8-2015

Evaluation of the Safety Effectiveness of Clearview Font and Fluorescent Yellow Sheeting on Michigan Freeways and Non-Freeways

Lusanni Mercedes Acosta Rodrieuez
Western Michigan University

EVALUATION OF THE SAFETY EFFECTIVENESS OF CLEARVIEW FONT AND FLUORESCENT YELLOW SHEETING ON MICHIGAN FREEWAYS AND NON-FREEWAYS

by

Lusanni Mercedes Acosta Rodriguez

A thesis submitted to the Graduate College in
partial fulfilment of the requirements for the
degree of Master of Science in Engineering
Civil Engineering
Western Michigan University
August 2015

Thesis Committee:

Valerian Kwigizile, Ph.D., Chair
Jun-Seok Oh, Ph.D.
Zhanbo Sun, Ph.D.
Diana Prieto, Ph.D.

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Halation or irradiation makes guide sign fonts difficult to read. Missing the necessary guide sign information causes anxiety and confusion to drivers, and hence may lead to crashes. In order to avoid or mitigate the situation a newer font, Clearview, is used to provide better readability at long distances. In a similar context the lack of brightness in sheeting material for warning signs reduces conspicuity of sings. Installation of fluorescent yellow sheeting has been done to provide signs with more noticeable and brighter materials. This observational before and after study is an evaluation of the safety and economic benefits of the Clearview fonts and fluorescent yellow sheeting installed in Michigan freeways and non-freeways. Safety Performance Functions (SPFs) and Crash Modification Factors (CMFs) for Clearview fonts and fluorescent yellow sheeting were developed. A perception survey was conducted to identify driver's preferences on the Clearview fonts and fluorescent yellow sheeting.

DEDICATION

This master thesis is dedicated to God who has given me the wisdom, intelligence, and strength to finish this step in life. Also, it is dedicated to my father, Jose Acosta, and mother, Gloria Rodriguez, who have always thought and given higher than the sky for me, thus, leading me to the most important achievements of my life.

AKNOWLEDGEMENTS

This project would have not been a reality without the help of God and support of several people. There are many thanks to give my chair adviser, Dr. Valerian Kwigizile, who helped in making sense of the confusions and misunderstandings in the study all the time I needed. In addition, thanks are given to my committee members, Dr. Jun-Seok Oh, Dr. Zhanbo Sun, and Dr. Diana Prieto who offered good direction and help during this important step of life. This space is also to thanks the remarkable support and funding provided by the Michigan Department of Transportation (MDOT). Finally, thanks to my family (Jose Acosta, Gloria Rodriguez , Luz Acosta, Gloris Acosta, and , Luz Ramirez), lab coworkers, especially Richard Boateng, Matthew Clark, Brenda Hodgell, Tejaswi Vangapattu and especial ones, such as Carlos Cruz, who underwent this process with me by always offering support, help, happiness, and love.

Lusanni Mercedes Acosta Rodriguez

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CHAPTER I

INTRODUCTION

As the Michigan Department of Transportation (MDOT) started implementing engineering countermeasures for drivers in 2006 evaluation of their safety impact was needed. While MDOT implemented many countermeasures, this thesis focuses on two of them: Clearview fonts and Fluorescent Yellow Sheeting.

Problem Statement

Halation or irradiation makes guide sign fonts difficult to be read. "Halation occurs when light reflected from a surface appears to exceed the boundaries of the surface and blend with an adjacent surface of a contrasting color. If halation occurs, a lowercase "e" could appear as an "a," "c," or "o," (Miles et al., 2014). Drivers missing the needed guide sign information become anxious and confused. In a similar context the lack of brightness in sheeting material for warning signs potentially reduce conspicuity of sings. "The conspicuity of a traffic sign is the most important factor related to whether or not it will be detected" (Gates et al., 2003). There are various circumstances where standard warning sign sheeting provides the appropriate conspicuity for the driving population. However, when involved in extreme conditions (e.g. areas with restricted sight distance) failing to detect a warning sign can potentially lead to severe consequences and thus death.

Even though most of the drivers have experienced the halation phenomenon from guide sign fonts and the lack of conspicuity from several warning signs, the elderly (65-and-above years) seems to be the most affected. They have more needs related with visibility issues. Fatality rates associated with older drivers reflect the fragility of older people and their needs for safety improvements. When the overall crash data in Michigan seems to be decreasing by 30% the crash rates associated with the elderly is 7.8%, for the last ten years.

Background and Motivation

To improve safety and driving experience for all drivers, especially older drivers, the Michigan Department of Transportation (MDOT) started implementing countermeasures on a systemic approach. Selected countermeasures involved the use of a newer font (Clearview) in guide signs for both freeways and non-freeways and the replacement of standard yellow sheeting by fluorescent yellow sheeting. Figures 1 and 2 provide with examples of the implemented countermeasures. The appearance of countermeasures exposed to both light conditions (daylight and dark) is also presented.

Figure 1 Example of Clearview Font (#1) and Standard Font (Series E-Modified) (#2)

Figure 2 Examples of Fluorescent Yellow (#1) and Standard Yellow Sheeting (#2)

Also, due to the fact that MDOT implemented the countermeasures for a period of time now, it is of high relevance the evaluation of the safety effectiveness of them. This is the sixth and last step in the standard procedure1 for *identifying and eliminating* (Shen and Gan, 2003) dangerous sites. Through the safety evaluation of the engineering improvement MDOT will be able to decide if continuing with the implemented countermeasures have safety benefits for drivers in Michigan.

Objectives

The purpose of this thesis is to evaluate the safety and economic benefits provided by Clearview font and fluorescent yellow sheeting in the Michigan driving population. The results and recommendations will serve as guidance to MDOT and related researchers for making future informed decisions. Also, since no evaluation has been performed on the installed countermeasures, the study aims to fill in this gap.

Scope of the Study and Thesis Format

This thesis is limited to the evaluation of only two of the countermeasures implemented by MDOT. Also, the whole driving age population is analyzed rather than a disaggregated group (e.g. older drivers only). Finally, the body of the content will be presented in seven chapters: literature review (Chapter 2), perception survey (Chapter 3), data collection (Chapter 4), evaluation methods (Chapter 5), results and discussion

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[1] The standard procedure for mitigating hazardous locations approved by the U.S. Congress through the 1966 Highway Safety Act consist of 6 steps:

1. Identifying highly hazardous locations on the basis of reported crash data,
2. Obtaining detailed design problems in the highly hazardous locations by conducting engineering studies,
3. Identifying possible countermeasures for hazardous locations,
4. Predicting the effects of potential countermeasures in terms of reduced numbers of crashes or reduced severities of crashes,
5. Implementing countermeasures with the highest net benefits on investment, and
6. Evaluating the effectiveness of the countermeasures after implementation.

(Chapter 6), economic analysis (Chapter 7), and conclusions, recommendations and limitations (Chapter 8).

CHAPTER II

LITERATURE REVIEW

Introduction

Developed by Meeker and Associates and the Pennsylvania transportation institute through the 1990's, the Clearview font style for guide signs aimed to improve legibility and decrease halation of highway sing legends. Issues to be addressed by the newer font included older drivers' visual necessities, and halation produced by high brightness in retro-reflective signs. Halation is reduced since Clearview fonts are having "more open interior spaces" leading better readability from distances when irradiation occurs (Garvey 1998). The space between letters, which is known as tracking, is intended to make words more distinctive as well. Similarly, in order to increase notice-ability of a sign materials used should be brighter and bigger. Fluorescent yellow sheeting aimed to help drivers ease in recognizing warning signs. Conspicuity was to be improved during both day and night times (Gates 2004).

Various departments of transportation and research teams have evaluated these countermeasures statewide and over-seas. Methodologies vary among researchers per each countermeasure. The literature review on these countermeasures in focused only on those studies highlighting the evaluation of the safety impacts of the installations.

Clearview Font on Guide Signs (freeway and non-freeway)

In 1997 Garvey et al. evaluated the Clearview fonts against the standard Highway Series D (all in uppercase) and the mixed-case Series E-modified, in Pennsylvania. The main objective of the study was to improve the old guide sign font (40 years old). Believing that with the old guide sign font older drivers experience irradiation or halation, the newer font aimed to help mitigating the issue. Daytime and nighttime controlled field experiments were carried out using 65-and-older drivers. Besides evaluating the fonts, the authors also studied the impacts provided from the sheeting material in the recognition distance. Results showed that the mixed-case in Clearview fonts highly performed against the all-upper case series D by 14% and 16% during daytime and nighttime, respectively. Finally, the Clearview font outperformed the Series E-Modified during nighttime using *high-brightness* materials by 16% as well. There was not difference between the newer font and E-modified during the daytime, however. These results were all obtained without increasing the size of the sign, which was a plus for the study.

In 2001 Carlson in Texas, evaluated the Clearview fonts using micro-prismatic yellow sheeting. The study was conducted to determine legibility provided by Clearview fonts on freeway guide signs. Series E-modified were used as standard fonts for comparison. The standard sheeting against which the micro-prismatic sheeting was compared to was the Type III sheeting. Field evaluation was the main methodology for the study. Participants were divided into age groups (18-34, 35-54, and greater than or equal 55 years) and the study was conducted during the nighttime. Results indicated that the Clearview fonts provide longer legibility distances than the standard font used, statistically. Improvements in legibility were of 44 and 41 feet for overhead and shoulder mounted guide signs, respectively. There was 11.9 % improvement in legibility by replacing Series E (Modified), Type III, with micro-prismatic sings with Clearview. Increments in time needed to read overhead sign in highway of 70 and 55 mph were of 24.1 and 19.8 percent, respectively. The author recommended replacing all new and renewed guide signs with Clearview fonts and micro-prismatic reflective sheeting.

In September 2010, Gray and Neuman in Arizona performed an evaluation of Clearview fonts for the Maricopa Association Government (MAG)'s project. The project evaluated the impacts of mounting Clearview fonts in street names for specific safety and mobility for all and older drivers. Using driving simulation and questionnaires on the driving experience the findings were obtained. Findings showed that the Clearview fonts provide better readability of the given sign, mostly during night time. Improvements in recognizing the sing were shown to be of 8 to 10 % overall. Also, it was possible to observe less turn errors, earlier lane changes, and driving closer to speed limit. These last contributions are important for drivers, especially elders, since they help to keep driving confidence, thus keeping mobility. It was recommended, to the MAG, adopting Clearview font sings where Standard fonts were. Figure 3 shows the examples of the overhead sign images for both types of fonts.

Figure 3 Example of Clearview Font (left) and Standard Font (Highway series 200, right)

Gowda (2010) performed the evaluation of safety impacts from Clearview fonts, in Kansas. The study was to determine the sign font combination with retro-reflective sheeting materials that would provide the maximum readability distance. Among the fonts were Clearview 5-W-R, Clearview 5-W, and Series E-Modified. Clearview 5-W is the equivalent for Series E-Modified. This type of font is used since MUTCD directs to use series E-Modified on any overhead or regular guide sign. Clearview 5-W-R is very comparable to Clearview 5-W; however the first one requires lesser signboard real estate than the second one. Retro-reflective sheeting materials were type 1, type 4 and DG3 as mentioned previously. According to MUTCD type 1 retro-reflective sheeting is the one used for guide signs. DG3 is a reflective sheeting manufactured by 3M. They claim "that its optical elements are 100% efficient, returning almost 60% of available light, nearly double that of traditional prismatic sheeting. According to 3M, the Type 4 sheeting is typically a un-metallized micro-prismatic retro-reflective element material," (Gowda, 2010). The methodology for evaluation included field and computer screen studies. Findings showed longer readability distances provided by the Clearview font than the standard E-modified font for guide signs. From results obtained in analyzed conditions, daytime and nighttime, the best combination of font and retro-reflective material is Clearview 5-W-R and type 4, respectively. Table 1 presents the combination from highest to least performance of fonts and retro-reflective materials. Recommendations were based on the combination that provided longer readability distances.

Table 1 Performance's Order for Combining Font Type and Retro-reflective Material

Order of Performance	Reflective Material	Font Type	Legibility Distance (Feet)
1.	Type 4	Clearview 5-W-R	377
2.	DG3	Clearview 5-W-R	365
3.	Type 1	Clearview 5-W	360
4.	Type 1	Series E-Modified	355
5.	Type 1	Clearview 5-W-R	352
6.	DG3	Series E-Modified	341
7.	Type 4	Clearview 5-W-R	322
8.	DG3	Clearview 5-W-R	321
9.	Type 4	Series E-Modified	282

In 2011, Frei et al. together with the Illinois Department of Transportation (IDOT) evaluated the use of Clearview fonts in the state. The evaluation was done through field survey and visual inspection. Four locations where chosen to survey drivers comparing the Clearview font and E-modified Series. Surveys were conducted in both urban and rural areas. It was intended to obtain information on legibility of the signs. From results approximately ten percent increment in sing readability and twenty six percent of the drivers have noticed the difference in signs in Illinois. Ninety percent of drivers say that Clearview signs are easier to read than standard signs. Also, models (binary logit models) were run to help in understating the factors affecting driver's perception in sign legibility and if sign in the roadway was easier to read. Thus, in terms of easiness to read the Clearview fonts are twice as much easier to than those in E-Modified series. Also, results from models did not show statistical significance for the increment in perception and sign readability when using Clearview fonts at highway speeds. However, they were preferred by drivers. Finally, it was recommended the continued use of the newer font along with high-retro-reflective sheeting; and development of a systematic sign inventory in order to address inconsistencies in signs noted by drivers.

Miles et al. (2014) performed the evaluation of guide signs using Clearview fonts in Minnesota. Besides Clearview fonts (type 5W) E-Modified, and Enhanced E-Modified series were evaluated for *overhead* and *shoulder-mounted* guide signs. Field evaluation was used for carrying out the study. Data based on legibility distance were recorded based on each word read; however, the analysis was completed based on the legibility index (LI). LI is the division of the legibility distance by the legend height. Statistical significant differences in LI were observed with respect to subject age, which were 18-35, and 65+, and time of the day (daytime and nighttime). Mean LI for 18-35 and 65+ were 68.9 and 45.2 for daytime and 50.2 and 36.4 for nighttime, respectively. Accordingly, the cost of implementing Clearview 5W is more expensive than E-modified. Cost is based on both license and increment of size in Clearview 5W than in E-modified. So, recommendations involved not using Clearview 5W and investment in policies or fonts that enhance safety but reduce the cost of signs.

An earlier study (in Texas) similar to the one carried out by Miles et al. (2014) evaluated the Clearview fonts versus the *Highway Gothic font series E (Modified)* (Holick et al., 2006) and found that legibility distances are longer using the newer font than the standard when used on a dark background guide signs with positive contrast of white letters. This knowledge helped the Federal Highway Administration (FHWA) adopting the Clearview font into their *Standard Highway Signs* book. Since the newer font has been evaluated using positive contrast signs, the authors evaluated it using negative contrast signs. Evaluation of the font was done through laptop-based surveys and closed-course field studies. Legibility and recognition was tested during night and day times. Results showed that for negative contrast signs the Clearview fonts perform the same as the standard fonts used, except in the case of nighttime. In nighttime recognition of the sign was slightly decrease when the standard font was replaced with Clearview font in negative contrast signs. Also, since there was not significance difference in using the Clearview font and the standard fonts used, recommendations led to continue using the standard font for negative contrast signs.

Fluorescent Yellow Sheeting

Jenssen et al. (1998) in Norway evaluated the effectiveness of implemented fluorescent retro-reflective materials in traffic control devices by using before and after studies. Field evaluation was carried out together with interviews on the treated site. Engineering measurements such as *mean daytime speed* and *speed and lane position measurements* were considered together with *eye-tracking measurements* as part of methodology for the study. These studies helped in visualizing driver's behavior in the presence of the fluorescent and non-fluorescent material. Main findings of this study included older drivers' detection of the fluorescent yellow signs sixty-five meters ahead versus the non-fluorescent signs; and significant reduction in space mean speeds for light vehicles. It was also found that the countermeasure provided higher conspicuity than ordinary signs and lead to reduction in speeds during daytime only in the *sharp left hand curves.* It was recommended to perform evaluation of applying the countermeasure in traffic signing permanently.

Three years later, Eccles and Hummer (2001) evaluated the fluorescent yellow warning signs in different hazardous sites in order to see improvements offered to drivers in a selected area, in North Carolina. A before and after study was developed in order to evaluate the effectiveness of the installation in different locations. She concluded that the countermeasure increase safety at highly hazardous locations such as reducing the number of non-stopping vehicles. Therefore it was recommended the use of fluorescent yellow sheeting in warning sings, mainly in hazardous areas. Since the study summarized only involved only hazardous locations, it was also recommended to develop the same study in other locations for broader safety impacts of the countermeasure.

Similarly, Burns et al. (2001) in Minnesota compared the photometric properties of a series of fluorescent and non-fluorescent materials (fluorescent yellow and fluorescent yellow-green sings). The study also aimed to fill in the gaps for the correlation between "laboratory characterization of sign materials and the photometric performance of sings on the roads," (Burns et al., 2001). Laboratory and field measurements were both performed on the *brightness and color of fluorescent yellow and fluorescent yellow-green* sings. Main findings showed that luminance (for daytime) of fluorescent yellow and fluorescent yellow-green sheeting was significantly higher than standard yellow signs under an extensive range of daylight conditions. The authors noticed that colors during daytime varied when measured in the laboratory as compared when measured in the field. However, for nighttime approximation in color and chromaticity between lab measurements and field measurements were very close, respectively. Finally, fluorescent materials were considered as potentially improving road safety.

From the evidence that fluorescent sings improve conspicuity, Neale et al. evaluated fluorescent sign colors on MUTCD for managing trailblazing situations, in Virginia. Evaluated colors included *black on fluorescent coral, fluorescent yellow on fluorescent purple*, *black on fluorescent yellow-green*, and *yellow on purple in non-*

fluorescent colors, (Neale et al., n.d.). Through field evaluation and questionnaires the analysis was carried out. The experiment was taken place using an instrumented vehicle on a manufactured test route. There was no significant difference from the field evaluation using the four color combinations. From questionnaires it was revealed that the preference of drivers per age groups (younger and older drivers) was the black on fluorescent yellow-green for nighttime and daytime for visibility. However, this color was later assigned for pedestrian, school and bicycle crossing signs by the Federal Highway Administration (FHWA). Finally, from the remaining combinations drivers preferred the fluorescent ones (black on fluorescent coral and fluorescent yellow on fluorescent purple) thus leaving the standard yellow on purple as the least in preference. In order to increase detection a larger arrow was recommended in the directional information along a *trailblazed* route. This would lead to reductions in the number of late braking maneuvers.

Schieber et al. (2002) in Iowa performed a laboratory experiment (Inattention Paradigm) to observe the effects of fluorescent sheeting (including fluorescent yellow-green and fluorescent yellow) on drivers. Two search experiments were performed: *unexpected fluorescent yellow-green target* (where participants needed to search for presented colored signs including fluorescent yellow-green and recognize those with *“up” direction*); and *yellow stimulus control condition* (where participants, of a different group, were presented with a set of signs similar to the first experiment but with fluorescent yellow and fluorescent red material). From experiments it was concluded that search time reductions are observed when in the contrary to what it was testes “expected” fluorescent yellow-green signs are used. A significant reduction in search time was observed to be of 300 msec. Also, findings showed that despite the fact that fluorescent yellow color is not as *vivid* as the other colors tested (fluorescent yellow-green and fluorescent red) the performance curve of these signs were almost identical to other fluorescent colors. In general, results showed improvement in “search conspicuity” but not necessarily in ‘attention conspicuity,” (Schieber, 2002).

In a similar study, Gates (2004) in Texas observed that fluorescent yellow sheeting provided improvements in sign conspicuity and driver behavior with relatively a small increased cost of implementation. For *fluorescent yellow chevrons* findings show 38 and 11percents decrease in edge line encroachment and excess in speed limits, respectively. It was noticed a 20 percent increase in vehicles starting to decelerate before reaching the sign: *Fluorescent yellow curve* warning. However, marginal effects were found in terms of *fluorescent yellow stop ahead* signs since speeds were only reduced during the night; Fluorescent *Yellow Exit Ramp Advisory* showed unpredictable effects on speed. It was recommended statewide implementation of fluorescent yellow micro-prismatic sheeting for fluorescent yellow Chevrons. Also, if installations of Fluorescent yellow chevrons are to occur in a specific location, all of the existing chevron should be replaced.

Research Study Designs: Experimental and Observational

There are two broad categories into which study designs fall: experimental and observational. “Experimental studies are planned where sites are selected at random for treatment and control,” (Carter et al., 2012). Elvik, 2011, argues that experimental studies are the most demanding way for establishing casualty. The main goal of experimental studies is to evaluate implemented safety improvements which sole purpose is evaluating effectiveness. These studies are not common due to high probability in liability concerns. On the other hand, observational studies are not planned and usually sites are not selected to be part of an experiment, but for other reasons such as improving safety. The most common studies are the observational since they consider safety measures for improving the roadway system. These studies use crash data to derive Crash Modification Factors (CMFs) only. CMFs are measures of the estimated effectiveness of safety countermeasures. Specifically, they are multiplicative factors used to calculate the *expected number of crashes* at a site after specific countermeasures are implemented (Gross et al., 2010).

Observational Studies

Observational studies are generally classified into before-after studies and cross-sectional studies. Gross et al, 2010, explains the difference between both studies by stating that "Before-after designs include a treatment at some period in time and a comparison of the safety performance *before* and *after* treatment for a site or group of sites. Cross-sectional designs compare the safety performance of a site or group of sites *with* the treatment of interest to similar sites *without* the treatment at a single point in time." Before after studies are less likely to lead to confounding since the same *roadway unit* is used potentially by same users in the before and after periods. They are less confounding when compared to cross- sectional studies (Carter et al., 2012).

However, several issues have been found in both studies when developing CMFs. Issues associated with before and after studies involve sample size requirement for smaller standard errors, and potential bias from changes in traffic volumes and reported crash history and regression-to-the-mean (RTM). "Regression-to-the-mean (RTM) is the tendency of sites with abnormally high or low crash counts to return (regress) to the usual mean frequency of crashes during the following years. The bias due to RTM will arise if sites are selected for treatment based on a randomly high short-term crash count. In this case, because of RTM, crashes at the treated site may come down after the treatment is implemented due to RTM even if the treatment does not have any effect," (Carter et al., 2012). When the application of a specific countermeasure is sufficient, the preferred type of study is the before and after. For insufficient occurrences when a countermeasure is applied the preferred method is the cross-sectional. However, data for deriving CMFs in the cross-sectional studies are rooted on a single time period under by assuming that the proportion of average crash frequency for treated or untreated locations is an approximation of the CMF for implementing the treatment. Since the application of both countermeasures (Clearview fonts and fluorescent yellow sheeting) is highly frequent in Michigan, a before and after study is reasonably selected for this study.

Types of Cross-Sectional Study Designs

Variations among cross-sectional studies include case- control and cohort studies. As presented in Gross et al., (2010), "case-control studies select sites based on outcome status (e.g., crash or no crash) and then determine the prior treatment (or risk factor) status within each outcome group". The relative effects of treatments are shown using case-control studies by using statistical approaches such as multiple logistic regressions thus examining the *risk/benefit* related to one factor while controlling the others. This method is very useful for studying unusual events since the number of cases and controls is predetermined. “In Cohort studies, sites are assigned to a particular cohort based on current treatment status and followed over time to observe exposure and event frequency” (ibid). In this case one cohort includes the treatment and the other acts as control group without the treatment. This type of study type can provide valid results for unusual treatments since sample is selected based on treatment status.

Types of Before-After Study Designs

Before and after studies that are used currently in the field include: naïve before-after study, before-after study with comparison group, Empirical-Bayes (EB) before-after study, full or hierarchical Bayes Before-After Study, and Intervention and Time Series Analysis Methods.

A naïve before-after study is a simple before-after comparison assessing the safety effects of treatments through direct comparison of crash frequencies of before and after periods. The distinctive naïve before-after study design does not account for potential bias due to RTM and does not account for trends or sequential effects.

In the case of before-after study with comparison group identification of an untreated comparison group similar to the treatment group is performed to account for sequential effects and *changes in traffic volume*. It is assumed that there are similar trends in crash counts in both treatment and comparison groups. Hauer (1997) suggests a comparability test that makes use of a series of *sample odds ratios* to determine if the trends in both groups are certainly comparable. This method, however, does not clearly account for RTM. Therefore, it is a practical method if selection of sites is not based on crash history or availability of a long before period is present thus reducing the potential bias due to RTM.

Moreover, “as with all before-after designs, the intent of the EB procedure is to estimate the expected number of crashes that would have occurred had there been no treatment and compare that with the number of reported crashes after the treatment was implemented” (Carter et al., 2012). This method has been demonstrated to correct for the potential bias due to RTM, account for *changes in traffic volume* and for *temporal effects* through the use of Safety Performance Functions (SPFs). A reference group is used to approximate the expected crash frequency from a Safety Performance Function (SPF). The obtained estimates, combined with the observed crash frequency in the before period (of the treatment group), approximate the *long-term* expected crash frequency with no treatment.

“In the case of the full or hierarchical Bayes, the distribution of likely values from the reference group is used instead of the point estimate. By using the distribution of likely values, more accurate estimates of the CMF and its variance are possible” (Carter et al., 2010).

Finally, intervention and time series analysis methods commonly are recognize to commonly use the Autoregressive Integrated Moving Average (ARIMA) method. The ARIMA method is based on the assumption that data follows a normal distribution. This assumption is been shown to be suitable for aggregate data (e.g. the number of crashes at county or state level). In order for these models to account to RTM bias, longer before period has to be considered.

CHAPTER 3

PERCEPTION SURVEY

Objective and Purpose

A survey was conducted in order to observe preference of installed countermeasures (Clearview fonts and fluorescent yellow sheeting). The analysis provides with the view for the preference of all drivers. A series of situations helped guide the participants to reminisce when he or she saw the countermeasure and thus provide with his or her preference over the standard installation. Also, this is the first survey addressing the lack of knowledge on driver's preferences on installed countermeasures in Michigan. By filling this gap, future informed decisions are taken related to analyzed countermeasures.

Data Collection

Survey data was collected by the Western Michigan University research team. The field survey was administered in four metro areas in Michigan: Kalamazoo, Grand Rapids, Lansing and Detroit. Four types of facilities were to be surveyed within a metro area: restaurants, grocery stores, senior centers and rest areas. Specific locations were randomly selected according to the following criteria: application of countermeasure in the area, high density of those needing improvement the most (according to research those greater than 65 years) and high number of crashes in the area. Using the aid of Google Earth, facilities were identified with their geographical information using the pinning tool of the program. Once pinned, locations were layered in ArcMap 10.0, which is an advanced application of Geographic Information System (GIS) software. ArcMap 10.0 helped in mapping facility locations, high frequency in number of crashes, and locations where the studied countermeasures were implemented. Crash data was obtained from Michigan Crash Records provided by the Office of Highway Safety Planning (OHSP).

A small pilot survey was conducted at Kalamazoo grocery stores and restaurants. The survey was carried out during business days of the last two weeks of May 2014. Since the main purpose of the survey was to observe the preference of drivers towards implemented countermeasures, the questionnaire and contents were structure appropriately. Driver demographics included location, date, gender, race, age group, and zip code. Each question in the survey reflected the area where the countermeasure is expected to improve the driving experience. Each interviewee was presented with pictures showing the implemented countermeasure as option one and the standard installation as option two. Participants could select a neutral or Non Applicable (N/A) option if they believe that they preferred both countermeasures equally or they were not exposed to either of the installations, respectively. Appendix A presents the survey questionnaire.

Methodology, Findings and Discussion

After processing the data, statistics were estimated from interviewees who have noticed the difference and those who never noticed the difference in installations prior to the survey. Descriptive statistics and chi-squares were the methodology used to classify the perception of the participants and the strength of preference, respectively. A sample of 1590 drivers was interviewed exceeding the target (1500). The distribution of all participants per age group is provided in Table 2.

Table 2: Distribution of survey participants by age and location

	Metro Area				
Age Group	**Detroit**	**Grand Rapids**	**Kalamazoo**	**Lansing**	**Total**
16-24_Years	38	51	54	48	191
25-34_Years	76	57	51	49	233
35-49_Years	70	109	77	92	348
50-64_Years	68	144	128	112	452
65-74_Years	49	50	50	102	251
75-84_Years	18	18	21	32	89
85+	8	2	5	11	26
Total	**327**	**431**	**386**	**446**	**1,590**

Clearview Fonts on guide Signs

For this countermeasure participants were asked to classify the easiness of the selected option (countermeasure vs standard) and to rate its legibility in the four situations (on high speed roads, from far distances, in inclement weather, and nighttime). Figure 4 shows the preferences of those who never noticed before versus those who noticed before the Clearview fonts while driving. From the figure it is evident that all drivers regardless of their age preferred the Clearview fonts (more than 60% on average) on high speed roads over the standard. Among those who never noticed the countermeasure before the majority preferred the countermeasure on high speed roads. There is no statistical evidence to suggest difference in preferences for the countermeasure per age group on high speed roads.

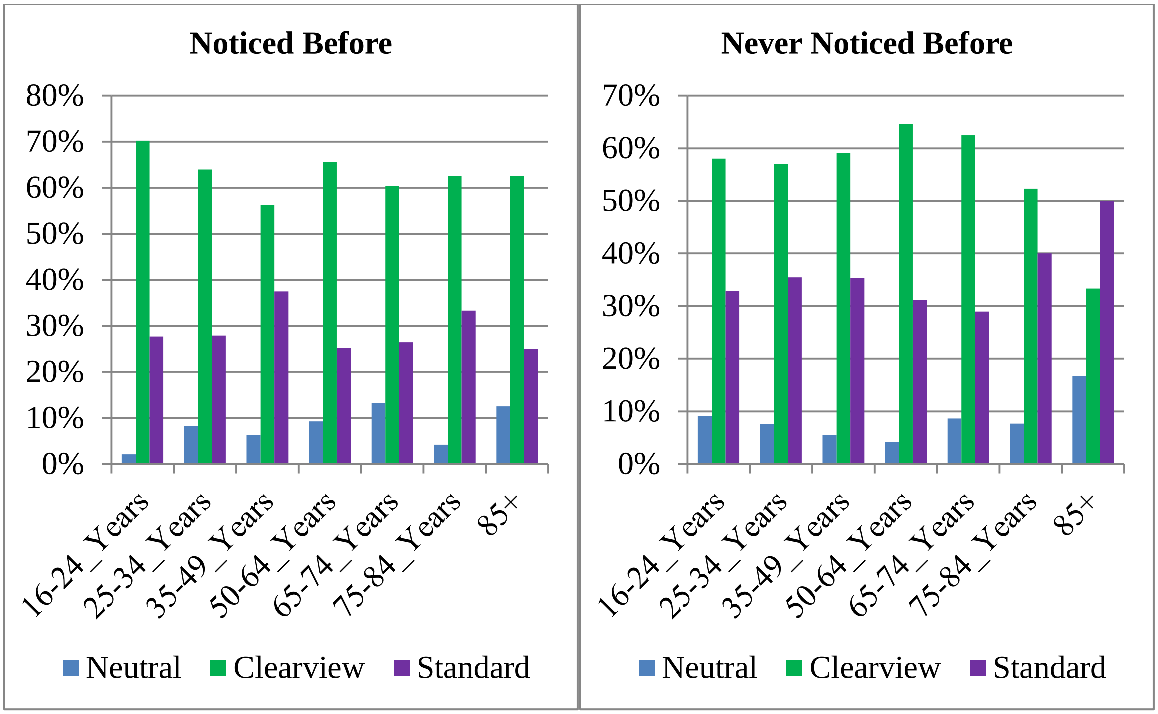


Figure 4 Preferences of Clearview fonts on high speed roads

Figure 5 presents that all drivers prefer the Clearview fonts from far distances disregarding their age group. In this case the elderly (85 years and above) overpasses the preference of the newer font by more than 70% among those who noticed the countermeasure before (while driving). Both young adults (25-34 years) and early elder (65-74 years) preferred the countermeasure the most when first interviewed. Since legibility from far distances is one of the main objectives in using Clearview fonts, this output supports the purpose of the installation. Again, there is no significant difference between the preferences of the countermeasure per age group.

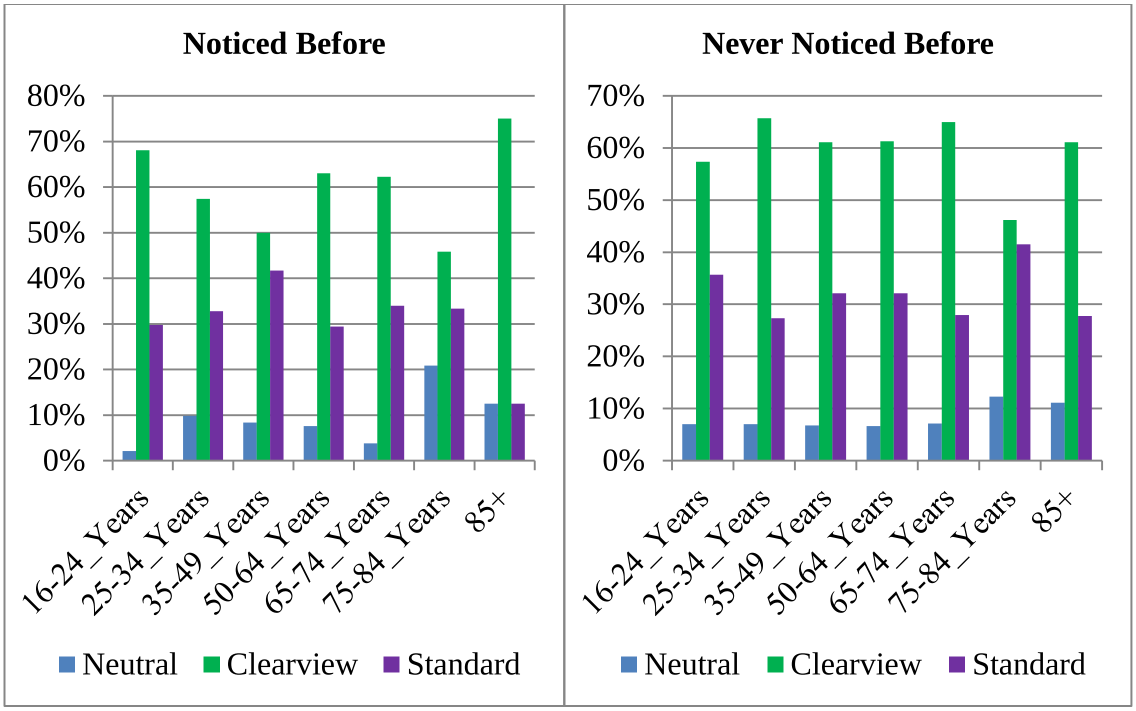


Figure 5 Preferences of Clearview Fonts from far distance

Moreover, Figure 6 presents the preference of the countermeasure versus standard in inclement weather. In this case those who never noticed the countermeasure before unexceptionally preferred the countermeasure. From Figure 6 it is revealed that for inclement weather the preference of the countermeasure is approximately 50% on average. There was not a massive selection of the countermeasure from the youngest (16-24 years) and eldest group (85 years and above) among who noticed it before. The results indicated that there is no significant difference between the preferences by age groups in inclement weather.

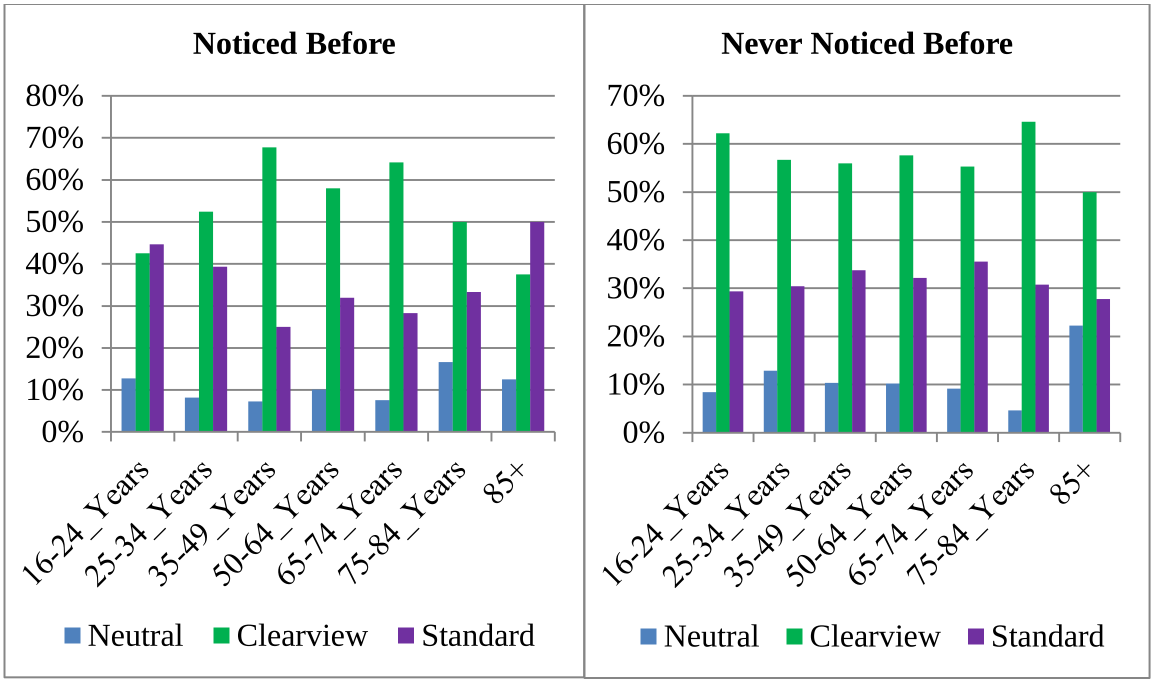


Figure 6 Preferences for Clearview fonts in inclement weather

Finally, Figure 7 presents the selection of the Clearview fonts and standard font in nighttime. It is evident from results that the Clearview fonts are preferred by all age groups. Among those who noticed the countermeasure before the elderly (85 years and above) preferred the Clearview fonts the most during nighttime. This is similar to the case of from far distances where this last group preferred the countermeasure the most. Also, results show that younger drivers (16-24 years and 25-34 years) preferred the most the countermeasure once they were presented for the first time, in nighttime. Again since it is crucial from this countermeasure to improve legibility in nighttime, this output helps visualizing that the objective is being fulfil at perception level. There is no statistical evidence to suggest difference in preferences for the countermeasure per age group during nighttime.

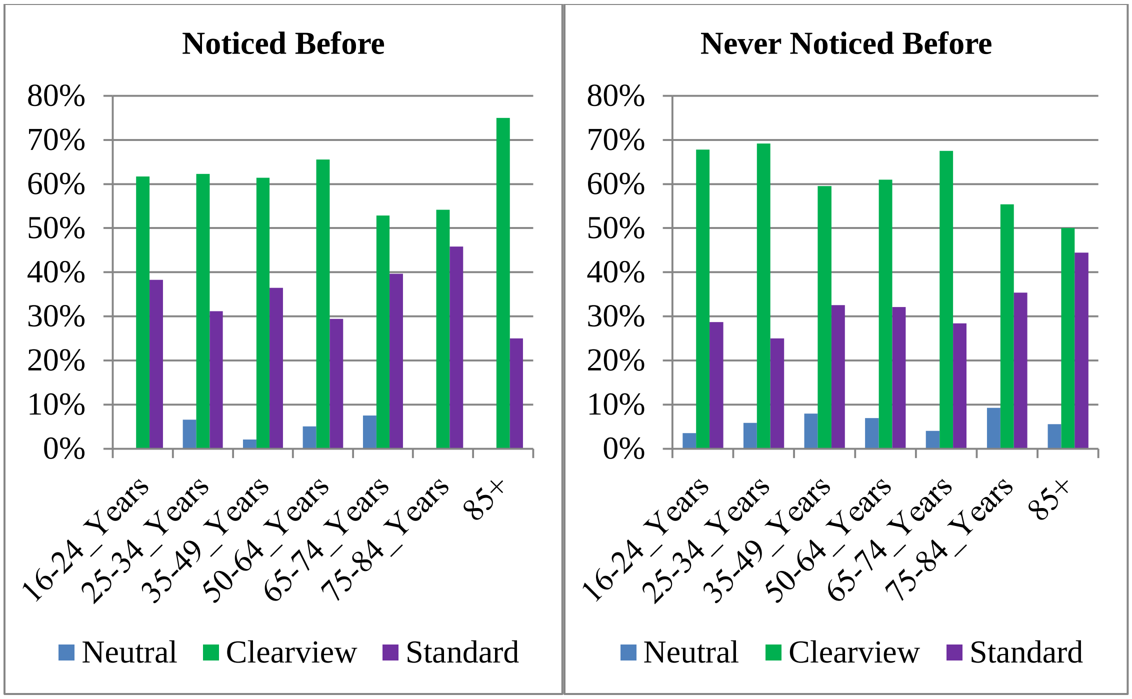


Figure 7 Preferences for Clearview fonts in night time

Fluorescent Yellow Sheeting

In the case of fluorescent yellow sheeting participants were asked to select and rate the easiness is identifying the presented warning sign material on high speed roads, in inclement weather, and in nighttime. Figure 8 shows the preferences between the countermeasure and standard installation on high speed roads by those who had noticed the differences before and those who never noticed the difference before. Results show that more than 70% on average preferred fluorescent yellow sheeting for warning signs. This is regardless of their awareness or not of the implemented countermeasure prior the interview day. From those who never noticed the difference before it is observed that more than 80% of the elderly (85 years and above) preferred the countermeasure. There is no statistical evidence to suggest difference in preferences for the countermeasure per age group on high speed roads.

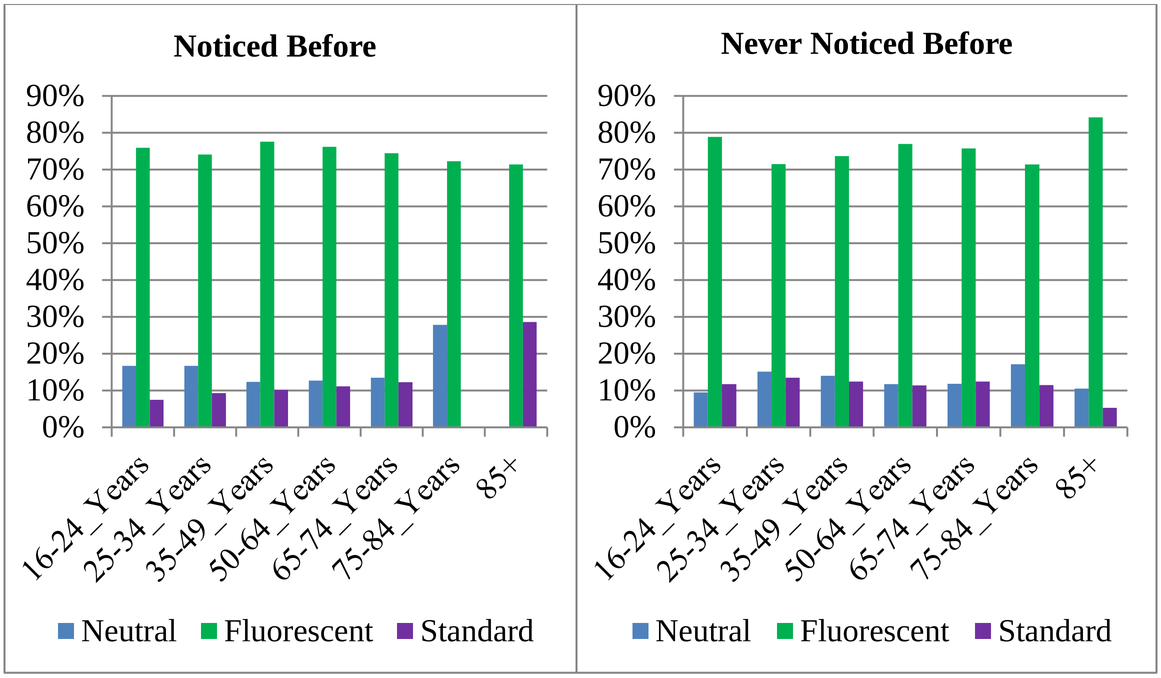


Figure 8 Preferences of fluorescent yellow sheeting on high speed roads

Figure 9 shows the results for selection of the fluorescent yellow sheeting and standard sheeting in inclement weather. More than 75% (on average) preferred the fluorescent yellow sheeting in inclement weather over the standard sheeting regardless of noticing the difference in installations before or not. There is no statistical evidence to suggest difference in preferences for fluorescent yellow sheeting per age group during inclement weather.

