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Evaluation of Michigan's Engineering Improvements for Older Drivers

FINAL REPORT

Valerian Kwigizile, Jun-Seok Oh, Ron Van Houten, Diana Prieto, Richard Boateng, Lusanni Rodriguez, Andrew Ceifetz, Joyce Yassin, Jeffrey Bagdade, and Patrick Andridge

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16. Abstract

In 2004, the Michigan Department of Transportation (MDOT) began a comprehensive program to implement engineering countermeasures to address the needs of older drivers. The countermeasures included the use of Clearview Font on Guide Signs (freeway and non-freeway), installation of Box Span signals, installation of pedestrian countdown signals, use of Fluorescent Yellow Sheeting on warning signs, and use of arrow-per-lane on guide signs. This study aimed at evaluating safety benefits of the selected countermeasures. Evaluation was performed through a perception survey of Michigan drivers and analysis of crash data. Safety Performance Functions (SPF) for these improvements were developed as part of the study. Crash Modification Factors (CMF) for each countermeasure were developed through the before-after analysis of crash data. Finally, the benefit cost analysis of each countermeasure was performed and is documented in this report.

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TABLE OF CONTENTS

LIST OF TABLES iv

LIST OF FIGURES v

EXECUTIVE SUMMARY vii

1 Introduction and Background 1

1.1 Research Problem and Motivation 1

1.1.1 Clearview Font on Guide Signs (freeway and non-freeway) 2

1.1.2 Box Span Signal Installation 2

1.1.3 Pedestrian Countdown Signal Installation 3

1.1.4 Fluorescent Yellow Sheeting 3

1.1.5 Arrow-Per-Lane Signing 4

1.2 Research Objectives 5

1.3 Scope of Research and Report Organization 5

2 Literature Review 6

2.1 Clearview Fonts on Guide Signs (Freeway and Non-Freeway) 6

2.2 Box Span Signal Installations 9

2.3 Pedestrian Countdown Signals (PCS) 11

2.4 Fluorescent Yellow Sheeting on Warning Signs 15

2.5 Arrow-Per Lane on Diagrammatic Signing 16

3 Survey of Michigan Drivers 23

3.1 Introduction 23

3.2 Survey Design and Administration 23

3.3 Analysis of Survey Data 24

3.3.1 Clearview Font on Guide Signs 25

3.3.2 Pedestrian Countdown Signal 28

3.3.3 Fluorescent Yellow Sheeting 30

3.3.4 Lane Use Arrows 33

3.3.5 Box Span Signal Installations 36

4 Data Collection 38

4.1 Clearview Font and Fluorescent Yellow Sheeting (Freeways and Non-Freeways) ... 39

4.2 Box Span Signal Installations 45

4.3 Pedestrian Countdown Signals (PCS) 47
4.4 Arrow-Per-Lane Signing 49
5 Development of Safety Performance Functions (SPFs) 53
5.1 Introduction 53
5.2 Modeling Approach 53
5.3 SPFs for Segments 55
5.3.1 SPF for Freeways 55
5.3.2 SPF for Urban Non-Freeway Segments 58
5.3.3 SPF for Rural Non-Freeway Segments 63
5.4 SPFs for Intersections 70
6 Estimation of Crash Modification Factors (CMFs) 80
6.1 Introduction 80
6.2 Empirical Bayes Method 80
6.3 Before-After with Comparison Group 82
6.4 CMF Results and Discussions 85
6.4.1 CMFs for Segments 85
6.4.2 CMFs for Intersections 89
7 Benefit-Cost Analysis 91
7.1 Introduction 91
7.2 Cost of Countermeasures 92
7.2.1 Clearview Font and Fluorescent Yellow Sheeting 92
7.2.2 Box Span Signal Installation 93
7.2.3 Pedestrian Countdown Signals 94
7.2.4 Arrow-Per-Lane Signing 94
7.3 Benefit-Cost Ratio Calculations 95
8 Conclusions and Recommendations 97
9 References 99
10 APPENDICES 105
10.1 Appendix 3.1. Survey Questionnaire and Analysis by All Ages 105
10.2 Appendix 4.1. Detailed Data Collected 120
10.3 Appendix 5.1. SPFs for drivers under 65 years old 123

10.4 Appendix 6.1. CMFs for Drivers Under 65 Years ... 129
10.4.1 Clearview Font and Fluorescent Yellow Sheeting on Freeways ... 129
10.4.2 Clearview Font and Fluorescent Yellow Sheeting on Urban Non-Freeways ... 130
10.4.3 Clearview Font and Fluorescent Yellow Sheeting on Rural Non-Freeways ... 131
10.4.4 Pedestrian Countdown Signals ... 132
10.4.5 Arrow-Per Lane ... 133
10.4.6 Box Span Signal Configuration ... 134

LIST OF TABLES

Table 3.1 Distribution of survey participants by age and location 24
Table 4.1 Type and source of data collected.. 38
Table 4.2 Example of MDOT's corridor data 39
Table 4.3 Summary of segments used for evaluation of Clearview font and Fluorescent Yellow Sheeting.. 41
Table 4.4 Summary of Variables Considered for Analysis of Clearview font and Fluorescent Yellow Sheeting on Freeways 43
Table 4.5 Summary of Variables Considered for Analysis of Clearview font and Fluorescent Yellow Sheeting on Non-Freeways (Urban Areas) 44
Table 4.6 Summary of Variables Considered for Analysis of Clearview font and Fluorescent Yellow Sheeting on Non-Freeways (Rural Areas) 45
Table 4.7 Number of sites selected by region.. 46
Table 4.8 Data collection summary for box span signal installations 47
Table 4.9 Data Collection Summary for Pedestrian Countdown Signals (PCS) 48
Table 4.10 Treatment and Comparison Sites Pairings for arrow-per-lane 49
Table 4.11 Summary of data used in analyzing arrow-per lane signs 52
Table 5.1 SPFs for freeway segments... 57
Table 5.2 SPFs for urban non-freeways.. 59
Table 5.3 SPFs for Non-Freeways (Rural) 64
Table 5.4 Testing significance of variables for box span SPFs 71
Table 5.5 SPFs for reference sites for box span... 73
Table 6.1 Summary of CMFs for Segments 86
Table 6.2 Crash reduction factors (in %) for segments 87
Table 6.3 CMFs for intersections.. 90
Table 6.4 Crash reduction factors (in %) for intersections 90
Table 7.1 Summary of installation costs for Fluorescent Yellow Sheeting and Clearview font . 93
Table 7.2 Sample box span signal installation costs... 93
Table 7.3 Arrow-Per Lane Costs 94
Table 7.4 Summary of Benefit-Cost Analysis 96

LIST OF FIGURES

Figure 1.1 Southbound I-375 in Detroit 2
Figure 1.2 Ford Road (M-153) & Beech Daly in Dearborn Heights 2
Figure 1.3 Pedestrian countdown signal 3
Figure 1.4 Warning sign with fluorescent yellow sheeting 3
Figure 1.5 Arrow-per lane signing (Courtesy: Google Image) 4
Figure 2.1 Clearview Font (left) and Standard (right) overhead signs (Source: Gray and Neuman, 2008) 7
Figure 2.2 Pedestrian countdown signal (left) vs. standard pedestrian signal (right) 11
Figure 2.3 Lane choice by sign type, presence of an option lane and age group (Source: Golembiewski et al., 2008) 21
Figure 2.4 Arrow-Per-Lane Guidance Sign 22
Figure 2.5 Diagrammatic Guidance Sign 22
Figure 3.1 Preference of Clearview fonts on high speed roads 25
Figure 3.2 Preferences of Clearview fonts from far distances 26
Figure 3.3 Preferences for Clearview fonts in inclement weather 27
Figure 3.4 Preferences for Clearview fonts in night time 27
Figure 3.5 Preference of pedestrian countdown signal in decision to start crossing 28
Figure 3.6 Preference of pedestrian countdown signal in adjustment of walking speed 29
Figure 3.7 Preference of pedestrian countdown signal in increasing feeling of safety 30
Figure 3.8 Preference of Fluorescent Yellow Sheeting on high speed roads 31
Figure 3.9 Preference of Fluorescent Yellow Sheeting in inclement weather 32
Figure 3.10 Preference of Fluorescent Yellow Sheeting in nighttime 33
Figure 3.11 Preference of lane use arrows in unfamiliar areas 34
Figure 3.12 Preference of lane use arrows from far distances 35
Figure 3.13 Preference of box span signals in finding proper lanes 36
Figure 3.14 Preference of box span signal in improving visibility 37
Figure 4.1 Distribution of potential segments for freeways and non-freeways 40
Figure 4.2 Sample site with multiple improvements 41
Figure 4.3 Distribution of sites with and without PCS (left) and 150ft buffer for data collection (right) 48
Figure 4.4 Treatment and comparison site locations for arrow-per-lane 50
Figure 5.1 Graphical presentation of SPFs for freeways 58
Figure 5.2 SPF for Total on non-Freeways (Urban) 60
Figure 5.3 SPF for FI on non-Freeways (Urban) 61
Figure 5.4 SPF for Total drivers 65yrs-and-older on non-Freeways (Urban) 62
Figure 5.5 SPF for FI drivers 65yrs-and-older on non-Freeways (Urban) 63
Figure 5.6 SPF for total drivers on undivided rural non-freeways without sidewalk 65

Figure 5.7 SPF for Total drivers 65yrs-and-older on undivided rural non-freeways without sidewalk 66
Figure 5.8 SPF for Total drivers on divided rural non-freeways without sidewalk 67
Figure 5.9 SPF for Total drivers on undivided rural non-Freeways with sidewalk........ 68
Figure 5.10 SPF for Total drivers 65yrs-and-older on divided rural non-freeways without sidewalk 69
Figure 5.11 SPF for Total drivers 65yrs-and-older on rural undivided non-freeways with sidewalk 70
Figure 5.12 SPF for Total Crashes (KABCO) - Presence of LT phase/LT lane/wide Median ... 74
Figure 5.13 SPF for Fatal/Injury Crashes (KABC)-Presence of LT phase/LT lane/wide Median 75
Figure 5.14 SPF for Angle Crashes (KABCO)-Presence of LT phase/LT lane/wide Median 76
Figure 5.15 SPF for Total Crashes Involving Drivers 65yrs-and-older-Presence of LT phase/LT lane/wide Median........ 77
Figure 5.16 SPF for Fatal/Injury Crashes Involving Drivers 65yrs-and-Older-Presence of LT phase/LT lane/wide Median........ 78
Figure 5.17 SPF for Angle Crashes Involving Drivers 65yrs-and-older - Presence of LT phase/LT lane/wide Median........ 79

EXECUTIVE SUMMARY

In 2004, in coordination with the North American Conference on Elderly Mobility, the Michigan Department of Transportation (MDOT) began a comprehensive program to implement engineering countermeasures to address the needs of older drivers. As part of this initiative, MDOT selected several countermeasures to apply on a systemic approach. The countermeasures included the use of Clearview fonts on guide signs (freeway and non-freeway), installation of box span signals, installation of pedestrian countdown signals, use of Fluorescent Yellow Sheeting on warning signs, and use of arrow-per-lane on guide signs. Since Michigan implemented these improvements for a number of years now, it is important that a comprehensive evaluation of their effectiveness be performed. This study aimed at evaluating safety benefits of the selected countermeasures. Specifically, the research objectives were twofold:

i. Evaluate the safety benefits of each of the studied improvements for all ages and for older drivers.
ii. Develop Safety Performance Functions (SPF) and Crash Modification Factors (CMF) for these improvements.

After conducting a comprehensive review of existing literature, it was determined that most of the evaluation studies conducted before, employed perception surveys or simulation. A limited number of studies have evaluated these countermeasures by examining actual crash data. In this study, however, actual crash data in the before and after periods were examined, in addition to a perception survey of all drivers, to estimate the safety benefits of each countermeasure. Benefit cost analysis was performed for each countermeasure. The field survey was administered in four metro areas in Michigan (Kalamazoo, Grand Rapids, Lansing and Detroit) at four types of facilities (restaurants, grocery stores, senior centers and rest areas). A total of 1,590 drivers participated in the survey. The survey results indicated that most countermeasures evaluated are preferred by all drivers and those with 65yrs-and-older, generally. The exception was the box span signal installation, where most drivers thought the diagonal signal installation improved visibility of the signals and helped them find the proper lane better.

While MDOT implemented Fluorescent Yellow Sheeting only prior to adoption of the Clearview fonts, the two countermeasures have been installed together since adoption of Clearview font. As a result, it was impossible to collect individual data and conduct an independent evaluation of Clearview font on guide signs. Data on Clearview font and Fluorescent Yellow Sheeting is presented together. The data collection for the remaining countermeasures (i.e., box span signals, pedestrian countdown signals, and arrow-per-lane signs) is presented individually.

The Safety Performance Functions (SPFs) were developed using non-treated sites for three countermeasures: Clearview font, Fluorescent Yellow Sheeting, and box span signal installations. It was not possible to develop SPFs for pedestrian countdown signals due to lack of reliable pedestrian exposure data. Also, there was no sufficient number of sites for developing SPFs for arrow-per lane signs. The SPFs were estimated by fitting the Negative Binomial model. For freeway segments, only segment length and Average Annual Daily Traffic (AADT) were found to impact segment crashes significantly. Reliable SPFs were estimated for total (all severities), total fatal and injury, total daytime and total nighttime crashes. There were no reliable SPFs for drivers 65yrs-and-older. Non-freeway segments were divided into two categories: urban and rural. For urban non-freeway segments, AADT, segment length, number of access points, and undivided roadway status were statistically significant factors affecting the number of crashes. For rural non-freeway segments, AADT, segment length, number of access points, undivided roadway, and lack of sidewalk were statistically significant factors affecting the number of crashes. For box span signal installations, analysis showed that the following factors affect crash occurrence significantly: AADT on major approach, AADT on minor approach, presence of left turn lane on minor approach, presence of left turn phase on major approach, presence of left turn phase on minor approach, and presence of wide medians.

To estimate Crash Modification Factors (CMFs), two commonly used approaches were employed: Empirical Bayes (EB) method (where reliable SPFs were obtained) and Before-After with Comparison Group (where no reliable SPFs were obtained or was impractical to develop SPFs). CMFs for segments are presented in Table E1, while the CMFs for intersections are presented in Table E2. Standard errors corresponding with the CMFs are shown in brackets, where available. It should be noted that although there were no specific sites where Clearview font signs were installed alone to allow direct development of CMFs for Clearview fonts, the CMFs for Fluorescent Yellow Sheeting only and a combination of Fluorescent Yellow Sheeting and Clearview font were used to estimate the CMFs for Clearview font signs. The following equation was used to estimate the CMF for Clearview font signs (CMF_{CV}) from the CMF for Fluorescent Yellow Sheeting only (CMF_{FY}) and the CMF for both Fluorescent Yellow Sheeting and Clearview font ($CMF_{CV\text{-}FY}$):

$$CMF_{CV} = \frac{CMF_{CV-FY}}{CMF_{FY}}$$

Table E1. Summary of CMFs for Segments

Countermeasure Information		All Severities (KABCO)	Fatal Injury (KABC)	All Severities (KABCO) Day	All Severities (KABCO) Night	All Severities 65yrs-and-Older	All Severities 65yrs-and-Older Day	All Severities 65yrs-and-Older Night
Freeways	Clearview & Fluorescent	0.759 (0.0190)	0.930 (0.0498)	0.798 (0.0261)	0.741 (0.0281)	*0.899 (0.144)	*0.912 (0.170)	*0.902 (0.270)
	Fluorescent Only	0.851 (0.0294)	0.963 (0.0733)	0.819 (0.0367)	0.998 (0.0534)	*0.998 (0.184)	*0.938 (0.209)	*0.913 (0.307)
	Clearview Only	0.892	0.966	0.974	0.742	0.900	0.972	0.988
Urban Non-Freeways	Clearview & Fluorescent	0.704 (0.0288)	0.711 (0.0602)	0.730 (0.0350)	0.657 (0.0514)	0.859 (0.0854)	0.895 (0.0975)	*0.964 (0.143)
	Fluorescent Only	0.949 (0.0288)	0.917 (0.0578)	0.932 (0.0342)	0.993 (0.0523)	0.963 (0.0675)	0.965 (0.0740)	*0.986 (0.0775)
	Clearview Only	0.742	0.775	0.783	0.662	0.892	0.927	0.978
Rural Non-Freeways	Clearview& Fluorescent	0.670 (0.0236)	*0.927 (0.0261)	0.716 (0.0385)	0.667 (0.0310)	0.783 (0.0741)	0.941 (0.120)	*0.977 (0.0835)
	Fluorescent Only	0.923 (0.0264)	*0.972 (0.0185)	0.883 (0.0396)	0.973 (0.0355)	0.895 (0.0675)	0.993 (0.0977)	*0.998 (0.0547)
	Clearview Only	0.726	0.954	0.811	0.686	0.875	0.948	0.979
Arrow-Per-Lane	All Crashes	*0.578 (0.0845)				*0.319 (0.0909)		

- ** Indicates CMFs estimated with B/A with comparison groups method*
- *Numbers in brackets are standard errors estimated for the CMFs*

Table E2. CMFs for intersections

Countermeasure Information		All Severities (KABCO)	Fatal Injury (KABC)	All Severities 65yrs-and-Older	Fatal Injury 65yrs-and-Older
Pedestrian Countdown Signal (PCS)	*All Drivers*	*0.946 (0.035)	*0.927 (0.072)	*0.849 (0.092)	*0.477 (0.117)
	All Pedestrians	*0.683 (0.173)	*0.804 (0.223)	*0.353 (0.211)	*0.449 (0.266)
Box Span Signal Installations	*All Crashes*	0.975 (0.040)	0.897 (0.079)	1.097 (0.099)	0.888 (0.164)
	Angle Crashes	0.876 (0.070)		0.841 (0.133)	

- ** Indicates CMFs estimated with B/A with comparison groups method*
- *Numbers in brackets are standard errors estimated for the CMFs*

The CMFs were applied to estimate crash cost benefits in an economic analysis of the treatments to assess the cost-effectiveness of the improvements. Benefit-to-cost analyses for the countermeasures were done by determining the expected crash reductions due to the presence of the countermeasure from the CMF and crash savings associated with the crash. Crashes were disaggregated by crash type and severity to the extent possible and unit crash costs for those types and severities were applied before aggregating to obtain an overall crash cost savings. MDOT provided generic costs for installing Fluorescent Yellow Sheeting and Clearview font signs. It was determined that implementing Clearview font sign costs $41 more than the previous MDOT standard font, while installing the Fluorescent Yellow Sheeting costs $46 more than the cost to install the old standard, Type IV yellow sheeting sign. Also, MDOT provided cost estimates for installing a diagonal span signal and a box span signal at sample intersections representing our treated sites. Based on 117 intersections with box span signal configuration, it was determined that the average installation cost for a box span signal is $83,239 compared to $49,957 for installing diagonal signal at the same site. This yields an average differential cost of $33,282 per intersection. The maintenance cost was regarded to be the same for diagonal and box span signal installation. For pedestrian countdown signal, it was determined that the cost for one countdown signal head is $291.90 compared to $185.63 for a standard pedestrian signal head. For a typical four-leg signalized intersection (with a total of 8 signal heads), the differential cost was determined to be

$850.16. The service life was assumed to be 30 years, while the maintenance cost was assumed to be the same for both pedestrian countdown signal and standard pedestrian signal. For the eight arrow-per lane sites evaluated in this study, it was determine that the average installation cost of arrow-per lane signs per site is $14,643 compared to $11,824 for standard diagrammatic signs. This yields the differential cost of $2,819 per site. The benefit-cost ratio (BCR) for each countermeasure was determined based on present values of crash savings and differential installation costs. The BCR results indicated that all countermeasures are economically beneficial, with the BCR values ranging from 13:1 for box span signal installations to 7,456:1 for installing Fluorescent Yellow Sheeting and Clearview font signs (combined) in urban non-freeway segments.

In conclusion, Clearview font legend on guide signs for both freeway and non-freeway, box span signal installation, pedestrian countdown signals, Fluorescent Yellow Sheeting on warning signs, and arrow-per-lane signs improve safety for not only drivers age 65yrs-and-older, but all ages. Since the benefits outweigh the cost significantly, replacement before the end of life should be considered.

1 Introduction and Background

1.1 Research Problem and Motivation

Michigan crash records for 2004-2013 showed that the number of drivers involved in all crashes reduced by 23.8 percent over the 10-year period, but increased by 2.4 percent for all older drivers' (65yrs-and-older). In the case of 65yrs-and-older drivers' involvement in fatal crashes, records showed an increase of 15.9 percent during the same time (OHSP, 2013). The increase in 65yrs-and-older driver crashes may be reflecting the increasing number of older persons in the population. Older-driver involvement in crashes can be expected to continue rising as the aging "baby boom" generation forms an increasing proportion of the driving and general population. The higher fatality rates associated with older road users may reflect the increased fragility of older persons. Over the past several years, the Michigan Department of Transportation (MDOT) in coordination with the Governors Traffic Safety Advisory Commission (GTSAC), has instituted several programs aimed at addressing the needs of older road users. These programs are outlined in the *Michigan Senior Mobility Action Plan*, which focuses on implementing a multidisciplinary approach (e.g. engineering, enforcement, education, and emergency services) towards improving safety and mobility. Many of these programs to assist older road users have the additional benefit of helping the general driving population. In 2004, in coordination with the North American Conference on Elderly Mobility, MDOT began implementing a comprehensive program to apply engineering countermeasures to address the needs of older drivers. As part of this initiative, MDOT selected several countermeasures to apply on a systemic approach. The countermeasures included the use of Clearview Font on Guide Signs (freeway and non-freeway), installation of Box Configuration signals, installation of pedestrian countdown signals, use of Fluorescent Yellow Sheeting on warning signs, and use of arrow-per-lane on guide signs.

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

MDOT's implementation of Clearview font for the legend on positive contrast guide signs was due to its effectiveness in enhancing sign legibility, particularly for older drivers. Its implementation coincided with Federal Highway Administration's (FHWA) 2004 interim approval of Clearview font in the Manual on Uniform Traffic Control Devices (MUTCD). The photo on the right in Figure 1.1 illustrates a comparison between Clearview (left sign) and Series E Modified (right sign).

Figure 1.1 Southbound I-375 in Detroit

1.1.2 Box Span Signal Installation

The box span configuration was initially recommended for implementation by AAA Michigan as part of the Road Improvement Demonstration Program in the late 1990's. Several local agencies including, most notably the City of Grand Rapids applied the box span to 25 intersections. An evaluation of those improvements found significant reductions in crash frequency and severity. A follow-up study found a significant reduction in red light running at locations with a box span signal configuration. As it helped improve the visibility and conspicuity of traffic signal displays, it was selected as one of MDOT's older driver focused safety countermeasures. Figure 1.2 shows the box span signal configuration.

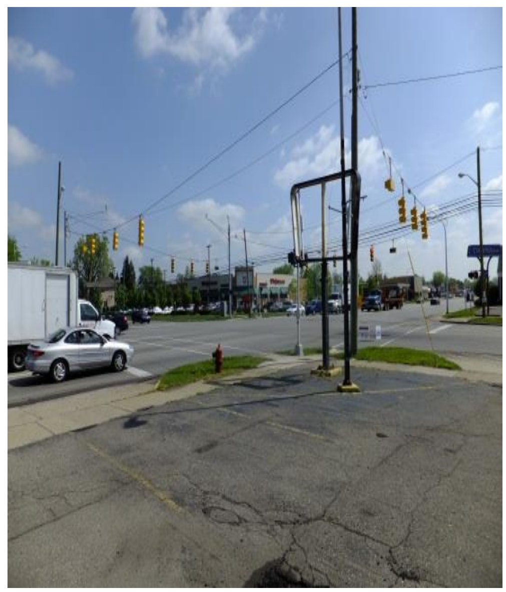

Figure 1.2 Ford Road (M-153) & Beech Daly in Dearborn Heights

1.1.3 Pedestrian Countdown Signal Installation

Pedestrian countdown signals were selected for inclusion in the initiative due to their effectiveness of enhancing safety for elderly pedestrians. This was based on the research in the *AAA Pedestrian Signal Safety for Older Persons* study which found that older pedestrians were more likely to be out of the crosswalk at the onset of steady DON'T WALK at crossings with countdown signals as opposed to locations with traditional pedestrian signals. This study corroborated the results of several other similar studies. The 2009 MUTCD now requires the use of pedestrian countdown signals. Figure 1.3 shows a pedestrian countdown signal.

Figure 1.3 Pedestrian countdown signal

1.1.4 Fluorescent Yellow Sheeting

The replacement of old standard, Type IV yellow sheeting with Fluorescent Yellow Sheeting increases conspicuity of drivers. A study by Krull (2000) tested two age groups: eighteen to twenty five, and fifty five to seventy five, in order to evaluate benefits of such installation. The difference was found between the two signs. Older drivers benefited the most since they detected the fluorescent yellow signs from a far distance ahead compared to the non-fluorescent signs. Figure 1.4 shows a sign with Fluorescent Yellow Sheeting.

Figure 1.4 Warning sign with fluorescent yellow sheeting

1.1.5 Arrow-Per-Lane Signing

The use of arrow-per-lane signing and improved visibility of signs (e.g. Fluorescent Yellow Sheeting) was originally recommended in the *2001 FHWA Highway Design Handbook for Older Drivers and Pedestrian*. In this design, the number of arrow shafts appearing on the sign matches the number of lanes on the roadway at the sign's location. This approach was found to be clearer to older drivers by indicating which lane they needed to be in when approaching a freeway interchange with optional exit lanes. Figure 1.5 shows the standard diagrammatic sign (left picture) and the arrows-per-lane sign (right picture).

Figure 1.5 Arrow-per lane signing (Courtesy: Google Image)

1.2 Research Objectives

Since Michigan implemented these improvements for a number of years now, it is important that a comprehensive evaluation of their effectiveness be performed. This study aimed at evaluating safety benefits of the selected countermeasures. Specifically, the research objectives were twofold:

i. Evaluating the safety benefits of each of the studied improvements for all ages and for older drivers.
ii. Develop Safety Performance Functions (SPF) and Crash Modification Factors (CMF) for these improvements.

1.3 Scope of Research and Report Organization

This research focused on quantification of safety impacts of the five improvements introduced in Section 1.1 above. Chapter 2 of this report presents the literature review focusing on the five engineering improvements being evaluated. Chapter 3 documents results and findings from a survey of Michigan drivers regarding their perceptions on the engineering improvements evaluated in this study. Chapter 4 presents a summary of all data collected for this study, while Chapter 5 presents the methodology and results on development of safety performance functions (SPFs). Chapter 6 presents the crash modification factors (CMFs) developed in this study, while Chapter 7 documents the economic analysis of the engineering improvements studied. Finally, Chapter 8 presents the conclusions and recommendations of this study.

2 Literature Review

This section covers the literature review related to each engineering improvement analyzed. These countermeasures have been evaluated by research teams and transportation departments in other states and countries. Methodologies used involve before and after observational and experimental studies, driving simulation, survey questionnaires, and computer screen presentations.

2.1 Clearview Fonts on Guide Signs (Freeway and Non-Freeway)

Developed by Meeker and Associates and the Pennsylvania Transportation Institute through a decade of research opening, the Clearview font style for guide signs aimed to improve legibility and decrease halation of highway sign legends (Frei, 2011 and Garvey, 1997). Not being able to clearly read the signs due to halation or irradiation was a safety problem on the roads. There were four main issues to be addressed by implementing this new font style: accommodation of older drivers needs without increasing the messages and sign sizes, improvement in recognizing the word pattern in highway signs, improvements of speed and exactness in recognizing destination, and minimization of halation in words produced by high brightness in retro-reflective signs for those with reduced contrast sensitivity (Alberta Infrastructure and Transportation 2006). Halation is reduced since Clearview fonts have "more open interior spaces" (Mitchell, 2010, Garvey 1998) improving the legibility of the sign from distances when irradiation occurs. The space between letters, which is known as tracking, is intended to make words more distinctive as well. Studies performed on the evaluation of this countermeasure are presented in this section.

In September 2010, Gray and Neuman performed an evaluation of Clearview fonts for the Maricopa Association Government (MAG)'s project. The project consisted of evaluating 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 approached. Findings showed that the Clearview fonts provide better readability of the given sign, mostly during night time. Improvements in recognizing the sign were shown to be of eight to ten percent 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, to adopt Clearview font signs where standard fonts were. Figure 2.1 shows the examples of the overhead sign images for both types of fonts.

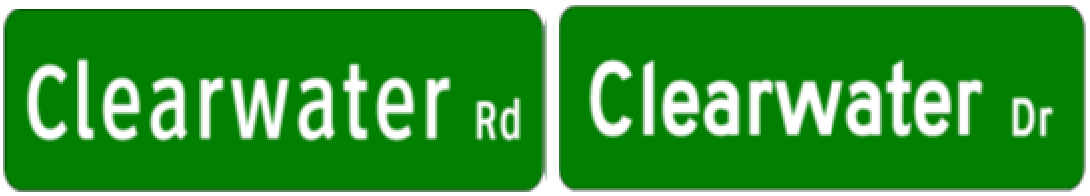

Figure 2.1 Clearview Font (left) and Standard (right) overhead signs (Source: Gray and Neuman, 2008)

In 2011, Frei conducted a field survey together with a visual inspection in Illinois. Driver responses to signs using Clearview font were the main purpose of the survey. Main findings were obtained from running a binary logit model. Approximately ten percent increment in sign 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. It was recommended to continue use of the font along with high-retro-reflective sheeting; and to develop a systematic sign inventory in order to address inconsistencies in signs noted by drivers.

A similar study was developed in Kansas by Gowda in 2010. In this case computer screen images were also considered besides the field evaluation. Findings showed longer readability distances were provided by the Clearview font than the standard E-modified font for guide signs. However, there was no readability differences found during day and night time. Recommendations included the use of Clearview 5-W-R with ASTM Type IV Sheeting for best results in readability. In the same context, Carlson (2001) conducted a study in Texas to determine the legibility of the Clearview alphabet on freeway guide signs constructed with microprismatic retroreflective sheeting. The Clearview legibility results were compared to the legibility of freeway guide signs constructed with the Series E (Modified) alphabet. Improvements in legibility were of 44 and 41 feet for overhead and shoulder mounted guide signs, respectively. It was also found that, sequentially, the differences between Type III guide signs with Series E (Modified) legends, microprismatic guide signs with Series E (Modified) legends, and microprismatic guide signs with Clearview legends were modest. However, the combined effect of switching from Type III guide signs with Series E (Modified) legends to microprismatic guide signs with Clearview legends were significant.

Miles et al, 2014, performed the evaluation of guide signs using Clearview fonts. 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 increase in size in Clearview 5W over 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 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) 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) in 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. During nighttime conditions, recognition of the sign was slightly decreased when the standard font was replaced with Clearview font in negative contrast signs. Also, since there was no significant difference in using the Clearview font and the series E (Modified) fonts used, the study recommended continued use of the series E (Modified) font for negative contrast signs.

2.2 Box Span Signal Installations

While there are a number of important factors and characteristics related to the safe operation of a signalized intersection, the conspicuity of traffic signal heads is a fundamental one. If there is too much visual clutter along the approach to the intersection, the signal heads can become “lost” in the background and make it much more difficult for motorists to identify and respond to the signal. One of the means for increasing signal visibility at an intersection is the installation of a box configuration signal layout. This type of installation provides several benefits, including increased conspicuity and the ability to provide a signal head for each approach lane. These traits help reduce confusion as to which signal head a driver should be obeying, as well as making the signal easier to see and react to. When drivers, especially those with diminished cognitive abilities, are able to see signal heads properly, they may avoid signal related crashes such as running red. While diagonal spans are generally least expensive to install, box configurations are considered superior in terms of signal visibility and comprehension. The two most common box configuration installations use either span wire or mast arm assemblies (Buckholz, 2014). Several studies have been conducted to look at the performance of several different types of signal installations to try and determine which provides the greatest safety benefits.

While safety improvements are paramount in selecting which type of signal installation to use, economic considerations often come in to play. This is especially true in light of recent years of budget cuts in many states and municipalities across the United States. Several studies have considered the impacts of box configuration signal installations in terms of both safety and economic analyses.

