SAFETY IMPACT OF WIDER PAVEMENT EDGE LINE MARKINGS

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

The primary purpose of pavement markings is to provide a visual cue to drivers to assist them with vehicle position along a roadway and to help them make a proper lane change decision. In the United States, the default pavement marking width is typically 4 inches and the color is white or yellow. The objective of this study was to determine the effectiveness of wider pavement markings with respect to enhancing traffic safety. The study collected and analyzed crash data at 38 locations in the State of Idaho. Before and after studies using comparison group and Empirical Bayes methods were applied to determine that if there was a relationship between the implementation of wider pavement markings and incidence of vehicle crashes. Safety performance functions (SPF) for run-off-the-road crashes (ROR) in Idaho for two-lane rural highways were also developed. This study concluded that wider pavement edge line markings have a positive effect on reducing the number of ROR crashes, especially fatal and serious injury crashes. For this reason, the implementation of wider pavement marking by agencies along two-lane rural highways is encouraged in order to provide a a long-term safety benefit for the motoring public. This study will recommend strategies for state DOTs to increase safety and suggest a need to revise the MUTCD definitions on marking widths. The research results showed that wide pavement marking implementation has the potential to reduce fatal and serious ROR crashes by 10.07 percent with an expected cost to benefit ratio of approximately 1:25.

Keywords: wider pavement markings, run-off-the-road crashes, Empirical Bayes and comparison group

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Pavement markings are generally used to express information to roadway users. They are part of a communication system for drivers, pedestrians and bicyclists. Figure 1.1 and 1.2 illustrate the same location (ID-55), one with a good pavement marking condition and one with a poor pavement markings condition, respectively.

Figure 1.1. Road with a poor pavement marking condition

The uniformity and continuity of the longitudinal pavement marking provide continuous information to the drivers with respect to roadway alignment, vehicle lateral positioning, and the performance of other significant driving-related tasks. The existence, quality, and pattern of this safety countermeasure are playing major roles in discerning the right road path for road users, especially at nighttime and under challenging environmental conditions.

Figure 1.2. Road with a good pavement marking condition.

Visibility and durability are significant limitations for pavement markings. Visibility of markings is affected by water, snow and dust that may obscure or otherwise cover pavement markings. Also, high road capacities and harsh weather may limit the durability of pavement markings.

Run-off-road (ROR) crashes happen once a vehicle leaves the road and hits a tree, a pole, and other natural or artificial object. Typically, most of these types of crashes involve a single vehicle. Most the ROR crashes results in serious injuries and fatalities; they are among the most serious all traffic crashes. This study focuses specifically on ROR crashes and hypothesizes that a significant reduction in ROR crashes warrants the use of wider edge lines (1). The results of a before-and-after study to examine the safety impact of wider pavement markings are presented in this thesis. Two different methods were employed to assess this impact: (a) a before-and-after comparison group analysis and (b) an Empirical Bayes before-and-after analysis. Also, this study contains a crash modification factor, which is another way of representing the expected effect of a countermeasure in terms of the percentage decrease in crashes using both before-and-after comparison group analysis and Empirical Bayes before-and-after analysis to have a new CMFs for widening pavement markings from 4 inches to 6 inches for four different types of crash circumstances.

Thirty-eight two-lane rural highway locations were selected in Idaho. At those locations had pavement marking widths of 4 inches before 2015 and 6 inches in 2016. All of the crashes that occurred in these locations were documented using the ITD web crash analysis reporting system. In order for an incident to be recorded as a `crash`, the damage to any property has to be greater than $1,500. To understand the correlation between using wider pavement markings and safety, run-off-road crashes were only selected from the crash data collected from the ITD web crash analysis, and only for rural-two lane highway segments.

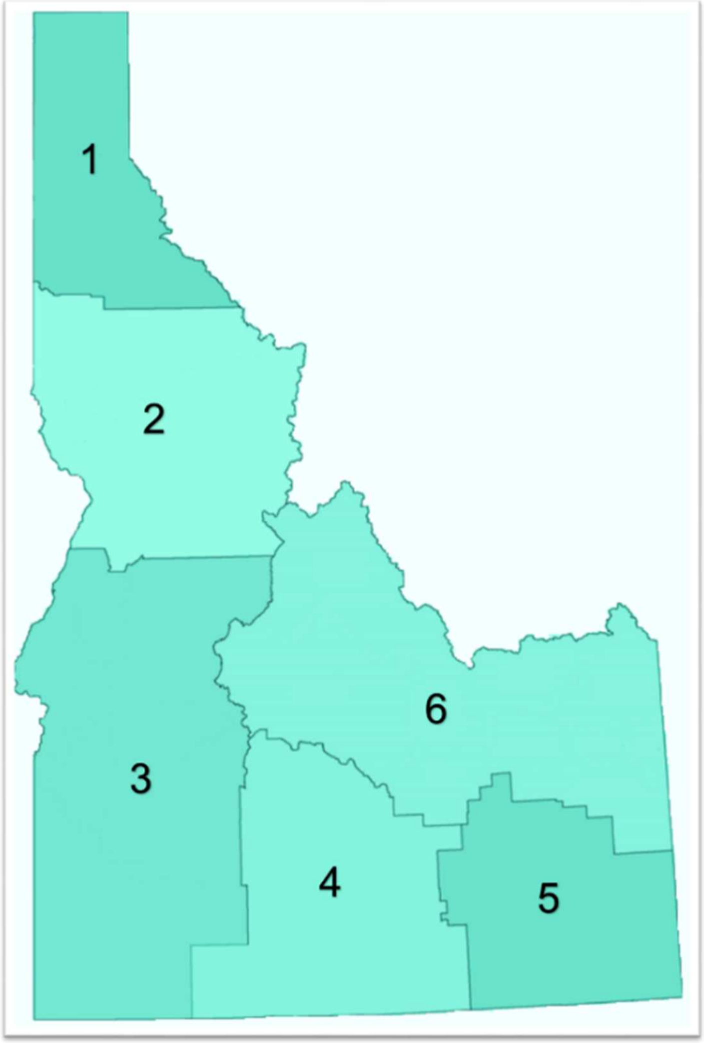

Figure 1.3. State of Idaho Highway District Map

1.2 Thesis Organization

The first part of Chapter 1 is an introduction to the thesis topic and articulates the goals of the research. The second chapter is a literature review which discusses basic principles, history, and recent research on wider pavement edge line markings. Chapter 3 is the methodology section, which describes the data and the methods used to conduct the statistical analyses. Chapter 4 includes analysis, results and the cost benefit ratio for implementing wider pavement markings. Chapter 5 discusses the results of the research and offers recommendations for future work.

CHAPTER 2 LITERATURE REVIEW

The width of the edge line pavement marking on a roadway can be an effective way to improve visibility, especially at night and under low visibility conditions. According to the Manual of Uniform Traffic Control Devices (MUTCD) (2), the minimum width of pavement markings is 4 inches; however, some agencies are implementing wider pavement markings to provide better visibility, particularly at locations that have high lane departure crashes, such as on sharp horizontal curves or at complex intersections. Based on survey data collected from different state agencies (3), the main reason for implementing wider longitudinal pavement markings is improved visibility as (identified by 57 % of respondents). The second reason is as an older driver countermeasure (19 %); the third reason is crash reduction (14 %).

2.1 Pavement Markings

One of studies to determine edge line markings impact was conducted in 2005 by Alexei. The study was about crash frequency analysis for rural two-lane highways with or without edge line markings. The research found that installing edge line markings on rural two-lane highways reduced the crash frequency by 26 percent. Also, the highest reduction in crash frequency was for curved segments. Furthermore, edge line markings have a role to reduce the speed related crashes during night (4).

Other study made by Xiaoduan in 2005, was investigating the impact of installation edge line markings on rural narrow two-lane highways in Louisiana. Before and after study was used to complete the study. The most highlighted result was that by using edge line markings, the risk of ROR crashes reduced specially at night time. However, the study showed no relation between using edge line markings and the average operation speed (5).

Later in 2012, the same researcher Xiaoduan introduced another study about safety improvement from edge line markings on rural two-lane highways. Three years of data before installation edge line markings and one year after was used in the study. The outcome of this research was that there is 17 percent reduction in crashes due to install edge line markings on rural two-lane highways in Louisiana (6).

2.2 Wider Pavement Markings

One of the earliest studies that related to wider pavement edge line markings was prepared by Cottrell in 1986. This study tested the effect of wide edge lines on lateral placement and speed on rural two-lanes. Before and after study was used to examine the difference between standard edge line width (4-inches) and after period edge line width (8-inches). The results showed there is no statistically significant difference between 4-inches and 8-inches edge line width (1). Also, there are two other studies was conducted early in 1987 and 1989 by Hall and Hughes respectively, and both of them reported that no significant difference in crash reduction as a result of increasing the edge line markings width (7), (8).