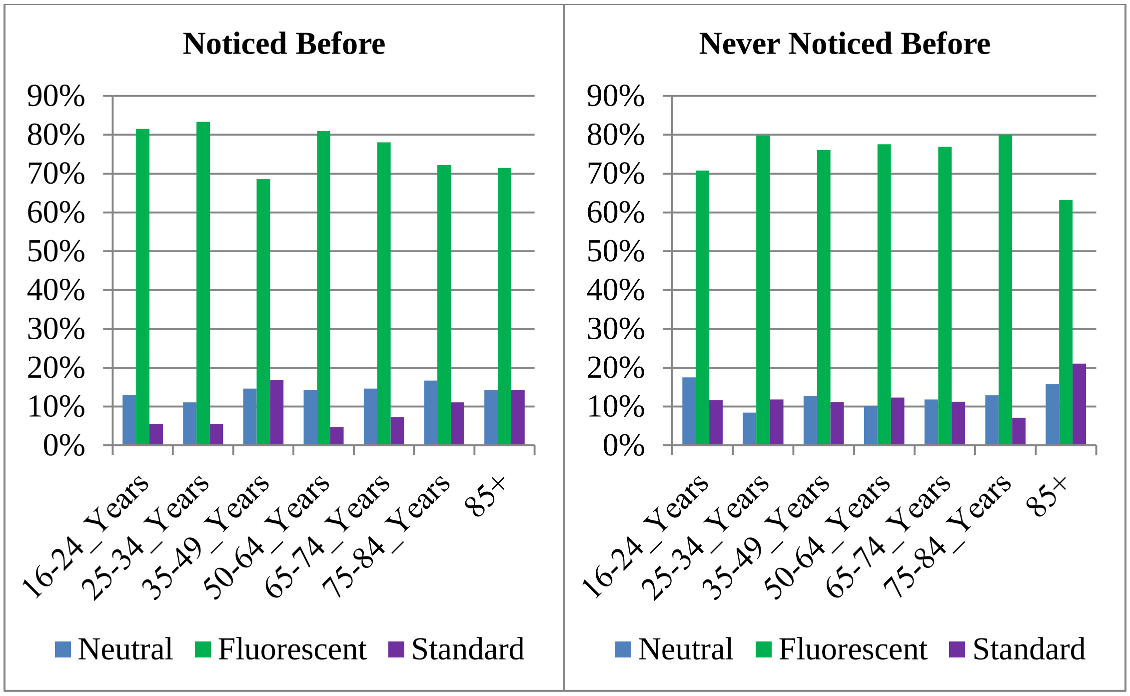


Figure 9 Preference of fluorescent yellow sheeting in inclement weather

Finally, Figure 10 shows the perception of drivers in relation to fluorescent yellow sheeting in nighttime. More than 70% on average selected the fluorescent yellow sheeting to be easier to recognize during this time of the day. The selection is shown to be with similar proportion among those who noticed and never noticed before the difference in installations. As past research suggest, this output presents that fluorescent yellow sheeting are highly helpful during the nighttime in recognizing the warning signs. No statistical evidence was found to suggest difference in preference for the countermeasure by age groups.

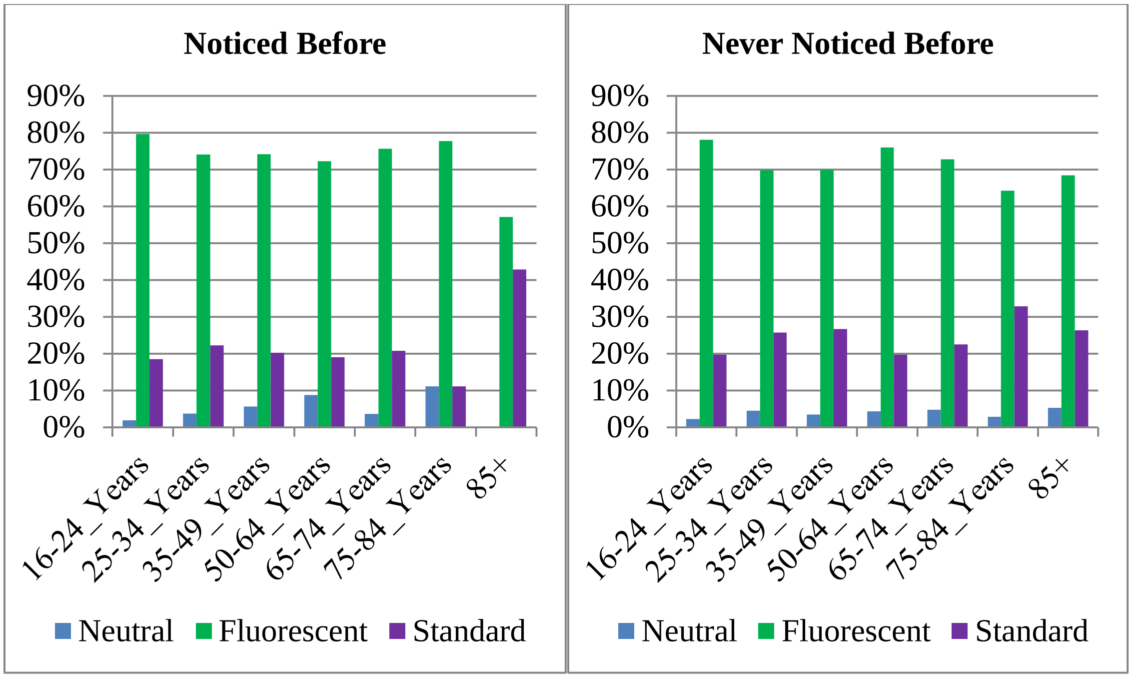


Figure 10 Preference of fluorescent yellow sheeting in Nighttime

In conclusion, preference for installed countermeasures was observed for all drivers, generally. Countermeasures are preferred on high speed roads, inclement weather, from far distance of the sign (in the case of Clearview fonts) and in night time. These findings are in accordance with literature review where researchers explain how helpful they are mostly during night time for all drivers and specially the elders. Even though they might not be recognize by name, they are being noticed by drivers in the state of Michigan. It is recommended that the same study be perform through either using a driving simulator or experimentally in a road segment for better responses. However, obtained responses perfectly prepared the platform for developing a crash analysis in this case. Observing the preference of the countermeasure just justifies the need of their scientific evaluation. Meanwhile basic recommendations suggest the continue usage of the countermeasures. The following chapters cover the methodology used for crash data analysis for evaluating the countermeasures.

CHAPTER 4

DATA COLLECTION

The intent of this chapter is to present the process of crash data collection for the countermeasures analyzed. Data collection was mainly divided into the selection of segments, crash data, and the suitability tests of selected sites. There were different factors that contributed to the data collection process: aid of available software, provided crash records and location of improvements. Most of the data was provided by MDOT (treatment sites, sufficiency files, crash records, implementation dates, differential costs for implementation of improvement and standard installations, and service life for each installation).

Selection of Segments

MDOT started installing fluorescent yellow sheeting in 2006. One year later (2007) both countermeasures (Clearview fonts and fluorescent yellow sheeting) started to be implemented together at the same site. Prior to year 2006 none of the countermeasures were installed in Michigan. Separating both countermeasures for data collection was, indeed, not possible for segments where installation occurred in 2007 or after. MDOT provided the records regarding to the location of both countermeasures. Records were the same for both installations differentiating only in the presence of the countermeasure (only one, both, or none). Table 3 presents an example of provided records. The lack or presence of countermeasures were labeled as follows: NN (none of the countermeasures has been installed), NY (only fluorescent yellow sheeting has been installed), and YY (both of them are installed).

Table 3 Example Data in MDOT's Corridor

Year	PR	PR_BMP	PR_EMP	PR_Miles	Route	Clearview?	Fl. Yellow?
2008	1540402	7.130	25.934	18.804	US-31	**Y**	**Y**
2006	657303	0.000	12.280	12.280	I-96	**N**	**Y**
2005	15007	11.659	24.659	13.000	US-131	**N**	**N**

By using the Physical Reference number Finder (PR FINDER) tool available at the MDOT's website, segments were extracted from corridors. The site locates the Physical Reference Beginning Miles Point (PR_BMP) and Physical Reference Ending Miles Point (PR_EMP) of a selected segment within a corridor. MDOT's Sufficiency files (files with segments data) provided with the segment needed information (geometric, geographic, physical, and more characteristics). Segments were identified with a specific number (Segment ID) to keep consistency. Geographic Information System (GIS) software was used to layer the identified segments (from the website). Figure 11 presents the study freeway segments. Criteria for selecting a potential segment included:

1. length of the segment to be less than 5 miles for freeways and less than 8 miles for non-freeways;
2. number of interchanges (for the case of freeways) or main intersections (for the case of non-freeways) to be less than or equal 2;
3. and shape of the segment not to be with high rate of curvature.

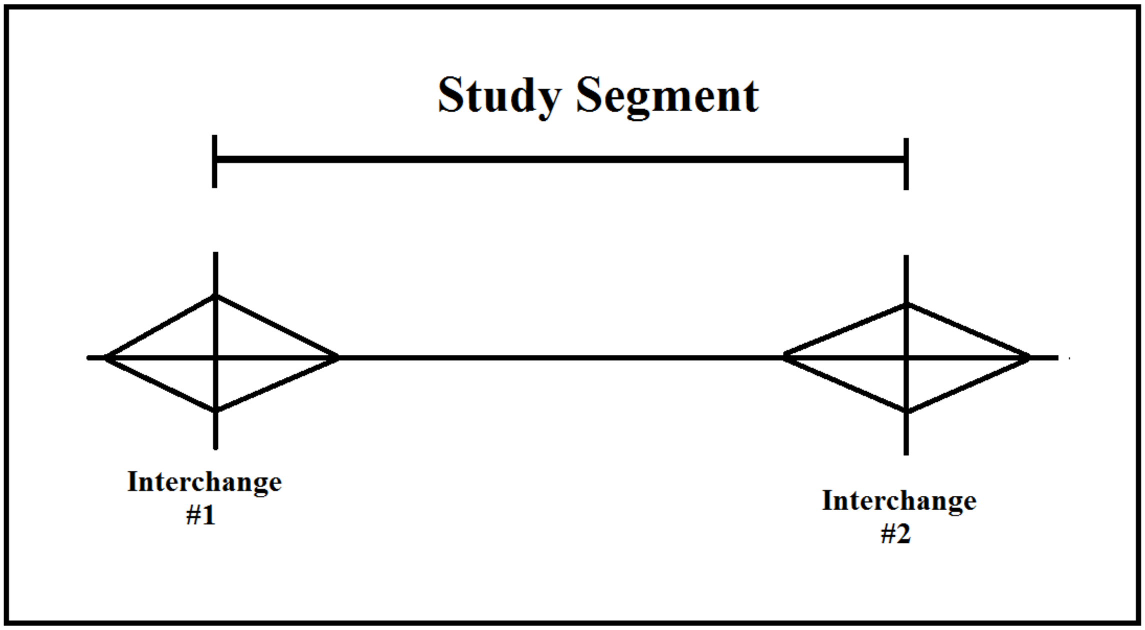


Figure 11 Definition of the Freeway Segment

Table 4 presents the total number of potential selected segments passing the criteria. Targets in selection were over 100 segments where it was possible. In the case of freeways where only fluorescent yellow sheeting were applied (NY) the selection was the lowest since approximately 30 sites were improved.

Table 4 Number of Selected Segments

Highway Classification	No Clearview nor Fluorescent (NN)	Fluorescent Only (NY)	Both Clearview and Fluorescent (YY)
Freeway	101	66	100
Non Freeway	108	100	100

However, few segments presented issues that were observed through inspecting sites using Google Earth images. Issues were related to the sign identification, multiple improvements and restrictions from improvement year. Issues with sign identification were related to sites with inverted status of improvement. For example, unimproved sites are supposed to have standard fonts on guide signs and standard yellow warning signs and vice-versa. Few segments were found to have Clearview fonts where they were in the unimproved list. Figure 12 shows an example of an improved sign found in a segment identified as not improved. This issue led to removal of few segments from the control site group (NN).

Figure 12 Location characteristics of an "Unimproved" Site in Michigan

Corridor	Region	Route	Clearview/Fluorescent?	Date of Google Image
Allegan and Kalamazoo Countries	Southwest	US-131	**NN (No Clearview/No Fluorescent)**	**August 2012**

Multiple improvements at a site were found to be an issue for subsequent crash analysis. Figure 13 presents a site with before and after periods of a site with multiple improvements. Having extra signage could be a potential cause of accidents related to truck drivers that are not aware of the implemented sign in early years of implementation. Such site could potentially bias the result if not removed from the sample.

Figure 13 I-75 from Oakland/Wayne County Lane to M-59 in before period (left) and after period (right)

Finally, sample size of chosen segments was affected by the improvement year of the segment. For example, sites for which improvement years were above 2012 were not considered since crash data analysis required at least two years before and after improvement at sites. After cleaning the data the remaining sites for unimproved sites were 93 from 101 and 104 from 108 in both freeways and non-freeways, respectively. Descriptive statistics of the geographical area of each highway classification was performed. The results showed that 75% of selected freeway segments were on urban areas. In the case of non-freeway selected segments were approximately 50% in urban and 50% in rural areas. Thus, the non-freeway data was disaggregated into urban and rural and the sample size was increased. Table 5 shows the summary of cleaned selected segments along with the highway classification and presence of improvement.

Table 5 Selected Segments for Freeways and Non-Freeways

Highway Classification	Neither Clearview nor Fluorescent (NN)	Fluorescent Only (NY)	Clearview & Fluorescent (YY)
Freeways	93	45	79
Non-Freeways (Urban)	92	59	34
Non-Freeways (Rural)	100	68	43

Among selected sites, there were few segments that were paired based on similar characteristics such as traffic volume, geographical location, and number of lanes. There were 45 (when both countermeasures were present) and 42 (when only one countermeasure was present) paired sites for freeways; 34 (both countermeasures) and 57 (only one countermeasure) for urban non- freeways, and 34 (for both countermeasures) and 52 (for one countermeasure) for rural non-freeways. Figure 14 shows the distribution of all selected segments in Michigan for freeways and non-freeways, respectively.

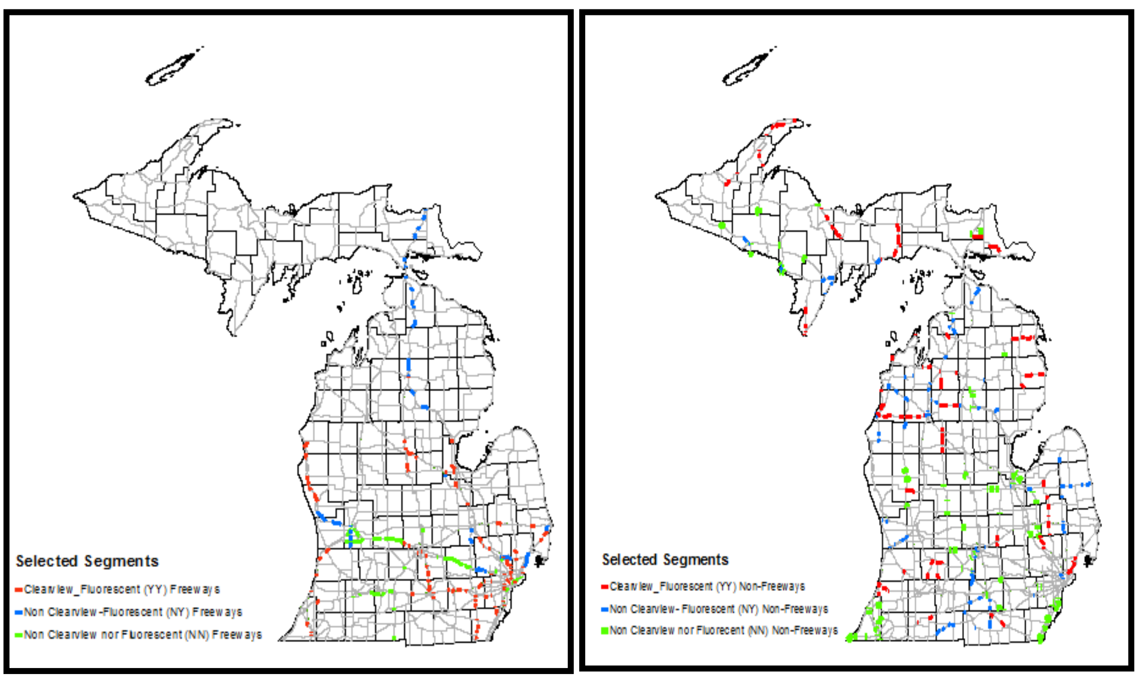


Figure 14 Selected segments on freeway (left) and non-freeway (right)

Selection of Crash Data

Raw files of crash data were barrowed from OHSP's Crash Records. The records had data on crash date, location, and lighting condition, fatality, driver's age and more. This record information was helpful for developing Crash Modification Factors (CMFs) for drivers' age groups, lighting condition and fatality (from the implemented countermeasures in Michigan).

Crash data collection included all sites analyzed: NN, NY and YY. NN sites were considered control or comparison and NY along with YY were the treated sites. Crash data ranged from years 2004 through 2013. For non-freeways crashes for collection were those at midblock areas of the selected segments. Intersections crashes were not in the scope of the study. A circular buffer of with 250 feet of radius helped in separating intersection crashes from segment crashes. Figure 15 shows the layout for midblock segments for non-freeways

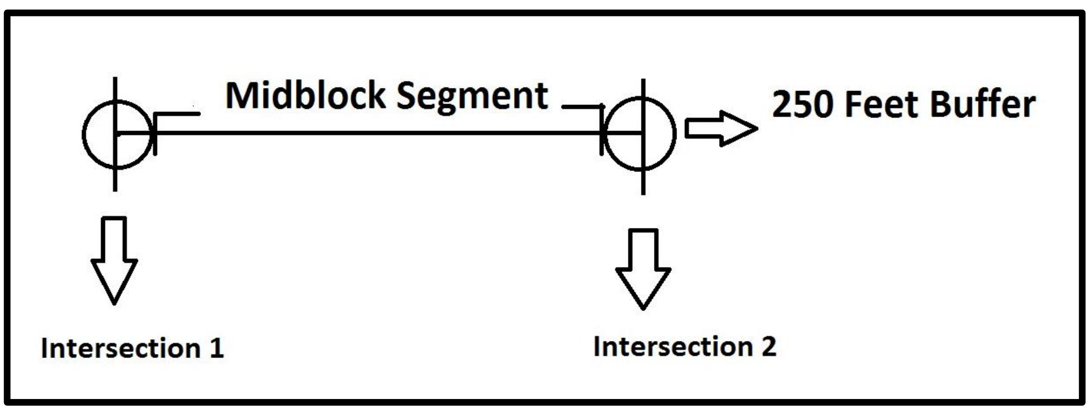
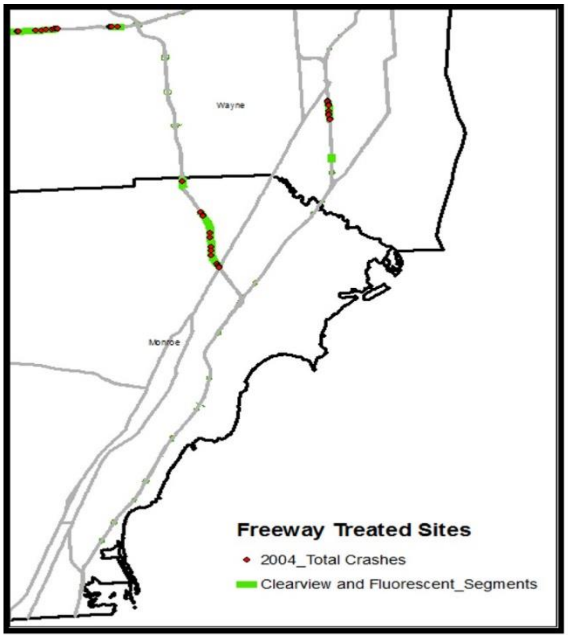


Figure 15 Presentations of Midblock Area and Buffer for Non-Freeway Segments

Figure 16 presents the intersected layers of crashes, buffer and segments for both freeways and non-freeways



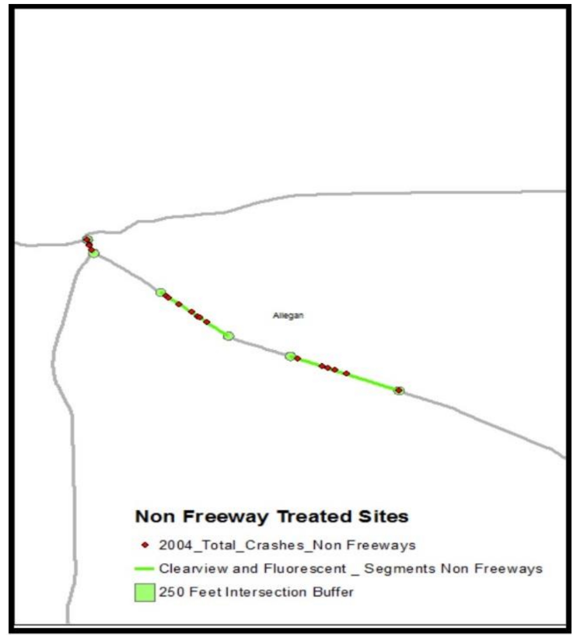


Figure 16 Treated Sites for freeways (left) and non-freeways (right)

Crash data was divided into ten crash conditions, which were the basic of the analysis. Also, since age groups as presented in Chapter 3 were several, at this level (data collection for crash analysis) they were aggregated into two main groups: under-65 years (from 16-64 years) and 65-and- above years. Crash conditions are listed as follows:

1. Total Crashes (All severities, KABCO)

Where: K stands for fatal injury, A stands for incapacitating injury, B stands for non-incapacitating injury, C stands for possible injury, and O stands for property damage only

2. Fatal/ Injury (KABC)
3. Total Day Crashes
4. Total Night Crashes
5. Total Under-65-years Crashes
6. Total Under-65-years Day Crashes
7. Total Under-65-years Night Crashes

8. Total 65-and-above-years Crashes
9. Total 65-and-above-years Day Crashes
10. Total 65-and-above-years Night Crashes

The main purpose of dividing data into the presented crash conditions was disaggregation to test if the improvements made had different impacts (by age, daytime, nighttime, and fatal classification). The statistical software STATA helped in organizing collected crash data. Data on improvement year, length, Average Annual Daily Traffic (AADT), road type, speed limit, number of lanes, median type, and others were collected per each crash condition. Google Earth helped in verifying for the geometric characteristics.

Table 6 presents the summary of variables (along with their descriptive statistics) considered in analyzing countermeasures on for freeways. Consideration for variables was based on their influence in segment crashes on freeways. The smallest and largest value from the variable is presented in “min” and “max” columns. There were discontinuous variables ranging from 0 to 1 (minimum and maximum). Proportions of the presence of these variables are reflected in the mean value. From the variable list median type and the presence of urban area were measured in proportions of the type present. The most frequent median was graded with Ditch (65%). Most of the freeways segments were on urban areas: 75%. Std. Dev. stands for the standard deviation of each variable form the mean values.

Table 6 Summary of Variables Considered for Analysis of Clearview font and fluorescent yellow sheeting on Freeways

Variables	Variable Description	Min.	Mean	Max.	Std. Dev.
Avg. Total Crashes	Average number of Crashes (2004-2013)	3	17.48	62	11.24
Length	Length of Segment (in Miles)	0.32	1.70	4.84	1.20
Avg. AADT	Average of Annual Average Daily Traffic	13,011	42,567	112,361	26,971
Avg. CADT	Average of Commercial Average Daily Traffic	556	3775	7177	1730
Number Lanes	Number of Lanes in Segment during peak hour conditions	2	2.40	4	0.51
Number of Interchanges	Number of Interchanges at ending points of Segment	0	1.01	2	0.70
Concrete Barrier	Median Type where : 1 = if present; 0 = Otherwise	0	0.32	1	0.47
Guardrail	Median Type where : 1 = if present; 0 = Otherwise	0	0.01	1	0.10
Graded with Ditch	Median Type where : 1 = if present; 0 = Otherwise	0	0.65	1	0.48
Urban	Geographical Location where: 1 if urban; 0 = rural	0	0.75	1	0.43

More variables were considered for the case of non-freeways as compared to freeways. There is more variation in traffic situations in non-freeways than in freeways. Table 7 provides with the summary of variables considered for analyzing urban non-freeways. Discontinuous variables were median type, road type, presence of sidewalk, presence of non-motorize facility, terrain type, and presence of parking area. From selected median type 79% was undivided. Most of the segments had level terrain (93%). Parking was not allowed in 95% of the sites. 61% of sites did not have sidewalk. The lack of non-motorize facilities was massively reflected in 91% of the sites. 42% of the segments were two way undivided.

Table 7 Summary of Variables Considered for Analysis of Clearview font and fluorescent yellow sheeting on Non-Freeways (Urban Areas)

Variables	Variable Description	Min	Mean	Max	Std. Dev.
Avg. of Total Crashes	Average number of total crashes observed (2004-2013)	0	12.20	64	13.84
Avg. AADT	Average of Annual Average Daily Traffic	2897	12355	32050	6952
Length	Length of Segment (in Miles)	0.23	1.01	4.46	0.73
Access Points	Total Number of Access Points within segment	0	11.01	65	10.71
Undivided MEDIAN	Median Type where : 1 = if present; 0 = Otherwise	0	0.79	1	0.41
Graded with Ditch	Median Type where : 1 = if present; 0 = Otherwise	0	0.11	1	0.31
Raised Island with Curb	Median Type where : 1 = if present; 0 = Otherwise	0	0.09	1	0.28
Flat (Paved & Unpaved)	Median Type where : 1 = if present;0 = Otherwise	0	0.01	1	0.10
Divided	Road Type where : 1 = if present; 0 = Otherwise	0	0.21	1	0.41
Two Travel Lanes with Center Left Turn Lane (CLTL)	Road Type where : 1 = if present; 0 = Otherwise	0	0.03	1	0.18
Four Travel Lanes CLTL	Road Type where : 1 = if present; 0 = Otherwise	0	0.27	1	0.45
One-Way Street System	Road Type where : 1 = if present;0 = Otherwise	0	0.07	1	0.25
Two-Way Undivided Road	Road Type where : 1 = if present; 0 = Otherwise	0	0.42	1	0.50
Level Terrain	Terrain of segment where: 1 if Level; 0 = otherwise	0	0.93	1	0.25

Variables	Variable Description	Min	Mean	Max	Std. Dev.
Rolling Terrain	Terrain of segment where: 1 if Rolling; 0 = otherwise	0	0.07	1	0.25
No Parking Allowed	Parking area where : 1 = if Not allowed; 0 = otherwise	0	0.95	1	0.23
Parking Allowed on one Side	Parking area where : 1 = if allowed on one side of segment ; 0 = otherwise	0	0.01	1	0.10
Parking Allowed on both Sides	Parking area where : 1 = if allowed on both side of segment ; 0 = otherwise	0	0.04	1	0.21
No Sidewalk	Sidewalk presence in segment where: 1 = if No sidewalk; 0 = otherwise	0	0.61	1	0.49
Sidewalk Present (One Side)	Sidewalk presence in segment where: 1 = if Sidewalk on one side; 0 = otherwise	0	0.15	1	0.36
Sidewalk Present (Both Sides)	Sidewalk presence in segment where: 1 = if Sidewalk on both sides; 0 = otherwise	0	0.24	1	0.43
No Non-Motorized	Non Motorize facility where : 1 = if No Non motorize facility; 0 = otherwise	0	0.91	1	0.28
Non-Motorized	Non Motorize facility where : 1 = if Non motorize facility; 0 = otherwise	0	0.09	1	0.28
Number of Lanes	Main number of lanes (through) in the segment	1	2.98	5	0.99
Lane Width	Predominant width of the traffic lanes for segment (in feet)	10	11.75	12	0.46
Speed Limit	predominant posted speed limit for segment (in mph)	25	45.11	55	8.58
Median Width	Main median width for divided segments (in feet)	0	13.13	33.61	196

Similar variables were considered for analysis in rural non-freeways to urban non-freeways. Table 8 presents the summary of variables considered in analysis for rural non-freeways. As in the case of urban non-freeways, the road type used the most was two-way undivided (87%). The median that was present in most of the sites was the undivided (94%). The sites selected were mostly in a level terrain than in a rolling terrain. There was a massive lack of parking area (98%), presence of sidewalk (93%) and non- motorize facilities (94%). The average speed limit for most of the sites was 55 miles per hour as expected in most rural areas.

Table 8 Summary of Variables Considered for Analysis of Clearview font and fluorescent yellow sheeting on Non-Freeways (Rural Areas)

Variables	Description	Min	Mean	Max	Std. Dev.
Avg. Number of Total Crashes	Average number of total crashes observed (2004-2013)	1	10.35	48	9.81
Avg. AADT	Average of Annual Average Daily Traffic	60	4876	13005	2886
Length	Length of Segment (in Miles)	0.36	3.25	13.37	2.53
Access Points	Total Number of Access Points within segment	0	9.36	44	7.32
Divided	Road Type where : 1 = if present; 0 = Otherwise	0	0.06	1	0.24
Two Travel Lanes CLTL	Road Type where : 1 = if present; 0 = Otherwise	0	0.04	1	0.20
Four Travel Lanes CLTL	Road Type where : 1 = if present; 0 = Otherwise	0	0.03	1	0.17
Two-way Undivided	Road Type where : 1 = if present; 0 = Otherwise	0	0.87	1	0.34
Undivided MEDIAN	Median Type where : 1 = if present; 0 = Otherwise	0	0.94	1	0.24
Graded with Ditch	Median Type where : 1 = if present; 0 = Otherwise	0	0.06	1	0.24
Level Terrain	Terrain of segment where: 1 if Level; 0 = otherwise	0	0.65	1	0.48
Rolling Terrain	Terrain of segment where: 1 if Rolling; 0 = otherwise	0	0.35	1	0.48
No Parking Allowed	Parking area where : 1 = if Not allowed; 0 = otherwise	0	0.98	1	0.14
Parking Allowed (both Sides)	Parking area where : 1 = if allowed on both side of segment ;	0	0.02	1	0.14

Variables	Description	Min	Mean	Max	Std. Dev.
	0 = otherwise				
No Sidewalk	Sidewalk presence in segment where: 1 = if No sidewalk; 0 = otherwise	0	0.93	1	0.26
Sidewalk Present (One Side)	Sidewalk presence in segment where: 1 = if Sidewalk on one side; 0 = otherwise	0	0.02	1	0.14
Sidewalk Present (Both Sides)	Sidewalk presence in segment where: 1 = if Sidewalk on both sides; 0 = otherwise	0	0.05	1	0.22
No Non-Motorized	Non Motorize facility where : 1 = if No Non motorize facility; 0 = otherwise	0	0.94	1	0.24
Lane Width	Predominant width of the traffic lanes for segment (in feet)	11	11.61	12	0.49
Number of Lanes	Main number of lanes (through) in the segment	2	2.12	4	0.48
Speed Limit	Main posted speed limit for the segment in miles per hour (MPH)	25	55	65	6.71

Comparison of Selected Segments

In order to test for comparability among treatment sites (NY and YY) and control sites (NN) two main processes were considered: observation of crash trends on a time series plot and sample odds ratio. The first process "compares a time series of target crashes for a treatment group and a candidate comparison group during a period before the treatment is implemented. If the annual trend in crash frequencies is similar to that of the treatment group (in the absence of treatment), then a candidate comparison group is a good one," (Gross et al, 2010). Figure 17 presents a time series plot of crashes for comparison and treatment groups passing the comparability test for freeways and non-freeways. The trends follow each other. Installation years for selected segments were 2007 and 2010 for freeways and non-freeways, respectively. Thus, crash trends covered those years with lack of improvement.

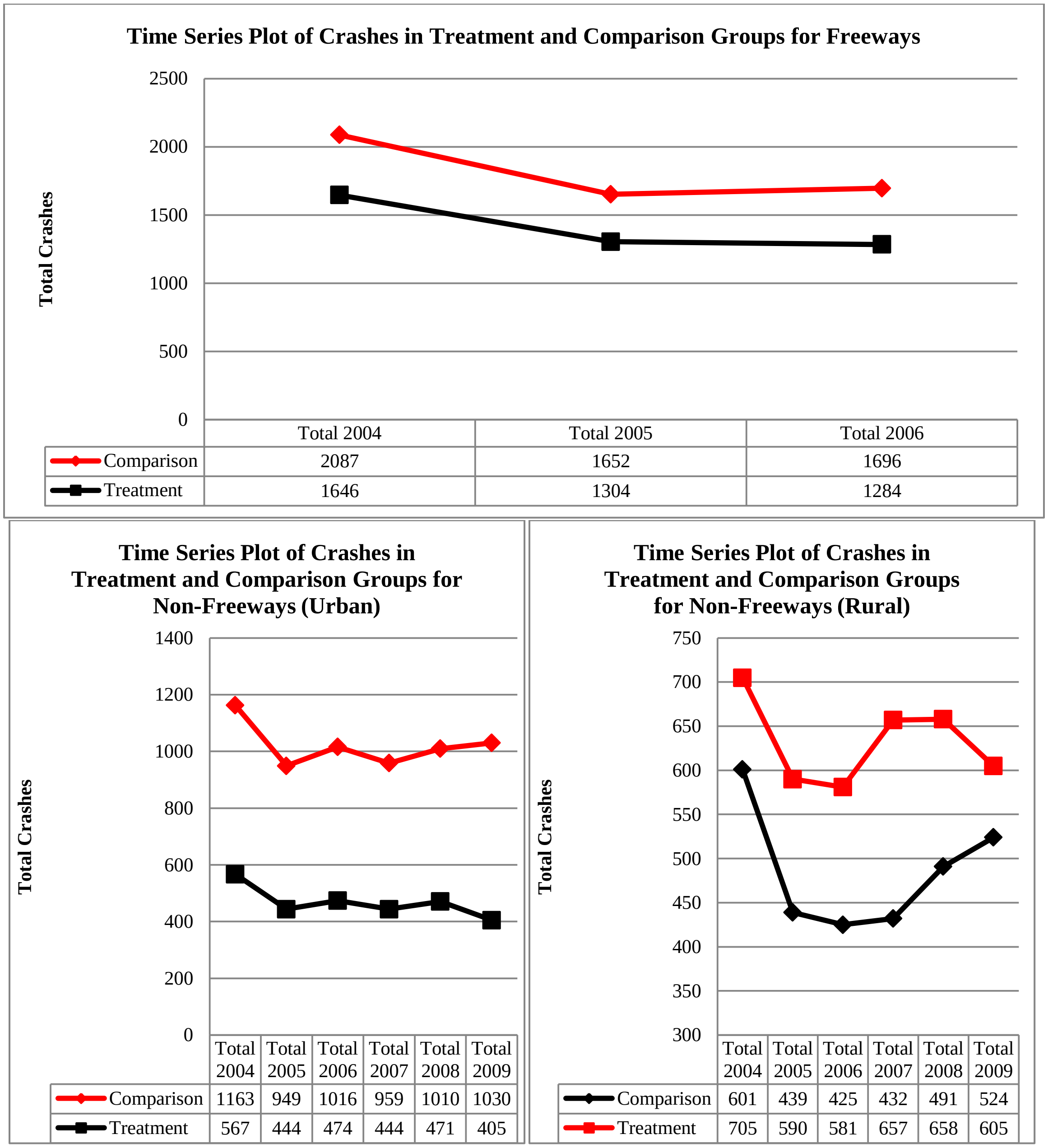


Figure 17 Time series plot of total crashes on freeways and non-freeways

Suitability of a comparison group is tested through sample odds ratio. "The sample odds ratios are computed for each before-after pair in the time series before the treatment is implemented. From this sequence of sample odds ratios, the sample mean and standard error are determined. If this sample mean is sufficiently close to 1.0 (i.e., subjectively close to 1.0 and the confidence interval includes the value of 1.0) then the candidate reference group is deemed suitable," (Gross et al., 2010). Sample odds ratio is determined as follows:

$$sample\ odds\ ratio = \frac{(Treatment_b * Comparison_a)/(Treatment_a * Comparison_b)}{1 + \frac{1}{Treatment_a} + \frac{1}{Comparison_b}}$$

Where:

$Treatment_b$: Total number of crashes in treatment group in initial year

$Treatment_a$: Total number of crashes in treatment group in following year

$Comparison_b$: Total number of crashes in comparison group in initial yea

$Comparison_a$: Total number of crashes in comparison group in following year

Sample odds ratios were calculated for the three cases (freeways, urban and rural non-freeways). The following is an example of calculating the sample odds ratio from the freeway data presented in figure 17.

$$sample\ odds\ ratio\ for\ Freeways\ (2004-2005) = \frac{(2087*1304)/(1652*1646)}{1 + \frac{1}{1652} + \frac{1}{1646}} = 0.999$$

The odds ratio confidence interval is calculated as presented as follows:

$$95\%\ Confidence\ Interval = mean\ \pm 1.96\ (\ Standard\ Error)$$

Finally, since 1 is included in the confidence interval of each analyzed group, it could be concluded that comparison groups are suitable. Sites are similar. Appendix B presents the odds ratios for the three cases and their statistical confidentiality.

CHAPTER 5

EVALUATION METHODS

Introduction

The intent of this chapter is to present the selected methodology in analyzing the crash data. There were two methods selected for the evaluation of the countermeasures: the Empirical Bayes (EB) method (main) and before and after with comparison groups (alternative). Each method is described in this chapter.

Empirical Bayes (EB) Method

The EB has been selected for evaluating the safety effectiveness of countermeasures in the states and over the seas. It has been a suitable method in analyzing crash data and few studies support it. In 2009, Srinivasan et al. performed the safety evaluation of improvements in curve delineation. Using the EB before and after method the research team accounted for the regression to the mean bias. Treatment evaluated included *new chevrons, horizontal arrows*, and *advance warning signs* improving the existing fluorescent yellow sheeting. From results reductions were observed in the number of crashes involving injury and fatality, 18%. Other reductions included crashes in conditions such as dark time of the day. The economic analysis revealed the cost-effectiveness the treatment provided.

A year later, Feldman et al., 2010, using a similar method evaluated safety effects from high-visibility school crosswalks using the EB method, in San Francisco. An even number of treated and untreated sites was used (54) in the analysis. There was a likely reduction of 37% in the number of accidents close to areas with *high-visibility* crosswalks. Authors recommended evaluating other factors affecting pedestrian safety. Three years later, Choi et al., 2013, estimated cause-based CMFs of safety countermeasures in five Korean expressways. *Speed enforcement cameras, rumble strips, delineator posts, barriers on the roadside, barriers in the median, a slide-prevention devices, illumination* and *delineators* (Choi et al., 2013) were installed as safety measures. Three years of data collection for before and after period was needed to develop the EB method (2000- 2008). Negative binomial regression was used in developing the Safety Performance Functions. CMFs were obtained from all countermeasures noticing crash reduction from all of them. A Full Bayes method was recommended for further and deeper study.

Description

The Empirical Bayes (EB) method is a statistical method which combines observed and predicted crash frequencies in order to obtain the expected crash occurrence in interested site, (Herbel et al., 2010). “The methodology is to more precisely estimate the number of crashes that would have occurred at an individual treated site in the after period had a treatment not been implemented,” (Gross et al., 2010). Based on the appreciation that accidents counts are not the only indication to the safety of comparable entities, this method is important for addressing two issues in safety estimation.

The method, first of all, increases the precision of estimation further than what is possible when there is the limit of using two to three years of crash history. Secondly, it corrects for the regression to the mean bias, which is the difference between a perceived reduction in crashes due to treatment and the actual reduction due to the same treatment. This issue is found since naturally crashes with high frequency tend to be followed by low crash frequency, and thus reduction is naturally observed in crashes, which is called regression to the mean (RTM). Predicted crash data are obtained from Safety Performance Functions (SPFs). “SPFs are crash prediction models. They are essentially mathematical equations that relate the number of crashes of different types to site characteristics. These models always include traffic volume (AADT) but may also include site characteristics such as lane width, shoulder width, radius/degree of horizontal curves, presence of turn lanes (at intersections), and traffic control (at intersections),” (Srinivasan et al., 2013). The SPF calculated in the EB method is built using exposure and crash data from numerous similar sites. There are five main steps in the EB method. After determining the SPFs, the over-dispersion parameter, the relative weights, estimation for expected crashes, and safety effectiveness index will complete the process, (Powers and Carson, 2004). The following sections expand on the description of each step.

Modeling Crash Data

Several accident prediction models have been developed in order to estimate the expected crash frequencies and to identify various factors related with crash occurrence. Persaud and Dzbik, 1993, stablish that it is impossible for regression models to consider every single factor affecting crashes. Indeed the focus of the most recent research has been on non-behavioral factors such as traffic flow characteristics, road geometry and environmental circumstances (Persaud and Dzbik, 1993). Moreover, the common relation that regression models have been used for is among crash frequency and explanatory variables. “The result of model strongly relies on the choice of regression technique.” Ordinary linear regression models follow the assumption “of a normal distribution for the dependent variable, a constant variance for the residuals, and the linear relationship existing between dependent and independent variables,” (Chengye and Prakash, 2013). Few authors (Jovanis and Chang, 1986; Abdel-Aty and Radwan, 2000) however, highlight that the conventional linear regression need to be use with caution due to the associated issues with non-negative and error terms.

In order to account for these related issues in conventional linear regression models Jovanis and Chang, 1986, recommended using generalized linear models using Poisson distribution error structure as a mean to describe the random, discrete and non-negative accidents. Response and explanatory variables are assumed to be exponentially related in a Poisson regression. A basic form of the Poisson prediction model is presented below as suggested by Eenink et al., 2008:

$$E\ (\lambda) = \alpha Q^{\beta} e^{\Sigma r_i x_i}$$

Where: $E\ (\lambda)$ (number of expected crashes) is a function of the traffic volume, Q, and α is a set of risk factors (*xi*). After attempting to use the Poisson regression model, Abdel-Aty and Radwan, 2000 rejected it due to differences in values of the mean and variance indicating over-dispersion of the crash data. Thus, the adoption of a superior alternative was incorporated to accommodate the over-dispersion negative binomial (NB) model. “The negative binomial regression model has been widely employed in vehicle accident analysis for rural highways, arterial roadways, urban motorways, and rural motorways,” (Chengye and Prakash, 2013). Other models such as zero-inflated Poisson and zero-inflated negative binomial are used when the data has a significant amount of zeroes and low mean values are present. (Miaou, 1994; Shankar et al., 1997; Lord et al., 2005).

The Model: The Negative Binomial Regression

The negative binomial model was found to be the best for the crash data analysis. The fact that crashes do not usually follow a normal distribution and that values of alpha (over-dispersion) parameters were far from zero in testing data strengthen the model selection. The model is depicted in this section.