In 1996 AAA Michigan worked with MDOT and several local agencies in Michigan using the Road Improvement Demonstration Program to identify and implement several low cost improvements centered on traffic signals, pavement markings, and signing. While the improvements were designed to benefit traffic safety for the general population, it was shown that they also played a significant role in improving traffic safety and operations for senior drivers specifically. To determine the extent of the impact on this specific demographic, an additional study was completed comparing senior drivers age 65 and older to a control group of adult drivers age 25 to 64. Various safety treatments were employed at the demonstration project intersections including replacing eight inch traffic signal lenses with twelve inch lenses, improving traffic signal placement, increasing the all-red clearance interval, adding left turn phasing where appropriate, signal head back plates, and the addition of permissive/protected left-turn phasing. One of the main goals of the improvements was to increase the visibility of traffic signals at the demonstration intersections. This was achieved in part by repositioning traffic signals that were closer to the curbs over their respective lanes. The various treatments employed at each of the intersections helped to improve signal head visibility. These improvements, in various combinations, were implemented at a total of 60 intersections in Detroit and Grand Rapids, MI. Crash rates between the two age groups were collected and compared using a Paired t-test which results indicated a significant decline in injury crashes for the senior driver population (Bagdade, 2004).

Another study conducted in 2011 assessed the safety impacts of post-mounted, diagonal span wire, and mast arm signal installations. Using a total of 12 intersections and two measures of effectiveness (yellow and red light running) a comparative analysis was conducted. The twelve intersections were located in Rochester, MI and Peoria, IL and were specifically selected in an attempt to keep other factors as constant as possible. In addition to controlling for intersection geometries and characteristics, attempts were made to control for other variables such as the average daily traffic and approach volumes, yellow interval length, speed limit, cycle length, and the presence of pedestrian countdown timers. Cameras were set up at each location to record traffic operations for later analysis. Only through vehicles were considered when counting yellow and red light running incidents. Data from each group of intersections were compared against each other using the Student's T-test and a 95% confidence level. The authors determined that, at a statistically significant level, mast arm signal installations produced lower rates of yellow and red light running than either diagonal span or post mounted signals installations. The authors attributed the reductions in yellow and red light running, at least in part, to the increased visibility of the mast arm signals (Schattler et al., 2011).

The literature reviewed to date suggests box configuration installations are an economically viable option with a track record for crash reductions. The Federal Highway Administration (FHWA) has proposed in the past to add a guidance statement in the Manual on Uniform Traffic Control Devices (MUTCD) recommending signal heads to be mounted overhead over each through lane, in addition to supplemental near-side and/or far-side post mounted signals for added visibility. Recommendations to reconfigure diagonal signal spans to ‘‘box’’ configuration signal layouts with far-side signal was also suggested to reduce red light running (Federal Register, 2008).

2.3 Pedestrian Countdown Signals (PCS)

Pedestrians tend to be confused when the pedestrian signal displays a flashing DON’T WALK phase. Their confusion is based on the expectation of a solid WALK signal rather than the negative sign or flashing hand. Pedestrian Countdown Signals (PCS) are the improvement of these standard pedestrian signs (Figure 2.2). Pedestrian countdown signals display the number of seconds left for a pedestrian to cross the street safely before the DON’T WALK sign appears (Huang, 2000). There are two main positive outcomes that a countdown signal provides to pedestrians. A pedestrian already in the street can decide whether to cross the street walking faster, with the remaining time before it reaches zero; and a pedestrian arriving at intersection can decide

Figure 2.2 Pedestrian countdown signal (left) vs. standard pedestrian signal (right)

not to cross if he or she has few seconds left. Different studies on evaluating the use of PCS are presented in this section.

Studies conducted by Sifrit et al (2011) used crash data from both the Fatality Analysis Reporting System (FARS) and General Estimates System (GES) from 2002-2006. Their studies generally revealed that, there is a high crash risk for older drivers at intersections. Also, Pollatsek et al (2012) conducted studies aimed at identifying and remediating failures of selective attention in older drivers at intersections. Specifically, the researchers' goal was to determine areas where older drivers can see and identify potential hazards at intersections. Their findings showed that, older drivers have serious issues with adequate identification of potential hazards at intersections. They however asserted that, this cannot be the only reason for high older drivers' crashes. McGwin et al (1999) carried out studies on "Characteristics of traffic crashes among young, middle-aged, and older drivers" and their study revealed higher intersection-related crashes among older drivers. Their finding was in line with findings from other authors such as Preusser, et al (1998). A study conducted by Alam et al (2008) on contribution of behavioral aspects of older drivers to fatal traffic crashes in Florida also showed that older drivers are mostly at fault in intersection crashes. These findings are also consistent with studies conducted by Rakotonirainy et al (2012).

Huang et al (2000) described a pedestrian countdown signal as a timer that displays the counting down of seconds left to cross a street where as the standard or traditional pedestrian signal displays messages such as "WALK or a walking person, Flashing Don't Walk or a Flashing hand and steady Don't Walk or a steady hand." The study considered 2 treated and 3 untreated sites and the effectiveness of the pedestrian countdown signals were evaluated based on; (a) Pedestrian compliance with the Walk signal, (b) Pedestrian who run out of time and (c) Pedestrian who began running when the flashing Don't Walk signal appeared. Their study revealed that pedestrian countdown signals had a positive effect of reducing the number of pedestrians who would have ran upon the appearance of flashing Don't Walk interval. It also revealed that pedestrian countdown signals may not be useful at some intersections because their effectiveness could be based on age differences. However, they recommended that pedestrian countdown signals may be promising at intersections that have higher older population by virtue of its added information regarding the time available to cross.

A study conducted in Washington by Elekwachi (2010) examined variables and behaviors of drivers at four intersections installed with pedestrian countdown signals compared to traditional pedestrian signals. The study variables considered in her research consisted of vehicles; (a) entering the intersection during the yellow phase (b) stopping during the yellow phase (c) stopping during the red phase (d) entering the intersection between the yellow and red phases (e) entering the intersection during the red phase and (f) the headway. Her findings revealed that pedestrian countdown signals had a statistically significant effect on both driver and pedestrian behavior.

Again, studies conducted on by Reddy et al (2008) employed a before-after study methodology to determine the effectiveness of pedestrian countdown signals by comparing the pedestrian behavior before and after installation of the devices. They concluded that, the pedestrian countdown signals seem to be effective in increasing the percentage of pedestrian crossings and decreasing the percentage of pedestrians who initiate crossing during the flashing “Don’t walk’’ indication. Their research and conclusion were based on only eight (8) intersections and they recommended that, further studies should focus on the use of crash data to quantify the safety impacts of pedestrian countdown signals.

Arhin et al (2011) used a before and after study approach to compare the two types of displays by pedestrian countdown signals which are Steady Walk (SW)-Flashing Don’t Walk (FDW) display and Flashing Don’t Walk (FDW) display. They assigned a before study approach to Steady Walk (SW)-Flashing Don’t Walk (FDW) where the countdown trickles at the beginning of the SW interval through the FDW interval whereas in the after period approach, the countdown coincides with the FDW interval. Their findings revealed that, a good number of intersections considered in their study had no statistical significant differences in the pedestrian crossing behaviors (using 5% significance level) because of the display type of the pedestrian countdown signals.

Pulugurtha et al (2004) carried out studies in the Las Vegas Metropolitan area. They considered 10 treated and 4 untreated sites in their study and data were collected both manually and electronically. Pedestrian surveys or interviews were also carried out to ascertain pedestrian understanding of the pedestrian countdown signals. Their findings showed that, countdown signals are effective in improving pedestrian safety. They however recommended a pedestrian crash study in the before and after installation of countdown signal to investigate its statistical significance. In addition, Schattler et al (2006) conducted a study in the city of Peoria, Illinois. Five treated and five untreated sites were selected for their study and because they had no before data for their studies, a comparison was made between pedestrian location within the crosswalk at different intervals of Walk, Flashing Don't Walk and a Steady Don't Walk displays. Their findings showed that, pedestrian countdown signals encourage pedestrian compliance as compared to the traditional pedestrian signals. Based on this and other findings from their study, they concluded that countdown signals do not increase risk-taking behavior on the part of motorists.

Pulugurtha et al (2010) conducted a before and after study with the aim of evaluating the effect of pedestrian countdown signals in reducing vehicle-pedestrian crashes and all crashes at signalized intersections. They considered a 5-month period in the before and after studies at 106 signalized intersections. Their findings revealed that there has been a statistically insignificant decrease in vehicle-pedestrian crashes but there was a significant decrease in all crashes (pedestrian and vehicle involvement). Moreover, studies conducted by Markowitz et al, 2006, considered a 21-month before and after study period at 14 signalized intersections. Their study results showed that, pedestrian countdown signals reduce pedestrian crashes and injuries. In addition, they found that pedestrian countdown signals reduced the number of pedestrians who complete crossing on red signal.

A report by Singer et al (2005) on pedestrian countdown signals enumerated both types of studies that were carried out during the period (laboratory and observational). The studies did not show any signs of pedestrian safety being compromised. However, their study showed that, older pedestrians are likely to be the greatest beneficiaries to the countdown signals. Finally, a report by Van Houten et al (2012) was aimed at evaluating the impact of new pedestrian countermeasure installations on pedestrian safety. The results revealed that both drivers and pedestrians had issues with how to respond to pedestrian hybrid beacons and rectangular rapid flashing beacons (RRFB). However, a statistical analysis on crash data at pedestrian countdown signals showed reduction in crashes, hence an improvement in pedestrian safety.

2.4 Fluorescent Yellow Sheeting on Warning Signs

According to research at University of South Dakota, the amount of time for an older driver to react before a difficult situation can be improved by using brighter sheeting materials such as fluorescent yellow signs. Fluorescent signs can be detected easier than non-fluorescent signs. This benefits all driver groups, and more specifically older drivers. Also, the fluorescent signs have been found to benefit pedestrians and bicyclists by improving conspicuousness of warning signs (Amparano, 2010). Research carried on evaluating the safety impacts of the countermeasure are presented in this section as follows.

In 2000, Eccles and research group in North Carolina University evaluated the countermeasure in order to study safety impacts of the retro-reflective materials. Fluorescent yellow warning signs were evaluated in different hazardous sites in order to see improvements offered to drivers in a selected area. A before and after study was developed in order to evaluate the effectiveness of the installation in different locations. She concluded that the countermeasure increases safety at highly hazardous locations such as reducing the number of non-stopping vehicles. Therefore it was recommended to use Fluorescent Yellow Sheeting in warning signs, mainly in hazardous areas. Since the study summarized involved only hazardous locations, it was also recommended to develop the same study in other locations for broader safety impacts of the countermeasure.

In a similar study in Texas, Gates (2003) 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 a 38 and 11 percent decrease in edge line encroachment and excess in speed limits, respectively. It was noticed that a 20 percent increase in vehicles started 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. A statewide implementation of fluorescent yellow micro-prismatic sheeting for fluorescent yellow Chevrons was recommended. Also, if installations of Fluorescent yellow chevrons are to occur in a specific location, all of the existing chevrons should be replaced.

Moreover, by including drivers' interviews, Jenssen (1998) in Norway evaluated the effectiveness of the implemented yellow sheeting by using before and after studies. 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. Furthermore, Schieber (2002) performed a laboratory experiment (Inattention Paradigm) to observe effects of Fluorescent Yellow Sheeting in drivers in South Dakota. Results showed improvement in "search conspicuity" but not necessarily in 'attention conspicuity." Also, it was found that performance curve of fluorescent yellow signs were almost identical to other fluorescent colors tested.

2.5 Arrow-Per Lane on Diagrammatic Signing

Since the construction of the US interstate highway system in the latter half of the 20th century, various guidance signs have been needed to help the motorist navigate through the expansive network. The need to deliver accurate and pertinent information to drivers as they pass a sign at higher speeds has focused attention on the efficiency and effectiveness of guidance signs and potential methods for improving their performance. Over the years, several studies have been conducted to assess the performance of a range of different guidance signing schemes, including diagrammatic guidance signs. While overall results have been mixed, diagrammatic guidance signs provide some benefits to motorists over more traditional text based signs.

Citing a lack of sufficient field tests, Kolsrud (1971) conducted a before and after field study in 1971 to compare standard and diagrammatic guidance signing. The periods were separated by a full year to help account for temporal changes in traffic flow. Several measures of effectiveness were derived from a questionnaire administered to drivers and data collected at the study interchanges. Some of the main measures of effectiveness included, "lane changing movements, lane placement, speed differences, and short headways". The author concluded that during the rush hour periods, diagrammatic signing provided no substantial benefit over the existing signing schemes. However, while it was not statistically significant, she did note a slight improvement in traffic performance during non-rush hour periods. Additionally, improvements in traffic performance were identified at the left hand exit interchange used in the study. Despite the lack of statistically significant improvement over the conventional signing, 93 percent of survey participants gave the diagrammatic signing a higher rating than the conventional. Additionally, 76 percent found them to be considerably more helpful than existing signage with an additional 17 percent finding them to be at least somewhat more helpful.

One of the earlier studies conducted in this area considered the use of diagrammatic guidance signs at several different types of interchanges (Shepard, 1974). The first, located in Petersburg, VA, was an interstate split. The second was located in northern Virginia and was selected due to its high volumes and two drop lanes within close proximity to each other. The third and final interchange was located in Chesapeake, Virginia and was selected due to its unique geometry, as there was both an interstate split and a major arterial exit. The study consisted of laboratory and field portions with all three interchange geometries studied in the laboratory and the first of the three studied in the field. Participants of the lab portion were shown film of the interchange and asked to select the lane required to reach a particular destination. Various diagrammatic signs were compared against the standard diagrammatic guidance signs with the participants' reaction time and number of correct responses recorded for analysis. At the first interchange, all three of the diagrammatic variations resulted in shorter reaction times than the existing guidance signing. The number of correct responses varied for each signing scheme depending on their location along the interchange approach. The existing guidance signs generally performed well, as did the second and third of the three diagrammatic signing schemes.

The second interchange saw similar results, with the existing guidance signs resulting in higher reaction times than the diagrammatic guidance signs. Each of the four signing schemes performed similarly to one another, with some variation depending on their location along the interchange approach. The final interchange also saw lower reaction times for the diagrammatic guidance signs as compared to the existing, but was only statistically significant at one of the locations tested along the approach. The numbers of correct responses recorded for each signing scheme at the two approach locations were mixed.

Overall, the diagrammatic signing resulted in lower reaction times than the conventional signing 21 out of 25 times, although only four of the 21 were statistically significant. When considering the number of correct responses the results were more mixed. In only nine of the 25 comparison tests did the diagrammatic signs results in a higher number of correct responses. Four of the comparison tests showed equal correct response rates with the remaining 12 identifying the existing signing as producing the most correct responses. The field portion of the study consisted of a before and after analysis at the first interchange using counts of erratic maneuvers as a primary measure of effectiveness. Using several statistical analyses, at a 90% confidence level, the authors found no statistically significant difference between the before and after periods. That being said, weaving maneuvers declined in the majority of cases. Despite this, and largely based on the results of the laboratory portion of the study, diagrammatic signs were recommended for each of the three interchange types.

Restricting the type of interchanges for diagrammatic guidance sign tests, Fred Hanscom conducted research in 1971 to study problems associated with high-speed interchanges. He identified several factors which could contribute to the complexity of an interchange, including closely spaced interchanges, high travel speeds, and a wide variety of exit configurations. In addition to the aforementioned factors, he identified the type of guidance signing as having a role in interchange traffic flow. To test this, he conducted a before and after study with standard and diagrammatic guidance signs and used the number of erratic maneuvers as a measure of effectiveness. He further separated erratic maneuvers into weaving, hesitation, stopping/backing, and partial weaving. Upon analysis of the results, he determined that there were fewer weaving maneuvers across the gore, which suggested safer traffic operation after the installation of the diagrammatic guidance signs.

Due to the relatively short length of the study period, the author noted increased tourist traffic present during the after period. To account for this he limited the analysis period to two days before and after the sign installation. When analyzing this truncated dataset Hanscom (1971) noted reductions in all types of erratic maneuvers after the diagrammatic guidance signs were installed.

The Federal Highway Administration (FHWA) has proposed changes to the standard statement to specify a specific design for diagrammatic signs. The diagrammatic sign is to consist of an up arrow per lane symbol, including the appropriate use of EXIT ONLY sign panels. This is the clearest and most effective method of displaying to road users the essential information about the proper lane use to reach their destinations. The FHWA states that the diagrammatic signing consisting of dotted lane lines on a single arrow shaft is too subtle to be easily recognized and understood by many road users, especially older drivers (Federal Register, 2008). This recommendation is consistent with the recommendation made in the *2001 FHWA Highway Design Handbook for Older Drivers and Pedestrians*. In the handbook, FHWA recommends that the diagrammatic guide signing should consist of upward arrows matching the number of lanes on the roadway (Staplin et al., 2001).

As evident from a number of studies, the type of interchange in question plays an integral role in determining which type of sign is best suited for providing information. The NCHRP conducted a study to look specifically at signing issues for two-lane exits with an option lane. This study also compared diagrammatic, arrow-per-lane, and standard guidance signs. They too used a driving simulator to determine the performance characteristics of each sign type using 96 participants. The measures of effectiveness identified for the study included the number of missed destinations, unnecessary lane changes, needed lane changes made close to the gore, the distribution of lane changes, the certainty of the driver about their lane choice, and the driver's opinion of the difficulty of the sign to understand. Overall the researchers did not find statistically significant differences in the performance of the sign types considered. That being said, they did note that drivers testing the diagrammatic guidance signs tended to make necessary lane changes sooner along the interchange approach. However they cautioned that this may have been due to chance effects.

After the driving simulator portion was completed, each participant answered a questionnaire. Of particular note were responses to two questions regarding the driver's confidence in their lane choice and the readability of the sign in question. The researchers found that the standard MUTCD and diagrammatic advanced guidance signs performed similarly, and both performed better than the other sign types being tested. In terms of a sign's legibility and comprehension, the standard MUTCD signs drew the highest ratings with the diagrammatic guidance signs following close behind. Ultimately the authors concluded that the best sign type for this particular type of interchange was a combination of the MUTCD advanced guidance signs and the Type II lane designation signs (Upchurch et al., 2004).

In a related study, drivers' comprehension of various guidance signing schemes were evaluated to determine which type performed the best. Again, arrow-per-lane (referred to as "modified diagrammatic" in the study) and diagrammatic guidance signs were tested against more conventional signs. The authors here conducted tests in several phases using both PowerPoint presentations of various guidance signs as well as a driving simulator.

Based on the results of the initial phases, the research made several recommendations for guidance signing. For left exit interchanges they recommend the use of standard MUTCD diagrammatic signs. For left lane drops, they found the modified diagrammatic signs performed better than other sign types. When considering right exit optional signs they again recommended the use of modified diagrammatic signs. Lastly, when considering freeway to freeway splits, their results suggested use of the current Texas standard signs as sufficient and potentially less expensive to produce than the larger diagrammatic guidance signs. In general, participants in the study, and specifically the driving simulator portion, preferred the diagrammatic signs over their text based counterparts. This was despite the fact that text base signs tended to perform equally well and better in some cases than diagrammatic signs. Additionally, the diagrammatic signs received more positive feedback from participants than their arrow-per-lane counterparts (Chrysler et al., 2007).

In 2008, researchers at the Turner-Fairbank Highway Research Center completed a study which compared the current standard diagrammatic signing to modified and arrow per lane guidance signs. They also considered the impacts of different geometric configurations including left and right exits, the number of exiting lanes, and the presence of option lanes. During the study, research participants were shown various guidance signs and given a target destination. Each participant then selected the lane they would select to reach said destination. The measures of effectiveness used for the study were the distance from the sign each participant made their decision as well as whether or not they made the correct lane choice. Of particular interest is the performance of the arrow per lane guidance signs which saw improved performance rates for older drivers specifically. As would be expected, the older drivers had to be closer to the guidance signs than younger drivers before making a lane choice decision. The average decision distance for an older driver was 24% closer to the sign than the average younger driver. In addition, older and younger driver decision distance was significantly improved for arrow per lane guidance signs versus the other sign types considered. Despite these improvements in sight distance, older drivers made more lane choice errors than the younger group of drivers with correct response rates of 70 and 87 percent, respectively. Arrow per lane guidance signs produced statistically significant increases in the number of correct responses for older drivers but produced similar response rates for younger drivers. Despite these improvements, the presence of option lanes at the interchange tended to reduce the magnitude of the improvements. Figure 2.3 illustrates the differences in lane choice performance by age group, sign type, and option lane presence.

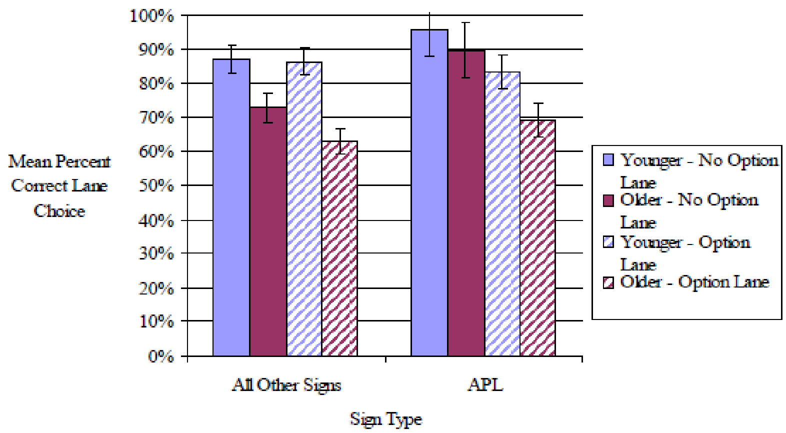

Figure 2.3 Lane choice by sign type, presence of an option lane and age group (Source: Golembiewski et al., 2008)

The other geometric characteristics were not found to have a significant effect on the performance of correct lane choices. The authors concluded that while arrow per lane guidance signs benefited all drivers in terms of improved guidance information, older driver performance improved to an even greater degree. They also recommend increasing font size to improve sight distance and conducting further research in the field to supplement their laboratory study (Golembiewski et al., 2008).

As noted in research conducted by Fitzpatrick et al. in 2013, the driving task can be subdivided into three parts; control, guidance, and navigation. Depending on the specific scenario, each task may require more or less of the driver's attention, which may in turn affect the resources they can devote to the other two. As such, it is important that guidance signs convey as much necessary information in a way that is easy to identify and comprehend as possible. This particular study identified several factors associated with the delivery of information to the driver. These include the level of uniformity of information provided to the driver, the uniformity of the roadway itself, the ability of the driver to detect the presence of the sign, the amount of information being presented to the driver and the time taken to read it, and the overall usefulness of the sign itself. Problems associated with any one of these factors may hinder the driver in reading and understanding the sign and hamper their ability to make any necessary changes to their route. For this study, the authors compared the performance of two types of signs, arrow-per-lane (Figure 2.4) and diagrammatic sign (Figure 2.5).

Figure 2.4 Arrow-Per-Lane Guidance Sign

To test their performance the authors conducted a simulation study using 42 participants across a range of age and educational groups. They tested several different scenarios and found that each sign type performed better than the other depending on the specific interchange geometry. The arrow-per-lane signs tended to produce better results when two exits were closely spaced with each other, while they both performed similarly well when option lanes were present. (Fitzpatrick et al., 2013).

Figure 2.5 Diagrammatic Guidance Sign

3 Survey of Michigan Drivers

3.1 Introduction

The main objective of the survey was to identify perspective and benefits of identified engineering improvements for older drivers. In order to compare preferences by the 65yrs-and-older drivers to other drivers, the survey targeted all drivers. The survey was conducted by interviewing licensed Michigan drivers at restaurants, senior centers and grocery stores, rest areas, and welcome centers.

3.2 Survey Design and Administration

The survey was intended to observe the preference of Michigan drivers between the engineering improvements (countermeasures) and their corresponding standard designs. Each interviewee was presented with pictures showing the implemented countermeasure as option one and the standard installation as option two. A rating system in a scale of 1 to 3 (1 = low; 2 = medium; 3 = high) was used to identify driver preferences between the countermeasures and standard installation in different situations. Participants had the opportunity to select neutral or not applicable (N/A) option if they believed that they did not prefer one design over the other or the countermeasure presented was not applicable to them, respectively. The field survey was administered in four metro areas in Michigan: Kalamazoo, Grand Rapids, Lansing and Detroit. Four types of facilities were surveyed within each metro area: restaurants, grocery stores, senior centers and rest areas. These locations were randomly selected according to the following criteria: application of countermeasure in the area, higher population of the 65yrs-and-older, and high number of crashes for the same group of population. Using the aid of Google Earth, facilities were identified with their geographical information using the pinning tool of the program. The target sample size was 1,500 drivers, constrained by availability of resources.

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. Prior to showing pictures and asking detailed questions, participants were asked for general information such as gender, race, age group (16-24; 25-34; 35-49; 50-64; 65-74; 75-84; 85+), and home zip code. If the participant was not a driver the interview was not conducted. Each question in the survey reflected the area where the countermeasure is expected to improve the driving experience. The full survey questionnaire and results are presented in Appendix 3.1. In order to distinguish the preferences, the participants were asked to state if they have noticed the difference between the countermeasure and standard installations being presented to them while driving in the field prior to the survey day. This was important to distinguish between preferences stated based on the pictures presented and those stated based on field experience.

3.3 Analysis of Survey Data

After processing the data, statistics were estimated from interviewees who have noticed the difference in installations prior to the survey. Descriptive statistics and chi-squares tests were the main methods to classify perception of participants and the strength of their preferences. A sample of 1,590 drivers, which is greater than the target, was interviewed. Surveys were distributed as evenly as possible across the four metropolitan areas. Table 3.1 presents the total number of participants per metro area. The survey participants who noticed the countermeasure before the interview were considered as a subgroup for the purpose of analysis.

Table 3.1 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**

3.3.1 Clearview Font on Guide Signs

For Clearview font on guide signs, participants were asked to identify which sign is easier to read in the four situations (on high speed roads, from far distances, in inclement weather, and in night time), and how they would rate its legibility. Figure 3.1 presents the preferences between the countermeasure and standard installation on high speed roads by those who had noticed the differences before (while driving) and those who never noticed the difference before. Most participants preferred Clearview fonts on guide signs, regardless of whether they had noticed the differences in the field before the interview day or not. Also, there was no statistical significant difference in preferences by the 65yrs-and-older drivers and all drivers.

Clearview Font – on high speed roads

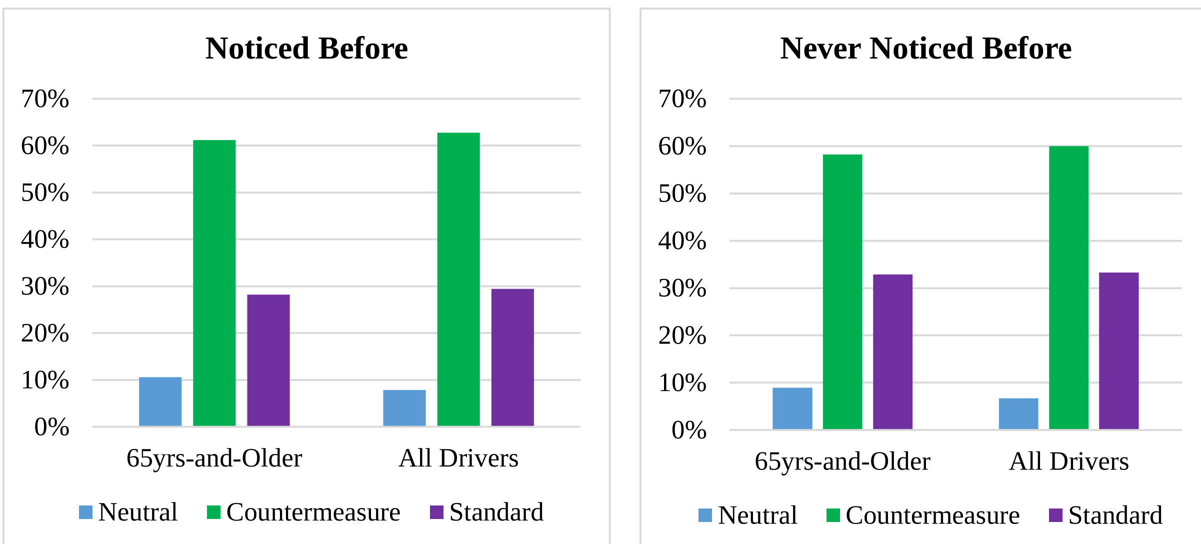

Figure 3.1 Preference of Clearview fonts on high speed roads

Figure 3.2 shows that drivers of all ages prefer Clearview font signs from far distances. There is no significant difference between the preference by the 65yrs-and-older drivers and all drivers.

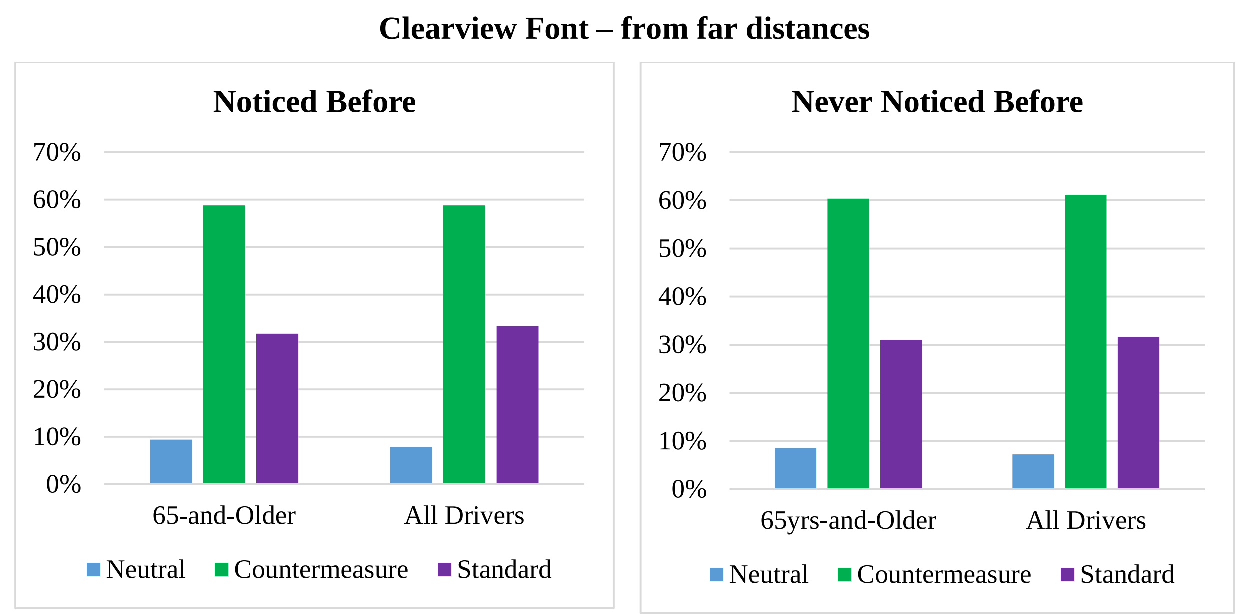

Figure 3.2 Preferences of Clearview fonts from far distances

Figure 3.3 shows that nearly 60 percent of both the 65yrs-and-older drivers and all drivers who had noticed the difference between Clearview font sign and the standard preferred the Clearview font in inclement weather. Those who had not noticed the difference before also think that the Clearview font increases legibility of the sign in inclement weather. The results indicated that there is no significant difference between the preferences by age groups.