The safety effect of wider pavement edge line markings was examined by Park in 2012 for two-lane rural highway. The study based on crash frequency data analysis for segments with and without wider edge line pavement markings. The data was collected for three states, Illinois, Michigan and Kansas. The method that use in analysis was an empirical Bayes before and after method. The results showed that there is a significant positive safety effects of using wider pavement edge line markings in two-lane rural highway (9).

Two other studies examined the relationship between run of road crashes and highway road characteristics. One was based on five years of ROR crashes in Illinois (10). The main objective of the research was to quantify the roadside safety of rural two-lane roadways on a seven-point pictorial scale; clear zone width and side slope were used to determine roadside hazard ratings. The results confirmed the relationship between ROR collisions and roadside features. The second study examined the benefits of safety edge to decrease the run of road crashes in Iowa (11). The researchers obtained data for crashes occurring along each selected road segment from 2004 through 2014. The crashes were reduced by 8-16% due to the treatment, depending on the type of the crash.

Two surveys have been conducted in the USA to document the state-of-practices for wider pavement markings. The first one was in 2002 and found that wider longitudinal pavement markings are very common in the Eastern United States. Twenty-two of 26 states located east of the Mississippi River use wider pavement markings to some degree; however, only seven of 24 states located west of the Mississippi River use them (12). A follow-up study in 2009 found an increase of five states using wider markings. Benefit-cost studies suggest that wider edge-lines reduce crash frequency and result in Return On Investment (ROI) ranging from $33.00 for every $1.00 invested to $55.00 for every $1 invested (13).

Table 2.1 studies that used before and after crash analysis to investigate the safety effect of wider pavement markings. The Table presents summary of their findings as well as the studies limitations (14),(15).

2.3 Empirical Bayes Method

The Empirical Bay (EB) method is an alternative test of efficacy conducted to predict the future performance of a treated intersection or road segment by weighting its past performance with an estimate based on data obtained from similar sites.

The EB method (16) assists researchers to expect the collision rates without any treatment on the basis of the collision counts from before the improvement was made and counts from a control set of untreated locations that are carefully coordinated with the study sites. The EB method depends on the fitting of the number of collisions with a negative binomial distribution. Powers and Carson (17) compared the accuracy in estimating the effects of the safety improvements for before-and-after studies using the EB method with the accuracy obtained with traditional least-squares regression models.

They found that the EB method deals with the regression-to-mean bias, which creates artificially high expectations of the benefit of a given improvement. The reason for this is that study sites are often chosen on the basis of their unusually high number of collisions. Because of the random nature of collisions, these numbers will decrease naturally over time, regardless of whether the study sites are treated or not. Powers and Carson's findings are in agreement with those of Hauer (18) who recommended that the EB method should be the favored approach to analyze safety improvement before and after a treatment.

Table 2.1. Summary of the Methodologies, Results, and Limitations of Previous Studies

Year	Author	Methodology	Location	Results	Limitations
1986	Cottrell Jr, Benjamin H	Naïve before–after crash	Virginia	There were no statistically significant differences between the 4- and 8-in. wide edge lines from the analysis of variance of lateral placement, lateral placement variance, encroachments by automobiles and trucks, mean speed, and speed variance (14).	Hampered by insufficient data and lack of experimental control.
1987	Hall, J. W.	Naïve before–after crash	New Mexico	Compared 8 in to 4 in markings and concluded that wide edge-lines do not have a significant effect on the incidence of ROR accidents. Wider lines have no safety benefit in terms of reducing crashes (7).	Hampered by insufficient data and lack of experimental control.
1989	Hughes, W E McGee, H W Hussain, S Keegel, J	Before-versus - after experimental design with a control group	Alabama Maine Massachusetts New Mexico Ohio South Dakota Texas	Rural roads with 5,000 and 10,000 vehicles per day no reduction in crash frequencies have been noticed but rural roads 24-foot-wide rural roadways with less than six-foot shoulders and ADT between 2,000 and 5,000 experienced a relative decrease in total crash rate, total crash frequency and injury/fatal crash rate (8).	
2009	Paul J. Carlson, Eun Sug Park, Carl K. Andersen	Empirical Bayes before–after evaluations negative binomial regression model	Illinois, Michigan Kansas	No safety improvement has been detected when 4 in markings replaced with 8 in markings on two-lane rural roadways with between 5,000 and 10,000 vpd (15).	The study is still ongoing during that time, not final results yet.
2012	Eun Sug Park Paul J. Carlsona Richard J. Porterb Carl K. Andersenc	1- Empirical Bayes, before-after analysis for Kansas data 2- Generalized linear segmented regression analysis for Michigan data 3- Cross-sectional analysis for Illinois data	Illinois, Michigan Kansas	The safety impact of using wider edge lines was statistically significant and reduction in single-vehicle crashes on rural, two-lane highways has been detected when using wider edge lines (9).	This study did not include nighttime traffic volumes in nighttime crash models.

Fitzpatrick and Park (19) were used the EB method to test the effectiveness of high-intensity activated crosswalk (HAWK) pedestrian crossing beacons to reduce the different types of crashes at a set of intersections in Tucson, Arizona. They assumed that the number of crashes fit a negative binomial distribution and successfully used the EB method to demonstrate that the HAWK beacons were effective at reducing pedestrian crashes and crashes in aggregate.

2.4 Crash Modification Factor

For developing and estimating the crash modification factors (CMFs) values, the previous studies that had been conducted on estimating CMFs based on the varieties of roadway characteristics or their conditions. One study provided a framework to assess CMFs for the same or similar treatment by using means of meta-regression statically analysis based on several studies (20). In this study, Elvik projected CMFs for applying the bypass and installing roundabout instead of signalized intersections based on population changes. CMFs value for both treatments was increase significantly with population. No doubt, to develop a good CMFs needs to a large amount of data (21).

In another study, Park et al. (22) conducted five different linear and non-linear regression analyses to develop CMFs by using two single treatments. The approach involved installation of shoulder rumble strips, widening the shoulder width, and a combination between installing shoulder rumble strips and widening shoulder width based on original shoulder width of treated sites. The results indicated that a significant reduction in crash rates was observed on roadway segments with shoulder widths of 9 feet or greater. Moreover, the results of all crashes showed that the shoulder rumble strips were associated with a reduction in crash rates on roadway segments with shoulder widths less than 7 feet. While widening shoulder width is more effective for roadway segments with shoulder width of 7 ft. or above. The coupled CMFs and roadway characteristics were achieved by implementing the CMFs.

Elvik developed CMFs for speed enforcement by applying six linear and non-linear statistical analyses. The influence of speed implementation on the injury crashes is illustrated by CMF as a function of the change in the level of speed implementation. The results showed that the accident rate decreased as level of enforcement increased. The non-linear logarithmic function best fitted data points from 13 previous studies but the inverse function also fitted the data well (23).

In another research, he measured the relationship between safety effects and radius of horizontal curves created on the studies from 10 countries. The study evaluated the summary crash modification function to estimate the international transferability of national crash modification functions which have been valued for the relationship between the accident rate and the radius of curve. It was obviously that the projected CMF seems to be a descriptive conclusion of these national functions. The results displayed the increase of accident rate with the decrease of radius of curve, moreover the relationship between accident rate and radius of curve looks to be the same in all countries (24).

2.5 Alternative Treatments for ROR Crashes

In 2003, the Montana Department of Transportation released a report on evaluation of the effectiveness of shoulder rumble strips in reducing off-road and roll-over crashes on Montana's highways (25). Before and after comparison analyses were conducted on three years crash data. Results illustrated a 23.5% decrease in the severity rate of off-road crashes and a 14.0% reduction in total ROR crashes due to the presence of shoulder rumble strips. The benefit cost ratio was calculated by dividing annual benefits by annual costs and was 19.5.

In 2007, Rushi et al. (26) performed an Empirical Bayes before-and-after study of 1995-2004 crash data from two-lane rural highways in Minnesota. The treatment sites for the study included 24 sites with total of 183 miles. The authors found that installing shoulder rumble strips on two-lane rural roads reduced ROR crashes. A 13% reduction in total ROR crashes and an 18% reduction in injury ROR total crashes except probably damage only crashes were realized.

CHAPTER 3 METHODOLOGY

To investigate the safety impact of wider pavement edge line markings on rural two-lane highways, we collected crash data from Idaho Transportation Department (ITD) web-site. The study of the Idaho crashes data included two separate analytical methods, the first one was before and after comparison groups study using control sites to get a realistic expected value of crash frequency and crash rate and compare those values to observed crashes after changing edge line markings width from 4 inches to 6 inches. The second method was Empirical Bayes before and after study including developing of safety performance functions to predict number of ROR crashes in rural two-lane high way in Idaho to end up with accurate expected crash frequency which compared with observed crashes after applying the wider pavement markings treatment.

