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Highway Patrol Investment Levels vs. Crash Outcomes

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A coordinated effort between the DOT&PF and the University of Alaska Anchorage (UAA) College of Engineering began in January 2015 on five highway corridors. Using information recorded by sensors installed on State of Alaska trooper vehicles, and crash reports gathered from the Alaska State Troopers (AST) and DOT&PF, large-scale data sets were established through geospatial data collection. This data underwent database filtering and organization, inputted into statistical models created for monthly and annual timeframes. Analyses revealed particular characteristics of the collected data, such as certain segments of the highway corridors with significantly higher enforcement presence compared to other portions of each highway. This project successfully verified that geospatial data from trooper vehicles, along with crash, citation and arrest data, might offer valuable correlations for the Department to monitor in the future. Analyses also revealed that inclusion of additional independent contributing factors and at least another 18 months of data collection are needed to achieve statistical significance for meaningful conclusions.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
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yd	yards	0.914		m	m	meters	1.09	yards	yd
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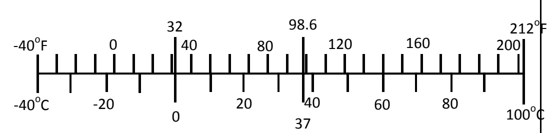
mi^2	square miles	2.59	kilometers squared	km^2	ha	hectares (10,000 m^2)	2.471	acres	ac
ac	acres	0.4046	hectares	ha					
		MASS (weight)					MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g	g	grams	0.0353	Ounces (avdp)	oz
lb	Pounds (avdp)	0.454	kilograms	kg	kg	kilograms	2.205	Pounds (avdp)	lb
T	Short tons (2000 lb)	0.907	megagrams	mg	mg	megagrams (1000 kg)	1.103	short tons	T
		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)		
^{o}F	Fahrenheit temperature	5/9 (^{o}F-32)	Celsius temperature	^{o}C	^{o}C	Celsius temperature	9/5 ^{o}C+32	Fahrenheit temperature	^{o}F
		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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ABSTRACT

Transportation enforcement agencies have typically relied on the number of citations issued during a given time period to measure the effectiveness of current enforcement levels. Although citations demonstrate the extent of enforcement, there is an absence of meaningful data on the impact of these activities on the number of vehicular crashes. In an effort to improve safety and evaluate optimal levels of investment in trooper patrols, Alaska's Department of Transportation and Public Facilities (DOT&PF) sought new methodology to correlate information on trooper vehicle presence with data on crash occurrences.

A coordinated effort between the DOT&PF and the University of Alaska Anchorage (UAA) College of Engineering began in January 2015 on five highway corridors. Using information recorded by sensors installed on State of Alaska trooper vehicles, and crash reports gathered from the Alaska State Troopers (AST) and DOT&PF, large-scale data sets were established through geospatial data collection. This data underwent database filtering and organization, inputted into statistical models created for monthly and annual timeframes. Analyses revealed particular characteristics of the collected data, such as certain segments of the highway corridors with significantly higher enforcement presence compared to other portions of each highway. This project successfully verified that geospatial data from trooper vehicles, along with crash, citation and arrest data, might offer valuable correlations for the Department to monitor in the future. Analyses also revealed that inclusion of additional independent contributing factors and at least another 18 months of data collection are needed to achieve statistical significance for meaningful conclusions.

SUMMARY OF FINDINGS

The research team successfully produced methodologies and infrastructure to collect, organize and analyze spatial information to correlate the presence of trooper vehicles and crash instances. One hundred devices were installed on various patrol vehicles to collect data at 30 second intervals, for a 12-month period, along five study corridors—Sterling Highway, Seward Highway, Richardson Highway, Parks Highway, and Glenn Highway. Data was gathered for the same 12 months from crash reports compiled by the Alaska State Troopers on those corridors. A binomial logistic regression was utilized for three levels of statistical analysis—by annual time period, monthly time period, and by relationship of physical presence of a patrol vehicle to crash occurrences. To assess optimal benefits for enforcement investment levels, a benefit/cost procedure was created based on an hourly cost rate for trooper patrols.

As a result of this study, mechanisms are now in place to collect and evaluate the data, along with additional data gathered over a longer period of time on shorter highway corridor sections to achieve a meaningful assessment of interactions between enforcement presence and crash outcomes. Specifically, data on traffic volumes, patrol presence, and crash occurrences on sample corridor sections reduced from 5 miles to 1-2 miles, will allow collection of necessary information on a) where traffic volumes are highest along the study corridor, and b) exactly where crashes have occurred. The statistical model used for this research is flexible enough to allow for recommended inclusion of other potential contributing/environmental factors associated with crash instances. These include the presence of intersections, side street traffic volumes and seasonal differences, such as icy roadway conditions, as well as relevant information on vehicle speeds, citations and arrests.

Chapter 1 – INTRODUCTION

Efforts to reduce fatal and severe injury crashes on highways are one of the top priorities of transportation agencies in the United States. In 2009, an estimated 5,505,000 traffic crashes occurred in the United States, resulting in 33,808 fatalities and 2,217,000 serious injuries (NHTSA, 2009). Both monetary and non-monetary costs are associated with crashes, with an economic cost estimated at around $230 billion per year (NHTSA, 2008). 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 2007, the national average was 1.39; Alaska was determined to be at 1.59 (AHSO, 2010). The Alaska Strategic Highway Safety Plan (SHSP) provides a framework of strategies and actions for reducing the most serious highway crashes by half by 2030.

In 2006, 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, head-on and multi-vehicle collisions. These designations have reduced the combined number of fatal and major injury crashes on the four TSCs by 50%. Typically building divided highways in Alaska with access management is documented as the primary way to achieve a 50 percent or higher reduction in serious injury, opposing vehicle crashes. Current Safety Corridor Audits suggest the lasting effect of this crash reduction requires a continued intensive effort that can have diminishing results over time, and that significant highway projects are recommended towards removing Safety Corridor designation. The Safety Corridor Audit Team—comprised of DOT&PF, 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 speeding, and 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 possible reduction in crashes is a key component of that assessment, allowing public officials to assign a dollar value to compare against the cost of building new roads on an annual cost basis or other measures.

Reductions in citations or arrests may falsely indicate a reduction in staff is possible, when enforcement may actually be serving to prevent dangerous illegal driving patterns. A new performance measure is required to correlate enforcement times within and around the high crash locations to find an appropriate balance. This project sought to create a method to link law enforcement presence with crash frequencies and severity, by including the impacts of citations and arrests on illegal driving behavior.

Collision reports, citations, and incident information from appropriate agencies, such as the DOT&PF and Alaska State Troopers, along with time and location information gathered by installation of sensors on trooper vehicles along targeted highway corridors, was analyzed to assess data characteristics and potential interactions. This information was used to calculate the benefit/cost ratio of enforcement investment levels.

Chapter 2 - LITERATURE REVIEW

A literature review explored published research relevant to the project. This review provided background on how the presence of patrol vehicles and automated enforcement psychologically affects driving behavior, and offered insights into the fiscal impacts of vehicle collisions. Databases utilized for the literature review included: *The Journal of Traffic Safety*, *Traffic Injury Prevention*, as well as publications from state transportation departments and the Federal Highway Administration (FHWA), Transportation Research Board (TRB), American Association of State and Highway Transportation Officials (AASHTO), National Cooperative Highway Research Program (NCHRP), National Highway Traffic Safety Administration (NHTSA), and other national and international organizations interested in highway and traffic safety. The review also included databases of the Transportation Research Information Services (TRIS) and the National Transportation Information Service (NTIS). For further information, see Appendix A.

Literature Review Findings

The literature provided valuable background on statistical relationships between crash instances and patrol distributions, enforcement effectiveness, enforcement psychology, and the economic impacts/costs of various types of vehicle crashes. Along with other non-monetary losses, the literature documented how costs associated with medical treatment, public services and property damage from vehicle crashes impose economic burdens on both involved and uninvolved parties. According to sources such as the *Handbook of Traffic Psychology*, the presence and active participation of law enforcement is an effective way to adjust driver behavior. This position is further reinforced by studies conducted in London, Uganda and parts of Europe, which reflect the frequency of fatal crashes and poor driver behavior is reduced by increased law enforcement presence. To be most effective, a cost-benefit analysis to determine optimal methods and frequency for dispatching patrol vehicles should guide investment in enforcement.

The report of primary interest was the *Evaluation of the Queensland Road Safety Initiatives Package*, published by the Monash University. This study had a similar scope to this research, including development of a statistical model and correlation of programs under the Road Safety Initiatives Package (RSIP) with crash occurrences. However, specific factors in the Monash University study present challenges for direct comparison of their research to this study. First, the Monash data collection effort occurred when the RSIP program was being implemented, allowing researchers to study the effects of the RSIP program both before and after implementation. The Monash study also had access to previous studies within the Monash region to justify utilization of a log-linear Poisson regression model. In contrast, data collected for this study did not employ a before-and-after scenario, as the effects of patrol vehicle presence were observed for each study corridor within one specific time period, with no previous studies of those areas available. This posed a challenge, as a higher level of detail is required to create a statistical model producing accurate results. Finally, the Monash study took place in an urban environment with a higher population density than the area of this study. The study corridors involved with this research are long highways spanning rural areas, having an impact on the characteristics of the enforcement and collision data.

Chapter 3 – METHODOLOGY

The literature review provided information on procedures used by similar studies to observe any interactions that may occur between the presence of enforcement and crash instances. Ambitious data collection was necessary to provide adequate sample data sets for the statistical analyses. The literature suggested the existence of a psychological factor associated with how patrol vehicle presence affects driver behavior. Studies conducted in certain countries like Queensland and in parts of the United States present evidence of such interaction, indicating a need for planning and development of methodologies for meaningful analysis.

This section details the methodologies developed for this study--from data collection and organization, to statistical analyses and the cost/benefit procedure used. This includes procedures for collecting information from trooper vehicles and crash databases, and technical aspects of database organization and filtration of collected data. Selection of an appropriate statistical model, its trial analyses and associated results, along with the procedure for calculating the benefit/cost ratio is also included.

Statistical Analysis

The nature of the data involved required development of three levels of analysis: macro, intermediate, and micro. The macro level analyzed data on an annual basis, whereas the intermediate level was on a monthly basis. While the micro level of analysis, which connects the physical presence of a trooper vehicle to the spatial presence of a crash instance, is ideal, due to the aggressive requirements of microanalysis and the constraint of having only 12 months of data, a microanalysis was not possible. More information follows about each level of analysis, including their associated results. For detailed information about patrol vehicle, crash and citation data, please see Appendix B.

Analysis Objectives

The goal of the statistical analysis was to determine whether a correlation exists between the presence of patrol vehicles and crash occurrences, and if so, to quantify the impact that presence has on the likelihood of crash occurrences. Based on a lack of available data, the desired accuracy in the results of the statistical analysis was not possible. However, these sample tests did reveal the nature of the data, observe the interaction between dependent and independent variables, and provide recommendations for a final methodology for how to achieve more accurate results in future research.

Regression Analysis

Working with the Department of Mathematical Sciences at the University of Alaska Anchorage, researchers determined that crash occurrences must use categorical, rather than numerical, values as follows. Crashes occurring within a hotspot area at a given time fall in the “yes” category. Crashes not occurring during that specific time fall in the “no” category. Due to the nature of crash occurrences in Alaska and the variety of factors that influence them, the statistical analysis took a conservative approach to its initial assumptions. In particular, researchers assumed crash instances are based on probability rather than on a log-linear relationship with other independent factors.

Based on feedback and recommendations, a binomial logistic regression—where the dependent variable is a dummy variable, coded 0 (did not occur) or 1 (did occur)—was the most appropriate approach to the statistical analysis. Under this regression, the presence of patrol vehicles was included as a numerical presence based on time, and the occurrence of crashes was a categorical dependent variable. To determine whether a correlation exists between independent variables and a dependent variable, logistic regression analysis is the traditional method. In this case, the question is "Does the current frequency of patrol vehicles in a given region and time interval have an effect on the probability of crashes occurring within that location?"

The results of the logistic regression analysis consist of the following: predicted probabilities, expected and observed values, and the p-value. The purpose of the p-value is to determine if a statistical correlation exists, and whether the model can make accurate, statistically significant predictions based on a 95% confidence interval. Although the 95% confidence interval is a strict correlation generally used for scenarios where all factors are in a controlled environment, since there are a variety of factors that affect crash outcomes, lowering the confidence interval requirement for future research may be appropriate. The binomial logistic regression model appears in Equation 1:

$$\ln\left(\frac{p}{1-p}\right) = b_0 + b_1x_1 + b_2x_2 + \ldots + b_kx_k \qquad \text{Equation 1}$$

where:

p = predicted probability
b_0 = constant
b_k = coefficient
x_k = dependent variable

If, for example, there is only one independent variable included in the model, the result appears in Equation 2:

$$\ln\left(\frac{p}{1-p}\right) = b_0 + b_1x_1 \qquad \text{Equation 2}$$

Once the above model is determined, the equation is modified to determine appropriate frequency of patrol vehicles for affecting the occurrence of crashes. Since the existing model is in logistic form, taking the natural log of the equation, setting the probability value at 0.5, and solving for $x_{1,}$ determines the required covariate value to affect the event outcome. Note that the model is specific only to the time and location of the data. This generates a new model, using a new set of sample data, every time an analysis is run.

Software Platform

Statistical analyses primarily utilized Statistical Package for the Social Sciences (SPSS) software developed by International Business Machines Corporation (IBM). SPSS is a program that runs under the Java Runtime Environment, and provides a user-interface that allows access to a variety of options, such as data input, query modifications, statistical analyses, and resulting outputs. Since the dependent variable (crashes) data exists in a binary state, the "Binary Logistic Regression" function ran the logistic regression analyses. When using its binary logistic regression function, the default parametric statistical test employed by SPSS is the Wald Test. Both the macro and intermediate levels of statistical analysis used the binary logistic regression function. Further detail is available in Appendix B.

Macro Analysis

The macro analysis includes the lowest level of data accuracy in the given sample population, with patrol vehicle spatial distributions compared to the presence of crash events over a 12 month period for each study corridor. Therefore, the analysis does not account for seasonal effects occurring on a monthly basis.

The first trial of the macro analysis included patrol vehicle presence, in units of hours, as the independent variable, and the binary presence of a crash instance as the dependent variable. Researchers ran Binary logistic regression and Poisson regression analyses during the first trial. The results of these analyses appear in Tables 1 and 2. Note that for the Poisson regression analysis, the dependent variable is not included in binary form, but rather as a quantitative summation over 12 months of crash data.

Highway	Raw Value of Significance	95% Confidence Achieved?	Coefficient
Glenn	0.219	No	N/A
Parks	0.087	No	N/A
Richardson	0.00023	Yes	0.038
Seward	0.446	No	N/A
Sterling	0.611	No	N/A

Table 1: Results of Macro Analysis, Logistic Regression, Trial 1

Highway	Raw Value of Significance	95% Confidence Achieved?	Coefficient
Glenn	5.72469E-05	Yes	0.00084927
Parks	1.11022E-16	Yes	0.001223
Richardson	6.5786E-11	Yes	0.003
Seward	0.689	No	N/A
Sterling	7.91313E-07	Yes	0.000875

Table 2: Results of Macro Analysis, Poisson Regression, Trial 1

The results of the macro logistic regression analysis indicate a strong statistical correlation between the presence of trooper vehicles and crash instances along the Richardson Highway. However, the resulting coefficient for the covariate of the logistic model is positive, indicating that relatively higher frequencies of patrol presence and crash instances exist within relatively close vicinities along Richardson Highway. Apart from the Richardson Highway, no statistical significance exists for all other study corridors under the macro logistic regression analysis. This could be indicative of the data characteristics of the Richardson Highway versus the other four study corridors. The Richardson Highway experiences the lowest traffic volumes versus other study corridors, which can result in the lowest probability of multivehicle crashes. As such, the data set for the Richardson Highway allows the model to observe the effects of patrol presence when crashes have or have not occurred within particular sections of the roadway. For perspective, Figure 1 shows locations of crash occurrences along the Richardson Highway within a one-year timespan. Figures 2 are similar for the Sterling Highway.

Based on Figure 1, within a yearly timeframe, a majority of the study sections along the Richardson Highway did not experience any crash instances, or perhaps the crashes were undocumented. By comparison, Figure 2 indicates that only 4 out of 25 five-mile sections of the Seward Highway did not have any crash occurrences. Similarly, based on Figure 3, only 5 out of 27 five-mile sections of the Sterling Highway received no crashes within a yearly period. Based on the results of Table 1, contrary to the results of the Seward and Sterling Highways, the binary logistic regression model for the Richardson Highway observed an interaction. Therefore, the Richardson Highway provided an adequate sample population of crash data at the macro level for the model.

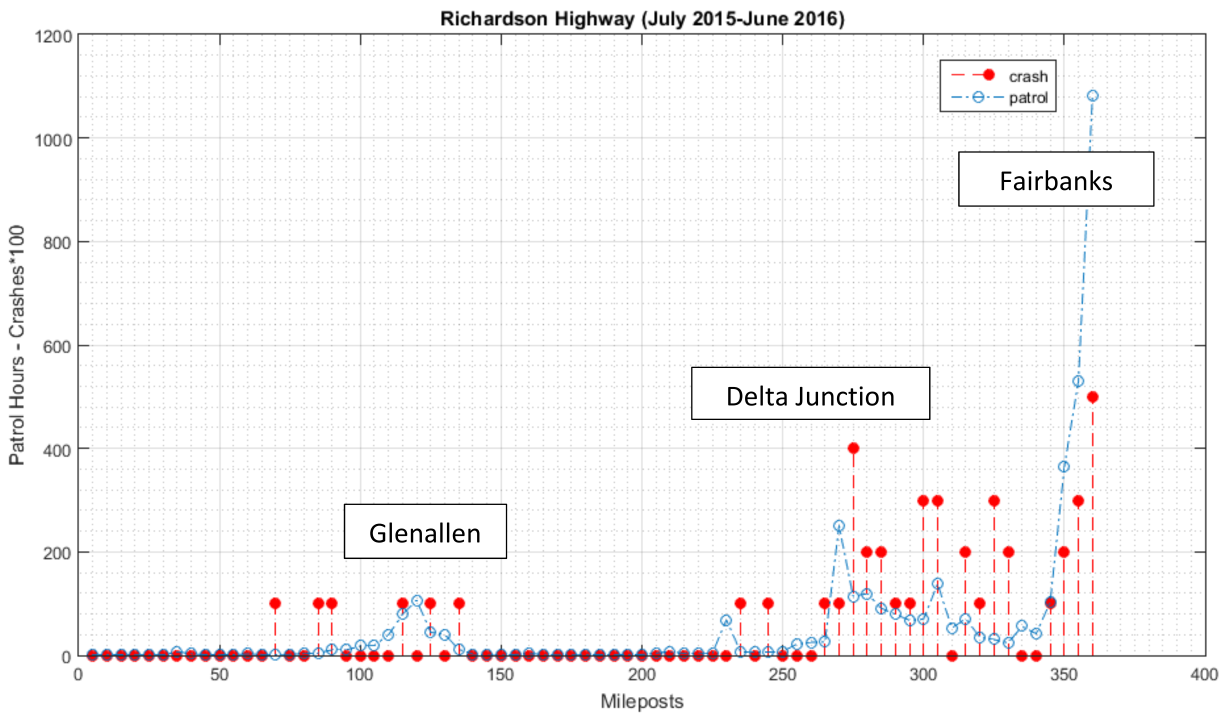

Figure 1: Number of Crashes along the Richardson Highway, Annual Timeframe

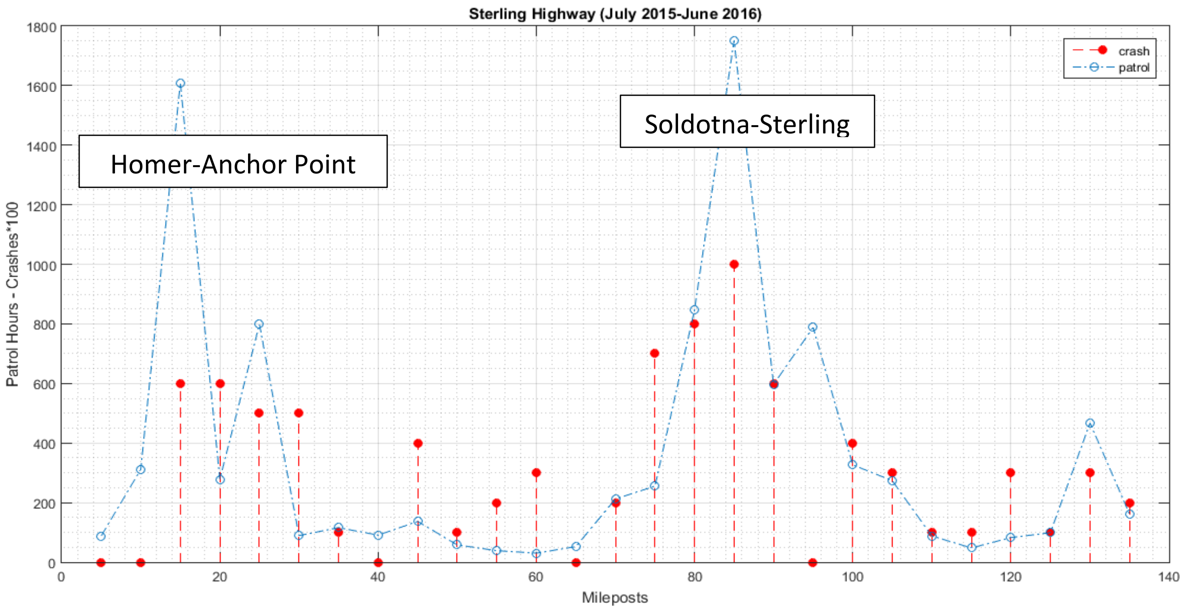

Figure 2: Number of Crashes along the Sterling Highway

The second trial of the macro analysis consisted of the same data inputs as the first trial. The primary difference, however, was the inclusion of Annual Average Daily Traffic (AADT) along each section of the study corridors. Inclusion of AADT as an independent variable in the sample population allowed the model to account for traffic volume differences along the study corridors, which may have a statistical interaction with crash instances. The AADT data used in the second trial of the macro analysis included permanent traffic recorder information provided in the 2014 Annual Traffic Report published by the DOT&PF. The AADT volumes from the Annual Traffic Report had grown to those of 2016 by applying a 2% annual growth factor before inclusion in the macro analysis.