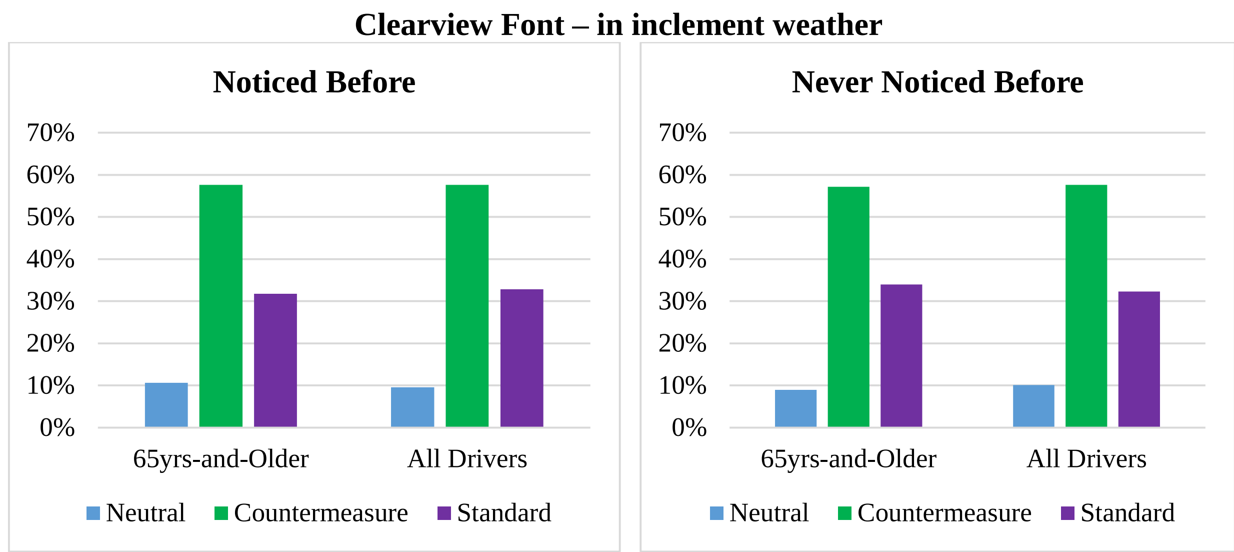

Figure 3.3 Preferences for Clearview fonts in inclement weather

Figure 3.4 shows perception of drivers regarding Clearview font signs in night time. The results show that the Clearview fonts are preferred by the 65yrs-and-older drivers and all drivers compared to the standard. Both drivers who had noticed the difference in field and those who had not noticed the difference in field preferred the Clearview font. Detailed analysis showed that the preference of Clearview font was even higher (75 percent) for the drivers age 85 and above.

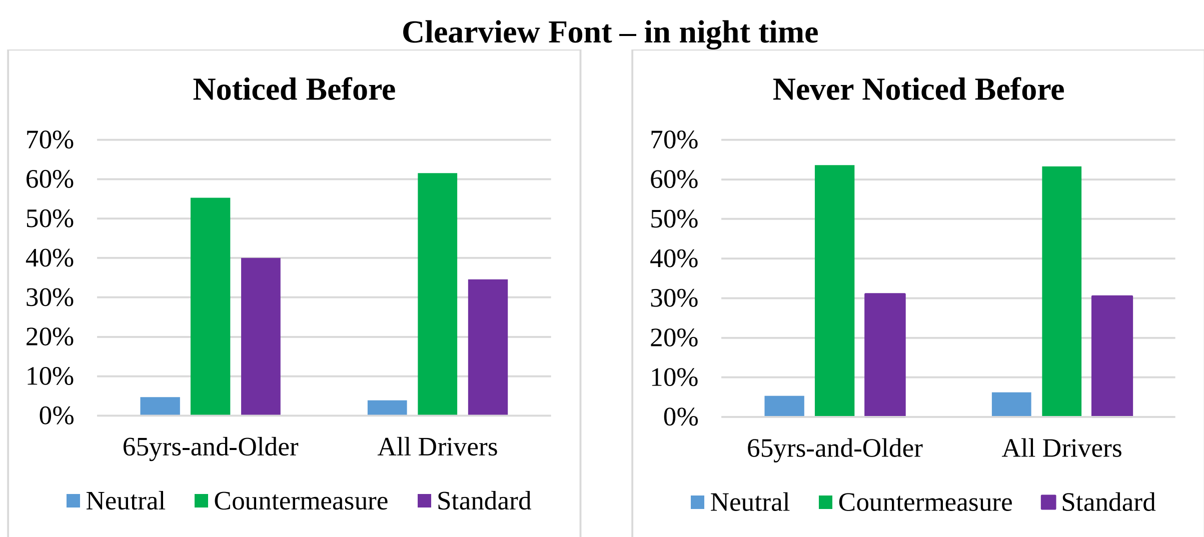

Figure 3.4 Preferences for Clearview fonts in night time

3.3.2 Pedestrian Countdown Signal

Participants were asked to rate the pedestrian countdown signal against the standard pedestrian signal in the following situations:

- Deciding whether to start crossing or not
- Adjusting walking speed
- Increasing my feeling of safety while crossing

Figure 3.5 presents the results on helpfulness of pedestrian countdown signal when deciding to start crossing or not. As expected, and consistent with other studies, more than 90 percent of participants who have noticed the difference between pedestrian countdown signal and standard pedestrian signal stated that they prefer the pedestrian countdown signal. On the other hand, about 85 percent of those who revealed that they had not noticed the difference between pedestrian countdown signal and standard signal thought that the pedestrian countdown signal would be helpful when deciding to start crossing or not.

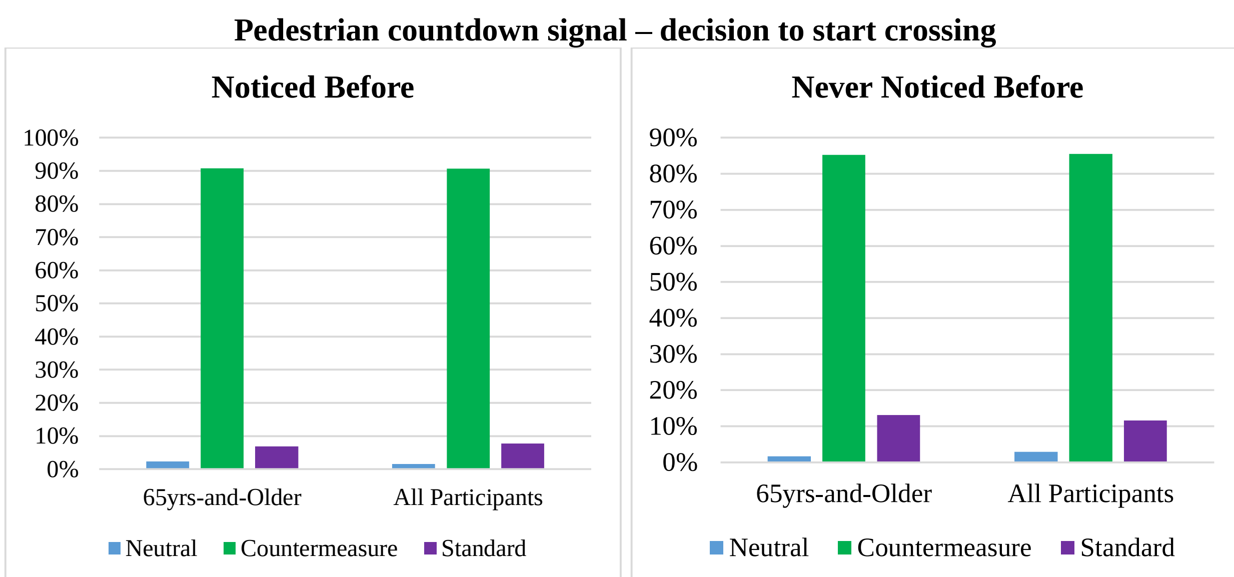

Figure 3.5 Preference of pedestrian countdown signal in decision to start crossing

Figure 3.6 presents the results on helpfulness of pedestrian countdown signal for adjustment in walking speed while crossing. Slightly more than 90 percent of participants who have noticed the difference between pedestrian countdown signal and standard pedestrian signal stated that they prefer the pedestrian countdown signal. Similarly, about the same percent of those who revealed that they had not noticed the difference between pedestrian countdown signal and standard signal thought that the pedestrian countdown signal would be helpful in adjustments in walking speed while crossing. Significant difference was not achieved across age groups.

Pedestrian countdown signal – Adjustment in Walking Speed

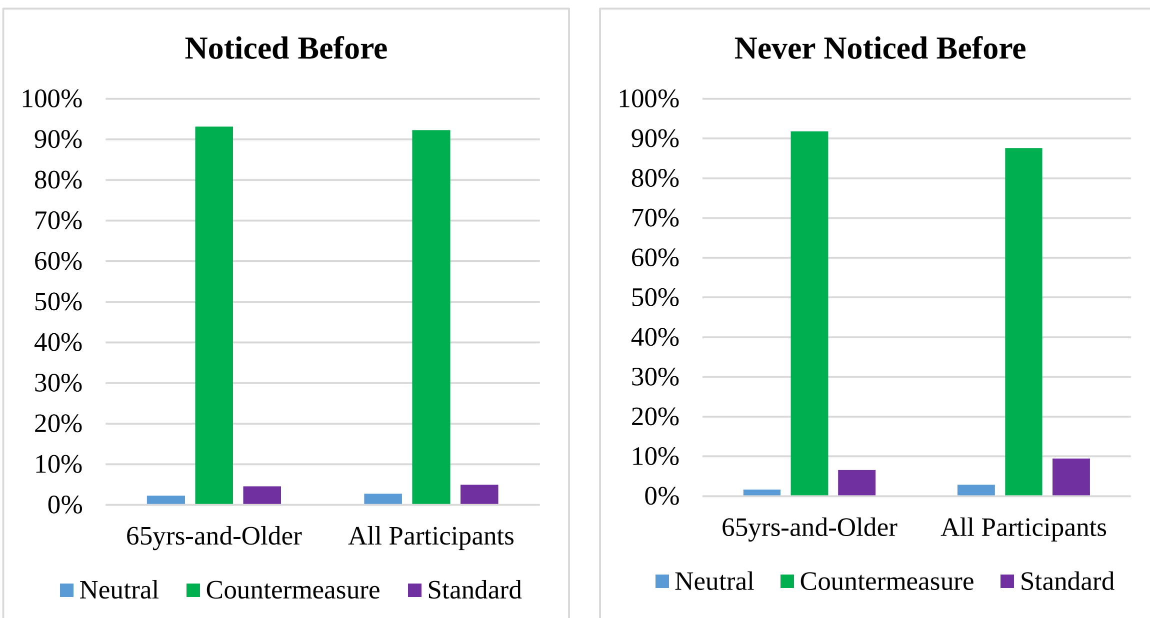

Figure 3.6 Preference of pedestrian countdown signal in adjustment of walking speed

Figure 3.7 shows the results on helpfulness of pedestrian countdown signal in increasing the feeling of safety when crossing the street. Similarly to the case of deciding whether to start crossing the street or not, approximately 93 percent of participants who have noticed the difference between pedestrian countdown signal and standard pedestrian signal stated that they prefer the pedestrian countdown signal. The group that reported not having noticed the countermeasure before was less prone to consider that pedestrian countdown signals against standard pedestrian signals would be helpful in increasing the feeling of safety. Significant difference was not achieved across age groups.

Pedestrian countdown signal – Increasing Feeling of Safety

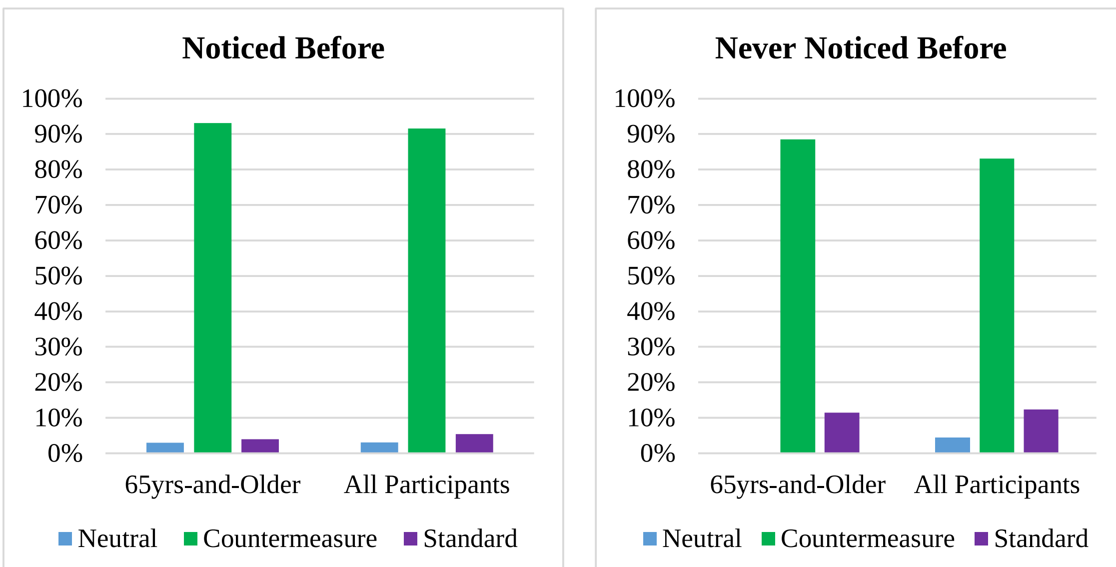

Figure 3.7 Preference of pedestrian countdown signal in increasing feeling of safety

3.3.3 Fluorescent Yellow Sheeting

For Fluorescent Yellow Sheeting, participants were asked to identify which yellow sheeting for warning signs is easier to recognize in the three situations (on high speed roads, in inclement weather, and in night time), and how they would rate it. Figure 3.8 presents the preferences between the countermeasure and standard installation on high speed roads by those who had noticed the differences before (while driving) and those who never noticed the difference before. It is evident that most participants preferred the Fluorescent Yellow Sheeting on warning signs (by more than 70 percent), regardless of whether they had noticed the differences in the field before the interview day or not. Also, there was no significant difference in preferences by the 65yrs-and-older drivers and all drivers.

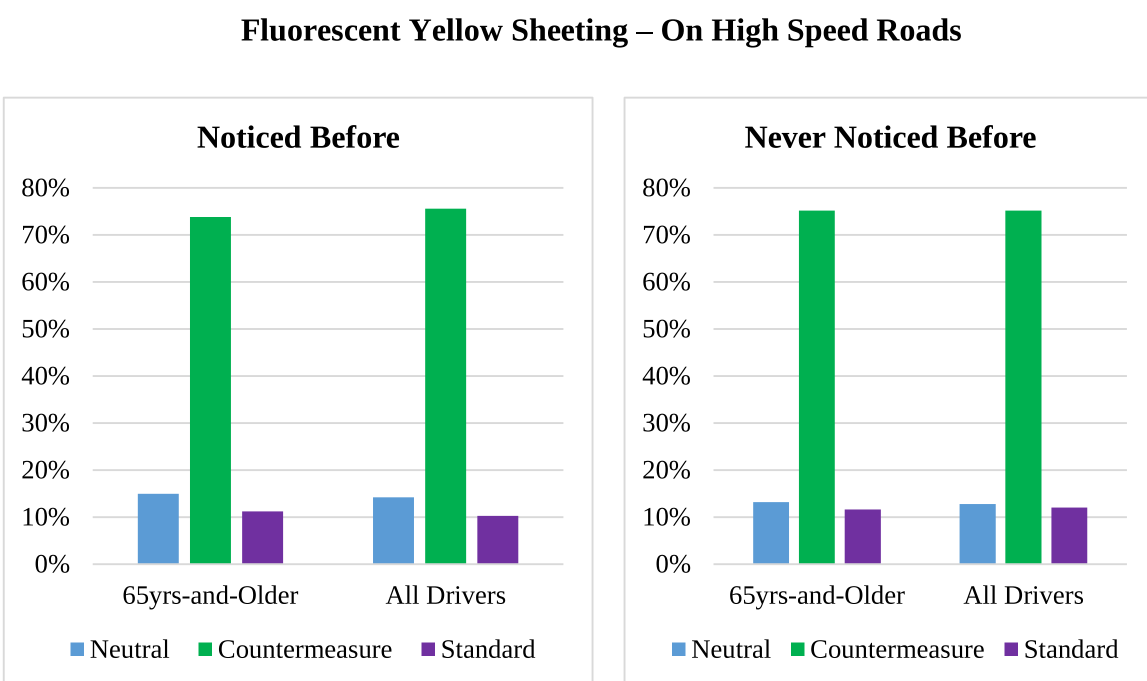

Figure 3.8 Preference of Fluorescent Yellow Sheeting on high speed roads

Figure 3.9 presents that nearly 80 percent of both the 65yrs-and-older drivers and all drivers who had noticed the difference between Fluorescent Yellow Sheeting and the standard, preferred the Fluorescent Yellow Sheeting in inclement weather. Those who had not noticed the difference before also with the same proportion (approximately) thought that Fluorescent Yellow Sheeting increases the recognition of the material in inclement weather. The results indicated that there is no significant difference between the preferences by age groups.

Fluorescent Yellow Sheeting – In Inclement Weather

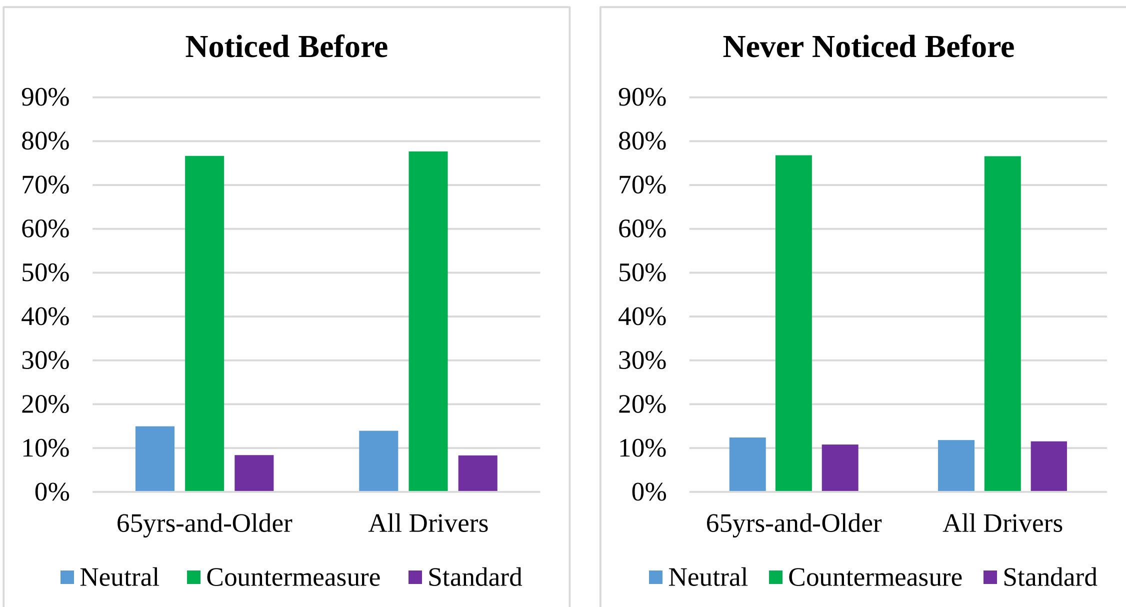

Figure 3.9 Preference of Fluorescent Yellow Sheeting in inclement weather

Figure 3.10 presents the perception of drivers regarding Fluorescent Yellow Sheeting in nighttime. The results show that the Fluorescent Yellow Sheeting is preferred by the 65yrs-and-older drivers and all drivers compared to the standard. Both drivers who had noticed the difference in field and those who had not noticed the difference in field preferred the Fluorescent Yellow Sheeting. This finding might be supportive of past research where the Fluorescent Yellow Sheeting benefited the elderly drivers the most during nighttime.

Fluorescent Yellow Sheeting – In Nighttime

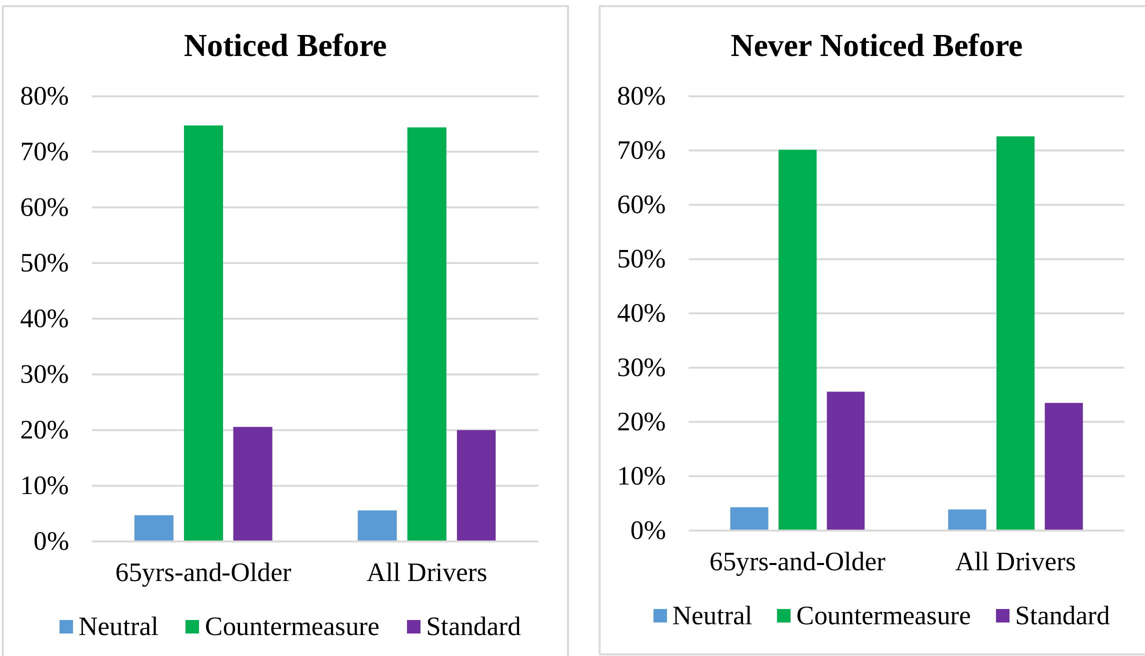

Figure 3.10 Preference of Fluorescent Yellow Sheeting in nighttime

3.3.4 Lane Use Arrows

Participants were asked to identify which directional guide sign is easier to recognize in unfamiliar areas and far distance of the sign, and how they would rate it. This is the case for lane use arrows for diagrammatic signing. Figure 3.11 shows the preferences between the lane use arrows and standard installation in unfamiliar areas by those who had noticed the differences before (while driving) and those who never noticed the difference before. It is clear that most participants preferred the countermeasure regardless of whether they had noticed the differences in the field before the interview day or not. No significant difference was found in preferences by the 65yrs-and-older drivers and all drivers.

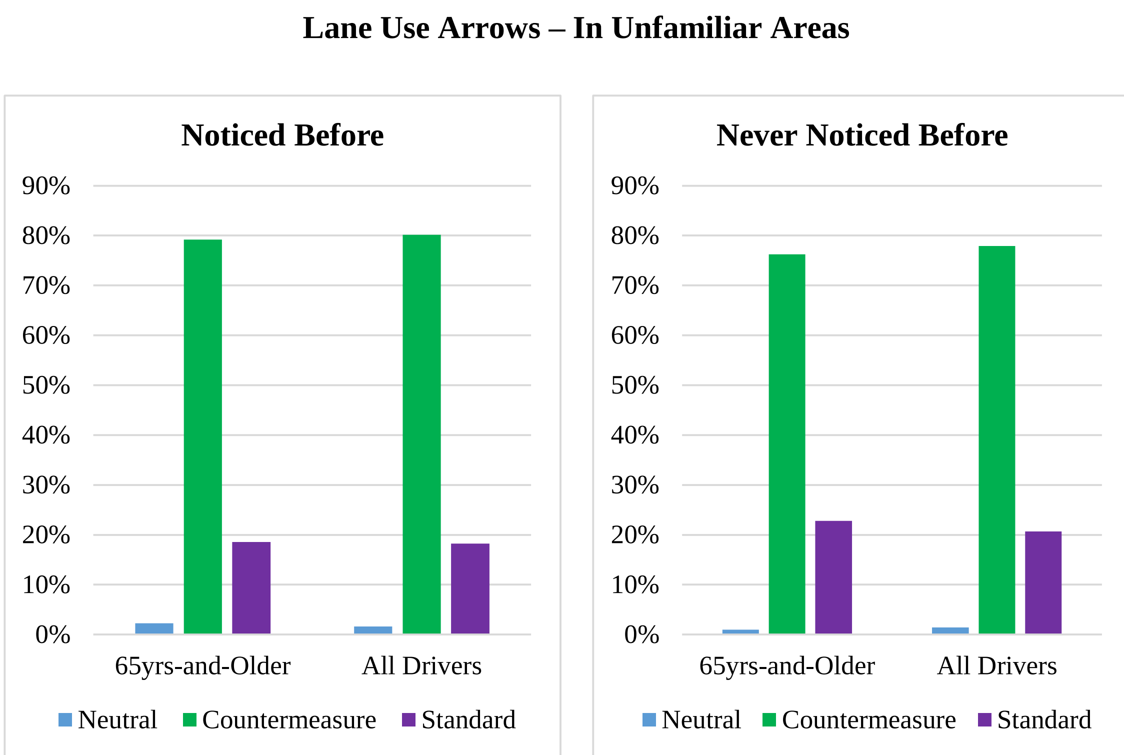

Figure 3.11 Preference of lane use arrows in unfamiliar areas

Figure 3.12 presents that drivers of all ages prefer the countermeasure from far distances. Among those who noticed the countermeasure before, 65yrs-and-older presented a slightly higher percent of preference for the lane use arrows against the standard than all drivers. However, there is no significant difference between the preference by the 65yrs-and-older drivers and all drivers.

Lane Use Arrows – From Far Distances

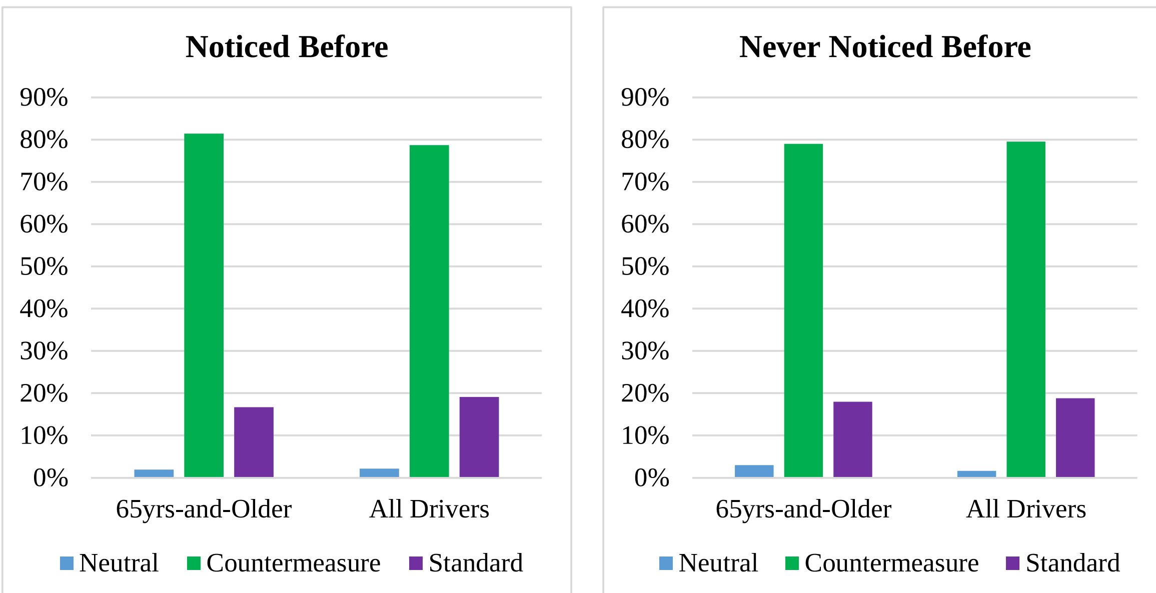

Figure 3.12 Preference of lane use arrows from far distances

3.3.5 Box Span Signal Installations

There were two situations in which participants needed to rate the helpfulness of the box span signals: in finding the proper lanes and improving visibility when approaching the intersection. Figure 3.13 shows the preferences between box span signal and diagonal span signal installations when finding the proper lane at the intersection by those who had noticed the differences before (while driving) and those who never noticed the difference before. Accordingly, the diagonal span seems to be more helpful in finding proper lanes at the intersection among those who noticed the countermeasure before and those who did not noticed it before. We cannot report significant difference in preferences by the 65yrs-and-older drivers and all drivers.

Box Span Signals – In Finding the Proper Lanes

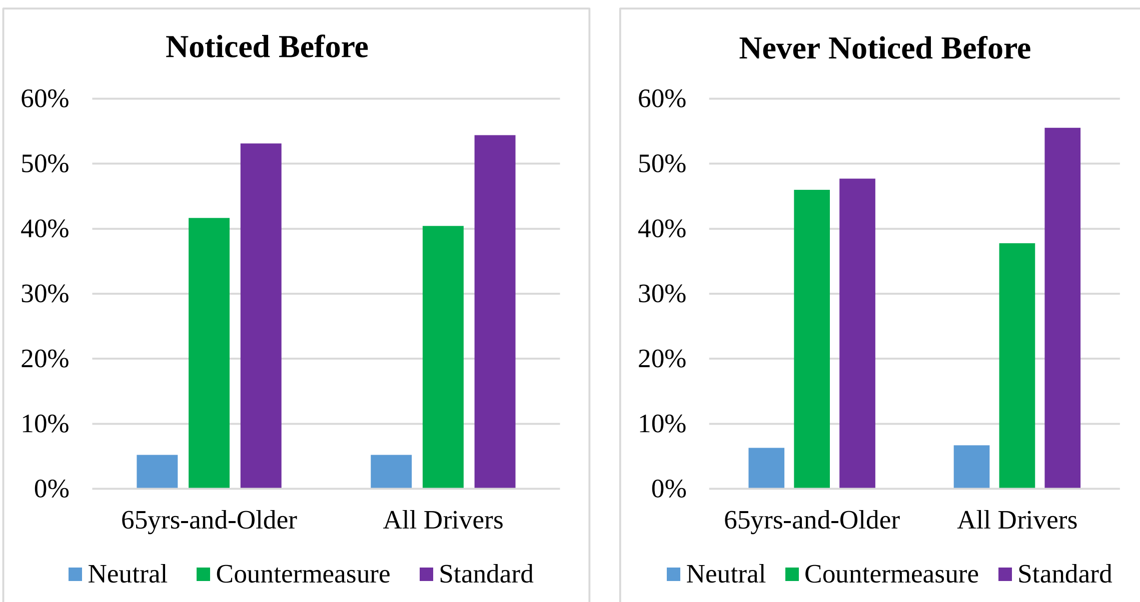

Figure 3.13 Preference of box span signals in finding proper lanes

Figure 3.14 shows the perception of drivers regarding box span signals in improving visibility. Similarly to the previous condition the diagonal span seems to be more helpful in improving visibility among all age groups of drivers. The preference for the standard installation is selected by both those who noticed the countermeasure before and those who did not notice it prior the interview. Less than 60 percent, however, thought that the diagonal span is more helpful than the box span in improving visibility overall. From the comments on the selection of the diagonal span drivers reveal that they are used to this installation and this draws them to select it.

Box Span Signals – In Improving Visibility

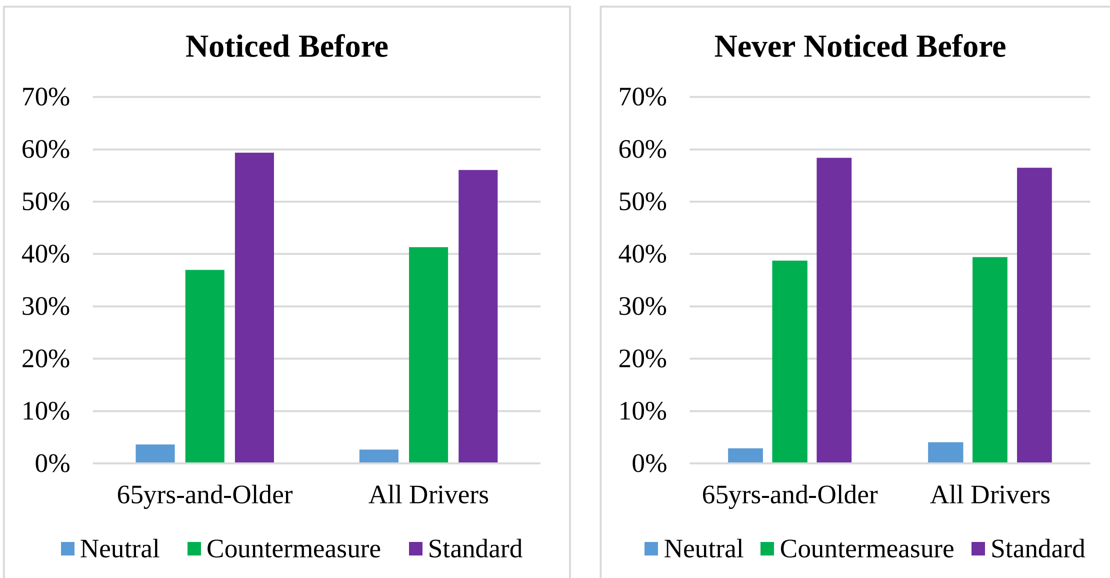

Figure 3.14 Preference of box span signal in improving visibility

In conclusion, the installed countermeasures are preferred by all drivers and those 65yrs-and-older, generally. The exception was on the box span signal installation. Most drivers thought the diagonal signal installation improved visibility of the signals and helped them find the proper lane better than the box span signal installation. It is also worth noting that evaluation of the effectiveness of box span signal installations on deterring red-light running may be necessary.