3.1 Crash and Exposure Measures Data

An Idaho vehicle collision report (VCR) must be completed by local law enforcement officials for every crash in Idaho that involves a motor vehicle, occurs on public property, and results in more than $1,500 in property damage for any one person involved or that results in an injury to any person involved. All VCR forms must be sent to ITD’s Office of Highway Safety (OHS), which maintains the state’s crash database. Crash data, used in this analysis, were obtained from ITD’s OHS crash database through a web-based crash analysis interface (WebCARS) (27). This online database, developed and maintained by ITD’s OHS, provided the crash data for each selected segment analyzed in this study. In addition to crash data, the geometric characteristics of two-lane rural state highways in Idaho were obtained from ITD’s OHS. The data included lane width, shoulder width, and shoulder type. Vehicle exposure data, in the form of Annual-Average-Daily-Traffic (AADT), were obtained from ITD’s Automatic Traffic Recorders (ATRs) (28).

Lane departure crashes, such as ROR and opposite-direction crashes, have been identified as the types of crashes that are most impacted by low quality road delineation. The most harmful events that contribute to roadway departure crashes vary, but most are related to visual deficiencies, loss of control, and/or misjudgment of reactions. In this study, only crashes that may have occurred as a result of poor edge line pavement markings were included in the analysis. The criteria for selecting these crashes included: crashes that occurred on rural two-way two-lane highways (excluding intersection crashes and crashes that occurred within city limits); daytime and nighttime crashes; dry and wet pavement surfaces' asleep, drowsy, and fatigued crashes; drunk or impaired driving crashes; and careless and distracted driving crashes. Crashes that occurred on icy or snowy surfaces and crashes related to animal collisions were excluded. After the removal of non-targeted crashes, the balance of crashes were primarily hit fixed object, hit other object, and overturn crashes.

Thirty-eight two-lane rural highways in Idaho were selected as test sites for this study. Eighty five percent of the test sites included in the study were randomly selected two-lane rural highway sections. The remaining 15% were test sections that experienced high incidences of lane departure crashes. The test sites, containing 175.39 miles, were marked with wide (6-inch) white edge line pavement markings. The control sites, totaling 168 miles, had regular (4-inch) white edge line pavement markings as shown in Figure 3.1. Full details of the test and control sections included in this study are presented in Table 3.1. The road segment crash rate was calculated using Equation 3.1.

$$\mathrm{R} = \frac{100 \text{ million} * \mathrm{C}}{365 * \mathrm{N} * \mathrm{V} * \mathrm{L}} \tag{3.1}$$

Where:

R = Crash rate for road segment expressed as crashes per 100 million vehicle-miles of travel (VMT)

C = Total number of crashes in the study period

N = Number of years of data

V = Number of vehicles per day (both directions)

L = Length of the roadway segment in miles

Figure 3.1. Edge line white painted pavement marking

Few types of crashes have been identified to be related to low quality road delineation. . The run-off-road (ROR) and opposite-direction crashes are the most targeted types of crashes in previous studies. The most harmful events that can contribute to the roadway departure vary, but most of them related are to visual deficiencies, loss of control, and misjudgment of reactions. For instance, ROR crashes occur when drivers attempt to avoid colliding with another vehicle, avoid an animal crossing, or lose control due to misjudging a curve. Elderly and impaired drivers are more susceptible to ROR crashes. The criteria that have used in selecting delineation-related crashes, especially edge-line pavement markings, are arranged as follows:

- Rural two-way highways only (non-intersection and non-interchange segments).
- All daytime and nighttime crashes have been included in the study. There is no need to analyze dark conditions only (dawn, dusk, and darkness).
- Dry and wet pavement surface condition were included in the study. Other conditions such as icy surfaces have been eliminated.
- The "Most Harmful Event" category represents the event that caused the crash in WebCARS database. The targeted crashes in this data are identified as all crashes

which might have a relationship to pavement markings' duty towards the driver such as right run-off-the-road crashes or other miscellaneous one vehicle crashes. After the removal of non-targeted crashes from WebCARS data, the remaining crashes were:

- Bridge Rail
- Concrete Traffic Barrier
- Culvert
- Delineator Post
- Ditch
- Embankment
- Fence
- Guardrail End
- Guardrail Face
- Immersion
- Mailbox
- Other Non-Collision
- Other Object Not Fixed
- Overturn
- Parked Car
- Pedalcycle
- Pedestrian
- Traffic Sign Support
- Tree
- Utility Pole
- Utility/Light Support
- Other Fixed Object

Table 3.1. Details of the Test and Control Site Characteristics

Route	AADT (2016) (Vehicle/day)	Right Shoulder Width (feet)	Segment Length of Control Sites (miles)	Segment Length of Test Sites (miles)
SH001	710	2	5.5	5.6
SH200	1900	2	7	7.3
SH041	4500	2	3	3.4
SH097	660	1	7	7.2
US095	1100	4	2	1.3
SH003	2100	2	3	2.8
SH003	1200	1	3	2.8
SH006	830	3	3	3.1
SH009	1100	4	6	6.3
SH099	570	1	3	2.8
US012	500	3	8	7.8
US095	3200	5	6	5.8
US020	2700	2	6	7.8
SH051	680	3	6	9
US095	1500	4	2	2.1
US095	2030	4	5	5.3
SH021	1800	2	6	6
US030	2000	4	3	1.2
SH075	2800	5	5	4.9
SH025	2800	5	5	4.9
SH024	2000	5	1	0.6
SH081	1500	1	3	2.6
SH021	570	3	5	5.5
SH046	490	4	2	1.8
SH046	440	4	4	4.5
I15 B	22000	4	2	2.2
US026	1200	5	6	7.5
SH034	1100	3	5	5.5
SH034	300	5	5	5.4
SH036	1000	2	5	4.8
SH036	860	4	4	4.2
SH031	2000	2	3	1
US093	3400	3	5	5.3
US093	920	1	6	5.7
US093	1400	1	5	7.5
SH043	3800	4	3	3.1
SH033	920	2	6	8.5

3.2 Before and After Comparison Group Analysis

Before and after comparison group analysis incorporates comparison group or control sites in the safety evaluation to estimate the crash frequencies that would have occurred on the test sites if no safety treatment had been implemented. This process is to make sure that any change in number of crashes is related to the treatment not to other circumstances by using sample odd ratio, a measure of the correlation between crash occurrence in the test and control sites. The expected crash count for the test sites that would have occurred in the after period without treatment ($N_{observed,T,A}$) is estimated from Equation 3.2.

$$N_{Expected,T,A} = N_{Observed,T,B} * \frac{N_{Observed,C,A}}{N_{Observed,C,B}} \tag{3.2}$$

Where:

$N_{Expected,T,A}$ = expected number of crashes without wider edge line markings treatment.

$N_{Observed,T,A}$ = observed number of crashes in the after period for the treatment group.

$N_{Observed,T,B}$ = observed number of crashes in the before period for the treatment group.

$N_{Observed,C,A}$ = observed number of crashes in the after period in the comparison group.

$N_{Observed,C,B}$ = observed number of crashes in the before period in the comparison group.

The variance in the estimates of the expected number of crashes at the test sites after applying the treatment can be calculated from Equation 3.3.

$$\text{Variance } (N_{Expected,T,A}) = N_{Observed,T,A}{}^{2} * \left(\frac{1}{N_{Observed,T,B}} + \frac{1}{N_{Observed,C,B}} + \frac{1}{N_{Observed,C,A}}\right) \tag{3.3}$$

3.3 Safety Performance Function (SPF)

Network screening is the process of identifying sites for further investigation and potential treatment. In network screening, Empirical Bayes (EB) is used to determine the expected crash frequency. An important component of the Empirical Bayes before-and-after analysis is the development of Safety Performance Functions (SPFs) for the test sections. SPFs are used to predict crash frequency for a given set of site conditions. The predicted crashes from the SPF can be used alone or in combination with the site-specific crash history (i.e., Empirical Bayes method) to compare the safety performance of a specific site under various conditions. The Empirical Bayes method is used to estimate the expected long-term crash experience, which is a weighted average of the observed crashes at the site of interest and the predicted crashes from SPFs.

SPF is a model that defines the relation between crash frequency and measure of exposure. In SPFs models, the predicted crash frequency is a function of both segment length and annual average daily traffic (AADT). Four conditions are represented in this paper which are all day total crashes, all day fatal and serious injuries crashes, night total crashes and night fatal and serious injuries crashes. Therefore, four SPF models were developed to deal with those deferent conditions. To develop the models, negative binomial regression was used. Such an approach models the expected number of crashes in each roadway segment as a function of one or more explanatory variables. Four equations used to predicted ROR crash in rural two-lane highway in Idaho are the outcome of developing SPF in this study. To apply the negative binomial regression models estimated in this study, the following functional form 3.4 should be used:

$$N_{spf} = \exp\left[\beta_0 + \beta_1 \times \ln(\text{Length}) + \beta_2 \times \ln(\text{AADT})\right] \tag{3.4}$$

Where:

N_{spf} = expected number of crashes on roadway segment;

β_0 = regression coefficient for constant;

β_1 = regression coefficient for segment length;

Length = roadway segment length (miles);

β_2 = regression coefficient for AADT; and,

AADT = average annual daily traffic (vehicle/day).