Let y_i represent the random variable (with non-negative integer) for the number of crash occurrence at a given roadway segment I within a time interval (for a year in this case), having i= 1, 2… n. The Poisson probability law will take y_i to follow form for a Poisson regression model:

$$P(y_i) = \frac{e^{(-\lambda)} * \lambda_i^{y_i}}{y_i!}$$

Where: P (y_i) represents the probability of road segment i with accidents y_i for a year, and λ_i represents the Poisson parameter for road segment i (expected number of crashes for a year on segment i) which is for example the mean of crash occurrence (E (y_i)). In the Poisson regression model Poisson parameter, $\lambda_{i,}$ and explanatory variables are assumed to follow a log-linear relationship as presented:

$$\lambda_i = E(y_i) = e^{\beta * X_i}$$

Where: X_i represents a vector of explanatory variables (traffic, road, and environmental characteristics and such) of a roadway segment i, and β represents a vector of unknown regression coefficients estimated from standard maximum likelihood.

Since the Poisson distribution assumes that the mean equals the variance the model using this regression is calculated very simply, which is the major advantage of distribution. “The relationship is known as equi-dispersion, which is also known as its restriction” (Chengye and Prakash, 2013). When the mean, E (y_i), is greater than the variance, Var (y_i), the data is said to be under-dispersed and over-dispersed when the oppositely, variance, Var (y_i), is greater than the mean, E (y_i). Thus the Poisson regression model is not appropriate to use when over-dispersion or under-dispersion takes place. The alternative model, then, is the negative binomial. By adding a gamma-distributed error term, this model reduces the assumption of equality among mean and variance. Equation (5.3) is rewritten as follows:

$$\lambda_i = E(y_i) = e^{\beta * X_i + \varepsilon_i}$$

Where: ε_i represents an error term for a gamma-distributed error term, $e^{\varepsilon i}$, with mean and variance 1 and α^2. The variance is difference from the mean (by adding ε_i) as presented in the following form

$$VAR(y_i) = E(y_i)[1 + \alpha E(y_i)] = E(y_i) + \alpha E(y_i)^2$$

Where: α represents the dispersion parameter. The dispersion parameter plays a significant role in determining or choosing the most appropriate regression to use. “When α is significantly different from zero, the distribution is under-dispersion or over-dispersion and the negative binomial model is appropriate. When α approaches zero, the variation is almost equal to the mean, and the distribution can be simply modelled by the Poisson regression technique,” (Chengye and Prakash, 2013).The negative binomial probability is in the following form:

$$P(y_i) = \frac{e^{(-\lambda_i * e^{\varepsilon_i})} * (\lambda_i * e^{\varepsilon_i})^{y_i}}{y_i!}$$

The previous form incorporating the error term, ε_i, with a gamma function as Γ (.) becomes:

$$P(y_i) = \frac{\Gamma(\left(\frac{1}{\alpha}\right) + y_i!)}{\Gamma\left(\frac{1}{\alpha}\right) * y_{i!}} * \left(\frac{\frac{1}{\alpha}}{\left(\frac{1}{\alpha}\right) + \lambda_i}\right)^{\frac{1}{\alpha}} * \left(\frac{\lambda_i}{\left(\frac{1}{\alpha}\right) + \lambda_i}\right)^{y_i}$$

Likewise in the Poisson model standard maximum likelihoods are used for estimating the negative binomial model. The resultant function for the likelihood is as follows:

$$L(\lambda_i) = \Pi_i * \frac{\Gamma\left(\left(\frac{1}{\alpha}\right) + y_i!\right)}{\Gamma\left(\frac{1}{\alpha}\right) * y_{i!}} * \left(\frac{\frac{1}{\alpha}}{\left(\frac{1}{\alpha}\right) + \lambda_i}\right)^{\frac{1}{\alpha}} * \left(\frac{\lambda_i}{\left(\frac{1}{\alpha}\right) + \lambda_i}\right)^{y_i}$$

Coefficient estimates (for β and α) are obtained through maximization of this function.

Thus negative binomial regression was used for developing safety performance functions (SPFs) in the analysis due to over-dispersion in crash data. The general form for SPFs was as follows:

$$N_{SPF} = e^{(\beta_o + \beta_i * X_i +, \ldots, + \beta_n * X_n)}$$

Where: N_{SPF} equals to the SPF for a crash condition, β_o and $\beta_{i \text{ through } n}$ are regression coefficients and $X_{i \text{ through } n}$ are influential variables for the specific crash condition.

The Over-Dispersion Parameters

The over-dispersion parameter is “used to account for varying degrees of over-dispersion between roadway segments attributable to differences in roadway traits and crash occurrences,” (Powers and Carson, 2004). Crash data was over-dispersed (variance was greater than the mean). Calculations of the over-dispersion parameters for each site (through using EB method) were in the following form:

$$K = 1/exp^{(C + Ln(L))}$$

Where: K refers to the overall over-dispersion parameter for the crash condition, L refers to the road segments length (in miles), and C refers to the regression coefficient from estimated model. Since length and other roadway segment characteristics are not constant, the overall over-dispersion parameter cannot be used. A unique over-dispersion parameter, k_i, must be instead determined. It is assumed that the segment length is the main determinant influencing values in over-dispersion parameters. The over-dispersion parameter per each individual segment is calculated as follows:

$$k_i = 1 + \alpha * exp^{(\beta_o + \beta_i * X_i +, \ldots, + \beta_n * X_n)}$$

Through non-linear regression the regression coefficient per each crash condition was found.

Relative Weights

In order to adjust degrees of variation in over-dispersion, a relative weight, w_i, is applied to every roadway segment. Relative weights for each specific segment are obtained using the following form:

$$w_i = \frac{1}{1 + K * \Sigma N_{predicted,B}}$$

Where: *K* refers to the over-dispersion parameter for segment *i*, $N_{predicted,B}$ refers to the predicted number of crashes from the SPF for segment i, and w_i refers to the relative weight of segment *i*.

Estimation for Expected Crashes

The expected number of crashes, $N_{expected}$, is calculated using as presented in the following form

$$N_{expected,B} = w_i * N_{predicted,B} + (1 - w_i) * N_{observed,B}$$

Where: $N_{expected,B}$ refers to the expected average crash occurrence for segment *i* for the entire before period, $N_{observed,B}$ refers to the observed crash occurrence for segment *i* for the entire before period, and W_i refers to the over-dispersion parameter for segment *i*. In order to account for differences between periods (before and after) in duration and traffic volume at each roadway segment i, the adjustment factor r_i is determined as follows

$$r_i = \frac{\Sigma N_{Predicted,A}}{\Sigma N_{predicted,B}}$$

Where: $N_{predicted,A}$ refers to the number of crashes predicted from SPF in entire after period at site i, $N_{predicted,B}$ refers to the number of crashes predicted from SPF in entire before period at site i, and r_i refers to the adjustment factor. Thus actual number of crashes expected in the after period is as follows:

$$N_{expected,A} = N_{expected,B} * r_i$$

Where: $N_{expected,A}$ refers to the number of crashes expected in after period at site i, and $N_{expected,B}$ refers to the number of crashes expected in before period at site i.

Safety Effectiveness Index

In this step the main goal is to express the resultant effectiveness of a treatment as a comparative difference in crash frequency among observed (actual) and expected. The direct difference between the observed and expected crash occurrence, in the form of odds ratio, can be calculated using in each site as follows:

$$OR_i = \frac{N_{observed,A}}{N_{expected,A}}$$

Where: $N_{observed,A}$ refers to the observed crash occurrence in the entire after period for site i, $N_{expected,A}$ refers to the number of crashes expected in entire after period at site i, and OR_i refers to the unadjusted odds ratio or direct resulting effectiveness from treatment. The safety effectiveness as percentage of crash change per each site is determined using:

$$\phi_i = 100 * (1 - OR_i)$$

The overall safety effectiveness is determined as follows:

$$OR' = \frac{\Sigma All_{Sites} N_{observed,A}}{\Sigma All_{Sites} N_{expected,A}}$$

However, this direct calculation of the effectiveness does not account for variability in effectiveness at each site. These uncertainties are corrected through adjusting the odds ratio or in this case the crash modification factor (CMF) as in the following form:

$$OR\ (CMF) = \frac{OR'}{1 + \frac{Var\{\Sigma All_{Sites} N_{expected,A}\}}{\{\Sigma All_{Sites} N_{expected,A}\}^2}}$$

Where:

$$Var\{\Sigma All_{Sites} N_{expected,A}\} = \Sigma All_{Sites}[(r_i)^2 * N_{expected,B} * (1 - w_i)$$

Odds ratios with values less than 1 lead to reduction in the number of crashes. For example, if the CMF is 0.759, the adjusted reduction is then 1 minus this number times 100, which leads to 24.10%. Precision and significance of the treatment effectiveness is determined by first obtaining the variance of the unbiased estimated OR. The variance is determined using the following form:

$$var\ (OR) = \frac{(OR')^2 * [\frac{1}{N_{observed,A}} + \frac{var\{\Sigma All_{sites} N_{expected,A}\}}{\{All_{sites} N_{expected,A}\}^2}]}{[1 + \frac{Var\{\Sigma All_{Sites} N_{expected,A}\}}{\{\Sigma All_{Sites} N_{expected,A}\}^2}]}$$

The standard error of the variance is as follows:

$$SE(OR) = \sqrt{Var(OR)}$$

The standard error of the safety effectiveness

$$SE(Safety\ Effectiveness) = 100 * SE(OR)$$

The standard error is the provider of certainty for the CMF. For greater certainty, relatively small standard errors are desired when compared to the magnitude of the CMF. Thus the statistical significance of the estimated safety effectiveness will be based on the ratio between safety effectiveness and standard error of safety effectiveness of treatment as follows:

$$\left|\frac{Safety\ Effectivenss}{SE(Safety\ Effectiveness)}\right|$$

If the ratio between safety effectiveness and standard error of safety effectiveness is less than 1.7, which rounds up from 1.64, the treatment effect is not significant at 90% confidence level. For values greater or equal 1.7 and greater or equal 2.0, which is an approximate for 1.96, statistical significance is said to be at 90% and 95%, respectively.

Before and After with Comparison Group Method: Introduction and Description

Due to the fact that not all crash condition had sufficient data to develop reliable SPF, which is the main part in performing the EB method, another method was needed for the analysis. This section covers the before and after with comparison groups alternative method. “A before and after with comparison group study uses an untreated comparison group of sites similar to the treated ones to account for changes in crashes unrelated to the treatment such as time and traffic volume trends,” (Gross et al., 2010).This is an appropriate method to use where suitable comparison group (As presented before in graphs) is available as alternative of the Empirical Bayes Method, mainly, when: Frequency in crashes is not considered in selection of sites. Suitability in comparison group was tested in Chapter 4. Thus, the main purpose of this section is to present the process taken when applying this method. Effectiveness through this method is obtained by comparing expected and observed crashes for period after treatment.

The expected number of crashes in the after period, $N_{expected,T,A}$, for a treatment groups, in the before and after with comparison groups, is determined as follows:

$$N_{expected,T,A} = N_{observed,T,B} * (\frac{N_{observed,C,A}}{N_{observed,C,B}})$$

Where: $N_{observed,T,B}$ refers to the number of crashes observed in the before period for the treated group, $N_{observed,C,B}$ refers to the number of crashes observed in the before period for the comparison group, and $N_{observed,C,A}$ refers to the number of crashes observed in the after period for the comparison group. The variance term for expected number of crashes is obtained as follows:

$$Var\left(N_{expected,T,A}\right) = N^2_{expected,T,A} * (\frac{1}{N_{observed,T,B}} + \frac{1}{N_{observed,C,B}} + \frac{1}{N_{observed,C,A}})$$

In this case the crash modification factor (CMF) is determined as follows:

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

Where: $N_{observed,T,A}$ refers to the number of crashes observed in the after period for the treated group. The variance term for the CMF is found though using the following term:

$$Var\ (CMF) = \frac{CMF^2[\left(\frac{1}{N_{observed,T,A}}\right) + \left(\frac{Var\left(N_{expected,T,A}\right)}{N^2_{expected,T,A}}\right)]}{\left[1 + \frac{Var\left(N_{expected,T,A}\right)}{N^2_{expected,T,A}}\right]^2}$$

Standard error and confidence interval of the CMF are determined as follows, respectively:

$$Standard\ Error = \sqrt{Var(CMF)}$$

$$Confidence\ Interval = CMF\ \pm Cummulative\ Probability.* Standard\ Error$$

In order to attain significance to certain effectiveness the confidence interval needed to exclude 1 at the tested confidence level. Accepted statistical confidence ranged from 85% to 95%.

CHAPTER 6

RESULTS AND DISCUSSION

The intent of this chapter is to cover the summary of findings of the study. For the case of freeways, seven crash conditions were analyzed using the EB method and three with the alternative method. For non-freeways eight and five conditions used the EB method in urban and rural, respectively; and two and five used the alternative method. Both safety performance functions (SPFs) and crash modification factors (CMFs) were developed and calculated for all crash conditions. The following sections cover these results along with the respective discussion.

Safety Performance Functions (SPFs)

Based on the fact that analyzed data was over-dispersed the negative binomial regression was used for developing the SPFs in freeway and non-freeway segments. Both urban and rural had different SPFs in the case of non-freeways.

Freeway Segments

Considered influencing variables for crash frequencies in freeways were presented in Chapter 4. In order to eliminate related and dependent variables a correlation test was performed. STATA helped in running the correlation. Final uncorrelated variables were used in the model. Appendix C (a) provides an example of the correlation test results along with how to determine significant influential variables. SPFs for freeways are presented as follows:

$$N_{Predicted} = exp^{(\beta_o + \beta_1 * L + \beta_2 * Ln_{AADT})}$$

Where:

$N_{Predicted}$ is the number of predicted crashes of a segment per year,

L is the segment length in miles,

AADT is the Annual Average Daily Traffic (AADT), and

$\beta_{o,}$ $\beta_{1,}$ and $\beta 2$ are the regression coefficients.

This SPF was applied only in crash conditions with sufficient data to hold function reliable. Table 9 presents SPFs for freeways. Regression coefficient, c, and alpha value, α, were determined from the negative binomial model as explained in Chapter 5. Precision of the model, standard error, is provided in parenthesis along with variable coefficients. Each variable coefficient is interpreted as follows: "for one unit change in the predictor variable, the difference in the logs of the expected counts of the response variable is expected to change by the respective coefficient, given the other predictor variables in the model are held constant," (IDRE, 2015). For example, the variable L (length of roadway segment) has a coefficient 0.270 for total crashes, which means that for every unit increase in length the expected log count of total crashes increases by 0.270. This is a positive number, thus number of crashes increase. Similarly for every increase in one unit of traffic volume (AADT), the expected log count of the total crashes increases by 0.974. The same principle applies to the remaining crash conditions. The largest crash rate is observed from traffic volumes where every on-unit increase in AADT increases fatal/injury crashes by 1.238.

Parameters from beta naught (β_o) represent the model estimates when traffic volume and length are evaluated at zero. However, evaluating length at zero is not reasonable. Again, alpha values are estimates of the over-dispersion parameters. Alpha values were greater than zero indicating dispersion in the data. Likelihood-ratio test of alpha=0 was used to statistically suggest that the alpha values were different from zero and the suitable model for the data was the negative binomial model. Regression coefficient (c values) provided with better estimates of over-dispersion parameters.

Table 9 Safety Performance Functions for Freeways

Crash Condition	β_1 (Std. Er.)	β_2 (Std. Er.)	β_o	α	c
Total	0.270 (0.041)	0.974 (0.088)	-7.718	0.0975	-0.581
Total Fatal Injury	0.229 (0.055)	1.238 (0.115)	-11.988	1.52E-07	0.416
Total Day	0.217 (0.044)	1.068 (0.096)	-9.183	0.0803	-0.198
Total Night	0.327 (0.041)	0.849 (0.092)	-7.297	0.0374	0.185
Total Under- 6-years	0.223 (0.050)	0.989 (0.111)	-8.742	0.0918	-0.084
Total Under- 65-years Day	0.174 (0.057)	0.966 (0.124)	-8.923	0.0684	0.152
Total Under- 65 Night	0.259 (0.060)	0.885 (0.134)	-8.652	6.19E-08	0.416
Total 65-and-above-years	alternative method [B/A with Comparison Groups] is used				
Total 65-and-above-years Day	alternative method [B/A with Comparison Groups] is used				
Total 65-and-above-years Night	alternative method [B/A with Comparison Groups] is used				

Graphical SPF forms, for each crash condition, were developed. Figure 18 present graphical SPFs for total, total day, total night and fatal/injury crashes. Using this form SPFs become more practical and useful when only depicted information is needed. For example, with AADT = 25,000 veh/day, the total night crashes per segment mile in freeways will be 5. Figure 19 provides with graphical SPFs for total under-65-years crashes in both daytime and nighttime. Again, results in both Figure 18 and Figure 19 are consistent with previous findings were number of crashes are directly proportional (increasingly) to traffic volume.

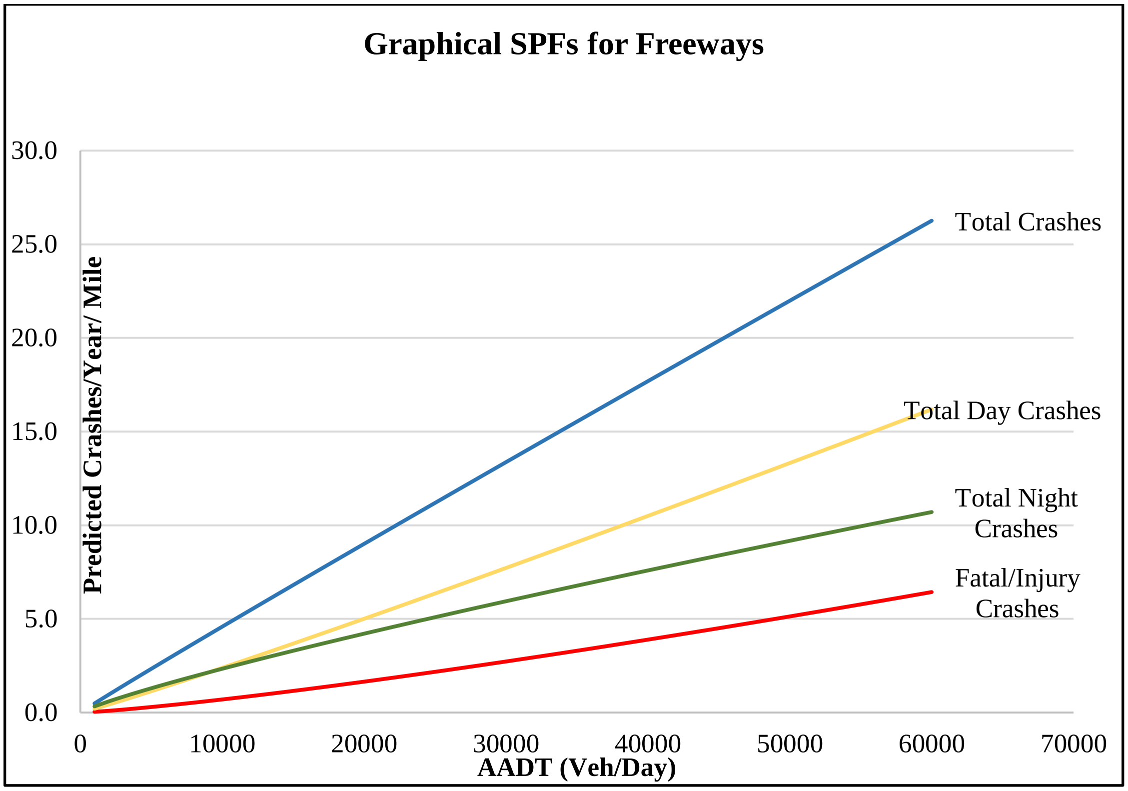


Figure 18 Graphical SPF form for Total (Day and Night) and FI Crashes on Freeways

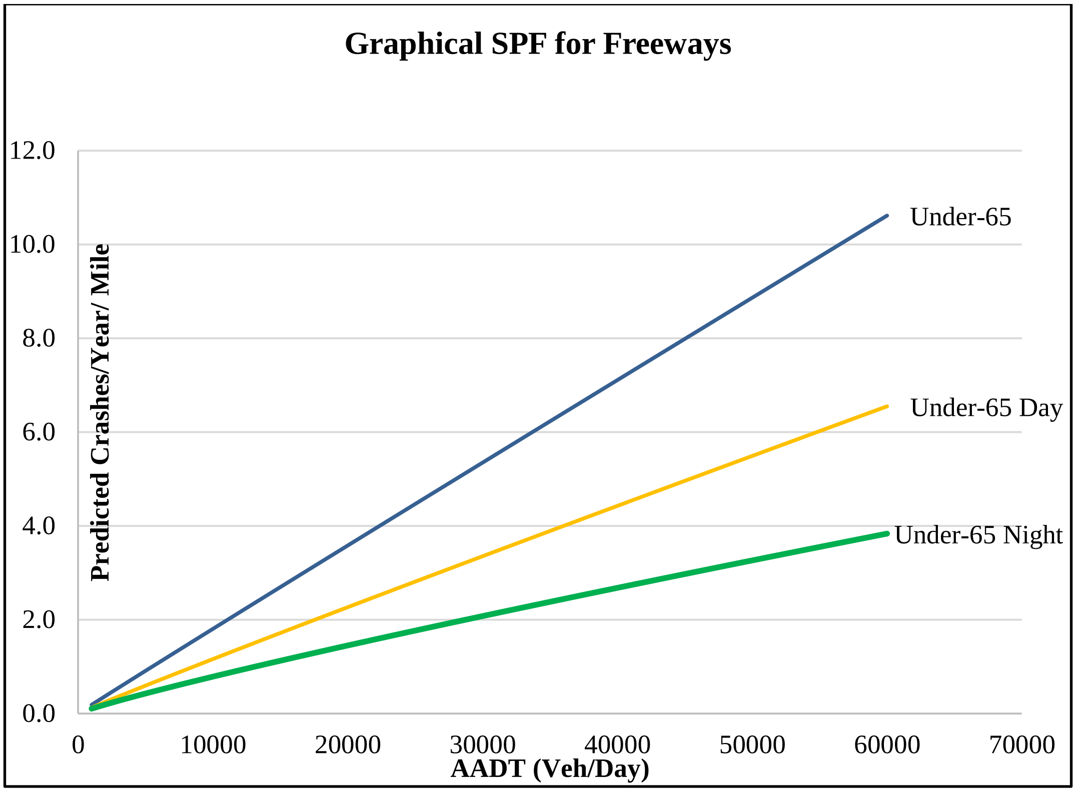


Figure 19 Graphical SPF form for under -65-years crashes on Freeway

Non-Freeway Segments

For the case of non-freeways, SPFs had more influencing variables significant to the model besides length and AADT: access points and undivided median. Access points in a road are one of the main causing of accidents since they interrupt the steady flow in traffic. The model used for urban areas is presented as follows:

$$N_{Predicted} = exp^{(\beta_0 + \beta_1 * Ln_{AADT} + \beta_2 * L + \beta_3 * AP + \beta_4 * UM)}$$

Where:

$N_{Predicted}$ is the number of predicted crashes of a segment per year,

L is the segment length in miles,

$AADT$ is the Annual Average Daily Traffic (AADT),

AP is the number of access points in segment, *UM* is the indicator for undivided road (1 when present; 0 otherwise), and

$\beta_{o,}$ $\beta_{1,}$ β_2, β_3 and β_4 are the regression coefficients.

Table 10 presents the SPFs for urban non-freeway segments. In this case only two crash conditions were analyzed using the alternative method. Results show that overall the expected log count of crashes are increases by 0.985 (AADT coefficient for total crashes) for every one-unit increase in the traffic volume. The increment of log count of total crashes is 0.462 for every one-unit increase in length. The log count of overall crashes also increases for one-unit increase in undivided median and number of access points by 0.397 and 0.025, respectively. The coefficient value for access points had the largest precision because of the lowest standard error (0.008) for total crashes. The estimate of model for total crashes when all variables (AADT, length, access points and undivided median) are zero is -7.998. Again, this number itself is not realistic as the length of the segment cannot be zero. The remaining coefficients for the other crash conditions are interpreted similarly. Overall, alpha values are greater than zero and proved over-dispersion in the data.

Table 10 Safety Performance Function for Non-Freeway (Urban)

Crash Condition	β_1 (Std. Er.)	β_2 (Std. Er.)	β_3 (Std. Er.)	β_4 (Std. Er.)	β_o	α	c
Total	0.985 (0.142)	0.462 (0.115)	0.025 (0.008)	0.397 (0.185)	-7.998	0.307	-0.722
Total Fatal Injury	1.046 (0.169)	0.467 (0.104)	0.018 (0.008)	0.513 (0.215)	-10.059	0.115	0.440
Total Day	1.044 (0.158)	0.343 (0.123)	0.032 (0.009)	0.455 (0.205)	-8.905	0.343	-0.596
Total Night	0.771 (0.141)	0.493 (0.090)	0.012 (0.006)	0.325 (0.178)	-7.049	0.068	0.503
Total Under- 65	1.154 (0.160)	0.376 (0.117)	0.026 (0.009)	0.543 (0.209)	-10.402	0.261	-0.148
Total Under- 65-years Day	1.231 (0.181)	0.311 (0.129)	0.029 (0.010)	0.486 (0.232)	-11.388	0.296	-0.055
Total 65-and-above-years	1.026 (0.176)	0.280 (0.108)	0.014 (0.008)	0.467 (0.228)	-9.812	0.086	0.520
Total 65-and-above-years Day	1.144 (0.223)	0.282 (0.139)	0.025 (0.011)	0.756 (0.299)	-11.600	0.203	0.411
Total Under- 65-years Night	alternative method [B/A with Comparison Groups] is used						
Total 65-and-above-years Night	alternative method [B/A with Comparison Groups] is used						

Figures 20 to 23 show the graphical SPF for urban areas under specified conditions. Provided graphical SPFs show main categories in analysis such as total, fatal injury, total under-65, and total 65-and-above crashes. For example, Figure 20 depicts that for a segment with no access points the maximum annual number of crashes per mile is 40 with a traffic volume of 60,000 veh/day. The same application can be done for figures 21, 22 and 23. Also, Figure 21 presents that the predicted annual number of crashes per mile is lower for fatal/ injury when compared to the total number of crashes under the same conditions (number of access points and traffic volume). Between under-65 years and 65-and-above years the highest prediction in crashes under specified conditions is among the younger group (See Figures 22 and 23) in urban non-freeways. Appendix C (b) provides with more graphical SPFs derived from Table 10.

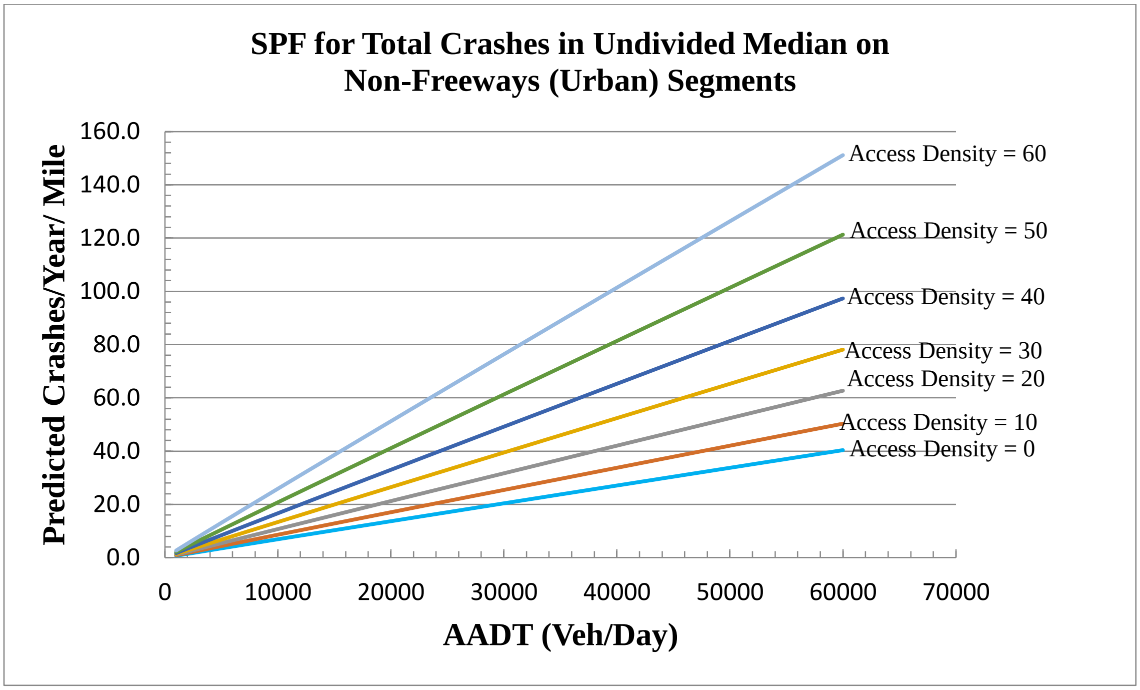


Figure 20 Graphical SPF form for Total Crashes in Undivided Median on Non-Freeways (Urban) Segments

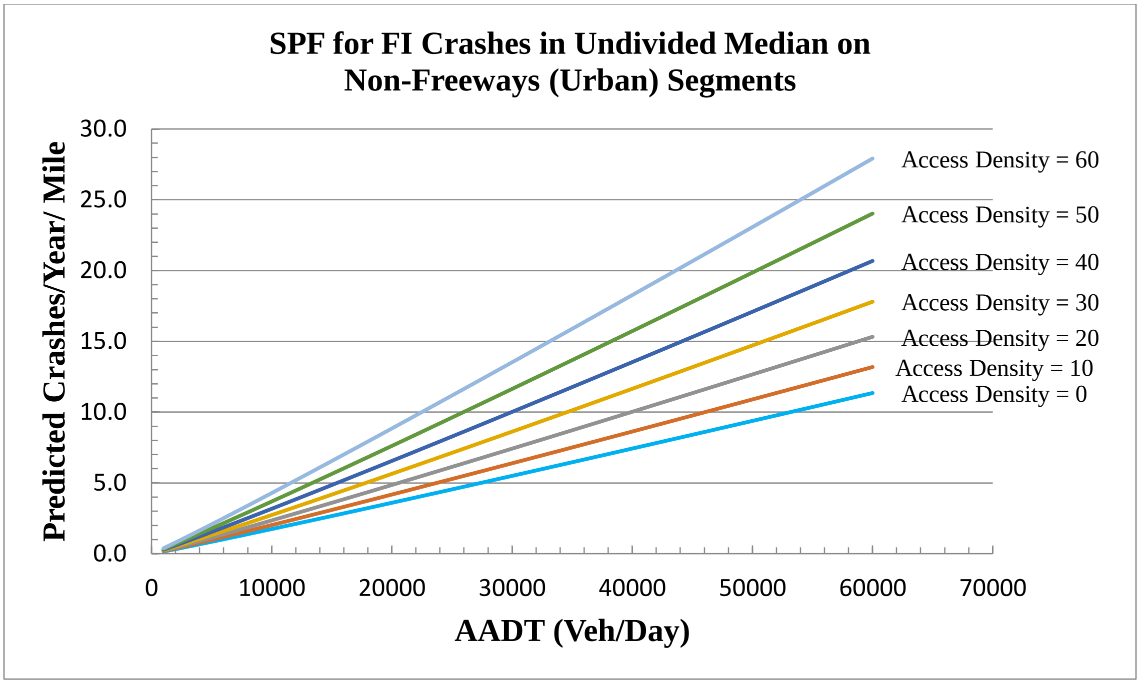


Figure 21 Graphical SPF form for total fatal injury (FI) crashes on urban non-freeways

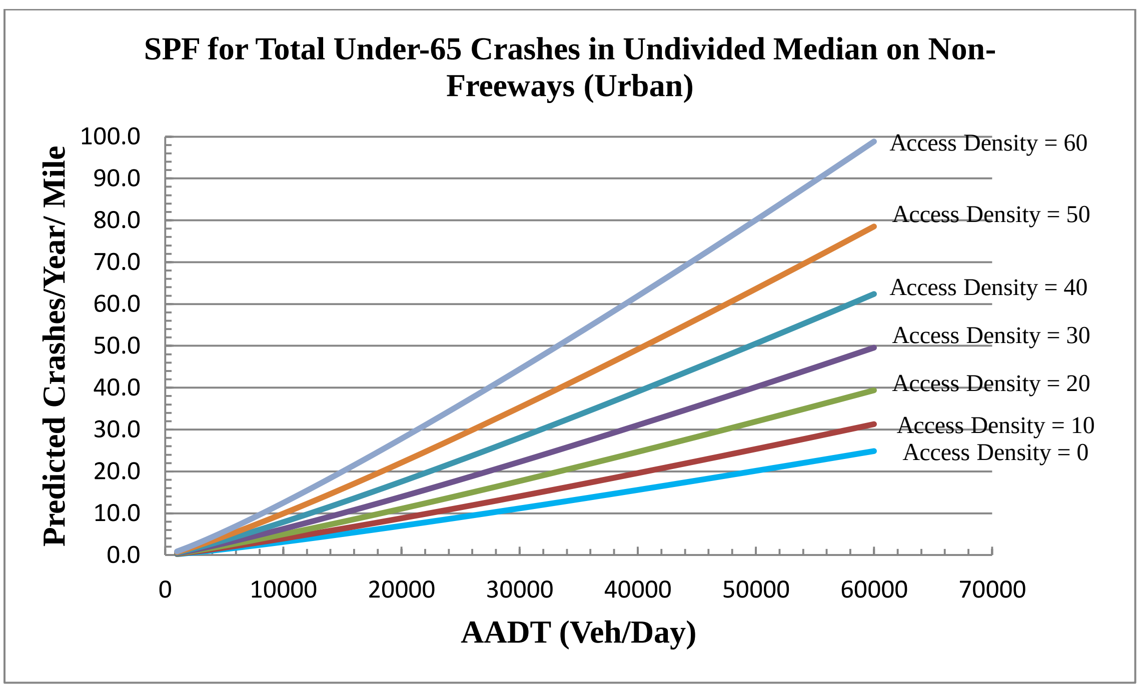


Figure 22 Graphical SPF form for total under-65 crashes on urban non-freeways

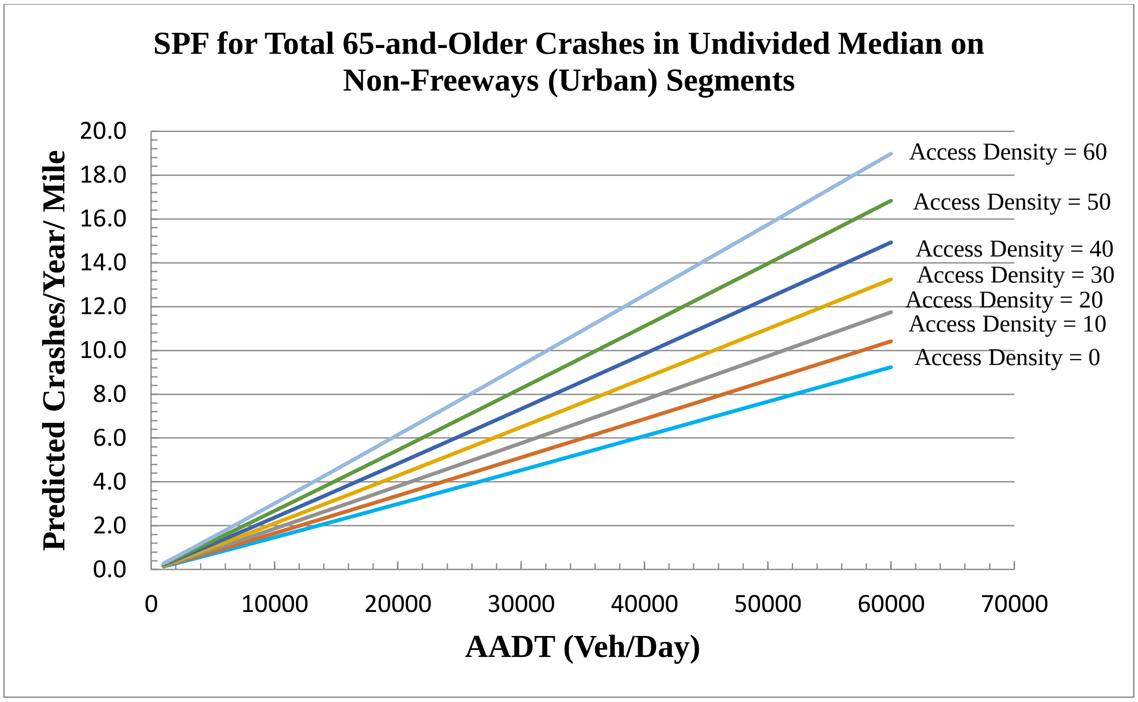


Figure 23 Graphical SPF form for total 65-and-above crashes on urban non-freeways

Moreover, SPFs for rural areas included the lack of sidewalk in the segment as a significant variable increasing the number of crashes besides length, AADT, access points and undivided median. The lack of sidewalk in non-freeway segments tends to potential pedestrian crashes. The model used for rural areas is presented as follows:

$$N_{Predicted} = exp^{(\beta_o + \beta_1 * Ln_{AADT} + \beta_2 * L + \beta_3 * AP + \beta_4 * UM + \beta_5 * NS)}$$

Where:

$N_{Predicted}$ is the number of predicted crashes of a segment per year,

L is the segment length in miles,

AADT is the Annual Average Daily Traffic (AADT),

AP is the number of access points in segment,

UM is the indicator for undivided road (1 when present; 0 otherwise),

NS is indicator on no sidewalk in the segment (1 if present; 0 otherwise), and

β_o, β_1, β_2, β_3 β_4, and β_5 are the regression coefficients.

Table 11 presents the SPFs for rural areas in non-freeways. Fifty percent of the crash conditions could develop reliable SPFs. Results reveal that the highest increase in log count for crashes is during nighttime in segments with undivided median. There is an increment of 0.965 in log count of total night crashes for every one-unit increase in segment with undivided medians. Although few variables were not significant in two crash conditions (total night and total 65-and-above-years day), all of were present in most of them (conditions).

Table 11 Safety Performance Functions for Non-Freeways (Rural)

Crash Condition	β_1 (Std. Er.)	β_2 (Std. Er.)	β_3 (Std. Er.)	β_4 (Std. Er.)	β_5 (Std. Er.)	β_o	α	c
Total	0.658 (0.080)	0.192 (0.032)	0.022 (0.009)	0.711 (0.246)	1.311 (0.315)	-6.090	0.125	-0.465
Total Day	0.743 (0.093)	0.134 (0.027)	0.033 (0.007)	0.510 (0.267)	0.941 (0.345)	-7.142	9.61E-08	0.142
Total Night	0.634 (0.100)	0.256 (0.029)	-	0.965 (0.344)	1.719 (0.493)	-7.020	0.209	-0.460
Total 65-and-above-years	0.453 (0.141)	0.091 (0.043)	0.039 (0.011)	0.784 (0.512)	0.787 (0.521)	-5.697	9.51E-08	0.142
Total 65-and-above-years Day	0.769 (0.230)	0.109 (0.060)	0.060 (0.014)	-	-	-7.985	1.27E-07	0.142
Total Fatal Injury	alternative method [B/A with Comparison Groups] is used							
Total Under-65-years	alternative method [B/A with Comparison Groups] is used							
Total Under-65-years Day	alternative method [B/A with Comparison Groups] is used							
Total Under-65-years Night	alternative method [B/A with Comparison Groups] is used							
Total 65-and-above-years Night	alternative method [B/A with Comparison Groups] is used							

Graphical form of main SPFs for rural non-freeway are presented in figures 24 and 25. In this case the maximum number of access points per mile was 30. This is justified by the nature of the rural area as compared to urban areas. There are more access points in urban areas than there are in rural. Once again only the main subcategories are presented. See Appendix 6.2 for other graphical SPFs derivations of Table 11.

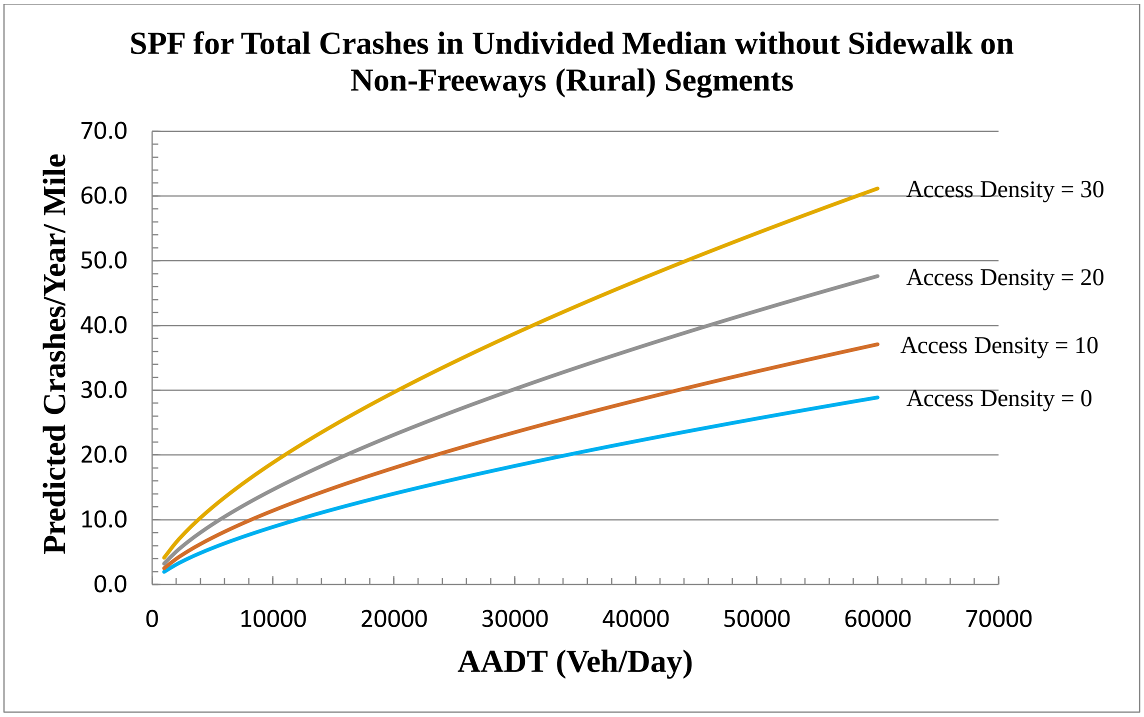


Figure 24 Graphical SPF form for total crashes on rural non-freeways

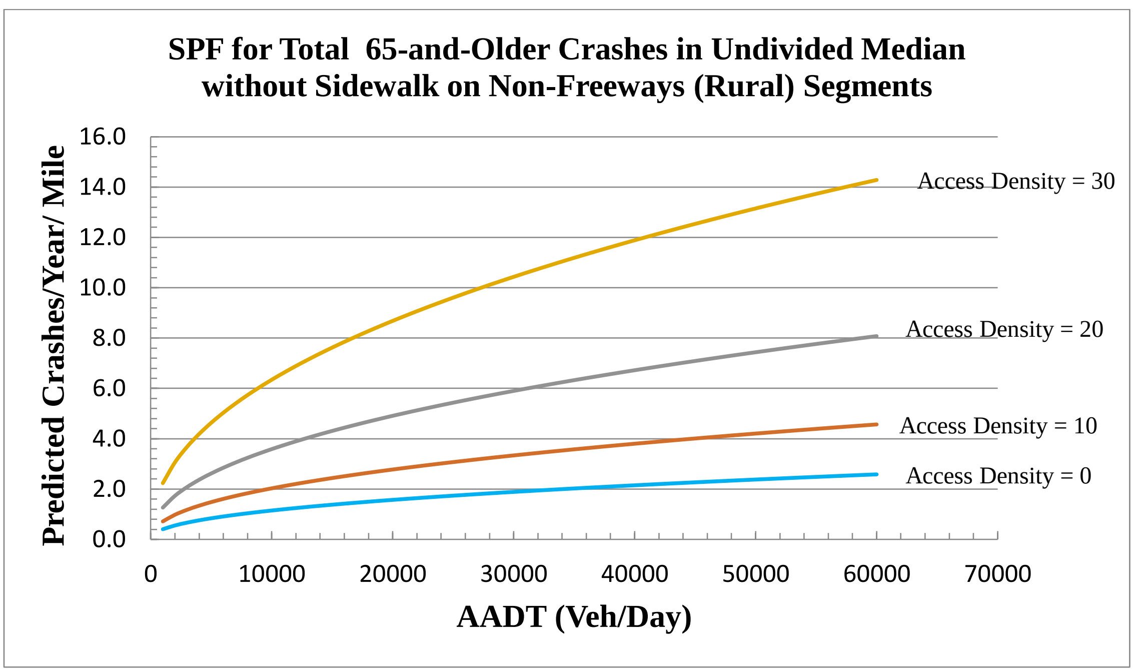


Figure 25 Graphical SPF form for total 65-and-above crashes on rural non-freeways

Crash Modification Factors (CMFs)

Crash Modification Factors (CMFs) were developed for each crash condition using the applicable methodology. Each CMF had a level of significance in terms of the reduction found. Also, it is appropriate to mention that even though there were no specific sites where only the Clearview font signs were installed to allow direct development of CMFs for the countermeasure, the CMFs for fluorescent yellow sheeting only and a combination of fluorescent yellow sheeting and Clearview font were used to estimate the CMF for Clearview. Estimation of the CMFs for Clearview font signs only (CMF_{CLO}) from the CMF for fluorescent yellow sheeting only (CMF_{FYO}) and the CMF for both fluorescent yellow sheeting and Clearview font ($CMF_{FY\text{-}CL}$) is as follows:

$$CMF_{CLO} = \frac{CMF_{FY-CL}}{CMF_{FYO}}$$

Table 12 presents the summary of each CMF per crash condition, type of improvement and highway classification. CMFs in Table 12 are adjusted from the methodology used as explained in Chapter 5. Appendix C (c) provides graphical representation unadjusted CMFs along with observed and expected number of crashes, reductions, statistical significance and standard error. In order to calculate percent reductions drawn from CMFs, one must perform the following operation: (1- CMF)*100. Table 13 provides with the summary of all reductions tied with CMFs equivalent to each crash condition and countermeasure.