Similar to the first trial, the second trial consisted of binary logistic regression and Poisson regression analyses. The results of the second trial appear in Tables 3 and 4.

Highway	Raw Value of Significance	95% Confidence Achieved?	Coefficient
Glenn	0.234	No	N/A
Parks	0.035	Yes	0.005
Richardson	0.000161	Yes	0.034
Seward	0.229	No	N/A
Sterling	0.414	No	N/A

Table 3: Results of Macro Analysis, Logistic Regression, Trial 2

Highway	Raw Value of Significance	95% Confidence Achieved?	Coefficient
Glenn	5.72469E-05	Yes	0.00084927
Parks	1.11022E-16	Yes	0.001223
Richardson	6.5786E-11	Yes	0.003
Seward	0.689	No	N/A
Sterling	7.91313E-07	Yes	0.000875

Table 4: Results of Macro Analysis, Poisson Regression, Trial 2

The results of the macro logistic regression analysis indicated that, with the inclusion of AADT data, two of the five study corridors achieved statistical significance between patrol presence and crash instances. The change in results between the first and second trials indicates that the inclusion of AADT data affects the outcome of the model. The results of the second trial also provide further elaboration on the data characteristics between the number of crashes, patrol vehicle presence, and traffic volumes within each corridor section. Note that the AADT data solely offers values reported by permanent traffic recorders. A TransCAD model was not utilized to interpolate traffic volumes between each of the recorders, so the AADT volumes between each permanent traffic recorder were interpreted as constant.

Peculiar characteristics were observed when comparing data within each highway section. Figure 3 shows the number of crashes, patrol vehicle presence in hours, and AADT for each corridor section along the Sterling Highway over a 12-month period. It is apparent that certain corridor sections experience significantly higher enforcement presence, in particular between milepost ranges 10-15 and 80-85. These two areas also experience relatively higher traffic volumes and crash frequencies. Basic observation leans toward an assumption that higher crash frequencies are accompanied by higher levels of enforcement, which could explain why the statistical model outputs a positive coefficient. However, this ignores other factors. For example, the presence of a trooper vehicle may depend on the severity of a crash event. If a fatal crash were to have occurred, the trooper would have to remain at the crash site for a minimum of 5 hours for proper crash scene review and documentation.

Intermediate Analysis

Since intermediate analyzes sample populations on a monthly basis and, therefore, allows for inclusion of seasonal effects, it includes a higher level of data accuracy compared to the macro analysis. This is crucial in Alaska, due to the different environments along roadways during the summer and winter months, with certain roadway conditions more likely to play a larger role in the occurrence of crash events. For example, intermediate analyses may describe scenarios in which rear-end vehicle collisions or ditch crashes occur more frequently during the winter months. Depending on the collected information from these crash events, this could be due to icy road conditions or low light visibility.

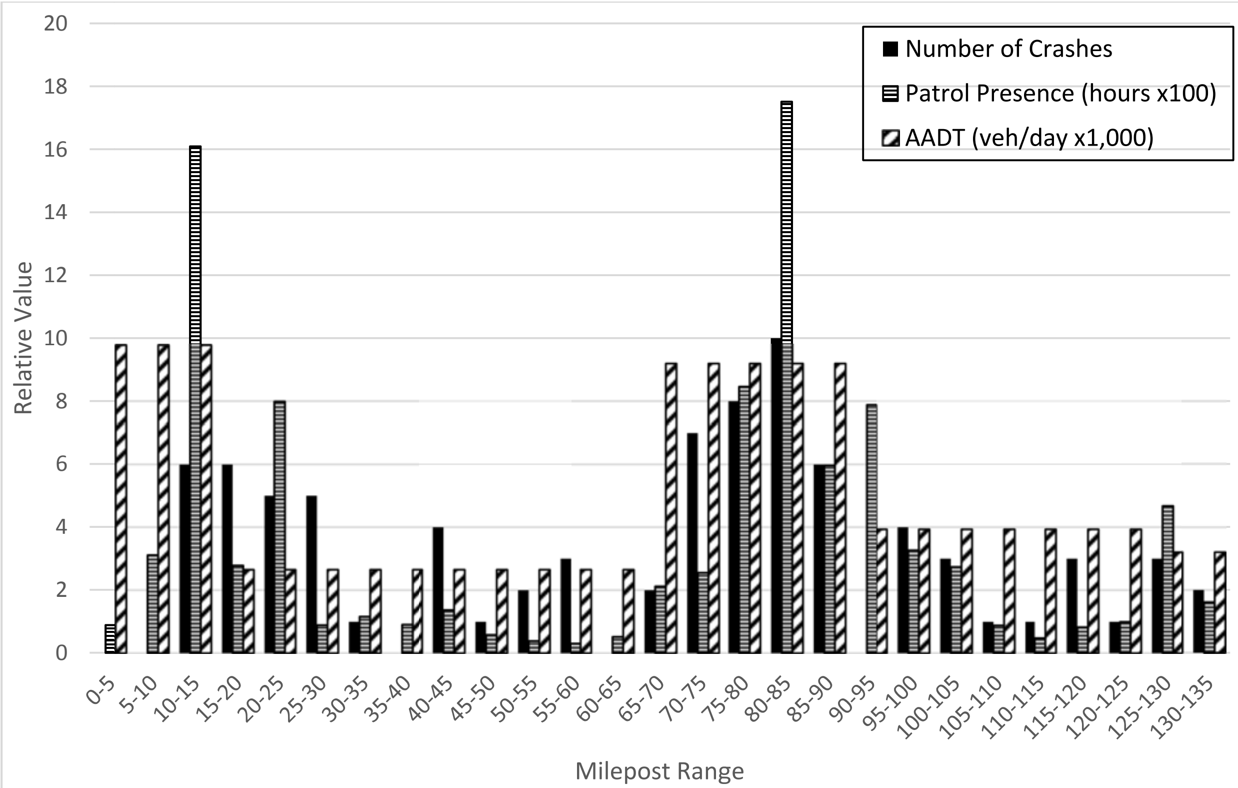

Figure 3: Data Characteristics of the Sterling Highway, Annual Timeframe

Similar to the macro analysis, the first trial of the intermediate analysis included the independent variable as patrol vehicle presence and the dependent variable as crash instances, in binary form. Due to the relative scarcity of crash instances along the study corridors on a monthly basis, only a logistic regression analysis was possible. The results of the first trial appear in Table 5. The table first presents the raw probability values for each sample data set. The second row of the table determines if a statistical significance exists based on the 95% confidence interval. If a particular sample data set has a statistically significant interaction, then the third row presents the coefficient value for the independent variable representing patrol vehicle presence. This coefficient determines how enforcement levels affect the probability of a crash occurrence. If the resulting statistical value is “Error,” no crashes occurred along any part of the study corridor within that particular monthly period. Since the dependent variable must take binary form, a logistic regression analysis is not possible for that particular period.

The results in Table 5 indicate that statistical significance between the presence of trooper vehicles and crash instances exists for particular areas along the Parks, Richardson, and Sterling Highways. These findings are similar to the macro level analysis, in that the Richardson Highway and the Parks Highway contained a larger sample data set of crash frequencies, which allowed the statistical model to study interactions more appropriately. This could be attributed to the relatively higher sample data points offered by the Richardson Highway and the Parks Highway, in comparison to the other three study corridors, as shown in the sample Figures 4 and 5 (four months were selected as examples).

Raw Value of Significance												
Highway	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**
Glenn	0.82	0.793	0.579	0.853	0.86	0.996	0.315	0.26	0.982	0.193	0.292	0.55
Parks	0.139	0.01	0.037	0.022	0.015	0.184	0.404	0.129	0.035	0.669	0.197	0.38
Richardson	0.014	0.272	0.034	0.006	0.015	0.951	0.304	0.928	0.975	Error	0.906	0.841
Seward	0.131	0.298	0.518	0.58	0.738	0.671	0.078	0.639	0.421	0.884	0.728	Error
Sterling	0.164	0.986	0.323	0.703	0.037	0.092	0.314	0.73	0.051	0.07	0.912	0.046
95% Confidence Interval Achieved?												
Highway	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**
Glenn	No	No	No	No	No	No	No	No	No	No	No	No
Parks	No	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No	No
Richardson	Yes	No	Yes	Yes	Yes	No	No	No	No	N/A	No	No
Seward	No	No	No	No	No	No	No	No	No	No	No	N/A
Sterling	No	No	No	No	Yes	No	No	No	Yes	No	No	Yes
Coefficient for Patrol Presence Independent Variable												
Highway	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**
Glenn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Parks	N/A	0.023	0.018	0.025	0.046	N/A	N/A	N/A	0.026	N/A	N/A	N/A
Richardson	0.22	N/A	0.144	0.104	0.211	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Seward	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sterling	N/A	N/A	N/A	N/A	0.047	N/A	N/A	N/A	0.023	N/A	N/A	0.062

Table 5: Results of Intermediate Analysis, Logistic Regression, Trial 1

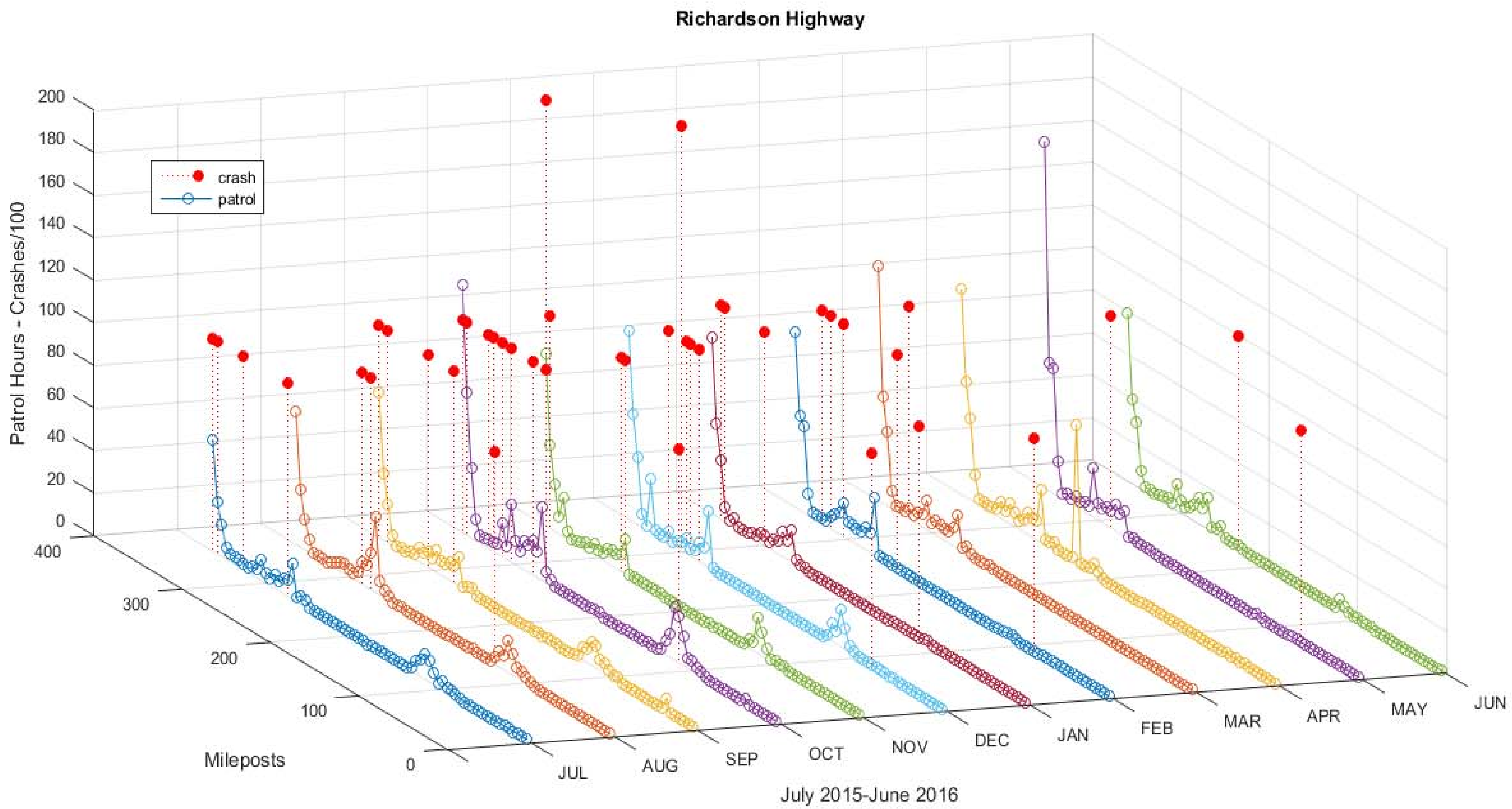

Figure 4: Number of Crashes along the Richardson Highway, Monthly Timeframe

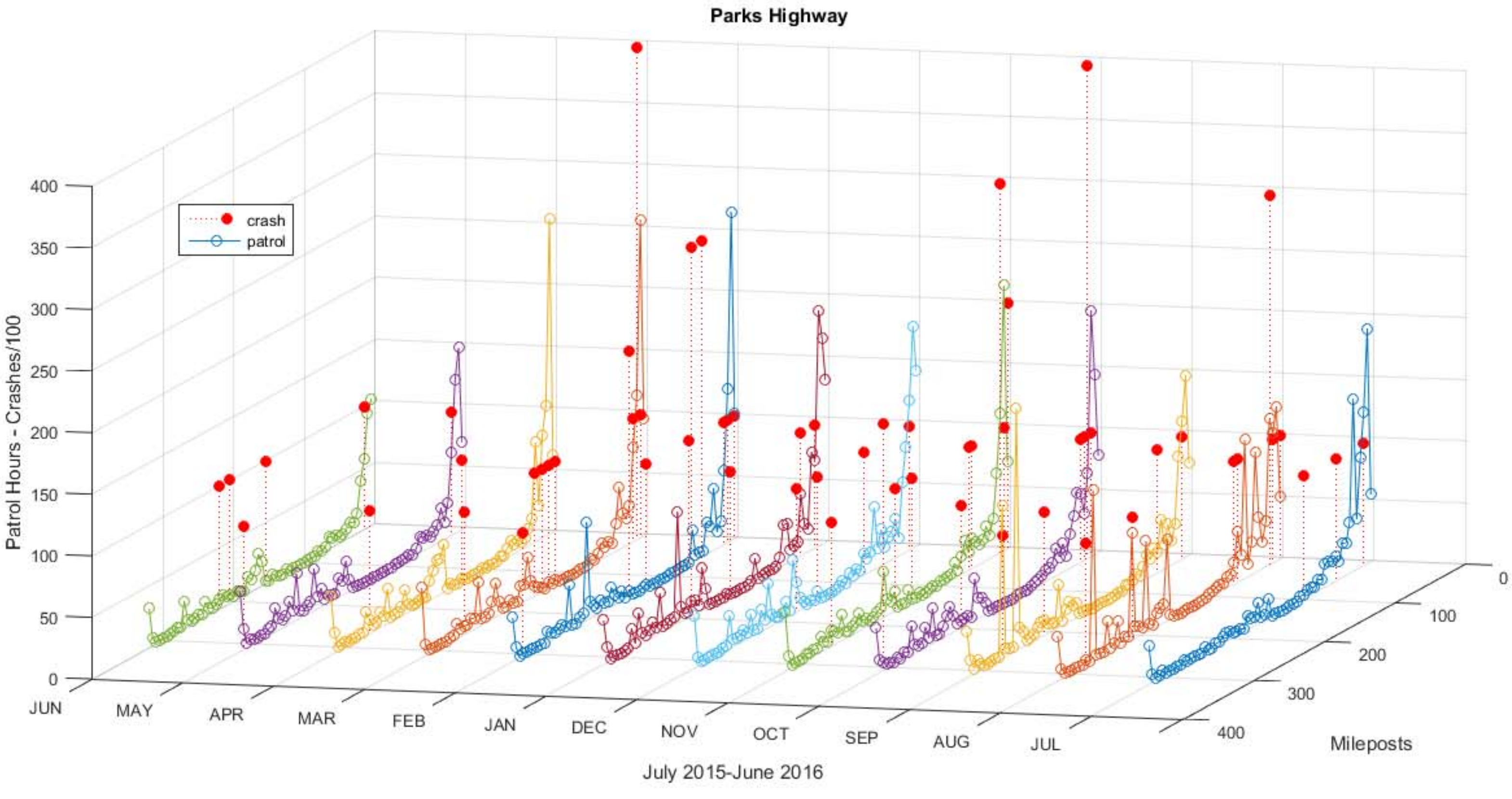

Figure 5: Number of Crashes along the Parks Highway, Monthly Timeframe

From the first trial, it is apparent that the number of sample data points is important when observing interactions between independent and dependent variables. A larger number of data points allow the statistical model to account for a variety of situations and provide a more accurate equation to describe what is actually occurring along the studied highways. The Richardson Highway and the Parks Highway benefit from having a larger number of data points in comparison to the Sterling Highway, the Glenn Highway and the Seward Highway. The primary method to increase the number of sample data points for all study corridors is to reduce the length of each highway section from 5 miles to 1 or 2 miles. If, for example, the sections along the Seward Highway were reduced from 5 miles to 1 mile, the total number of sample data points would increase from 25 to 125. The statistical model would then be able to study potential interactions at a more intimate level. Similarly, on the Richardson Highway, the total number of sample data points would increase from 72 to 360, although the Richardson Highway would still have relatively scarce crash data available compared to other corridors, such as the Seward Highway. Increasing the total sample size to 360 would further distribute the already limited number of crash data points, and could potentially affect the accuracy of the analysis results.

The second trial of the intermediate analysis included the same inputs as the first trial, with the addition of monthly Average Daily Traffic Volumes (MADT) as an independent variable for each roadway area. The MADT volumes came from permanent traffic recorder data detailed in the 2014 Alaska DOT&PF Annual Traffic Report, after an increase to 2016 levels. The results of the second trial appear in Table 6. Once again, “Error” indicates that no crashes occurred along a study corridor within a particular monthly period of time. Similar to the first trial, the results in Table 6 indicate that statistical significance between the presence of trooper vehicles and crash instances exists for particular areas along the Parks Highway, the Richardson Highway, and the Sterling Highway. However, the number of corridor sections where statistical significance exists changed from the first trial, indicating the inclusion of traffic volumes as an independent variable has some effect. Still, the resulting coefficients of the logistic regression model were positive.

Table 6 reflects statistically significant interactions between patrol presence and crash occurrences for 7 of the 12 months along the Parks Highway. When plotting crash frequencies, inclusion of patrol vehicle presence and MADT for each roadway section, by month (see Figures 6, 7, 8, 9, 10, 11, 12 and13), certain data characteristics appear. For example, locations along the Parks Highway receiving higher enforcement levels are similar month-to-month. In particular, a relatively higher presence of troopers appears between mileposts 0 and 35 for each month. Likewise, crash frequencies are found to be higher between mileposts 0 and 35, though this is not always the case for each month. One peculiarity in the MADT data is a significant spike in traffic volume for milepost range 310-315. This particular area also has a relatively higher frequency of enforcement presence. However, the MADT value inputted for Sections 1 through 35 may be inaccurate, since no permanent traffic recorders exist within this region and, therefore, it was necessary to assume a constant MADT. The remaining 2-dimensional and 3-dimensional images for the rest of the corridors are located in Appendix C.

