2.009x$

The following figures represent the percentage of crash reduction with different levels of trooper presence for individual highways (Figure C-4) as well as for all corridors combined (Figure C-5). The figures suggest that trooper enforcement is most efficient on the Richardson Highway whereas it is least efficient on the Parks Highway. A 100% presence of troopers on the Richardson Highway could reduce motor vehicle collisions by about 94%. Here, 100% presence of troopers means that a trooper is present at every 30 second interval within all 500 ft. geofences. This value is purely theoretical, as it would not be possible to provide a 100% trooper presence. It does, however, give a sense of the overall relationship between trooper presence and number of crashes. For example, to achieve a specific reduction in crashes (y), trooper presence should meet the corresponding level (x).

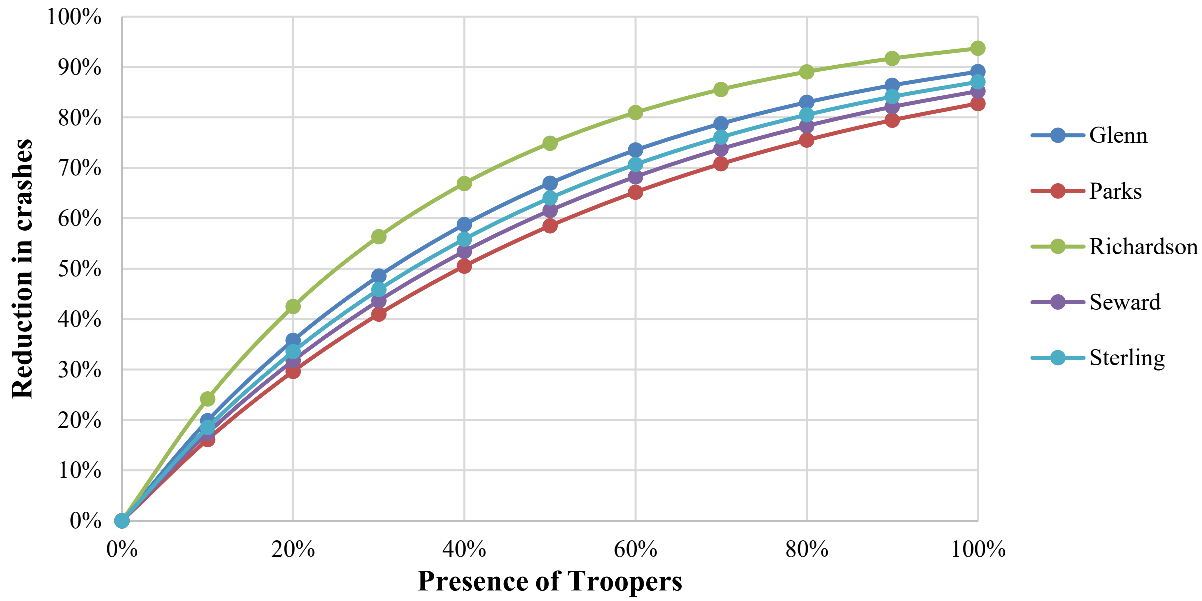

Figure C-4: Reduction in crashes with presence of troopers for individual highway corridors

On average, using the overall model, the greatest possible crash reduction percentage is 86%. Again, this level of enforcement is purely theoretical. However, if the target crash reduction is 55% and the current enforcement level is at 20%, then this model could be used to recommend a doubling of the enforcement level to 40%.