Table 12 Summary of CMFs for Freeways and Non-Freeways (Urban and Rural)[2]

Highway Classification/ Improvement Type		Total	Total Fatal Injury	Total Day	Total Night	Total Under-65-years	Total Under-65-years Day	Total Under-65-years Night	Total 65-and-above-years	Total 65-and-above-years Day	Total 65-and-above-years Night
Freeways	Clearview & Fluorescent	0.759***	0.930	0.798***	0.741***	0.759***	0.807***	0.728***	0.899	0.912	0.902
	Fluorescent Only	0.851***	0.963	0.819***	0.998	0.846***	0.872***	0.902	0.998	0.938	0.913
	Clearview Only	0.892	0.966	0.974	0.742	0.897	0.925	0.807	0.902	0.972	0.988
Non Freeways Urban	Clearview & Fluorescent	0.704***	0.711***	0.730***	0.657***	0.707***	0.720***	0.929***	0.859**	0.895	0.964
	Fluorescent Only	0.949**	0.917	0.932***	0.993	0.895***	0.875***	0.989	0.963	0.965	0.986
	Clearview Only	0.742	0.775	0.783	0.662	0.790	0.823	0.939	0.892	0.927	0.978
Non Freeways Rural	Clearview& Fluorescent	0.670***	0.927***	0.716***	0.667***	0.868***	0.772***	0.923***	0.783***	0.941	0.977
	Fluorescent Only	0.923***	0.972*	0.883***	0.973	0.916***	0.848***	0.947***	0.895	0.993	0.998
	Clearview Only	0.726	0.954	0.811	0.686	0.948	0.910	0.975	0.875	0.948	0.979

[2] Significance of each CMF per crash condition within a specific highway classification per improvement type is described in the following list:

1. Underlined CMF refer to EB method; not underlined CMF refers to B/A with comparison Groups
2. * Significant at 85% Confidence Level
3. ** Significant at 90% Confidence Level
4. *** Significant at 95% Confidence Level
5. No star refers to No significant

Table 13 Summary of Percent Reductions for Freeways and Non-Freeways (Urban and Rural)

Highway Classification/ Improvement Type		Total	Total Fatal Injury	Total Day	Total Night	Total Under-65-years	Total Under-65-years Day	Total Under-65-years Night	Total 65-and-above-years	Total 65-and-above-years Day	Total 65-and-above-years Night
Freeways	Clearview & Fluorescent	24.10	7.00	20.20	25.90	24.10	19.30	27.20	10.00	8.80	9.80
	Fluorescent Only	14.90	3.70	18.10	0.20	15.40	12.80	9.80	0.20	6.20	8.70
	Clearview Only	10.81	3.43	2.56	25.75	10.28	7.45	19.29	9.82	2.77	1.20
Non Freeways Urban	Clearview & Fluorescent	29.60	28.90	27.00	34.30	29.30	28.00	7.10	14.10	10.50	3.60
	Fluorescent Only	5.10	8.30	6.80	0.70	10.50	12.50	1.10	3.70	3.50	1.40
	Clearview Only	25.82	22.46	21.67	33.84	21.01	17.71	6.07	10.80	7.25	2.23
Non Freeways Rural	Clearview& Fluorescent	33.00	7.30	28.40	33.30	13.20	22.80	7.70	21.70	5.90	2.30
	Fluorescent Only	7.70	2.80	11.70	2.70	8.40	15.20	5.30	10.50	0.70	0.20
	Clearview Only	27.41	4.63	18.91	31.45	5.24	8.96	2.53	12.51	5.24	2.10

Interpretation of CMF Results

Overall, reductions are observed in all crash conditions, which highlights the effectiveness of all countermeasures in different conditions even though not all results are statistically significant. From Table 13 it can be noticed that in both highway classifications and despite of the type of improvement there are significant reductions in the total number of crashes. Reductions are 24.10% ((1-0.759)*100) for freeways; and 29.60% ((1-0.704)*100) and 33.00% ((1-0.670)*100) for urban and rural non-freeways, respectively. The highest precision overall is found in the reduction of total crashes on freeways with the smallest value of 0.0190. See Appendix C (b) for CMFs' standard errors. Most of the reductions in total crashes are at 95% confidence level.

Disregarding the type of highway classification these results tie to previous finding where by using both countermeasures significant improvements were found. For example, Carlson (2001) found 11.9% increase in sign legibility using Clearview fonts and micro-prismatic sheeting while this study finds almost double of Carlson' findings in crash reductions. It is logical that crash reductions are tied to improvement in sign legibility. Also, not only sign legibility is improved but legibility distance using both countermeasures as Gowda found in Kansas (2010). Again, improvements in the number of crashes indicate improvement in legibility distance using both countermeasures.

Figure 26 presents a graphical representation of the CMF for the total number of crashes. In this case the unadjusted reduction is estimated by subtracting from one the direct ratio between the observed crashes in the after period (2823) divided by the expected number of crashes in the after period (3720) times a hundred (for percent reductions) as explained in Chapter 5. In this case unadjusted and adjusted reductions were very similar.

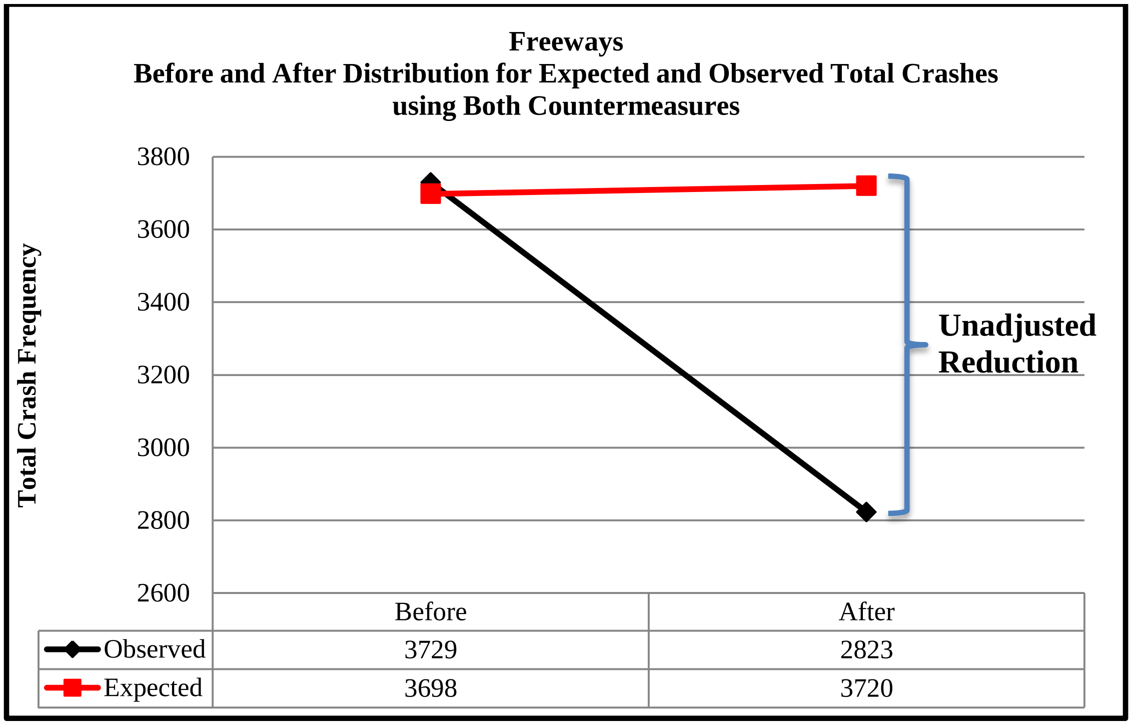
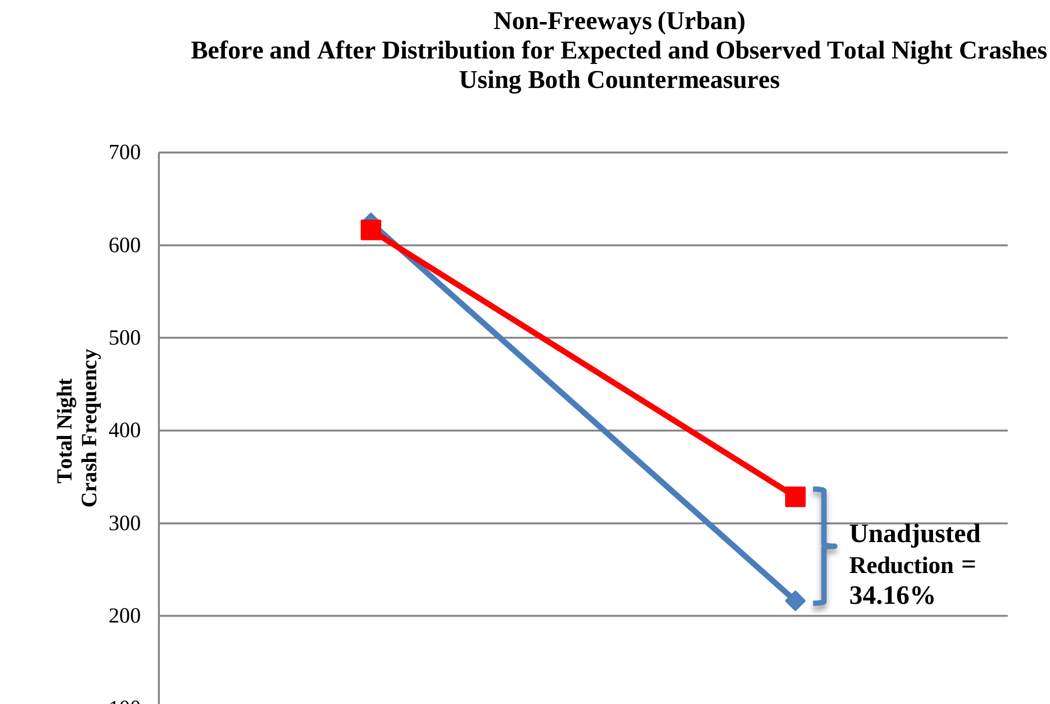


Figure 26 Total Crashes for Freeways using Both Countermeasures

Moreover, fatal/injury crashes are reduced using the countermeasures. The highest fatal/injury crash reduction (28.90%) derives from both countermeasures in urban non-freeways. This is an important finding since non-freeways are more hazardous than freeways due to their changes in complex traffic condition (e.g. changes in intersection type, speed limit, road type, number of lanes, etc.). The usage of Clearview fonts provides the highest benefit in this area with 22.46%.

Furthermore, both day and nighttime reductions are observed in the number of crashes. Higher improvements are observed during the nighttime as Garvey (1997) in Pennsylvania and Gray and Neuman (2010) in Arizona found when compared to daytime reductions. For example, the total reduction in nighttime (25.90%) for freeways using both countermeasures is 5.70% more than daytime (20.20%). The same application can be done for the remaining conditions since all nighttime reductions are larger than daytime (using both countermeasures). Overall, the nighttime crash reductions were the largest in the summarizing CMF Table 12 (when using both countermeasures): 27.20% (for under-65-years at night) on freeways, 34.30% (for total night crashes) on urban non-freeways, and 33.30% (for total night crashes) on rural non-freeways. Figure 27 presents the highest reduction occurring during nighttime using both countermeasures in urban non-freeways: 34.30%. The results ((1-(216/328))*100) present the unadjusted reduction of 34.16%, which helps for visualization purposes.

Daytime improvements are significant and support the fact that countermeasures were designed to improved sign legibility and conspicuity in both lighting conditions. Also, from findings it seems to be that fluorescent yellow sheeting are more helpful during the day as Burns et al. (2001) and Clearview fonts during the night when applied individually. For example, for freeways there is a 0.20% reduction for total night crashes using fluorescent yellow sheeting only while the reduction during the daytime is 18.10%. Also, for Clearview fonts there is a reduction of 25.75% in total night crashes while the daytime reduction is only 2.56% on freeways. However, not all reductions are significant with the presence of only one countermeasure.



	Before	After
Observed	624	216
Expected	616	328

Figure 27 Total Night Crashes for Non-Freeways (Urban) using Both Countermeasures

Regarding the analyzed age groups it is noticed that both age populations, younger and older, are benefiting from the countermeasures. Larger crash reductions are observed for the younger (under-65-years) group when compared to the older (65-and-above-years) group, except in the case of rural non-freeways. Reductions in younger drivers are more significant, 95% mostly, than those in the older groups. Only in two cases reductions in younger drivers were at all insignificant. Reductions for these cases were 9.77% and 1.11% in freeways and non-freeways urban areas, respectively, using only one countermeasure in nighttime. Lastly the only significant reductions in the group of older drivers were found in total crashes when both countermeasures were applied in non-freeways urban and rural areas. Reductions were 14.09% (at 90 % confidence level) and 21.69% (at 95% confidence level), respectively. Older drivers tend to avoid driving on freeways (mostly during nighttime). This might be the reason for much insignificance in older drivers' freeway reductions.

Other crash reductions are observed based on highway classification (freeways and non-freeways). This division in highway classification provides with unique results: this is the first study analyzing reductions in crash data from Clearview fonts and fluorescent yellow sheeting together in urban and rural areas. Other researchers have performed experimental and observational studies of the countermeasures in urban and rural areas such as Frei et al. (2013). He found 10% improvement in sing legibility using surveys in Illinois. The study covered urban and rural areas where the countermeasures were implemented.

Generally, it is noticed that reductions are consistent with the number countermeasures installed as to be the expected naturally. When both countermeasures are applied reductions are higher than when only one is. In the case of total crashes, where all results are significant, it is observed that in freeways reduction provided by one countermeasure is half of the one provided by both. This is important since it assures the effectiveness of both countermeasures.

Finally, results are discussed based on the improvement type. While being the crash condition with higher reduction rates, night time presented the lowest crash rates when using only fluorescent yellow sheeting was present, 0.24%. This draws the attention to another aspect: over- signed areas with warning signs. According to few interviewees, in the perception survey, sometimes sequential yellow warning signs are more distracting than the actual function: holding the attention. This seems to be an issue for few people transiting this areas (e.g. probably at areas where *sharp* curves are followed with several chevrons and dear signs). However, the need of those signs is supported by obtained results in hazardous areas such as rural non-freeways as suggested in results for younger drivers in night time. Eccles in her study supports the frequent application of the countermeasure in such areas after obtaining improvement in the number of vehicles reacting before it.

CHAPTER 7

COST – BENEFIT ANALYSIS

Introduction

Besides understanding the expected reduction related to a specific or multiple countermeasures in the number of crashes, it is also important to know its cost-effectiveness, (Fayish et al., 2010). The intent of this chapter is to cover the economic analysis of the countermeasures analyzed. Cost- benefit analysis helps states and local agencies to know if implementing a countermeasure out-weights the costs.

Crash costs for the analyzed crash conditions were extracted from a report where traffic crash costs and casualty are provided in Michigan (Kostyniuk et al., 2011). Table 14 provides with a summary of Michigan crash costs for different crash severity and overall. From Table 14 weighted average costs on total, fatal and injury (FI) and property damage only (PDO) were used for the analysis.

Table 14 Michigan Crash Costs for KBCO Crashes

Traffic Crash Casualty Severity	Traffic Crash Casualties	Traffic Crash Costs	Traffic Crash Costs/ Traffic Crash Casualties
Fatal (K)	871	$3,146,015,418	$3,611,958
Incapacitating Injury (A)	6511	$1,495,225,106	$229,646
Non-Incapacitating Injury (B)	16149	$1,105,092,219	$68,431

Traffic Crash Casualty Severity	Traffic Crash Casualties	Traffic Crash Costs	Traffic Crash Costs/ Traffic Crash Casualties
Possible Injury (C)	48271	$1,926,495,610	$39,910
Property Damaged Only (O)	382424	$1,411,144,560	**$3,690**
Weighted Average Cost			
Fatal Injury (KABC)	**$106,860.93**		
Total (KABCO)	**$19,998.80**		

Countermeasure Costs in Michigan

For implementing a guide sign with Clearview font and warning sign with fluorescent yellow sheeting it costs MDOT $41.07 and $45.76 US dollars. These costs are obtained from subtracting the total costs in implementing the countermeasure from the cost if the standard font or warning sign material was used. Table 15 provides the summary of the installation cost for both Clearview fonts and fluorescent yellow sheeting. These costs are applicable to both freeways and non-freeways.

Table 15 Summary of installation costs for Clearview font and fluorescent yellow sheeting

Countermeasure	Average Installation Cost for Countermeasure	Average Installation Cost for Standard	Average Differential Cost (Improvement – Standard)
Clearview Font Sign (100 sites)	$3,162.67	$3,121.59	$ 41 per sign
Fluorescent Yellow Sheeting Sign (100 sites)	$398.11	$ 352.35	$46 per sign

Nominal Discount Rate and Service Life

The Office of Management and Budget (OMB), executive office of the president, issued an amendment to OMB Circular No.A-94, where *guidelines and discounts rates* are delivered for benefit-costs analysis of federal programs (Donovan, 2015). Nominal discounts rates for year 2015 are presented in Table 16. These discounts rates provide figures for projects lasting 3 to 30 years. The information was used for estimating the discount rate for 15 year of life service in countermeasures of 2.95%. Signs in Michigan used this amount of years for life service.

Table 16 Discount Rates per Project Life Service

Nominal Discount Rates (in Percent)					
Three Year	Five- Year	Seven- Year	Ten- Year	Twenty-Year	Thirty –Year
1.7	2.2	2.5	2.8	3.1	3.4

Methodology used: Present Value

The methodology used for determining all benefit to cost ratio (BCR) was present values of crash saving and costs related to analyzed countermeasures. Using the service life of signs in Michigan, 15 years, and nominal discount rate, 2.95%, the discounted present value of benefits, crash savings, is determined as follows:

$$PV_{benefits} = (\text{Total Average Annual Saving}) \times \left(\frac{(1+R)^n - 1}{R * (1+R)^n}\right)$$

Where:

$PV_{benefits}$ equals to the Present value of savings,

R equals to the discount rate (in decimals),

n equals to the Service life (years), and

$$\text{Average Annual Savings(Benefit)} = (\text{Reductions in FI Crashs} * \text{FI Crash Cost}) + (\text{Reduction in PDO} * \text{PDO Crash Cost}).$$

Reductions in crashes were determined by subtracting observed crashes from expected crashes. This was the case of total and fatal and injury (FI) crashes. For example, reduction in fatal and injury (FI) crashes was calculated by subtracting the observed crashes from the expected FI crashes. Property Damage Only (PDO) reductions were then determined as the difference between reduction in total crashes and reduction in FI crashes.

Finally, estimation of the benefit-cost ratio (BCR) was as follows:

$$BCR = \frac{PV_{benefits}}{PV_{costs}}$$

PV_{costs} were calculated by multiplying the number of signs in each segment with the cost difference presented in Table 15.

Benefit to Costs Ratios (BCRs)

Table 17 provides with a summary of the average costs and benefits (savings) for each countermeasure within freeways and non-freeways segments. BCRs suggest that countermeasures are both saving crash costs. Benefits overwhelm the costs incurred in the improvements. The larger BCR is observed in urban non-freeways using both countermeasures. Since benefits presented in Table 17 are inclusive and represent total savings only total BCRs are presented. BCR for every crash condition can definitively be estimated. Thus, it can be concluded that countermeasures are cost effective and could be continue implemented for both safety and economy.

Table 17 Summary of Benefit to Cost Ratios per Countermeasure

Improvements		Crash Reductions (per year)							Costs and Benefits			
Site Type	Countermeasure	CMF Total Crashes	Average Total Crashes **Observed**	Average Total Crashes **Reduced**	CMF FI Crashes	Average FI Crashes **Observed**	Average FI Crashes **Reduced**	Average PDO Crashes **Reduced (Total - FI)**	Average Annual Savings	Present Value Benefits	Present Value Costs	Benefit to Cost Ratio (BCR)
Freeway Segments	Clearview Font & Fluorescent Yellow Sheeting	0.759	8.42	2.67	0.930	1.96	0.15	2.53	$25,085.86	$300,559.34	$110.65	2716
	Fluorescent Yellow Sheeting Only	0.851	13.74	2.41	0.963	2.77	0.11	2.30	$19,853.37	$237,867.64	$57.92	4107
Non-Freeways Urban Segments	Clearview Font &Fluorescent Yellow Sheeting	0.704	8.94	3.76	0.711	1.94	0.79	2.97	$95,395.08	$1,142,949.75	$153.29	7456
	Fluorescent Yellow Sheeting Only	0.949	11.47	0.62	0.917	2.52	0.23	0.39	$25,806.96	$309,199.01	$76.09	4064
Non-Freeways Rural Segments	Clearview Font &Fluorescent Yellow Sheeting	0.67	2.71	1.33	0.927	0.33	0.03	1.31	$7,565.81	$90,647.66	$83.20	1090
	Fluorescent Yellow Sheeting Only	0.923	3.90	0.32	0.972	0.35	0.01	0.31	$2,241.29	$26,853.41	$46.25	581

CHAPTER 8

CONCLUSION, RECOMMENDATIONS AND LIMITATIONS

After performing crash analysis on Clearview fonts and Fluorescent yellow sheeting, improvements in the number of crashes are observed: time of the day and age group. Improvements are mostly significant for all drivers in both freeways and non-freeways. However, although significance was not the strength of the reduction in few specific cases such as older drivers, reduction was found in all of them.

Moreover, it was observed that higher rates in reduction were in freeways for night time when both countermeasures were installed. This helps to visualize that the main purpose of the countermeasures in freeways is fulfilled and reflected in reduction of crashes: reading guide sign fonts clearer. Also, countermeasures provide larger crash reductions when both are installed, which was an output naturally expected.

In addition, it was observed that higher crash reductions related to older drivers (65-and-above years) occurred significantly in rural non-freeways using both countermeasures. Also, fatal/injury crashes were significantly reduced in urban areas as compared to rural and freeways. Countermeasures are helping improving the number of crashes in the state of Michigan during time of the day: lighted and dark, fatality and age groups: younger and older. Finally, countermeasures are not only providing safety benefits through reducing the number of crashes but are also economically justifiable. Overwhelming benefit to costs ratios (BCR) are obtained from the countermeasures overall. Thus implementation of countermeasures today will provide economic benefits.

As the driving population in Michigan prefers the installed Clearview fonts on guide sings and fluorescent yellow sheeting in warning sings, it is strongly recommended to continue its usage since scientifically they provide economic and safety benefits to the state and thus nationwide. MDOT can continue with the work started in 2006 by replacing all standard guide sign fonts and yellow sheeting with Clearview fonts and fluorescent yellow sheeting in Michigan.

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Appendix A

SURVEY QUESTIONNAIRE

Survey Questionnaire

Introduction:

Hi! "Western Michigan University and the Michigan Department of Transportation (MDOT) are conducting a survey of road users to identify their perspectives on the benefits of engineering safety improvements implemented by MDOT in Michigan over the past few years. Would you like to participate? The survey will take 10 minutes."

BELLOW IS TO BE FILLED BY OBSERVER

City: ________________________

Location of Site: ________________

Date: ________________

Gender: ☐ Male ☐ Female

Race: ☐ Caucasian ☐ Black or African American ☐ Asian ☐ Hispanic ☐ Other

Beginning of Survey:

Are you currently driving in the state of Michigan?

☐ Yes

☐ No

What is your age group in years?

☐ 16-24 ☐ 25-34 ☐ 35-49 ☐ 50-64 ☐ 65-74 ☐ 75-84 ☐ 85+

What is your home **ZIP CODE**? ________________

Countermeasure #1: Clearview Font on Guide Signs (freeway and non-freeway)

Hold both pictures in front of participant and proceed with questioning…

Which sign is easier to read in the following situations, and how would you rate its legibility on a scale of 1 to 3 (1 = low; 2 = medium; 3 = high)?

Option #1 (Clearview Font)					Option #2 (Standard Font)			
On high speed roads								
NA	3	2	1	Neutral	1	2	3	NA
From far distances								
NA	3	2	1	Neutral	1	2	3	NA
In inclement weather								
NA	3	2	1	Neutral	1	2	3	NA
In Night Time								
NA	3	2	1	Neutral	1	2	3	NA

- Remarks: ______________________________

Have you ever noticed the difference in fonts used for signs while driving prior to this interview?

☐ Yes

☐ No

☐ I do not know

Countermeasure #2: Fluorescent Yellow Sheeting

Hold pictures in front of participant and proceed with questioning…

1. Which sign is easier to recognize in the following situations, and how would you rate it on a scale of 1 to 3 (1 = low; 2 = medium; 3 = high)?

Option #1 (Fluorescent yellow sheeting)					Option #2 (Standard yellow sheeting)			
On high speed roads								
NA	3	2	1	Neutral	1	2	3	NA
In inclement weather								
NA	3	2	1	Neutral	1	2	3	NA
In Night Time								
NA	3	2	1	Neutral	1	2	3	NA

Remarks: ____

1. Have you ever noticed the difference in fonts used for signs while driving prior to this interview?

☐ Yes

☐ No

☐ I do not know

Are there any other engineering improvements that you would like to be implemented in Michigan?

☐ Yes

☐ No

If **YES**, please specify improvements below.

____

____

Are you willing to provide your contact information which we could use to contact you if we need additional information?

☐ Yes

☐ No

If **YES**, record information:

Name: ____

Address: ____

Primary phone number: ____

Email address: ____

Appendix B

SAMPLE ODDS RATIO

Sample Odds Ratio for Total Crashes

Freeways

Years	**2004-2005**	**2005-2006**
Sample Odds Ratio	0.999	0.958
Mean	0.979	
Standard Error	0.0296	
95 % Confidence Interval	Min (0.921)	Max (1.037)

Non-Freeways (Urban)

Years	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**
Sample Odds Ratio	0.957	0.994	0.989	1.004	0.841
Mean	0.957				
Standard Error	0.0674				
95 % Confidence Interval	Min (0.825)	Max (1.089)			

Non-Freeways (Rural)

Years	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**
Sample Odds Ratio	1.141	1.013	1.108	0.878	0.859
Mean	0.999				
Standard Error	0.1292				
95 % Confidence Interval	Min (0.747)	Max (1.253)			

Appendix C

SPFS AND CMFS RESULTS

SPFS AND CMFS RESULTS

a. Example of Correlation Test

Variables with correlation values higher than 0.5 were removed based on their importance in the study (e.g. if there was correlation among Ln Avg. AADT and concrete barrier median, Ln Avg. AADT was kept).

	Length	**Ln Avg. AADT**	**Ln Avg. CADT**	**Number Lanes**	**Number Inter-Changes**	**Concrete Barrier**	**Guardrail**	**Graded With ditch**	**urban**
Length	1								
Ln Avg. AADT	-0.465	1.000							
Ln Avg. CADT	0.021	0.346	1.000						
Number of lanes	-0.312	**0.727>0.5**	0.082	1.000					
Number Inter-changes	-0.058	0.118	-0.012	0.200	1.000				
Concrete Barrier	-0.446	**0.695 >0.5**	0.114	0.678	-0.044	1.000			
Guardrail	0.033	-0.012	0.005	0.123	-0.002	-0.072	1.000		
Graded with Ditch	0.458	**0.679>0.5**	-0.092	-0.654	0.012	-0.931	-0.141	1.000	
urban	**0.721>0.5**	0.507	-0.003	0.446	0.188	0.396	0.060	-0.425	1.000

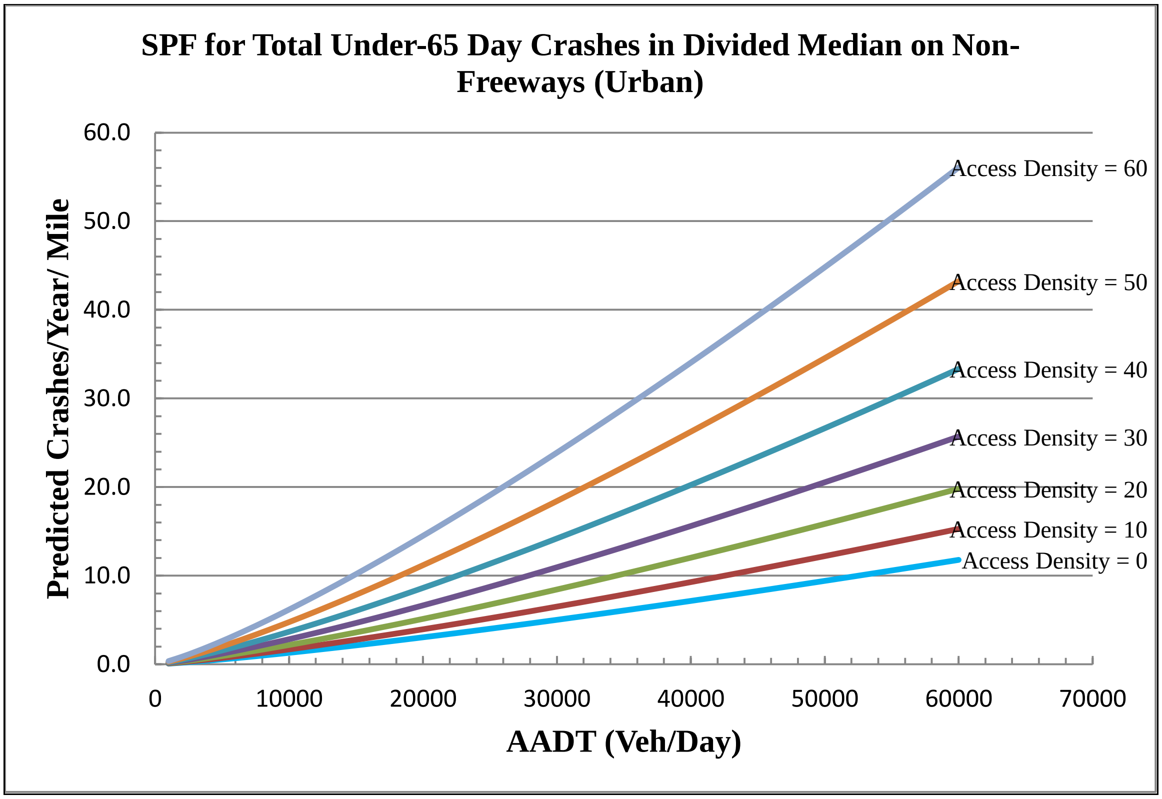
Variables with “check marks” are those used for developing SPF for freeways. In running the model two were considered influential based on their statistical significance: Length and Ln Avg, AADT. Since the critical value for 95% confidence interval is 1.96 every z-value (critical value) of the variables was used to determine the significance of the variable. If the z-value was smaller than 1.96 the variable was insignificant and vice-versa. Uncorrelated and influential variables are thus:

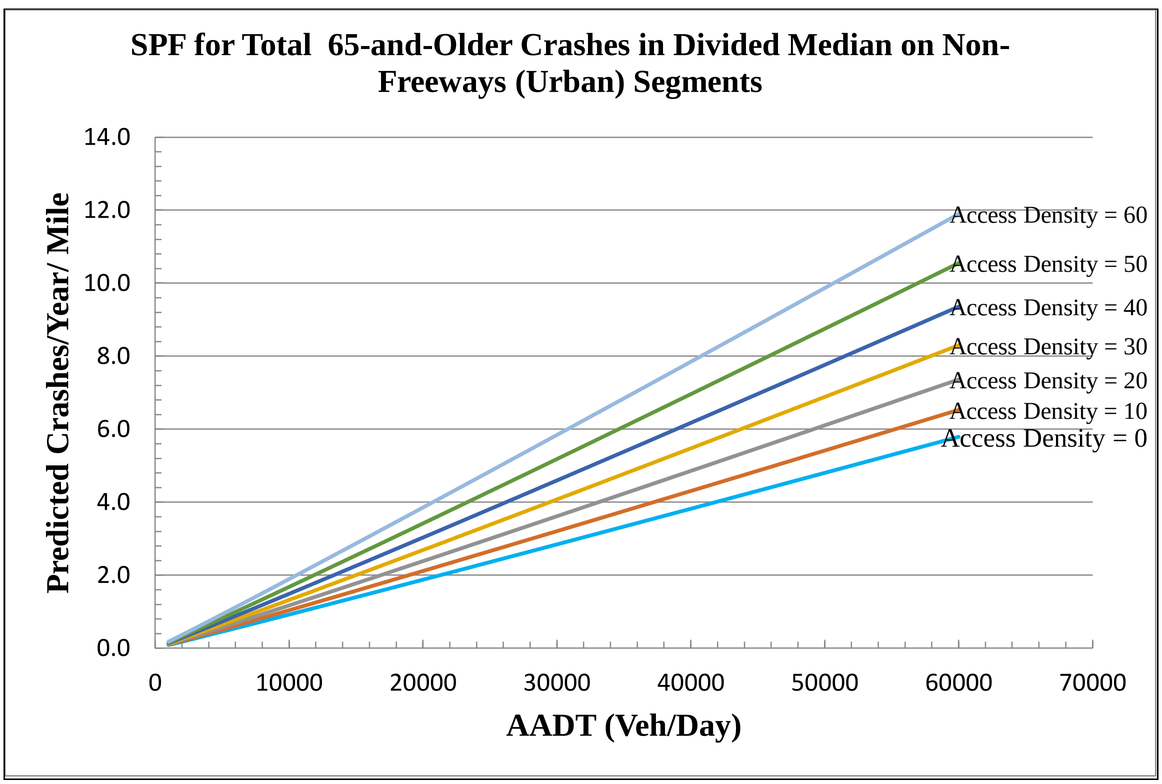
Variables (95% C.L)	**Coefficient**	**Standard Error**	**Z Value**	**P>|z|**
Length	.276	.0412	**6.69 > 1.96**	0.000
Ln Avg. AADT	1.007	.0984	**10.23 > 1.96**	0.000
Ln Avg. CADT	-.0471	.0911	-0.52	0.605
No. Interchanges	-.0607	.0588	-1.03	0.302
Guardrail	.0998	.391	0.26	0.798

This process was done for non-freeways in urban and rural areas.

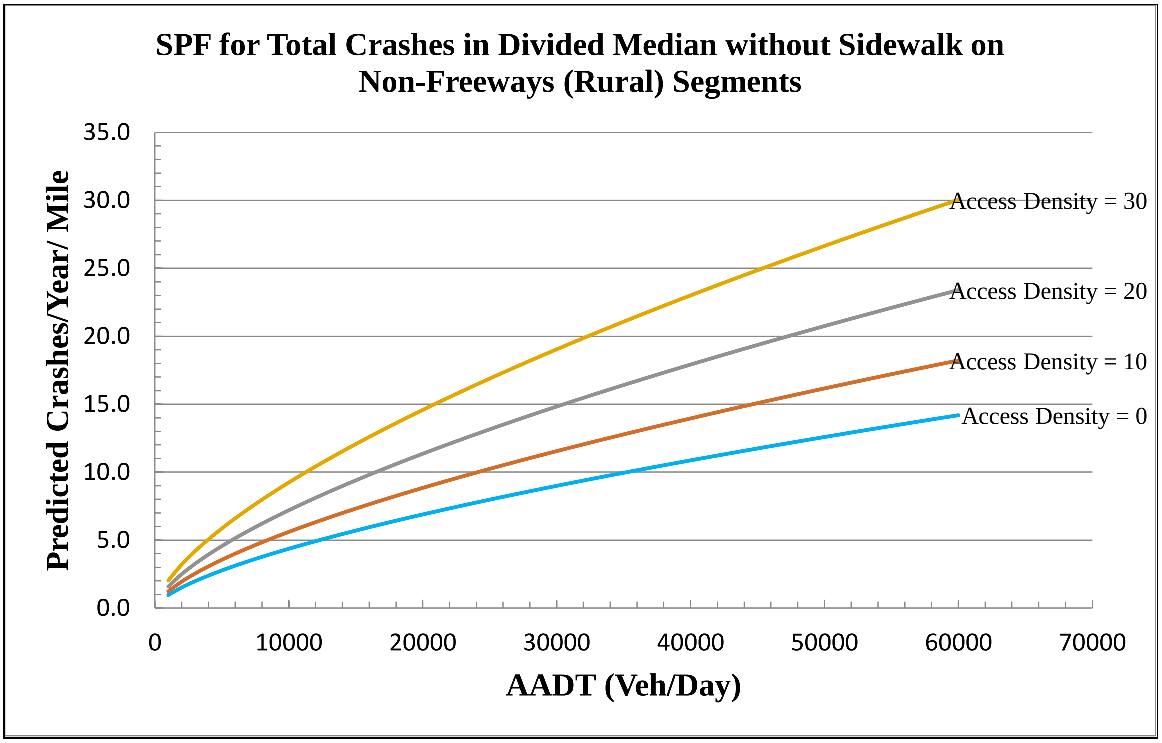
b. Graphical SPFs Results

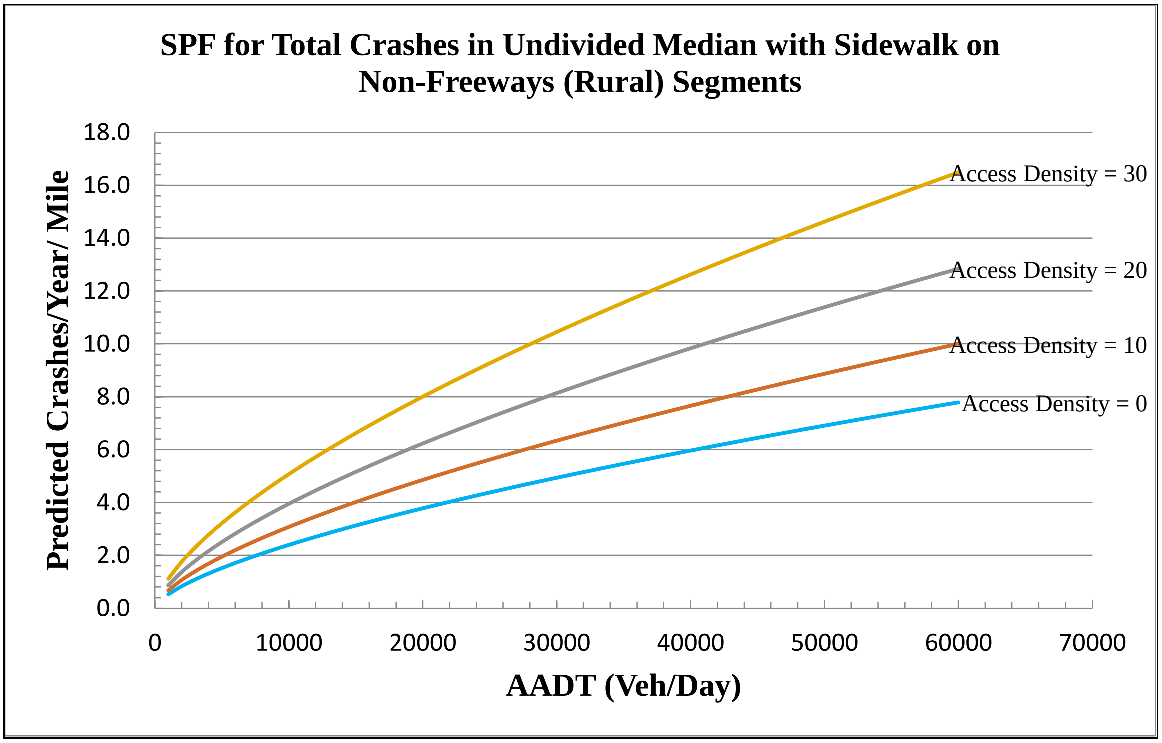
Permutations in SPFs are presented in this section. Even though the influential variables were presented in the main content in Chapter 6, other combinations are drawn from results. Since presence of median and sidewalk are not continuous this combination in graphical representation of SPF was possible.