Raw Value of Significance												
Highway	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**
Glenn	0.923	0.828	0.835	0.715	0.597	0.078	0.259	0.781	0.987	0.995	0.971	0.83
Parks	0.129	0.007	0.03	0.014	0.014	0.102	0.02	0.008	0.03	0.696	0.15	0.257
Richardson	0.035	0.018	0.097	0.001	0.074	0.428	0.11	0.604	0.816	ERROR*	0.93	0.488
Seward	0.324	0.267	0.672	0.634	0.978	0.714	0.407	0.4	0.597	0.834	0.764	ERROR*
Sterling	0.366	0.789	0.278	0.894	0.195	0.256	0.931	0.891	0.082	0.149	0.929	0.097
95% Confidence Interval Achieved?												
Highway	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**
Glenn	No	No	No	No	No	No	No	No	No	No	No	No
Parks	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No
Richardson	Yes	Yes	No	Yes	No	No	No	No	No	N/A	No	No
Seward	No	No	No	No	No	No	No	No	No	No	No	N/A
Sterling	No	No	No	No	No	No	No	No	Yes	No	No	No
Coefficient for Patrol Presence Independent Variable												
Highway	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**
Glenn	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Parks	N/A	0.026	0.022	0.059	0.052	N/A	0.075	0.041	0.033	N/A	N/A	N/A
Richardson	0.347	0.276	N/A	0.191	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Seward	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sterling	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 6: Results of Intermediate Analysis, Logistic Regression, Trial 2

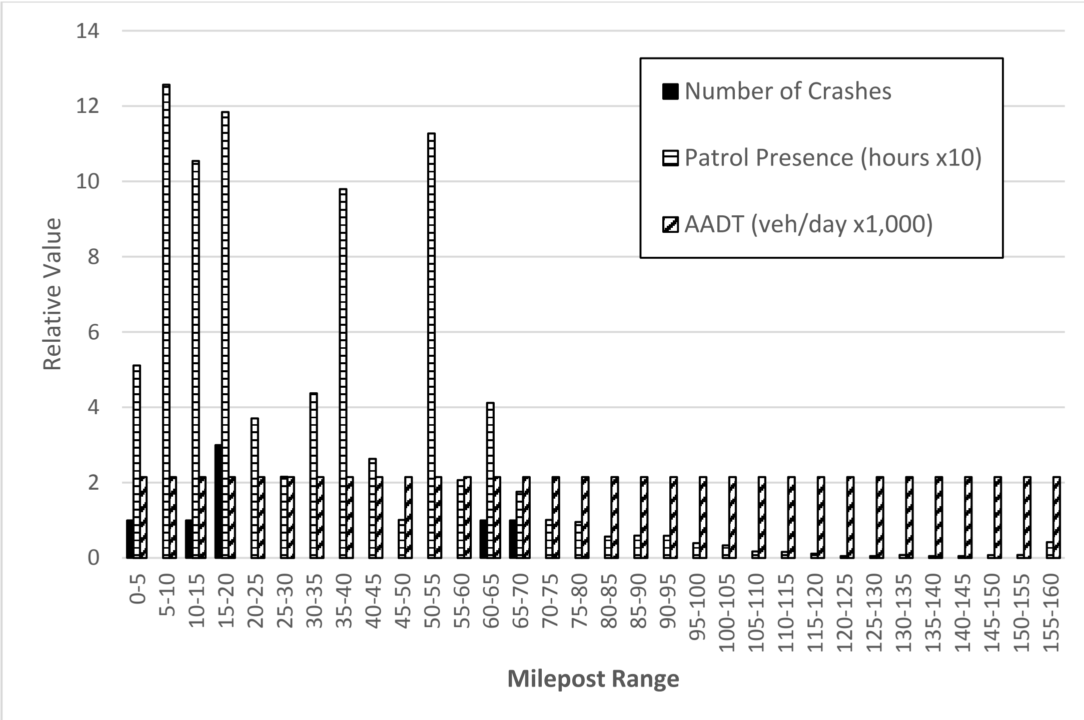

Figure 6: Data Characteristics of the Parks Highway, Month of August 2015 Part 1

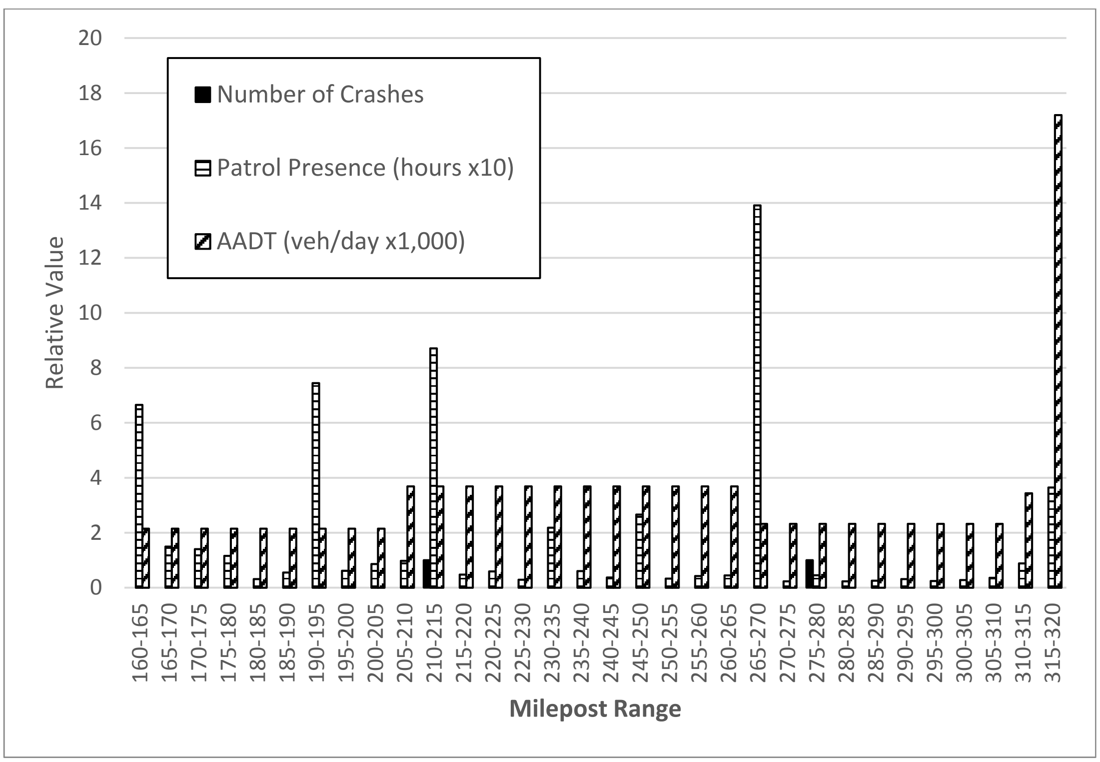

Figure 7: Data Characteristics of the Parks Highway, Month of August 2015 Part 2

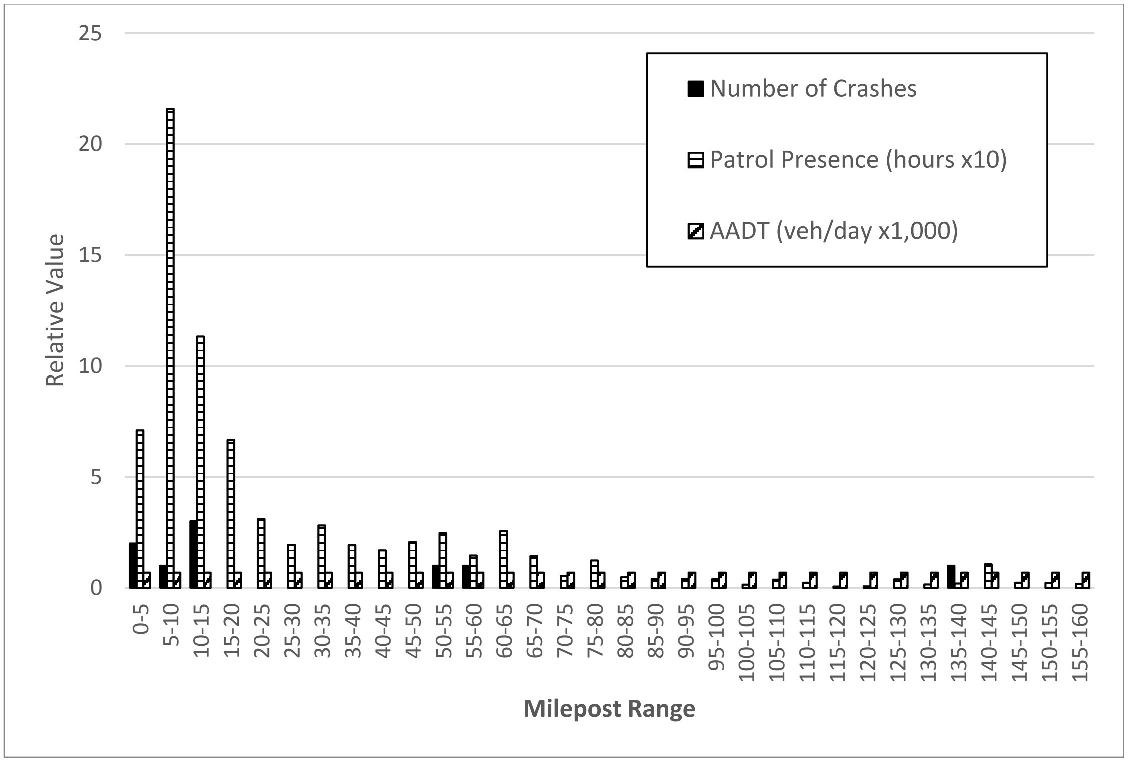

Figure 8: Data Characteristics of the Parks Highway, Month of November 2015 Part 1

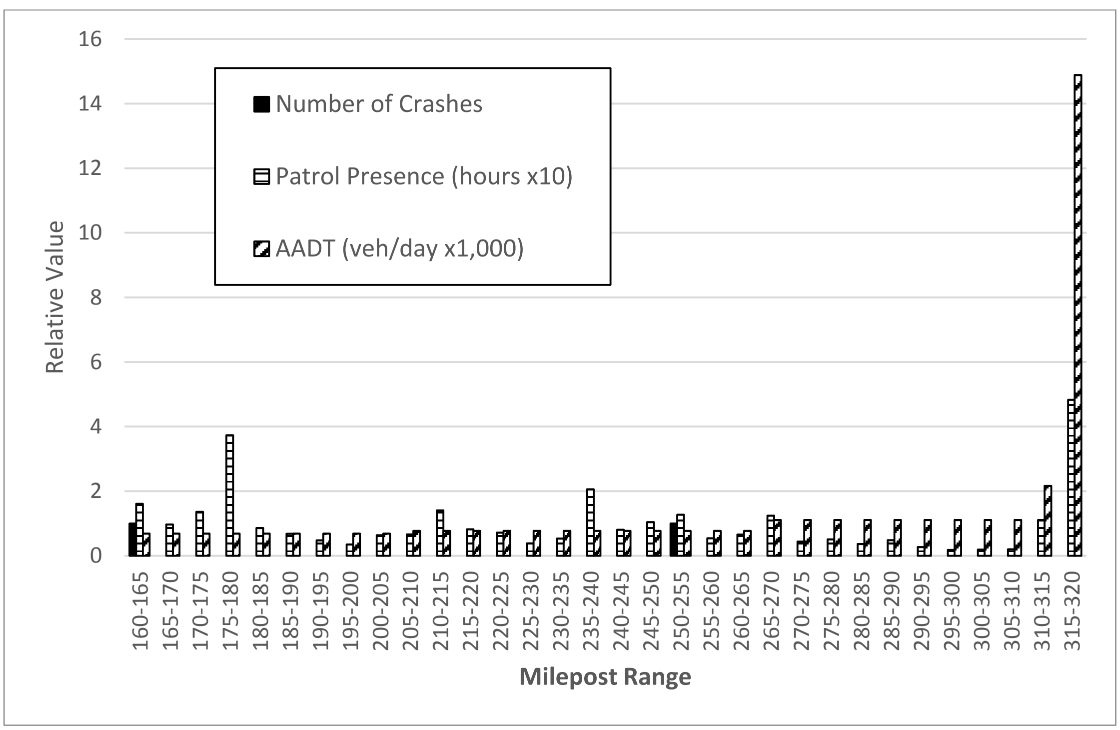

Figure 9: Data Characteristics of the Parks Highway, Month of November 2015 Part 2