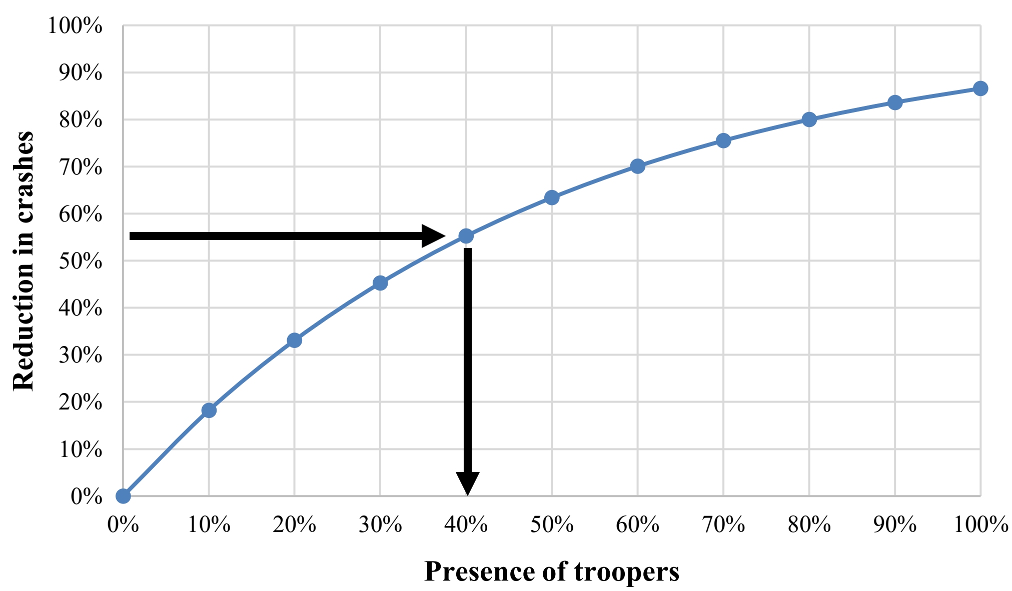

Figure C-5: Reduction in crashes with presence of troopers for all corridors together

Micro Analysis Using Other Variables

Micro analysis was also performed at a 95% confidence interval using three new variable types: traffic volume (AADT), pavement surface conditions (surface temperature, dry, wet, and icy), and weather conditions (snow only). The pavement surface conditions and the weather condition data were collected via Alaska's Road Weather Information System (RWIS), where data are recorded at fixed stations along the five highways (Figure C-6). The dependent variable remained crash events in binary form. The independent variable surface temperature and AADT were measured as scales, similar to how the Road Weather Information System (RWIS) displays data. Pavement surface conditions and weather conditions were entered as binaries. The category considered for different pavement conditions are shown in Table C-9.

Table C-9: Different pavement conditions considered in the analysis

From RWIS	Considered in the analysis	Type of data in the model	Coded for the model
Temperature	Temperature	Scale	-
Dry Error Other	Dry	Nominal	"Yes" = 1 "No" = 0
Wet Chemically wet Trace Moisture	Wet	Nominal	"Yes" = 1 "No" = 0
Ice Watch Ice Warning	Icy	Nominal	"Yes" = 1 "No" = 0