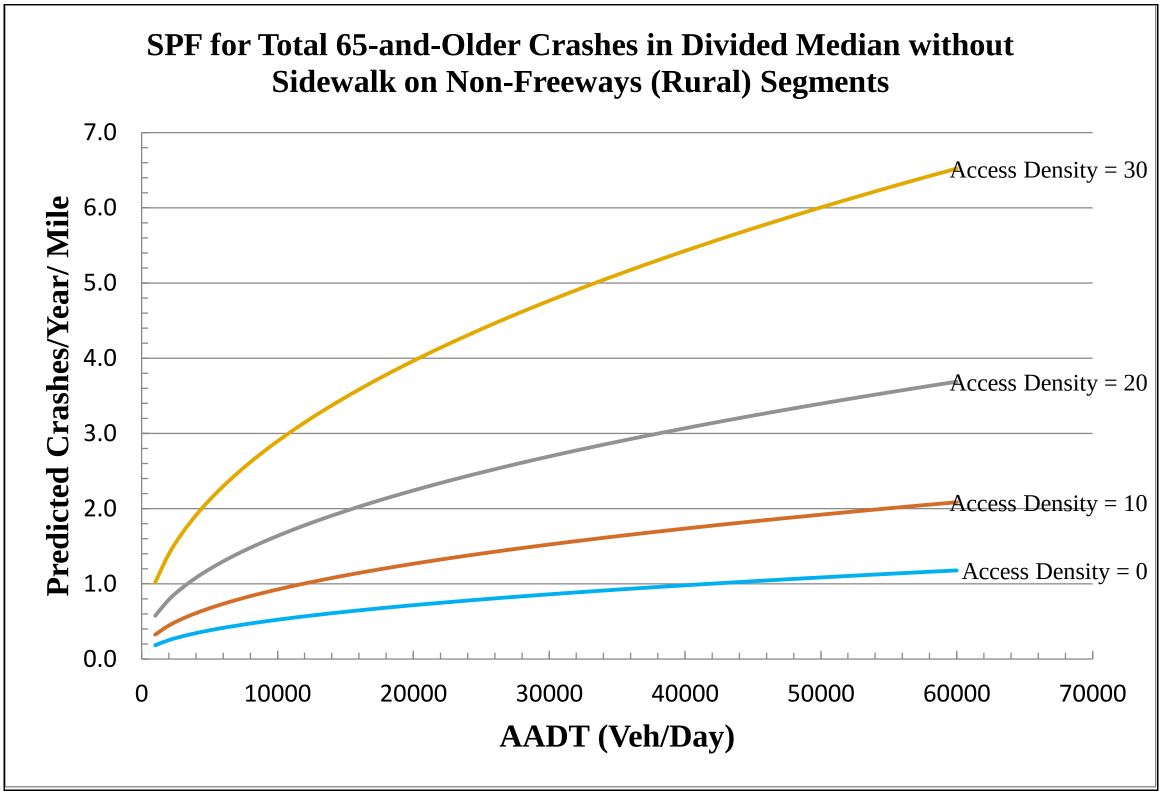

SPF for Total Under-65 Day Crashes in Divided Median on Non-Freeways (Urban)
Predicted Crashes/Year/ Mile
AADT (Veh/Day)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10000
20000
30000
40000
50000
60000
70000
Access Density = 60
Access Density = 50
Access Density = 40
Access Density = 30
Access Density = 20
Access Density = 10
Access Density = 0

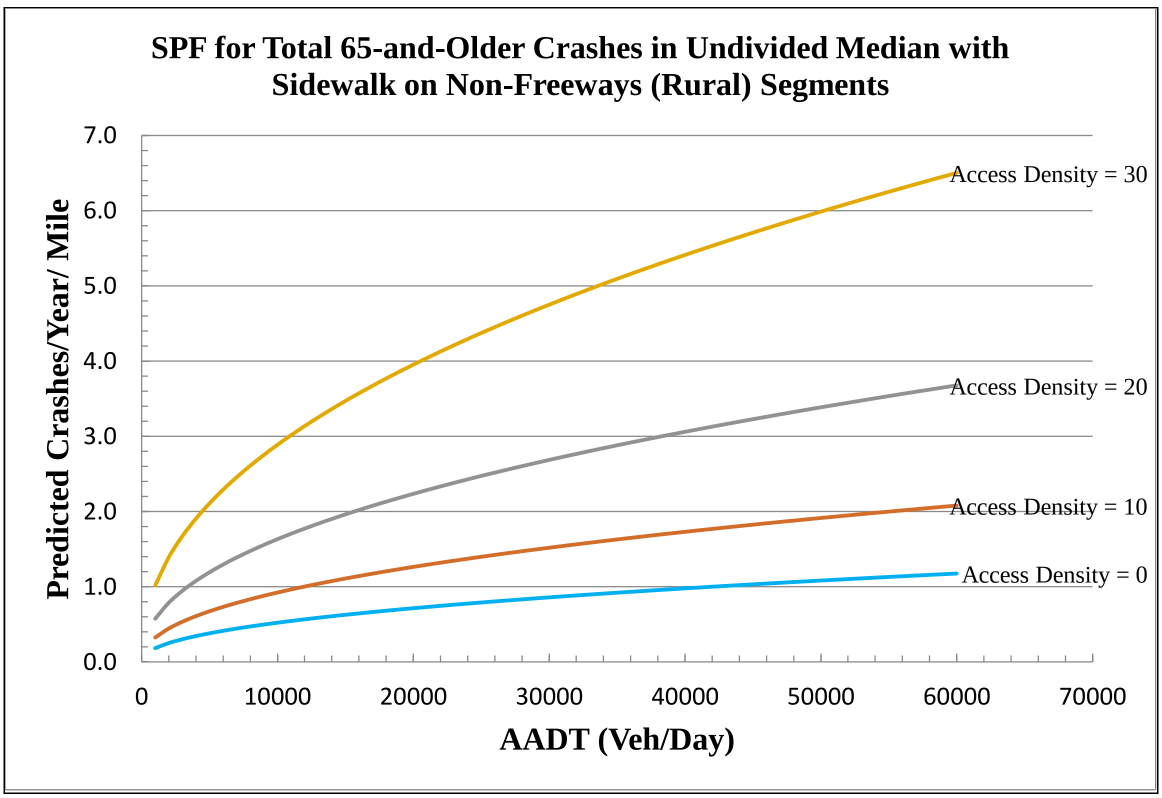

SPF for Total 65-and-Older Crashes in Divided Median on Non-Freeways (Urban) Segments
Predicted Crashes/Year/ Mile
AADT (Veh/Day)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
10000
20000
30000
40000
50000
60000
70000
Access Density = 60
Access Density = 50
Access Density = 40
Access Density = 30
Access Density = 20
Access Density = 10
Access Density = 0

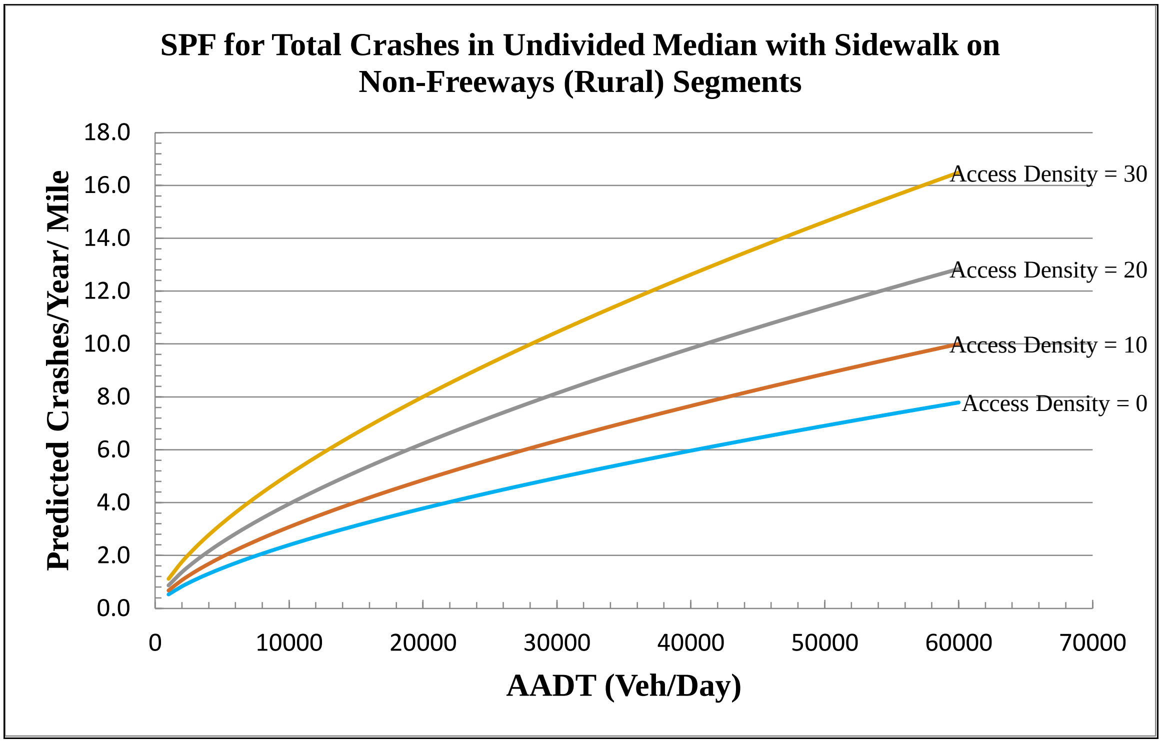
Rural Non-Freeways

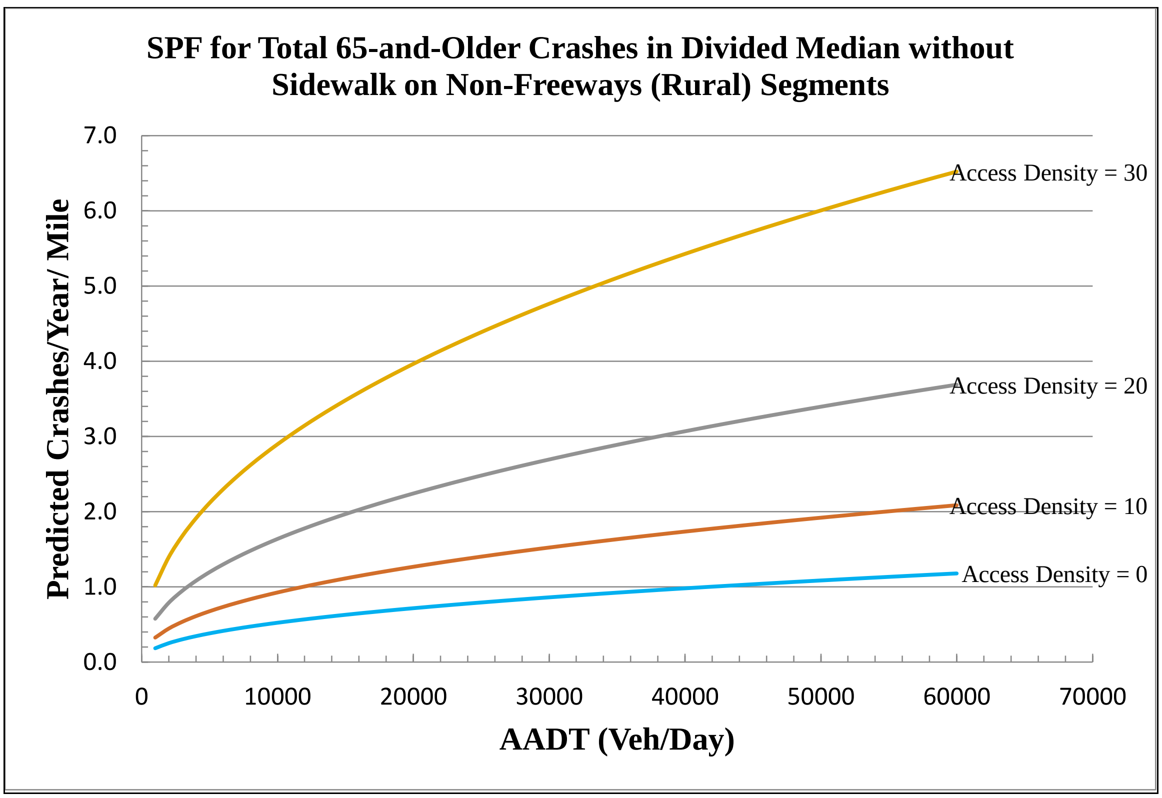


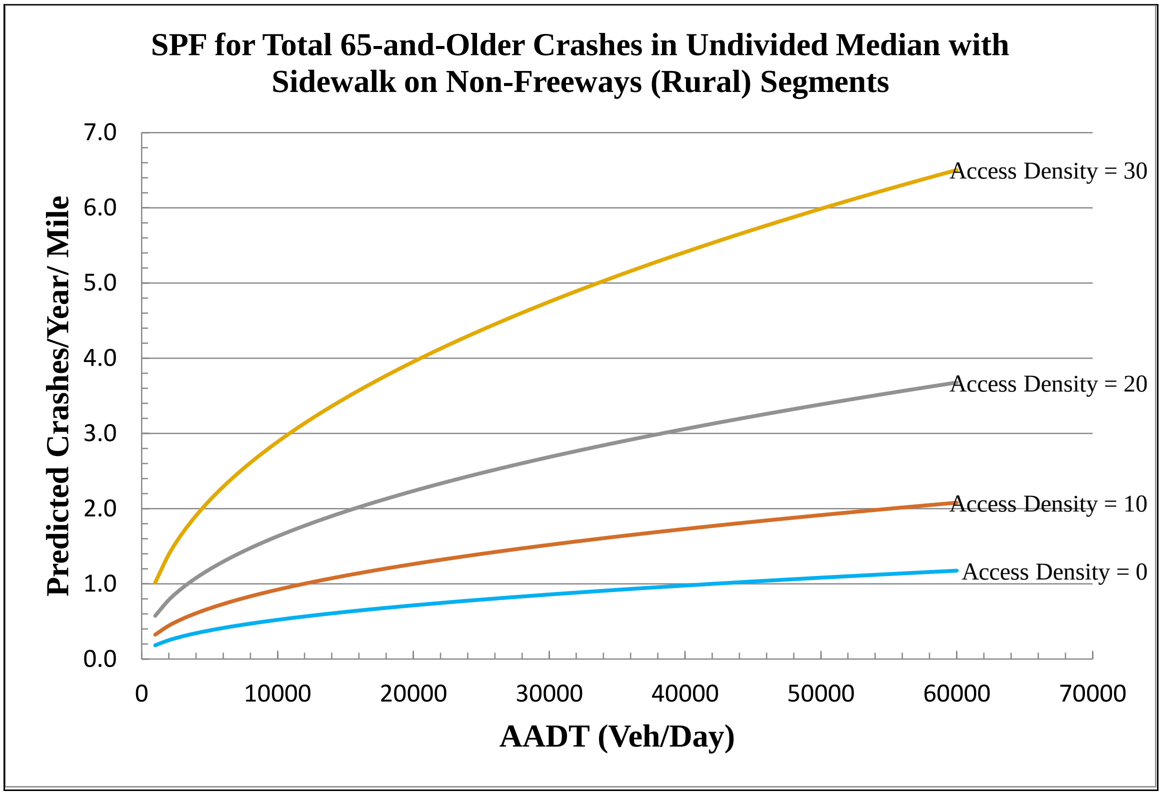



SPF for Total 65-and-Older Crashes in Divided Median without Sidewalk on Non-Freeways (Rural) Segments
Predicted Crashes/Year/ Mile
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Access Density = 30
Access Density = 20
Access Density = 10
Access Density = 0
0
10000
20000
30000
40000
50000
60000
70000
AADT (Veh/Day)


SPF for Total 65-and-Older Crashes in Undivided Median with Sidewalk on Non-Freeways (Rural) Segments
Predicted Crashes/Year/ Mile
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Access Density = 30
Access Density = 20
Access Density = 10
Access Density = 0
0
10000
20000
30000
40000
50000
60000
70000
AADT (Veh/Day)


SPF for Total Crashes in Undivided Median with Sidewalk on Non-Freeways (Rural) Segments
Predicted Crashes/Year/ Mile
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
10000
20000
30000
40000
50000
60000
70000
AADT (Veh/Day)
Access Density = 30
Access Density = 20
Access Density = 10
Access Density = 0

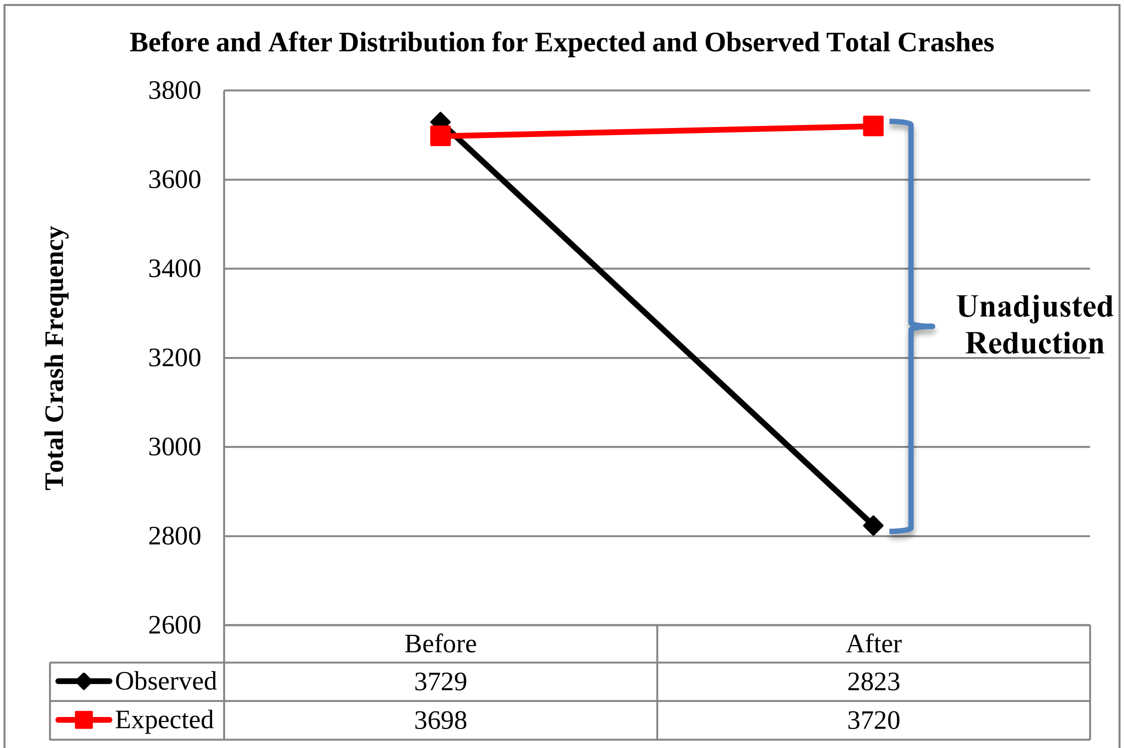

SPF for Total 65-and-Older Crashes in Divided Median without Sidewalk on Non-Freeways (Rural) Segments
Predicted Crashes/Year/ Mile
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
10000
20000
30000
40000
50000
60000
70000
AADT (Veh/Day)
Access Density = 30
Access Density = 20
Access Density = 10
Access Density = 0


SPF for Total 65-and-Older Crashes in Undivided Median with Sidewalk on Non-Freeways (Rural) Segments
Predicted Crashes/Year/ Mile
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
10000
20000
30000
40000
50000
60000
70000
AADT (Veh/Day)
Access Density = 30
Access Density = 20
Access Density = 10
Access Density = 0

c. Graphical CMFs Results

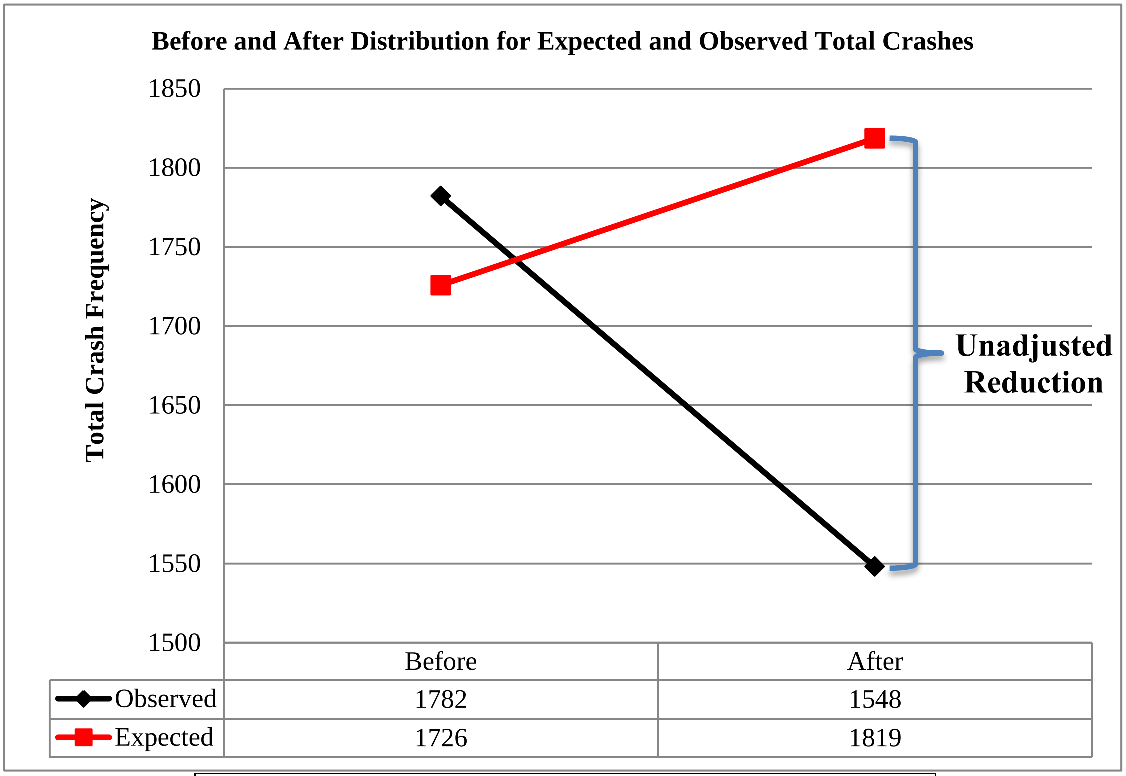
Empirical Bayes Method Results for Freeways

<u>Total Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting</u>



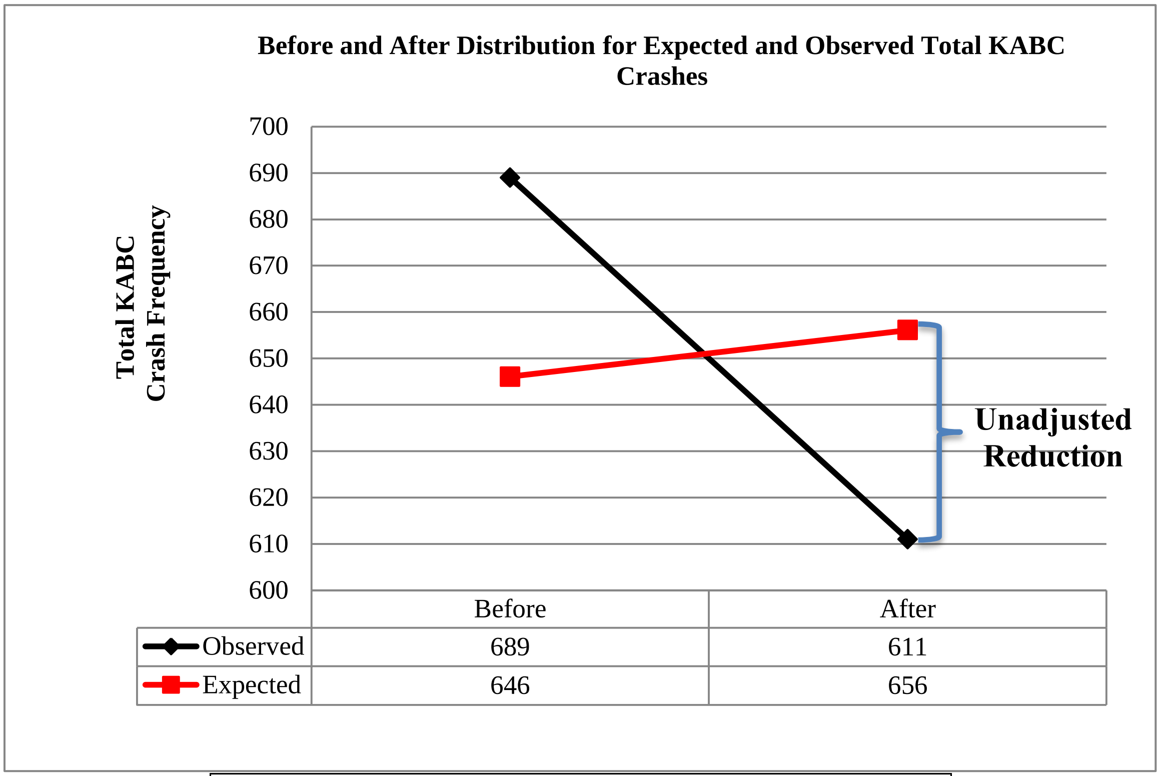
Total Crashes using Both Countermeasures	
Adjusted Reduction	24.13%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.759
Standard Error	0.0190

Total Crashes - Presence of Fluorescent Yellow Sheeting only



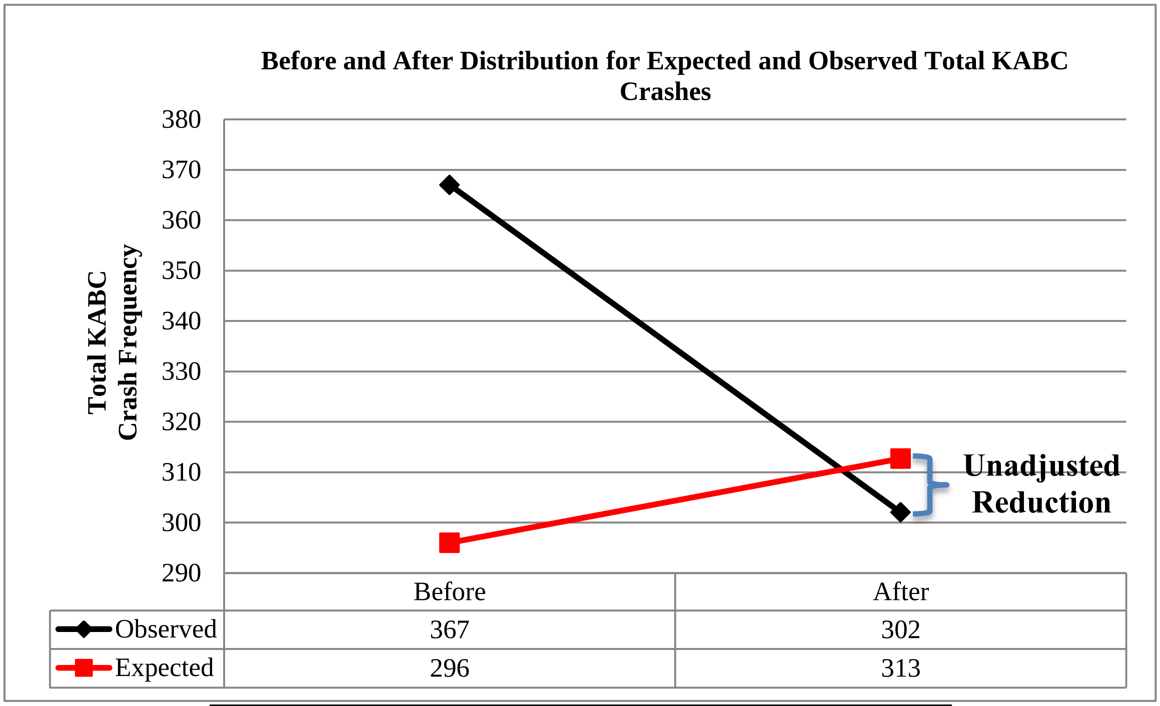
Total Crashes using One Countermeasure	
Adjusted Reduction	14.92%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.851
Standard Error	0.0294

Total FATAL INJURY Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



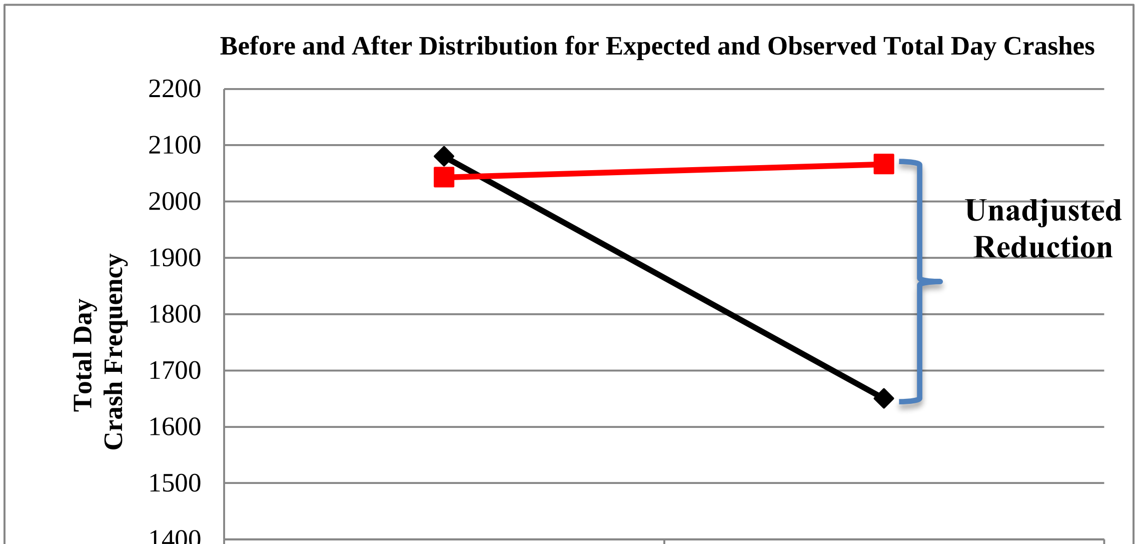
Total FATAL INJURY Crashes using Both Countermeasures	
Adjusted Reduction	6.99%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.930
Standard Error	0.0498

Total FATAL INJURY Crashes - Presence of Fluorescent Yellow Sheeting only



Total FATAL INJURY Crashes using One Countermeasure	
Adjusted Reduction	3.67%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.963
Standard Error	0.0733

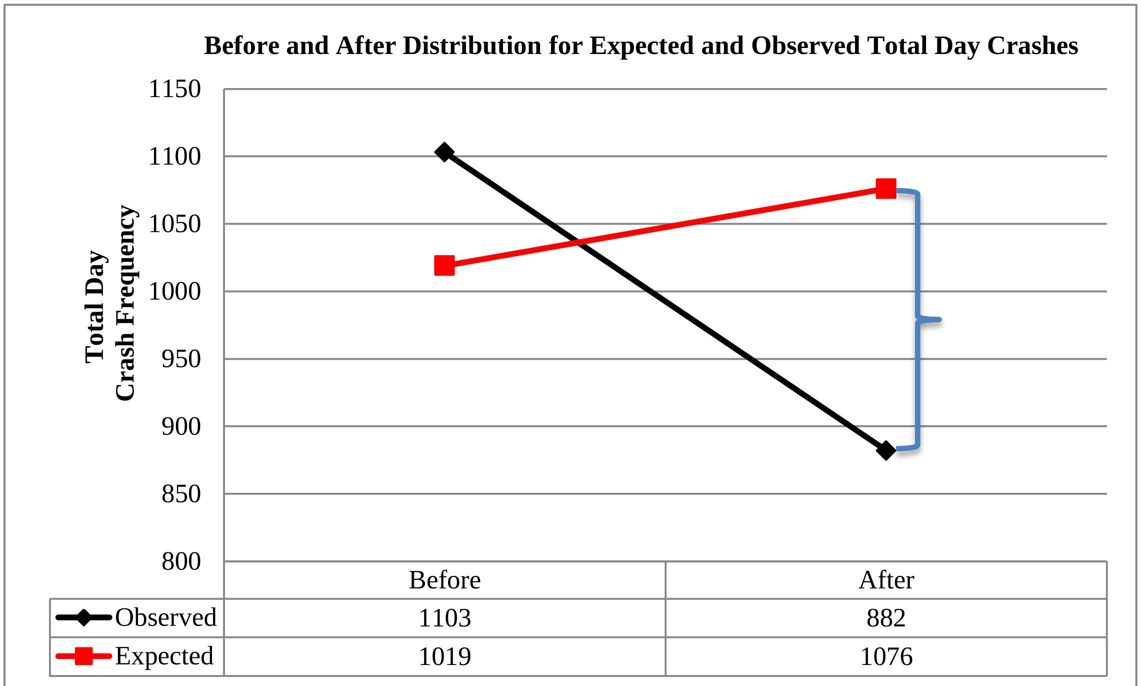
Total Day Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Observed	2080	1650
Expected	2043	2066

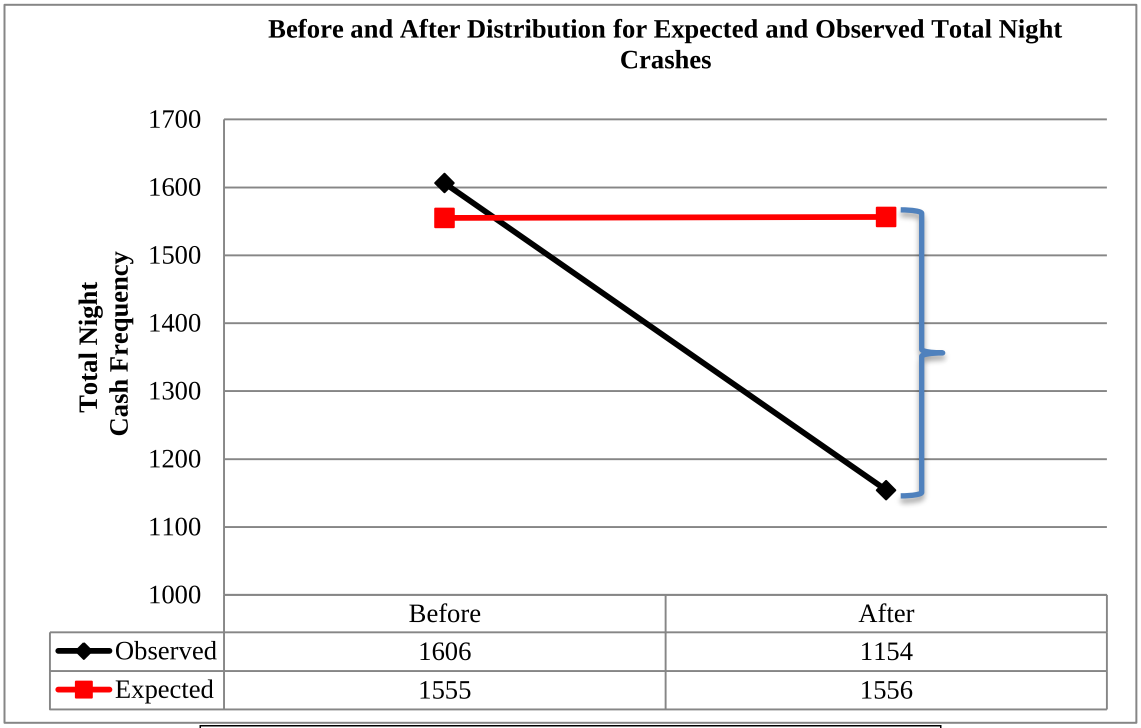
Total Day Crashes using Both Countermeasures	
Adjusted Reduction	20.18%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.798
Standard Error	0.0261

Total Day Crashes - Presence of Fluorescent Yellow Sheeting only



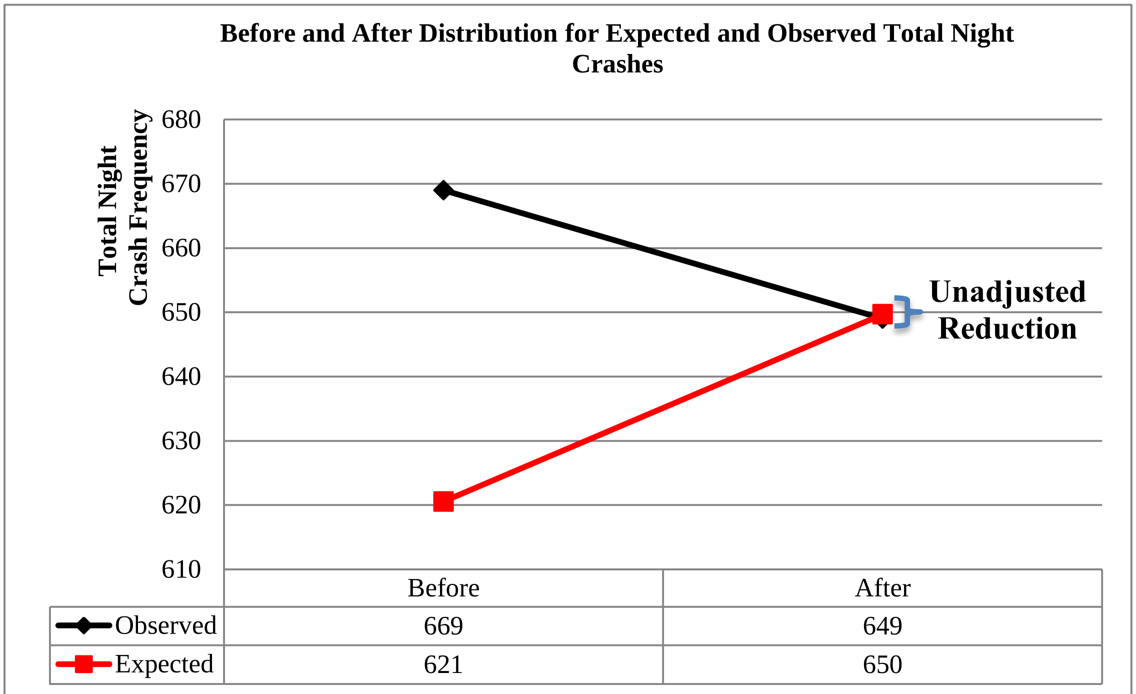
Total Day Crashes using One Countermeasure	
Adjusted Reduction	18.10%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.819
Standard Error	0.0367

Total Night Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



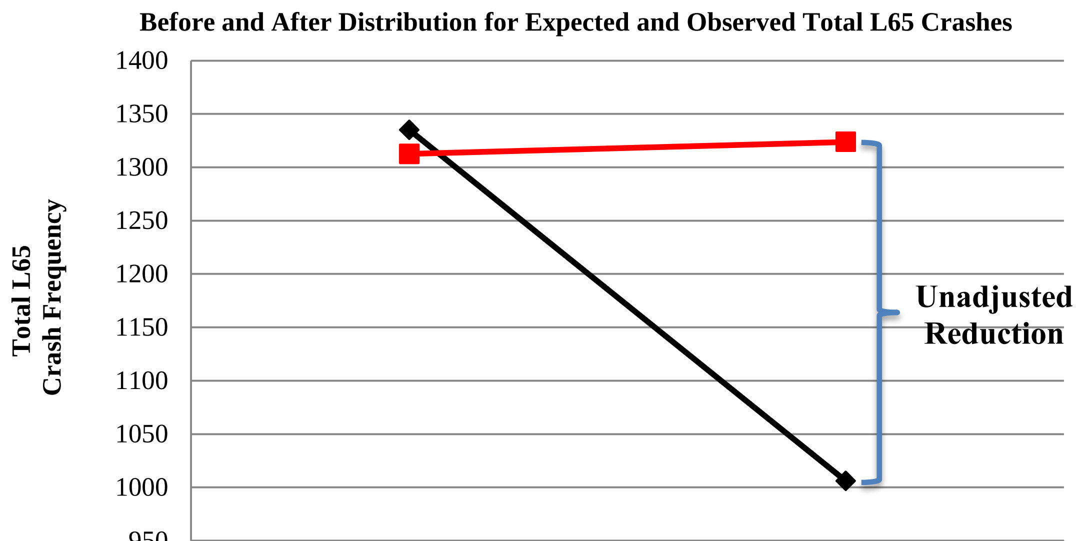
Total Night Crashes using Both Countermeasures	
Adjusted Reduction	25.90%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.741
Standard Error	0.0281

Total Night Crashes - Presence of Fluorescent Yellow Sheeting only



Total Night Crashes using One Countermeasure	
Adjusted Reduction	0.24%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.998
Standard Error	0.0534

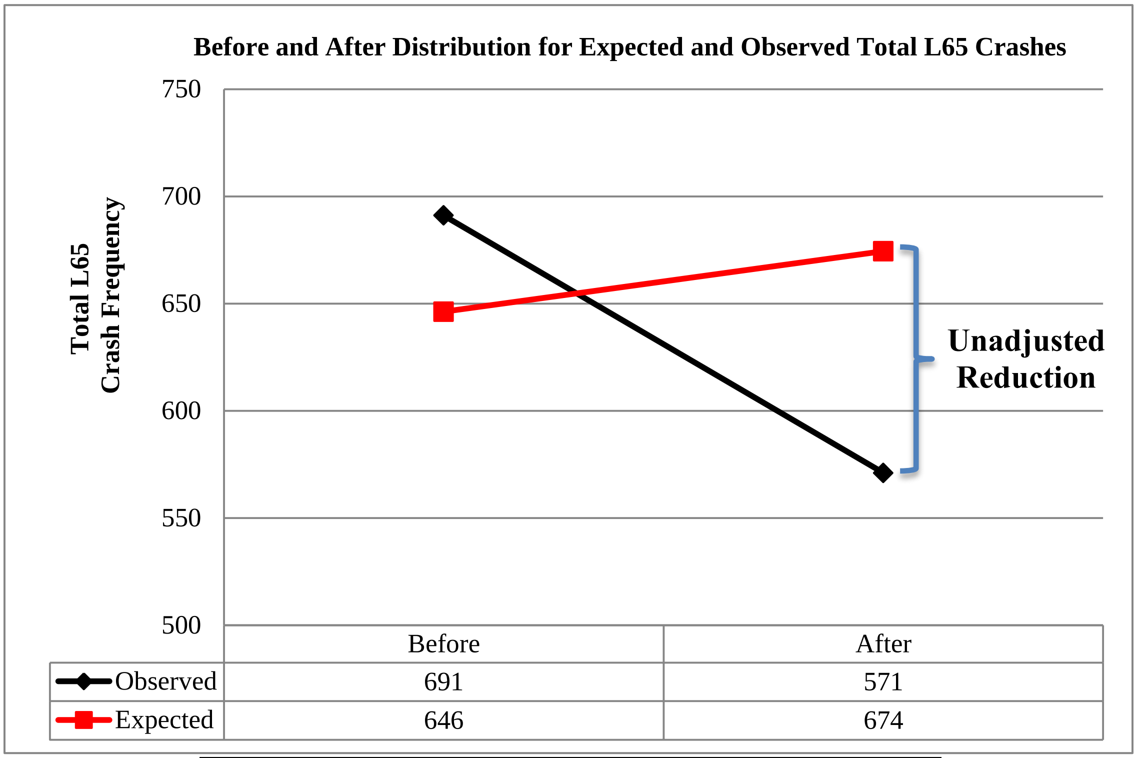
Total Younger Drivers (UNDER-65) Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Observed	1335	1006
Expected	1312	1324

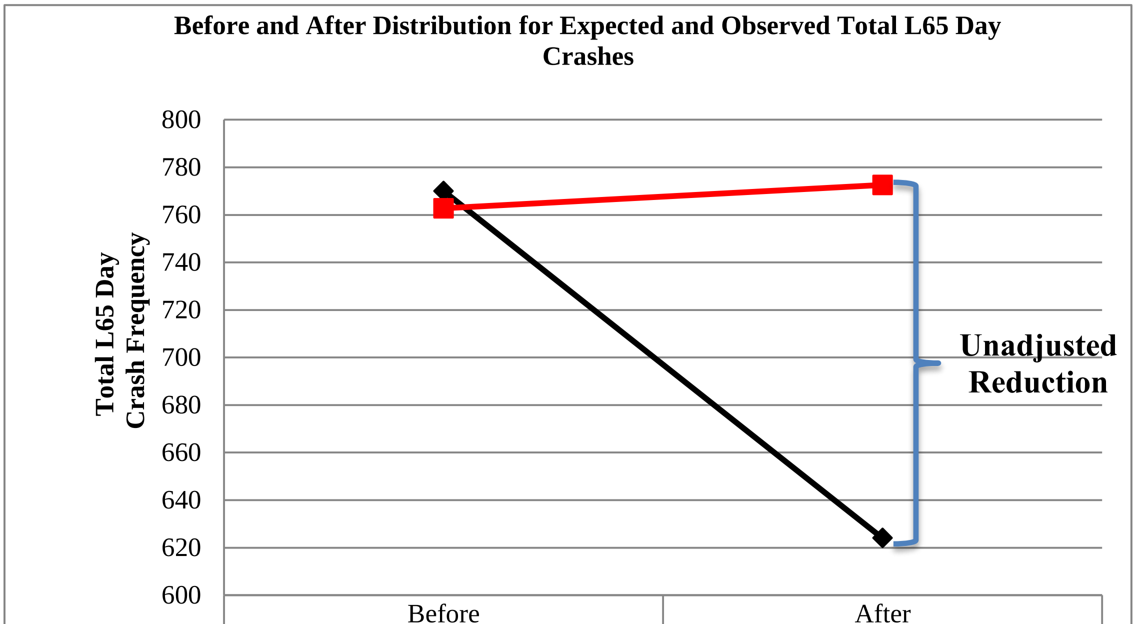
Total UNDER-65 Crashes using Both Countermeasures	
Adjusted Reduction	24.06%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.759
Standard Error	0.0312