3.4 Empirical Bayes Before-After Studies

After develop safety performance functions, an (EB) adjustment can be applied to the crash predictions. The EB method uses a weighted average between observed crash history for a site and the predicted frequency from the SPF to obtain a better estimate of predicted crash frequency, as described in the equation 3.5.

$$\mathrm{N_{EB}} = \mathrm{W} * \ \mathrm{N_{pr}} + (1 - \mathrm{W}) * \mathrm{N_{obs}} \tag{3.5}$$

Where:

$\mathrm{N_{EB}}$ = EB adjusted predicted crash frequency (crashes/year);
W = weight for EB adjustment;
$\mathrm{N_{pr}}$ = predicted crash frequency from the SPF (crashes/year); and,
$\mathrm{N_{obs}}$ = observed mean crash frequency from crash history (crashes/year).

The strength of the EB method is in the use of a weighting factor (W) that is based on sound logic and on real data; it is based on the crash frequency predicted by the SPF and the mostly overdispersion parameter. Overdispersion results from the variance exceeding the mean in the crash frequency distribution. The weighting factor is obtained from the SPF model using Equation 3.6.

$$\mathrm{W} = \frac{1}{1 + \frac{\sum \mathrm{N_{pr}}/\mathrm{L}}{\mathrm{K}}} \tag{3.6}$$

Where:

$\sum \mathrm{N_{pr}}$ = sum of predicted crash frequency for each year of crash history;
L = segment length (miles),
K = overdispersion parameter from the SPF model.

After estimating the expected crash values, the safety effectiveness (θ) is projected and the standard deviation of θ is calculated according to Equations 3.7 and 3.8.

$$\theta = \frac{\mathrm{A_{sum}}/\mathrm{B_{sum}}}{1 + [\mathrm{Var}(\mathrm{B_{sum}})/\mathrm{B_{sum}^2}]} \tag{3.7}$$

$$\mathrm{Stddev}(\theta) = \left[\frac{\theta^2\{[\mathrm{Var}(\mathrm{A_{sum}})/\mathrm{A_{sum}}^2]+[\mathrm{Var}(\mathrm{B_{sum}})/\mathrm{B_{sum}}^2]\}}{[1+\mathrm{Var}(\mathrm{B_{sum}})/\mathrm{B_{sum}^2}]^2}\right]^2 \tag{3.8}$$

Where:

$\mathrm{A_{sum}}$ = sum of observed crash frequency; and,
$\mathrm{B_{sum}}$ = sum of expected crash frequency.

Figure 3.2 illustrates how the Empirical Bayes method work. Using predicted crashes calculated by safety performance functions for ROR crashes without applying the treatment and observed ROR crash history data before the treatment for test sites to end up with more accurate expected number of crashes without using the treatment. Then compare this expected value with the observed number of crashes for test sites after receiving the treatment.

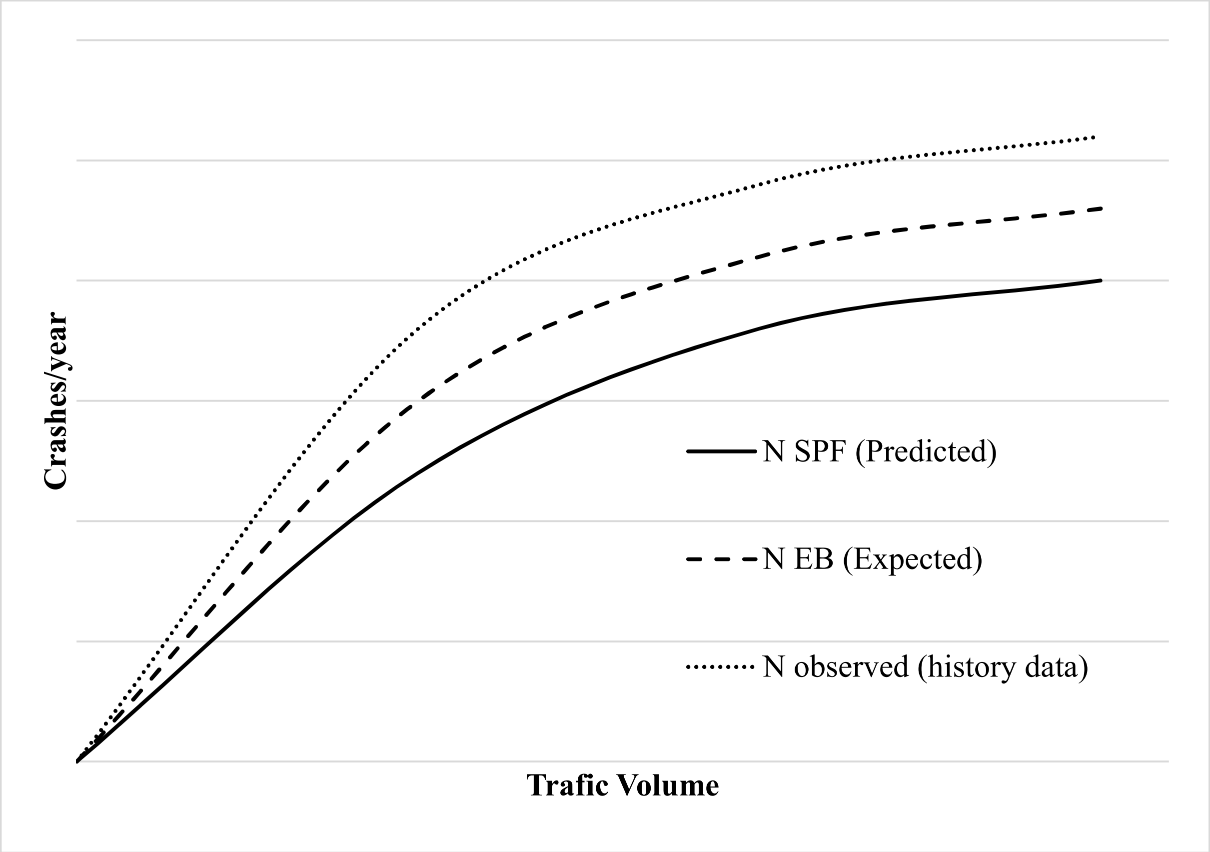

Figure 3.2. Illustration of Regression-to-the-Mean and Empirical Bayes Estimate.

3.5 Goodness of Fit Measures

Goodness-of-fit statistics are used to scale the level to which estimated models fit the study data. Table 3.2 shows the statistical measures for evaluating goodness-of-fit and statistical adequacy of the model. In this study, R-squared, a mean absolute deviance (MAD), mean prediction bias (MPB), and a mean square prediction error (MSPE) are used to determine how well the models fit the observed data.

Table 3.2. Validation Performance Measures

Validation measure	**Equation**	**Description**
MAD	$\mathrm{MAD} = \frac{\sum_{i=1}^{n} \lvert \hat{Y}_i - Y_i \rvert}{n}$	MAD is the sum of the absolute value of predicted validation observations minus observed validation observations, divided by the number of validation observations. It gives the average magnitude of variability of prediction. Smaller MAD values are favored to larger values (29).
MSPE	$\mathrm{MSPE} = \frac{\sum_{i=1}^{n} (\hat{Y}_i - Y_i)^2}{n}$	MSPE is the sum of squared differences between observed and predicted crash frequencies, divided by the sample size minus the number of model parameter. MSPE is typically used to assess error associated with a validation or external data sets. A lower value for MSPE indicates a better model (29).
MPB	$\mathrm{MPB} = \frac{\sum_{i=1}^{n} (\hat{Y}_i - Y_i)}{n}$	The MPB is the sum of predicted accident frequencies minus observed accident frequencies in the validation data set, divided by the number of validation data points. The MPB can be positive or negative. This statistic provides a measure of the magnitude and direction of the average model bias as compared to validation data. The smaller the average prediction bias, the better the model is at predicting observed data (29).
R-squared		R-squared is the proportion of variance in the dependent variable (number of ROR crashes) which can be explained by the independent variables (AADT and segment Length). Its value is always between 0 and 100%. In general, the higher the R-squared, the better the model fits your data; however, there are important conditions for this guideline (30).

3.6 Study Designs to Develop CMFs

The crash modification factor (CMF) is defined as the expected changes in crash frequency because of applying a specific treatment or countermeasure. The highway safety manual (HSM) part D volume 2 contains a variation of CMFs for different type of treatments (31). The comparison group before and after study and Empirical Bays before and after were used to develop crash modification factor for wider pavement edge line markings treatment with increase in markings width by 2 inches (4 inches to 6 inches). The following methodology of developing CMFs using before and after with comparison group study and Empirical Bayes before-after study was introduced in Federal Highway Administration (FHWA) report called "A Guide to Developing Quality Crash Modification Factors" (32).