4 Data Collection

This chapter presents details on data collection for each countermeasure analyzed. While MDOT implemented Fluorescent Yellow Sheeting prior to adoption of the Clearview fonts, the two countermeasures have been installed together since adoption of Clearview font. As a result, it was impossible to collect individual data and conduct an independent evaluation of Clearview font on guide signs. Data on Clearview font and Fluorescent Yellow Sheeting is presented together. The data collection for the remaining countermeasures (i.e., box span signals, pedestrian countdown signals, and arrow-per-lane signs) is presented individually. Table 4.1 presents the type and sources of data collected in this study. A summary of all data collected is presented in this chapter, while detailed data, including data for drivers under 65 years, are included in Appendix 4.1.

Table 4.1 Type and source of data collected

Data Type	Data Collection Strategy and Source Used
Treatment Site Locations	Treatment sites identified by MDOT and provided to the research team.
Reference Site Locations	Sufficient similar reference sites were identified for each of the countermeasure.
Crash Data	Crash data were collected for each of the reference and treatment sites both before and after implementation.
Traffic Volume Data	Average Annual Daily Traffic (AADT) volumes were collected for each of the reference and treatment sites.
Geometric and operational characteristics	Basic geometric and operational characteristics were collected from MDOT's Sufficiency File and other online sources such as Google Earth Pro.
Implementation Dates	MDOT provided the locations and implementation dates for each treatment site.
Differential Costs	MDOT provided the differential costs between implementation of improvement and standard
Service Life of Countermeasures	MDOT provided service life for each countermeasure

4.1 Clearview Font and Fluorescent Yellow Sheeting (Freeways and Non-Freeways)

The Clearview font and Fluorescent Yellow Sheeting were both implemented in the same corridors on Michigan roads most of the time. However, there were corridors where only Fluorescent Yellow Sheeting was implemented in 2006. Beginning from 2007, both countermeasures have been implemented together. The corridors where MDOT implemented the countermeasures were divided into shorter segments consistent with the MDOT 2012 Sufficiency Files. The segments were grouped into three categories:

a. segments where none of the countermeasures have been installed (NN),
b. segments where only Fluorescent Yellow Sheeting has been installed (NY), and
c. segments where both Clearview font and Fluorescent Yellow Sheeting have been installed (YY).

Table 4.2 presents an example of the information provided by MDOT's corridors. The information in the table is an example of data for freeways and non-freeways.

Table 4.2 Example of MDOT's corridor data

Year	PR	PR_BMP	PR_EMP	PR_ Miles	Route	Clearview?	Fl. Yellow?
2008	859302	8.102	26.927	18.825	US-31	Y	Y
2008	857509	8.101	26.910	18.809	US-31	Y	Y
2008	1540402	7.130	25.934	18.804	US-31	Y	Y
2006	550606	15.092	27.460	12.368	I-75	N	Y
2006	550607	15.171	27.512	12.341	I-75	N	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
2005	3390106	8.145	21.138	12.993	US-131	N	N
2005	924504	0.000	12.608	12.608	I-69	N	N

Segments were extracted from MDOT's corridors using the Physical Reference number finder (PR FINDER) tool available on the MDOT's website. The site locates the Physical Reference Beginning Mile Point (PR_BMP) and Physical Reference Ending Mile Point

(PR_EMP) for a selected segment within the corridor. The location of the segment was identified in Geographic Information System (GIS) and shapefiles were created for integration with other geospatial data. Criteria for a segment to be included in analysis included length of the segment to be less than 5 miles for freeways and less than 8 miles for non-freeways; number of interchanges (for the case of freeways) or main intersections (for the case of non-freeways) to be less than or equal 2; and shape of the segment not to be with high rate of curvature. Figure 4.1 shows the distribution of potential segments for freeways and non-freeways, respectively.

Freeways **Non-Freeways**

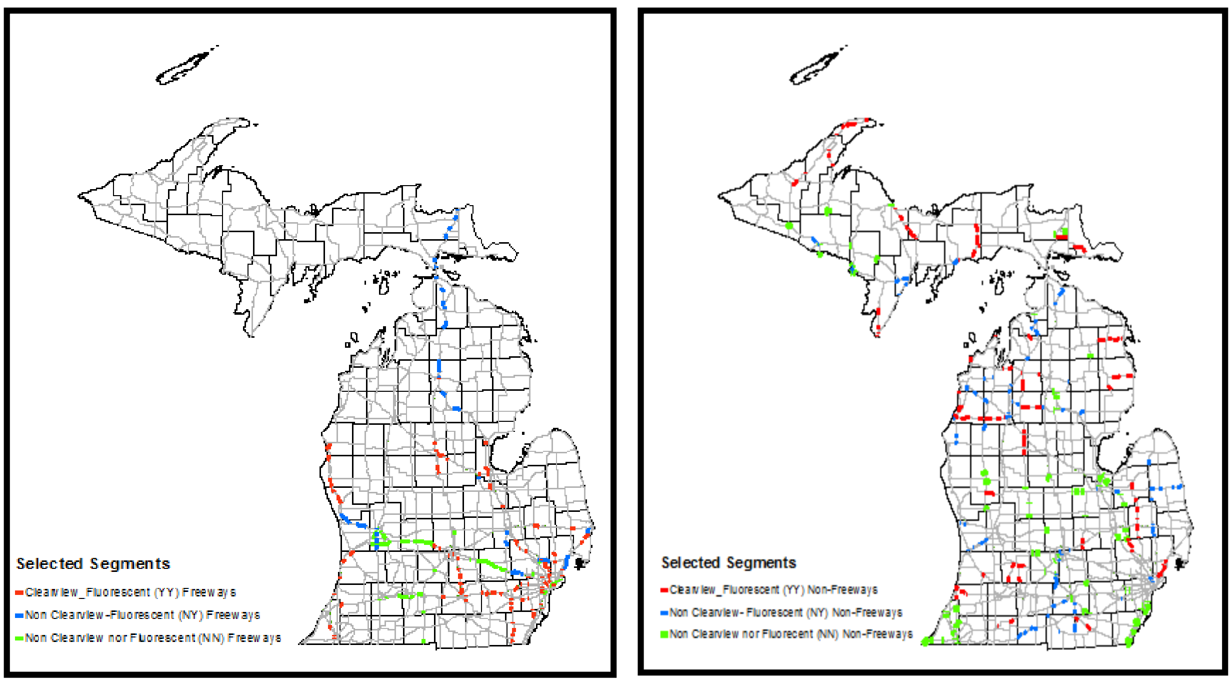

Figure 4.1 Distribution of potential segments for freeways and non-freeways

From the list of potential segments, the final list of sites for evaluation was obtained by removing segments with issues. These issues included the improvement year and implementation of multiple improvements. To conduct before-after analysis, at least two years of crash data before the implementation and two years in the after period was desired for each site. Crash data available was limited to 2004-2013, hence constraining selection of final segments to those improved were between 2006 and 2011. Also, it was found that the improvement of a number of segments was associated with implementation of multiple countermeasures (or additional improvements when the target countermeasure was installed). For example, Figure 4.2 shows a site where implementation of Clearview font sign was associated with installation of additional sign restricting trucks to use right two lanes. Such segments were removed from the sample size to avoid potential bias resulting from presence of extra improvement(s). Table 4.3 presents the final number of segments used for evaluation of Clearview font signs and Fluorescent Yellow Sheeting for both freeways and non-freeways.

Before Period **After Period**

Figure 4.2 Sample site with multiple improvements

Table 4.3 Summary of segments used for evaluation of Clearview font and Fluorescent Yellow Sheeting

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

Crash data were collected for three types of sites analyzed: NN, NY and YY. The NN sites were considered control or comparison sites since no improvement was done there. Treatment sites were NY and YY. Using the intersection by location tool in ArcMap 10.0, crashes were imported and intersected with selected segments. Crash data analyzed ranged from 2004 through 2013. In the case of non-freeways, crashes analyzed were those in the midblock areas of the selected segments, since intersection crashes were not in the scope of this study. In order to separate intersection crashes from those in the midblock, a circular buffer of 250 feet of radius was created at the end of each segment.

Using the GIS software (ArcMap) and statistical software (STATA), crash data was organized and merged with geometric characteristics obtained from the MDOT sufficiency files. Sufficiency files provided information about the geometric characteristics as well as geographical location of each segment. Segments were assigned a unique identified number to ensure consistency. PR numbers helped in locating selected segments within improved corridors provided by MDOT. There were ten crash conditions to be analyzed in this study: total crashes, fatal injury (KABC) crashes, total day crashes, total night crashes, total crashes for drivers under 65 years old, total drivers under 65 years day crashes, total drivers under 65 years night crashes, total 65yrs-and-older crashes, total 65yrs-and-older day crashes, and total 65yrs-and-older night crashes. Other characteristics such as length, Average Annual Daily Traffic (AADT), road type, speed limit, number of lanes, median type, and others were also collected from Sufficiency files. Verification of geometric characteristics was performed through Google Earth. Tables 4.4 through 4.6 present all variables considered for analysis and their descriptive statistics.

Table 4.4 Summary of Variables Considered for Analysis of Clearview font and Fluorescent Yellow Sheeting on Freeways

Variables	Variable Description	Min.	Mean	Max.	Std. Dev.
Length	Length of Segment (in Miles)	0.32	1.70	40.84	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	3,775	7,177	1,730
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

Table 4.5 Summary of Variables Considered for Analysis of Clearview font and Fluorescent Yellow Sheeting on Non-Freeways (Urban Areas)

Variables	Variable Description	Obs.	Min	Mean	Max	Std. Dev.
Avg. of Total Crashes	Average number of total (KABC) crashes observed (2004-2013)	92	0	12.20	64	13.84
Avg. AADT	Average of Annual Average Daily Traffic	92	2,897	12,355	32,050	6,952
Length	Length of Segment (in Miles)	92	0.23	1.01	4.46	0.73
Access Points	Total Number of Access Points within segment	92	0	11.01	65	10.71
Undivided MEDIAN	Median Type where : 1 = if present; 0 = Otherwise	92	0	0.79	1	0.41
Graded with Ditch	Median Type where : 1 = if present; 0 = Otherwise	92	0	0.11	1	0.31
Raised Island with Curb	Median Type where : 1 = if present; 0 = Otherwise	92	0	0.09	1	0.28
Flat (Paved & Unpaved)	Median Type where : 1 = if present;0 = Otherwise	92	0	0.01	1	0.10
Divided	Road Type where : 1 = if present; 0 = Otherwise	92	0	0.21	1	0.41
Two Travel Lanes with Center Left Turn Lane (CLTL)	Road Type where : 1 = if present; 0 = Otherwise	92	0	0.03	1	0.18
Four Travel Lanes CLTL	Road Type where : 1 = if present; 0 = Otherwise	92	0	0.27	1	0.45
One-Way Street System	Road Type where : 1 = if present;0 = Otherwise	92	0	0.07	1	0.25
Two-Way Undivided Road	Road Type where : 1 = if present; 0 = Otherwise	92	0	0.42	1	0.50
Level Terrain	Terrain of segment where: 1 if Level; 0 = otherwise	92	0	0.93	1	0.25
Rolling Terrain	Terrain of segment where: 1 if Rolling; 0 = otherwise	92	0	0.07	1	0.25
No Parking Allowed	Parking area where : 1 = if Not allowed; 0 = otherwise	92	0	0.95	1	0.23
Parking Allowed on one Side	Parking area where : 1 = if allowed on one side of segment ; 0 = otherwise	92	0	0.01	1	0.10
Parking Allowed on both Sides	Parking area where : 1 = if allowed on both side of segment ; 0 = otherwise	92	0	0.04	1	0.21
No Sidewalk	Sidewalk presence in segment where: 1 = if No sidewalk; 0 = otherwise	92	0	0.61	1	0.49
Sidewalk Present (One Side)	Sidewalk presence in segment where: 1 = if Sidewalk on one side; 0 = otherwise	92	0	0.15	1	0.36
Sidewalk Present (Both Sides)	Sidewalk presence in segment where: 1 = if Sidewalk on both sides; 0 = otherwise	92	0	0.24	1	0.43
No Non-Motorized	Non Motorize facility where : 1 = if No Non motorize facility; 0 = otherwise	92	0	0.91	1	0.28
Non-Motorized	Non Motorize facility where : 1 = if Non motorize facility; 0 = otherwise	92	0	0.09	1	0.28
Number of Lanes	Main number of lanes (through) in the segment	92	1	2.98	5	0.99
Lane Width	Predominant width of the traffic lanes for segment (in feet)	92	10	11.75	12	0.46
Speed Limit	predominant posted speed limit for segment (in mph)	92	25	45.11	55	8.58
Median Width	Main median width for divided segments (in feet)	92	0	13.13	33.61	196

Table 4.6 Summary of Variables Considered for Analysis of Clearview font and Fluorescent Yellow Sheeting on Non-Freeways (Rural Areas)

Variables	Description	Obs.	Min	Mean	Max	Std. Dev.
Avg. Number of Total Crashes	Average number of total (KABC) crashes observed (2004-2013)	100	1	10.35	48	9.81
Avg. AADT	Average of Annual Average Daily Traffic	100	60	4,876	13,005	2,886
Length	Length of Segment (in Miles)	100	0.36	3.25	13.37	2.53
Access Points	Total Number of Access Points within segment	100	0	9.36	44	7.32
Divided	Road Type where : 1 = if present; 0 = Otherwise	100	0	0.06	1	0.24
Two Travel Lanes CLTL	Road Type where : 1 = if present; 0 = Otherwise	100	0	0.04	1	0.20
Four Travel Lanes CLTL	Road Type where : 1 = if present; 0 = Otherwise	100	0	0.03	1	0.17
Two-way Undivided	Road Type where : 1 = if present; 0 = Otherwise	100	0	0.87	1	0.34
Undivided MEDIAN	Median Type where : 1 = if present; 0 = Otherwise	100	0	0.94	1	0.24
Graded with Ditch	Median Type where : 1 = if present; 0 = Otherwise	100	0	0.06	1	0.24
Level Terrain	Terrain of segment where: 1 if Level; 0 = otherwise	100	0	0.65	1	0.48
Rolling Terrain	Terrain of segment where: 1 if Rolling; 0 = otherwise	100	0	0.35	1	0.48
No Parking Allowed	Parking area where : 1 = if Not allowed; 0 = otherwise	100	0	0.98	1	0.14
Parking Allowed (both Sides)	Parking area where : 1 = if allowed on both side of segment ; 0 = otherwise	100	0	0.02	1	0.14
No Sidewalk	Sidewalk presence in segment where: 1 = if No sidewalk; 0 = otherwise	100	0	0.93	1	0.26
Sidewalk Present (One Side)	Sidewalk presence in segment where: 1 = if Sidewalk on one side; 0 = otherwise	100	0	0.02	1	0.14
Sidewalk Present (Both Sides)	Sidewalk presence in segment where: 1 = if Sidewalk on both sides; 0 = otherwise	100	0	0.05	1	0.22
No Non-Motorized	Non Motorize facility where : 1 = if No Non motorize facility; 0 = otherwise	100	0	0.94	1	0.24
Lane Width	Predominant width of the traffic lanes for segment (in feet)	100	11	11.61	12	0.49
Number of Lanes	Main number of lanes (through) in the segment	100	2	2.12	4	0.48
Speed Limit	Main posted speed limit for the segment in miles per hour (MPH)	100	25	55	65	6.71

4.2 Box Span Signal Installations

MDOT provided a list of 133 treatment locations with box span installations. All installations were made between 2006 and 2011. The locations were reviewed, and 117 locations were considered as treatment sites. Fifteen of the locations provided by MDOT were identified to be at median crossovers. These median crossover locations were removed from the study due to the geometric configurations and limited crash data. Other locations were removed due to lack of data. It has been identified that the list of box span installations provided by MDOT is not a comprehensive list of all locations. It has been assumed that these locations were either installed before 2006 or after 2011; therefore sufficient crash data does not exist.

Reference sites (locations with diagonal span installations) were chosen randomly. Aerial imagery and street view were utilized to compile a list of intersections that consist of diagonal span configurations on MDOT routes. A total number of 327 locations were identified in the entire state. Table 4.7 shows the breakdown of locations for each region. Within each region, a proportional number of reference sites were identified to match the treatment site locations for a total of 100 reference locations. Table 4.7 identifies the number of reference sites chosen from each region. The reference sites were selected randomly.

Table 4.7 Number of sites selected by region

Region	Treatment Sites	Reference Sites
University	30	25
Metro	26	23
Southwest	36	30
Grand	12	11
Bay	0	0
North	7	6
Superior	6	5
Total	117	100

Data that were collected for the treatment and reference site locations include: latitudinal and longitudinal points, crash data, geometric and operational characteristics, and implementation costs. Data collection summary is presented in the following Table 4.8.

Table 4.8 Data collection summary for box span signal installations

Statistics	Variables														
	Major Road AADT	Minor Road AADT	# of Thru Lanes on Major					# of Thru Lanes on Minor				Exclusive LT Lane on Major	Exclusive LT Lane on Minor	Exclusive LT Phase on Major	Exclusive LT Phase on Minor
			0	1	2	3	4	0	1	2	3				
Minimum	3,220	471													
Maximum	66,316	53,080													
Mean	18,476	7,094													
Frequency			1	40	46	5	8	6	78	12	4	77	65	11	7

4.3 Pedestrian Countdown Signals (PCS)

A total of 93 treated sites (44 on state roads and 49 on local roads) were selected randomly from a list of intersections with pedestrian countdown signals provided by MDOT. In addition, 97 comparison sites (48 on state roads and 49 on local roads) were selected randomly based on the AADT, geometric characteristic and land use characteristics of the treated sites. Installation dates of the pedestrian countdown signals for each intersection was obtained from MDOT. Geographic coordinates of these intersections were obtained using Google Earth Pro and Google search engine.

Crash data from 2004-2013 were collected for each of the treated and non-treated sites in the three years before and after period of installation of the pedestrian countdown signals using ArcGIS 10.0 with shape files made from Michigan crash records. Crashes were collected within 150 feet buffer radius as shown in Figure 4.3. Crash conditions considered in the analysis are as follows: total crashes (all severities), total crashes (fatal and injury), drivers 65yrs-and-older (all severities), drivers 65yrs-and-older (fatal and injury), total pedestrian (all severities), total pedestrian (fatal and injury), pedestrian 65yrs-and-older (all severities), and pedestrian 65yrs-and-older (fatal and injury). Crash data considered for pedestrian countdown signals is presented in Table 4.9.

Pedestrian Countdown Signals (PCS) Site and Crash Selection

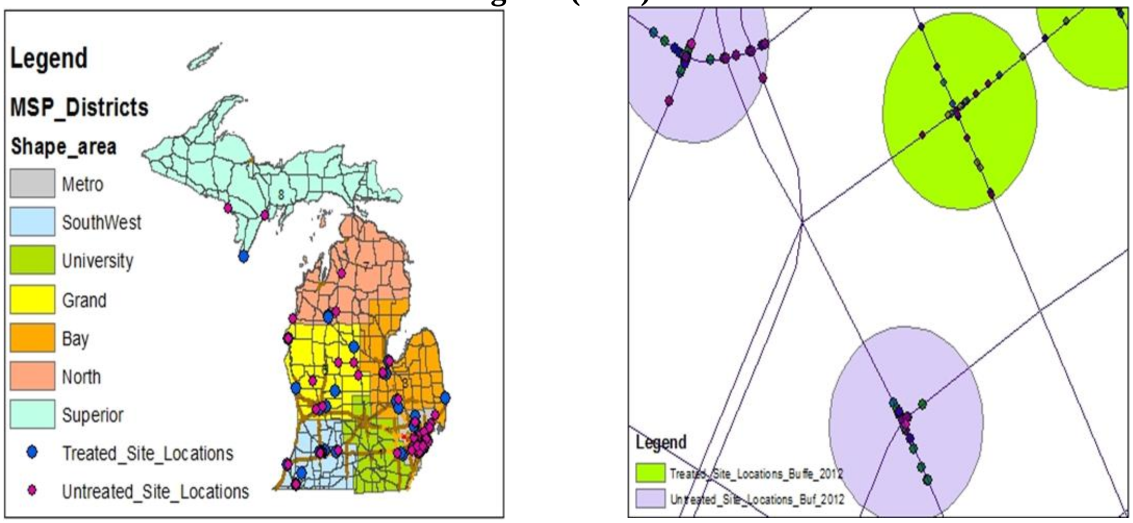

Figure 4.3 Distribution of sites with and without PCS (left) and 150ft buffer for data collection (right)

Table 4.9 Data Collection Summary for Pedestrian Countdown Signals (PCS)

NO	TYPE OF CRASH	PERIOD	TREATED SITES STATISTICS				UNTREATED SITES STATISTICS			
			Mean	Std. Dev.	Min.	Max.	Mean	Std. Dev.	Min.	Max.
1	Total Crashes	Before	11.312	9.218	1	44	11.474	8.829	0.67	34
	KABCO	After	9.849	10.521	0	62	10.311	8.774	0.67	50
2	Total Crashes	Before	2.484	2.22	0	10	2.395	1.996	0	8.67
	Fatal and Injury	After	2.247	2.796	0	16	2.269	2.098	0	11.33
3	Elderly Drivers 65yrs-and-older	Before	1.194	1.345	0	6	1.246	1.259	0	5.33
	KABCO	After	1.043	1.532	0	11	1.326	1.388	0	7
4	Elderly Drivers 65yrs-and-older	Before	0.183	0.416	0	2	0.209	0.344	0	1.33
	Fatal and Injury	After	0.129	0.423	0	3	0.321	0.454	0	2
5	Total Pedestrian	Before	0.312	0.551	0	3	0.158	0.297	0	1.67
	KABCO	After	0.183	0.441	0	2	0.147	0.268	0	1
6	Total Pedestrian	Before	0.247	0.503	0	3	0.139	0.26	0	1.33
	Fatal and Injury	After	0.495	0.775	0	4	0.115	0.241	0	1
7	Elderly Pedestrians 65yrs-and-older	Before	0.018	0.076	0	0.3	0.014	0.066	0	0.33
	KABCO	After	0.013	0.071	0	0.5	0.014	0.082	0	0.67
8	Elderly Pedestrian 65yrs-and-older	Before	0.018	0.076	0	0.3	0.014	0.082	0	0.67
	Fatal and Injury	After	0.013	0.071	0	0.5	0.01	0.076	0	0.67

4.4 Arrow-Per-Lane Signing

MDOT provided eight locations that have the arrow-per-lane signing installed in the state. A list of potential comparison sites, locations which have older versions of diagrammatic signing installed, was also provided for review. The list of potential comparison sites was reviewed and preliminary geometric data were collected for each site to better pair them with each treatment location. There were several pairings where precise matches were not possible however, and in each case the next best location was selected. Additional information for each of the paired sites were collected to facilitate a comparison during the before and after periods of the treatment sign installations as well as between the treatment sites and their specific references pairings. The latitudinal/longitudinal points, crash data, and geometric and operational characteristics were collected for both the treatment locations and the comparison locations. Table 4.10 and Figure 4.4 provide the treatment and comparison site pairings as well as the general location of each site.

Table 4.10 Treatment and Comparison Sites Pairings for arrow-per-lane

	Treatment Site	Comparison Site
Pair 1	I-96 & I-196	US-23BL & M-14
Pair 2	US-23 & I-75	I-96 & US-131/M-37
Pair 3	Mound Rd & I-696	US-23 & I-75
Pair 4	I-696 & Mound Rd	I-275 & I-696
Pair 5	I-75 Service Dr & M-102	Southfield & M-102
Pair 6	I-696 Service Dr & 11 Mile	Jefferson Ave & I-375
Pair 7	I-696 Off Ramp & Mound Rd	I-496 & Larch St
Pair 8	US-127 & I-496 Split	Chrysler Fwy & I-75

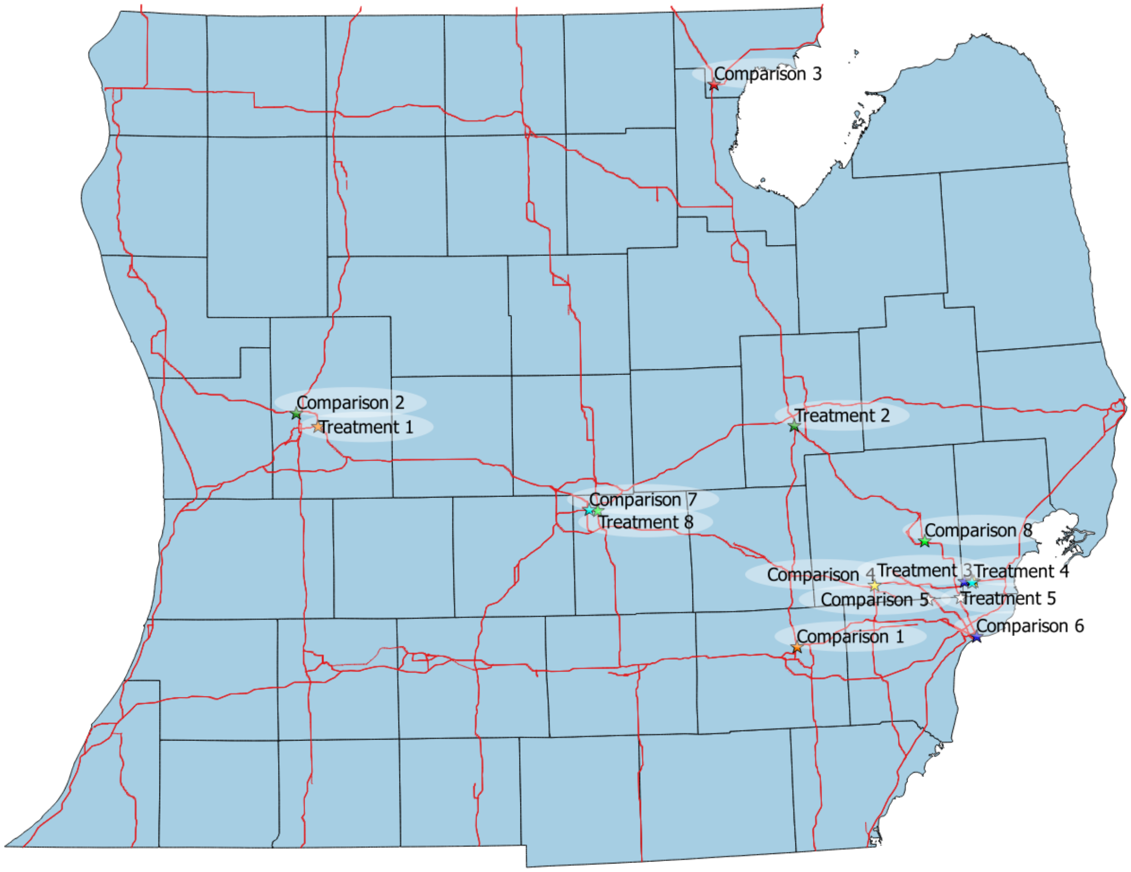

Figure 4.4 Treatment and comparison site locations for arrow-per-lane

Crash data for each treatment and comparison site was collected and tabulated to provide a summation for Total, Fatal, and Injury crashes for the area between the gore and the location of the first advanced sign as well as the influence area in advance of the first sign. For select locations crash data was tabulated for additional signs within the series. This distance was determined using the decision sight distance for the facility. Traffic volume data was also collected for each site for the mainline. Several locations are located on off ramps or service drives resulting in some gaps in information.

Geometric characteristics were collected using Google Earth and Street-view Imagery and consisted of features such as distance between signs, laneage at the exit, and the presence of curvature and grades where appropriate. The latitudinal and longitudinal points for each sign within the series were also collected. To prepare both sets of locations for comparison during the before and after periods as well as across the treatment and comparison groups, several steps were taken. The first was to divide the before and after periods based on the installation date of the treatment site sign. To reflect this break the comparison site periods were divided in the same manner, based on the year their respective treatment site sign was installed. After determining the year ranges for the before and after period for each location, each length of facility was divided into smaller segments. While there is some variation based on the individual site's geometric characteristics, each facility was generally divided into the decision sight distance leading up to the first diagrammatic sign as well as the length from the sign itself to the final gore area. Additionally, to account for differences in the distances from the study signs to the gore as well as the varying lengths of the before and after periods, crash rates were calculated for each segment in crashes per mile per year. In this way the sites could be compared more directly. Table 4.11 shows the summary of crash data and other characteristics observed at both the treated sites and comparison sites.

Table 4.11 Summary of data used in analyzing arrow-per lane signs

Pair	Category	Location	Facility Type	Full Length (DSD to Gore)	Mainline Speed Limit (mph)	Geometry	Thru Lanes	Option Lanes	Exit Only Lanes	Exit Lane Position	Total Crashes (C/mi/yr)	
											Before	After
1	C	US-23B NB to M-14	US Route	3,800’	70	Tangent	0	1	2	Split	9.41	22.42
	T	I-96 WB to I-196	Interstate	12,300’	70	Hor. Curve	0	1	2	Split	29.72	19.1
2	C	I-96 EB to US-131	Interstate	12,300’	70	Tangent	1	1	1	L	26.56	39.03
	T	US-23 SB to I-75	US Route	5,600’	70	Tangent	1	1	1	L	37.27	33.24
3	C	US-23 WB to I-75	US Route	1,600’	70	Tangent	1	1	1	R	0.57	1.14
	T	Mound Rd SB to I-696	Interstate On-Ramp	1,600’	50	Tangent	0	1	1	R	23.81	17.14
4	C	I-696 WB to I-275/I-96/M-5	Interstate	1,600’	70	Hor. Curve	1	1	0	R	11.42	6.85
	T	I-696 WB to Mound Rd	Interstate Off-Ramp	1,600’	70	Hor. Curve	1	1	0	R	10.67	10.83
5	C	M-39 Service Dr NB to M-102 (8 Mile)	Collector	1,600’	40	Tangent	1	1	1	R	31.09	20.73
	T	I-75 Service Dr NB to M-102(8 Mile)	Collector	950’	40	Tangent	1	1	1	L	5.81	7.75
6	C	Jefferson Ave EB to I-375/I-75	Collector	750’	35	Tangent	2	1	1	L	73.29	70.92
	T	I-696 Service Dr WB to 11 Mile/I-696	Collector	1,000’	40	Hor. Curve	0	1	1	Split	54.95	35.71
7	C	I-496 WB On-Ramp to Larch/Cedar St	Interstate On-Ramp	350’	N/A	Tangent	1	1	1	R	10.1	15.15
	T	I-696 EB to Mound Rd	Interstate Off-Ramp	4,600’	70	Tangent	0	1	1	Split	9.55	9.04
8	C	I-75 NB	Interstate	5,800’	70	Hor. Curve	2	1	1	L	51.91	60.39
	T	US-127 NB to I-496	US Route	3,200’	60	Hor. Curve	1	1	1	L	114.85	52.9

5 Development of Safety Performance Functions (SPFs)

5.1 Introduction

Safety Performance Functions (SPFs) are prediction models used to estimate crash frequencies under specific conditions. Data collected from reference sites were used to develop the SPFs presented in this chapter. Data collection, as described in Chapter 4 above, involved manual verification of sites through Google Earth and Google Street View. The SPFs were developed for three countermeasures: Clearview font, Fluorescent Yellow Sheeting, and box span signal installations. It was not possible to develop SPFs for pedestrian countdown signals due to lack of reliable pedestrian exposure data. Also, there was not a sufficient number of sites for developing SPFs for arrow-per lane signs.