Total Younger Drivers (UNDER-65) Crashes - Presence of Fluorescent Yellow Sheeting only



Total UNDER-65 Crashes using One Countermeasure	
Adjusted Reduction	15.45%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.846
Standard Error	0.0470

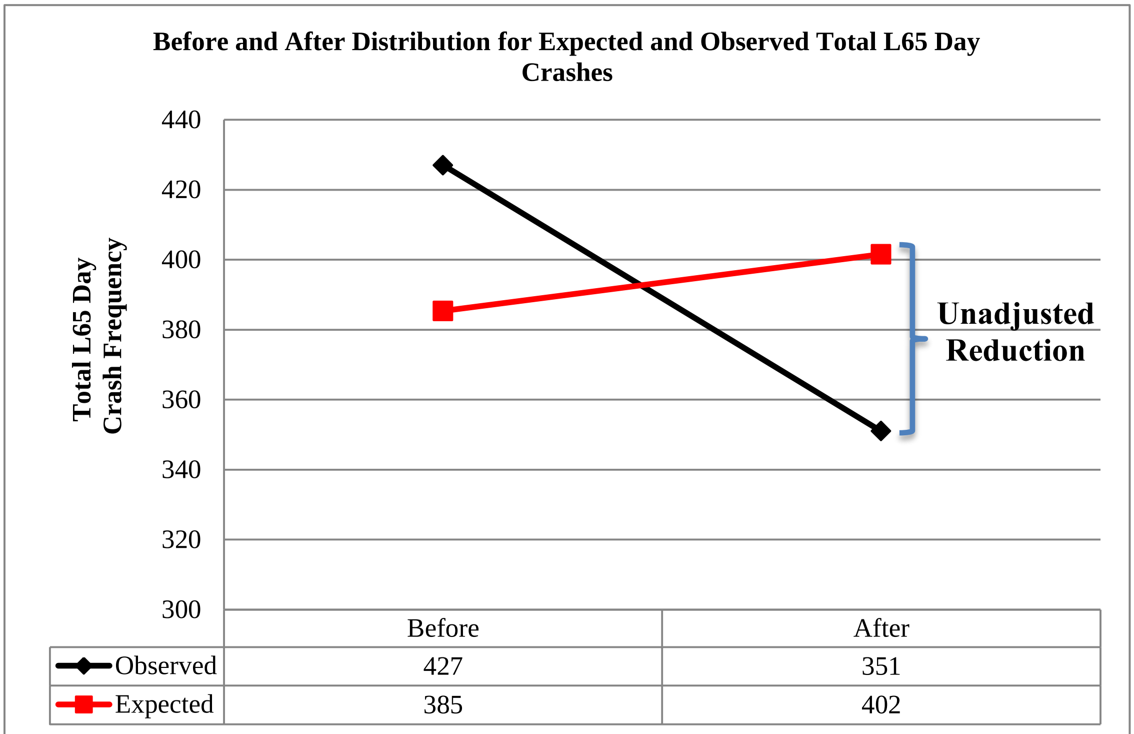
Total Younger Drivers (UNDER-65) Day Crashes- Crashes Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Observed	770	624
Expected	763	773

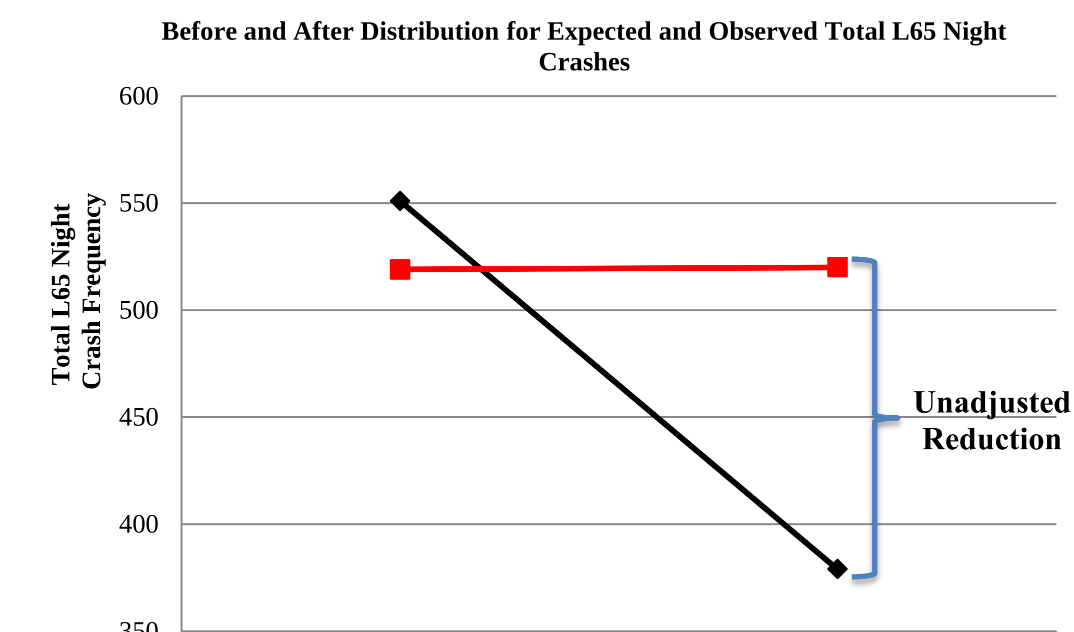
Total UNDER-65 Day Crashes using Both Countermeasures	
Adjusted Reduction	19.32%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.807
Standard Error	0.0420

Total Younger Drivers (UNDER-65) Day Crashes- Presence of Fluorescent Yellow Sheeting only



Total UNDER-65 Day Crashes using One Countermeasure	
Adjusted Reduction	12.77%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.872
Standard Error	0.0612

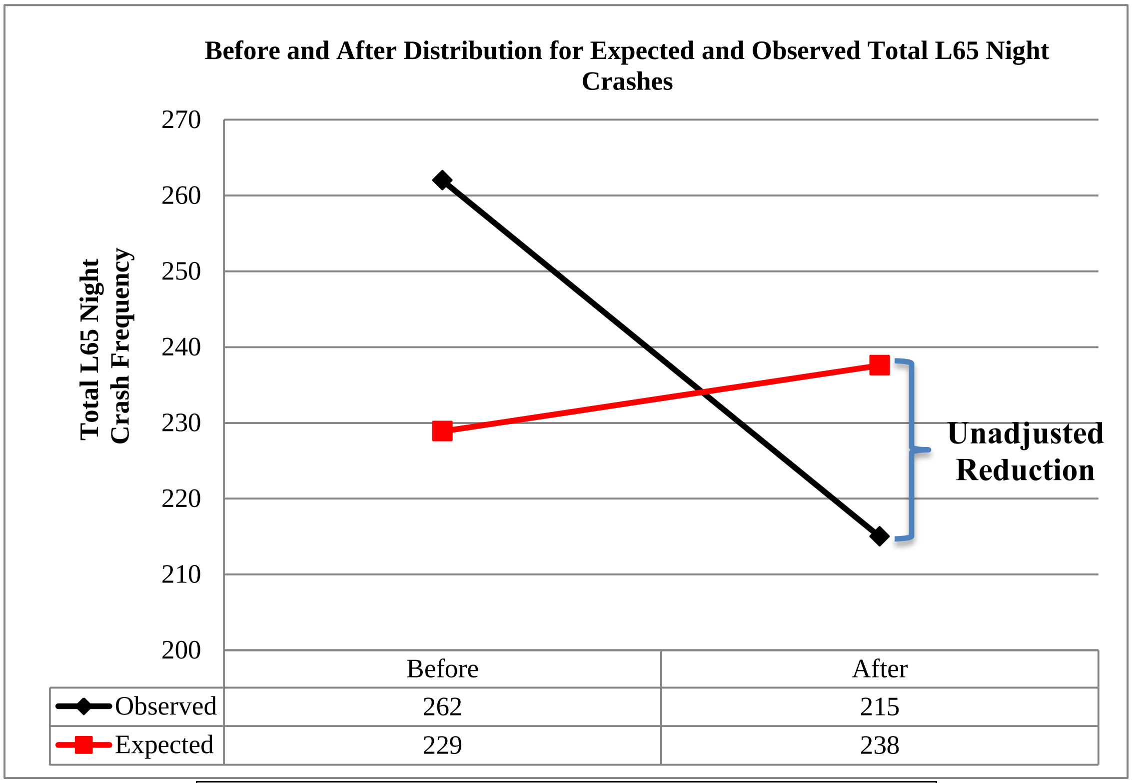
Total Younger Drivers (UNDER-65) Night Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Observed	551	379
Expected	519	520

Total UNDER-65 Night Crashes using Both Countermeasures	
Adjusted Reduction	27.21%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.728
Standard Error	0.0463

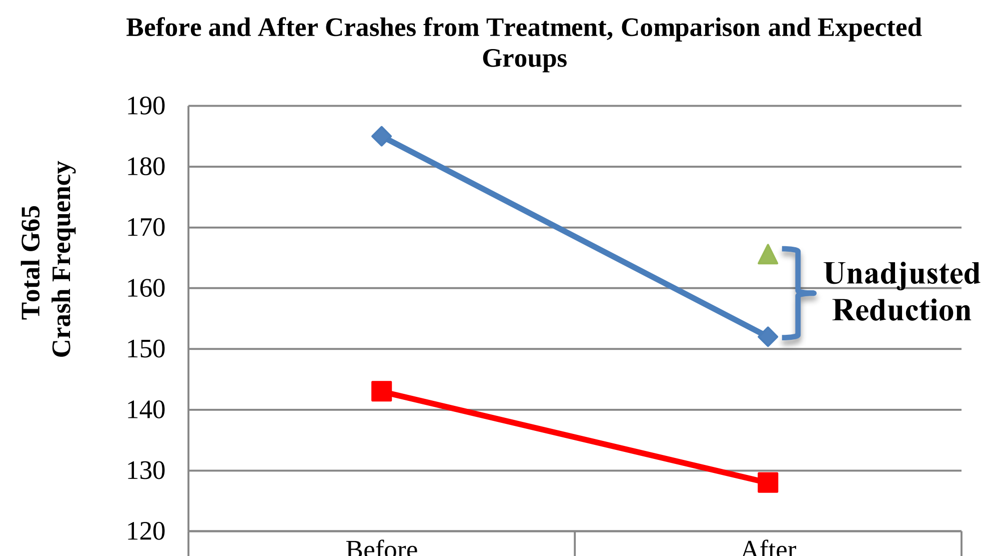
Total Younger Drivers (UNDER-65) Night Crashes - Presence of Fluorescent Yellow Sheeting only



Total UNDER-65 Night Crashes using One Countermeasure	
Adjusted Reduction	9.77%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.902
Standard Error	0.0786

Before and After with Comparison Groups Method for Freeways

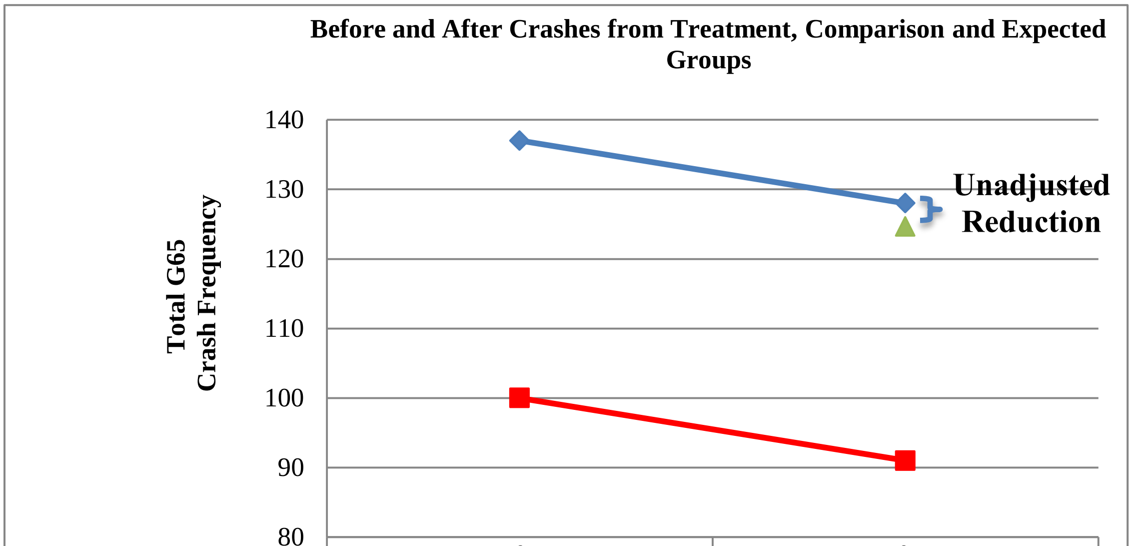
Total Older Drivers (65-AND-ABOVE) Crashes- Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Treatment Group	185	152
Comparison Group	143	128
Expected		166

Total 65-AND-ABOVE Crashes using Both Countermeasures	
Adjusted Reduction	10.03%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.899
Standard Error	0.144

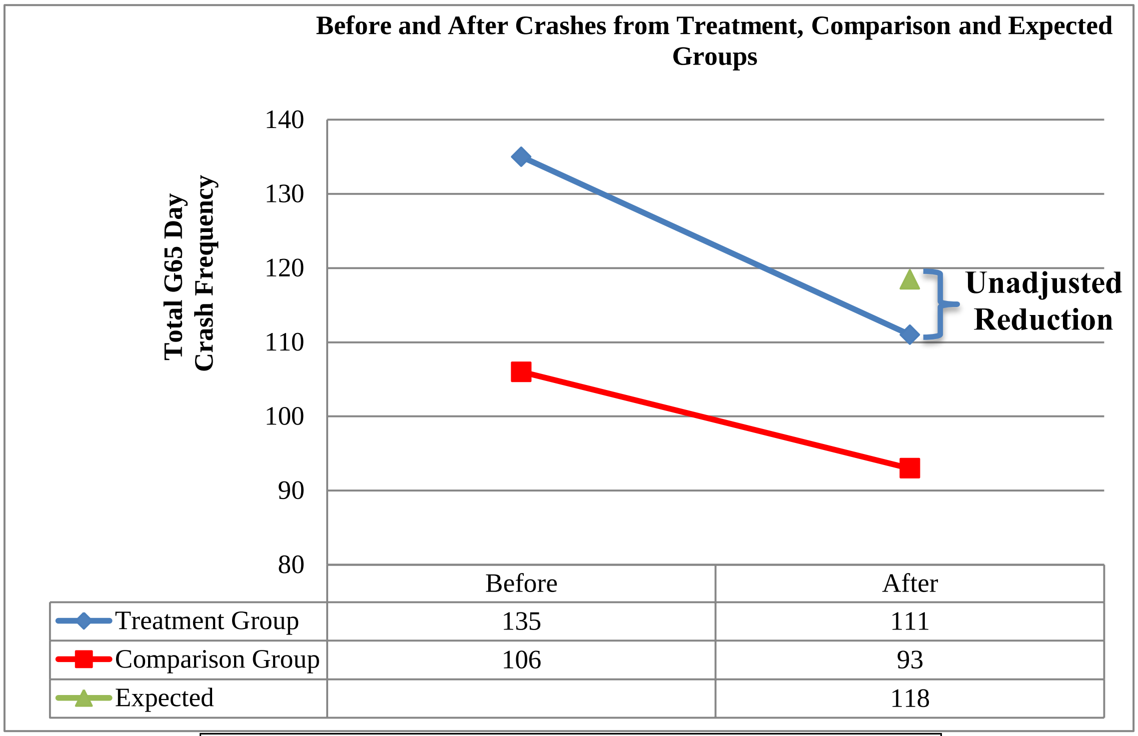
Total Older Drivers (65-AND-ABOVE) Crashes- Presence of Fluorescent Yellow Sheeting only



	Before	After
Treatment Group	137	128
Comparison Group	100	91
Expected		125

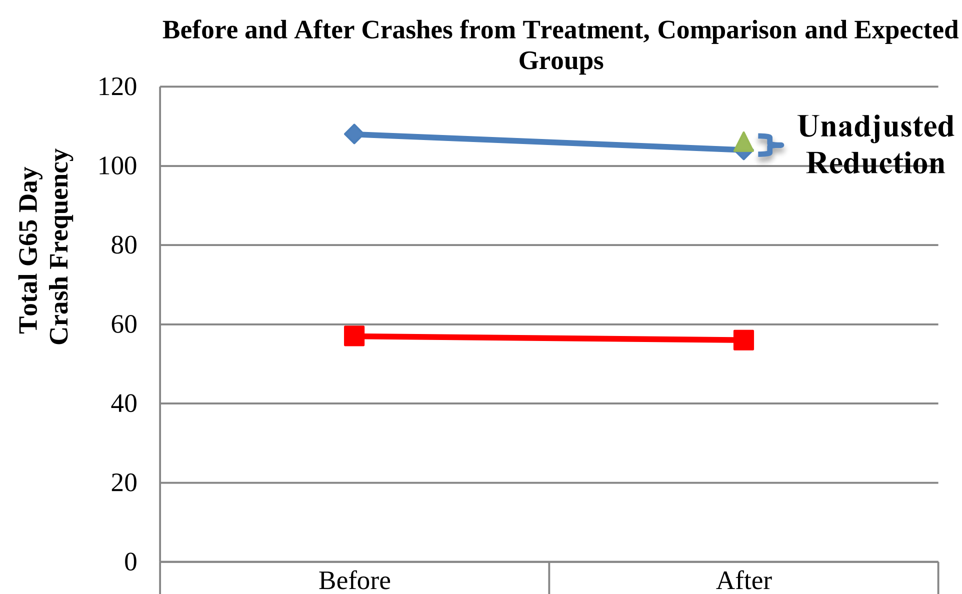
Total 65-AND-ABOVE Crashes using One Countermeasure	
Adjusted Reduction	0.15%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.998
Standard Error	0.184

Total Older Drivers (65-AND-ABOVE) Day Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



Total 65-AND-ABOVE Day Crashes using Both Countermeasures	
Adjusted Reduction	8.80%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.912
Standard Error	0.170

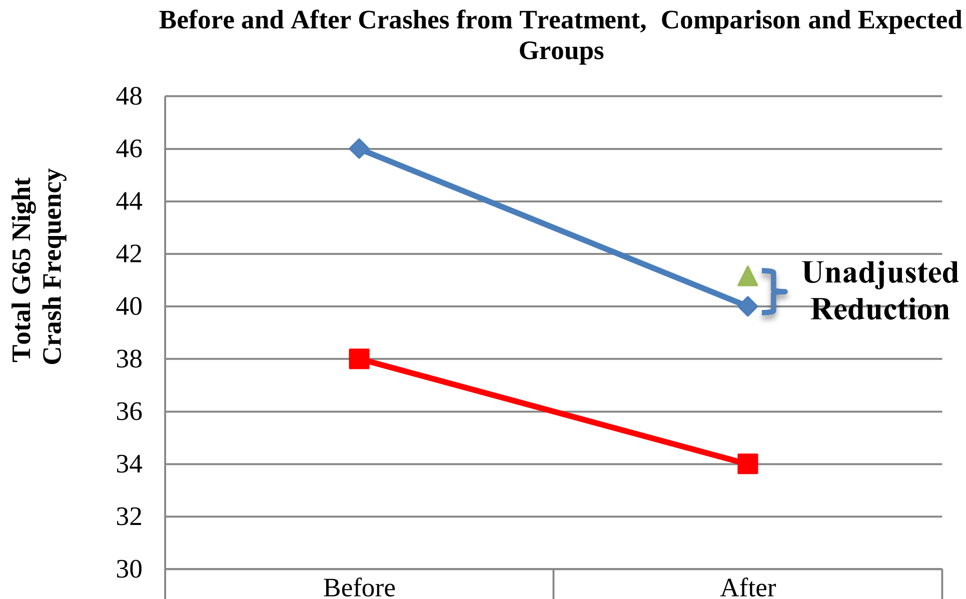
Total Older Drivers (65-AND-ABOVE) Day Crashes- Presence of Fluorescent Yellow Sheeting only



	Before	After
Treatment Group	108	104
Comparison Group	57	56
Expected		106

Total 65-AND-ABOVE Day Crashes using One Countermeasure	
Adjusted Reduction	6.17%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.938
Standard Error	0.209

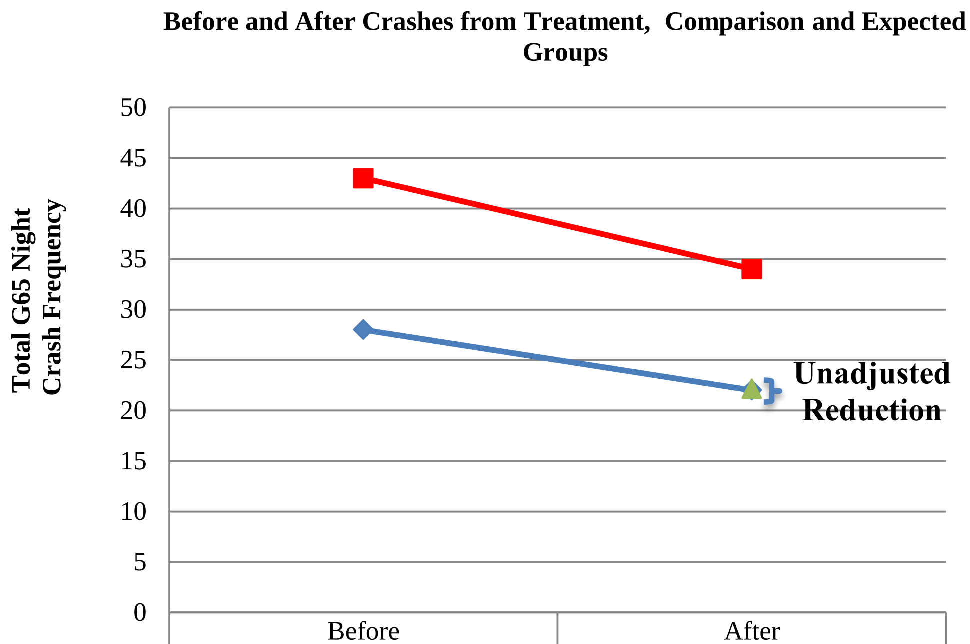
Total Older Drivers (65-AND-ABOVE) Night Crashes- Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Treatment Group	46	40
Comparison Group	38	34
Expected		41

Total 65-AND-ABOVE Night Crashes using Both Countermeasures	
Adjusted Reduction	9.80%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.902
Standard Error	0.270

Total Older Drivers (65-AND-ABOVE) Night Crashes - Presence of Fluorescent Yellow Sheeting only

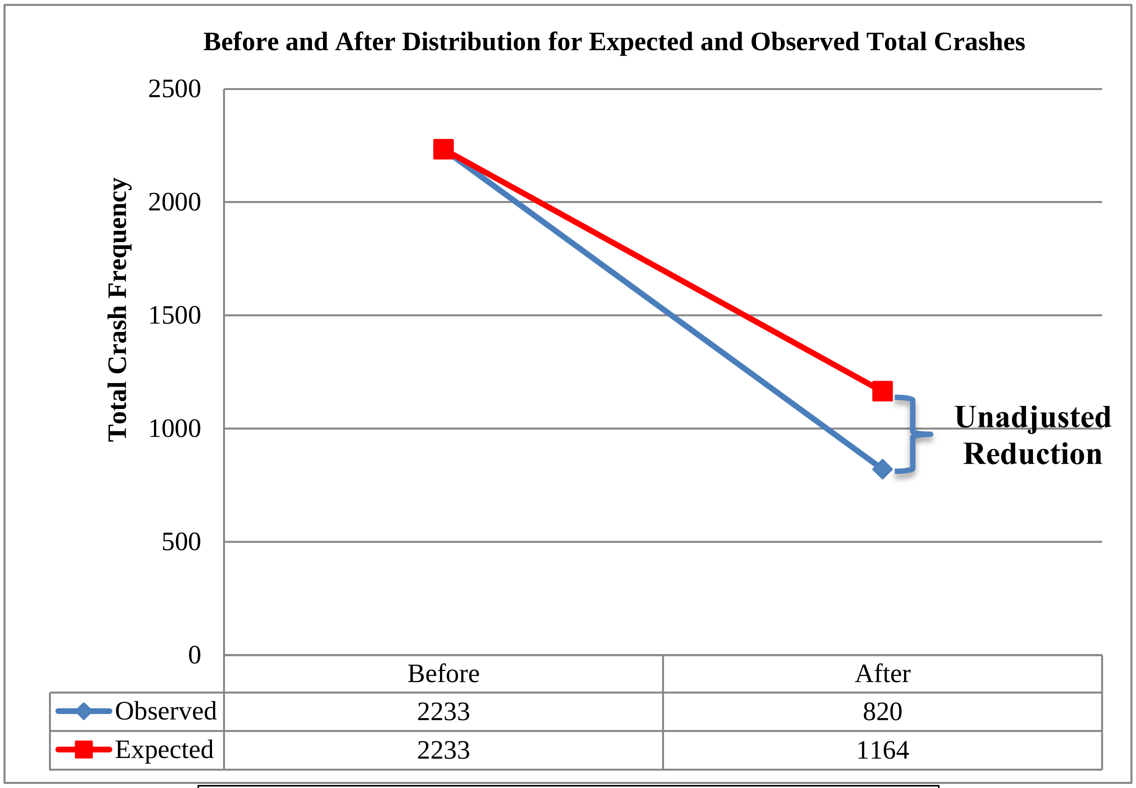


	Before	After
Treatment Group	28	22
Comparison Group	43	34
Expected		22

Total 65-AND-ABOVE Night Crashes using One Countermeasure	
Adjusted Reduction	8.69%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.913
Standard Error	0.307

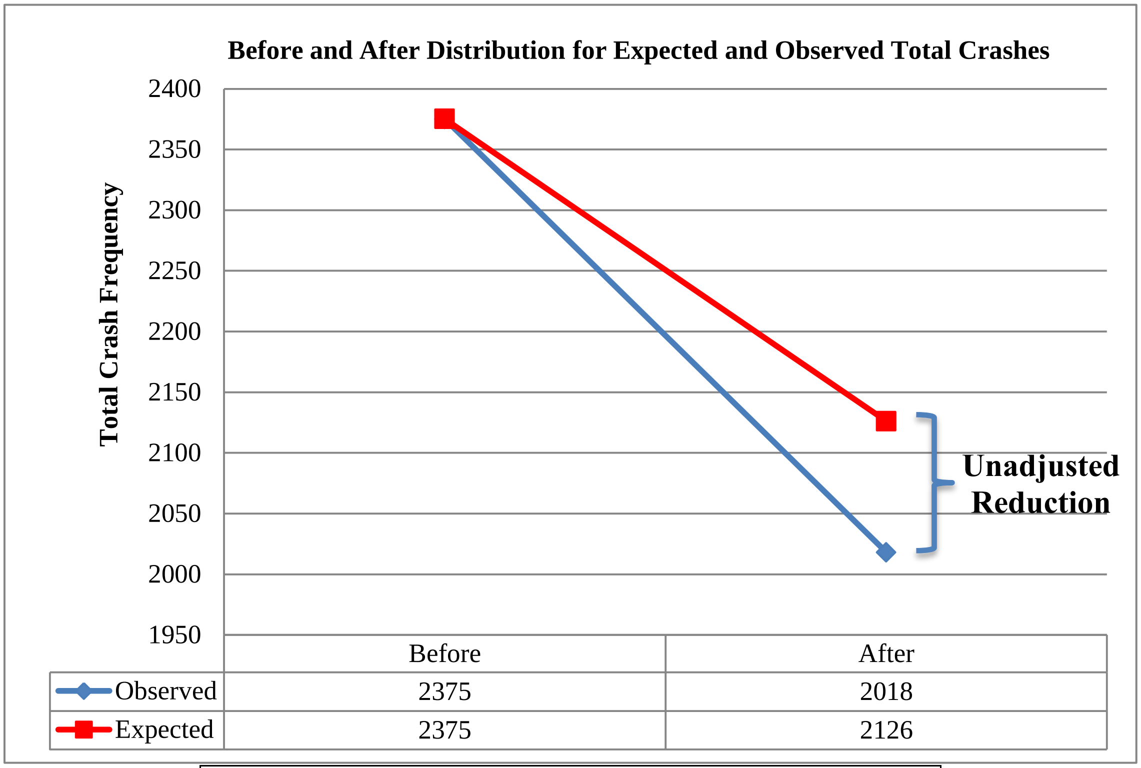
Empirical Bayes Method Results for Non-Freeways in Urban Areas

Total Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



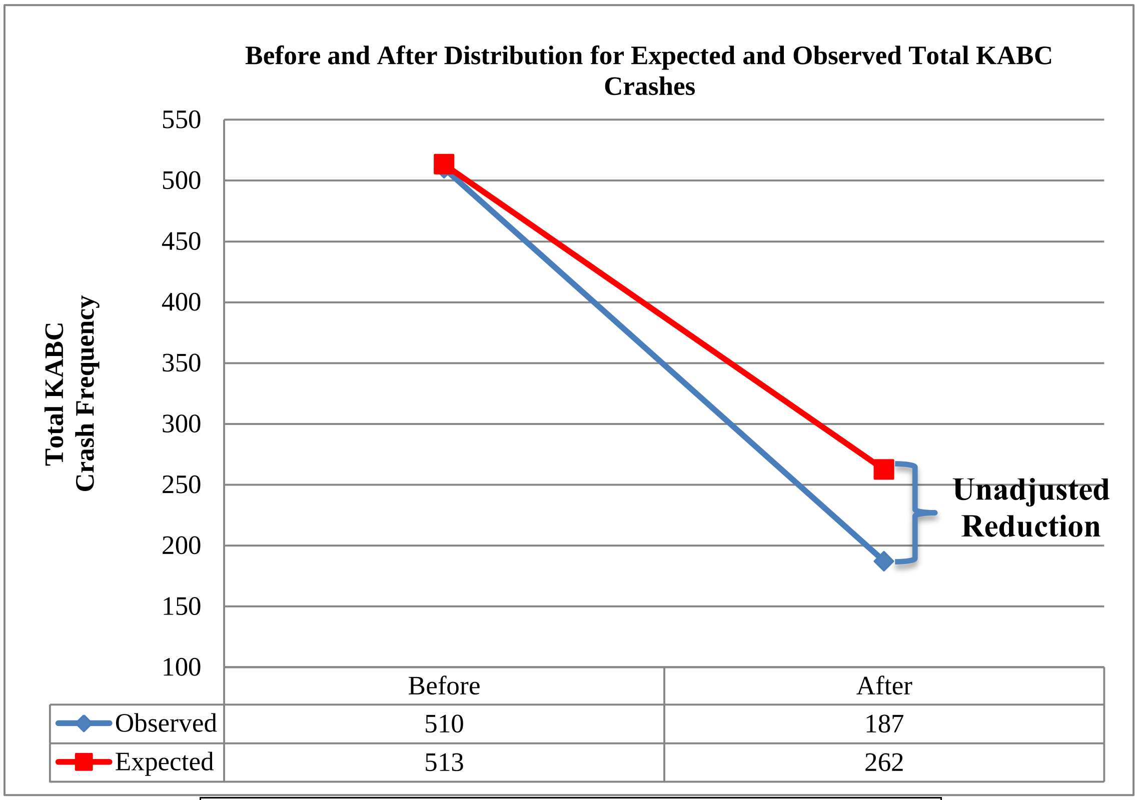
Total Crashes using Both Countermeasures	
Adjusted Reduction	29.59%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.704
Standard Error	0.0288

Total Crashes - Presence of Fluorescent Yellow Sheeting only



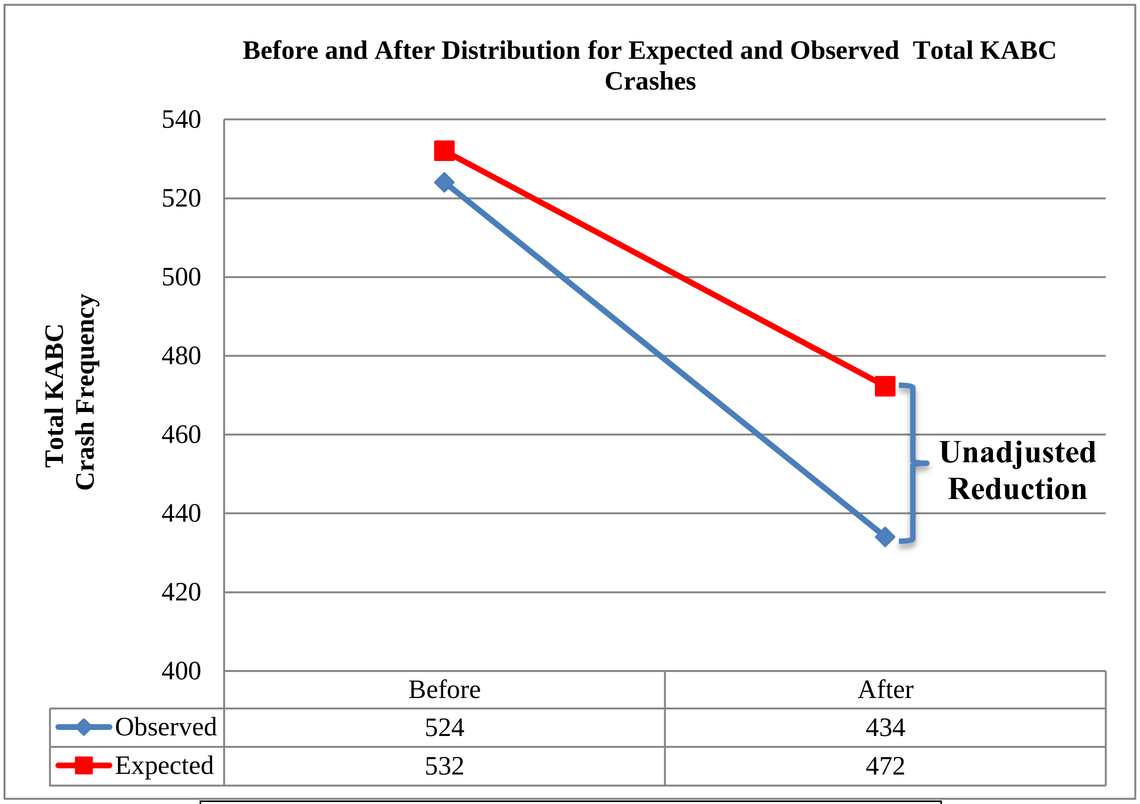
Total Crashes using One Countermeasure	
Adjusted Reduction	5.13%
Statistical Significance	90% Confidence Level
Crash Modification Factor (CMF)	0.949
Standard Error	0.0288

Total FATAL INJURY Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



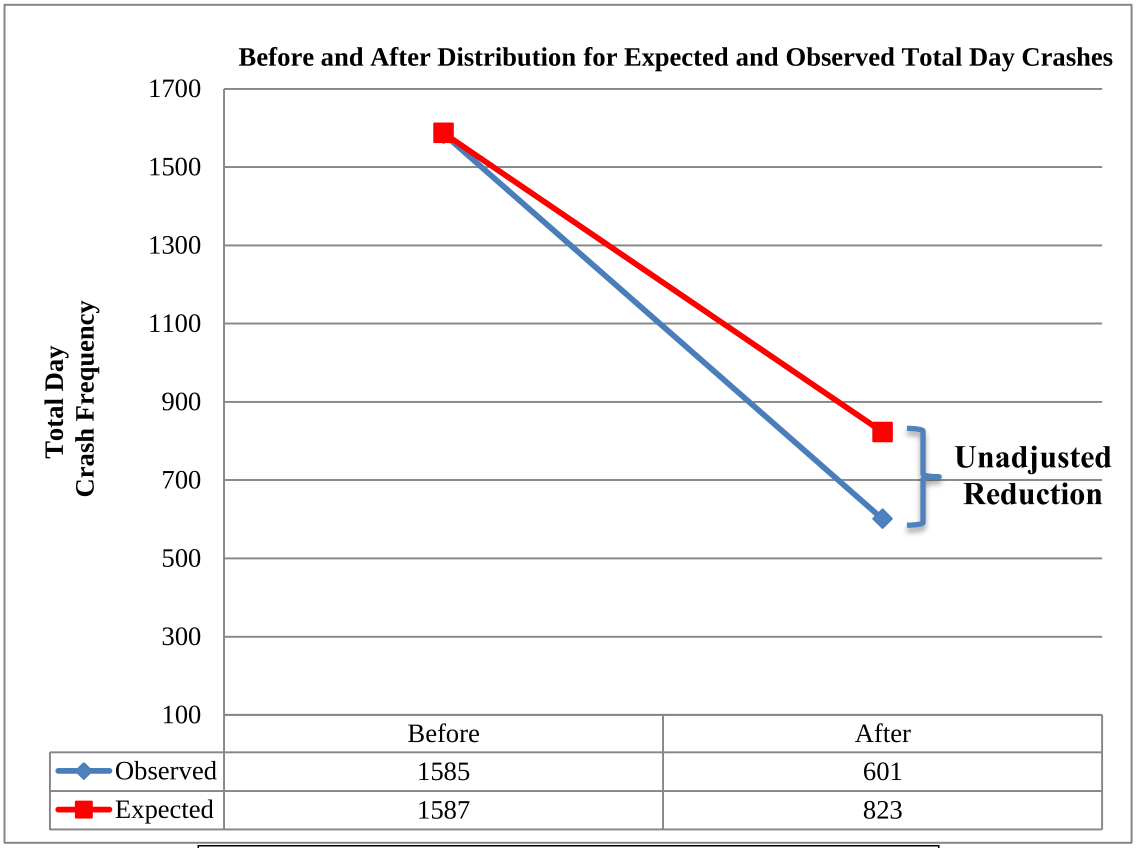
Total FATAL INJURY Crashes using Both Countermeasures	
Adjusted Reduction	28.87%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.711
Standard Error	0.0602

Total FATAL INJURY Crashes - Presence of Fluorescent Yellow Sheeting only



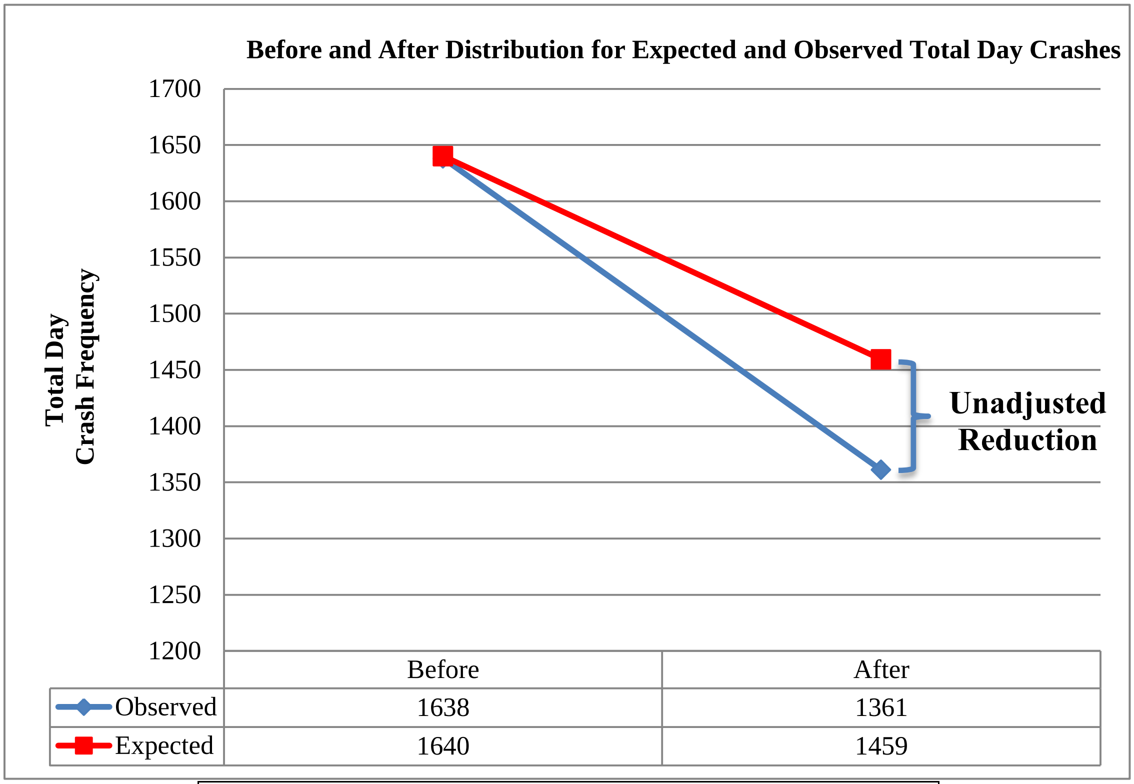
Total FATAL INJURY Crashes using One Countermeasure	
Adjusted Reduction	8.25%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.917
Standard Error	0.0578

Total Day Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



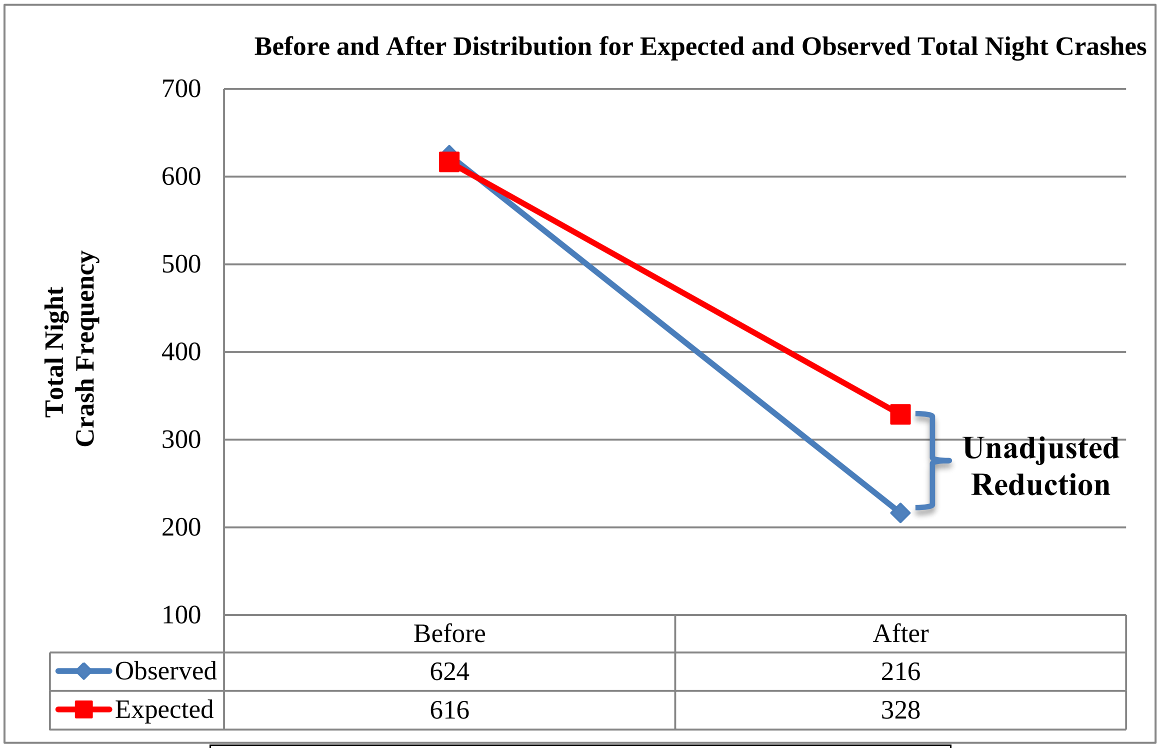
Total Day Crashes using Both Countermeasures	
Adjusted Reduction	27.02%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.730
Standard Error	0.0350