3.6.1 Develop CMFs Using Before and After with Comparison Group Study

Using the same methodology of calculating the expected number of crashes using control sites as provided earlier in this chapter. The CMF for wider pavement markers was calculated by adding the observed crashes for both the treatment and comparison groups for the two-time periods before-after. The summary of notations and the data for comparison group method are shown in table 3.3. The CMF and its variance are estimated from Equation 3.9 and 3.10. It will give a value that indicate to how the number of ROR crashes will change after applying the wider pavement edge line for rural two-lane highway in Idaho.

$$\mathrm{CMF} = \frac{\left(\frac{N_{\mathrm{observed,T,A}}}{N_{\mathrm{expected,T,A}}}\right)}{1+\frac{\mathrm{Var}(N_{\mathrm{expected,T,A}})}{{N_{\mathrm{expected,T,A}}}^{2}}} \tag{3.9}$$

$$\mathrm{variance(CMF)} = \frac{\mathrm{CMF}^2\left(\frac{1}{N_{\mathrm{observed,T,A}}}\right)+\left(\frac{\mathrm{Var}(N_{\mathrm{expected,T,A}})}{{N_{\mathrm{expected,T,A}}}^{2}}\right)}{\left(1+\frac{\mathrm{Var}(N_{\mathrm{expected,T,A}})}{{N_{\mathrm{expected,T,A}}}^{2}}\right)^{2}} \tag{3.10}$$

Table 3.3. Summary of Notation and data for Comparison Group Method

Comparison Group		
Crash type	$N_{observed,C,B}$	$N_{observed,C,A}$
Total Crashes	42.0	43.0
Night Crashes	14.0	19.0
Fatal and severe injury crashes	4.2	4.0
Fatal and severe injury night crashes	3.0	1.0

Treatment Group		
Crash type	$N_{observed,T,B}$	$N_{observed,T,A}$
Total Crashes	45.8	48.0
Night Crashes	20.0	18.0
Fatal and severe injury crashes	11.6	8.0
Fatal and severe injury night crashes	6.4	4.0

Where :

$N_{observed,T,B}$= observed number of crashes in the before period for the treatment group.

$N_{observed,T,A}$= observed number of crashes in the after period for the treatment group.

$N_{observed,C,B}$= observed number of crashes in the before period in the comparison group.

$N_{observed,C,A}$= observed number of crashes in the after period in the comparison group.

3.6.2 Develop CMFs Using Empirical Bayes Before-After Study

The before–after empirical Bayes (EB) method, is established based on a study that was conducted by Hauer (16), the methodology of expecting the number of crashes without treatment and safety effectiveness provided earlier in this chapter. CMF is computed by using the EB method based on the predicted crashes which is calculated by using SPF for before - after period and the observation grope of treatment before-after. Using the notation and the data for the empirical Bayes method are shown in table 3.5. The variance of $\mathrm{N}_{\mathrm{expected,T,A}}$ is estimated approximately from Equation 3.11, CMF from equation 3.9 and the variance of CMF from equation 3.10 as provided before. The cumulative probability factors for confidence intervals are shown in Table 3.4 as provided in the previous section.

$$\mathrm{Var}\ (\mathrm{N}_{\mathrm{expected,T,A}}) = \mathrm{N}_{\mathrm{expected,A}} \times \frac{\mathrm{N}_{\mathrm{predicted,A}}}{\mathrm{N}_{\mathrm{predicted,B}}} \times (1 - \mathrm{w}) \tag{3.11}$$

Where:

$\mathrm{N}_{\mathrm{expect,T,A}}$ = expected crash frequency in the after period for the treatment group.

$\mathrm{N}_{\mathrm{predicted,A}}$ = predicted number of crashes (i.e., sum of the SPF estimates) in the after period.

$\mathrm{N}_{\mathrm{predicted,B}}$ = predicted number of crashes (i.e., sum of the SPF estimates) in the before period.

Table 3.4. Summary of Notation and data for empirical Group Method

After				
Crash type	$N_{observed,T,A}$	$N_{predicted,T,A}$	$N_{expect,T,A}$	$w_{,T,A}$
Total Crashes	48.0	39.2	42.6	0.57
Night Crashes	18.0	15.6	15.8	0.89
Fatal and severe injury crashes	8.0	9.0	8.9	0.97
Fatal and severe injury night crashes	4.0	4.5	4.4	0.97
Before				
Crash type	$N_{observed,T,B}$	$N_{predicted,T,B}$	$N_{expect,T,B}$	$w_{,T,B}$
Total Crashes	45.8	37.6	39.9	0.59
Night Crashes	20.0	14.6	15.8	0.87
Fatal and severe injury crashes	11.6	8.7	8.7	0.97
Fatal and severe injury night crashes	6.4	4.8	4.8	0.97

Where:

$N_{observed,T,B}$ = observed number of crashes in the before period for the treatment group.

$N_{observed,T,A}$ = observed number of crashes in the after period for the treatment group.

$N_{predicted,T,B}$ = predicted number of crashes (i.e., sum of the SPF estimates) in the before period.

$N_{predicted,T,A}$ = predicted number of crashes (i.e., sum of the SPF estimates) in the after period.

$N_{expect,T,A}$ = expected crash frequency in the after period for the treatment group.

$N_{expect,T,B}$ = expected crash frequency in the before period for the treatment group.

$w_{,T,A}$ = a weight factor of SPF in the after period for the treatment group.

$w_{,T,B}$ = a weight factor of SPF in the before period for the treatment group.

3.6.3 The Quality of Crash Modification Factors

Standard Error and confidence interval used to show how the developed CMF values is good or poor. Small standard error (SE) indicate to a good estimation of CMF values. Also, confident interval describe how CMF values are valid since the confident interval is a function of standard error as provided in Equation 3.12. The standard error is simply the square root of the variance of CMF. The width of the confidence interval increases gives indication for uncertainty in the estimate of the CMF. If the confidence interval does not include 1.0, it can be stated that the CMF is significant at the given confidence level. However, if the value of 1.0 falls within the confidence interval (i.e., the CMF could be greater than or less than 1.0), it can be stated that the CMF is insignificant at that confidence level. Insignificant CMFs are better to be noted because the treatment could possibly result in positive or negative change in crashes or no change at all. Equation 3.12 is used for calculating the confidence interval, the cumulative probability factors for common confidence intervals are shown in Table 3.4.

$$\text{Confidence Interval } = \text{CMF} \pm (\text{Cumulative Probability} * \text{Standard Error}) \tag{3.12}$$

Table 3.5. Cumulative probability factors for common confidence intervals.

Confidence Level	Cumulative Probability
80%	1.28
85%	1.44
90%	1.64
95%	1.96
98%	2.33
99%	2.58

CHAPTER 4 ANALYSIS AND RESULTS

4.1 Before and After Comparison Group Analysis

A before-and-after comparison group analysis was conducted to examine the potential safety effect of wider pavement marking. Paired t-tests were used to compare the average number of crashes and average crash rates during the before and after periods. The t-test analysis was conducted for four groups of crashes: total crashes, total night crashes, fatal and severe injury crashes, and fatal and severe injury night crashes. The before period covered the five-year period from 2010 to 2014 (before the implementation of the wide pavement markings treatment); the after period covered crashes that occurred during 2016.

Table 4.1 shows the results of the comparison group before-and-after t-test for average crash frequencies (crash/mile/year). A P-value of 0.05 or less indicates that the differences between the before and after crashes values are statistically significant at the 95 percent confidence level. The results show that the average number of crashes decreased by 3.3%, while the fatal and severe injury crashes decreased by 22.6% after the implementation of wider pavement markings. These reductions, however, are not statistically significant at the 95 percent confidence level. While night crashes experienced a marginal increase (1.9%) after the implementation of wider pavement markings, fatal and severe injury night crashes showed a statistically significant reduction of 23.5% as a result of wider pavement marking implementation.

Table 4.1. Comparison Group Before-and-After T-Test Results for Average Crash Frequencies Per Mile

Crash type	**Before (2010-2014)**	**After (2016)**	**Percent Change**	**P-Value**
Total Crashes	1.21	1.17	-3.31	0.279
Night Crashes	0.53	0.54	1.89	0.173
Fatal and severe injury crashes	0.31	0.24	-22.58	0.126
Fatal and severe injury night crashes	0.17	0.13	-23.53	0.005

Table 4.2 shows the results of the comparison group before-and-after t-test for crash rates (crash/million mile travelled /year). The results show that the average crash rate for total crashes, night crashes, fatal and severe injury crashes, and fatal and severe injury night crashes decreased after the implementation of wide pavement marking. The percent crash rate reduction for total crashes, night crashes, and fatal and severe injury crashes are 12.22 percent, 8.81 percent, and 18.68 percent, respectively. These crash rate reductions, however, are not statistically significant at the 95 percent confidence level (the fatal and severe injury crash rate reduction of 18.68 percent is statistically significant at the 90 percent confidence level). Again, fatal and severe injury night crashes showed a statistically significant crash rate reduction, at the 95 percent confidence interval, of 39.39 percent as a result of wider pavement marking implementation.