5.2 Modeling Approach

Standard count data probability models were used to estimate the parameters of the SPFs. When modeling crash counts, Poisson regression analysis or Negative Binomial (NB) regression analysis can be used (Yaacob et al, 2011; Zlatoper, 1989; Lord, 2006; Chin and Quddus, 2003; Miaou and Lum, 1993; and Noland and Quddus, 2004). The choice between the two model types depends on the relationship between the mean and the variance of the data. If the mean is equal to the variance, the data is assumed to follow a Poisson distribution, and hence the Poisson regression analysis can be performed. However, as a result of possible positive correlation between observed accident frequencies, overdispersion may occur (Hilbe, 2011). Accident frequency observations are said to be overdispersed if their variance is greater than their mean. If overdispersion is detected in the data, NB regression analysis should be used. Standard textbooks (for example Hilbe 2011; Greene 2012; and Washington et al 2011) present clear derivation of the Poisson, and Negative Binomial (NB) models. According to the Poisson distribution, the probability $P(y_i)$ of intersection i having y_i crashes in a given time period (usually one year) can be written as:

$$P(y_i) = \frac{EXP(-\lambda)\cdot\lambda_i^{y_i}}{y_i!}$$

where λ_i denotes the Poisson parameter for intersection *i*. By definition, λ_i is equal to the expected number of crashes in a given time period for intersection *i*, $E[y_i]$. According to Washington et al. (2011), the expected number of crash occurrences λ_i, can be related to a vector of explanatory variables, $\boldsymbol{X}_i$ as follows:

$$\lambda_i = EXP(\boldsymbol{\beta}\boldsymbol{X}_i)$$

where $\boldsymbol{\beta}$ represents a vector of estimable parameters. Under the Poisson assumption, the mean and variance of crashes occurring at an intersection in a year are equal (i.e. $E[y_i] = Var[y_i]$). With *N* observations, the parameters of the Poisson model can be estimated by maximum likelihood method with a function which can be shown to be as follows:

$$LL(\beta) = \sum_{i=1}^{N}[-EXP(\boldsymbol{\beta}\boldsymbol{X}_i) + y_i\boldsymbol{\beta}\boldsymbol{X}_i - \ln(y_i!)]$$

The Poisson assumption of equal mean and variance of the observed crash occurrences is not always true. To handle the cases where the mean and variance of crashes are not equal, the Poisson model is generalized by introducing an individual, unobserved effect, ε_i, in the function relating crash occurrences and explanatory variables as follows:

$$\lambda_i = EXP(\boldsymbol{\beta}\boldsymbol{X}_i + \varepsilon_i)$$

in which $EXP(\varepsilon_i)$ is a gamma-distributed error term with mean one and variance α^2. With such a modification, the mean λ_i becomes a variable that follows binomial distribution. The mean-variance relationship becomes:

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

If α is equal to zero, the negative binomial distribution reduces to Poisson distribution. If α is significantly different from zero, the crash data are said to be overdispersed (positive value) or underdispersed (negative value). As stated earlier, overdispersion is a result of possible positive correlation between observed accident frequencies. When α is significantly different from zero, the resulting negative binomial probability distribution is:

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

where $\Gamma(x)$ is a value of the gamma function, y_i is the number of crashes for site *i*.

5.3 SPFs for Segments

SPFs for Clearview font signs and yellow fluorescent warning signs were developed based on carefully selected roadway segments. For non-freeways, rural segments were analyzed separately from urban segments.

5.3.1 SPF for Freeways

The SPFs for freeways were estimated by fitting a Negative Binomial model using the data presented in Chapter 4. The resulting equation was as follows:

$$N_{SPF} = e^{\beta_0+\beta_1*(\mathrm{L})+\beta_2*\ln(AADT)}$$

Where

N_{spf} is the total number of roadway segment crashes per year

AADT is the Annual Average Daily Traffic on the freeway segment

L is the length of the freeway segment (in miles)

β_0, β_1, and β_2 are regression coefficients.

Fitting the NB generates alpha value (α) which was then used to calculate the overdispersion parameter (k_i) for each of the treated freeway segment *i*. The overdispersion parameter is a function of the expected mean of the crash counts as follows:

$$k_i = 1 + \alpha * e^{\beta_0+\beta_1*(\mathrm{L})+\beta_2*\ln(AADT)}$$

The estimated overdispersion parameter (k_i) for a freeway segment is then modeled against the segment length as follows:

$$k_i = \frac{1}{e^{(c+\ln(L))}}$$

where c is the non-linear regression coefficient.

Table 5.1 presents the parameters estimated for freeway SPFs, in which only segment length and AADT were found to impact segment crashes significantly. As expected, higher values of both segment length and natural logarithm of AADT are associated with increase in the number of crashes observed per year. The impact of these variables was statistically significant at the 95 percent confidence level. However, there was no statistically reliable SPFs for the 65yrs-and-older drivers. Appendix 5.1 presents the SPFs for drivers under 65 years old.

Table 5.1 SPFs for freeway segments

Crash Category	β_1 (std. error)	β_2 (std. error)	β_0	c
Total (all severities)	0.270 (0.041)	0.974 (0.088)	-7.718	-0.581
Total Fatal/Injury	0.229 (0.055)	1.238 (0.115)	-11.988	0.416
Total Day	0.217 (0.044)	1.068 (0.096)	-9.183	-0.198
Total Night	0.327 (0.041)	0.849 (0.092)	-7.297	0.185
65yrs-and-Older Drivers	No reliable SPF			
65yrs-and-Older Drivers Day	No reliable SPF			
65yrs-and-Older Drivers Night	No reliable SPF			

Alternatively, the SPFs shown in Table 5.1 can be presented graphically as shown in Figure 5.1. This allows for easy applicability of the SPFs in predicting the number of crashes per year per mile for a given segment AADT and crash category.

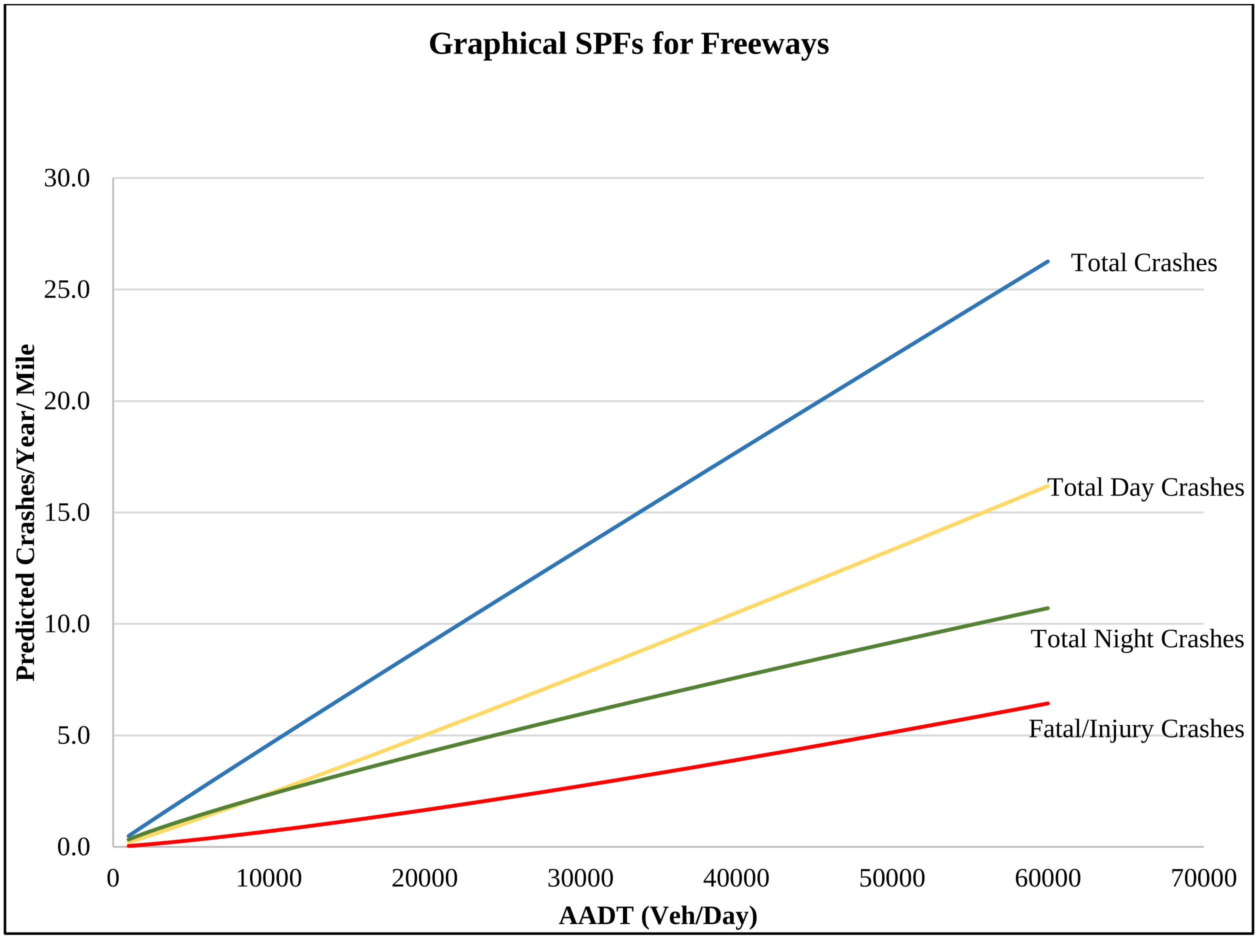

Figure 5.1 Graphical presentation of SPFs for freeways

5.3.2 SPF for Urban Non-Freeway Segments

For urban non-freeway segments, AADT, segment length, number of access points, and undivided roadway status were statistically significant factors affecting the number of crashes. Mathematically, the model can be shown as follows:

$$N_{SPF} = e^{(\beta_0 + \beta_1 * \ln(\text{AADT}) + \beta_2 * L + \beta_3 * AP + \beta_4 * UR)}$$

Where

N_{spf} is the total number of roadway segment crashes per year

AADT is the Annual Average Daily Traffic on the freeway segment

L is the length of the non-freeway segment (in miles)

AP is the number of access points in the segment

UR indicates whether the roadway is undivided (undivided = 1, otherwise = 0)

β_0, β_1, β_2, β_3, and β_4 are regression coefficients.

Table 5.2 shows the parameters estimated together with their standard errors. There was no reliable SPF for drivers 65yrs-and-older during the night time. The SPFs for drivers under 65 years are presented in Appendix 5.1. The positive coefficients indicate that longer segments and higher traffic volumes (AADT) are associated with high number of crashes. Similarly, the number of access points in a segment of undivided roadway are likely to increase the number of crashes in the segment. These findings are consistent with previous studies.

Table 5.2 SPFs for urban non-freeways

Crash Category	**B_1 (std. error)**	**B_2 (std. error)**	**B_3 (std. error)**	**B_4 (std. error)**	**β_0**	**c**
Total (all injuries)	0.985 (0.142)	0.462 (0.115)	0.025 (0.008)	0.397 (0.185)	-7.998	-0.722
Total Fatal/Injury	1.046 (0.169)	0.467 (0.104)	0.018 (0.008)	0.513 (0.215)	-10.059	0.440
Total Day	1.044 (0.158)	0.343 (0.123)	0.032 (0.009)	0.455 (0.205)	-8.905	-0.596
Total Night	0.771 (0.141)	0.493 (0.090)	0.012 (0.006)	0.325 (0.178)	-7.049	0.503
65yrs-and-Older Drivers Total	1.026 (0.176)	0.280 (0.108)	0.014 (0.008)	0.467 (0.228)	-9.812	0.520
65yrs-and-Older Drivers Day	1.144 (0.223)	0.282 (0.139)	0.025 (0.011)	0.756 (0.299)	-11.600	0.411
65yrs-and-Older Drivers Night	No reliable SPF					

Figure 5.2 through Figure 5.5 are sample graphical presentations of the SPFs shown in Table 5.2. The graphical charts can be used to estimate the number of crashes per year per mile in a given segment under specified conditions.

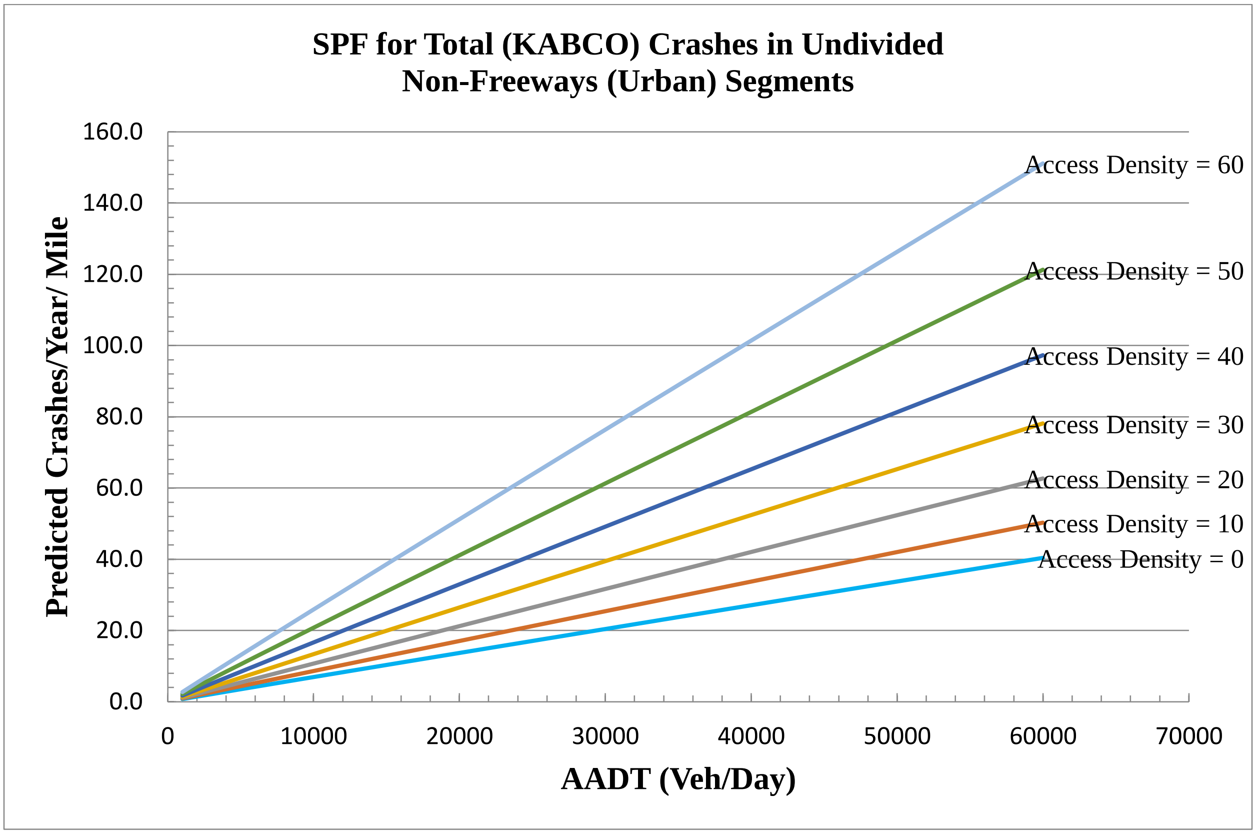

Figure 5.2 SPF for Total on non-Freeways (Urban)

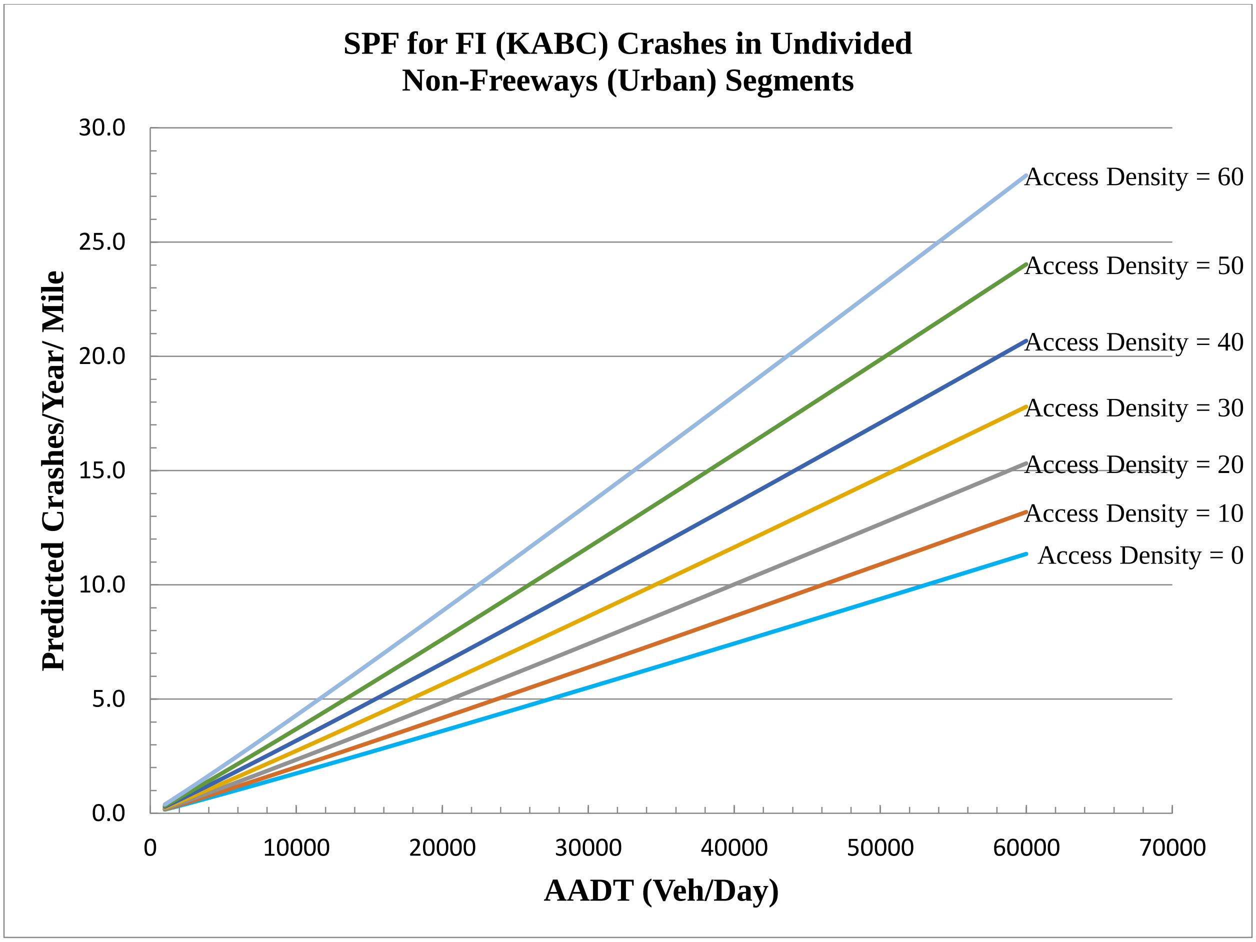

Figure 5.3 SPF for FI on non-Freeways (Urban)

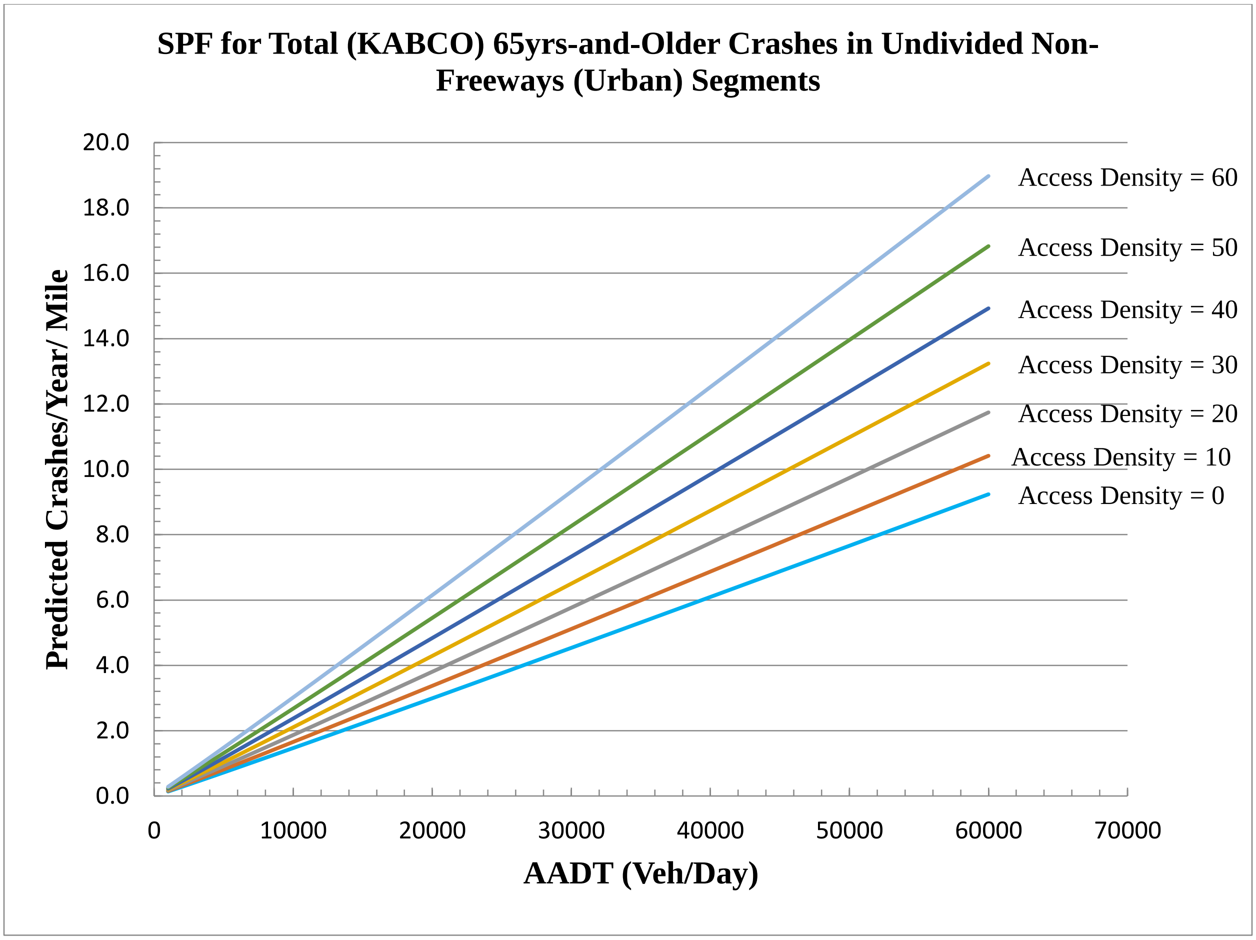

Figure 5.4 SPF for Total drivers 65yrs-and-older on non-Freeways (Urban)

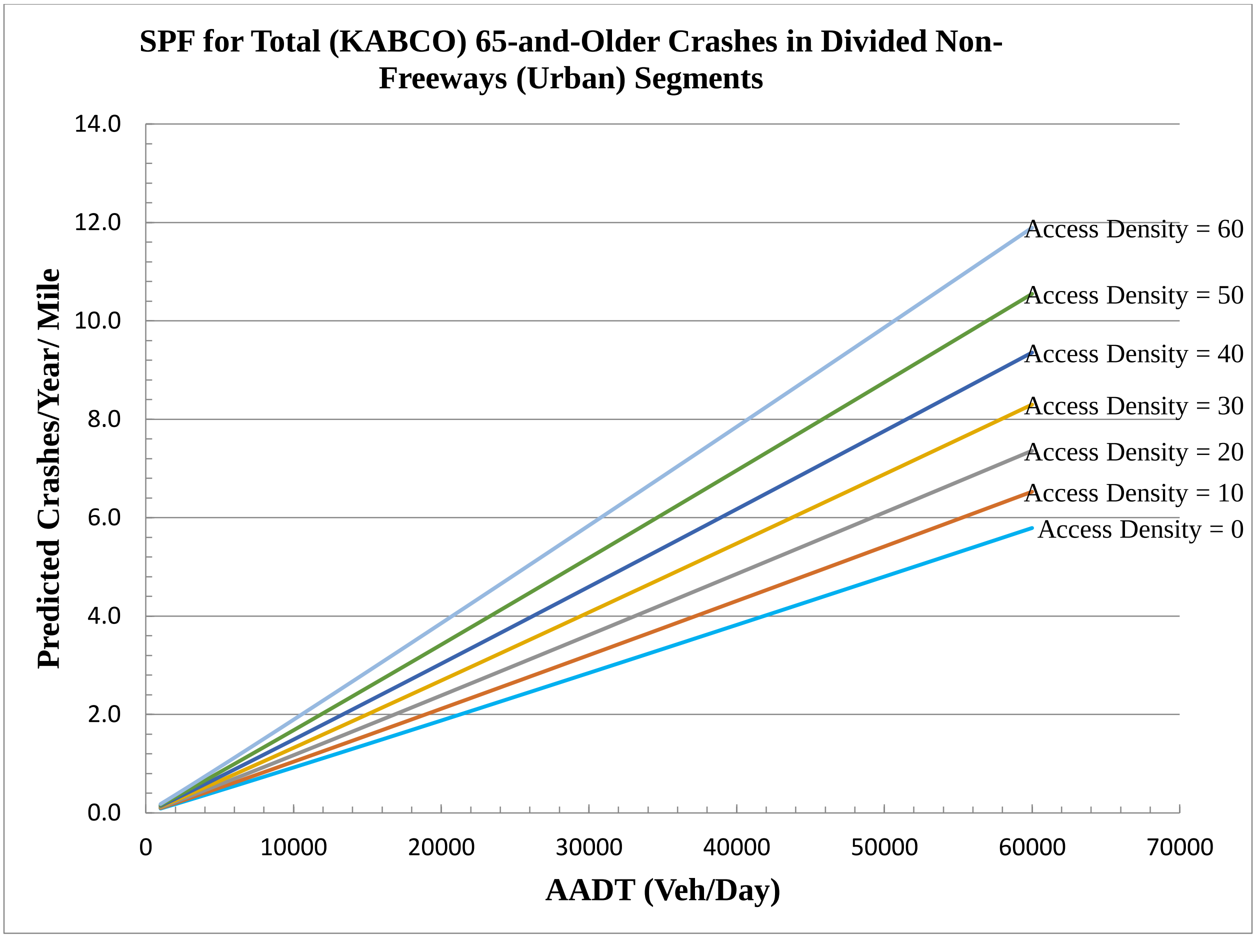

Figure 5.5 SPF for FI drivers 65yrs-and-older on non-Freeways (Urban)

5.3.3 SPF for Rural Non-Freeway Segments

For rural non-freeway segments, AADT, segment length, number of access points, undivided roadway, and lack of sidewalk were statistically significant factors affecting the number of crashes. Mathematically, the model can be presented as follows:

$$N_{SPF} = e^{(\beta_0 + \beta_1 * \ln(\text{AADT}) + \beta_2 * L + \beta_3 * AP + \beta_4 * UR + \beta_5 * NS)}$$

Where

N_{spf} is the total number of roadway segment crashes per year

AADT is the Annual Average Daily Traffic on the freeway segment

L is the length of the non-freeway segment (in miles)

AP is the number of access points in the segment

UR indicates whether the roadway is undivided (undivided = 1, otherwise = 0)

NS indicates a segment without sidewalk (no sidewalk = 1, otherwise = 0)

β_0, β_1, β_2, β_3, β_4, and β_5 are estimable coefficients.

Table 5.3 shows the parameters estimated and their standard errors. There was no reliable SPF for drivers 65yrs-and-older during the night time. Also, the SPF for fatal and injury crashes for all drivers was not reliable. The positive coefficients indicate that longer segments and higher traffic volumes (AADT) are associated with high number of crashes. Similarly, more access points are likely to increase the number of crashes in undivided roadway segments. Furthermore, absence of sidewalk is associated with more crashes in a segment. It should be noted that the number of access points did not influence night time crashes for all drivers, while undivided roadway status and absence of sidewalk had a statistically weak influence on the number of crashes involving drivers 65yrs-and-older.

Table 5.3 SPFs for Non-Freeways (Rural)

Crash Category	B_1 (std. error)	B_2 (std. error)	B_3 (std. error)	B_4 (std. error)	B_5 (std. error)	β_0	c
Total (all severities)	0.658 (0.080)	0.192 (0.032)	0.022 (0.009)	0.711 (0.246)	1.311 (0.315)	-6.090	-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	0.142
Total Night	0.634 (0.100)	0.256 (0.029)	-	0.965 (0.344)	1.719 (0.493)	-7.020	-0.460
65yrs-and-Older Drivers Total	0.453 (0.141)	0.091 (0.043)	0.039 (0.011)	0.784 (0.512)	0.787 (0.521)	-5.697	0.142
65yrs-and-Older Drivers Day	0.769 (0.230)	0.109 (0.060)	0.060 (0.014)	-	-	-7.985	0.142
Total Fatal/Injury	No reliable SPF						
65yrs-and-Older Drivers Night	No reliable SPF						

Figure 5.6 through Figure 5.11 are graphical presentations of the models presented in table 5.3. The graphical presentations of the SPFs allow the user to estimate the number of predicted crashes per year per mile graphically.