Total Day Crashes - Presence of Fluorescent Yellow Sheeting only



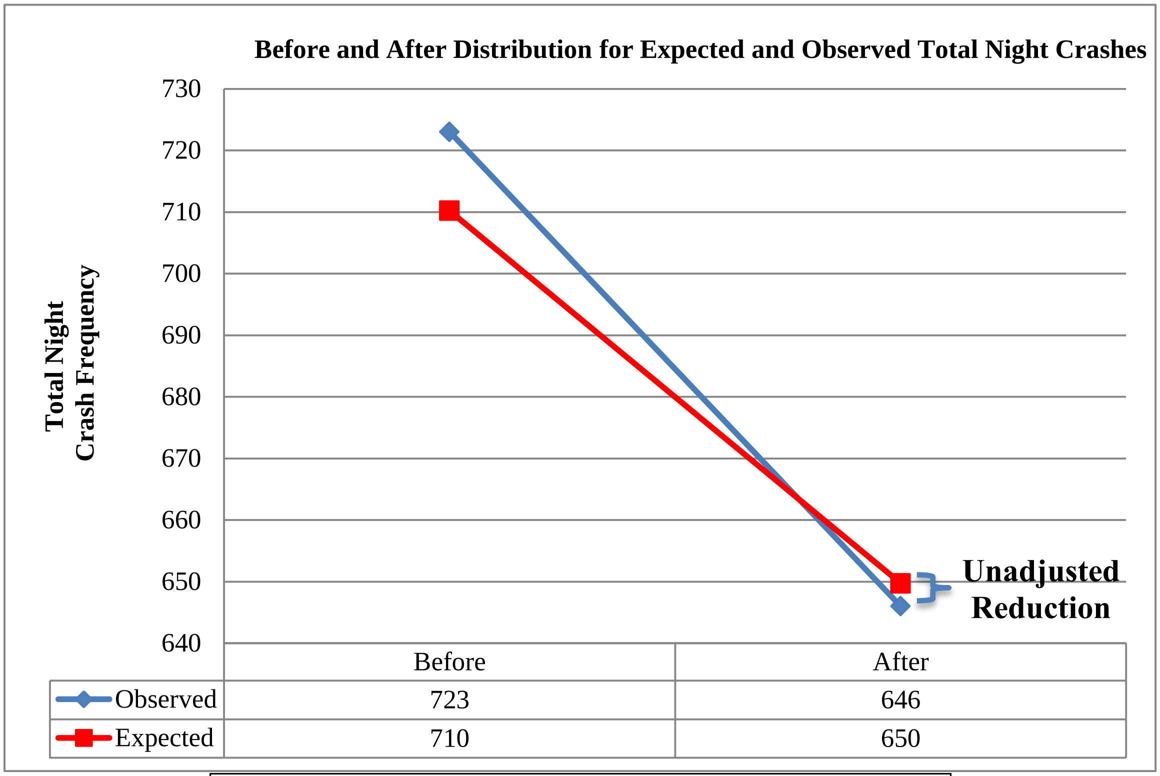
Total Day Crashes using One Countermeasure	
Adjusted Reduction	6.79%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.932
Standard Error	0.0342

Total Night Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



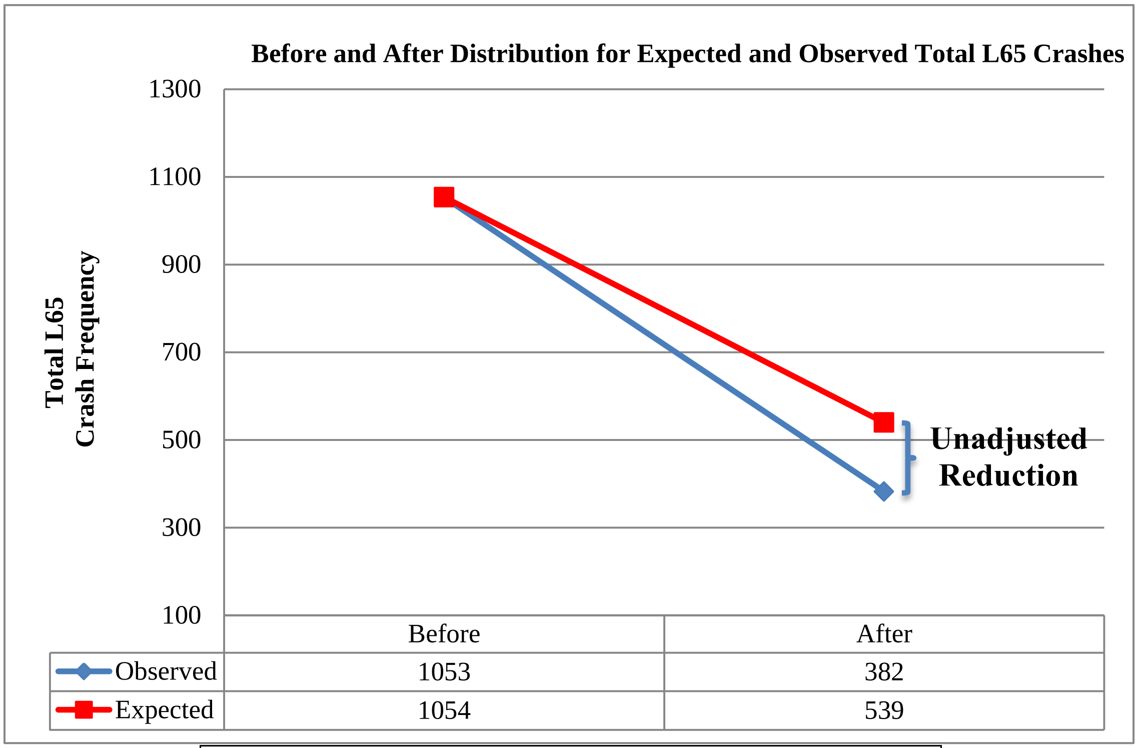
Total Night Crashes using Both Countermeasures	
Adjusted Reduction	34.34%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.657
Standard Error	0.0514

Total Night Crashes - Presence of Fluorescent Yellow Sheeting only



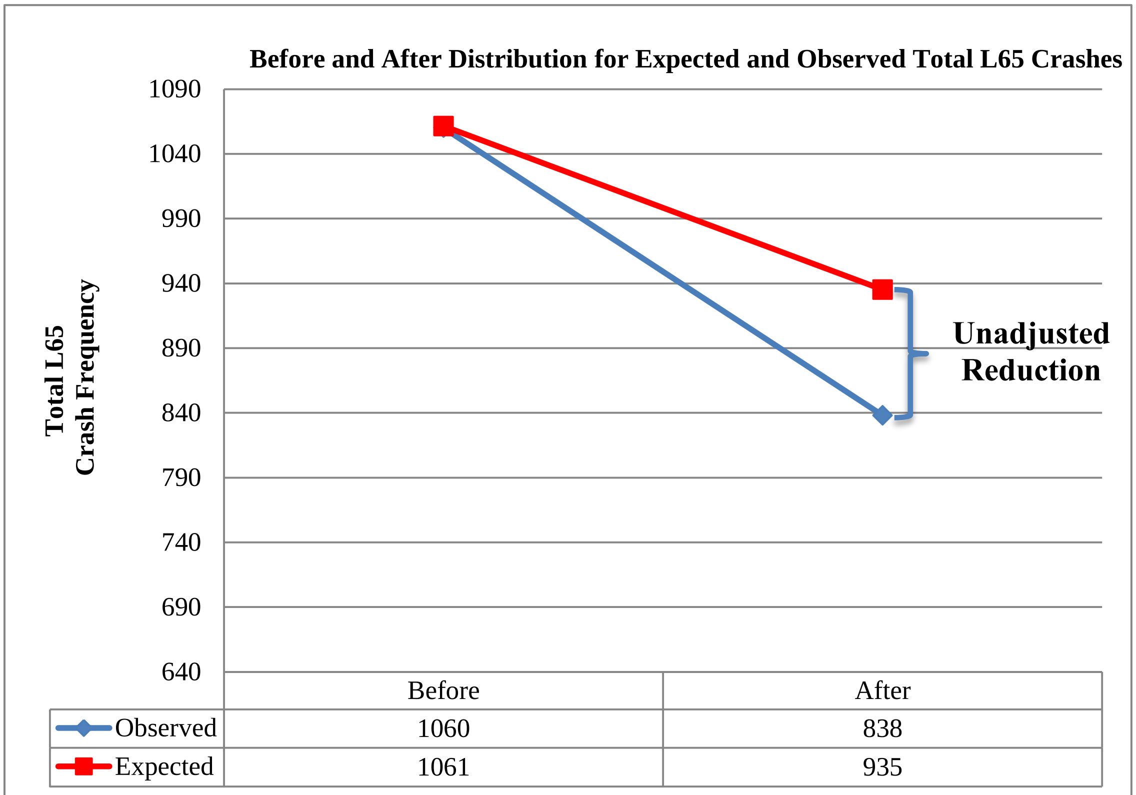
Total Night Crashes using One Countermeasure	
Adjusted Reduction	0.69%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.993
Standard Error	0.0523

Total Younger Drivers (UNDER-65) Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



Total UNDER-65 Crashes using Both Countermeasures	
Adjusted Reduction	29.25%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.707
Standard Error	0.0422

Total Younger Drivers (UNDER-65) Crashes - Presence of Fluorescent Yellow Sheeting only

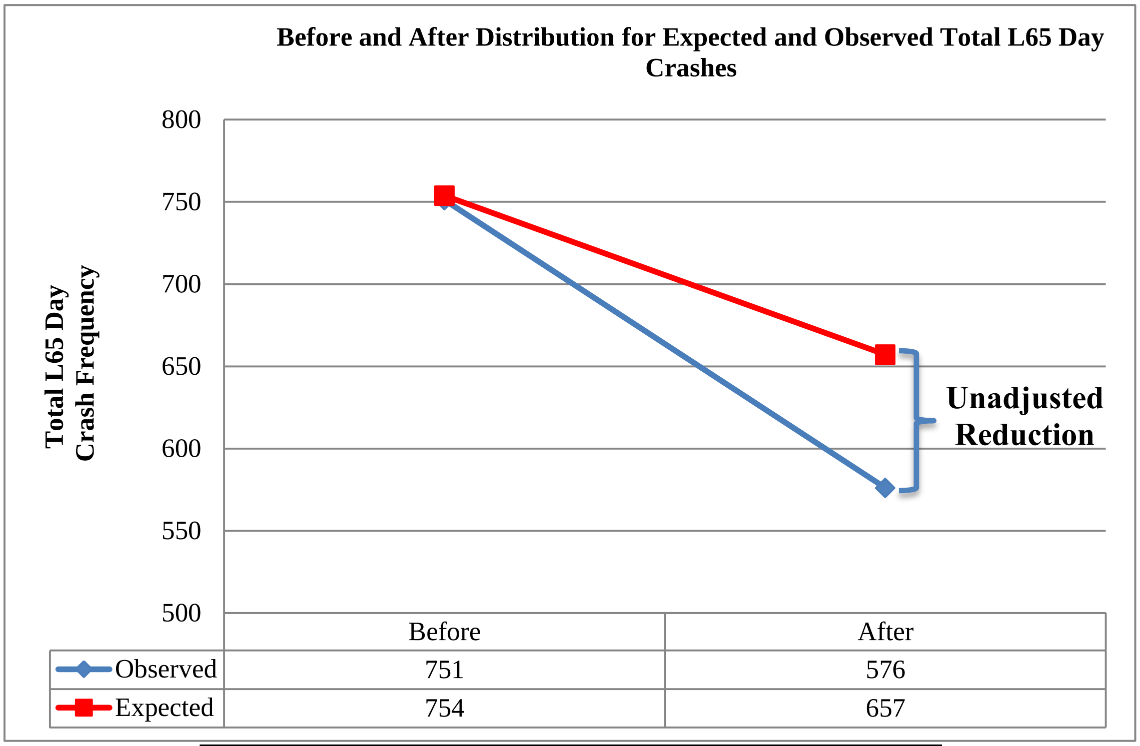


Total UNDER-65 Crashes using One Countermeasure	
Adjusted Reduction	10.47%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.895
Standard Error	0.0412

Total Younger Drivers (UNDER-65) Day Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting

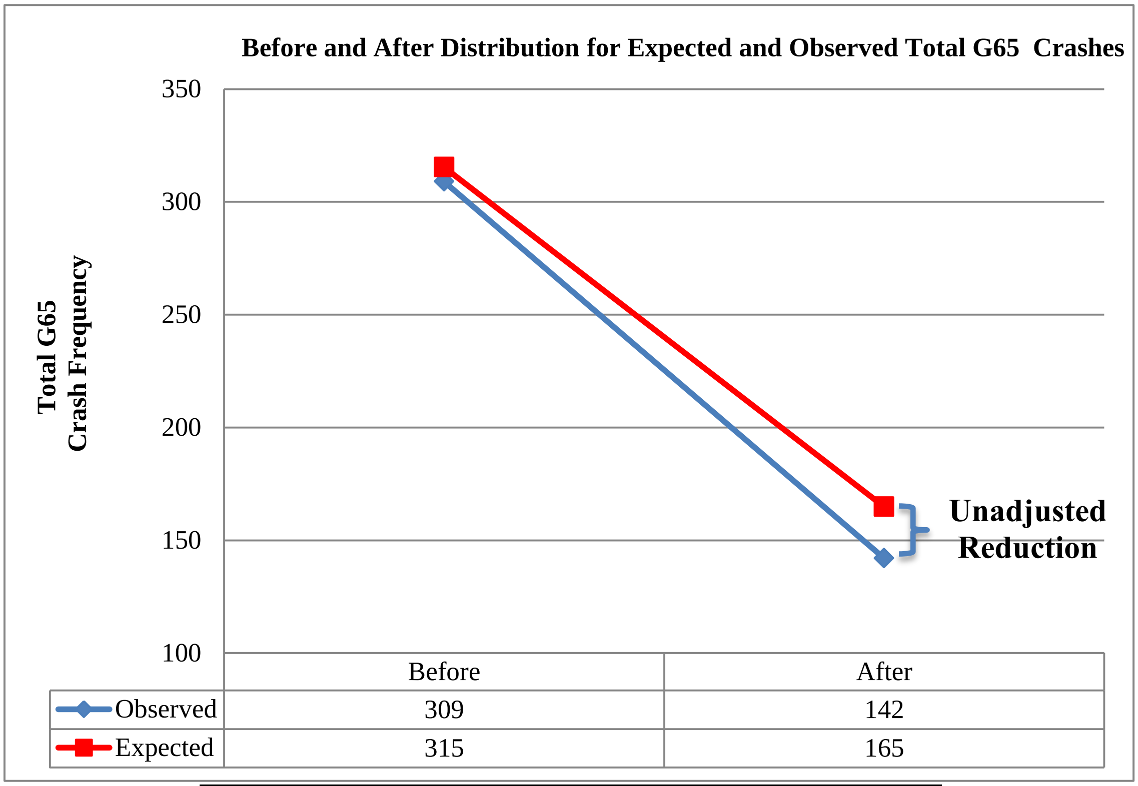
Total UNDER-65 Day Crashes using Both Countermeasures	
Adjusted Reduction	28.03%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.720
Standard Error	0.0496

Total Younger Drivers (UNDER-65) Day Crashes - Presence of Fluorescent Yellow Sheeting only



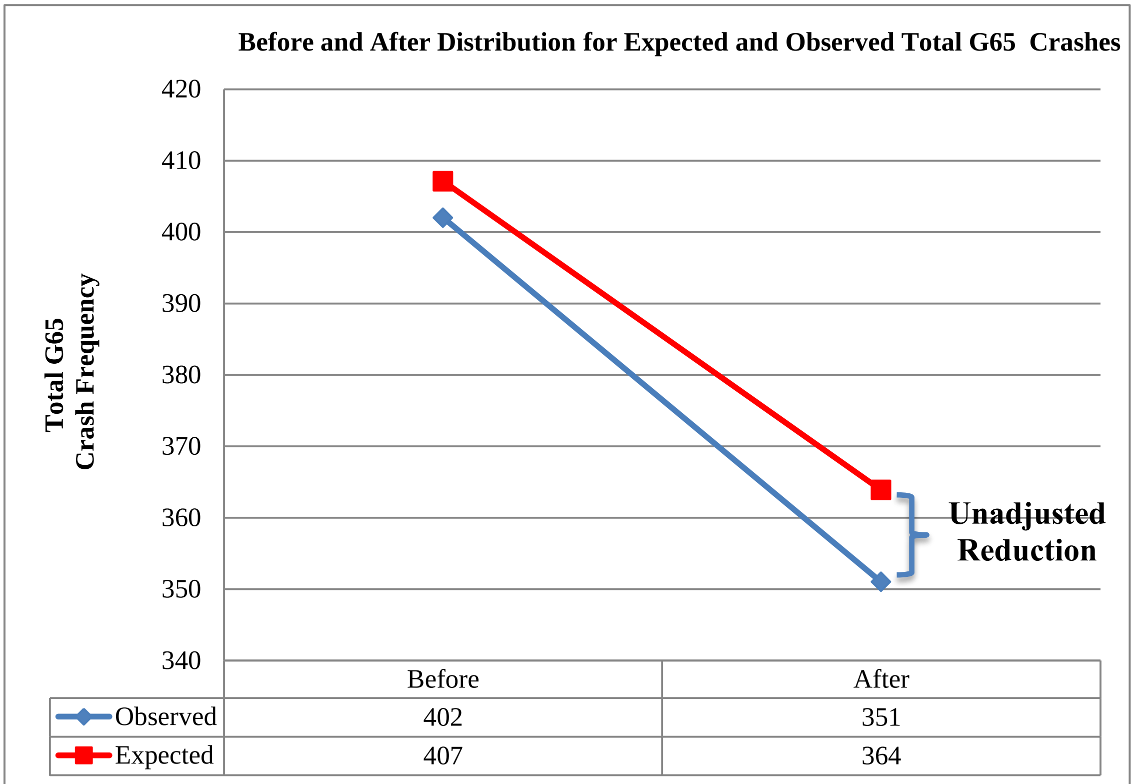
Total UNDER-65 Day Crashes using One Countermeasure	
Adjusted Reduction	12.45%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.875
Standard Error	0.0481

Total Older Drivers (65-AND-ABOVE) Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



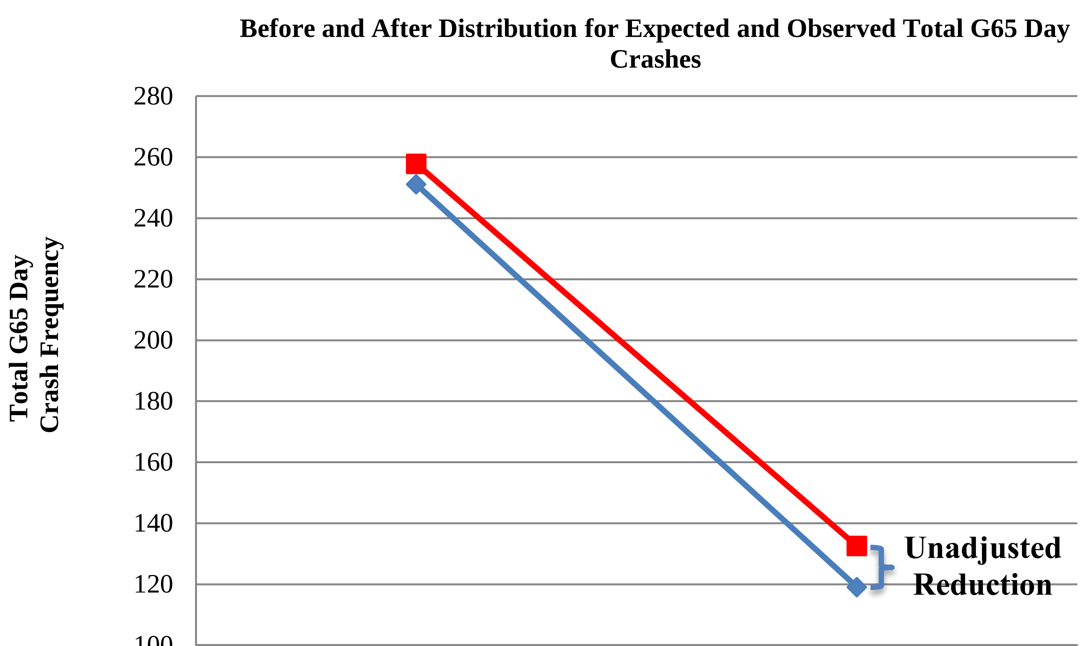
Total 65-AND-ABOVE Crashes using Both Countermeasures	
Adjusted Reduction	14.09%
Statistical Significance	90% Confidence Level
Crash Modification Factor (CMF)	0.859
Standard Error	0.0854

Total Older Drivers (65-AND-ABOVE) Crashes - Presence of Fluorescent Yellow Sheeting only



Total 65-AND-ABOVE Crashes using One Countermeasure	
Adjusted Reduction	3.73%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.963
Standard Error	0.0675

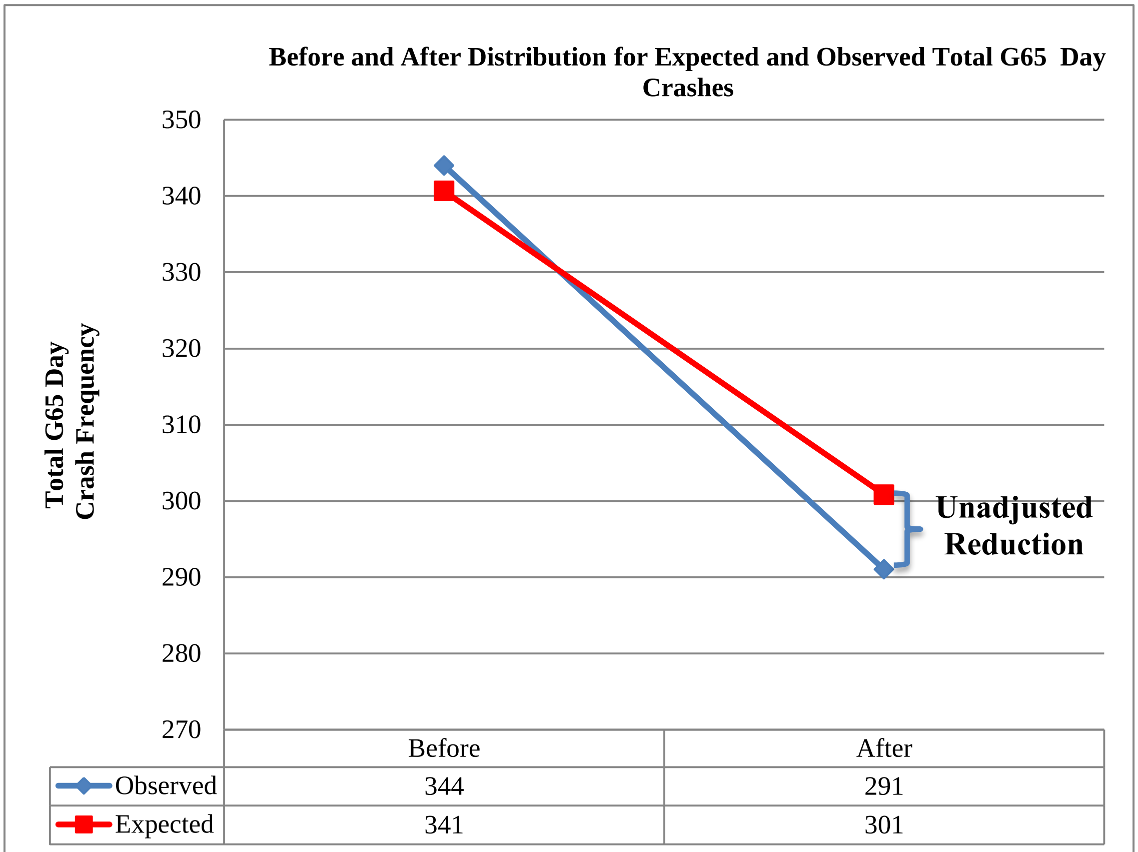
<u>Total Older Drivers (65-AND-ABOVE) Day Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting</u>



	Before	After
Observed	251	119
Expected	258	132

Total 65-AND-ABOVE Day Crashes using Both Countermeasures	
Adjusted Reduction	10.48%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.895
Standard Error	0.0975

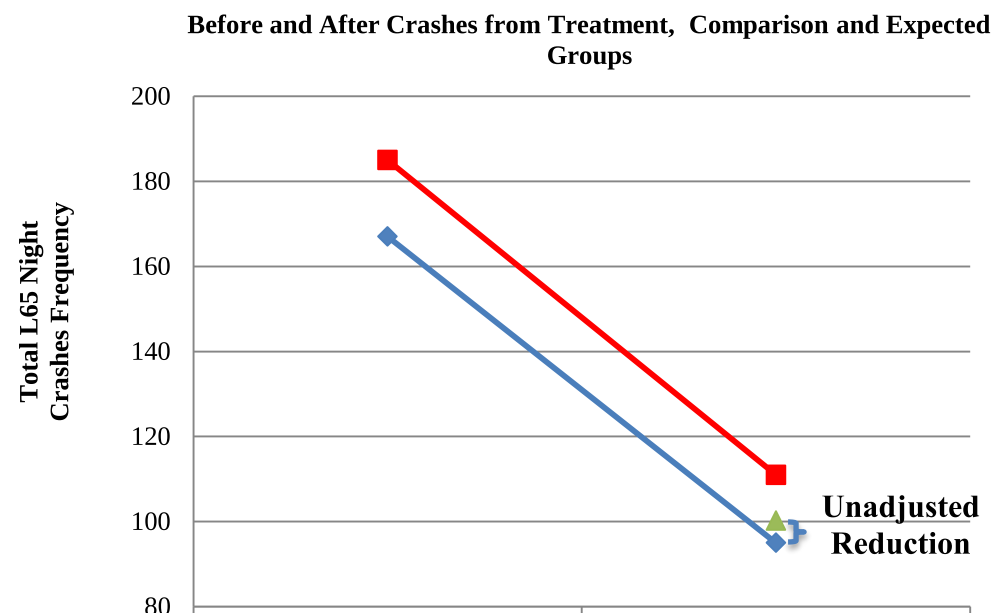
Total Older Drivers (65-AND-ABOVE) Day Crashes - Presence of Fluorescent Yellow Sheeting only



Total 65-AND-ABOVE Day Crashes using One Countermeasure	
Adjusted Reduction	3.50%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.965
Standard Error	0.0740

Before and After with Comparison Groups Method for Non-Freeways in Urban Areas

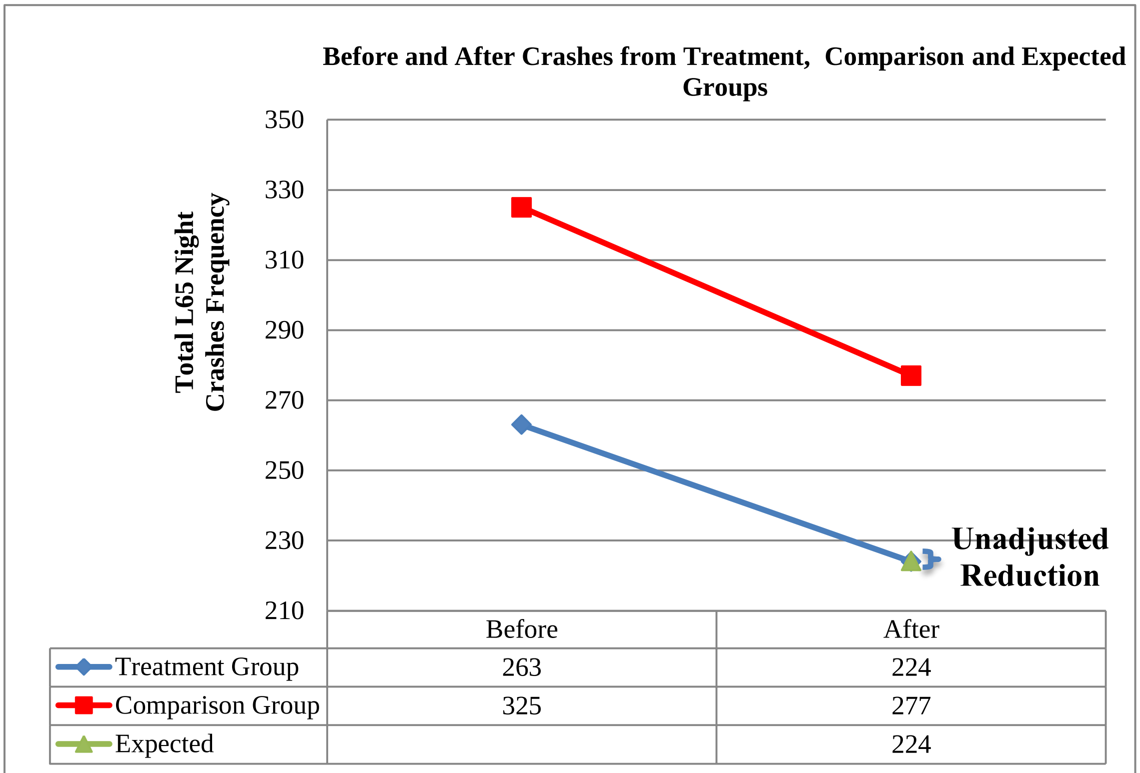
Total Younger Drivers (UNDER-65) Night Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Treatment Group	167	95
Comparison Group	185	111
Expected		100

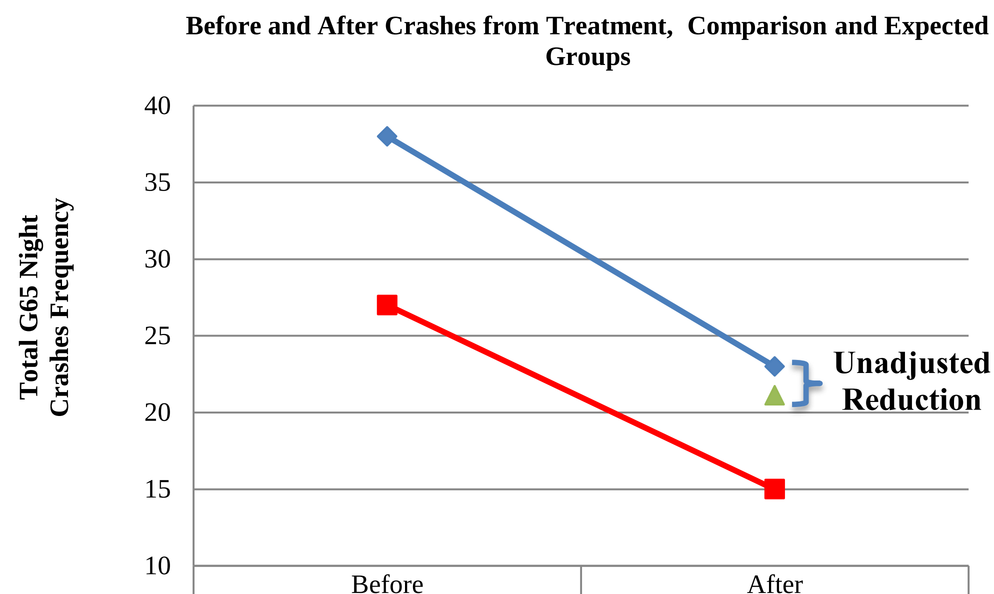
Total UNDER-65 Night Crashes using Both Countermeasures	
Adjusted Reduction	7.09%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.929
Standard Error	0.0262

Total Younger Drivers (UNDER-65) Night Crashes - Presence of Fluorescent Yellow Sheeting only



Total UNDER-65 Night Crashes using One Countermeasure	
Adjusted Reduction	1.11%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.989
Standard Error	0.0145

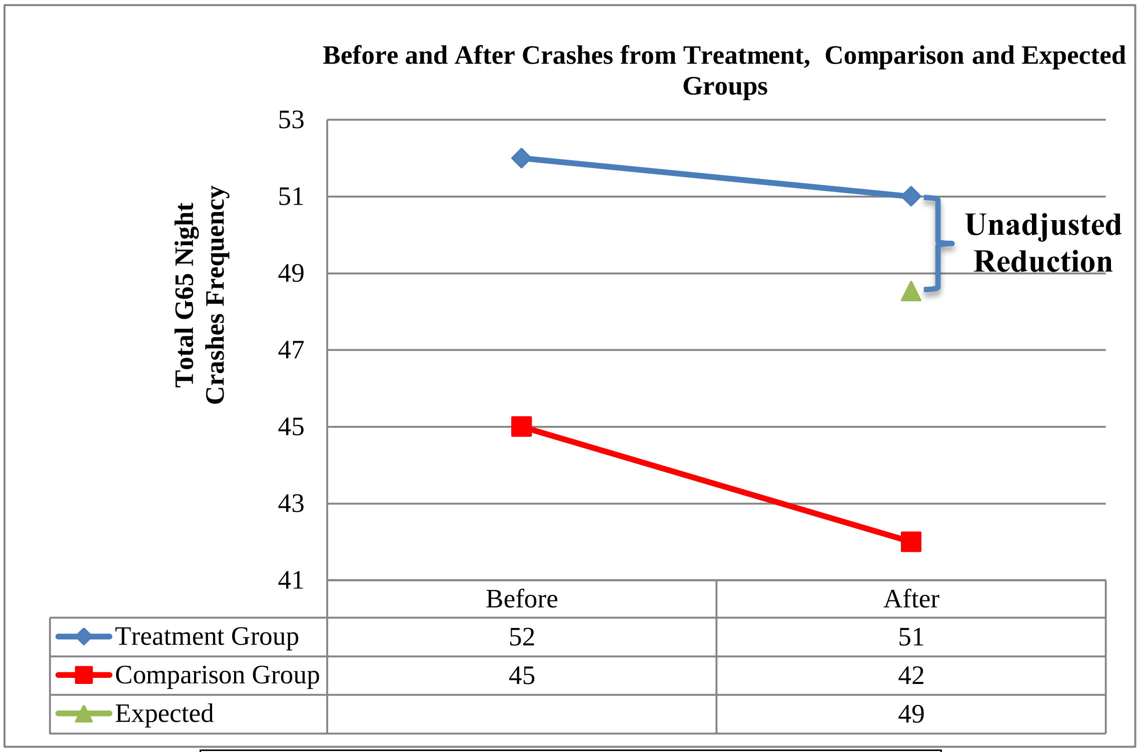
Total Older Drivers (65-AND-ABOVE) Night Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Treatment Group	38	23
Comparison Group	27	15
Expected		21

Total 65-AND-ABOVE Night Crashes using Both Countermeasures	
Adjusted Reduction	3.59%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.964
Standard Error	0.143

Total Older Drivers (65-AND-ABOVE) Night Crashes - Presence of Fluorescent Yellow Sheeting only



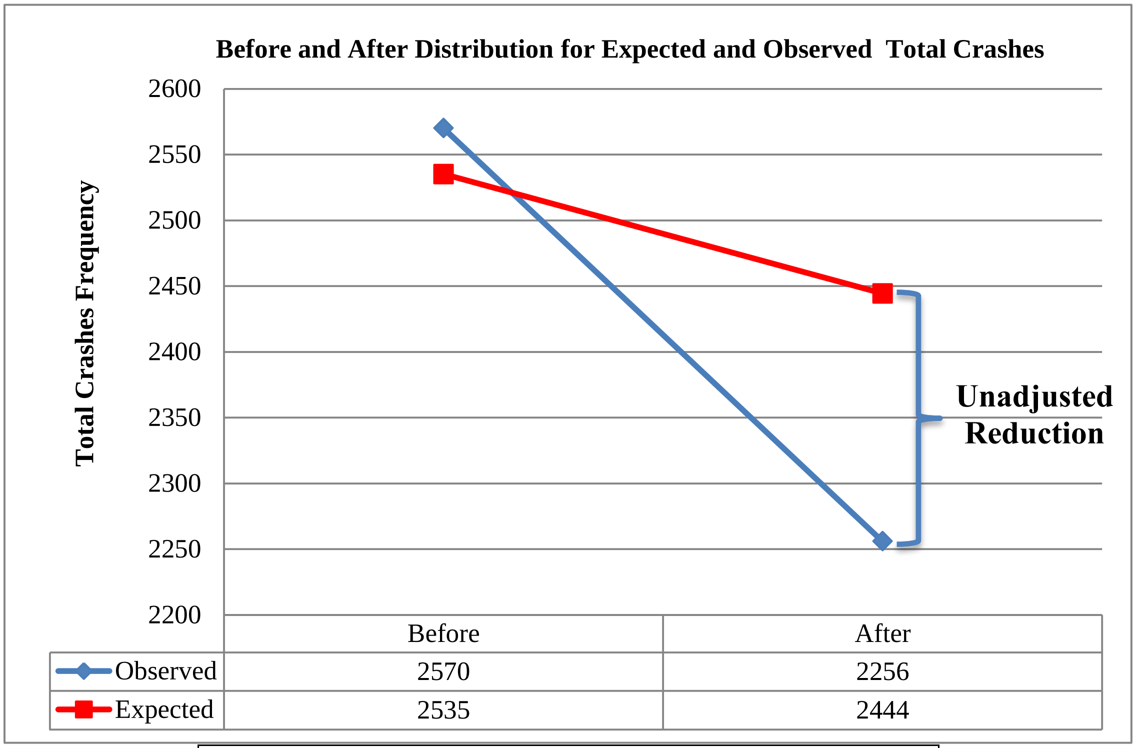
Total 65-AND-ABOVE Night Crashes using One Countermeasure	
Adjusted Reduction	1.36%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.986
Standard Error	0.0775

Empirical Bayes Method Results for Non-Freeways in Rural Areas

Total Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting

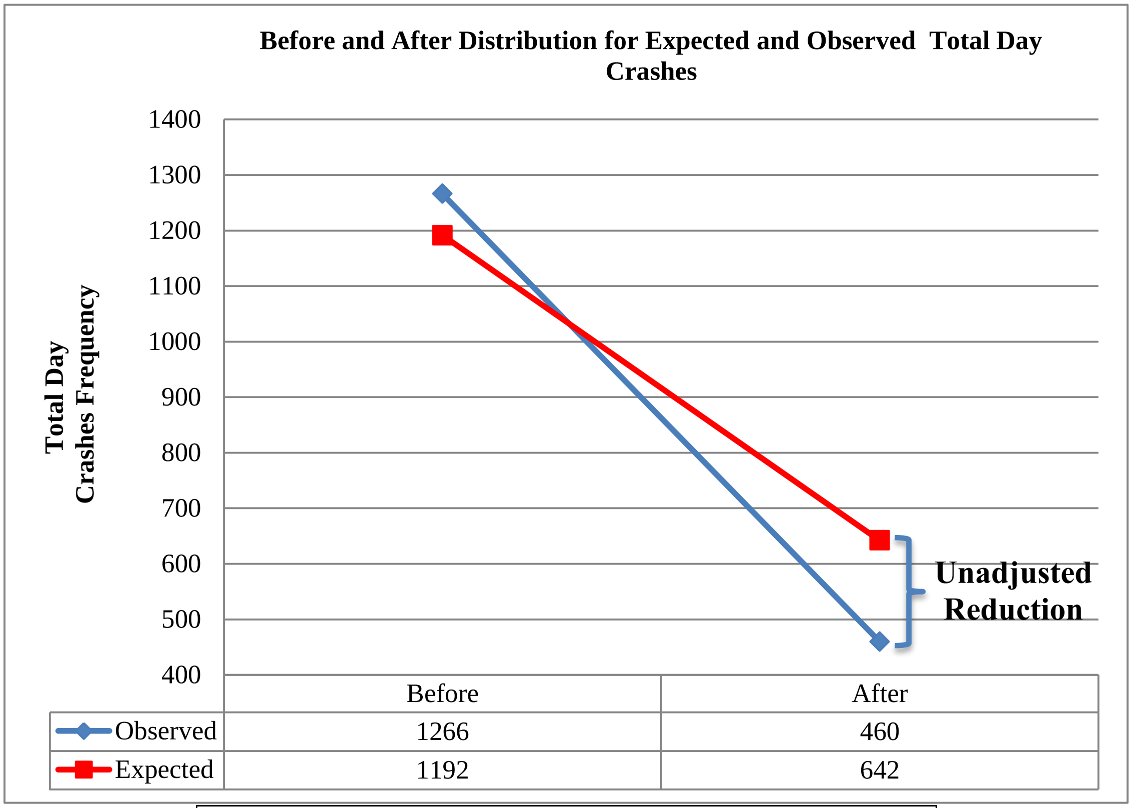
Total Crashes using Both Countermeasures	
Adjusted Reduction	32.99%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.670
Standard Error	0.0236

Total Crashes - Presence of Fluorescent Yellow Sheeting only



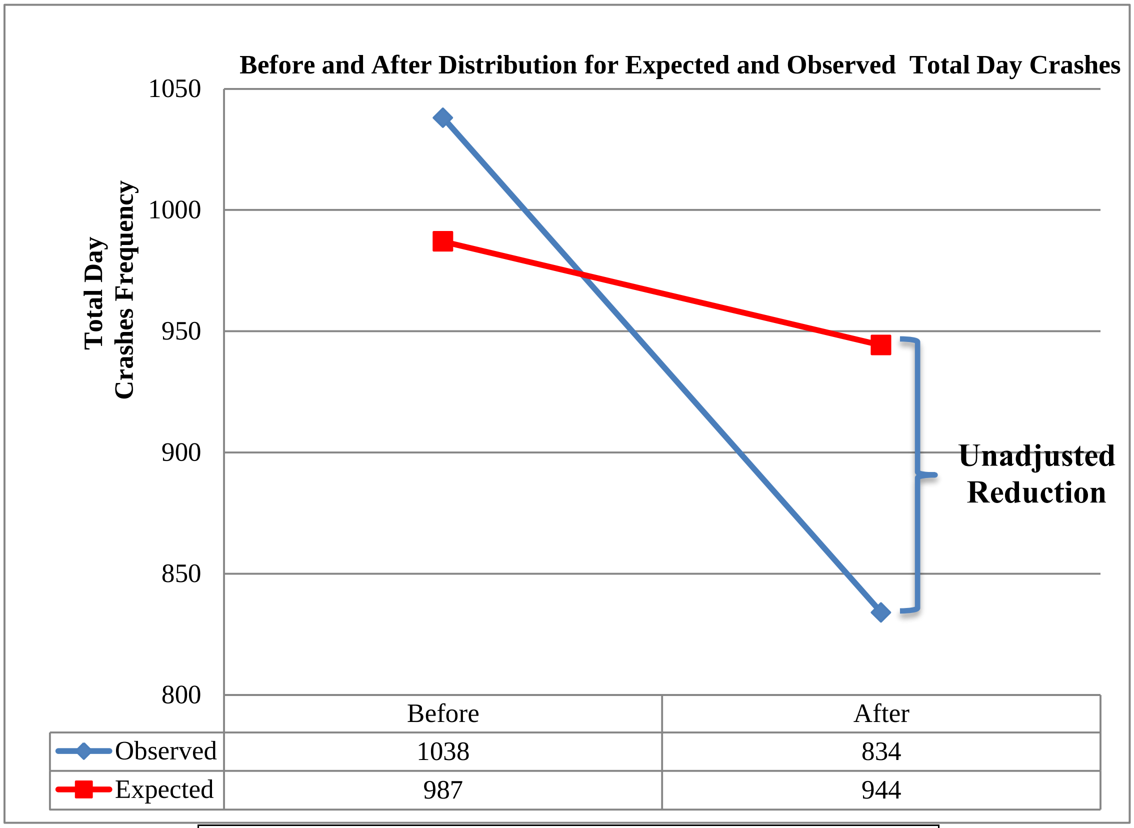
Total Crashes using one Countermeasure	
Adjusted Reduction	7.74%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.923
Standard Error	0.0264