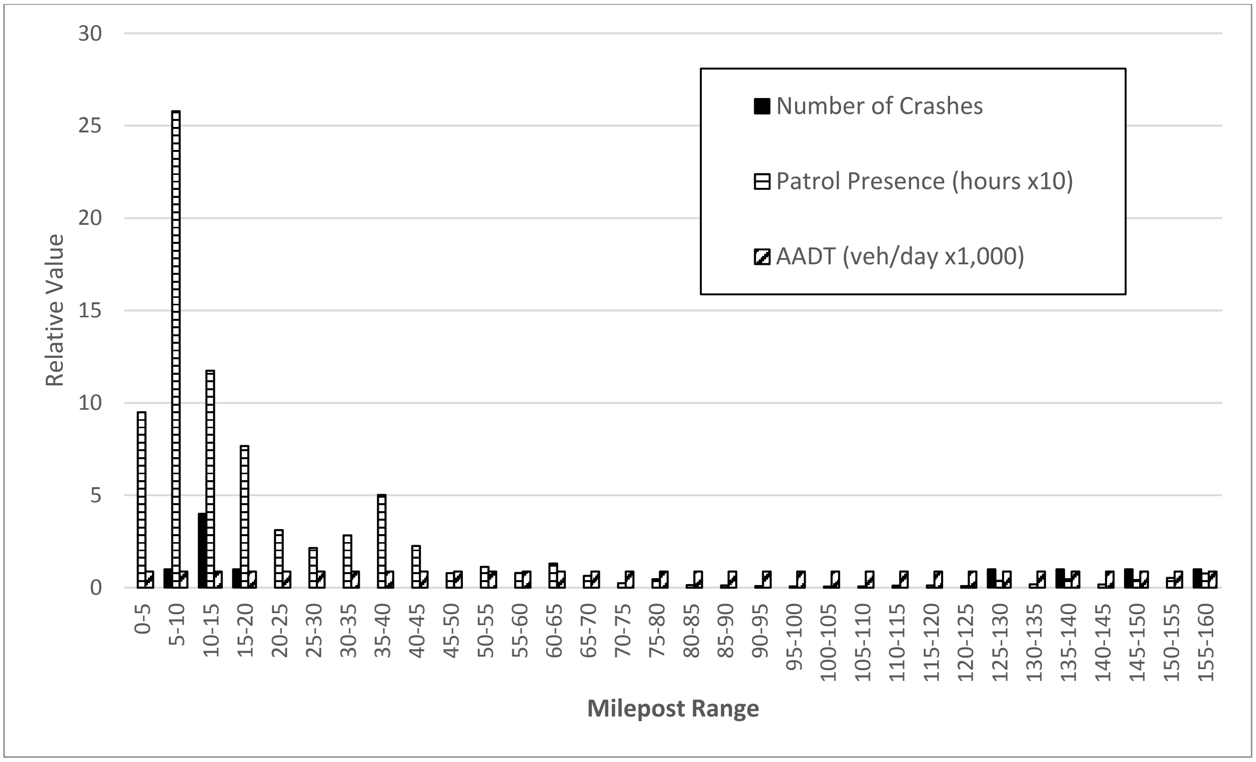

Figure 10: Data Characteristics of the Parks Highway, Month of March 2016 Part 1

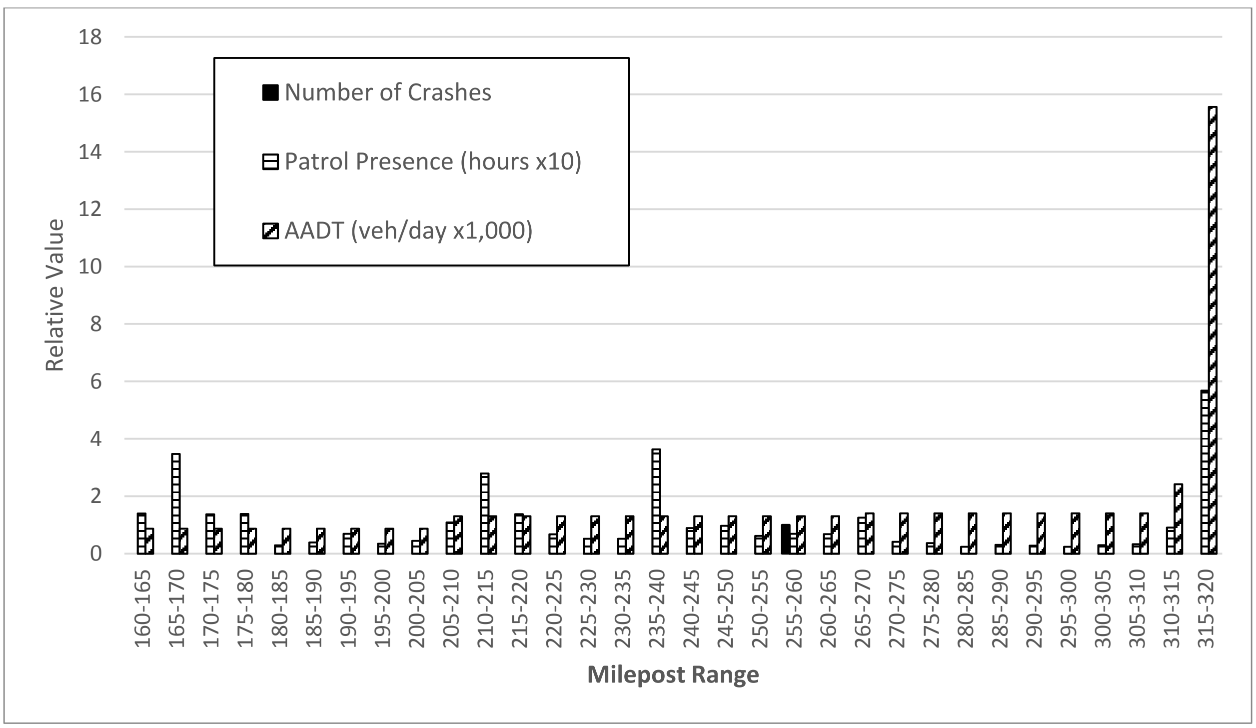

Figure 11: Data Characteristics of the Parks Highway, Month of March 2016 Part 2

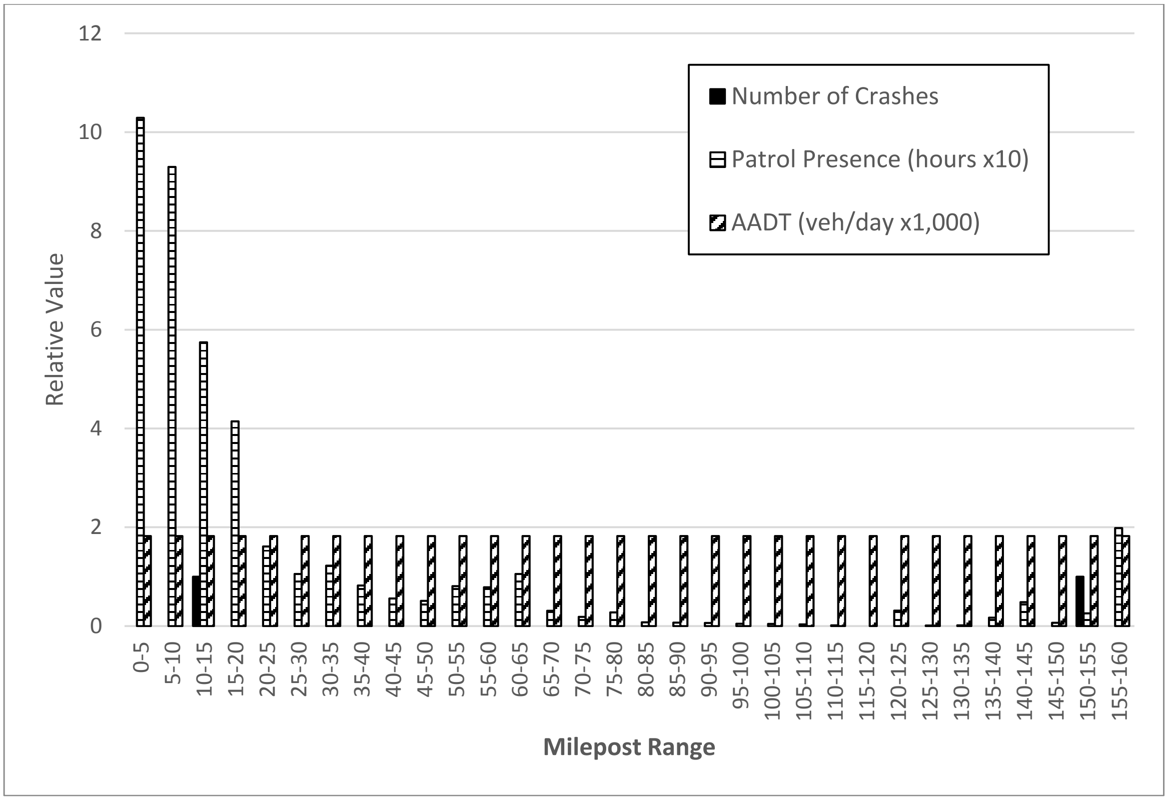

Figure 12: Data Characteristics of the Parks Highway, Month of June 2016 Part 1

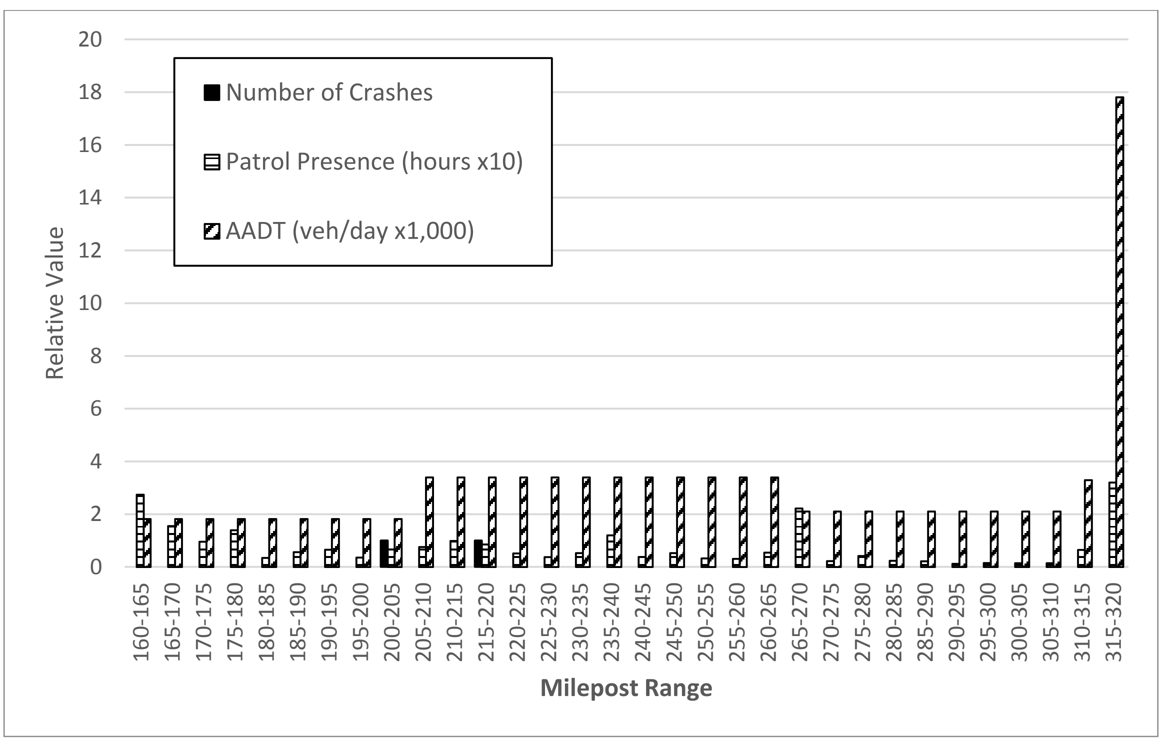

Figure 13: Data Characteristics of the Parks Highway, Month of June 2016 Part 2

Microanalyses

The microanalysis serves as the most meticulous methodology for analyzing the relationship between the presence of patrol vehicles and the occurrence of crash events. This level of analysis correlates the physical presence of trooper vehicles with the location of crash event occurrences. This level of detail, which requires a rapid refresh rate of data from patrol car sensors, is required for higher accuracy in determining the exact location of each vehicle.

Because the micro level requires analysis on a daily basis, there must be an adequate sample size of crash events on a daily basis to provide an adequate statistical correlation. If there is an insufficient sample size of crash events, the results of the statistical analysis are less meaningful, and achieving statistical correlations becomes too difficult. To correct this issue, multiple years of data collection should take place to expand the number of data points in the sample population. This will also allow the statistical model to account for a larger variety of scenarios.

Microanalysis was not possible in this study due to the limited sample sizes of crash data along each study corridor. This challenge arose because:

1) Alaska’s long highways and relatively low population density, compared to the more common highly populated urban environments present in other states, results in a decreased likelihood and frequency of crash events within specific highway sections on a daily basis.

2) The research team only had access to crash data from the Alaska State Troopers, which may not account for all crash events in recent years along certain study corridors. For example, the primary peculiarity of the data provided by the Alaska State Troopers for the Sterling Highway is the absence of crash events within the vicinity of the Soldotna area. Correspondence with the Alaska State Troopers revealed that the sample data did not include crash data from the City of Soldotna Police Department. This is similar to other large population areas with their own enforcement jurisdiction such as Anchorage area, Wasilla and Fairbanks.

Due to these factors, the results and recommendations of this project include only on the intermediate and macro analyses. Still, the outcome of this level of analysis provided the necessary infrastructure for solid future statistical correlations. The addition of two to three years of sample data will improve the outcomes of the statistical analyses.

Analysis with Combined Sample Data

To determine how a larger sample size affects the results, researchers combined information from all study corridors into one large sample data set. This approach not only benefited from a larger number of data points, but this analysis accounts for common themes and interactions for sample highway corridors in Alaska. By combining patrol presence, AADT and crash instance data between the five study corridors, a total of 223 data points was achieved, and the model observed statistically significant interactions with the patrol presence and AADT variables. Two combined analyses were conducted--one based on a yearly time period and the other at the intermediate level, which used data from the month of October. The results of both analyses appear in Table 7.

	Macro Level (One Year Period)	Intermediate Level (Month of October)
For Patrol Presence Variable		
Raw P-Value	0.000393	0.002667
Achieved Statistical Significance?	Yes	Yes
Resulting Coefficient	0.004005	0.015213
For AADT/MADT Variable		
Raw P-Value	0.027	0.855611
Achieved Statistical Significance?	Yes	No
Resulting Coefficient	-0.000057	0.000004

Table 7: Results for Combined Analysis

Due to the 5-mile section limitation, the required diversity of scenarios was not possible at the macro level when only using a sample data set from one highway. However, the interaction between patrol presence and crash occurrences revealed by the combined sample data set revealed a highly significant correlation at the macro level. Interestingly, AADT also had a statistically significant interaction with crash instances, indicating that traffic volumes have the potential for being a contributing factor.

Conclusion from Analysis Testing

Results of the macro and intermediate analyses indicate that achieving statistical significance between the presence of patrol vehicles and crash instances using binomial logistic regression is possible using geospatial data along Alaska highways. The results also confirm that limited sample sizes can adversely affect the accuracy of the statistical model. Shrinking highway sections and pursuing further data collection efforts over a longer time can remedy this. In addition to a higher sample population, the more covariate factors inputted into the model, the more accurate the model. Note that the statistical results of the tests performed utilized only two covariates, which calls the usefulness of the results into question. However, these results confirm that patrol vehicle geospatial information is a significant factor in the determination of crash event probabilities. Additionally, these results describe characteristics of data, and ways these peculiarities should be accounted for in future research.

To achieve meaningful, accurate results detailing the reality of crash occurrences along Alaska highways, additional independent factors must be included in the model. For example, the AADT volumes included in the sample data came from permanent traffic recorders. However, these recorders are located in limited places along the study corridors, which required the research team to interpolate traffic volumes in locations between the recorders. To account for the location of major intersections along study highways, AADT volumes for side streets carrying relatively higher traffic could also be included in the sample data, though this will depend on available traffic information for intersecting facilities. This would allow the model to account for crashes occurring at intersections. This could serve as a significant factor in the statistical analyses, as recent research conducted by the University of Alaska Anchorage Civil Engineering Department suggests a high statistical correlation between the presence of intersections and the occurrence of crashes in Alaska.

Due to the seasonal variation of weather in Alaska, it is recommended that roadway conditions be included as an independent factor in the model. Inclusion of roadway conditions will allow the model to describe the interaction between certain crash types occurring at relatively greater frequency for specific months of the year. Roadway condition data could be collected from the Road Weather Information System (RWIS), a network of meteorological and pavement sensors along highway systems in Alaska. Coordination with DOT&PF is required if this effort is undertaken, as the RWIS is maintained by the State of Alaska.

Benefit/Cost Analysis

Though the methodologies provided in Section 3.3 allow for determination of whether police enforcement levels have a statistical impact on crash occurrences along study corridors, it is also necessary to compare costs associated with crash occurrences and enforcement levels to determine the economic efficiency of such enforcement levels.

Following is the proposed process for performing a benefit/cost analysis. Due to the limited results produced by the statistical analyses, a true benefit/cost analysis was not possible, but rather, researchers used mock data and results to demonstrate the benefit/cost methodology. This provides an example framework for how the benefit/cost analysis would be implemented once larger sample datasets are available.

Mock Data Analysis Objectives

The object of the benefit/cost analysis is to quantify a ratio for comparing the estimated cost benefit of a given enforcement level using the costs associated with patrol time. Application of the calculated ratio determines if current enforcement levels are economically justified.

Mock Data Analysis Methodology-Proof of Concept

Calculations of benefit/cost ratio include a given set of data and values for benefit and cost. The value of benefit consists of the direct and indirect costs associated with the number of crashes statistically estimated to be avoided by a given patrol enforcement level along a highway. Detailed examples of these calculations are offered in Appendix E.

Chapter 4 – CONCLUSION

The goal of this research was to produce methodologies for observing the interaction between highway enforcement levels and crash occurrences along Alaska corridors. The team developed processes and scripts to organize data into highway sections along certain study corridors, and import it into databases stored in SQL Server for analysis. The research team also developed a procedure for conducting a benefit/cost analysis, to allow users to determine the economic effectiveness of enforcement investment levels.

Recommended Methodologies

Due to the nature of collisions occurring along highways and the unique environmental aspects of Alaska, it was determined that binomial logistic regression is the most suitable statistical analysis to use for this research. The benefit of using a logit model is that it assumes the occurrence of crashes are based on probability, which, given the multitude of factors involved with collision events in Alaska, is a conservative assumption. Additionally, the research team observed a scarcity of collision data along the study corridors on a monthly basis, which posed the challenge of preparing a proper sample data set for the analysis. The logistic regression provides the advantage of minimizing this issue by treating crash events as categorical variables, rather than relying on their quantitative values.

Seasonal variations in traffic patterns and environmental conditions in Alaska necessitated different levels of statistical analysis. The macro level analyzed enforcement presence and crash instances on an annual period, whereas the intermediate level worked with a monthly timeframe. The micro level represents the ideal analysis, allowing correlation of the physical presence of a trooper's vehicle with the presence of a crash event. However, the micro level of analysis was infeasible due to the demanding requirements of such analysis and the scarcity of crash data currently available to the research team. This issue can be mitigated through future data collection efforts along the highway corridors to make micro level analysis feasible.

The research team conducted statistical analyses on data collected from Verizon Network Fleet servers on enforcement spatial information and collision reports from Alaska State Troopers. A server was established at the University of Alaska Anchorage College of Engineering to collect, organize and filter data sets using Microsoft SQL Server. Queries and scripts organized spatial information into five-mile segments along study corridors, which provided the necessary sample populations to run the statistical analyses. Once the sample data sets were organized in databases, binomial logistic regression analyses were conducted on yearly and monthly time periods for all five study corridors, which consisted of the Glenn Highway, the Parks Highway, the Richardson Highway, the Seward Highway, and the Sterling Highway. The time-spatial presence of patrol vehicles was the independent variable, and the categorical descriptions of crash instances served as the dependent variable. In later trials, annual and monthly daily traffic volumes along segments of the study corridor were included as an independent variable.

Finally, a benefit/cost analysis procedure using the results of the statistical analyses was developed. The procedure used equations generated from the logistic regression models and direct crash costs provided by the FHWA KABCO, with indirect crash costs provided by the U.S. DOT National Highway Traffic Safety Administration to estimate the monetary benefit of enforcement. The equations relied on an estimated hourly cost of enforcement, as provided by the Alaska DOT&PF. Using the calculated benefit and cost values yielded the benefit/cost ratio necessary help agencies determine investment feasibility.

Findings/Interpretations of Analyses

The results of the statistical analyses indicated it is possible to achieve probability values within the 95% confidence interval using spatial information for patrol vehicles and crash instances in Alaska. The logit coefficients for the patrol presence variable in the statistical models were found to be positive. However, the sample data inputted into the statistical models are relatively simple, as the only covariates included were trooper vehicle presence and highway traffic volumes. Based on similar studies conducted in other parts of the United States or in other countries, a variety of descriptive factors involved with crash occurrences in those studies have yet to be included in the statistical models. In addition, the sample data sets for crash data were relatively sparse, with collected crash data coming only from the DOT&PF; other local enforcement agencies have historical collision reports that were not electronically available to the research team. This relative lack of crash data hindered the accuracy of the statistical results. Five-mile roadway segments established the sample population for each data set, while, the interaction between patrol presence and crash occurrences may be more sophisticated and require shorter corridor sections to accurately assess these effects.

Based on these challenging factors, although the results of the statistical analyses indicate that binomial logistic regression is an adequate model to describe these interactions, more data is required to allow the logistic model to accurately describe any statistically significant interactions between enforcement levels and crash occurrences. In particular, the more sample data points that are included in the data inputs, the more likely the statistical model is able to observe various scenarios necessary to identify how the interactions between crash occurrences and their contributing factors actually behave. Additional contributing factors will also need to be included as data inputs. For example, the research observed changes in the results with inclusion of traffic volumes for each corridor section, indicating that enforcement presence is not the only independent factor affecting crash occurrences along Alaska highways. Roadway conditions and side street volumes are additional factors for consideration.

Due to the questionable results of the statistical analyses, this study did not test the benefit/cost procedure using these results. Therefore, no meaningful interpretations of the benefit/cost analysis are available.

Recommendations for Future Research

The primary goal for future research is the inclusion of more data, including consideration of more independent factors involved with crash occurrences—such as roadway conditions, intersecting side street traffic volumes, hours involving high alcohol consumption—and socio-economic factors such as unemployment, population density and urban/rural environments. In particular, roadway condition in Alaska is a critical seasonal factor to include in determining which crash events are attributable to icy road conditions. It is also important for the statistical model to account for the presence of major intersections along highways, as it can then describe why certain sections of a highway experience relatively higher frequencies of crash occurrences than other sections. This can also indicate why a larger presence of patrol vehicles occurs in particular sections of the study corridors. Additionally, special attention should be taken for occurrences outside of typical patrol activities in which troopers are stationary during investigations.

Once larger datasets are acquired from the continued data collection effort, additional statistical analyses will be performed. Based on more accurate crash data, reduction of the highway sections virtually established along the study corridors from five-mile to one/two-mile sections is possible. In particular, reducing the length of each virtual highway section will increase the total number of data points inputted into the statistical analyses for each corridor, effectively expanding the inputted sample populations. This should be a critical goal, as reduction in section length can help strengthen the feasibility of using a binomial logistic regression to describe interactions at the macro/annual level. Additionally, it will enable micro level analyses for more accurate description of the interaction between the physical presence of trooper vehicles and crash occurrences.

Another long-term goal of future research should be inclusion of citations data in the analysis, as citations act as a deterrent for poor driving behavior, even when a crash does not occur. This can help the statistical model account for the relationship citations have to the probability of crashes occurring along a particular corridor. Similarly, this also applies to incident reports. Implementation of citations and incident reports into the sample data sets is feasible, since these reports have longitude, latitude and time/date information included, so citations and incidents could be included in sample data sets as independent factors.

Although the process for determining the benefit/cost ratio for optimum investment in trooper enforcement now exists, it still needs to be tested using more accurate data gathered and analyzed according to these recommendations for future research.

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Appendix A – Literature Review

Methodologies

A research report entitled *Multinomial Logistic Regression Model for Single-Vehicle and Multivehicle Collisions on Urban U.S. Highways in Arkansas* (Bham, 2012) in the Journal of Transportation Engineering detailed the use of a multinomial logistic regression model to examine statistical relationships between single or multiple vehicle collisions and different collisions types such as angular, head-on and sideswipe. Although analyses to assess highway safety based on crash counts and crash rates traditionally utilize negative binomial regression, for crash analyses based on crash severity as a binary response variable, logistic regression models are required. The primary objective of the multivariate analysis is to identify factors more likely to cause a specific type of collision. The multinomial logistic regression model allowed for multiple dependent categorical variables, including multiple independent variables. This allowed use of the logit models produced by the analyses to estimate the risk of multivehicle collision types compared with single vehicle collisions. The results of the analyses were interpreted in terms of the odds ratio, which helps determine the actual effects of the estimated coefficients. In particular, the odds ratio of an estimated coefficient indicates how the odds of an event occurring were affected by a crash. To interpret the actual effects, values of the coefficients were transformed to their original scale.

The research report entitled *Identification of Crash-Contributing Factors, Effects of Spatial Autocorrelation and Sample Data Size* (Manepalli, 2013), published by the Transportation Research Board of the National Academies. The report details the process in which the researchers used sets of crash data to examine similarities in crash-contributing factors among different counties in the state of Arkansas. Moran's I and Getis-Ord statistics were used to produce the spatial correlations, and a multinomial logistic regression was used to identify the effect of each crash-contributing factor. The author noted the importance of examining the validity of sample sizes used in statistical analyses, such as the level of data provided for each county, to identify factors that contribute to crashes throughout the state. In particular, researchers must account for crash data clusters that more frequently share common crash-contributing factors by utilizing spatial autocorrelation. The multinomial logistic regression model can be used to determine the relative risk among crashes, after similarities between crash events are identified using spatial autocorrelation. Sample data, organized by counties with the highest crash severity index, provided the basis of the analysis. The crash severity index considered the frequency of crashes involving fatalities, incapacitating injuries, moderate injuries, complaints of pain, and property damage. The author noted that a high crash severity index indicates a large number of crash frequencies at various levels of severity, providing greater variability in crash data and larger sample sizes.

An article entitled *Combining Service Patrol and Crash Data for Use in Highway Safety and Operational Analyses* (Fang, 2008) addressed the relationship between incident data collected using freeway service patrols, and data stored in crash databases. The paper discusses the process of combining information collected from data sources for use in both highway safety and incident operational analyses. Similarities in geographic distributions, dataset overlap, combined use of databases, and database improvements factored into the research. For geographical data distributions, the statistical analysis used two-sample Kolmogorov-Smirnov Goodness-of-Fit Test to examine the correlation between the distributions of the recorded crash data and data along freeway segments. For two records to be identified as a match between two separate databases, the crash location—as assigned by segment numbers—has to be in both records. The record matching process also requires the service time stamp to be within a one-hour time interval of the crash database time stamp. The study also uses safety ratios based on data obtained from the crash databases to compare with the calculated results obtained from both the historical and service patrol databases. The paper then recommends combination of the data from both databases to account for deficiencies in either source. All variables were checked for multicollinearity by use of a variance inflation factor before use of the multinomial logistic regression model. The variance inflation factor was found to be less than 10 for all involved variables, indicating that multicollinearity was not observed.

The article, *Finite Mixture Modeling for Vehicle Crash Data with Application to Hotspot Identification* (Park and Dominique, 2014), addresses the growing popularity of using finite mixture regression models to analyze highway safety. Finite mixture models assume that the observations of a sample data set arise from two or more unobserved components. Both fixed and varying parameter models have been useful in explaining the dispersive nature of crash data. The research in the article focused on investigating the relative performance of the finite mixture model and the traditional negative binomial model in terms of hotspot identification. Rural multilane segment crash data for divided highways in California and Texas provided a basis for the analysis. The results showed that the difference measured by the percentage deviation in orders of ranking were small for the particular dataset. However, the ranked results indicated that the finite mixture model was more reliable than the negative binomial model.