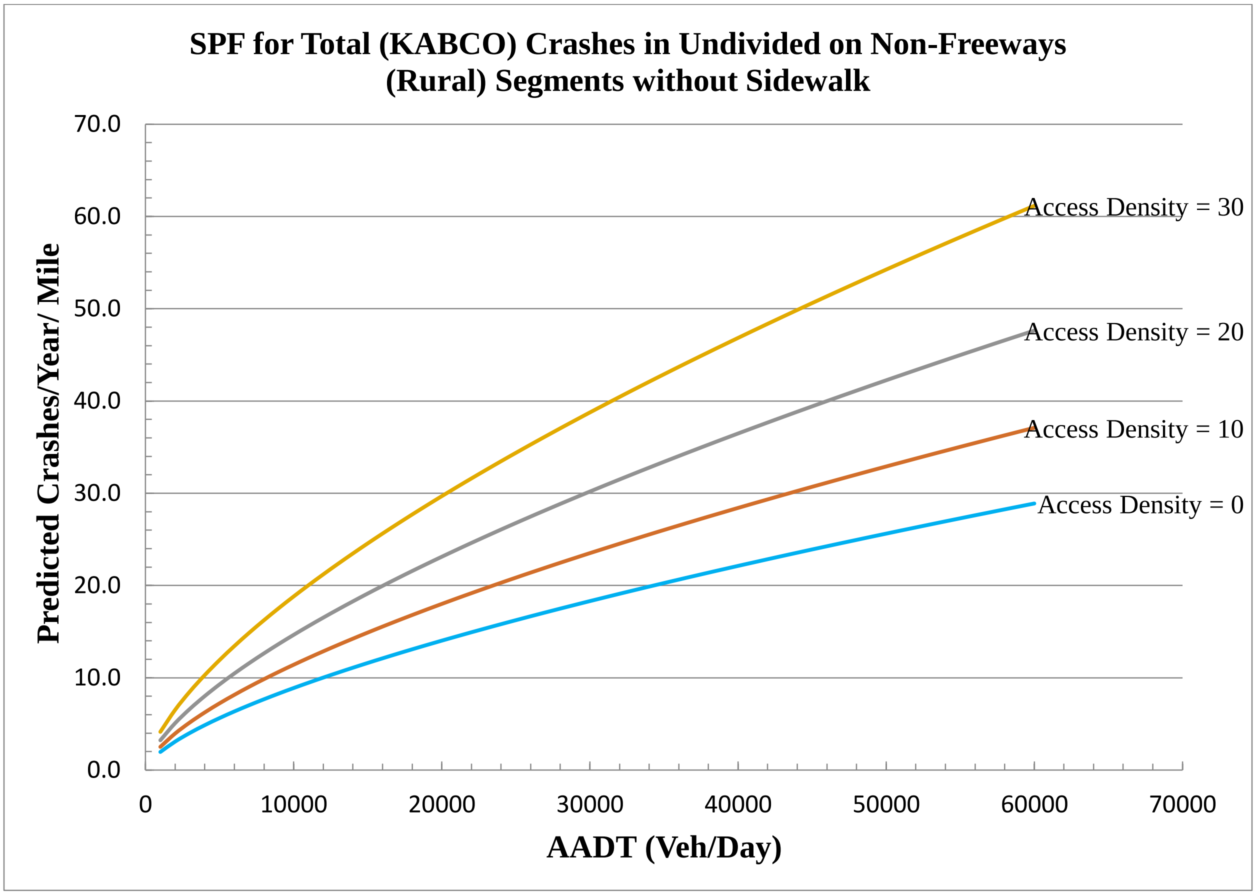

Figure 5.6 SPF for total drivers on undivided rural non-freeways without sidewalk

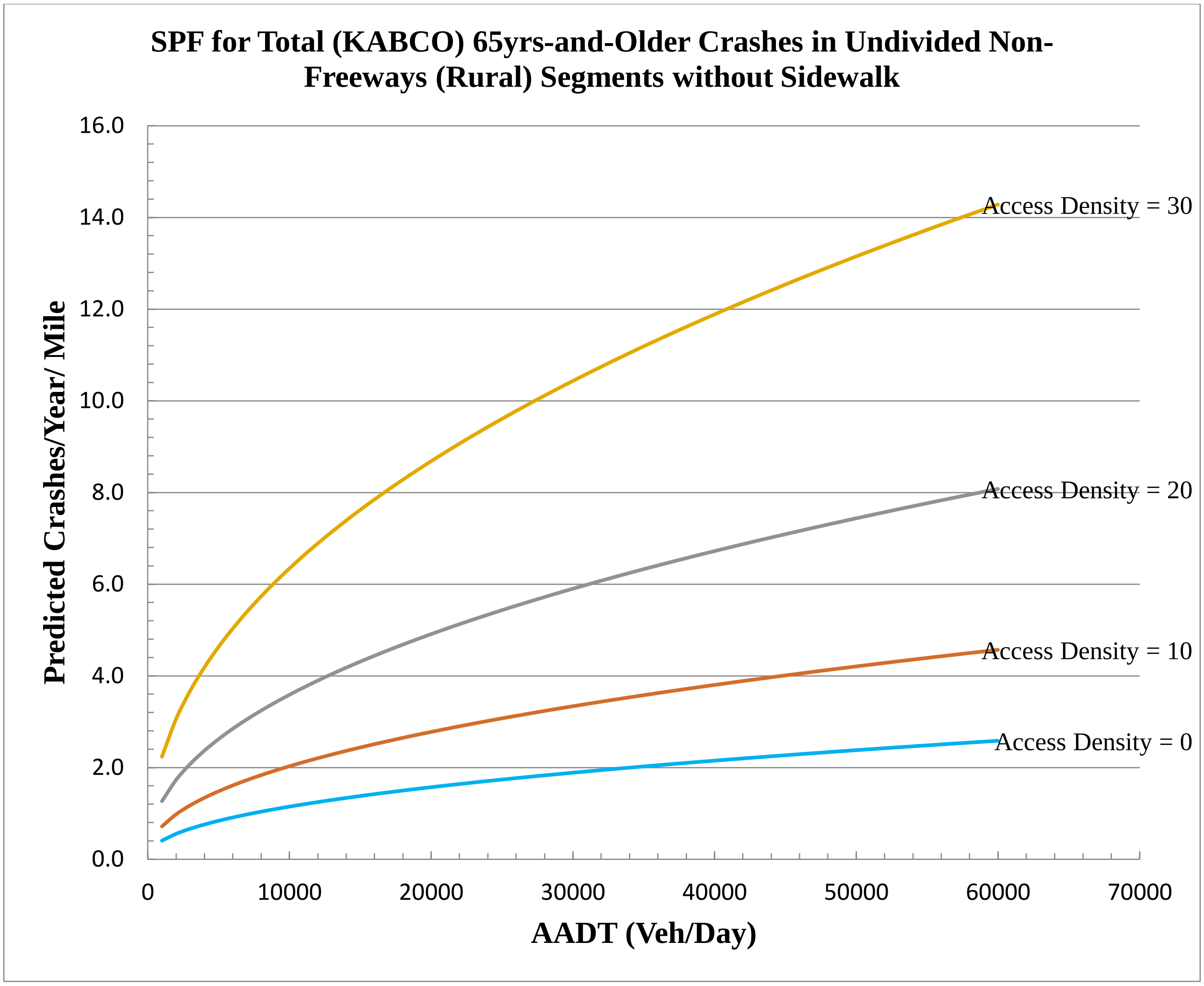

Figure 5.7 SPF for Total drivers 65yrs-and-older on undivided rural non-freeways without sidewalk

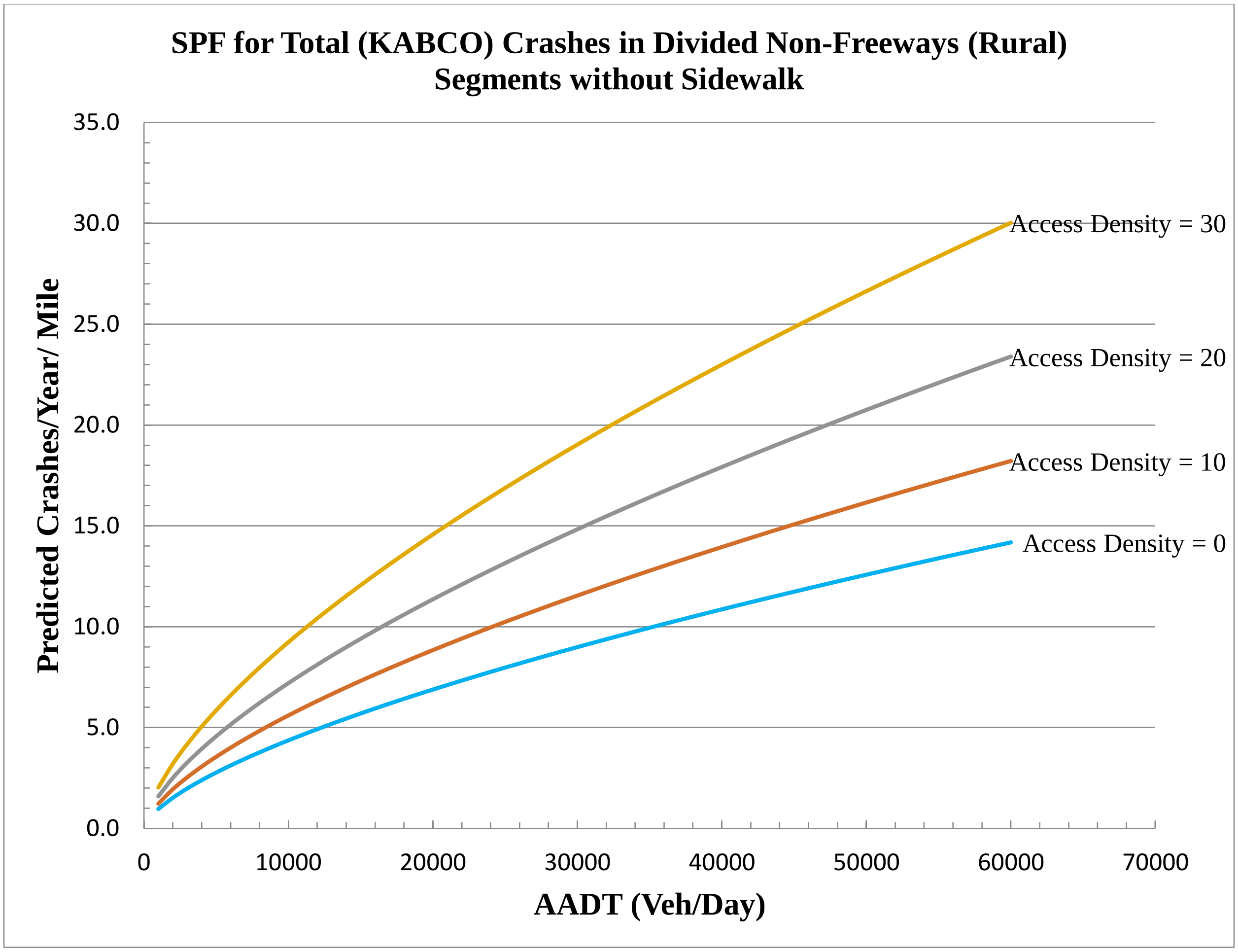

Figure 5.8 SPF for Total drivers on divided rural non-freeways without sidewalk

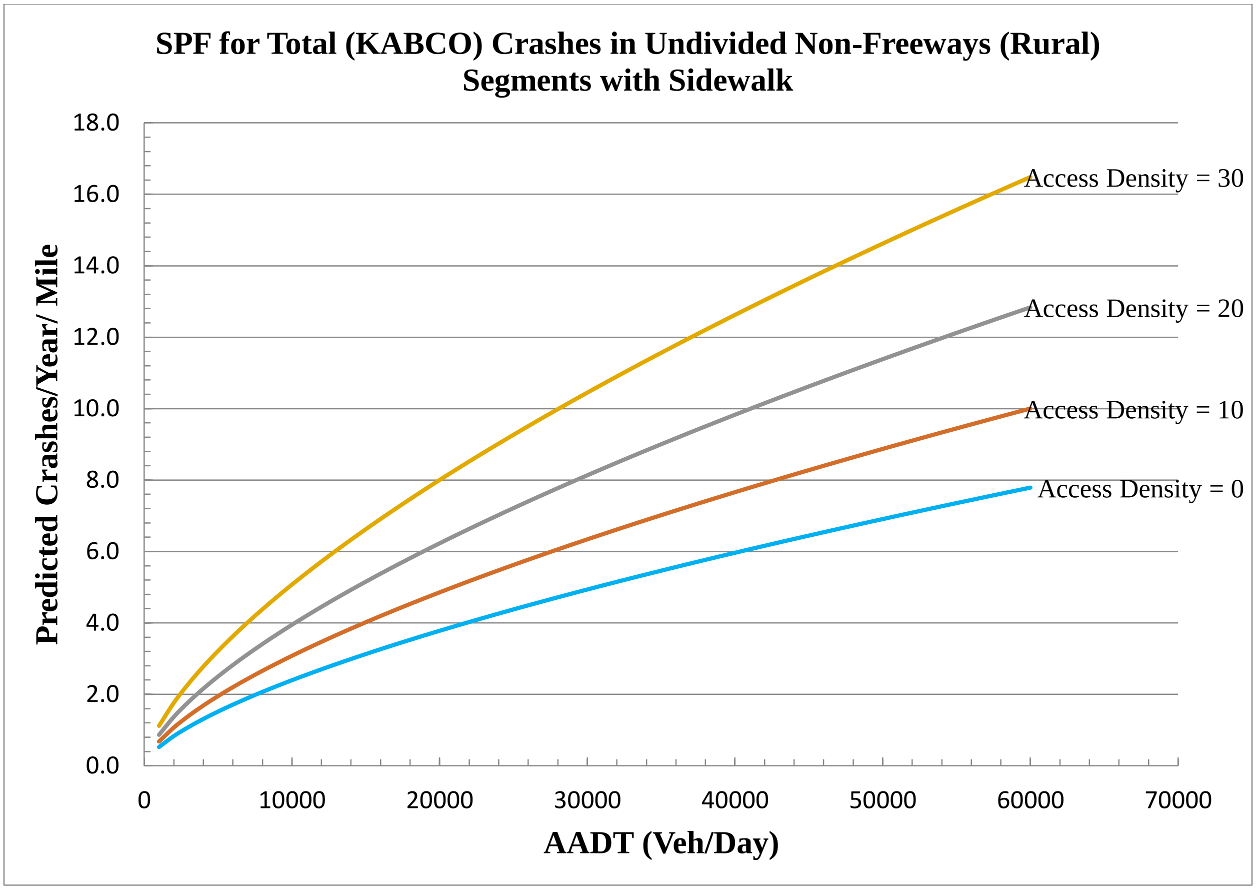

Figure 5.9 SPF for Total drivers on undivided rural non-Freeways with sidewalk

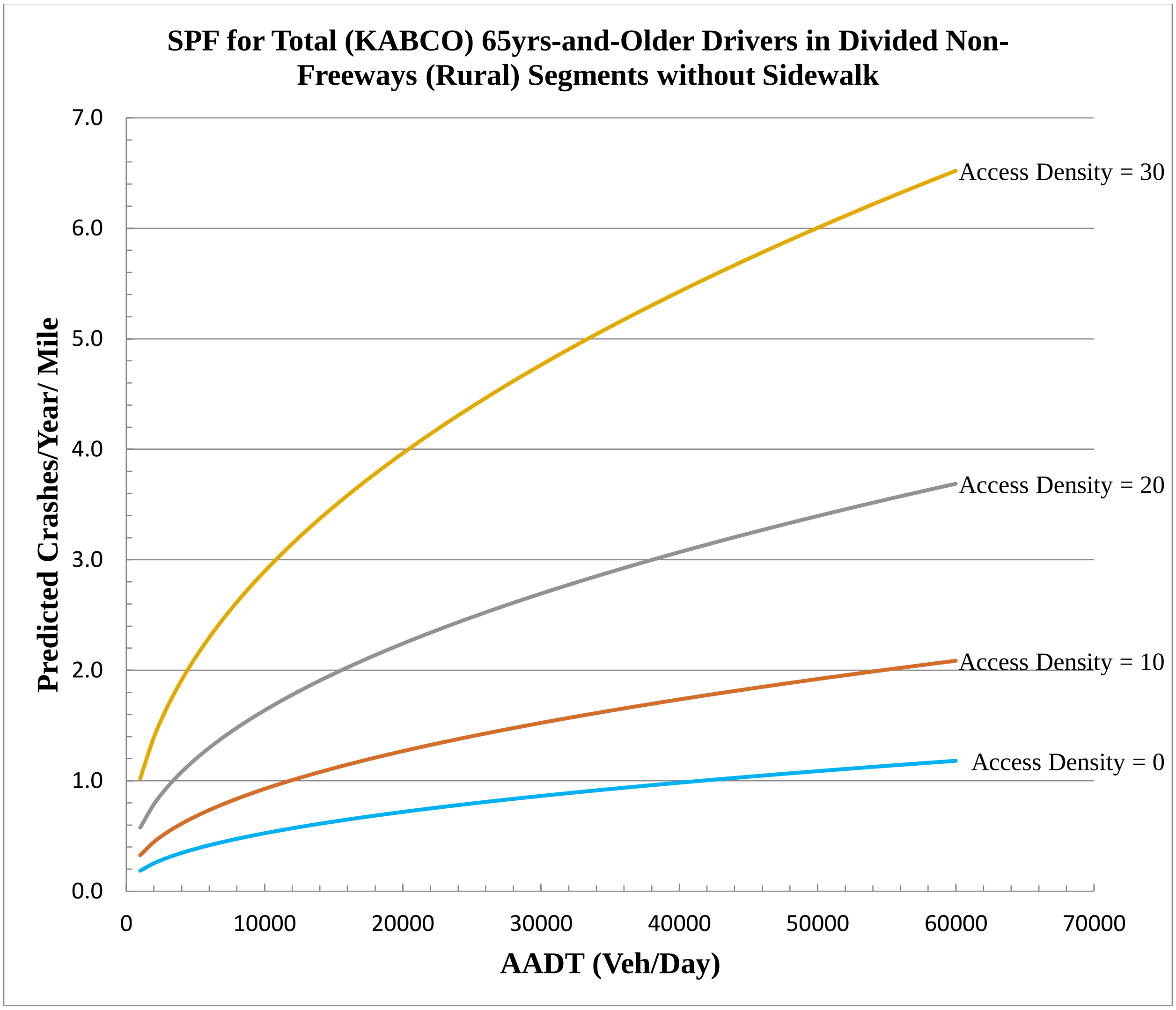

Figure 5.10 SPF for Total drivers 65yrs-and-older on divided rural non-freeways without sidewalk

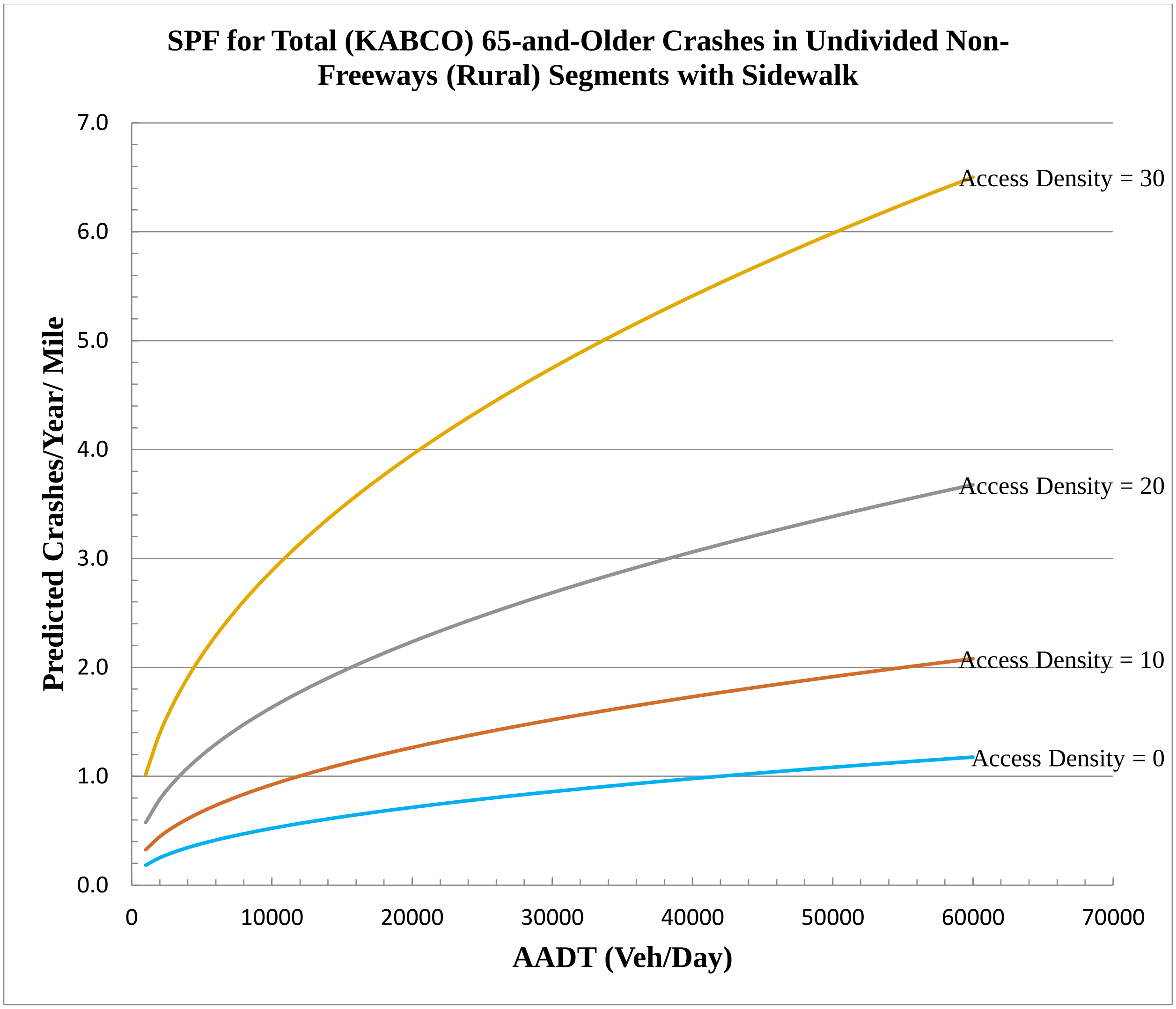

Figure 5.11 SPF for Total drivers 65yrs-and-older on rural undivided non-freeways with sidewalk

5.4 SPFs for Intersections

In this research, two types of intersection improvements were analyzed: pedestrian countdown signals and box span signal installation. Due to lack of reliable pedestrian exposure measures, SPFs were only developed for box span signal installation. SPFs for the following crash conditions were estimated:

- Total Crashes, All Severities, All Ages

- Total Crashes, Fatal & Injury Severities, All Ages
- Angle Crashes, All Severities, All Ages
- Total Crashes, All Severities, ≥65 Years
- Total Crashes, Fatal & Injury Severities, ≥65 Years
- Angle Crashes, All Severities, ≥65 years

The reference site data, with a sample size of 100, were used to estimate the required SPF coefficients. A negative binomial error distribution was assumed, which is consistent with the state of research in developing these models. Separate models were sought for each crash type analyzed, divided into different age categories: all ages, drivers under 65 years and drivers 65yrs-and-older years. The variables tested for significance in each category for the different crash types are shown in Table 5.4. The significant variables were considered in the SPF model, but not all significant variables were included in the SPF model, due to lack of acceptable statistical justification (e.g. significant strong correlation between variables).

Table 5.4 Testing significance of variables for box span SPFs

	Major AADT	Minor AADT	Major thru lanes	Minor thru lanes	Major LT Lane	Minor LT Lane	Major LT Phase	Minor LT Phase	3-leg	4-leg	Wide Median
All Ages											
Total Crashes	✓	✓				✓		✓			✓
FI Crashes	✓	✓				✓		✓			✓
Angle Crashes	✓	✓				✓					
65yrs-and-Older Drivers											
Total Crashes	✓	✓					✓	✓			
FI Crashes	✓	✓									
Angle Crashes	✓	✓				✓	✓				

The final SPF estimated for box span signal installations can be written as follows:

$$N_{SPF} = e^{\left(\beta_0 + \beta_1 * \ln(\mathrm{Maj}_{\mathrm{AADT}}) + \beta_2 * (\mathrm{Min}_{\mathrm{AADT}}) + \beta_3 * (\mathrm{Min}_{\mathrm{LTL}}) + \beta_4 * (\mathrm{Maj}_{\mathrm{LTP}}) + \beta_5 * (\mathrm{Min}_{\mathrm{LTP}}) + \beta_6 * (\mathrm{WM})\right)}$$

Where

N_{spf} is the total number of roadway segment crashes per year

Maj_{AADT} is the Annual Average Daily Traffic on major approach

Min_{AADT} is the Annual Average Daily Traffic on minor approach

Min_{LTL} indicates presence of left turn lane on minor approach

Maj_{LTP} indicates presence of left turn phase on major approach

Min_{LTP} indicates presence of left turn phase on minor approach

WM indicates presence of wide median

β_0, β_1, β_2, β_3, β_4, β_5, and β_6 are estimable coefficients.

The SPFs developed are provided in Table 5.5. The parameter π, which is the over dispersion parameter of the negative binomial distribution for the models, is estimated during the development of the SPFs. This parameter is used in the EB methodology. All the models met the chi-square goodness of fit test, except for total crashes for all drivers and total crashes for drivers under 65 years (Appendix 5.1).

Table 5.5 SPFs for reference sites for box span

	β_0	B_1	B_2	B_3	B_4	B_5	B_6	π
All Ages								
Total Crashes	-5.84	0.34	0.50	0.29	-	0.54	0.32	0.71
FI Crashes	-7.95	0.42	0.48	0.45	-	0.23	0.33	2.57
Angle Crashes	-6.53	0.30	0.49	0.30	-	-	-	1.10
Drivers 65yrs-and-Older								
Total Crashes	-6.18	0.26	0.47	-	-0.41	0.58	-	2.51
FI Crashes	-6.95	0.26	0.39	-	-	-	-	5.18
Angle Crashes	-9.14	0.52	0.35	0.58	-0.53	-	-	3.19

Figure 5.12 through Figure 5.17 presents the SPFs shown in Table 5.5 graphically. The graphs allow for estimation of average crash frequency per year given the specific conditions identified.

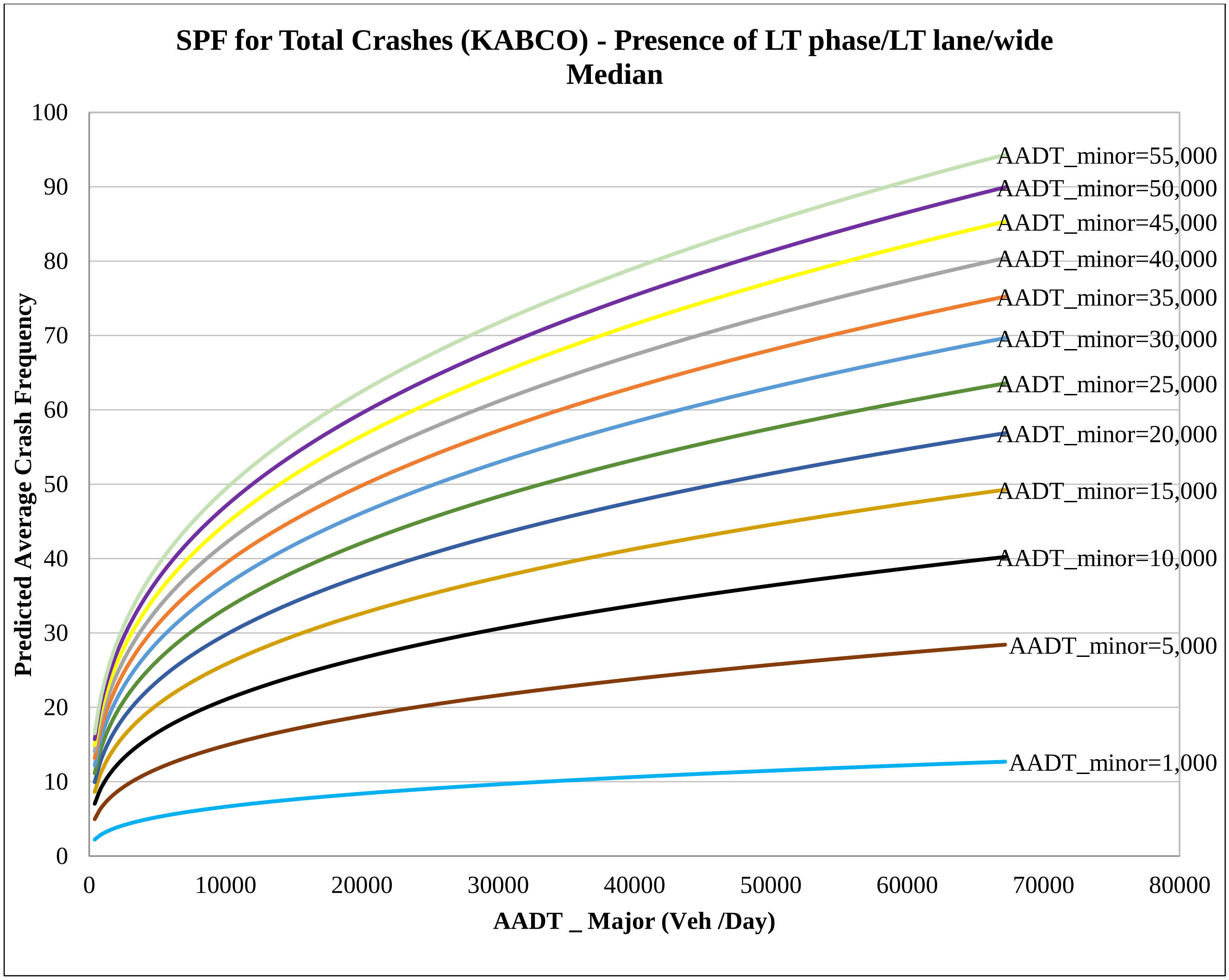

Figure 5.12 SPF for Total Crashes (KABCO) - Presence of LT phase/LT lane/wide Median

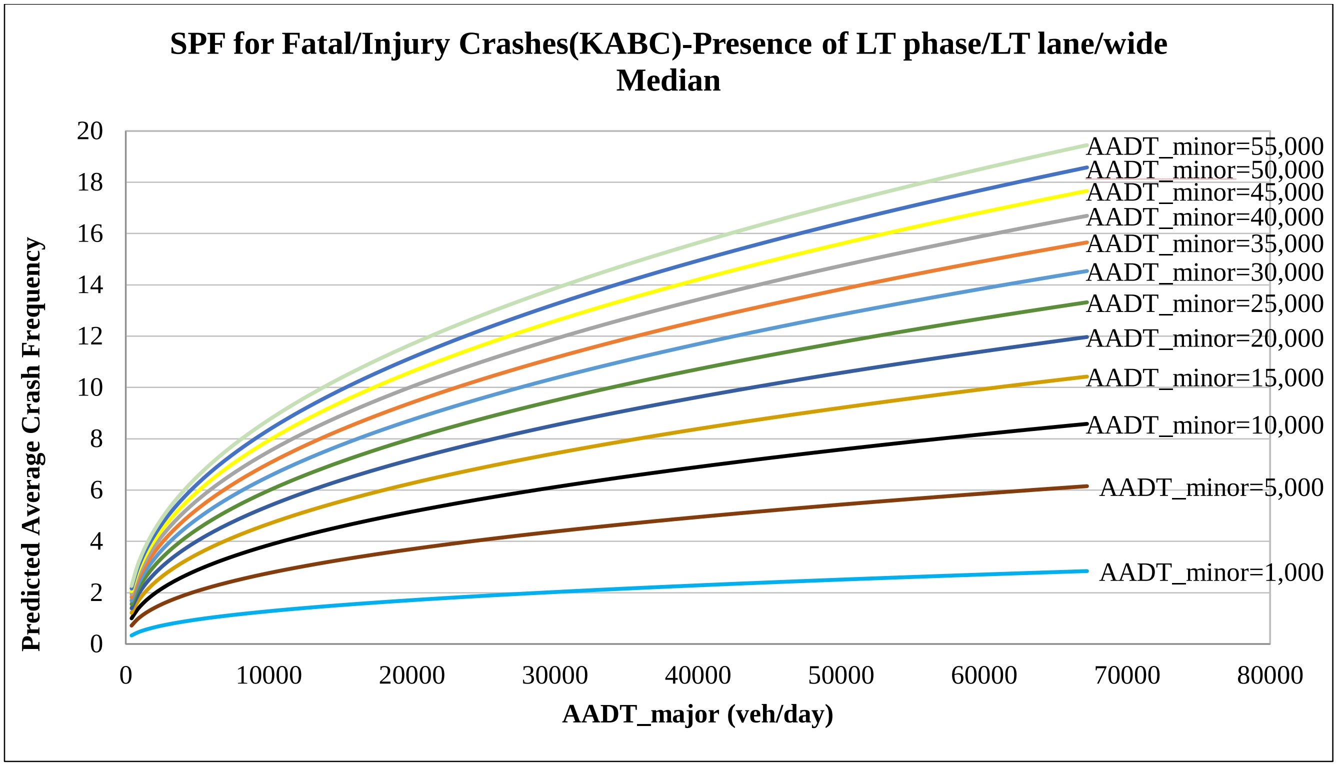

Figure 5.13 SPF for Fatal/Injury Crashes (KABC)-Presence of LT phase/LT lane/wide Median

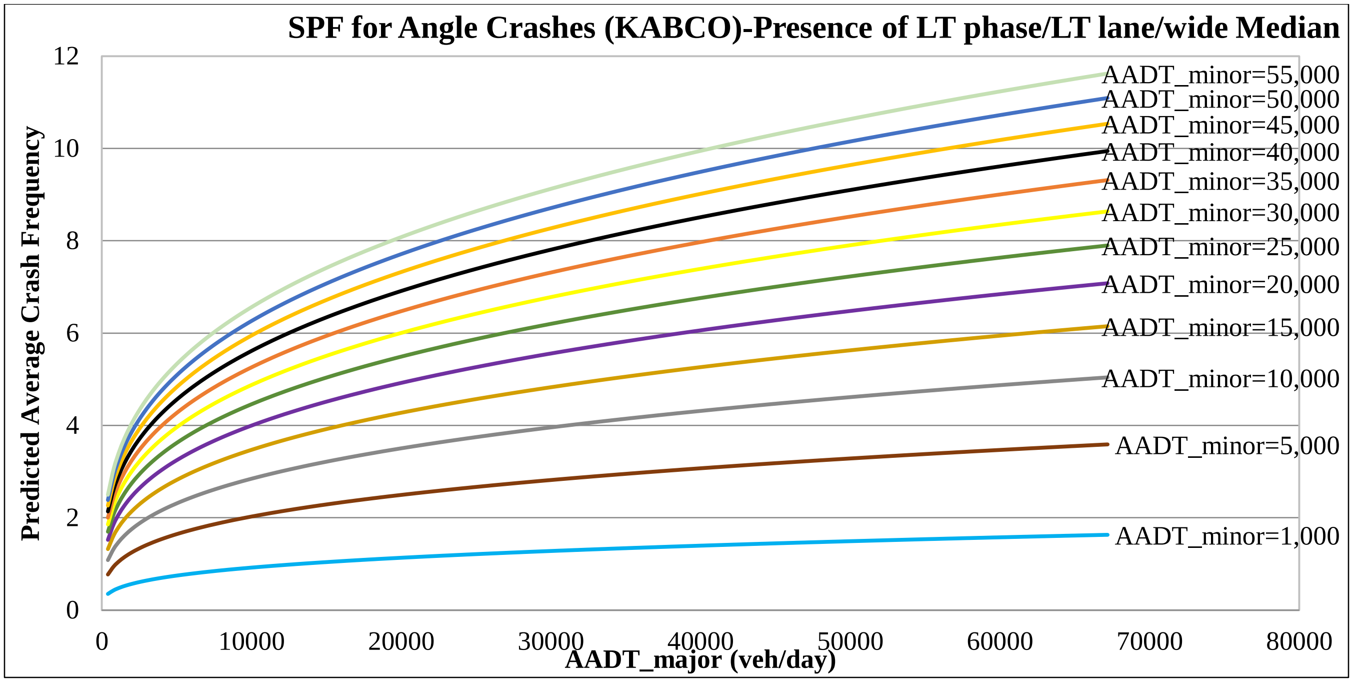

Figure 5.14 SPF for Angle Crashes (KABCO)-Presence of LT phase/LT lane/wide Median