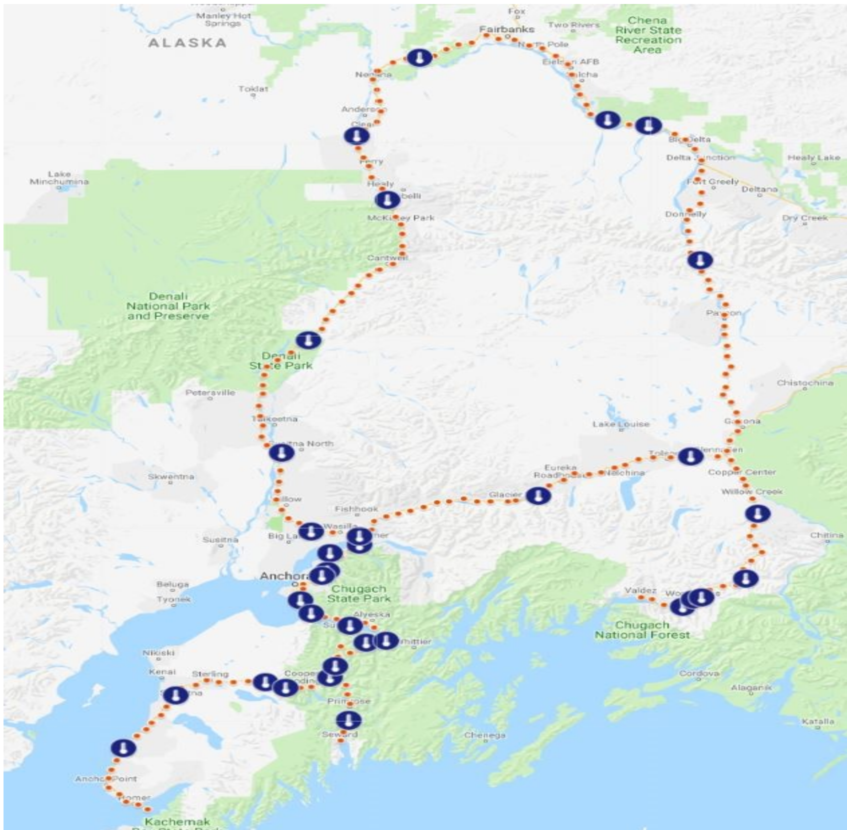

Figure C-6: RWIS stations along the highways

The results are shown in the Table C-10. The P-value, coefficients, and odd ratio from the model are given for each variable to observe if any significant relationship exists, as well as to know the nature of the relationship. The third column of the table represents analysis results for pavement surface temperature. The correlation between surface temperature and crashes is found to be significant only on the Glenn Highway. The coefficients and odd ratios suggest that the effect of temperature is different on different corridors.

The binary regression analysis results for traffic volume depict statistical significance for the relation between crashes with pavement surface temperature except on the Seward and Sterling Highways. However, the odd ratios for each highway are close to 1, which indicates that AADT has very little effect on crash occurrence.

The different pavement surface conditions had differing effects. Icy surface conditions did not have any influence on crashes, whereas both dry and wet surfaces had some effect on the Parks, Richardson, and Seward Highways, though the relationship was not statistically significant. On the Parks Highway, the probability of a crash increased in dry surface conditions and decreased in wet surface conditions. The probable number of crashes in dry surface conditions on both the Richardson and Seward Highways is unrealistically high.

Finally, the results for presence of snow show a positive effect on the number of crashes on the Glenn, Seward, and Sterling Highways, though the relationships are not statistically significant.

The odd ratios and coefficients for snowy conditions indicate a low probability of crashes in snow weather condition.

Table C-10: Analysis results from the regression analysis of the other variables with crashes

		Temperature	AADT	Snow	Dry	Wet	Icy
Glenn	Coefficients	0.024864	-6.00E-05	-10.032	N/A	N/A	N/A
	P-value	0.014629	0.052247	0.980131	N/A	N/A	N/A
	Odd ratio	1.025176	0.99994	4.4E-05	N/A	N/A	N/A
Parks	Coefficients	-0.0012	-6.60E-05	N/A	0.030843	-0.42306	N/A
	P-value	0.80975	0.000161	N/A	0.954597	0.707862	N/A
	Odd ratio	0.998801	0.999934	N/A	1.031324	0.655039	N/A
Richardson	Coefficients	-0.01174	-0.00014	N/A	11.03583	0.17186	N/A
	P-value	0.273813	0.034975	N/A	0.994245	0.999931	N/A
	Odd ratio	0.988329	0.99986	N/A	62058.33	1.187512	N/A
Seward	Coefficients	-0.00483	-2.60E-05	-11.0495	11.12286	0.163753	N/A
	P-value	0.639456	0.755416	0.972078	0.978037	0.999971	N/A
	Odd ratio	0.995182	0.999974	1.59E-05	67701.26	1.177923	N/A
Sterling	Coefficients	0.012462	-6.40E-05	-10.3909	N/A	N/A	N/A
	P-value	0.13317	0.110461	0.964451	N/A	N/A	N/A
	Odd ratio	1.01254	0.999936	3.07E-05	N/A	N/A	N/A

The unusual results for traffic volumes are due to the fact that AADT is measured annually, while crash occurrence is measured in 30 second intervals. For AADT to be a viable measure for analysis, traffic volume would need to be measured at the time of the crash, which is not currently possible. Similarly, the overall results for both pavement conditions and weather conditions are not significant because the data collected from RWIS were measured in 10 minute intervals, not 30 second intervals. Additionally, some of the pavement condition data were recorded as 'Error,' 'Other,' and '?,' which were considered as dry in the analysis. Moreover, the data collected from RWIS were based on 34 fixed stations in the study corridors (Figure C-6), which does not necessarily represent the actual conditions in each geofence.