Table 4.2. Comparison Group Before-and-after T-Test Results for Average Crash Rate

Crash type	Before (2010-2014)	After (2016)	Percent Change	P-Value
Total Crashes	63.84	56.04	-12.22	0.148
Night Crashes	26.46	24.13	-8.81	0.261
Fatal and severe injury crashes	17.67	14.37	-18.68	0.095
Fatal and severe injury night crashes	8.85	5.32	-39.89	0.006

4.2 Safety Performance Functions

Total ROR crash data for rural two-lane highway in Idaho in 2016 was used to develop SPFs. Those locations have almost the same road characteristics of the test sites. The output of the Negative Binominal regression for the SPF for total crashes and fatal and severe injury crashes are presented in Table 4.3. The four negative binomial regression models were completed using SPSS, a statistical analysis software. Only data that is completely in base conditions which means having 4 inch as pavement markings width, was used in this part of the analysis. The output from SPSS gives regression coefficients for the intercept and for any of the explanatory variables these coefficients are represented by β_0, β_1 and β_2. Table 4.3 shows the regression coefficients produced by SPSS for the regression analyses for two-lane highways. For night fatal and serious injuries model, there was not enough data to predict the model; however, SPF estimates for that condition were taken as a percentage of the SPF of the total night crash estimates.

Table 4.3. SPSS Coefficients Output

Model	Parameter	Estimate	Std. Error
All Day Total crashes	β0	-4.256	1.486
	β1	0.996	0.12
	β2	0.381	0.147
	Overdispersion parameter	0.822	-
All Day Fatal and Serious Injuries	β0	-4.832	1.441
	β1	0.817	0.121
	β2	0.294	0.151
	Overdispersion parameter	0.149	-
Night Total Crashes	β0	-7.478	2.118
	β1	1.099	0.16
	β2	0.607	0.194
	Overdispersion parameter	0.258	-

4.3 Goodness of Fit Measures

For evaluation of the previous models, four statistical tests had been considered. As shown in Table 4.4, MAD values are between 1 and 6 and for MPB values, they are ranging from 0 to -0.5. Lower MAD and MPB values indicate to a good to model assumptions. Also for R-squared values, they are ranging from 0.47 to 0.64 which indicate to a good models if it compared with the values of R-squared in Highway safety manual (31). The values of MSBE depends on the number of crashes, which is why it is resulting in values as high as 187.42 for the all-day total crashes model and low value as 3.66 for the all-day fatal and serious injuries model.

Table 4.4. Performance Measure for SPFs

Model	**MAD**	**MPB**	**MSBE**	**R-Squared**
All Day Total crashes	5.91	-0.37	187.42	0.61
All Day Fatal and Serious Injuries	1.27	-0.04	3.66	0.47
Night Total Crashes	2.82	-0.49	36.31	0.64

4.4 Empirical Bayes Before-After Studies

After verifying those models, predicted and expected crashes using the EB method were calculated for the test sites for each condition. Table 4.5 provides an executive summary for the test sites observed, predicted using SPF models and expected crashes using the EB method. Total crashes in both condition all day and night have observed crashes more than the expected crashes; however, observed fatal and serious injuries are significantly lower than expected. Safety effectiveness has been calculated for the three conditions. Only the all day fatal and serious injuries condition recorded high negative difference values between the observed and expected crashes (see Table 4.5). Safety effectiveness values indicate to the rate of the reduction in crashes. There is almost an 11% reduction in crashes for fatal and serious injuries conditions. In Figure 4.1, the SPF estimate is weighted with the observed crash count to estimate N (EB-Adjusted) as described previously in the methodology chapter. The Empirical Bayes estimate falls between the values of observed and SPF.

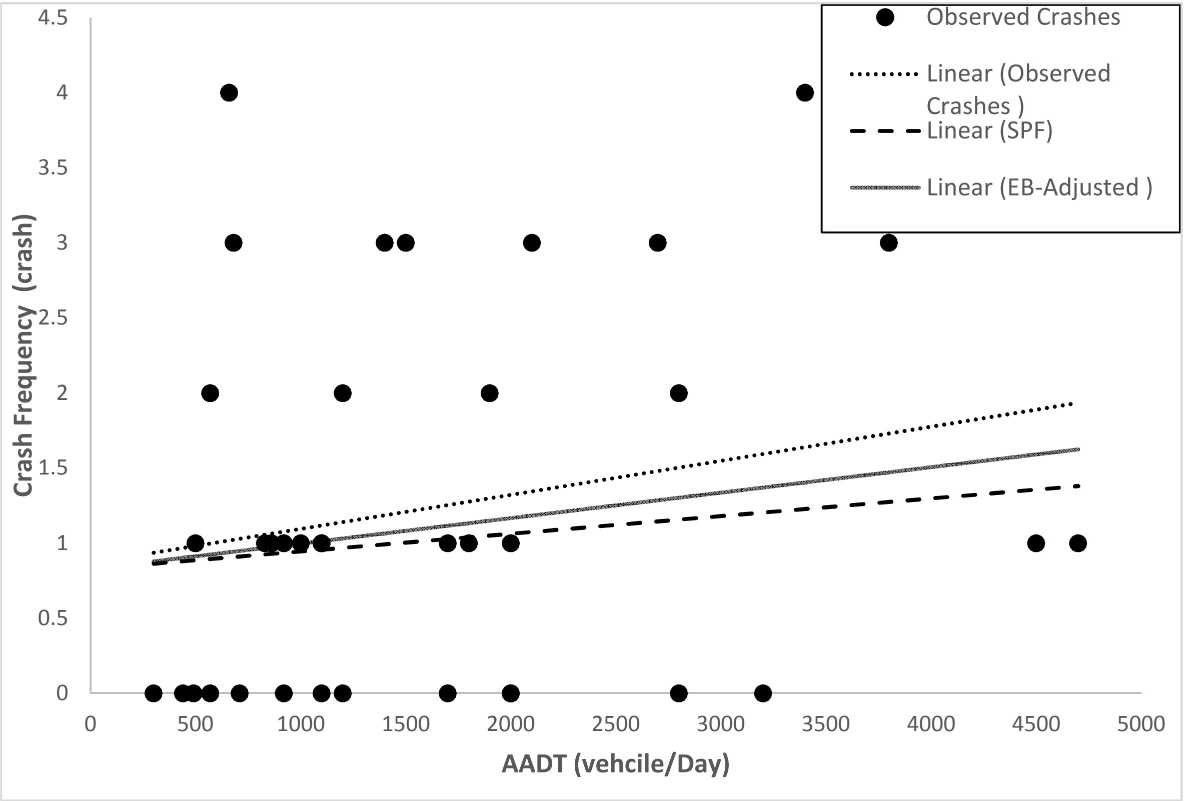

Figure 4.1. Empirical Bayes Estimate for all day total crashes.

Table 4.5. Comparison between Observed, SPF and EB Estimated Crash Frequencies

Crash Type	Count of Crashes After Treatment	Expected Results Without Treatment Using SPF			Expected Results Without Treatment Using EB		
		Number of Crashes	Percentage Change in Crashes θ	SD	Number of Crashes	Percentage Change in Crashes θ	SD
All Day Total crashes	48	39.2	3.1	0.03	42.7	2.8	0.03
All Day Fatal and Serious Injuries	8	9.1	-10.9	0.05	9.0	-10.7	0.05
Night Total Crashes	18	14.6	22.9	0.06	19.5	15.9	0.06
Night and Serious Injuries	4	4.5	-10.9	0.06	4.4	-10.7	0.06

4.5 Study Designs to Develop CMFs

The results of computing CMF by using the comparison group method are shown in Table 4.6 with both the values of and variance of CMF. The results of computing CMF by using the empirical group method are shown in Table 4.7 with the values of CMF and the variance of CMF. Table 4.8 provides a summary of CMF using the two methods and provide standard error and confident interval.

In Before-After with Comparison Group Studies, night time all crashes have a significant CMF in Before-After with Comparison Group Studies with 90% as a confidence level also, for all day fatal and serious injuries has a significant CMF with 95% as a confidence level. The rest of CMF` results are not significant with the interval level of 90% and 85%. For CMFs developed based on EB study, all results are not significant with the confident interval level of 95%, 90% and 85%.