The article entitled *Computing What the Public Wants: Some Issues in Road Safety Cost-Benefit Analysis* (Hauer, 2010) argues that, though a cost-benefit analysis may justify the investment of public money and project priority, the analysis is deficient in certain areas. First, estimates used by cost-benefit analysis computation for the value of statistical life and injury are inconsistent with the value of time estimates, and are usually not provided with government guidance for consistency. Second, the basis for the cost-benefit analysis relies on premises of New Welfare Economics, which, in terms of roadway safety, apply only to uncommon circumstances. Although the computation of present values can be questionable when accounting for future lives and time, it is required in a cost-benefit analysis. Because time savings were valued higher in comparison to life, with the value of lives saved in the future generally discounted and diminished, the cost-benefit analysis was biased against road safety investments.

Traffic Enforcement Effectiveness

Chapter 31 of *Enforcement in the Handbook of Traffic Psychology* (Porter, 2011) provides insight into the psychological and sociological aspects of traffic enforcement. Traffic enforcement is a function of social control in various theoretical structures. The Learning Theory better explains the effectiveness of enforcement as operator conditioning. Conditions that occur before the behavior of interest shape that behavior, and consequences that occur after the behavior of interest increase or decrease the probability of the behavior occurring again. Aspects of the Learning Theory include rules which are societal and culturally driven, as well as dynamic conditioning achieved by watching others undergoing consequences for their behavior, and law enforcement officers acting as discriminatory stimuli to signal people to modify their behavior appropriately. Reinforcement and punishment are two primary consequences that affect behavior. Reinforcement is any stimulus that strengthens a behavior in a positive or negative manner, and punishment is any stimulus that decreases the likelihood its previous associated behavior will occur again. The book debates whether live officers or automated enforcement is more effective. One of the main advantages of automated enforcement is it allows a higher consistency of stimuli for learning behavior. On roadway segments and intersections that are too busy or dangerous for officers to effectively deter violations, automated enforcement can also be installed. However, there have been studies that indicate the constant presence of automated enforcement may become less effective over time, as the public becomes accustomed to the equipment. The chapter also discusses the benefits of enforcement in reducing crashes and casualties. Despite observed reductions in citation and fatality instances due to uninterrupted enforcement, the book indicates that there has been little change in the rate of DUI-related instances. In order to improve the effectiveness of traffic enforcement, it is important to increase the perceptions of the public that enforcement is constantly prevalent.

The book entitled *The Psychology of Driving: Factors of Traffic Enforcement* (Hellijas, 2007) discusses the various psychological factors associated between driver behavior and traffic law enforcement. When reasonable treatment and given proper consideration of the driver's circumstances is applied, this study states at least 95% of all drivers will try to cooperate with enforcement. Specifically, enforcement is more effective when the driver feels that the officers are trying to help, which allows the driver to behave better and try to cooperate. This prevents conditions that result in accidents or violations of a traffic regulation. The book indicates that maintaining enforcement effectiveness in adjusting driver behavior is more difficult when transitioning from an urban to a rural environment due to the changing densities of enforcement officers along roadways. It is also more difficult for a driver to adjust their speed and general attention when passing from a lesser populated area driving at higher speeds to a more densely populated with lower speeds. The book also discusses "spot enforcement," a purely psychological method of controlling driver behavior by concentrating patrols in areas where accidents have been most frequent. This method creates uncertainty among drivers, making them cautious within these particular areas. The hot spot area selections should be a function of the accident statistics division to determine which areas have the most accidents in a given period. The patrol units can then use the generated data to plan their timed routes to increase their effectiveness in "spot enforcement."

The *Alaska Highway Safety Performance Plan* is included in the *Alaska Highway Safety Plan* (latest draft is 2015) to assess performance targets for reducing annual trends to a goal of zero fatalities on roadways. Sample performance targets include reduction of overall fatalities, serious injuries and impaired driving fatalities. Other goals of the plan include increases in seat belt use and reductions in speeding instances. Program examples of the *Alaska Highway Safety Plan* include High-Visibility DUI Enforcement, in which an effective countermeasure for reducing impaired driving fatalities and injuries is highly visible enforcement. With a budget of $90,000, the program will fund local agencies to conduct data-driven enforcement operations in high-risk areas. Another program under the *Alaska Highway Safety Plan* includes Statewide Law Enforcement Liaison (LEL) Impaired Driving, in which the statewide LEL assists police agencies in analyzing their crash data to identify impaired driving hot spots and corridors, and help in implementing high-visibility enforcement strategies.

The National Highway Traffic Safety Administration (NHTSA) published a report entitled *Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices Seventh Edition, 2013*, which acts as a basic reference to assist State Highway Safety Offices in selecting traffic safety countermeasures for highway safety problem areas. The guide describes strategies and countermeasures that are relevant to highway safety offices, summarizes their use, effectiveness, costs and implementation time. A program example listed in the report includes Publicized Sobriety Checkpoint Programs, in which, at specific checkpoints along a roadway, law enforcement officers stop vehicles to check if the driver is impaired. Based on eleven studies conducted (which accounted for thirteen states that utilized the program), the checkpoint method is determined to reduce alcohol-related fatalities, injuries, and property damage crashes by approximately 20% each. Another recommended program includes Publicized Saturation Patrol Programs, in which a large number of law enforcement officers patrol a specific area for a set time to increase visibility of enforcement. A demonstration program conducted in 2008 in Michigan revealed that saturation patrols could be effective in reducing alcohol-related fatal crashes when accompanied by intensive publicity.

A report entitled *Advanced Patrol Routing with On-Call Response for Effective Resource Management* (Hardin and Keskin, 2011) had a goal of maximizing the visibility of state troopers during hot times along highways, while minimizing the costs associated with the utilization of state troopers. The analysis is based on benefit maximization and cost minimization, focusing on certain segments of highways with high frequency crash rates of different severity over a given time period. Part of the report identifies the right start and stop locations for state troopers at the beginning and end of their shift. However, the model proposed in the report has certain advantages, such as conserving multiple temporary stations whose locations need to be determined, as opposed to a single location. This way, more hot spots could be covered, as opposed to being out of accessibility range with just one station. Another advantage of the proposed model includes spanning multiple patrol shifts, as the locations of the hot spots and temporary stations dynamically change and temporary station locations tie the multiple time periods together.

A report entitled *Evaluation of the Queensland Road Safety Initiatives Package* (Monash University Accident Research Centre, 2003) evaluates the effectiveness of the Road Safety Initiatives Package (RSIP) developed by Queensland Transport and the Queensland Police Service. RSIP is a continuation of the Holiday Period Road Safety Enforcement and Education Campaign implemented in 2002 to 2003. The goal of RSIP is to target the road toll through increased hours of speed camera operation, increased hours of on-road police enforcement to target driver behavior, such as drunk driving, speeding, fatigue and non-seat belt wearing. The report also lists recommendations for increasing mass-media publicity to target consequential driver behavior, as well as increasing hours for police-involved education activities. The data collection time period ranged from January 1998 to January 2004, which allowed the researchers to account for effects before and after implementation of the RSIP. Factors included in the data collection effort consisted of hours of camera operations and number of active sites by region, data on monthly compliance with randomized speed camera operations, hours of spatial information concerning on-road enforcement, number of mobile phone and seat belt offences detected, and television advertising for each screened ad. Using the collected data, the researchers used a Poisson regression model to evaluate the RSIP crash effects. The researchers assumed that crash count data follow a Poisson distribution, and that the crash effects interaction could be described using a log-linear model. To their benefit, previous studies conducted in Queensland support this evaluation method. As such, the null hypothesis under testing is that there is no association between the RSIP and observed crash outcomes. With 11 independent variables included in the model, the analysis results revealed that specific programs under the RSIP achieved statistical significance in affecting crash outcomes. In particular, many of the programs resulted in negative regression coefficients, indicating that these programs resulted in attributable crash reductions.

In an article entitled *Effects of Enforcement Intensity on Alcohol-impaired Driving Crashes* (Fell, Waehrer, Voas, Auld-Owens and Carr, 2014), the objective of the research was to investigate the effects of law-enforcement intensity in a sample of communities. Factors such as deterrence of arrests per capita, frequency of sobriety checkpoint operations, annual number of traffic stops per capita, enforcement presence, and the number of general traffic enforcement citations per capita were the basis of the analysis of law-enforcement influence. The methodology included the use of nationwide data on the local prevalence of impaired driving from the 2007 National Roadside Survey (NRS), including measures of DUI enforcement activity provided by police departments who participated in the 2007 NRS. Log-linear regression established relationships between the intensity of enforcement and the prevalence of impaired driving crashes in 26 communities. The results indicated that a 10% increase in the DUI arrest rates is associated with a 1% reduction in the DUI-related crash rate.

An article entitled *The Effects of Increased Police Enforcement along a Route in London* (Walter, Broughton, and Knowles, 2011) was published, detailing a trial carried out in London in 2008 to investigate the effects of increasing the level of traffic policing in a busy urban area. The operation ran for four weeks and increased the visible presence of police on a six-mile stretch of the A23 of South London. Two teams of six officers and one sergeant deployed in two shifts per weekday along the route using static and mobile policing methods in a variety of enforcement vehicles. The paper summarizes the effects of the operation in terms of the number of offenses detected by the police and the effects on driver behavior observed by a series of roadside surveys. The results showed that vehicle speeds reduced during operation along the route and surrounding areas.

An article entitled *Cost-effectiveness of Traffic Enforcement: Case Study from Uganda* (Bishai, Asiimwe, Abbas, Hyder and Bazeyo, 2008) assessed the costs and potential effectiveness of increasing traffic enforcement in Uganda. In October of 2004, the Ugandan Police department deployed enhanced traffic safety patrols on four major roads to the capital of Kampala. The research involved interviews with 10 police stations along the patrolled highways, to review monthly data on traffic citations and associated casualties between 2001 and 2005. A times-series regression analysis was used to determine if a statistically significant interaction occurred in changing the number of traffic-related fatalities. Costs during that timeframe were assessed in U.S. currency in 2005. The results of the research showed that the annual cost of deploying four squads of traffic patrols (20 officers, four vehicles including administration services) estimated at $72,000. Since deployment, the number of citations increased substantially, with a value of $327,311 annually. Monthly crash data before and after the patrol intervention showed a statistically significant drop of 17% in roadway-related fatalities after the patrol intervention. The results indicate that the average cost-effectiveness of better road safety enforcement in Uganda is $603 per avoided death.

An article was published entitled *Traffic-law Enforcement and Risk of Death from Motor Vehicle Crashes: Case-Crossover Study* (Redelmeier, Tibshirani and Evans, 2003), detailing research into whether traffic convictions, because of their direct effect on the recipient, might be associated with a reduced risk of fatal motor vehicle crashes. Researchers identified licensed drivers in Ontario, Canada, who had been involved in fatal crashes in the past 11 years, and used a case-crossover design study to analyze the protective effect of recent convictions on individual drivers. The findings showed that the risk of a fatal crash in the month after a conviction was about 35% lower than in a comparable month, with no conviction for the same driver. The benefit lessened substantially after two months, and was no longer significant by three to four months. The driver's age, previous convictions and other personal characteristics did not alter the benefit. However, the benefit was greater for drivers that received speeding violations with penalty points than without penalty points.

The objective of the report, *Traffic Enforcement in Europe: Effects, Measures, Needs and Future* (Makinen, 2003), is to identify issues involved in traffic law enforcement in Europe, including an examination of traditional and new enforcement approaches, while assessing their potential to improve driver compliance for increased safety along roadways. The policing function in relation to events such as speeding and drunk driving, was assessed by a qualitative analysis. The primary method of enforcement utilized in Europe is deterrence. Empirical evidence shows that not only does deterrence work in experiments; it can also be cost effective. As part of the report, a joint re-analysis of different studies of changes in enforcement levels found that increased enforcement could reduce injury accident rates by an average of 6% to 17%. However, the marginal effect of increasing the amount of enforcement becomes gradually smaller. The report also considers the application of automated camera systems for enforcement, suggesting that automated enforcement can achieve maximum deterrence through a minimum number of notices. This will ensure that drivers are aware of the areas covered by camera installations due to enforcement visibility.

Crash Cost Estimation and Safety Investment

The 2009 Federal Highway Administration (FHWA) KABCO scale is an injury scale derived from the Highway Safety Improvement Program Manual to establish crash costs. Law enforcement frequently uses the scale developed by the National Safety Council (NSC) to identify costs associated with fatal, incapacitating, non-incapacitating, possible and no injury accidents. The 2005 FHWA study entitled *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries* provides crash cost estimates for several combinations of KABCO injury severities for 22 injury crash types. The document relies on states to use their own developed crash costs to calculate safety benefits. However, if a state has not developed crash costs specific to their state, then KABCO recommends using comprehensive crash costs to determine crash injury severity levels derived from the *2009 Highway Safety Manual, First Edition*.

A report entitled *Crash Costs in the United States by Crash Geometry* (Zaloshinja, Miller, Council, and Persaud, 2005) estimated the costs per crash for three policy-coded crash severity groupings. Researchers merged previously developed costs per victim by abbreviated injury scale (AIS) scores into U.S. crash data files scoring injuries in both AIS and police-coded severity scales, to estimate injury costs. The results indicated that the most expensive crashes were non-intersection fatal/disabling injury crashes on a road with a speed limit of 50 miles per hour or higher, where multiple vehicles crashed head-on, resulting in over $1.69 million per crash. The report noted that the annual cost of police-reported run-off-road rollovers and collisions with property represented 34% of the total costs.

The National Highway Traffic Safety Administration published a report entitled *Traffic Safety Facts* in 2012, which provides crash data information for trends, crash types, and vehicle types involved in crashes, and statistics about drivers and passengers. A majority of the report presents data derived from the Fatality Analysis Reporting System (FARS) and the National Automotive Sampling General Estimates System (GES), such as statistics for fatal crashes, property-damage-only crashes, and crashes with nonfatal injuries. Specifically, the report lists crash rates, number of fatal crashes and percent of alcohol-impaired driving by month, time of day, day of week, and crash severity. The document also lists fatal crash and fatality statistics for each state based on crash event type, roadway function class, and driver blood alcohol concentration.

The publication entitled *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries* (FHWA, 2005) presents estimates for the economic and comprehensive costs per crash for six KABCO groupings within 22 selected crash types, and within 2 speed limit categories. The comprehensive costs include nonmonetary losses, such as medically related costs, emergency services, property damage, lost productivity, and Monetized Quality-Adjusted Life Years. The cost estimates were developed with costs per victim keyed on the Abbreviated Injury Scale (AIS). U.S. traffic crash data files, which scored injuries in both AIS and KABCO scales, were used to produce per crash estimates. For example, the report indicates that crashes that fall under categories K and A, and occur along a roadway with a speed limit greater than 50 miles per hour, have a mean human capital cost per crash of $465,397, including a mean comprehensive cost per crash of $1,389,804.

The National Highway Traffic Safety Administration published a report entitled, *The Economic Impact of Motor Vehicle Crashes 2000.* The document presents the results of an analysis of motor vehicle crash costs in the United States in the year 2000. Based upon lifetime costs associated with 28 million damaged vehicles, 5.3 million non-fatal injuries and 821 fatalities, the total economic cost of motor vehicle crashes in 2000 was $230.6 billion. Of this total cost, $59 billion was associated with property damage, while $61 billion accounted for lost market productivity. Medical expenses totaled $32.6 billion, while travel delay accounted for $25.6 billion. Each fatality resulted in an average discounted lifetime cost of $977,000. Public revenues paid for approximately 9% of all motor vehicle crash costs, costing taxpayers in the United States $21 billion in 2000. The reported also noted that, in almost 80% of these cases, alcohol was the cause of the crash. Crashes that resulted from drivers exceeding the speed limit resulted in a cost of $21 billion in 2000.

An article entitled *Costs and Functional Consequences of U.S. Roadway Crashes* (Miller, 1993) emphasized comprehensive lifetime costs associated with injuries or damage resulting from vehicle crashes. The article also estimated the functional capacity loss and probability of permanent work-related disability resulting from nonfatal injuries. Rather than using monetary crash costs in resource allocation, the document used comprehensive costs that more appropriately relate the value of life (lost wages, household production, and quality of life) versus travel time. The results of the analysis indicated that any injuries resulting from a vehicle crash could substantially shorten functional lifespan, from an average loss of 0.015% to a minimum of 35% with an average maximum of 70%. As an example, the analysis found that a total 1.2 million functional years were lost in 1988 due to crashes involving Maximum Abbreviated Injury Scale (MAIS) 3 injuries.

A report entitled *The Economic and Societal Impact of Motor Vehicle Crashes, 2010* (NHTSA, 2014) analyzed crash data to determine the economic impacts for varying crash types. The report found that, in the year 2010, crashes caused $24 million dollars in vehicle damage. Of the total $277 billion in crash-related expenses for 2010, $76 billion was from property damage. Medical expenses accounted for $35 billion, and other costs due to the crashes, such as congestion, excess fuel consumption, and travel delay, accounted for $28 billion.

Appendix B – Data Collection and Import

Data Collection

The statistical analysis utilized sample data from two primary database sources: geo-spatial information for patrol vehicles, and crash incident data. As a result, the data collection effort consisted of two primary processes, the first being trooper vehicle monitoring. In 2014, the University of Alaska Anchorage, College of Engineering's Department of Civil Engineering coordinated with the Alaska DOT&PF and the Alaska State Trooper to install 100 sensors in certain patrol cars to spatially track vehicle movement in terms of location, speed and time of reference, and send all collected information to a designated server at regular intervals. These time intervals were adjustable, based on the desired level of accuracy needed to describe the movement of each trooper vehicle. With DOT&PF and Alaska State Trooper coordination, the Department of Civil Engineering established a contract with Verizon to use their Network Fleet services, which provides GPS fleet tracking and diagnostics. The Network Fleet servers collected all information sent out by the devices installed in the trooper vehicles. The collected data was accessible to the research team by requesting activity reports based on specified timeframes.

The second primary process of the data collection effort was downloading collision, citation and incident reports from servers maintained by the Alaska DOT&PF and the Alaska State Troopers. All crash reports were available in electronic format to achieve seamless database integration. All reports were generated by troopers at the time and location of a crash occurrence, which presented an issue with the accuracy of the crash reports. In particular, it is common for a trooper to arrive at the scene of a collision event later than when the event actually took place. As a result, accuracy of the crash reports was largely dependent on the trooper's judgement of when and how the collision event took place based on available evidence and testimony at the scene. The exact location of the collision is also subject to the trooper's judgement. All crash reports in paper or electronic form are initially stored in databases maintained by the Department of Motor Vehicles (DMV). Information transfer occurs from DMV databases to a designated server, after the Alaska DOT&PF or Anchorage Police Department requests a set of crash reports

A Microsoft SQL Server 2014 installed on a separate server stored, organized, processed and analyzed the data for this research. The software allowed configuration to extract data downloaded from outside sources and organize the information into tables known as database templates. These templates only store information relevant to the statistical analysis and, with utilization of SQL Script, can automatically sort, format, and categorize the stored data. All tables within the templates included the following columns for organization of the data: time, date, latitude and longitudinal coordinates. For example, researchers established a database template that stored and organized trooper vehicle data from the activity reports downloaded from the Verizon Network Fleet service. The activity detail reports provided by Network Fleet contained fields such as position, speed, heading, street name, date, time and sensor status. The SQL Server import utility imported the activity detail reports in CSV file format into Microsoft SQL Server 2014.

Once the data is imported into the local server database, the imported data was then automatically sorted into field columns under the database. SQL Server uses rows and columns to organize all imported data. Each field received a specific column, and each row contained data about a specific trooper vehicle at a specific time. Since not all fields provided in the activity detail reports were utilized in the statistical analysis, to reduce excessive data storage and streamline the databases, queries written under Structured Query Language (SQL) were utilized to extract and organize relevant data. The SQL queries allowed large amounts of data to be organized and sorted efficiently, while extracting only time, date, latitude, longitude and vehicle identification number (VIN).

To extract the fields of interest, the SELECT command was used in a query consisting of a piece of code to perform an operation on a database. In this case, the query was set up to select specific fields from the database:

```
SELECT [Lattitude], [Longitude], [Date], [Time], [VIN]
FROM [ActivityDetail 1]
```

The above query allows the research team to filter any fields desired. However, the above query still resulted in large quantities of data. To reduce data stored in the database and improve the efficiency of, the datasets are further restricted over certain regions of space. Researchers applied the following dataset filters:

- The analysis only studied trooper activity along the five study corridors, and
- The analysis only studied trooper activity within "hotspot" regions of the four study corridors.

In order to achieve the above dataset filters, the activity detail reports, which sort trooper vehicle data in 20 second intervals, was organized into a database with vehicles organized by their respective spatial information within the specified study corridors and hotspot regions. To apply these filters based on spatial information, the technique of geo-fencing was used.