In summary, the additional variables collected to improve the crash prediction model will not be considered because they may not reflect the actual conditions during crash events and were not statistically significant. This will lead to a simplified model that considers only trooper presence as a predictor of crash occurrence.

Appendix D – Benefit/Cost Analysis

The benefit/cost analysis was performed following the proposed method described in Phase I. Mock data were used to demonstrate the benefit/cost analysis in Phase I because actual analysis was not possible at the time due to limited data from the statistical analyses. The Phase II benefit/cost analysis was created based on the results of the micro analysis, which is presented in Appendix C. The benefit/cost analysis can help decision makers compare the benefits of crash reduction to the cost of trooper enforcement on each of the five highways.

Benefit/cost ratios are calculated using a given set of data and values for benefits versus costs. Benefits are determined by the direct and indirect costs associated with the estimated crash reduction. Costs are determined by the proposed increase in trooper patrol hours.

Calculation of Benefits

The crashes that occurred on each highway during the study period (July 2015 to December 2017) were divided into six severity levels, as shown in Table D-1. The PD level (property damage) consists of crashes in which property damage only (PDO) was sustained and crashes in which property damage was sustained in addition to an injury.

Table D-1: Crash severity levels

Highways	Fatal Injury	Serious Injury	Minor Injury	Possible Injury	PD	None
Glenn	3	8	31	13	21	52
Parks	5	20	72	23	47	232
Richardson	3	9	25	10	29	99
Seward	2	13	39	18	52	87
Sterling	2	11	54	19	38	116

Table D-2 shows the probabilities of crash events with and without trooper presence, which were calculated using the logistic regression equation given in Appendix C. Finally, the estimated reduction in crashes with current enforcement levels are shown in the last column.

Table D-2: Effects of the patrol vehicle presence in reducing crashes

HW	Predicted from Micro analysis				Observed		Reduction in Crashes
	No. of Crashes Without Trooper presence	No. of Crashes With observed Trooper presence	Reduction in Crashes	Percentage of crash reduction	Total Observed Crashes	Predicted Crashes (Without PH)	
Glenn	208.1	198.8	9.3	4.7%	122	128.01	6.01
Parks	176.1	168.0	8.1	4.8%	388	407.63	19.63
Richardson	351.8	337.7	14.1	4.2%	169	176.37	7.37
Seward	259.1	229.5	29.6	12.9%	202	231.90	29.90
Sterling	195.2	179.0	16.2	9.1%	227	249.61	22.61

Table D-3 shows the percentage of crashes for each severity level for the study corridors. Since the PD level contains both PDO crashes and PD plus injury crashes, the total percentage would be more than 100%. The values in the second column of Table D-4 are the estimated number of crashes that would have occurred beyond the actual number of crashes if there had been no trooper presence during the study period. The remaining columns address the reduction in crashes of each crash severity level.

Table D-3: Percentage of each severity level

Highways	Fatal Injury	Serious Injury	Minor Injury	Possible Injury	PD
Glenn	2.46%	6.56%	25.41%	10.66%	17.21%
Parks	1.29%	5.15%	18.56%	5.93%	12.11%
Richardson	1.78%	5.33%	14.79%	5.92%	17.16%
Seward	0.99%	6.44%	19.31%	8.91%	25.74%
Sterling	0.88%	4.85%	23.79%	8.37%	16.74%

Table D-4: Proportion of the reduction in crashes due to patrol presence

Highways	Total reduction in crashes	Fatal Injury	Serious Injury	Minor Injury	Possible Injury	PD
Glenn	6.01	0.15	0.39	1.53	0.64	1.03
Parks	19.63	0.25	1.01	3.64	1.16	2.38
Richardson	7.37	0.13	0.39	1.09	0.44	1.26
Seward	29.90	0.30	1.92	5.77	2.66	7.70
Sterling	22.61	0.20	1.10	5.38	1.89	3.78

The FHWA's KABCO scale costs were used to determine the direct costs associated with each crash severity type. The values in Table D-5 are those costs in 2016 dollars. The KABCO scale was developed by the National Safety Council (NSC) and is frequently used by law enforcement for classifying injuries:

K – Fatal;

A – Incapacitating injury;

B – Non-incapacitating injury;
C – Possible injury; and
O – No injury.