Total Day Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



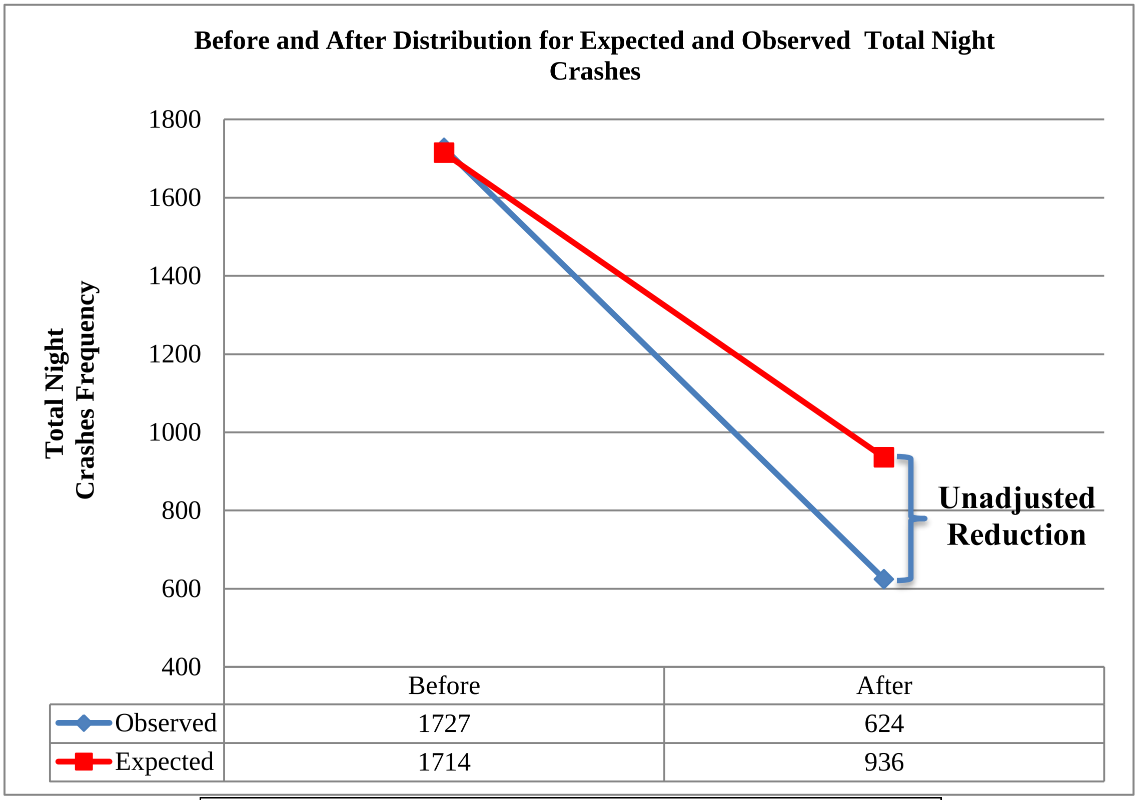
Total Day Crashes using Both Countermeasures	
Adjusted Reduction	28.41%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.716
Standard Error	0.0385

Total Day Crashes - Presence of Fluorescent Yellow Sheeting only



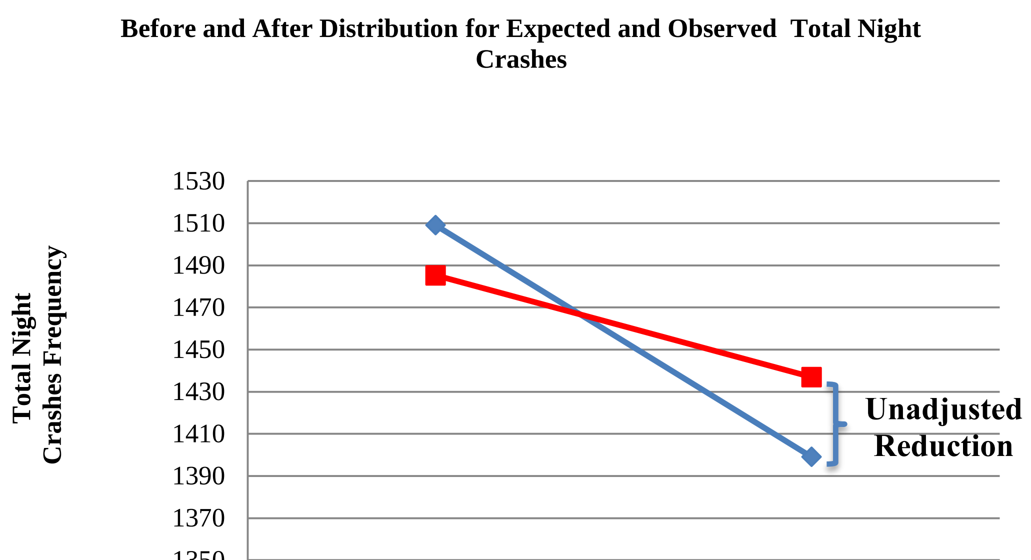
Total Day Crashes using one Countermeasure	
Adjusted Reduction	11.75%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.883
Standard Error	0.0396

Total Night Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



Total Night Crashes using Both Countermeasures	
Adjusted Reduction	33.34%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.667
Standard Error	0.0310

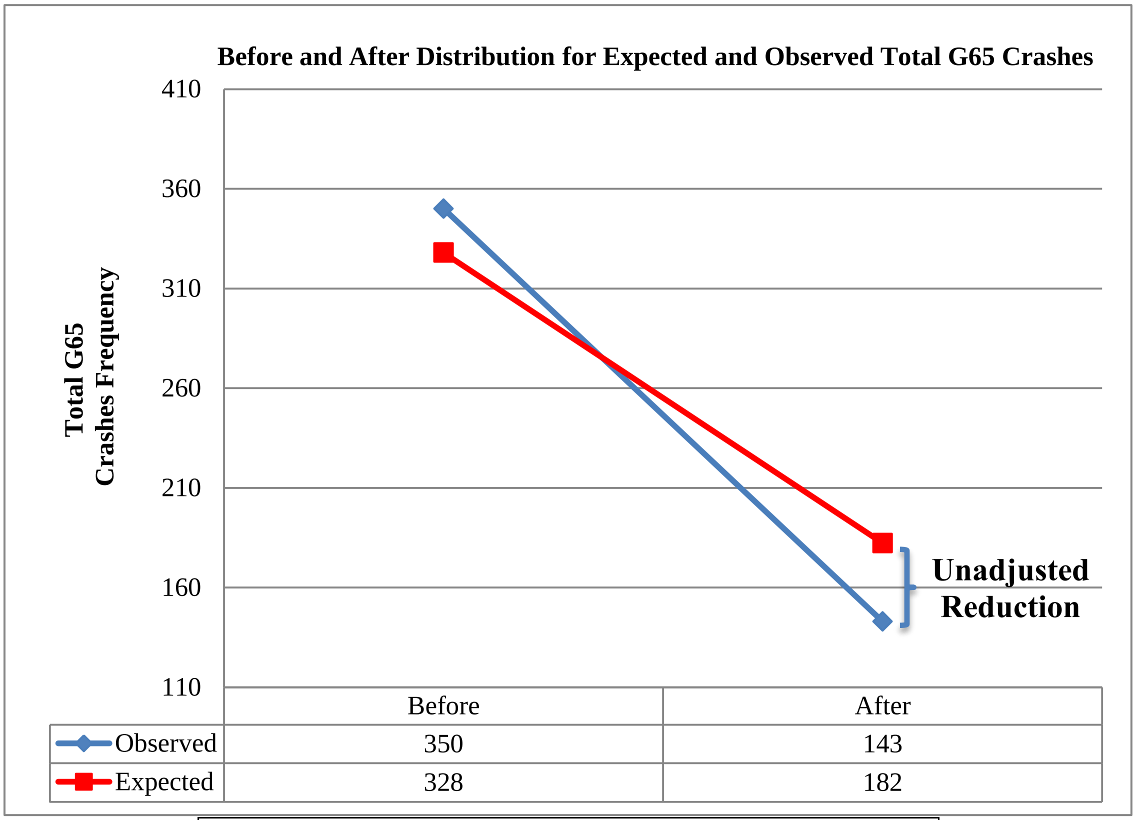
Total Night Crashes - Presence of Fluorescent Yellow Sheeting only



	Before	After
Observed	1509	1399
Expected	1485	1437

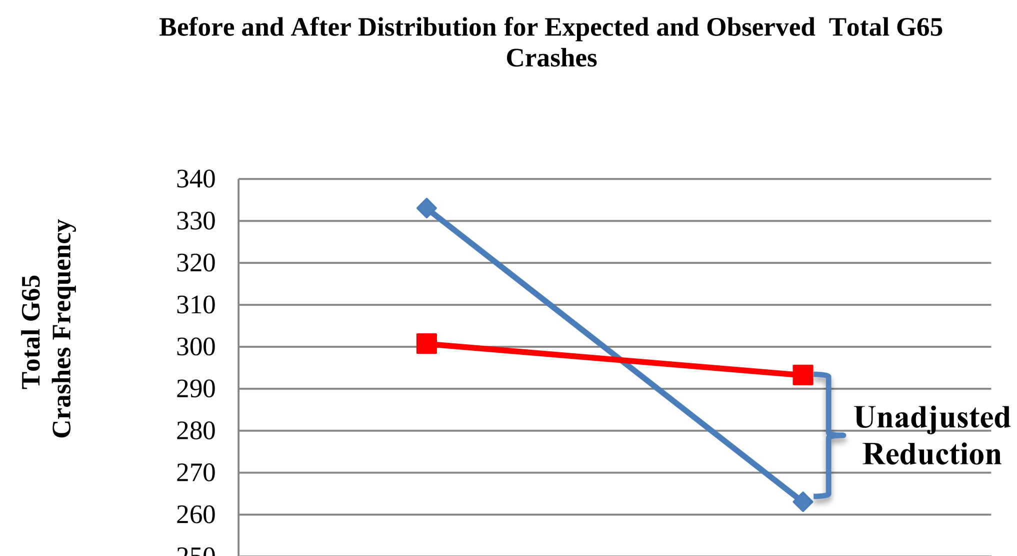
Total Night Crashes using one Countermeasure	
Adjusted Reduction	2.70%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.973
Standard Error	0.0355

Total Older Drivers (65-AND-ABOVE) Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



Total 65-AND-ABOVE Crashes using Both Countermeasures	
Adjusted Reduction	21.69%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.783
Standard Error	0.0741

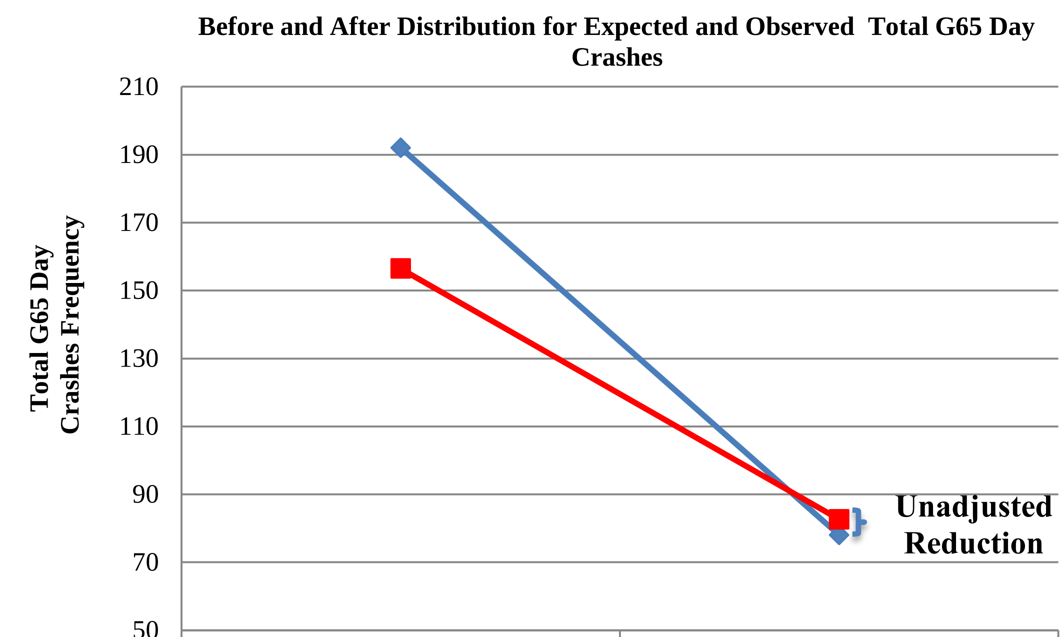
Total Older Drivers (65-AND-ABOVE) Crashes - Presence of Fluorescent Yellow Sheeting only



	Before	After
Observed	333	263
Expected	301	293

Total 65-AND-ABOVE Crashes using one Countermeasure	
Adjusted Reduction	10.49%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.895
Standard Error	0.0675

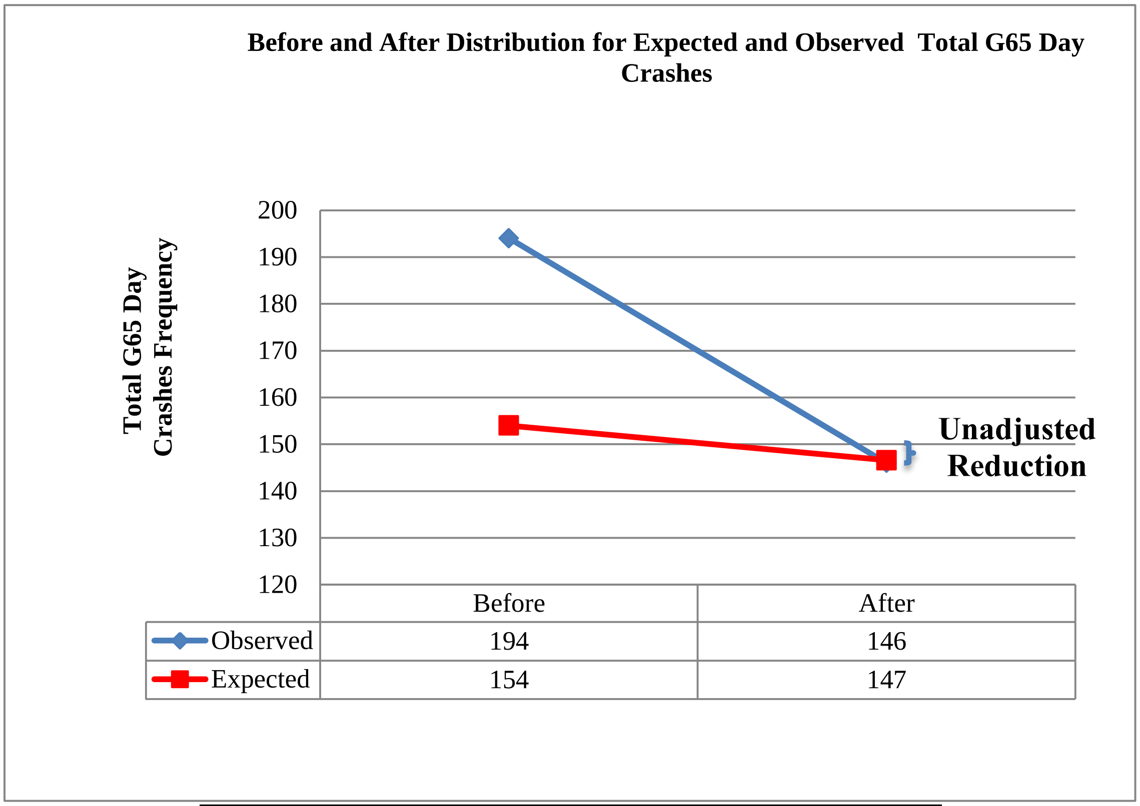
Total Older Drivers (65-AND-ABOVE) Day Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Observed	192	78
Expected	156	83

Total 65-AND-ABOVE Day Crashes using Both Countermeasures	
Adjusted Reduction	5.92%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.941
Standard Error	0.120

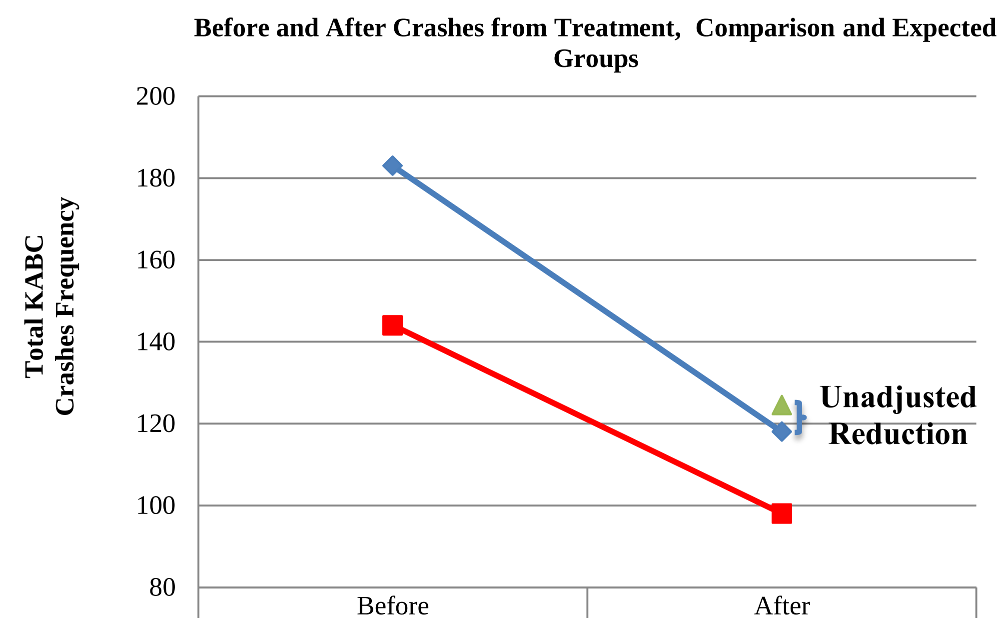
Total Older Drivers (65-AND-ABOVE) Day Crashes- Presence of Fluorescent Yellow Sheeting only



Total 65-AND-ABOVE Day Crashes using one Countermeasure	
Adjusted Reduction	0.68%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.993
Standard Error	0.0977

Before and After with Comparison Groups Method for Non-Freeways in Rural Areas

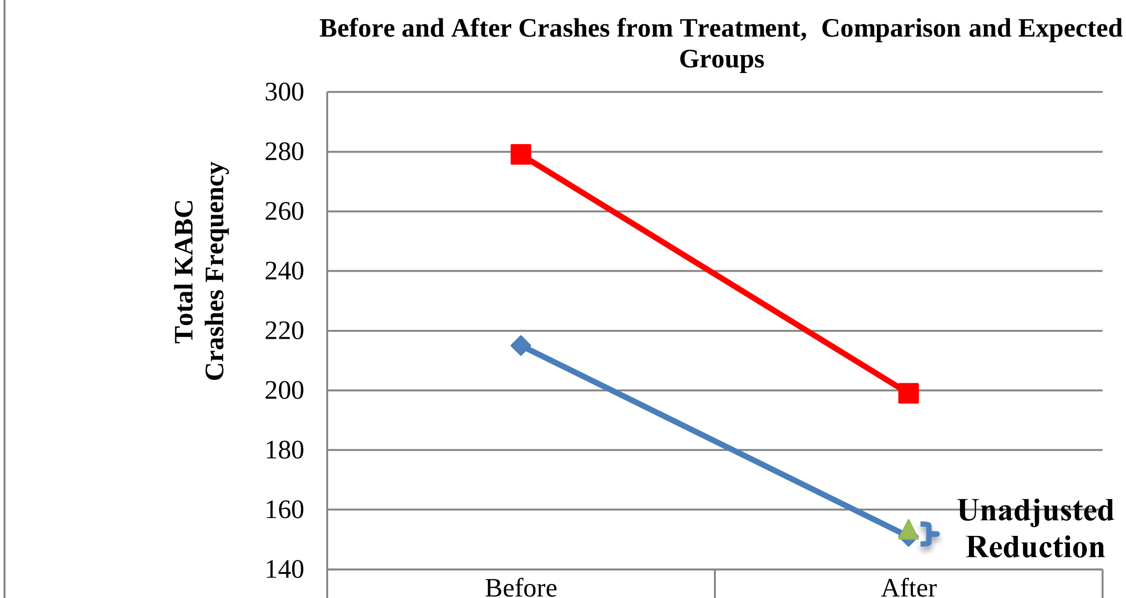
<u>Total FATAL INJURY Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting</u>



	Before	After
Treatment Group	183	118
Comparison Group	144	98
Expected		125

Total FATAL INJURY Crashes using Both Countermeasures	
Adjusted Reduction	7.35%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.927
Standard Error	0.0261

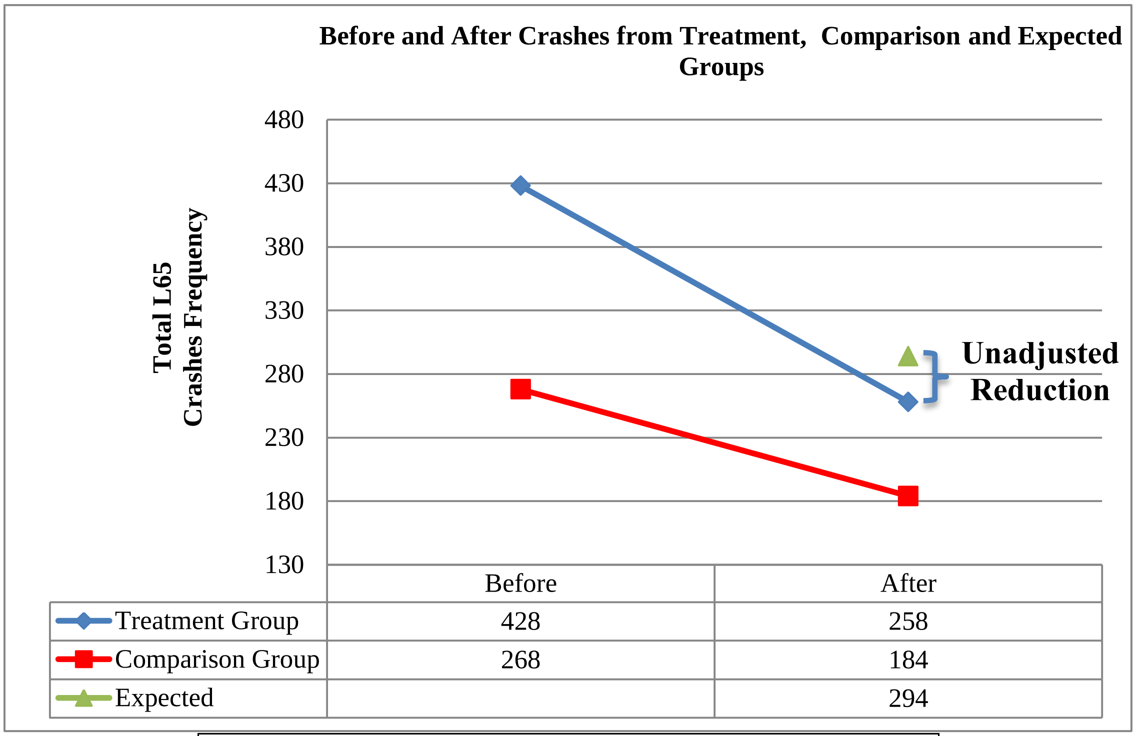
Total FATAL INJURY Crashes - Presence of Fluorescent Yellow Sheeting only



	Before	After
Treatment Group	215	151
Comparison Group	279	199
Expected		153

Total FATAL INJURY Crashes one Countermeasure	
Adjusted Reduction	7.09%
Statistical Significance	85% Confidence Level
Crash Modification Factor (CMF)	0.972
Standard Error	0.0185

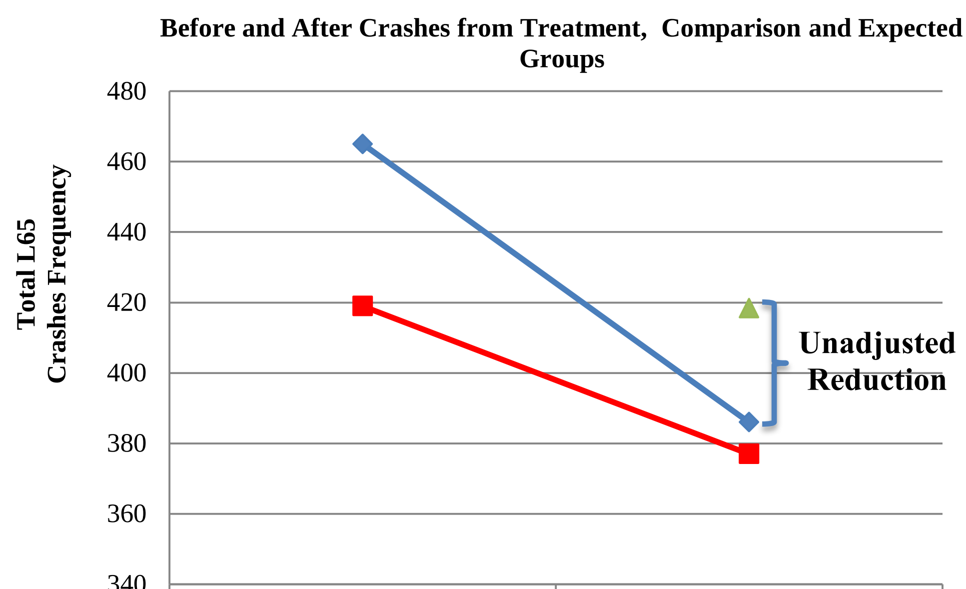
Total Younger Drivers (UNDER-65) Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Treatment Group	428	258
Comparison Group	268	184
Expected		294

Total UNDER-65 Crashes using Both Countermeasures	
Adjusted Reduction	13.20%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.868
Standard Error	0.0115

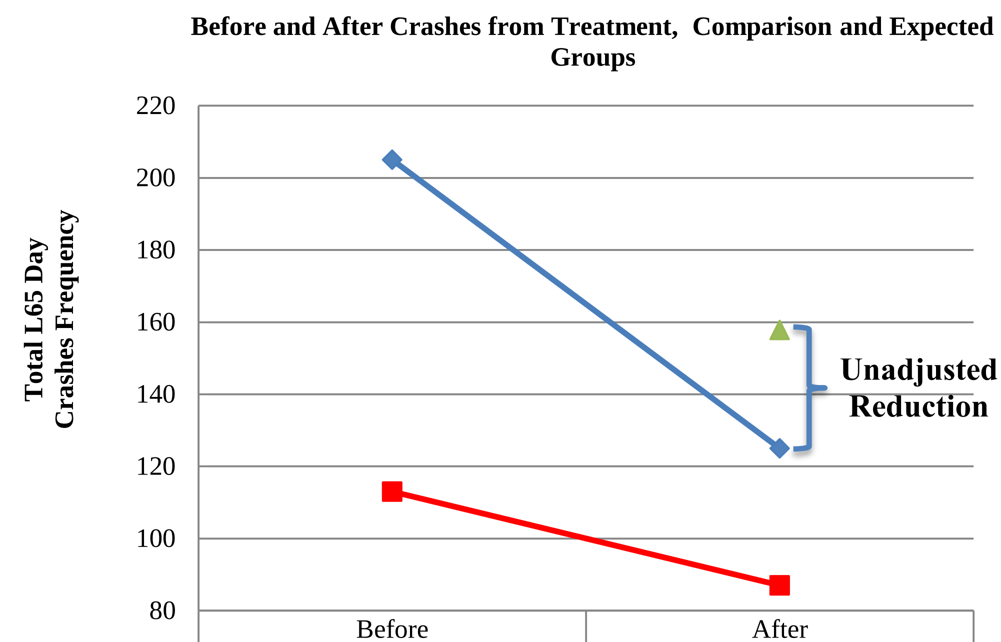
Total Younger Drivers (UNDER-65) Crashes - Presence of Fluorescent Yellow Sheeting only



	Before	After
Treatment Group	465	386
Comparison Group	419	377
Expected		418

Total UNDER-65 Crashes using one Countermeasure	
Adjusted Reduction	8.40%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.916
Standard Error	0.00815

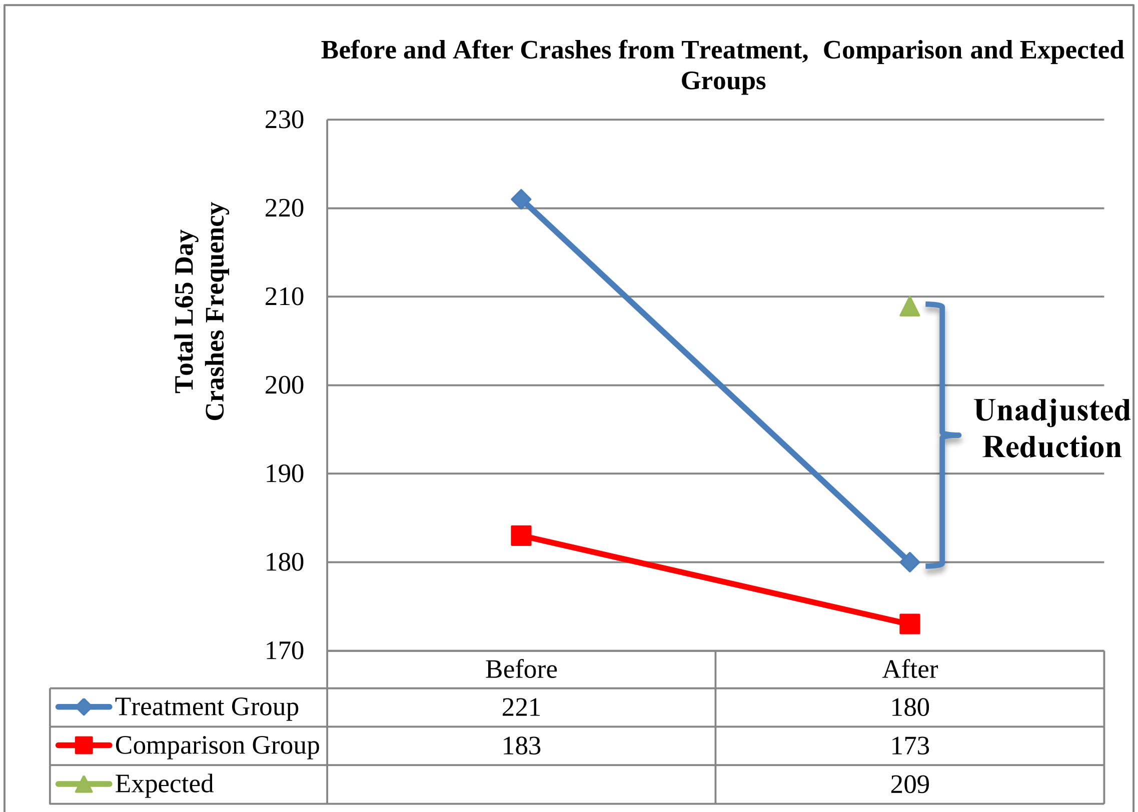
<u>Total Younger Drivers (UNDER-65) Day Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting</u>



	Before	After
Treatment Group	205	125
Comparison Group	113	87
Expected		158

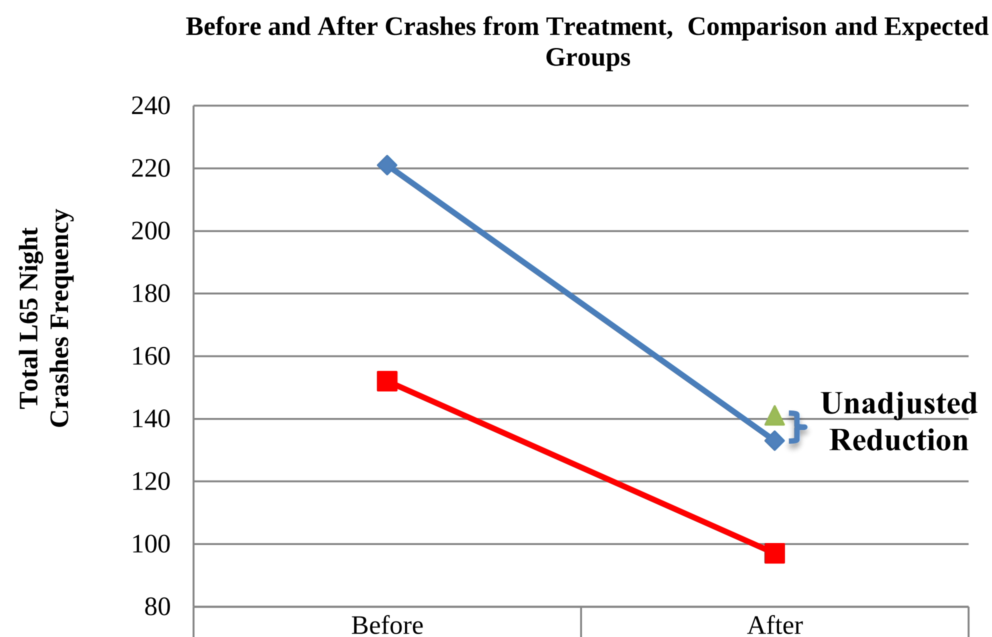
Total UNDER-65 Day Crashes using Both Countermeasures	
Adjusted Reduction	22.75%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.772
Standard Error	0.0193

Total Younger Drivers (UNDER-65) Day Crashes - Presence of Fluorescent Yellow Sheeting only



Total UNDER-65 Day Crashes using one Countermeasure	
Adjusted Reduction	15.18%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.848
Standard Error	0.0151

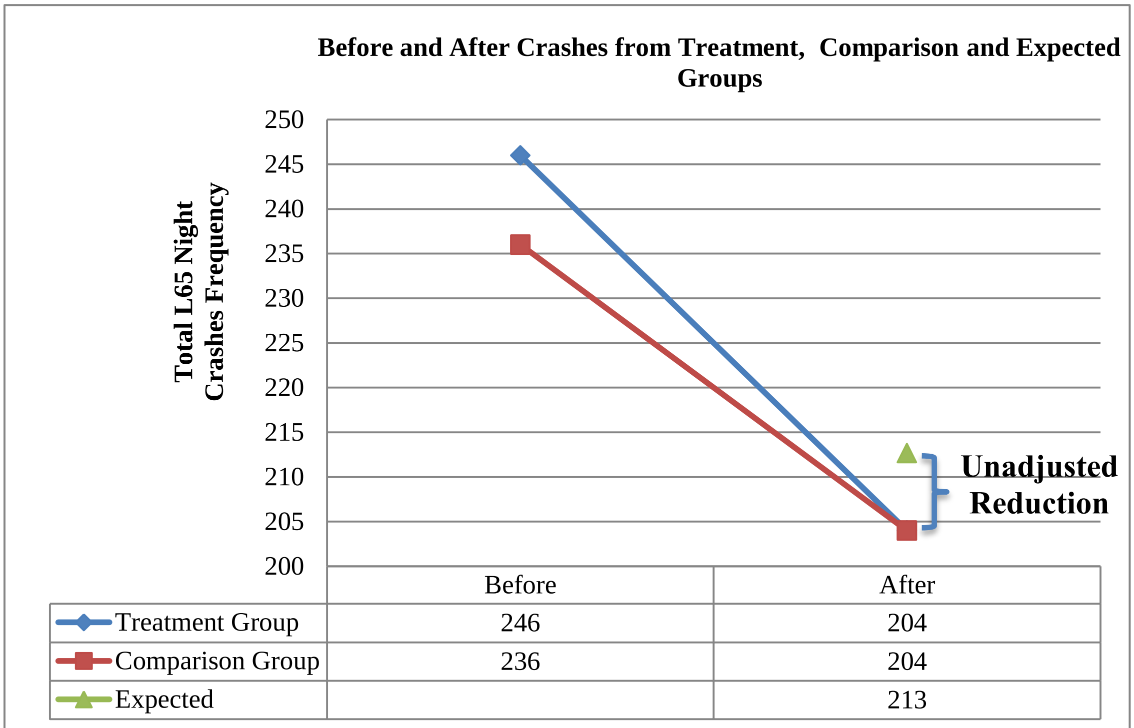
Total Younger Drivers (UNDER-65) Night Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Treatment Group	221	133
Comparison Group	152	97
Expected		141

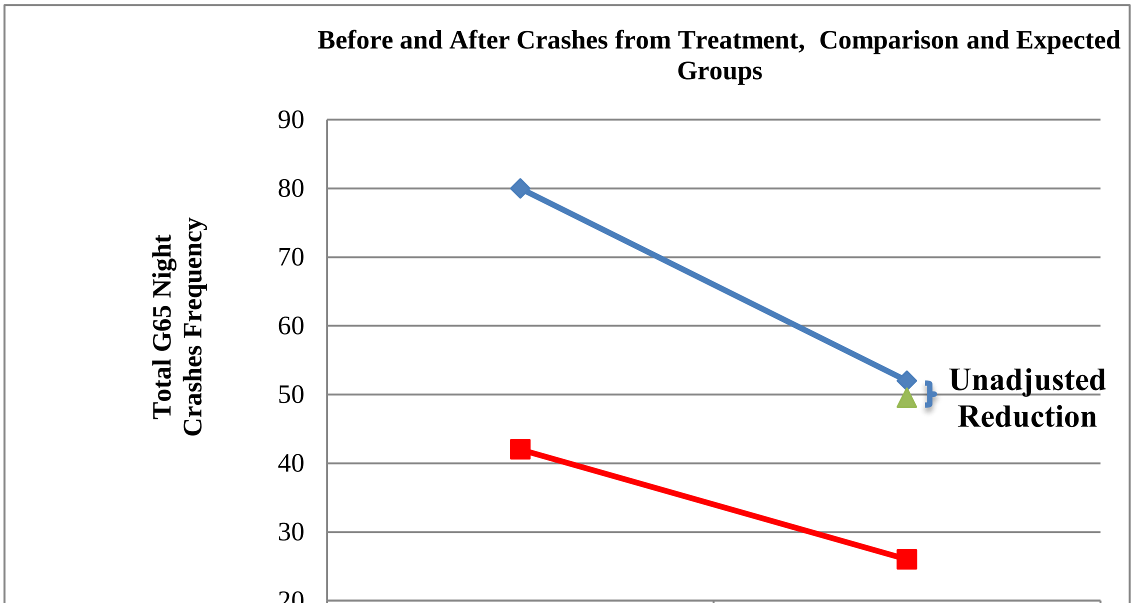
Total UNDER-65 Night Crashes using Both Countermeasures	
Adjusted Reduction	7.67%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.923
Standard Error	0.0241

Total Younger Drivers (UNDER-65) Night Crashes - Presence of Fluorescent Yellow Sheeting only



Total UNDER-65 Night Crashes using one Countermeasure	
Adjusted Reduction	5.32%
Statistical Significance	95% Confidence Level
Crash Modification Factor (CMF)	0.947
Standard Error	0.0160

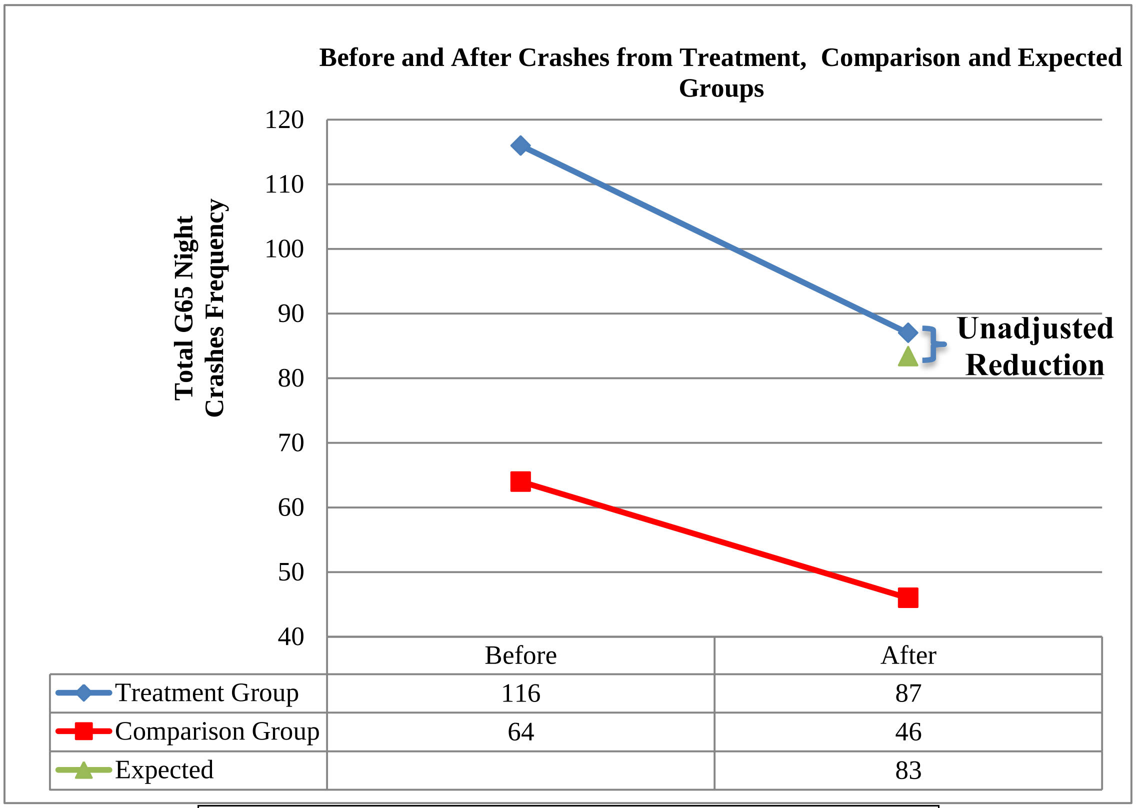
Total Older Drivers (65-AND-ABOVE) Night Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting



	Before	After
Treatment Group	80	52
Comparison Group	42	26
Expected		50

Total 65-AND-ABOVE Night Crashes using Both Countermeasures	
Adjusted Reduction	2.30%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.977
Standard Error	0.0835

Total Older Drivers (65-AND-ABOVE) Night Crashes - Presence of Fluorescent Yellow Sheeting only



	Before	After
Treatment Group	116	87
Comparison Group	64	46
Expected		83

Total 65-AND-ABOVE Night Crashes using one Countermeasure	
Adjusted Reduction	0.24%
Statistical Significance	No Statistically Significant
Crash Modification Factor (CMF)	0.998
Standard Error	0.0547