Geo-fences are polylines defined by vertices assigned by latitudinal and longitudinal coordinates. Geo-fences allow users to define a section along a highway based on a geographical polyline, which enables the monitoring of information within this defined region. Verizon Network Fleet system provides this function by default. This research drew polylines around major highways of interest in Alaska, such as the Glenn Highway, the Parks Highway, the Richardson Highway, the Sterling Highway and the Seward Highway. After the geo-fence polylines were specified on the Verizon Network Fleet site, monthly reports were then generated for each geo-fence to inform the research team which trooper vehicles have entered or exited the geo-fenced areas. The geo-fence reports also allowed the research team to obtain time of entry, exit and duration of stay for each trooper vehicle within each geo-fenced region. Using geo-fence reports and activity detail reports, filters can be applied to retain vehicle, highway, time and location data. This allows the research team to generate custom reports which provide the vehicle identification numbers of the trooper vehicles and their respective positions, but only when they are within one of the geo-fenced regions.

Patrol Vehicles Spatial Data

The sensors attached to each patrol vehicle send out the following information to the Verizon Network Fleet database every 20 seconds: vehicle label, driver identification, vehicle identification number, date of the information, ignition status, address, city, state, zip code, county, latitude, longitude, odometer, average speed (mph), instantaneous speed (mph), max speed (mph), patrol groups, and movement status. Troopers coded Vehicle identification information as a security measure to ensure privacy. Collected data allowed users to request reports summarizing a group of data by various factors, using date to identify the time, day, month and year the data point was received.

Understanding of patrol vehicle movement requires a data point, and observation of the average, instantaneous and max speeds. In particular, the speed reports reflected the average speed of a patrol vehicle over a 20-second period. The instantaneous speed only reported the speed of the patrol vehicle from the instant a data point is pinged from the sensor. Finally, the max speed describes the highest recorded speed of the patrol vehicle over the 20-second period. If, for example, the average instantaneous and max speeds were equal to 0 mph, then it was apparent that the patrol vehicle was stationary during that time period. If all speeds were roughly equal to a particular speed, such as 55 mph, then it was apparent that the patrol vehicle was traveling at a constant speed during the time period. Note that if the patrol vehicle had to accelerate temporarily and then maintained a constant speed for most of the time period, the max speed would be greater than the average speed.

There are also other ways to determine the movement of the patrol vehicle based on peculiar characteristics of the speed data. For example, if three data points (average speed = 25 mph, instantaneous speed = 25 mph, max speed = 25 mph) occurred, followed by one data point (average speed = 15 mph, instantaneous speed = 0 mph, max speed = 25 mph), then followed by seven data points (average speed = 0 mph, instantaneous speed = 0 mph, max speed = 0 mph), it can be assumed that for the first 60 seconds, speed was constant, then for 20 seconds the patrol vehicle began slowing down to a stationary position. The patrol vehicle then remained in a stationary position for 140 seconds. If the data point after the stationary period included the following (average speed = 7 mph, instantaneous speed = 23 mph, max speed = 23 mph), then the patrol vehicle is most likely leaving its stationary position and accelerating back to the original constant speed of 25 mph.

Crash and Citation Data

Researchers collected and organized crash data on citations, collision reports, and reports detailing incidents. Of the three types, collision reports typically include more information about crash incidents, such as locations relative to nearby intersections or side roads, injuries that were involved, and collisions types. All crash data was derived from police reports collected from the Alaska Police Department through DOT&PF and stored on servers maintained by the Department of Motor Vehicles (DMV). The accuracy of information, such as distance from nearby intersections, or where the crash occurred along a highway, was dependent on the trooper. Similar to the patrol vehicle data from Network Fleet, the crash data included latitudinal and longitudinal coordinates approximating the location of the crash instance, with an associated date and time.

Under each crash instance, the collision reports include the manner in which the collision occurred, such as a front end to rear end collision between the involved vehicles, an angle collision, sideswipe, and more. The collision reports also include descriptions of the injuries involved for each crash instance, such as suspected minor injury, possible injury, serious injury, fatality, etc. It is also possible that no injuries occurred, though property damage was involved, so researchers also included the status of property damage during a crash under a separate column.

The citation and incident reports also include latitudinal and longitudinal coordinates as well as time and date of each occurrence. Citations are not associated with crashes, but rather violations drivers have committed such as speeding, running a red light, and failure in wearing a seatbelt. Incident reports detail committed offenses, such as driving while under the influence of alcohol, leaving the scene of an accident, or reckless driving.

Data Import Procedure

The procedure detailed below includes methods to collect and process trooper vehicle data and collisions/citations data. These methods include the usage of programming languages such as MATLAB, JavaScript and SQL.

The data collection procedure included the following programs and services:

- Google Chrome by Google
- MyMaps by Google
- GPS Visualizer KML to TXT converter-(http://www.gpsvisualizer.com/convert_input)
- MATLAB R2015a by MathWorks
- Verizon Network Fleet by Verizon-(http://www.networkfleet.com/)
- Microsoft Excel 2013 by Microsoft
- Windows Server 2012 R2 by Microsoft
- SQL Server 2014 Management Studio by Microsoft
- SQL Server Data Tools 2015 by Microsoft

The complete procedure for importing data is in Appendix D.

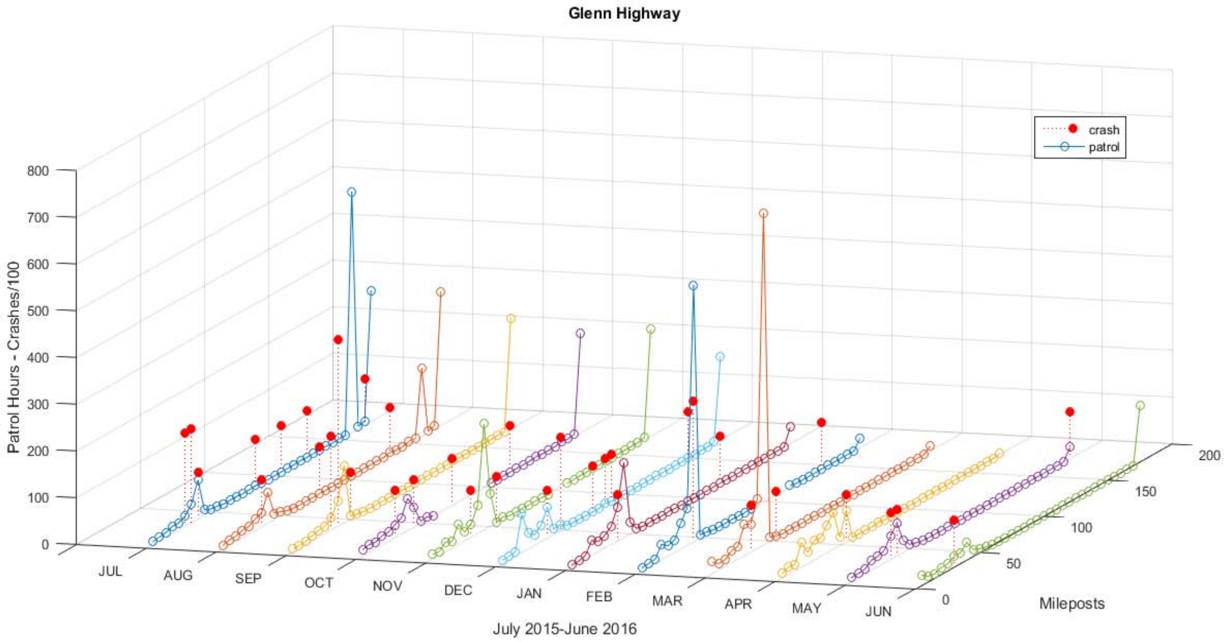
Regression Analysis

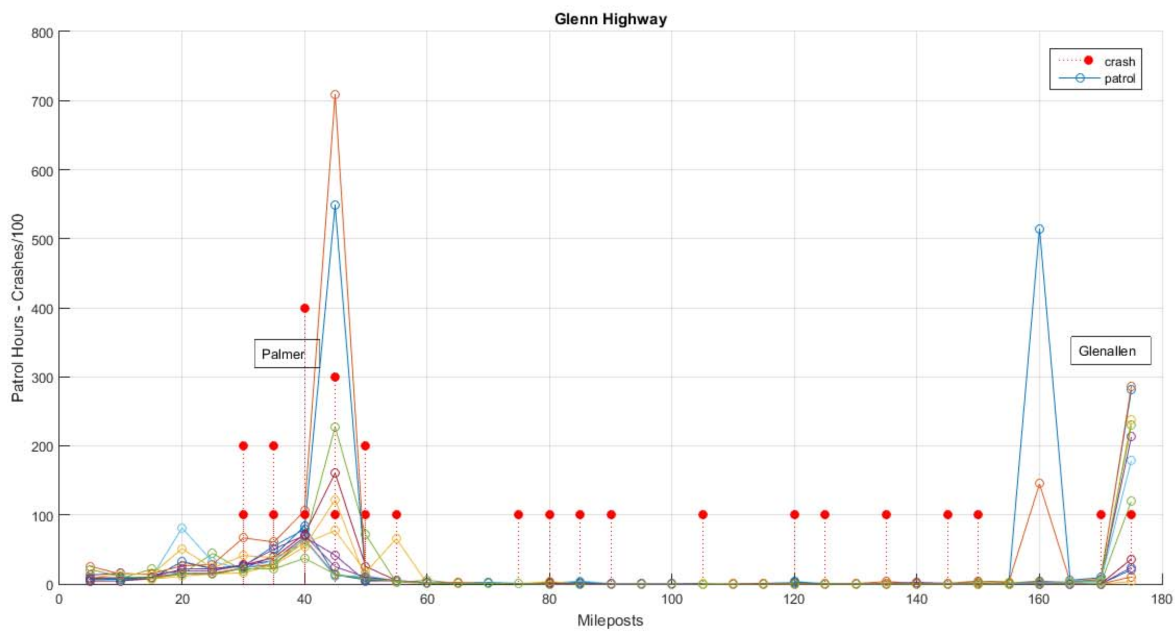
Based on feedback and recommendations, a binomial logistic regression—where the dependent variable is a dummy variable, coded 0 (did not occur) or 1 (did occur)—was the most appropriate approach to the statistical analysis. Under this regression, the presence of patrol vehicles was included as a numerical presence based on time, and the occurrence of crashes was a categorical dependent variable. To determine whether a correlation exists between independent variables and a dependent variable, logistic regression analysis is the traditional method. In this case, the question is "Does the current frequency of patrol vehicles in a given region and time interval have an effect on the probability of crashes occurring within that location?" The logistic distribution constrains the estimated probabilities to lie between 0 and 1. If the probability is closer to 1, then the set of data falls within Group 1, indicating that, given the inputted independent variables (frequency of patrol vehicles), the event (instance of a crash) is predicted to occur. If the probability is closer to 0, then the set of data falls within Group 2, indicating that, given the inputted independent variables, the event is predicted not to occur. If the probability approaches or equals 0.50, the inputted independent variables do not have an effect on likelihood of the occurrence of an event.

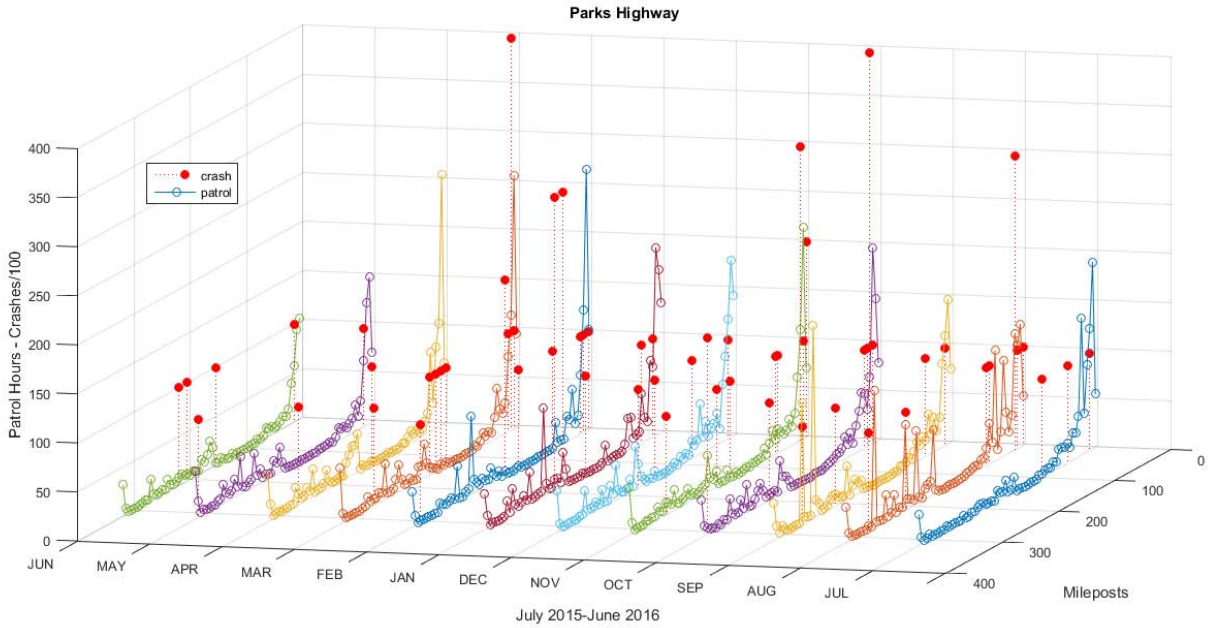
Poisson Regression Analysis

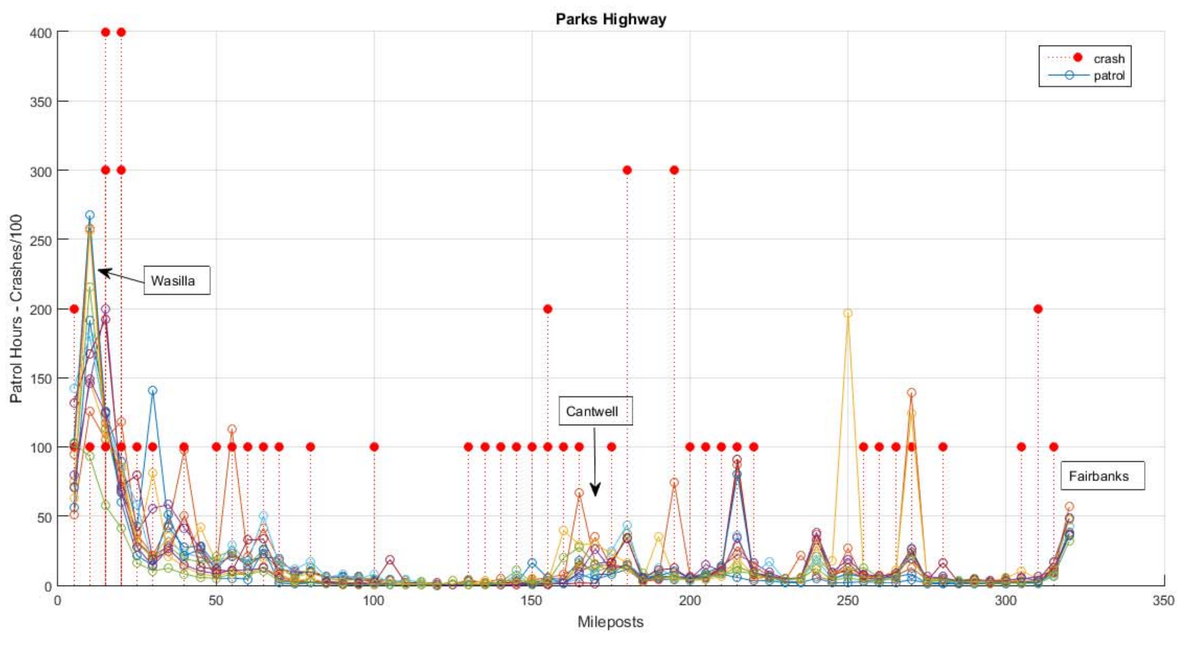
In addition to the logistic regression analyses, the macro level analyses utilized Poisson regression analyses. At the macro level, since the sample size accounts for a time period of one year, higher numbers of crash events are included. The potential shortcoming of a logistic regression analysis is that it can only account for crash events in binary form, ignoring the quantitative value of crash events occurring along a study corridor on an annual basis. The advantage with a Poisson regression is that it allows raw quantities to be inputted for the dependent variable. However, the Poisson regression is a generalized linear model, which assumes that the logarithm of its expected value can be modeled through a linear combination of covariates. Usage of the Poisson regression for this research assumes that a log-linear relationship exists between the presence of crash events, trooper enforcement and other independent factors. Though other studies suggest that a log-linear relationship can exist in urban environments, the independent factors involved along highway systems in Alaska are unique due to seasonal effects and relatively low population density. Despite a lack of previous studies that confirm such a relationship exists here in Alaska, it researchers recommend that the binary logistic regression analysis be used to determine the statistical relationship. The Poisson regression is only included under the macro analysis as a means of discussion for this research. It is possible to use SPSS to run a Poisson regression analysis. Under "Generalized Linear Models," selecting the function "Poisson Log-Linear," with crash instances as the response, and patrol presence as the predictor. By default, SPSS uses the Wald Test to determine the statistical significance of the interaction.