Table D-5: KABCO costs in 2016 dollars

Injury Severity Level	Comprehensive Crash Cost (2016)
Fatality (K)	$ 9,500,000.00
Disabling Injury (A)	$ 660,000.00
Evident Injury (B)	$ 130,000.00
Possible Injury (C)	$ 70,000.00
Property Damage Only (O)	$ 7,300.00

The value of time was used as the indirect cost, shown in Table D-6 in the original 2010 dollars and the inflated 2016 dollars.

Table D-6: Indirect costs of crashes

	Urban Interstates / Expressways	Urban Arterials	Urban Other	Rural Interstate / Principal Arterials	Rural Other
2010 Indirect Costs (Value of Time only) per each crash					
Fatal Crashes	$97,908.00	$6,937.00	$1,031.00	$6,532.00	$417.00
Injury Crashes	$20,683.00	$1,542.00	$452.00	$1,209.00	$107.00
PDO Crashes	$17,596.00	$934.00	$272.00	$1,228.00	$88.00
2016 Indirect Costs (Value of Time only) per each crash					
Fatal Crashes	$116,907.27	$8,283.14	$1,231.07	$7,799.55	$497.92
Injury Crashes	$24,696.58	$1,841.23	$539.71	$1,443.61	$127.76
PDO Crashes	$21,010.54	$1,115.24	$324.78	$1,466.30	$105.08

The direct and indirect cost savings associated with the estimated crash reduction are shown in Table D-7. The highways are considered rural principal arterials, and indirect costs for the value of time were selected on this basis. Total benefits are presented in the last column.

Table D-7: Calculation of total benefits along each highway

Highways	Fatal Injury	Serious Injury	Minor Injury	Possible Injury	PDO	Total Benefits
Glenn	1,405,385	260,722	200,768	45,762	9,070	1,921,708
Parks	2,404,918	669,226	478,765	83,127	20,843	3,656,879
Richardson	1,243,857	259,600	143,301	31,155	11,086	1,688,999
Seward	2,814,306	1,272,616	758,692	190,326	67,465	5,103,405
Sterling	1,893,818	724,626	706,905	135,190	33,176	3,493,715

Calculation of Costs

The calculation of costs was based on the actual total patrol hours of each corridor within the study period. With assistance from Alaska DOT&PF and the Alaska State Troopers, an hourly rate of $150 was determined, which includes wages, gas usage, and vehicle maintenance. The total cost of patrolling each highway is shown in Table D-8.

Table D-8: Total cost calculations

Highways	Total Patrol Hours	Total Cost
Glenn	12706.22	$ 1,905,932
Parks	25819.92	$ 3,872,988
Richardson	6863.841	$ 1,029,576
Seward	14823.25	$ 2,223,487
Sterling	19564.27	$ 2,934,641

With the total benefit and cost values determined, the benefit/cost ratio was calculated using Equation 1 from FHWA's KABCO webpage.

$$\text{Benefit/Cost Ratio} = PVB/PVC \qquad \text{Equation 1}$$

Where PVB = Present value of benefits
PVC = Present value of costs

The benefit/cost ratios for each study corridor are presented in Table D-9. The benefit/cost ratios suggest that the current trooper presence on the Glenn, Richardson, Seward, and Sterling Highways is economically justifiable. However, the ratio on the Parks Highway is slightly less than 1, which indicates that the trooper presence on that highway could become economically justifiable with either an increase in benefits or reduction in costs. This could likely be accomplished without a reduction in patrol hours by redistributing trooper presence along these corridors to areas with a higher number of crashes, thereby reducing the number of crashes.

Table D-9: Benefit/Cost Value

Highways	Total Benefits	Total Cost	Benefit/Cost
Glenn	$ 1,921,708	$ 1,905,932	1.01
Parks	$ 3,656,879	$ 3,872,988	0.94
Richardson	$ 1,688,999	$ 1,029,576	1.64
Seward	$ 5,103,405	$ 2,223,487	2.30
Sterling	$ 3,493,715	$ 2,934,641	1.19