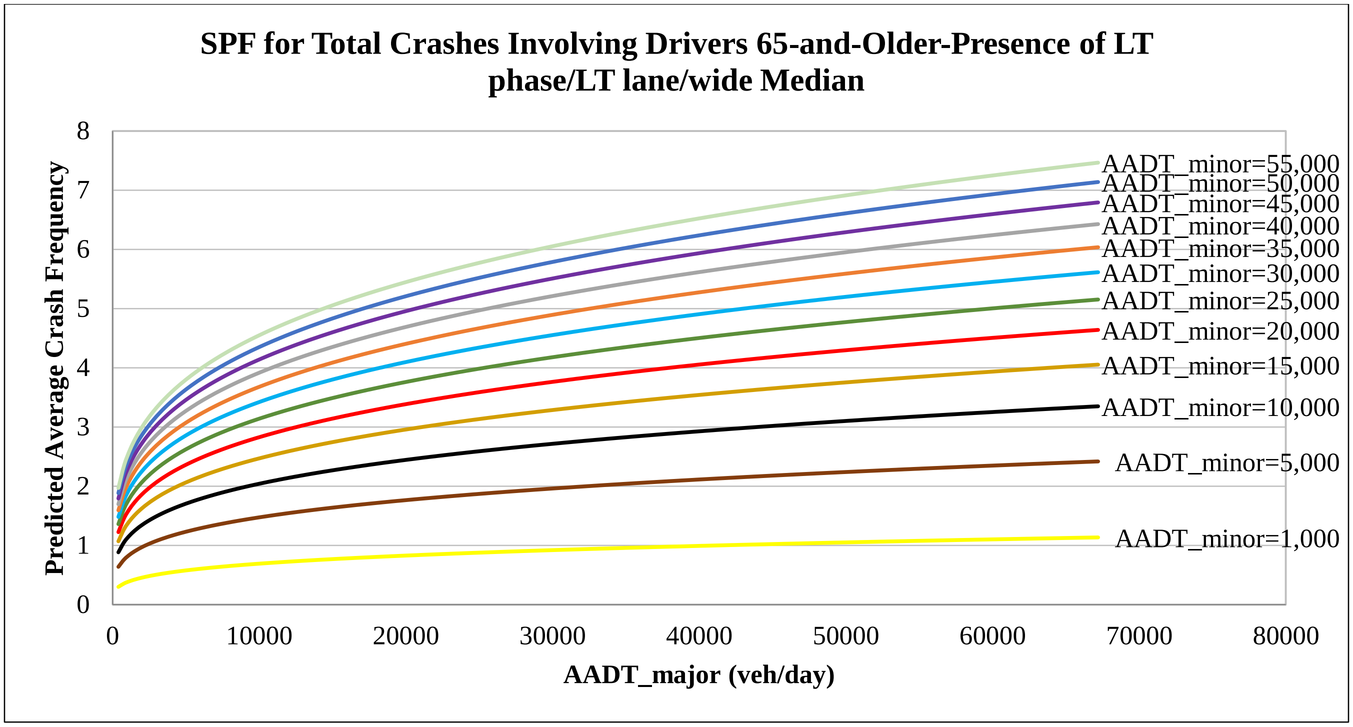

Figure 5.15 SPF for Total Crashes Involving Drivers 65yrs-and-older-Presence of LT phase/LT lane/wide Median

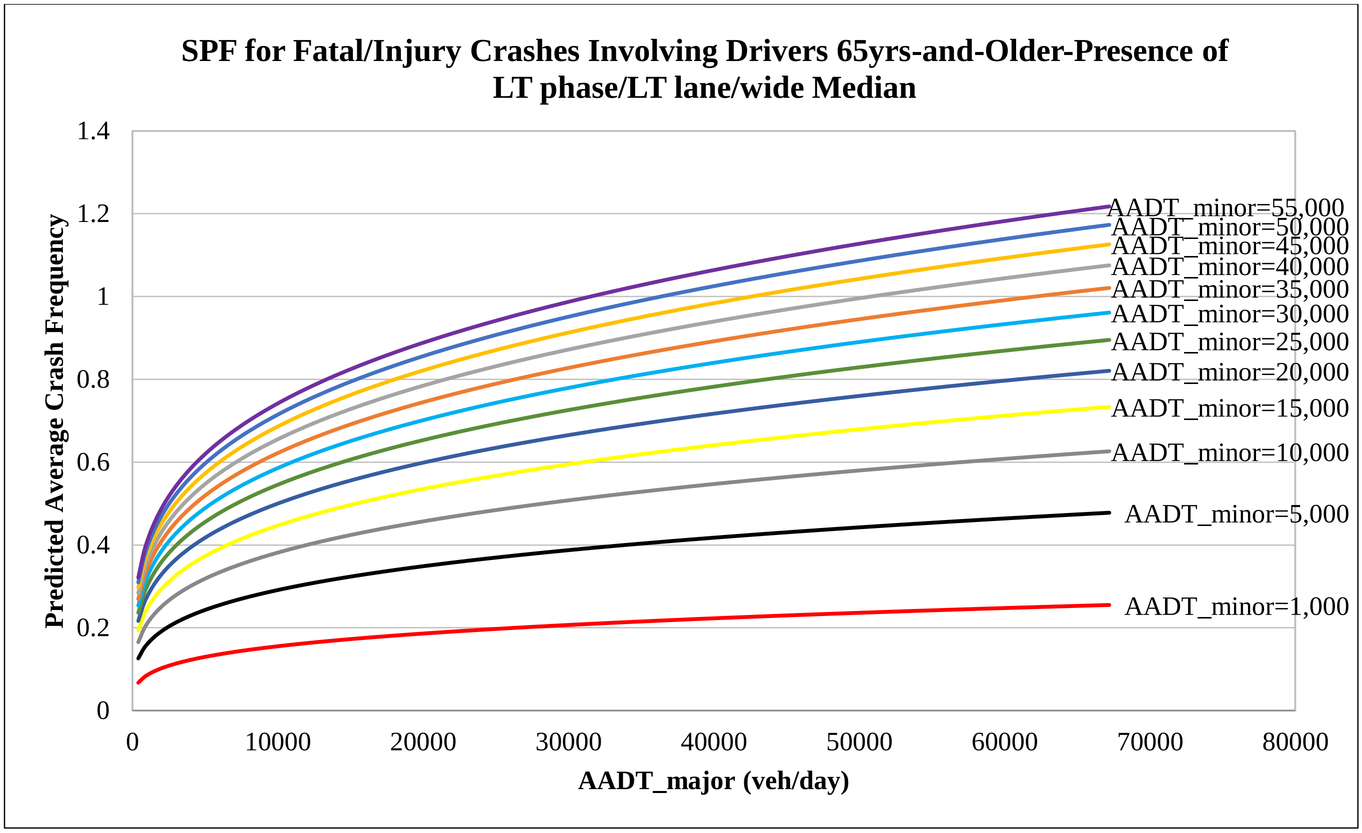

Figure 5.16 SPF for Fatal/Injury Crashes Involving Drivers 65yrs-and-Older-Presence of LT phase/LT lane/wide Median

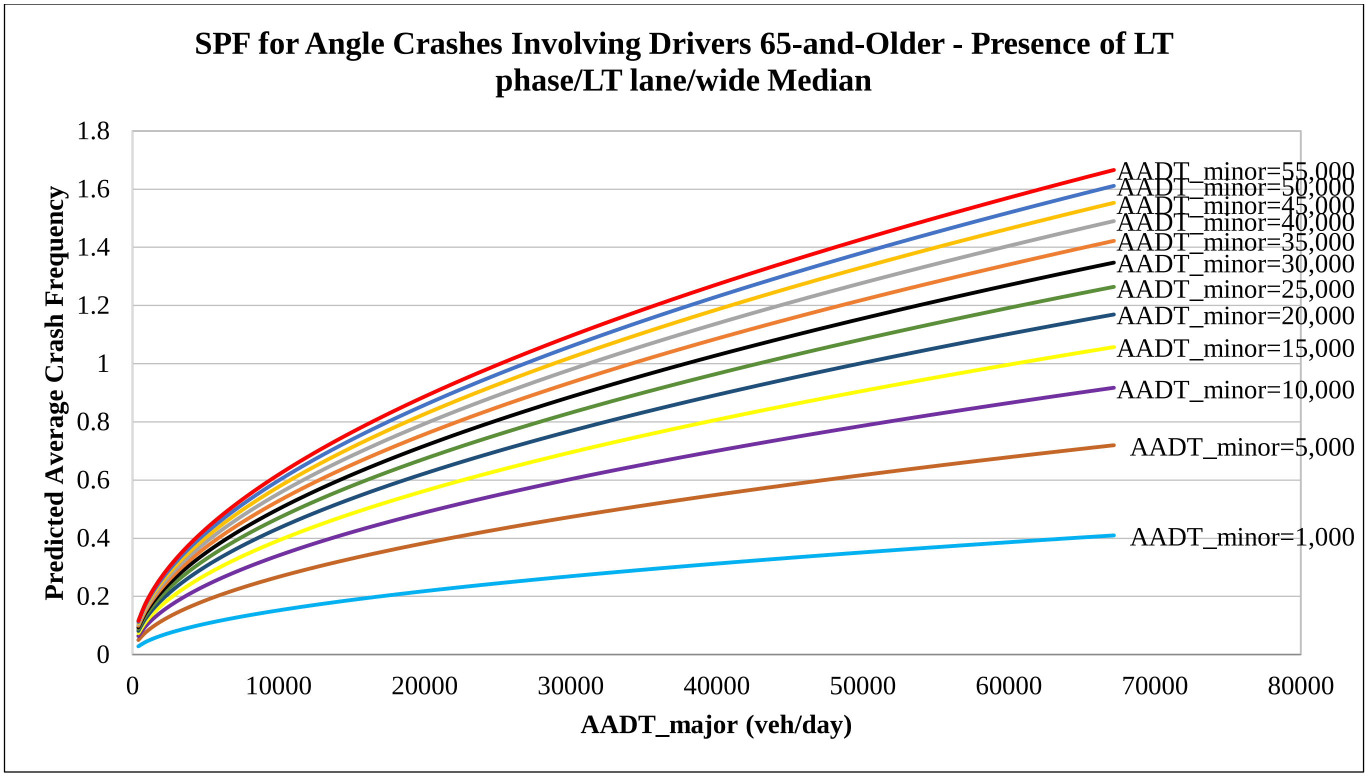

Figure 5.17 SPF for Angle Crashes Involving Drivers 65yrs-and-older - Presence of LT phase/LT lane/wide Median

6 Estimation of Crash Modification Factors (CMFs)

6.1 Introduction

The two approaches used to estimate Crash Modification Factors (CMFs) are presented in this chapter: Empirical Bayes (EB) method (where reliable SPFs were obtained) and Before-After with Comparison Group (where no reliable SPFs or impractical to develop SPFs). This chapter discusses the two methods in detail and provides the CMF results obtained. Although it was the intent of the research team to evaluate all countermeasures and crash conditions using the EB method, limitations on data needed to develop reliable SPFs called for application of an alternative method.

6.2 Empirical Bayes Method

The state of the art empirical Bayes (EB) methodology has been used by many researchers to conduct before-after studies. For example, in 2009 Srinivasan 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. Treatments evaluated included new chevrons, horizontal arrows, and advance warning signs – all with improvements to existing Fluorescent Yellow Sheeting. The results showed reductions in the number of crashes involving an injury and/or fatality by 18 percent. Other reductions included crashes in conditions such as nighttime conditions. The economic analysis revealed the cost-effectiveness the treatment provided. A year later, Feldman (2010) used a similar method to evaluate the safety effects of 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 percent in the number of accidents close to areas with high-visibility crosswalks. Authors recommended evaluating other factors affecting pedestrian safety. Three years later, Choi (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, slide-prevention devices, illumination and delineators 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.

In the EB evaluation of the effect of a treatment (Hauer, 1997; Hauer et al., 2002; Harkey et al, 2008, Persaud et al, 2010) the change in safety for a given crash type at a treated location is given by:

$$B - A$$

where *B* is the expected number of crashes in the "after" period if there was no treatment and *A* is the number of observed crashes in the after period. Because of changes in safety that may result from changes in traffic volume, from regression-to-the-mean and from trends in crash reporting and other factors, the count of crashes before a treatment by itself is not a good estimate. Instead, *B* is estimated from an EB procedure in which a safety performance function (SPF) is used to first estimate the number of crashes that would be expected in each year of the "before" period at locations with traffic volumes and other characteristics similar to a treatment site being analyzed. The expected number of crashes (*m*) before the treatment, which is estimated by combining the sum of these annual SPF estimates (*P*) with the count of crashes (*x*) in the before period at the treatment site, is calculated as:

$$m = w_1(x) + w_2(P)$$

The weights w_1 and w_2 are estimated as:

$$w_1 = \frac{P}{(P + \frac{1}{k})}$$

$$w_2 = \frac{1}{k(P + \frac{1}{k})}$$

where *k* is the over dispersion parameter of the negative binomial distribution that is assumed for the crash counts used in estimating the SPF.

The value of k is estimated from the SPF calibration process with the use of a maximum likelihood procedure. A factor determined by dividing the sum of the annual SPF predictions for the after period by P, the sum of these predictions for the before period, is then applied to m to account for the length of the after period and differences in traffic volumes between the before and after periods. In this procedure, an estimate of B as well as its variance is obtained. For all (or a given subset of) treatment sites, the estimate of B is then summed over all sites to obtain B_{sum} and compared with the count of crashes during the after period in that group (A_{sum}). Furthermore, the variance of B is also summed over all treatment sites of interest. Finally, the index of safety effectiveness (θ) is estimated as:

$$\theta = \frac{\left(A_{sum/B_{sum}}/B_{sum}\right)}{\{1 + [var(B_{sum})/(B_{sum}^2)]\}}$$

The standard deviation of θ is given by:

$$Stdev(\theta) = \left[\theta^2 \frac{\{[var(A_{sum})/(A_{sum}^2)] + [var(B_{sum})/(B_{sum}^2)]\}}{[1 + var(B_{sum})/(B_{sum}^2)]^2}\right]^{0.5}$$

The percent change in crashes can be estimated as 100(1- θ).

6.3 Before-After with Comparison Group

In order to evaluate the effectiveness and the safety impacts of countermeasures where SPFs were not reliable to apply the EB method, a before-after with comparison group methodology as described by Fayish and Gross (2010) and Hauer (1991), was used. In this method, a comparison group refers to a group of control sites that are selected based on similar traffic and geometric characteristics as the treated sites. Crash data from the comparison sites are used to estimate crashes that would have occurred at the treated sites if these sites had no treatment. The strength of this method vehemently depends on the similarities of the comparison sites to the treated sites as described by Shen and Gan (2003).

Qualitative evaluation of suitability and comparability of the non-treated sites can be done by plotting the crashes in the before years for both treated and untreated sites. If graphs trace each other well, it could be an indicator of suitability of comparison group site as described by Gross et al (2010). In terms of quantitative evaluation of the suitability and comparability of the non-treated sites, Gross et al (2010) discussed the use of sequence of sample odd ratios. In this, the sample odd ratios for each before-after pair can be computed using total crashes before treatment as follows:

$$Sample\ Odds\ Ratio = \frac{(T_{before} * C_{after})/(T_{after} * C_{before})}{(1 + \frac{1}{T_{after}} + \frac{1}{C_{before}})}$$

Where:

T_{before} = Total crashes for the treatment sites in year a,

T_{after} = Total crashes for the treatment sites in the year b,

C_{before} = Total crashes for the comparison group in year a,

C_{after} = Total crashes for the comparison group in year b.

A 95% confidence interval can be estimated as *mean* $\pm 1.96 *$ *Std. Dev.* If the confidence interval includes 1 with relatively small variance, the comparison group samples can be deemed suitable and similar to the treated samples.

The before-after with comparison group method is based on the following two basic assumptions that; (a) There is similar change in the factors that influenced safety in the before-after installation of countdown signals at both the treated and non-treated sites (comparison group) and (b) changes in these factors influenced safety at the treated and non-treated sites in the same way. This means that, the change in the number of crashes recorded before and after installation of the countermeasure at treated sites would be the same proportion as that of the non-treated sites if there were no countermeasure installed (Shen and Gan 2003). In addition to the above assumptions, geometric characteristics of the various intersections as well as other factors such as traffic data for both major and minor roads, type of intersection, median type, land use characteristics and number of lanes were some of the factors considered in choosing the comparison group as described by Fayish et al (2010). The main steps in the before-after with comparison group method is well described by Gross et al (2010). Suppose:

N_{TB}= number of crashes recorded in the before period at the treatment sites,
N_{TA} = number of crashes recorded in the after period at the treatment sites,
N_{CB}= number of crashes recorded in the before period at the comparison sites,
N_{CA}= number of crashes recorded in the after period at the comparison sites.

The comparison ratio describing how the number of crashes is expected to change in the absence of the treatment can be computed as follows:

$$Comparison\ ratio = \frac{N_{CA}}{N_{CB}}$$

The expected number of crashes for the treatment group that would have occurred in the after period without the installation of countdown signals ($Nexp_{TA}$) is estimated as:

$$Nexp_{TA} = (N_{TB})\left(\frac{N_{CA}}{N_{CB}}\right)$$

The variance of the expected number of crashes in the after period without treatment $Var(Nexp_{TA})$ is estimated as:

$$\mathrm{Var}(Nexp_{TA}) = (Nexp_{TA})^2\ \left(\frac{1}{N_{TB}} + \frac{1}{N_{CB}} + \frac{1}{N_{CA}}\right)$$

In order to compute the number of expected crashes after the installation of the treatment, a multiplicative factor called crash modification factor (*CMF*) as well as its variance [*var. (CMF)*] can be estimated as shown below:

$$\mathrm{CMF}= \frac{\frac{N_{TA}}{Nexp_{TA}}}{\left[1+\left(\frac{var(Nexp_{TA})}{{Nexp_{TA}}^2}\right)\right]}$$

$$Var(CMF) = CMF^2 \left\{ \frac{\left(\frac{1}{N_{TA}}\right) + \left(\frac{var(Nexp_{TA})}{Nexp_{TA}{}^2}\right)}{\left[1 + \left(\frac{var(Nexp_{TA})}{Nexp_{TA}{}^2}\right)\right]^2} \right\}$$

Furthermore, in order to measure the certainty or uncertainty in the crash modification factor, standard error and confidence interval can be computed as follows:

$$standard\ error = \sqrt{var(CMF)}$$

$$confidence\ interval = CMF \pm cumulative\ Probability * standard\ error$$

After estimating the CMF, crash reductions (in percent) can be obtained as 100*(1-CMF).

6.4 CMF Results and Discussions

6.4.1 CMFs for Segments

CMF results for segments and intersections are presented separately. CMFs for segments include those estimated for Clearview font signs, Fluorescent Yellow Sheeting, and arrow-per-lane signs. CMFs for intersections include those derived for box span signal installation and pedestrian countdown signals. The standard error associated with each CMF are also presented in parentheses. Furthermore, the method used to estimate each CMF (EB or before-after with comparison group) is identified. Table 6.1 presents the CMFs developed for segments while Table 6.2 shows the reductions (in percentage) derived from the CMFs. CMFs for drivers under 65 years old are presented in Appendix 6.1. It should be noted that although there were no specific sites where Clearview font signs were installed alone to allow direct development of CMFs for Clearview fonts, 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. The following equation was used to estimate the CMF for Clearview font signs (CMF_{CV}) from the CMF for Fluorescent Yellow Sheeting only (CMF_{FY}) and the CMF for both Fluorescent Yellow Sheeting and Clearview font ($CMF_{CV\text{-}FY}$):

$$CMF_{CV} = \frac{CMF_{CV-FY}}{CMF_{FY}}$$

Table 6.1 Summary of CMFs for Segments

Countermeasure Information		All Severities (KABCO)	Fatal Injury (KABC)	All Severities (KABCO) Day	All Severities (KABCO) Night	All Severities 65yrs-and-Older	All Severities 65yrs-and-Older Day	All Severities 65yrs-and-Older Night
Freeways	Clearview & Fluorescent	0.759 (0.0190)	0.930 (0.0498)	0.798 (0.0261)	0.741 (0.0281)	*0.899 (0.144)	*0.912 (0.170)	*0.902 (0.270)
	Fluorescent Only	0.851 (0.0294)	0.963 (0.0733)	0.819 (0.0367)	0.998 (0.0534)	*0.998 (0.184)	*0.938 (0.209)	*0.913 (0.307)
	Clearview Only	0.892	0.966	0.974	0.742	0.900	0.972	0.988
Urban Non-Freeways	Clearview & Fluorescent	0.704 (0.0288)	0.711 (0.0602)	0.730 (0.0350)	0.657 (0.0514)	0.859 (0.0854)	0.895 (0.0975)	*0.964 (0.143)
	Fluorescent Only	0.949 (0.0288)	0.917 (0.0578)	0.932 (0.0342)	0.993 (0.0523)	0.963 (0.0675)	0.965 (0.0740)	*0.986 (0.0775)
	Clearview Only	0.742	0.775	0.783	0.662	0.892	0.927	0.978
Rural Non-Freeways	Clearview& Fluorescent	0.670 (0.0236)	*0.927 (0.0261)	0.716 (0.0385)	0.667 (0.0310)	0.783 (0.0741)	0.941 (0.120)	*0.977 (0.0835)
	Fluorescent Only	0.923 (0.0264)	*0.972 (0.0185)	0.883 (0.0396)	0.973 (0.0355)	0.895 (0.0675)	0.993 (0.0977)	*0.998 (0.0547)
	Clearview Only	0.726	0.954	0.811	0.686	0.875	0.948	0.979
Arrow-Per-Lane	All Crashes	*0.578 (0.0845)				*0.319 (0.0909)		

- ** Indicates CMFs estimated with Before-After with comparison groups method*
- *Numbers in brackets are standard errors estimated for the CMFs*

Table 6.2 Crash reduction factors (in %) for segments

Countermeasure Information		All Severities (KABCO)	Fatal Injury (KABC)	All Severities (KABCO) Day	All Severities (KABCO) Night	All Severities 65yrs-and-older	All Severities 65yrs-and-older Day	All Severities 65yrs-and-older Night
Freeways	Clearview & Fluorescent	24	7	20	26	10	9	10
Freeways	Fluorescent Only	15	4	18	0.20	0.20	6	9
Freeways	Clearview Only	11	3	3	26	10	3	1
Urban Non Freeways	Clearview & Fluorescent	30	29	27	34	14	11	4
Urban Non Freeways	Fluorescent Only	5	8	7	1	4	4	1
Urban Non Freeways	Clearview Only	26	23	22	34	11	7	2
Rural Non Freeways	Clearview& Fluorescent	33	7	28	33	22	6	2
Rural Non Freeways	Fluorescent Only	8	3	12	3	11	1	0.20
Rural Non Freeways	Clearview Only	27	5	19	31	13	5	2
Arrow-Per-Lane	All Crashes	42				68		

Note: Positive means reduction; Negative means increase

Table 6.1 and Table 6.2 show that overall, reductions are observed in all crash conditions. CMFs for drivers under 65 years are provided in Appendix 6.1. Statistically, there is significant reduction in total (all severities) crashes resulting from implementation of the countermeasure. Reduction in fatal and injury crashes is observed in both rural and urban non-freeways as a result of installing Fluorescent Yellow Sheeting and Clearview font signs. Statistically significant reductions were observed especially when the two countermeasures were installed together (i.e., 29 percent in urban areas and 7 percent in rural areas). Another significant value in the same crash condition was observed in the case of the presence of Fluorescent Yellow Sheeting only in non-freeways rural areas with a reduction of 8%. Arrow-per-lane signs exhibited a statistically strong reduction in total (all severities crashes), with a reduction of 42 percent.

In terms of time of the day, all reductions resulting from Fluorescent Yellow Sheeting and Clearview font signs during daytime were found to be statistically significant. Dusk and dawn crashes were included in nighttime crashes during analyses. In all situations analyzed the impact in day time showed significant reductions, at 95% confidence level, while in night time the significant values were observed only where the Clearview fonts were included. The significant nighttime reductions resulting from both Clearview font and Fluorescent Yellow Sheeting were 26 percent, 34 percent, and 33 percent for freeways and non-freeways urban and rural areas, respectively. These reductions are consistent with the fact that Fluorescent Yellow Sheeting and Clearview font signs are probably very important in non-freeways. Freeways are, in principle, much safer than roads with at-grade crossings. The design standards eliminate the frictions that are responsible to a vast majority of crashes: grade crossings, left turns, opposite traffic (since they have medians by design), etc. They also maintain higher design speeds and capacity than less safe local streets (Pedestrian Observations, 2015). However, certain skills (e.g. such as being able to react safely before missing an exit, driving at high speeds, etc.) are needed for driving in freeways that to avoid potential accidents (American Automobile Association, 2005). Sign improvements that make the signs visible and easy to read are necessary in both freeways and non-freeways.

Regarding age groups it was determined that overall, Clearview font signs and Fluorescent Yellow Sheeting reduce crashes involving drivers 65yrs-and-older. However, the significant reductions were observed when both Clearview font signs and Fluorescent Yellow Sheeting were installed together (14 percent reduction in urban non-freeways and 22 percent reduction in rural non-freeways). Even though there was a crash reduction in different periods of the day for this age group, none of them were statistically significant. The arrow-per-lane signs indicated a reduction of 68 percent in sideswipe crashes involving the drivers 65yrs-and-older.

6.4.2 CMFs for Intersections

Intersection sites evaluated in this study were those with box span signal installations and pedestrian countdown signals. For box span signal installations, CMFs were estimated for the following crash types:

- Intersection Total Crashes (all ages and drivers 65yrs-and-older)
- Intersection Fatal and Injury Crashes (all ages and drivers 65yrs-and-older)
- Angle Crashes (all ages and drivers 65yrs-and-older)

The results from the EB analysis for the all age category and the 65yrs-and-older category are shown in Table 6.3. The Empirical Bayes (EB) methodology outlined in the HSM in combination with the SPFs developed in the previous task, was utilized to calculate the expected crash frequency without treatment in the after period. A traditional before-after analysis was also conducted for comparison purposes. The significance testing was performed based on the methodology outlined in the HSM.

For pedestrian countdown signals, the evaluation was done using the before-after with comparison group methodology as described earlier in the report. The following crash categories were used in evaluating the effectiveness of pedestrian countdown signals:

- Total crashes (all drivers, all severities)
- Fatal and injury crashes (all drivers)
- Total crashes (drivers age 65yrs-and-older)
- Fatal and injury crashes (drivers age 65yrs-and-older)
- Total pedestrian crashes (all ages)
- Fatal and injury pedestrian crashes (all ages)
- Pedestrian age 65yrs-and-older total crashes
- Pedestrian age 65yrs-and-older fatal and injury crashes

Crashes during the before and after installations of the pedestrian countdown signal for the various categories under study were used in the computations for the expected crashes at the treatment locations in the after period. Table 6.3 presents the CMFs obtained while Table 6.4 presents the crash reductions (in percent) associated with these CMFs.

Table 6.3 CMFs for intersections

Countermeasure Information		All Severities (KABCO)	Fatal Injury (KABC)	All Severities 65yrs-and-Older	Fatal Injury 65yrs-and-Older
Pedestrian Countdown Signal (PCS)	*All Drivers*	*0.946 (0.035)	*0.927 (0.072)	*0.849 (0.092)	*0.477 (0.117)
	All Pedestrians	*0.683 (0.173)	*0.804 (0.223)	*0.353 (0.211)	*0.449 (0.266)
Box Span Signal Installations	*All Crashes*	0.975 (0.040)	0.897 (0.079)	1.097 (0.099)	0.888 (0.164)
	Angle Crashes	0.876 (0.070)		0.841 (0.133)	

- ** Indicates CMFs estimated with Before-After with comparison groups method*
- *Numbers in brackets are standard errors estimated for the CMFs*

Table 6.4 Crash reduction factors (in %) for intersections

Countermeasure Information		All Severities (KABCO)	Fatal Injury (KABC)	All Severities 65yrs-and-Older	Fatal Injury 65yrs-and-Older
Pedestrian Countdown Signal (PCS)	*All Drivers*	5	7	15	52
	All Pedestrians	32	20	65	55
Box Span Signal Installations	*All Crashes*	3	10	-10	11
	Angle Crashes	12		16	

Note: Positive means reduction; Negative means increase

7 Benefit-Cost Analysis

7.1 Introduction

The change in safety for each site as a result of implementation of the countermeasure is represented by the CMFs presented in Chapter 6. The CMFs were applied to estimate crash cost benefits in an economic analysis of the treatments to assess the cost-effectiveness of the improvements to date. Benefit to cost analyses for the countermeasures were done by determining the expected crash reductions due to the presence of the countermeasure from the CMF and crash savings associated with the crash. Crashes were disaggregated by crash type and severity to the extent possible and unit crash costs for those types and severities were applied before aggregating to obtain an overall crash cost savings.

A report by Kostyniuk et al (2011) documents average cost of traffic crash in the state of Michigan as $19,999. Using the same report, it was determined that fatal/ Injury (FI) and property damaged only (PDO) crash cost averaged $106,861 and $3,690, respectively. Their estimates were based on both monetary costs which relate to medical care, emergency responses, and non-monetary costs (quality-of-life) pertaining to the state of Michigan.

Reduction in fatal and injury (FI) crashes was determined by subtracting the observed crashes from the expected FI crashes, while reduction in total crashes was obtained by subtracting observed total crashes from expected total crashes. The reduction in Property Damage Only (PDO) crashes was then determined as the difference between reduction in total crashes and reduction in FI crashes. Finally, annual crash saving was computed as follows:

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

All benefit-cost ratio (BCR) calculations were based on present values of crash saving and costs associated with a given countermeasure. A discount rate of 3.4, associated with a 30 years of service life, was used for pedestrian countdown and box span signal installation. For signs (Fluorescent Yellow Sheeting, Clearview font, and arrow-per-lane), a discount rate of 2.95 percent was used. The service life for signs was assumed to be 15 years. The discounted present value of benefits (crash saving) was determined from the estimated annual crash saving as follows:

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

Where:

PV = Present value of savings,

R = discount rate (in decimals),

N = Service life (years).

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

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

7.2 Cost of Countermeasures

7.2.1 Clearview Font and Fluorescent Yellow Sheeting

MDOT provided generic costs for installing Fluorescent Yellow Sheeting and Clearview font signs. It was determined that implementing Clearview font sign costs $41 more than the previous MDOT standard font, while installing the Fluorescent Yellow Sheeting costs $46 more than the cost to install the old standard, Type IV yellow sheeting sign. Table 7.1 provides a summary of installation costs for Clearview font signs and Fluorescent Yellow Sheeting. These costs are applicable to both freeways and non-freeways. It was determined that the difference in maintenance costs is negligible and the service life is the same for both the standard and the improvement.

Table 7.1 Summary of installation costs for Fluorescent Yellow Sheeting and Clearview font

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

7.2.2 Box Span Signal Installation

MDOT provided cost estimates for the installation of a diagonal span configuration and a box span configuration at four sample locations outlined in Table 7.2. These cost estimates were used to estimate the differential cost at each of the treatment locations to be utilized in the economic analysis.

Table 7.2 Sample box span signal installation costs

Intersection Type	Diagonal Span	Box Span	Differential Cost
Wide intersection, 2 signal head on each approach, no left-turn phasing	$57,600	$105,200	$47,600
2 signal heads on each approach, no left-turn phasing	$48,000	$80,200	$32,200
2 signal heads on each approach, plus left-turn signal on major	$47,500	$72,400	$24,900
2 signal heads on each approach, plus left-turn signal on major and minor	$60,500	$83,000	$22,500

Based on 117 treated sites, it was determined that the average installation cost for a box span signal is $83,239 compared to $49,957 for installing diagonal signal at the same site. This yields an average differential cost of $33,282 per intersection. The maintenance cost was regarded to be the same for diagonal and box span signal installation.

7.2.3 Pedestrian Countdown Signals

For pedestrian countdown signal, it was determined that the cost for one countdown signal head is $291.90 compared to $185.63 for a standard pedestrian signal head. For a typical four-leg signalized intersection (with a total of 8 signal heads), the differential cost was determined to be $850.16. The service life was assumed to be 30 years, while the maintenance cost was assumed to be the same for both pedestrian countdown signal and standard pedestrian signal.