Table 4.6. CMF by using the comparison group method

Crash type	$\mathbf{N}_{(\text{expected},T,A)}$	**Var** $\mathbf{N}_{(\text{expected},T,A)}$	**CMF**	**Variance (CMF)**	**SE of the CMF**
Total Crashes	46.9	151.49	0.96	0.07	0.27
Night Crashes	27.1	128.24	0.56	0.05	0.23
Fatal and severe injury crashes	11.0	70.09	0.46	0.06	0.24
Fatal and severe injury night crashes	2.1	6.78	0.75	0.16	0.40

Table 4.7. CMF by using Empirical Bayes Before-After Studies

Crash type	$\mathbf{N}_{(\text{expected},T,A)}$	**Var** $\mathbf{N}_{(\text{expected},T,A)}$	**CMF**	**Variance (CMF)**	**SE of the CMF**
Total Crashes	42.7	43.11	1.10	0.06	0.23
Night Crashes	15.9	14.18	1.07	0.12	0.34
Fatal and severe injury crashes	9.0	5.16	0.84	0.12	0.35
Fatal and severe injury night crashes	4.5	1.62	0.83	0.19	0.43

Table 4.8. Evaluated CMF of wider pavement markings

Calculation Method	**Crash Modification Factor (standard error)**			
	All day (KABCO)	Night Time (KABCO)	All day (KA)	Night Time (KA)
Before-After with Comparison Group Studies	0.96 (0.26)	0.56** (0.23)	0.46*** (0.24)	0.75 (0.39)
Empirical Bayes Before-After Studies	1.09 (0.23)	1.07 (0.33)	0.84 (0.34)	0.83 (0.43)

* Significant at a 85% confidence level,
** Significant at a 90% confidence level,
*** Significant at a 95% confidence level.

4.6 Cost-Benefit Ratio For Wider Pavement Marking

The 2012 to 2016 Crash data shows a total of 173 fatal and 533 serious injury ROR crashes in two-lane rural highways in Idaho, with an average cost of approximately $382.05 million a year. With an estimated additional cost of $0.04 per lane-foot to increase the width of the right shoulder edge line pavement marking from 4 inch to 6 inch, the total additional cost of painting the two lane rural highway segments in Idaho (approximately 4,600 miles) with 6-inch edge line pavement marking, instead of the currently used 4-inch markings, is approximately $1.95 M. Wide pavement marking implementation has the potential to reduce fatal and serious ROR crashes by 10.07 percent with an expected cost savings of $48.1 million. The cost to benefit ratio of implementing wide pavement marking is approximately 1:25.

CHAPTER 5 CONCLUSION

5.1 Conclusion

The results of a before-and-after study to examine the safety effect of wider pavement markings was presented in this thesis. Two different methods were employed: before-and-after Comparison Group analysis and Empirical Bayes before-and-after analysis. This study provides sufficient evidence to recommend that wider pavement edge line markings are effective in reducing crashes on rural, two lane highways, especially in preventing fatal and serious injury crashes.

The results of the comparison group analysis show that the average crash rate for total crashes, night crashes, fatal and severe injury crashes, and fatal and severe injury night crashes decreased after the implementation of wide pavement marking. The percent crash rate reduction for total crashes, night crashes, and fatal and severe injury crashes are 12.22 percent, 8.8%, and 18.7%, respectively. These crash rate reductions, however, are not statistically significant at the 95 percent confidence level (the fatal and severe injury crash rate reduction of 18.7% is statistically significant at the 90 percent confidence level). Again, fatal and severe injury night crashes showed a statistically significant crash rate reduction, at the 95 percent confidence interval, of 39.4% as a result of wider pavement marking implementation.

The results of Empirical Bayes analysis are consistent with the results obtained from the comparison group analysis. For crash frequency, the Empirical Bayes unbiased estimates for the reduction of crashes as a result of the implementation of wider pavement markings are 17% and 14%for total crashes and fatal and severe injury crashes, respectively. For crash rates, these reductions are 5.53% and 12.59%, respectively. The reduction in crash rates for total crashes in statistically significant at the 90 percent confidence level. The reduction in crash rates for fatal and severe injury crashes is statistically significant at the 95 percent confidence level. Two CMFs were significant: the nighttime all crashes value was 0.56 at the 95% confidence level and the all day fatal and serious injury crashes value was 0.46 at the 90% confidence level. The calculated cost-to-benefit ratio of implementing wider pavement marking throughout the state’s two-lane rural highway segments is approximately 1:25.

Future work concerns deeper analysis of how much the increase in pavement markings width should be to satisfy the highest safety effectiveness with best cost, new proposals to try different methods, or simply curiosity. Also, the impact of using wider pavement edge line markings on heavy vehicles since the driver of the heavy vehicle (HV) is more far away from the pavement markings than the driver of car due to the elevation of the HV seats. Finally, Test the impact of pavement markings retroreflectivity on this study.

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APPENDIX A

Note: the decrease values showed in Tables A.1, Tables A.2, Tables A.3 and Tables A.4 means that the exact percent of reduction cannot be calculated because of zero values in count of crashes after treatment.

Table A.1. Detailed SPF and EB Calculation for all day crashes

Route	Count Of Crashes After Treatment	Expected Results Without Treatment Using SPF		Expected Results Without Treatment Using EB	
		Number of Crashes	Percentage difference	Number of Crashes	Percentage difference
SH001	0	0.96	Decrease	0.54	Decrease
SH003	3	0.73	75.8	1.58	47.4
SH200	2	1.83	8.7	1.93	3.5
SH041	1	1.19	-19.0	1.10	-9.6
SH003	2	0.59	70.4	1.05	47.3
US095	0	0.27	Decrease	0.22	Decrease
SH097	4	1.20	70.0	2.59	35.2
SH009	1	1.27	-27.0	1.13	-13.2
US095	0	1.78	Decrease	0.72	Decrease
SH128	1	0.78	22.1	0.87	13.4
SH099	2	0.44	77.8	0.86	57.0
SH006	1	0.57	42.8	0.71	29.1
US012	1	1.17	-17.1	1.09	-8.7
US095	0	0.51	Decrease	0.36	Decrease
US095	1	1.27	-26.8	1.13	-13.1
US020	3	2.22	25.9	2.72	9.2
SH051	3	1.52	49.3	2.34	21.9
SH021	1	1.47	-46.9	1.21	-21.2
SH046	0	0.27	Decrease	0.22	Decrease
SH075	2	1.43	28.3	1.74	13.0
SH025	0	1.42	Decrease	0.66	Decrease
SH081	3	0.59	80.2	1.38	53.9
SH021	0	0.87	Decrease	0.51	Decrease
SH046	0	0.65	Decrease	0.42	Decrease
US030	1	0.31	69.0	0.45	54.9
SH024	0	0.16	Decrease	0.14	Decrease
US026	0	1.57	Decrease	0.69	Decrease
SH036	1	0.93	6.9	0.96	3.9
SH036	1	0.78	22.4	0.86	13.7
SH034	1	1.12	-12.2	1.06	-6.4
SH034	0	0.67	Decrease	0.43	Decrease
US093	4	1.65	58.7	3.01	24.9
SH033	0	1.61	Decrease	0.69	Decrease
SH043	3	1.02	66.1	1.92	36.0
US093	1	1.07	-7.3	1.04	-3.9
US093	3	1.67	44.4	2.44	18.7
SH031	0	0.25	Decrease	0.21	Decrease
I15 B	2	1.39	30.5	1.72	14.2

Table A.2. Detailed SPF and EB Calculation for all day fatal and serious injury crashes

Route	Count Of Crashes After Treatment	Expected Results Without Treatment Using SPF		Expected Results Without Treatment Using EB	
		Number of Crashes	Percentage difference	Number of Crashes	Percentage difference
SH001	0	0.24	Decrease	0.23	Decrease
SH003	0	0.18	Decrease	0.18	Decrease
SH200	2	0.37	81.3	0.45	77.3
SH041	0	0.25	Decrease	0.24	Decrease
SH003	0	0.16	Decrease	0.15	Decrease
US095	0	0.09	Decrease	0.08	Decrease
SH097	0	0.29	Decrease	0.28	Decrease
SH009	0	0.29	Decrease	0.28	Decrease
US095	0	0.36	Decrease	0.34	Decrease
SH128	0	0.18	Decrease	0.18	Decrease
SH099	1	0.13	86.8	0.15	85.3
SH006	1	0.16	84.2	0.18	82.5
US012	1	0.29	71.4	0.31	68.7
US095	0	0.14	Decrease	0.13	Decrease
US095	0	0.28	Decrease	0.27	Decrease
US020	0	0.43	Decrease	0.40	Decrease
SH051	1	0.34	65.5	0.37	62.5
SH021	0	0.32	Decrease	0.30	Decrease
SH046	0	0.09	Decrease	0.09	Decrease
SH075	0	0.30	Decrease	0.29	Decrease
SH025	0	0.30	Decrease	0.29	Decrease
SH081	0	0.16	Decrease	0.15	Decrease
SH021	0	0.22	Decrease	0.22	Decrease
SH046	0	0.18	Decrease	0.18	Decrease
US030	0	0.09	Decrease	0.09	Decrease
SH024	0	0.05	Decrease	0.05	Decrease
US026	0	0.34	Decrease	0.33	Decrease
SH036	0	0.23	Decrease	0.22	Decrease
SH036	0	0.20	Decrease	0.19	Decrease
SH034	0	0.26	Decrease	0.25	Decrease
SH034	0	0.19	Decrease	0.18	Decrease
US093	0	0.33	Decrease	0.32	Decrease
SH033	1	0.35	Decrease	0.38	Decrease
SH043	0	0.23	Decrease	0.22	Decrease
US093	1	0.26	74.3	0.28	71.7
US093	0	0.35	Decrease	0.34	Decrease
SH031	0	0.08	Decrease	0.08	Decrease
I15 B	0	0.26	Decrease	0.25	Decrease