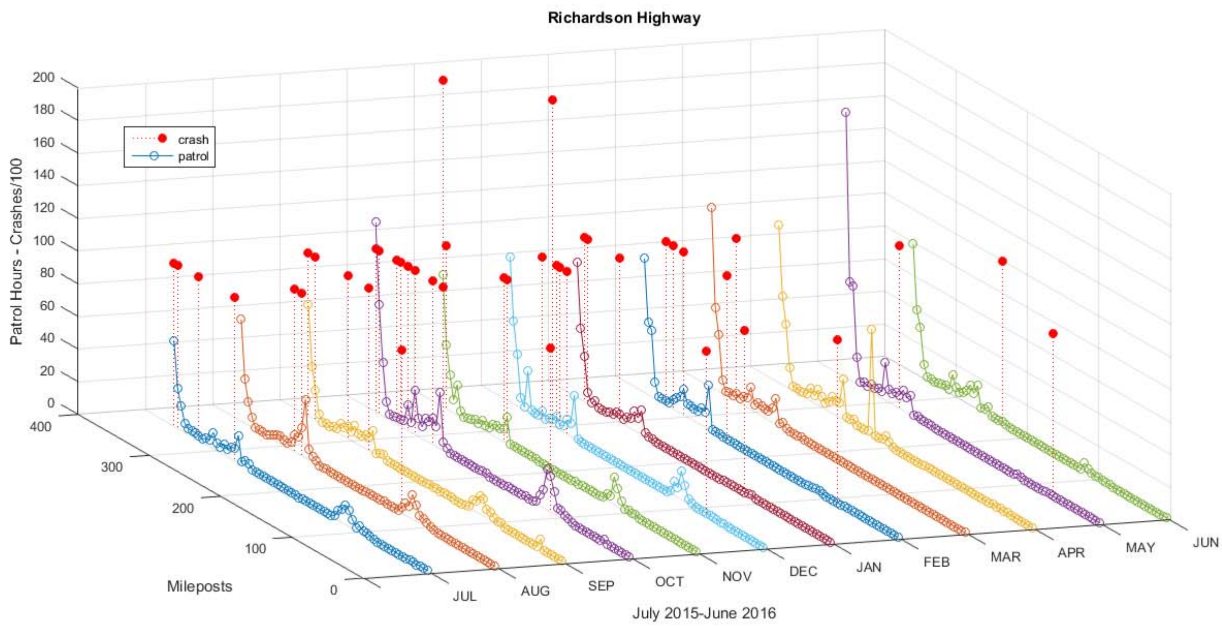
Appendix C – Graphs of Corridors

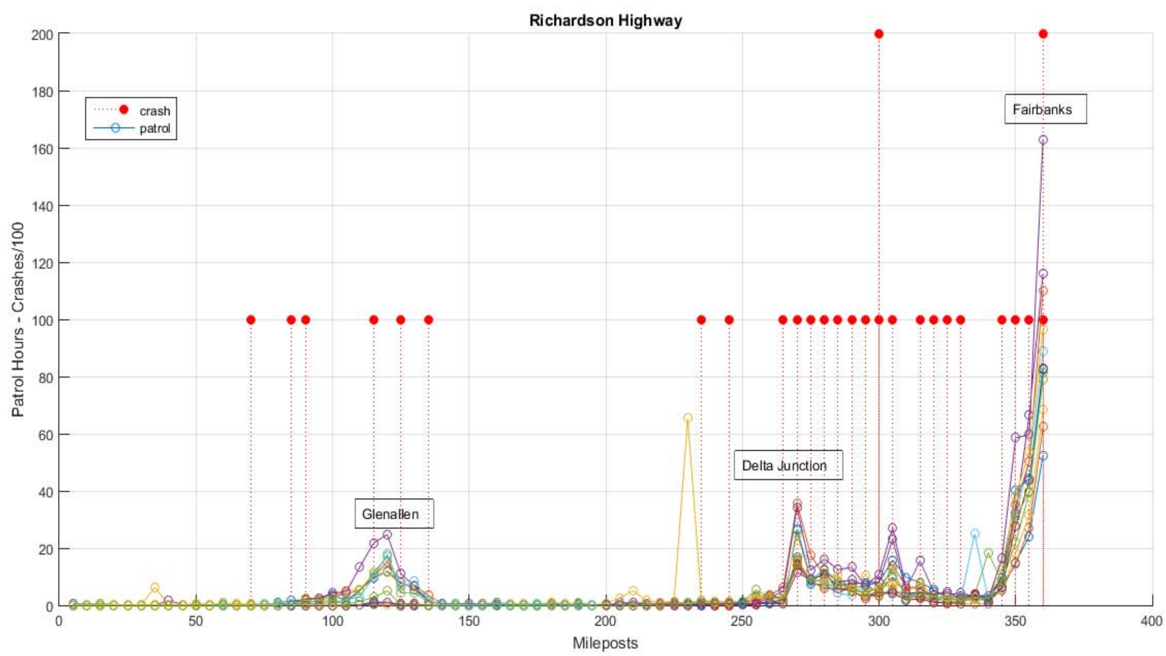


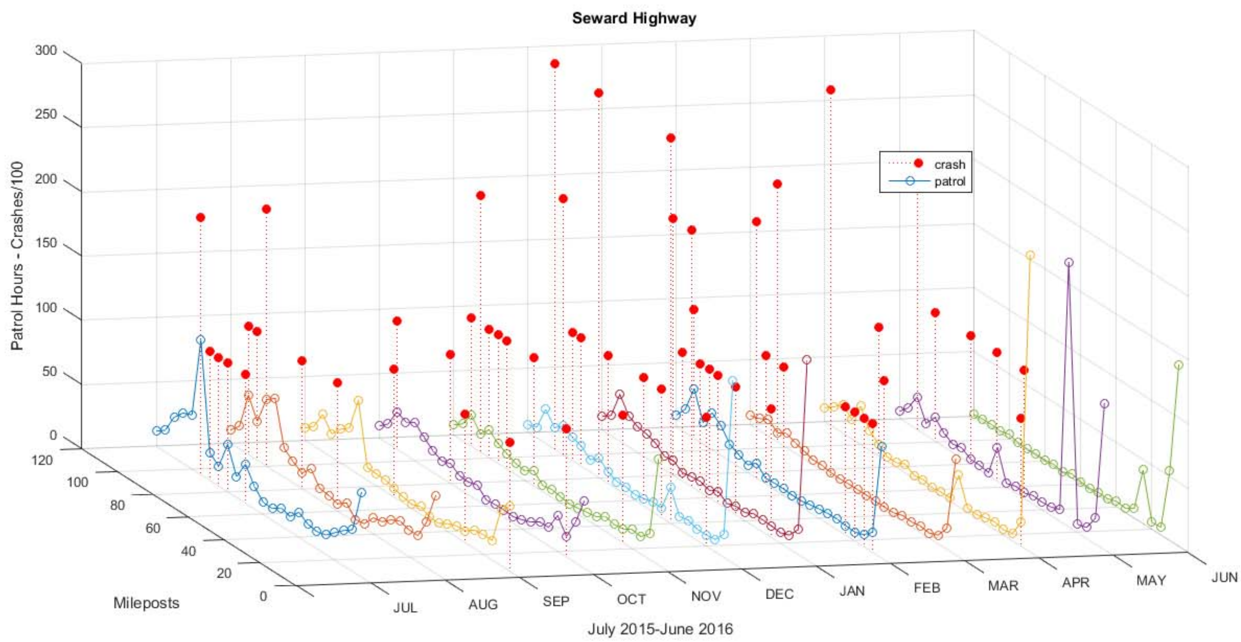



Parks Highway
crash
patrol
Patrol Hours - Crashes/100
400
350
300
250
200
150
100
50
0
JUN
MAY
APR
MAR
FEB
JAN
DEC
NOV
OCT
SEP
AUG
JUL
July 2015-June 2016
0
100
200
300
400
Mileposts

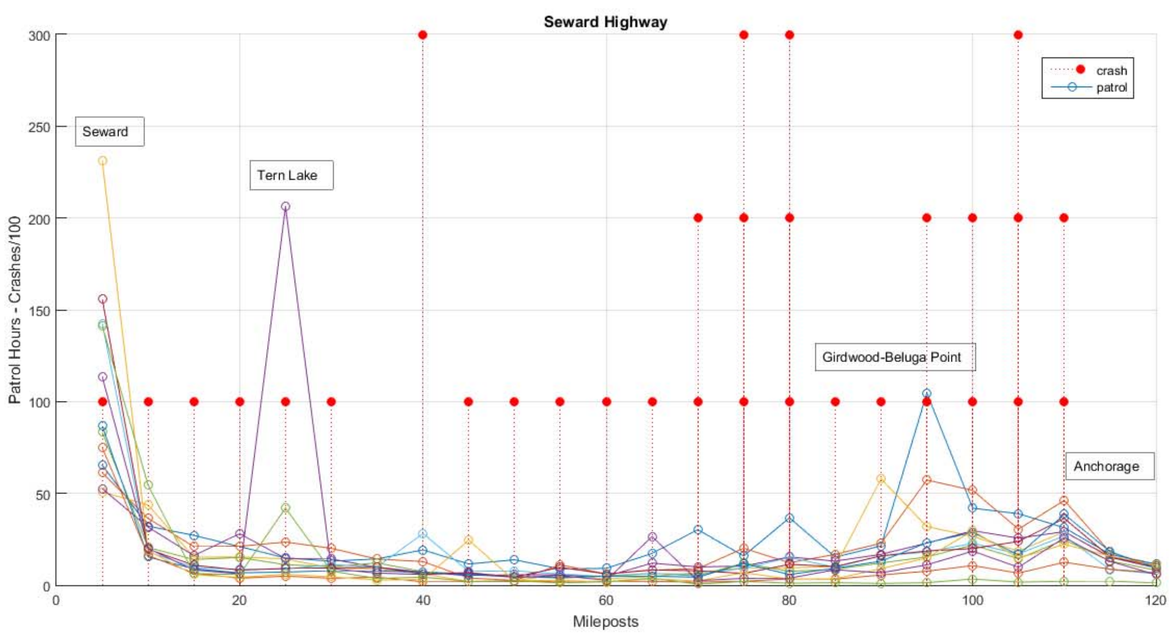

Parks Highway
crash
patrol
Patrol Hours - Crashes/100
Wasilla
Cantwell
Fairbanks
0
50
100
150
200
250
300
350
400
Mileposts


Richardson Highway
crash
patrol
Patrol Hours - Crashes/100
Mileposts
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
July 2015-June 2016

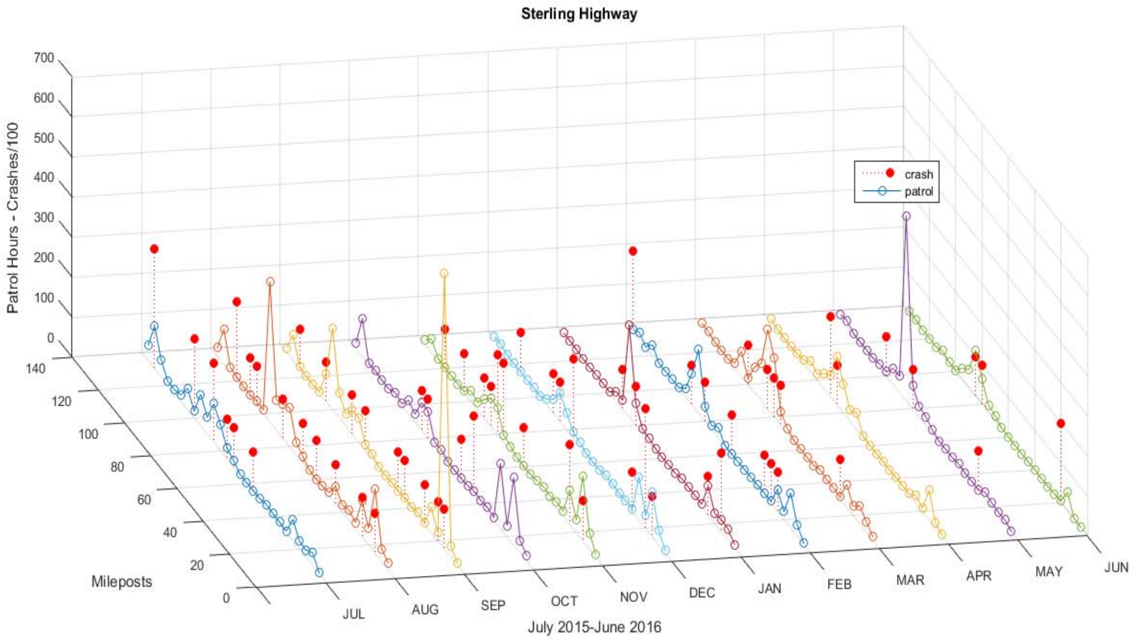

Richardson Highway
crash
patrol
Fairbanks
Delta Junction
Glenallen
Patrol Hours - Crashes/100
Mileposts



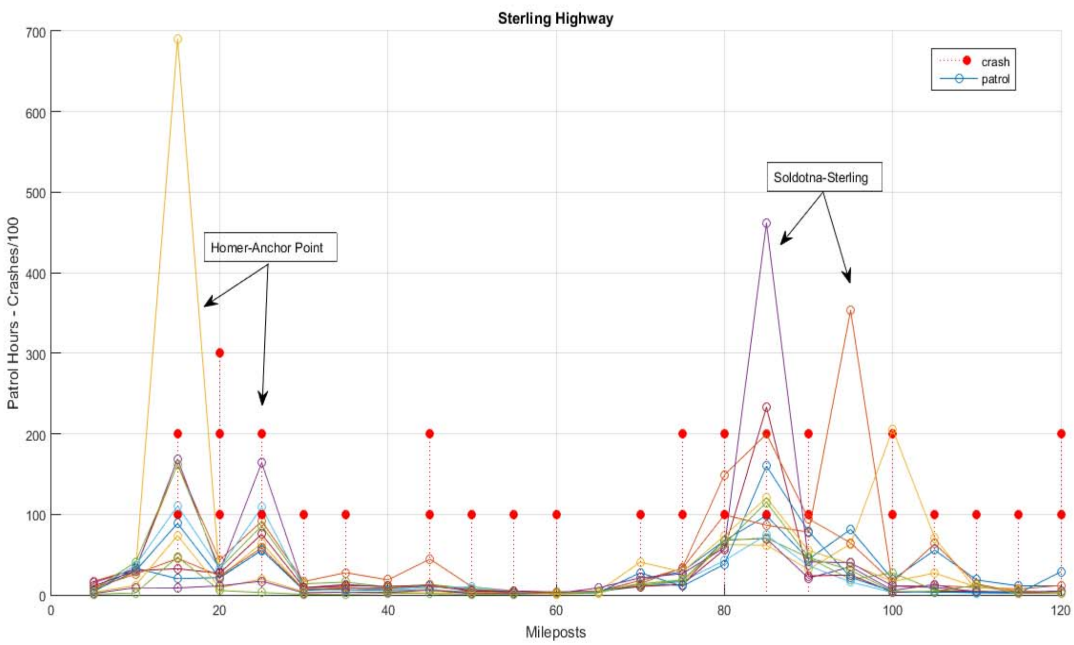
Seward Highway
Patrol Hours - Crashes/100
300
250
200
150
100
50
0
crash
patrol
120
100
80
60
40
20
0
Mileposts
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
July 2015-June 2016



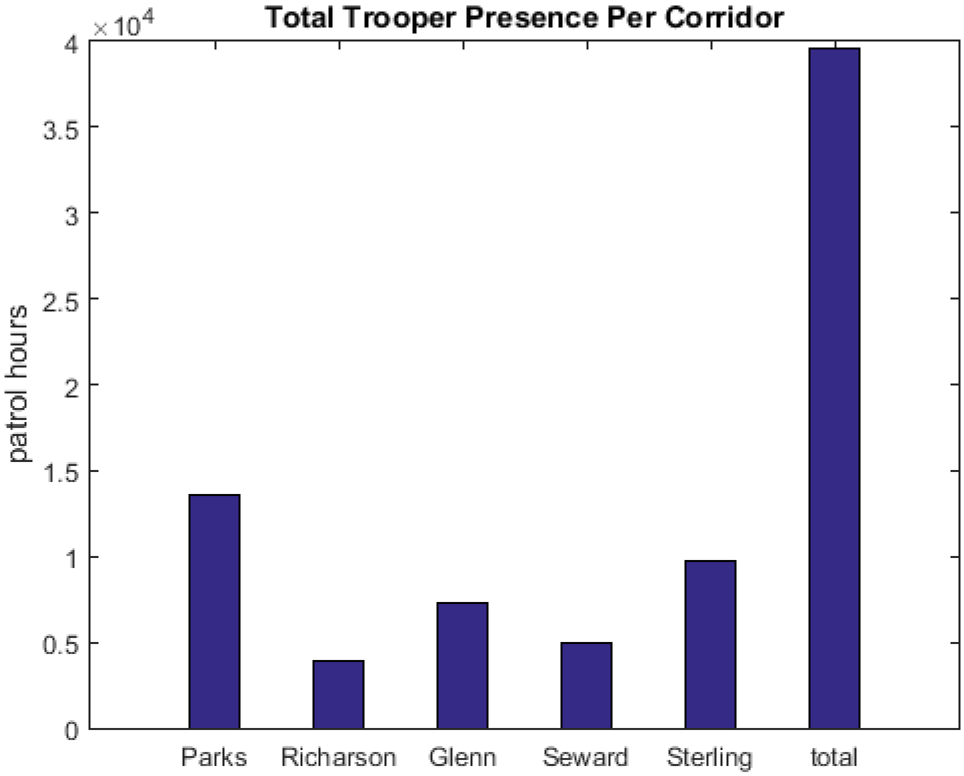
Seward Highway
Patrol Hours - Crashes/100
crash
patrol
Seward
Tern Lake
Girdwood-Beluga Point
Anchorage
300
250
200
150
100
50
0
0
20
40
60
80
100
120
Mileposts

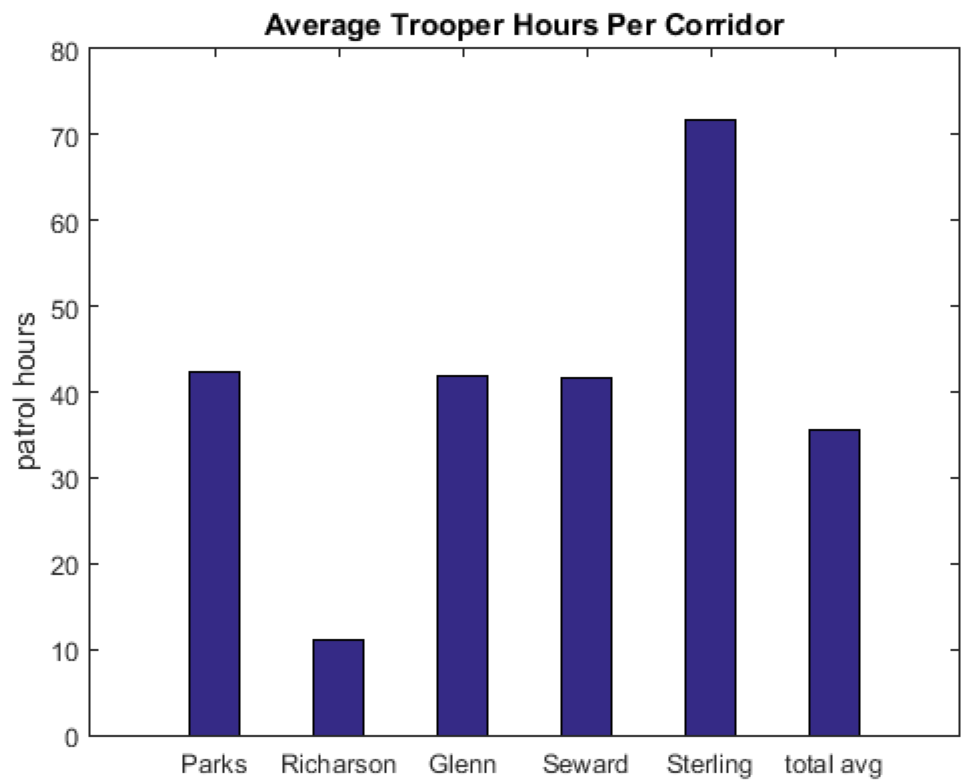


Sterling Highway
Patrol Hours - Crashes/100
crash
patrol
Mileposts
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
July 2015-June 2016



Sterling Highway
Patrol Hours - Crashes/100
crash
patrol
Homer-Anchor Point
Soldotna-Sterling
Mileposts

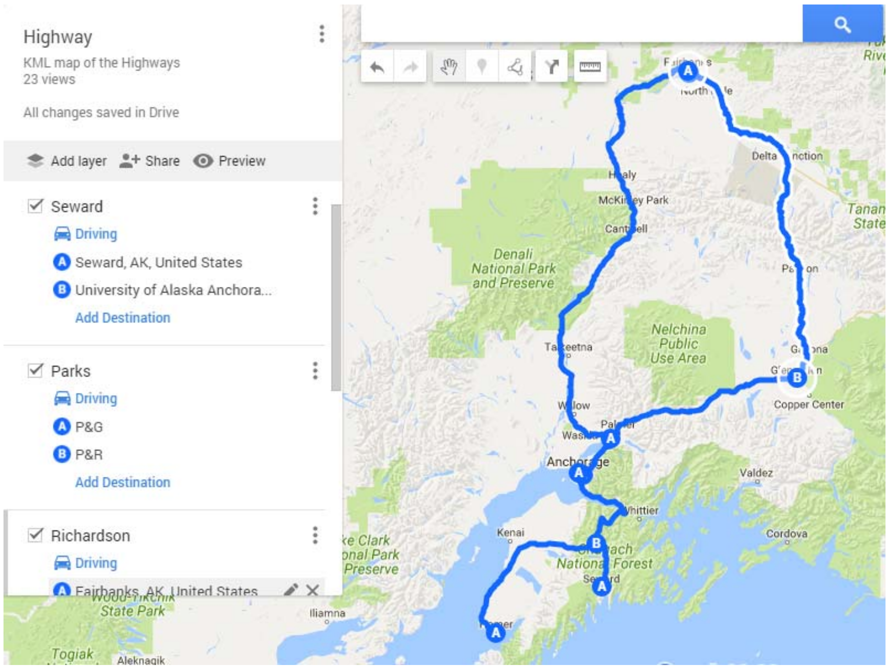

Total Trooper Presence Per Corridor
×10^4
4
3.5
3
2.5
2
1.5
1
0.5
0
patrol hours
Parks
Richarson
Glenn
Seward
Sterling
total


Average Trooper Hours Per Corridor
80
70
60
50
40
30
20
10
0
patrol hours
Parks
Richarson
Glenn
Seward
Sterling
total avg

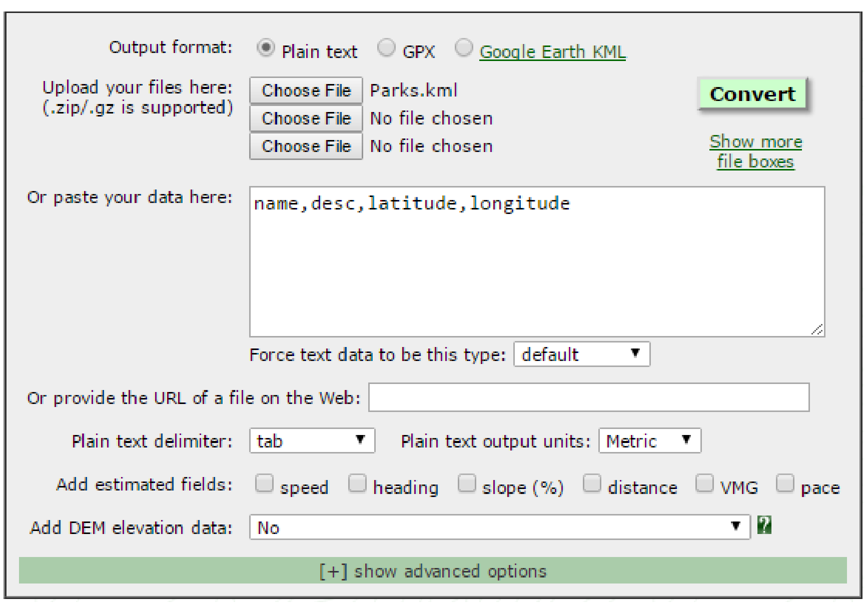
Appendix D – Patrol Vehicle Data Collection Procedure

The procedure for collecting trooper vehicle data consists of the following 10 steps:

1) Create a map of the Parks, Richardson, Glenn, Seward and Sterling Highways in separate layers using MyMaps and download a KML file of each Highway layer into a folder called Highways.

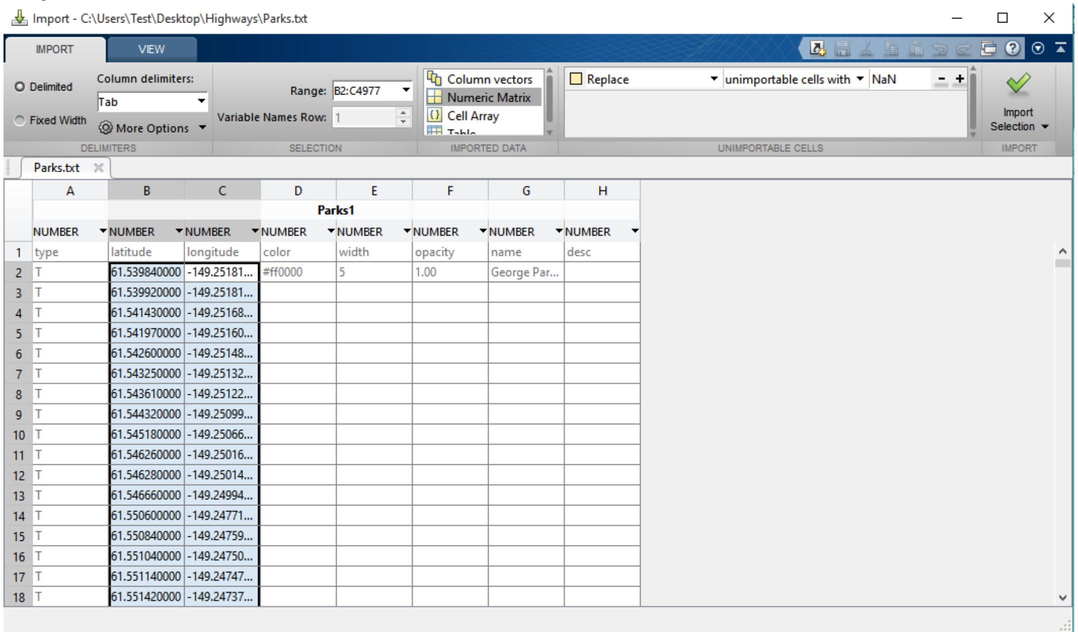


2) Open GPS visualizer in Google Chrome, load the KML files of the highways into the visualizer and output a tab delimited TXT file for each highway. Save the TXT files into the Highways folder as well.

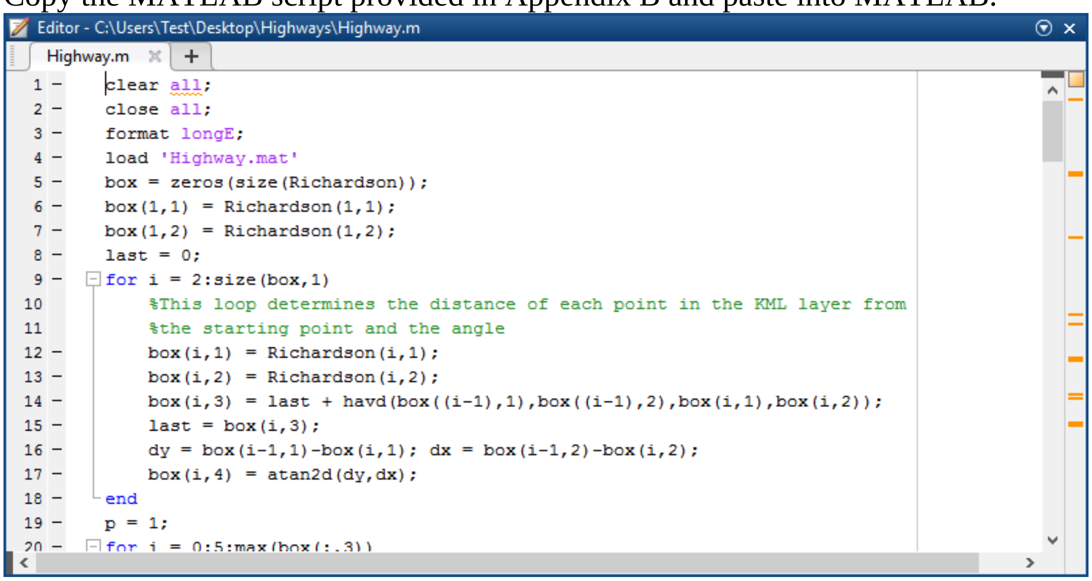


3) Open MATLAB and use the data import tool to load the latitude and longitude columns from each of the five TXT files into a MATLAB numeric array. Name each numeric array with the

name of its respective Highway. Save the five numeric highways as Highway.mat in the Highways folder.

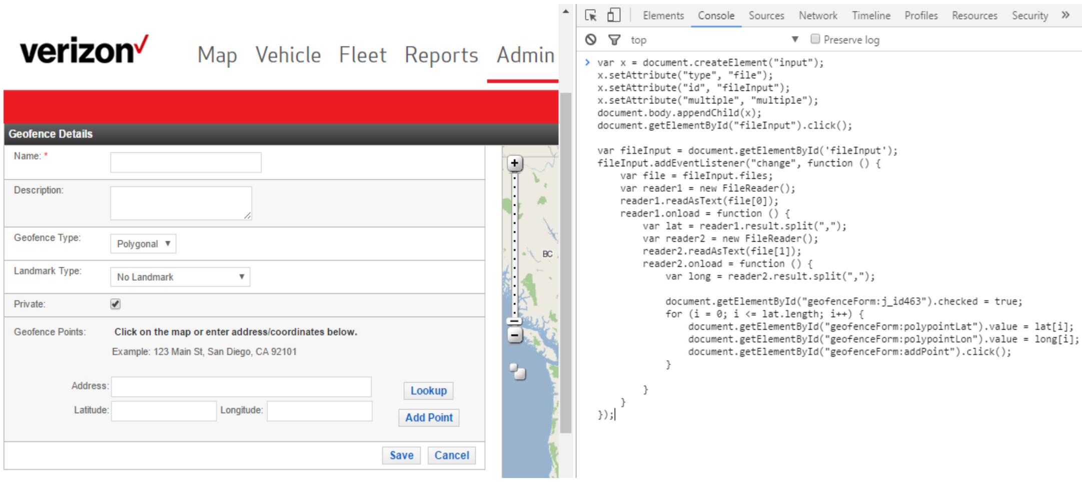


4) Copy the MATLAB script provided in Appendix B and paste into MATLAB.

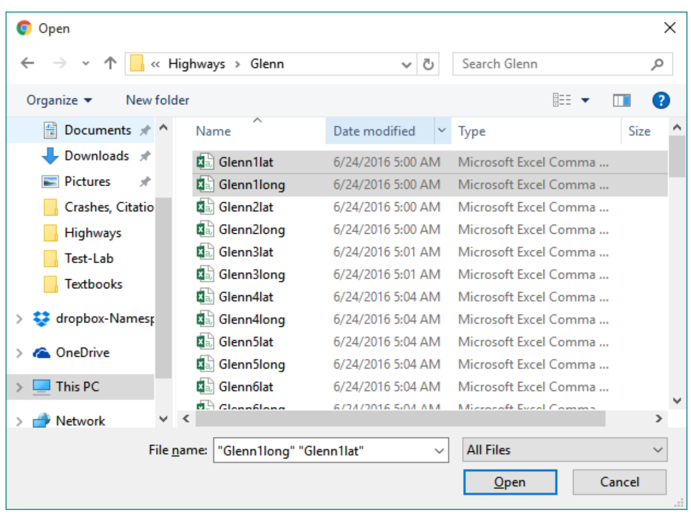


a) Save the script as Highway.m in the Highways folder.
b) Create five separate subfolders within the Highways folder, one for each major highway and change the MATLAB directory to the subfolder of the highway currently being scripted upon.
c) Run the script for each five-mile section in each of the respective highways, keeping in mind to change the directory to the subfolder for each new highway. Note that for this research, five-mile sections were selected for the geofenced areas to create an adequate sample size for each study highway. These sections can be reduced in length by modifying their respective geofence polylines defining their boundary.

5) In each of five separate highway subfolders within the Highways folder, there should be a list of CSV files (two for each Geofence).

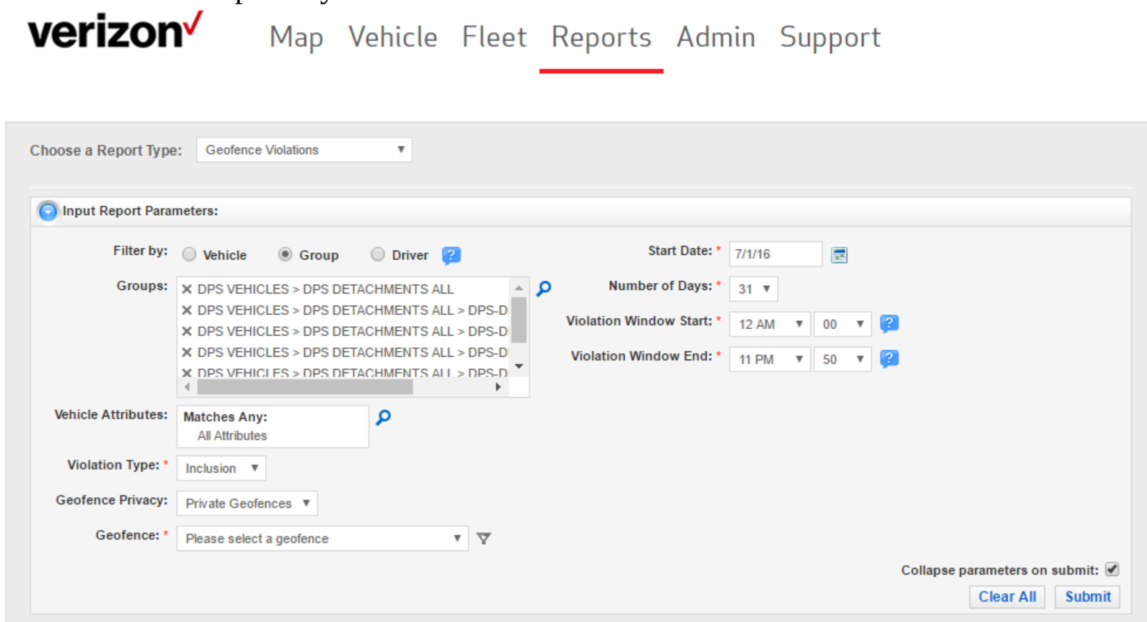


a) Open Google Chrome and navigate to Network Fleet. Sign in to Network Fleet and choose the "Manage Geofences" option in the "Admin" tab.
b) Click on the "Create Geofence" button in the upper right hand corner.
c) Once the page is loaded, click on the dropdown menu denoting "Geofence Type" and select the "Polygonal" option.
d) Press the "F12" button on the keyboard and click on the "Console" tab to gain access to the JavaScript console. Right click inside the JavaScript console and select the "Clear console" option.
e) Copy the JavaScript code provided in Appendix C and paste into the JavaScript console and press enter.
f) A file input dialog box will appear, prompting for two file inputs. Navigate to a specific highway subfolder within the Highways folder, hold down the "Ctrl" key and select the "Lat" and "Long" CSV files pertaining to a "Geofence". Press enter once the two files are selected.



g) The coordinate data for the Geofence will be automatically entered, however the name of the Geofence must be entered manually. Once complete, inspect the resulting files for any errors in naming convention.
h) Steps b) through g) must be repeated for each “Geofence” in each highway subfolder.

6) Once all “Geofences” are complete, the Geofence reports can be generated. The date and time a trooper vehicle entered the “Geofence” area and the duration of stay within the “Geofence” are the primary factors of interest.



a) Within the Network Fleet Utility, choose the “Reports” tab and select the “Run Report” option. Select the drop-down menu labeled “Choose a Report Type” and select the “Geofence Violations” option.
b) Select the “Group” button in the “Filter by:” field. Then select the blue magnifying glass button in the “Groups:” field and select the “DPS Detachments All” checkbox within the “DPS Vehicles” group.
c) In the “Violations Type:” field, select “Inclusion” from the drop-down menu, and select the “Private Geofences” option from the “Geofence Privacy:” field.
d) In the “Geofence:” field, select every Geofence from which data is to be extracted.
e) Select the Start Date, set the “Number of Days:” to 31, and set the “Violation Window” between 12:00 AM and 11:50 PM.

Press Submit, click the “Excel” checkbox and then press the Send button to send the activity via email.

Potential Implementation Benefit/Cost Analysis Into SQL Server

A benefit/cost analysis is possible using manual methods of calculation. However, the researchers implemented the statistical and benefit/cost analyses in SQL Server. This approach offered the advantages of reducing dependence on third party software outside of SQL Server, and allowed the analysts direct access to the databases, eliminating the need for data exportation. However, the basic SQL commands provided by SQL Server do not include the necessary statistical analysis functions. As a result, the research team searched for third party script packages for installation into SQL Server to provide these statistical functions. The software package XleratorDB Statistics offered the most appropriate solution.

XleratorDB is a set of pre-assembled SQL scripts providing native statistical functions in SQL Server. If a user intends to use this set of scripts for a particular database, installation of XleratorDB for that database is required. Note that it is not possible to install XleratorDB as a native feature in SQL Server to allow its statistical functions to be used for any database by default. Instead, the user must manually install XleratorDB for every database for which they intend to run the scripts.

The process of running a binomial logistic regression analysis in SQL Server, including the logical process of conducting the benefit/cost ratio procedure, appears in Appendix D.

Appendix E – Benefit/Cost Analysis Example

For example, assume that during the month of July in 2016 that the total time presence of patrol vehicles along the Sterling Highway was 900 hours. During this time, 13 crash instances occurred, which consisted of the following:

- 1 fatality
- 2 minor injuries
- 2 possible injuries
- 4 property damage occurrences
- 3 instances where property damage or injury did not occur

Of the total crash instances in the month of July:

- 7.7% of total instances involved fatalities
- 15.4% of total instances involved minor injuries
- 15.4% of total instances involved possible injuries
- 30.8% of total instances involved property damage
- 23.1% of total instances did not involve property damage or any injury

The first step for calculating the benefit value was to determine if there is a statistical correlation between crash instances and patrol presence during the month of July along the Sterling Highway. A mock binomial logistic regression analysis was conducted, and the resulting significance factor for patrol presence was found to be 0.045, indicating that statistical significance exists. A model was produced based on equation 3.

$$\ln\frac{p}{1-p} = -1.059 - 0.004x \qquad \text{equation 3}$$

This equation indicates that for every hour of patrol vehicle presence, the logistical odds of a crash occurring decreases by 0.004. However, it is necessary to approximate how much the 900 hours of patrol vehicle presence affected the probability of crash events occurring within the month of July. This probability reduction must be expressed as a percentage and not in logistical terms. Therefore, the probability of a crash event occurring assuming no patrol vehicles were present during that time period must be calculated as follows:

$$\ln\frac{p}{1-p} = -1.059 - 0.004(0\,patrol\ vehicle\ hours) = -1.059$$

The predicted probability of a crash event occurring would be:

$$\frac{e^{-1.059}}{1+e^{-1.059}} = 25.75\%$$

The above value was then compared to the probability of a crash event occurring during 900 hours of patrol vehicle presence:

$$\ln\frac{p}{1-p} = -1.059 - 0.004(900\,patrol\ vehicle\ hours) = -4.659$$

The predicted probability of a crash event occurring would be:

$$\frac{e^{-4.659}}{1+e^{-4.659}} = 0.939\%$$

From the results, it could be assumed that the 900 hours of patrol vehicle presence reduced the probability of a crash event occurring by 25.75% - 0.939% = 24.8%. This reduction in probability was then associated with the number of crashes which occurred during the month of

July along the Sterling Highway. Specifically, because 13 crashes occurred with 900 hours of patrol vehicle present, it was then estimated how many more crashes would have occurred if no patrol vehicles were present during that particular time period. This is approximated as follows:

$$\frac{13\ crashes\ with\ 900\ patrol\ hours}{100\% - 24.8\%} = \ 17.3\ crashes\ without\ 900\ patrol\ hours$$

From the above calculation, it is estimated that at least 4 more crashes would have occurred if 900 hours of patrol vehicle presence did not exist along the Sterling Highway during the month of July. This difference of 4 crash instances was then used to calculate the benefit.

To determine the direct costs associated with each crash type, the FHWA, KABCO costs must be consulted. Table 8 includes FHWA, KABCO costs inflated to 2016.

Injury Severity Level	**Comprehensive Crash Cost (2016)**
Fatality (K)	$9,500,000
Disabling Injury (A)	$660,000
Evident Injury (B)	$130,000
Possible Injury (C)	$70,000
Property Damage Only (O)	$7,300

Table 8: KABCO Costs, 2016

Note that the KABCO costs are based on the United States Department of Transportation Value of Statistical Life (VSL) Index, which is defined as the additional cost individuals would be willing to bear for improvements in safety which reduce the expected number of fatalities by one. Therefore, the above costs do not consider the indirect costs associated with crashes such as traffic congestion and loss of economic productivity.

To account for these indirect costs of crashes, a report produced by the U.S. DOT National Highway Traffic Safety Administration entitled *The Economic and Societal Impact of Motor Vehicle Crashes, 2010 (Revised)* was consulted. In part of the report, costs associated with traffic congestion caused by crash events were calculated for different crash types and various highway facilities. The report indicates that the most significant indirect cost associated with crashes is the value of time lost. In particular, the value of time is defined as a significant time penalty for those affected, which can be valued based on wage rates and the value people place on their free time. For this research, the value of time will serve as the indirect cost associated with crash events. Because the value of time costs provided in the report are 2010 values, these costs were inflated to 2016 based on an inflation rate of 3.0%, which is the same rate used for the inflating the KABCO costs. The calculated values are included in Table 9.

	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

Table 9: Indirect Costs of Crashes

Because the Sterling Highway is a rural principal arterial, the indirect costs associated with the estimated crash reduction can now be included in the benefit calculation:

Benefit (900 patrol hours, direct and indirect costs) =

((4 crash reduction) * (0.077 fatality %) * (9500000 KABCO cost + 7799.55 indirect cost)**)** +
((4 crash reduction) * (0.154 minor injury %) * (130000 KABCO cost + 1443.61 indirect cost)**)** +
((4 crash reduction) * (0.154 possible injury %) * (70000 KABCO cost + 1443.61 indirect cost)**)** +
((4 crash reduction) * (0.308 property damage %) * (7300 KABCO cost + 1466.30 indirect cost)**)** +
= $3,064,180.87

Once the value of benefit was determined, the cost associated with the duration of patrol vehicle presence along the study corridor was calculated. Continuing the above example, the cost is based on the 900 hours of patrol presence within the month of July. To calculate the total cost, an hourly rate was assigned for each patrol vehicle hour. Based on correspondence with the Alaska DOT&PF and the Alaska State Troopers, it was determined that the hourly rate for patrol vehicle presence, including the trooper's wage, gas mileage, and vehicle maintenance, comes to $150 per hour. Therefore, the total cost for the month was calculated as follows:

Cost (July) = (900 patrol hours) * ($150 / hour) = $135,000

With the total benefit and cost values determined, the benefit/cost ratio was calculated using equation 4 from FHWA's KABCO webpage.

Benefit / Cost Ratio = PVB / PVC　　　　equation 4

where: PVB = Present value of benefits
PVC = Present value of costs

For the July example:

PVB = $3,064,180.87

PVC = $135,000

Therefore:

Benefit / Cost Ratio = ($3,064,180.87) / ($135,000) = 22.7

According to FHWA's website, a project is economically justifiable if the ratio is greater than 1.0. For the July example, because the ratio was calculated to be 22.7, the 900-hour patrol vehicle investment along the Sterling Hwy in the month of July is economically justified. From here, transportation agencies can adjust the number of hours to optimize the presence of trooper vehicles along a particular highway.

As an additional note from FHWA's website, the benefit/cost ratio is not applicable for comparing various countermeasures or multiple projects at various sites, which would require an incremental benefit/cost analysis.