Table A.3. Detailed SPF and EB Calculation for Night all crashes

Route	Count Of Crashes After Treatment	Expected Results Without Treatment Using SPF		Expected Results Without Treatment Using EB	
		Number of Crashes	Percentage difference	Number of Crashes	Percentage difference
SH001	0	0.28	Decrease	0.25	Decrease
SH003	3	0.33	88.9	0.59	80.2
SH200	1	0.68	32.3	0.74	26.4
SH041	1	0.66	33.7	0.72	27.7
SH003	1	0.23	77.2	0.28	71.8
US095	0	0.12	Decrease	0.11	Decrease
SH097	3	0.32	89.2	0.58	80.7
SH009	1	0.41	59.0	0.48	52.0
US095	0	0.81	Decrease	0.64	Decrease
SH128	0	0.48	Decrease	0.41	Decrease
SH099	1	0.14	86.4	0.17	82.7
SH006	0	0.19	Decrease	0.18	Decrease
US012	0	0.29	Decrease	0.26	Decrease
US095	0	0.23	Decrease	0.21	Decrease
US095	1	0.48	51.7	0.55	44.7
US020	2	0.91	54.7	1.16	42.2
SH051	1	0.40	60.4	0.46	53.5
SH021	1	0.56	44.4	0.62	37.6
SH046	0	0.09	Decrease	0.08	Decrease
SH075	2	0.64	67.8	0.88	56.0
SH025	0	0.64	Decrease	0.53	Decrease
SH081	0	0.25	Decrease	0.23	Decrease
SH021	0	0.24	Decrease	0.22	Decrease
SH046	0	0.17	Decrease	0.16	Decrease
US030	1	0.16	83.6	0.21	79.4
SH024	0	0.10	Decrease	0.09	Decrease
US026	0	0.50	Decrease	0.43	Decrease
SH036	0	0.31	Decrease	0.28	Decrease
SH036	0	0.25	Decrease	0.23	Decrease
SH034	1	0.37	62.9	0.44	56.1
SH034	0	0.15	Decrease	0.14	Decrease
US093	0	0.78	Decrease	0.62	Decrease
SH033	0	0.46	Decrease	0.53	Decrease
SH043	0	0.55	Decrease	0.46	Decrease
US093	1	0.33	66.5	0.40	60.0
US093	1	0.56	44.0	0.63	37.2
SH031	0	0.14	Decrease	0.17	Decrease
I15 B	0	1.37	Decrease	0.95	Decrease

Table A.4. Detailed SPF and EB Calculation for Night fatal and serious injuries crashes

Route	**Count Of Crashes After Treatment**	**Expected Results Without Treatment Using SPF**		**Expected Results Without Treatment Using EB**	
		Number of Crashes	**Percentage difference**	**Number of Crashes**	**Percentage difference**
SH001	0	0.11	Decrease	0.11	Decrease
SH003	0	0.14	Decrease	0.14	Decrease
SH200	1	0.21	79.1	0.22	77.7
SH041	0	0.23	Decrease	0.22	Decrease
SH003	0	0.11	Decrease	0.11	Decrease
US095	0	0.07	Decrease	0.07	Decrease
SH097	0	0.12	Decrease	0.12	Decrease
SH009	0	0.15	Decrease	0.15	Decrease
US095	0	0.24	Decrease	0.24	Decrease
SH128	0	0.19	Decrease	0.19	Decrease
SH099	1	0.08	92.5	0.08	91.9
SH006	0	0.09	Decrease	0.09	Decrease
US012	0	0.11	Decrease	0.11	Decrease
US095	0	0.11	Decrease	0.11	Decrease
US095	0	0.17	Decrease	0.17	Decrease
US020	0	0.26	Decrease	0.25	Decrease
SH051	1	0.14	86.1	0.15	85.1
SH021	0	0.19	Decrease	0.18	Decrease
SH046	0	0.06	Decrease	0.06	Decrease
SH075	0	0.21	Decrease	0.21	Decrease
SH025	0	0.21	Decrease	0.21	Decrease
SH081	0	0.12	Decrease	0.12	Decrease
SH021	0	0.10	Decrease	0.10	Decrease
SH046	0	0.08	Decrease	0.08	Decrease
US030	0	0.09	Decrease	0.09	Decrease
SH024	0	0.07	Decrease	0.07	Decrease
US026	0	0.17	Decrease	0.17	Decrease
SH036	0	0.13	Decrease	0.12	Decrease
SH036	0	0.11	Decrease	0.11	Decrease
SH034	0	0.14	Decrease	0.14	Decrease
SH034	0	0.07	Decrease	0.07	Decrease
US093	0	0.24	Decrease	0.23	Decrease
SH033	0	0.16	Decrease	0.16	Decrease
SH043	0	0.20	Decrease	0.20	Decrease
US093	1	0.13	86.9	0.14	86.0
US093	0	0.18	Decrease	0.18	Decrease
SH031	0	0.09	Decrease	0.09	Decrease
I15 B	0	0.40	Decrease	0.39	Decrease

Cost-benefit analysis: Figure B.1 and B.2 are smart chart to describe how cost benefit analysis have been conduct.

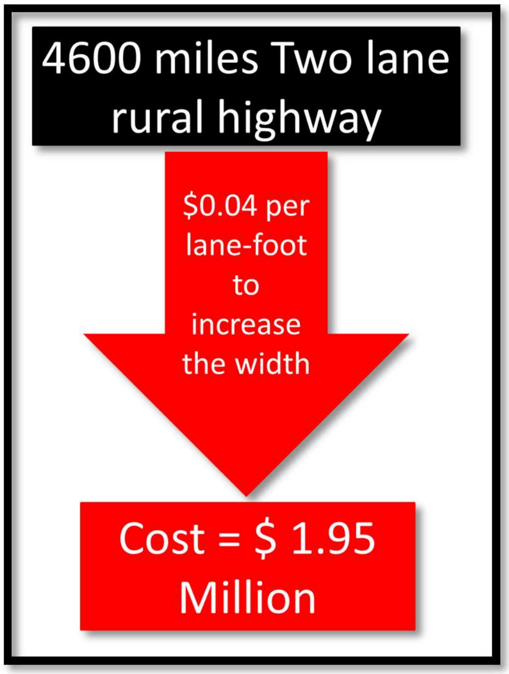

Figure A.1. Cost analysis for increasing pavement markings by 2 inches.

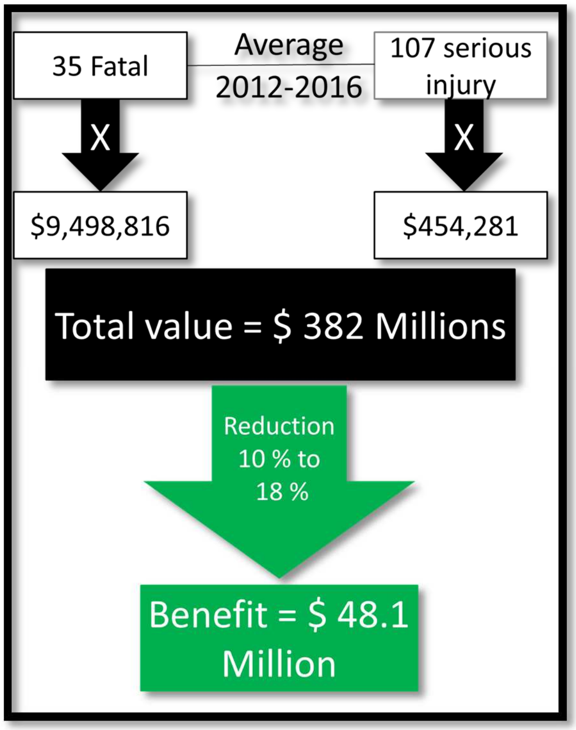

Figure A.2. Safety benefit analysis due to use wider pavement markings.