7.2.4 Arrow-Per-Lane Signing

MDOT provided sign sizes for generic standard diagrammatic signs and arrow-per-lane signs as outlined below in Table 7.3. The unit price was retrieved from MDOT's "2015 Average Unit Prices" spreadsheet. The differential cost is the difference in installation between a standard diagrammatic sign and an arrow-per-lane sign. These are the costs utilized in the economic analysis.

Table 7.3 Arrow-Per Lane Costs

Generic Sign w/ # of lanes		Width (ft)	Height (ft)	Total Sft	Unit Price	Total	Differential Cost
2 Lanes	Diagrammatic	28	11.5	322	$22.06	$7,103	$1,390
	Arrow-Per-Lane	27.5	14	385	$22.06	$8,493	
3 Lanes	Diagrammatic	28	11.5	322	$22.06	$7,103	$3,398
	Arrow-Per-Lane	34	14	476	$22.06	$10,501	
4 Lanes	Diagrammatic	28	11.5	322	$22.06	$7,103	$6,177
	Arrow-Per-Lane	43	14	602	$22.06	$13,280	

With eight sites evaluated in this study, it was determine that the average installation cost of arrow-per lane signs per site is $14,643 compared to $11,824 for standard diagrammatic signs. This yields the differential cost of $2,819 per site.

7.3 Benefit-Cost Ratio Calculations

Table 7.4 presents a summary of BCR calculations for each countermeasure. The BCR are based on savings and costs per mile, in the case of segment sites, and per intersection for intersection sites. These values were determined based on crashes involving all drivers (or pedestrians for the case of pedestrian countdown signal) due to the fact that a countermeasure benefiting older drivers proved to benefit all drivers. While it is possible to estimate the BCR for older drivers only, the BCR values presented in Table 7.4 are inclusive and represent the total benefits associated with the countermeasures.

Based on the BCR obtained through economic analysis it can be concluded that the countermeasures are not only reducing the number of crashes but also providing significant annual cost savings. The larger benefit is observed in non-freeways urban areas when both Clearview font and Fluorescent Yellow Sheeting are used. Other countermeasures such as Pedestrian Countdown Signals (PCS) and Arrow-Per-Lane diagrammatic signs provided high BCR. The Box Span installations provided an economic benefit overall.

Table 7.4 Summary of Benefit-Cost Analysis

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
Intersections	Box Span Signal Installation	0.975	9.09	0.23	0.897	1.93	0.22	0.01	$23,724.43	$441,859.51	$33,282.00	13
Intersections	Pedestrian Countdown Signals (PCS) Installations	0.946	9.75	0.56	0.927	2.24	0.18	0.38	$20,252.72	$377,200.09	$822.74	458
Freeway Segments	Arrow-Per-Lane Diagrammatic Signing	0.578	23.21	16.95					$338,893.85	$4,060,363.06	$2,818.75	1440

8 Conclusions and Recommendations

The objective of this research was to evaluate the safety benefits of each of the studied improvements for all ages and for older drivers: Clearview font legend on guide signs for both freeway and non-freeway, Box Span Signal Installation, Pedestrian Countdown Signals, Fluorescent Yellow Sheeting on Warning Signs, Arrow-Per-Lane Signs and develop Safety Performance Functions (SPF) and Crash Modification Factors (CMF) for these improvements.

Arrow-Per-Lane signs reduce crashes significantly. The 65yrs-and-older driver total crashes can be reduced by up to 68% compared to the reduction of 42% in crashes for all drivers. The benefit-cost ratio for an average site is about 1440:1. The improvement is strongly preferred by the 65yrs-and-older drivers when in unfamiliar areas and when trying to understand a sign from a far distance.

The box span signal installation reduces overall crashes. Angle crash reduction is significant for all drivers. There is a crash reduction in angle crashes and overall fatal/injury crashes for the 65yrs-and-older drivers. All crashes and fatal/injury crashes are reduced for All Drivers. The benefit-cost ratio for an average intersection is 13:1.

Pedestrian countdown signals reduce pedestrian and all crashes. They significantly reduce total crashes for all drivers (5 percent reduction), total crashes for the 65yrs-and-older drivers (15 percent), and fatal/injury crashes for all drivers (7 percent), and fatal/injury crashes for 65yrs-and-older drivers (52 percent). Furthermore, the pedestrian countdown signals reduce total crashes for all pedestrians (32 percent reduction), total crashes for 65yrs-and-older pedestrians (65 percent), fatal/injury crashes for all pedestrians (20 percent), and fatal/injury crashes for the 65yrs-and-older pedestrians (55 percent). The benefit-cost ratio for an average intersection installed with pedestrian countdown signal is 459:1. Survey results indicated that pedestrians strongly prefer the improvement when deciding to start crossing and when deciding to adjust walking speed.

Fluorescent Yellow Sheeting and Clearview font were found to reduce crashes for 65yrs-and-older as well as for all drivers. Reduction percent is relatively higher when both countermeasures are installed together (relative to just Fluorescent Yellow Sheeting). The average benefit-cost ratio based on average segment mile are 2,716:1 for Clearview font and Fluorescent Yellow Sheeting on freeways, 7,456:1 for Clearview font and Fluorescent Yellow Sheeting on Urban Non-freeways, and 1,090:1 for Clearview font and Fluorescent Yellow Sheeting on rural non-freeways. The benefit-cost ratio for Fluorescent Yellow Sheeting only on freeways is 4,107:1 while the benefit-cost ratio for Fluorescent Yellow Sheeting only on urban non-freeways is 4,064:1 and for Fluorescent Yellow Sheeting only on rural non-freeways is 581:1.

The survey results indicated that Fluorescent Yellow Sheeting is preferred on high speed roads, inclement weather and nighttime. Also, the survey participants preferred Clearview font signs in high speed roads, inclement weather and from far distance.

This study recommends to continue installation of the countermeasures as they reduce crashes and are economically beneficial. Since the benefits outweigh the cost significantly (except box span installation), replacement before the end of life should be considered.

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10 APPENDICES

10.1 Appendix 3.1. Survey Questionnaire and Analysis by All Ages

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:

1. Are you currently driving in the state of Michigan?

   ☐ Yes

   ☐ No

2. What is your age group in years?

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

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

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

<u>Hold both pictures in front of participant and proceed with questioning…</u>

4. 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: ______________________________________

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

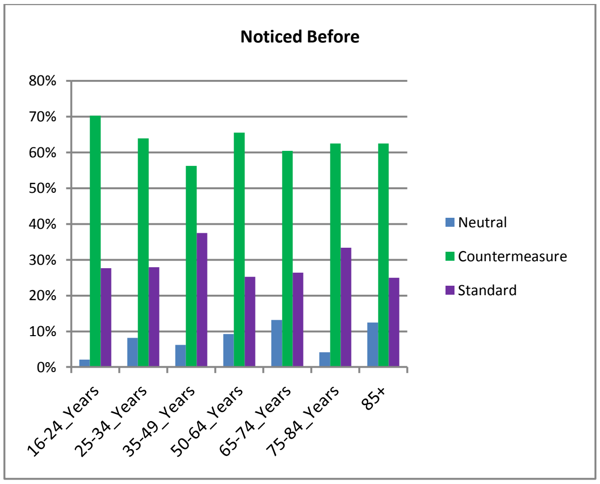
☐ Yes

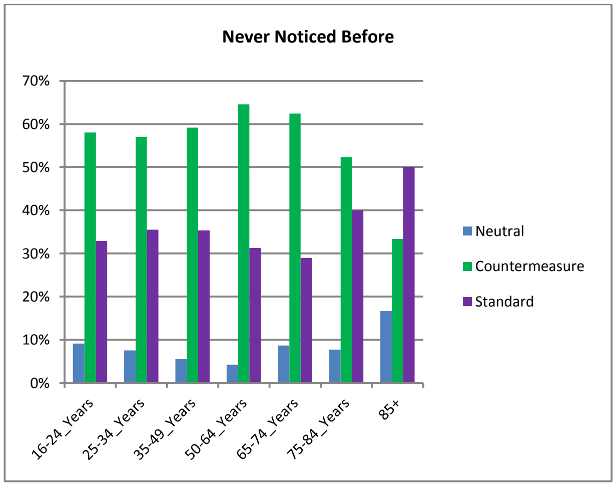
☐ No

☐ I do not know

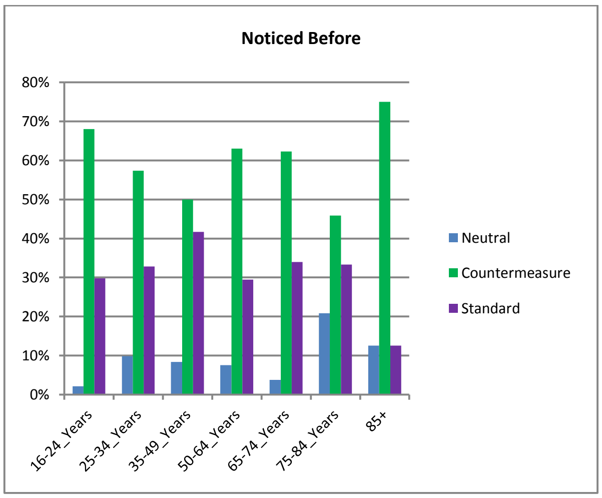
Clearview fonts Results

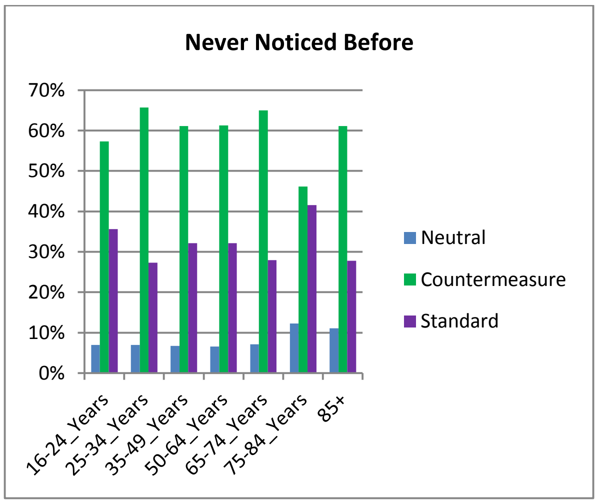
On High Speed Roads



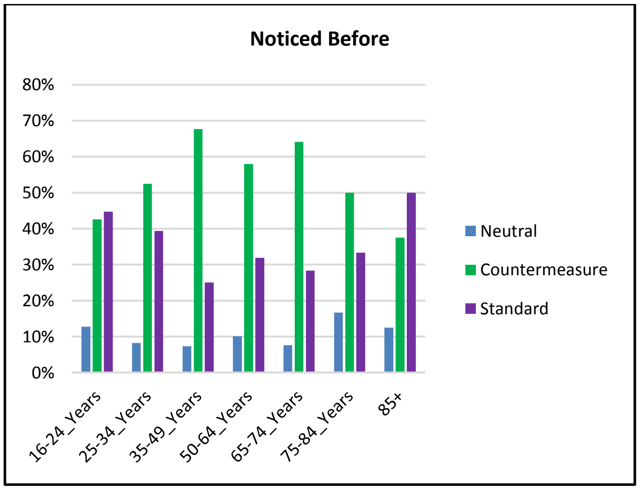


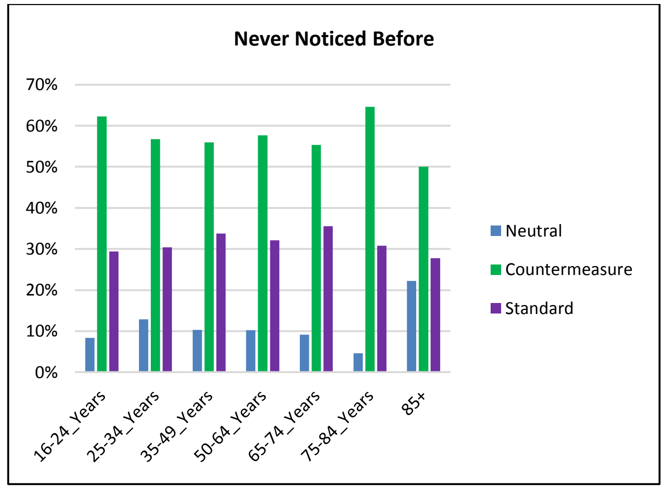
From Far Distance



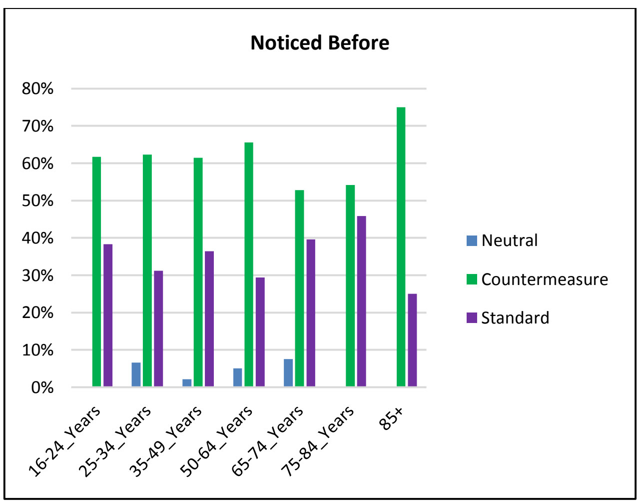


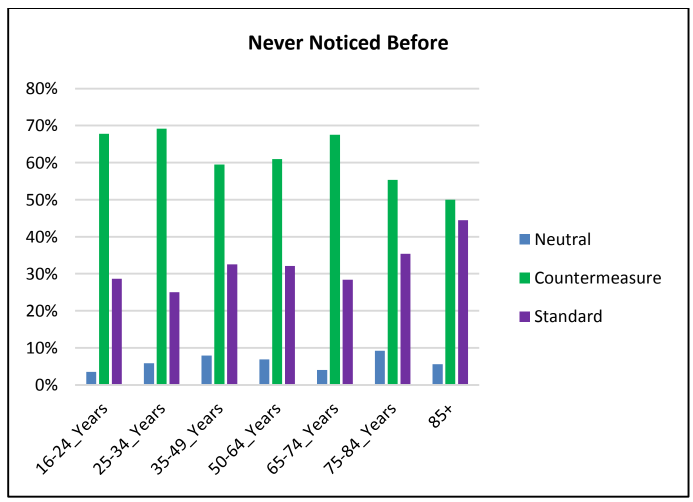
In Inclement Weather





In Nighttime





Countermeasure #2: Box Span Signal Installations

<u>Hold pictures in front of participant and proceed with questioning…</u>

#1

#2

1. Which signal layout makes it easier to see the signal heads, and how would you rate its usefulness on a scale of 1 to 3 (1 = low; 2 = medium; 3 = high)?

Option #1 (Box Span)					*Option #2 (Diagonal)*			
Improving Visibility of Signal Heads								
NA	3	2	1	Neutral	1	2	3	NA
Finding the Proper Lane at Intersection								
NA	3	2	1	Neutral	1	2	3	NA

- Remarks: ____________________________________

2. Have you ever noticed the difference in layouts of traffic lights while driving prior to this interview?

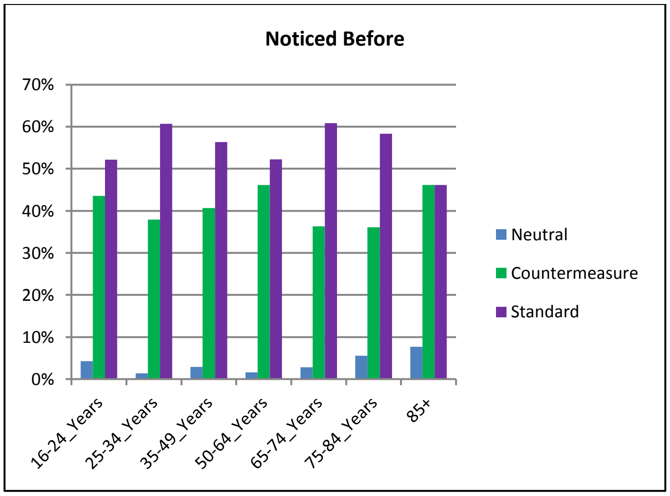
☐ Yes

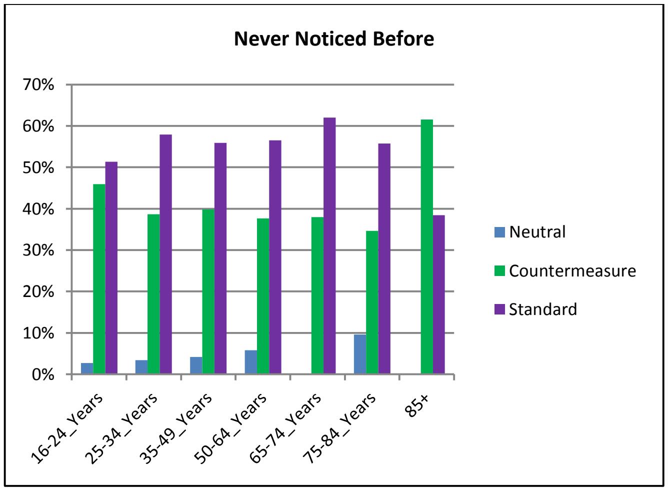
☐ No

☐ I do not know

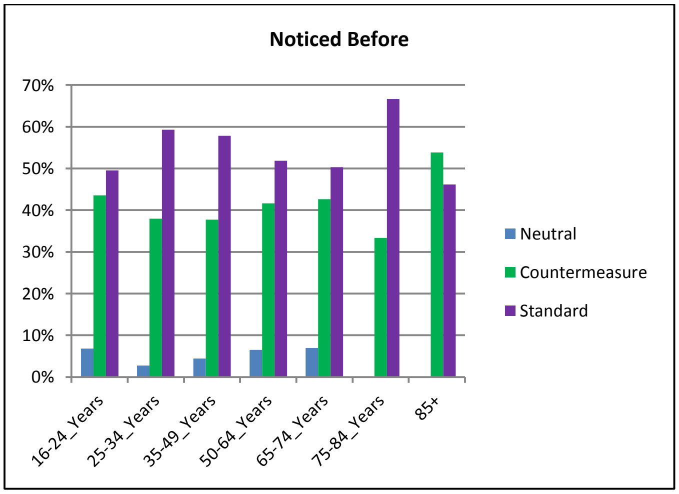
<u>Box Span Signal Installation Results</u>

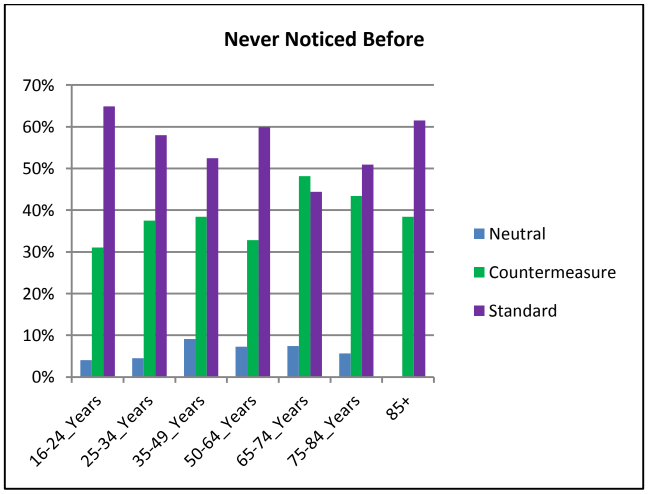
Improving Visibility





Finding Proper Lane





Countermeasure #3: Pedestrian Countdown Signals (PCS)

<u>Hold pictures in front of participant and proceed with questioning…</u>

#1 #2

3. Which paired of sign display is more helpful in the following situations, and how would you rate its helpfulness on a scale of 1 to 3 (1 = low; 2 = medium; 3 = high)?

<table>
<tr><td colspan="4">Option #1 (Pedestrian Signal With Countdown)</td><td colspan="5">Option #2 (Pedestrian Signal Without Countdown)</td></tr>
<tr><td colspan="9">Deciding whether to start crossing the street or not</td></tr>
<tr><td>NA</td><td>3</td><td>2</td><td>1</td><td>Neutral</td><td>1</td><td>2</td><td>3</td><td>NA</td></tr>
<tr><td colspan="9">Adjusting Walking Speed</td></tr>
<tr><td>NA</td><td>3</td><td>2</td><td>1</td><td>Neutral</td><td>1</td><td>2</td><td>3</td><td>NA</td></tr>
<tr><td colspan="9">Increasing Feeling of Safety while Crossing</td></tr>
<tr><td>NA</td><td>3</td><td>2</td><td>1</td><td>Neutral</td><td>1</td><td>2</td><td>3</td><td>NA</td></tr>
</table>

- Remarks: ___________________________________

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

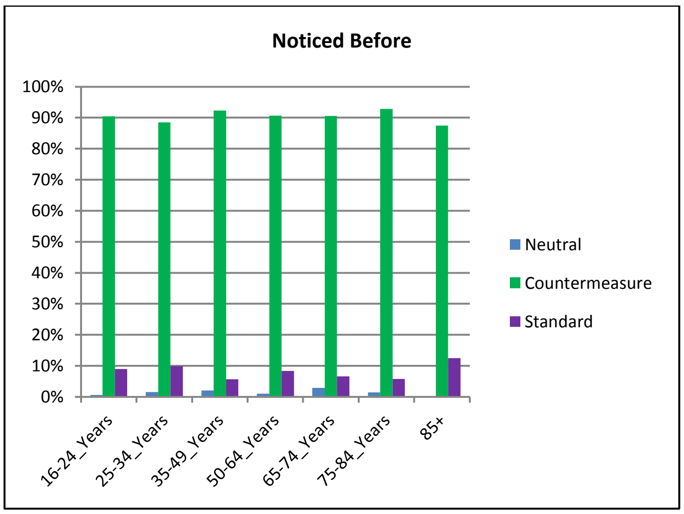
☐ Yes

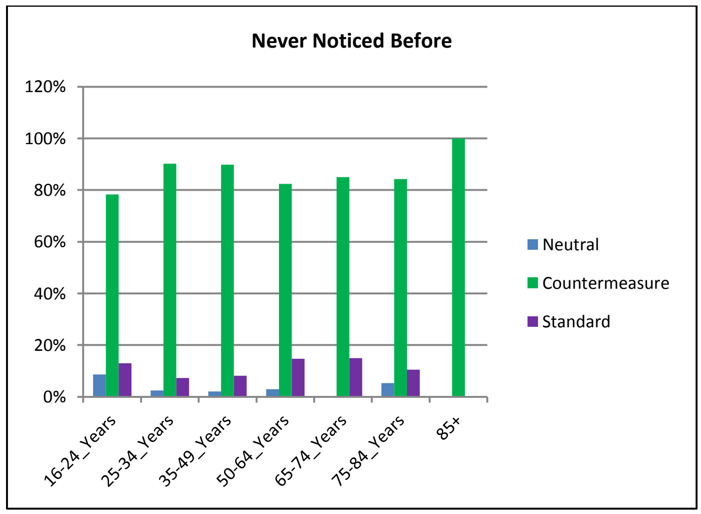
☐ No

☐ I do not know

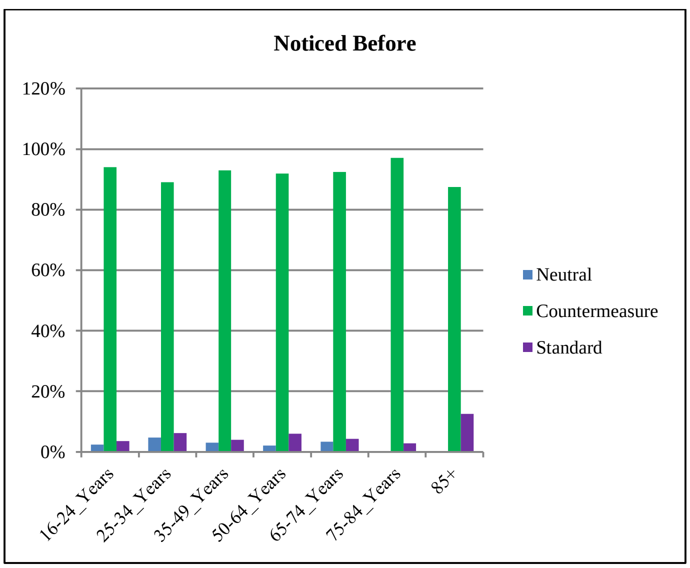
<u>Pedestrian Countdown Signals (PCS) Results</u>

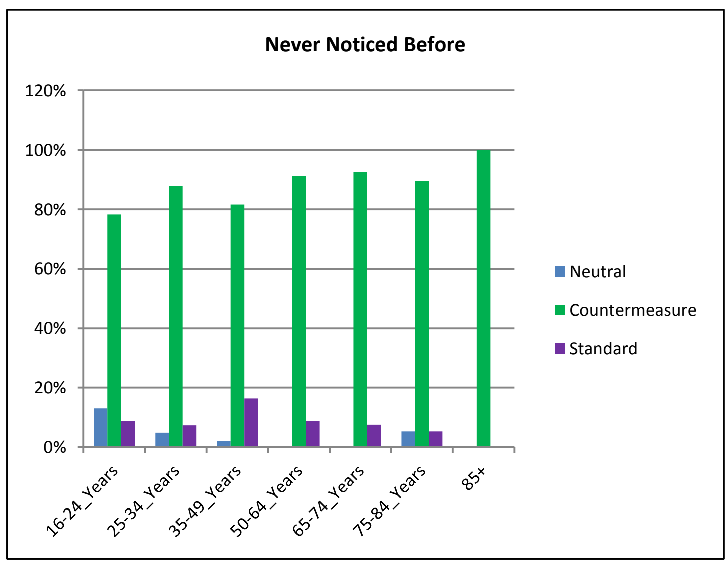
Deciding to Cross the Street



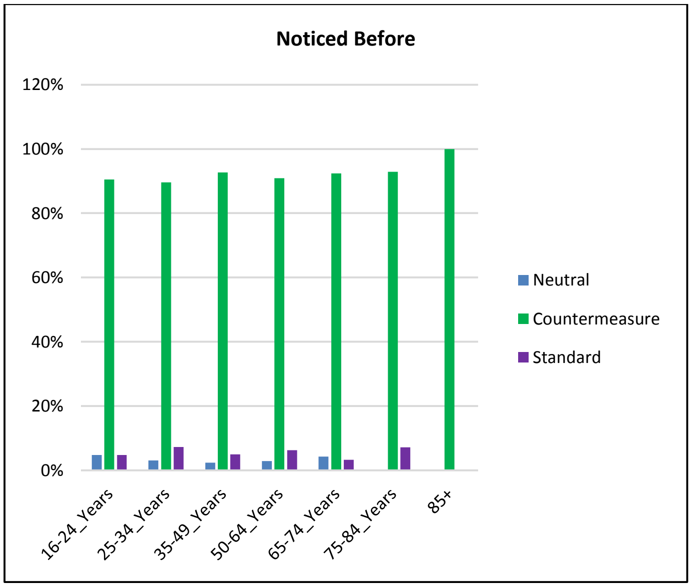


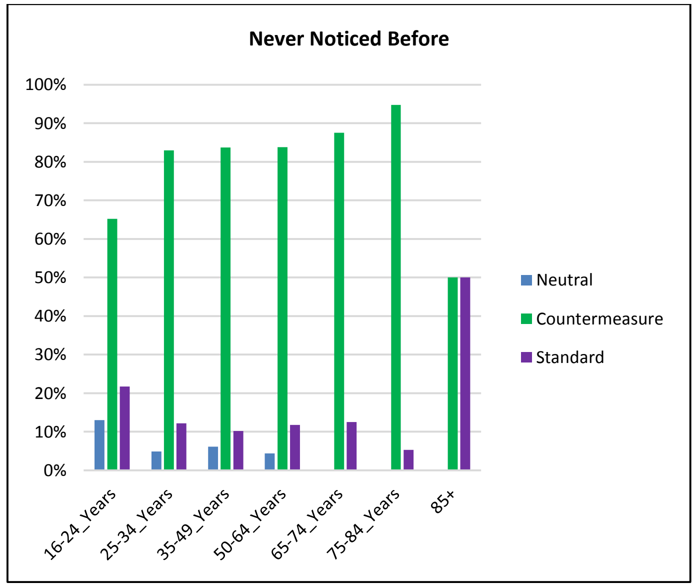
Adjusting Walking Speed





Increasing Feeling of Safety





Countermeasure #4: Fluorescent Yellow Sheeting

Hold pictures in front of participant and proceed with questioning…

5. 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: ____

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

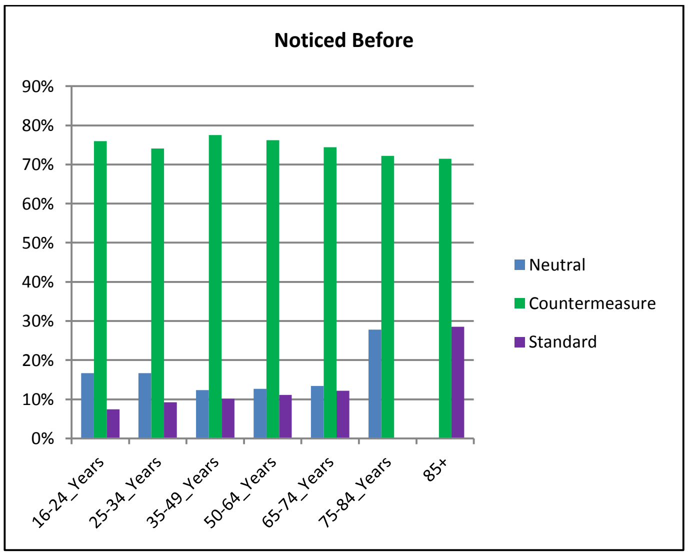
☐ Yes

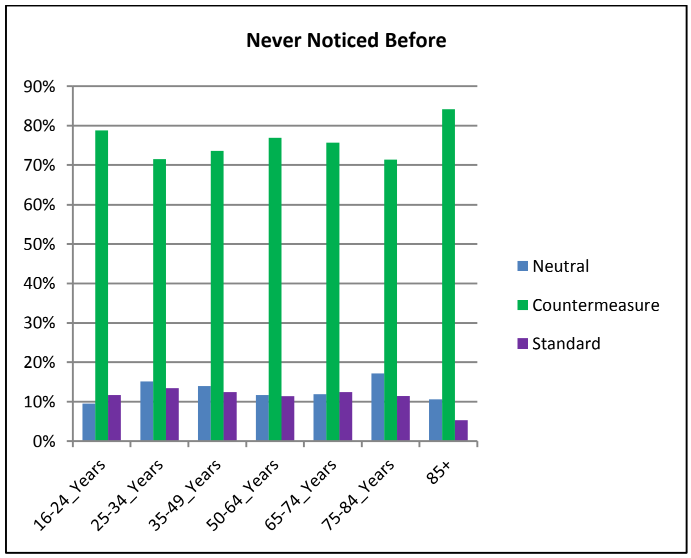
☐ No

☐ I do not know

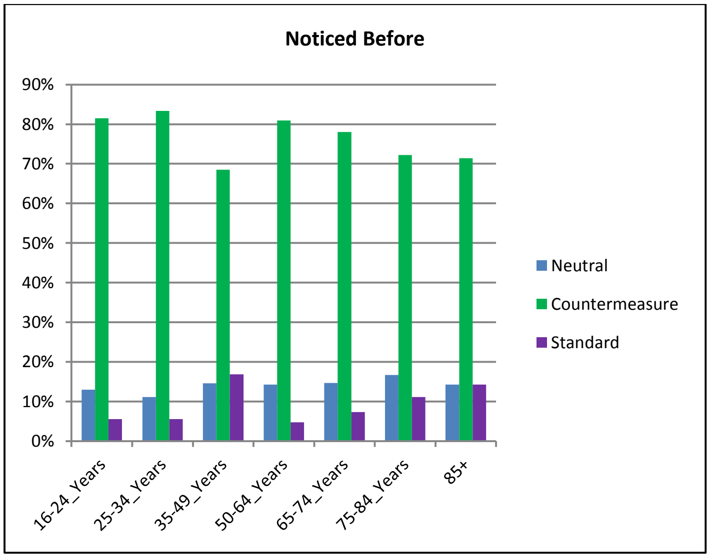
Fluorescent Yellow Sheeting Results

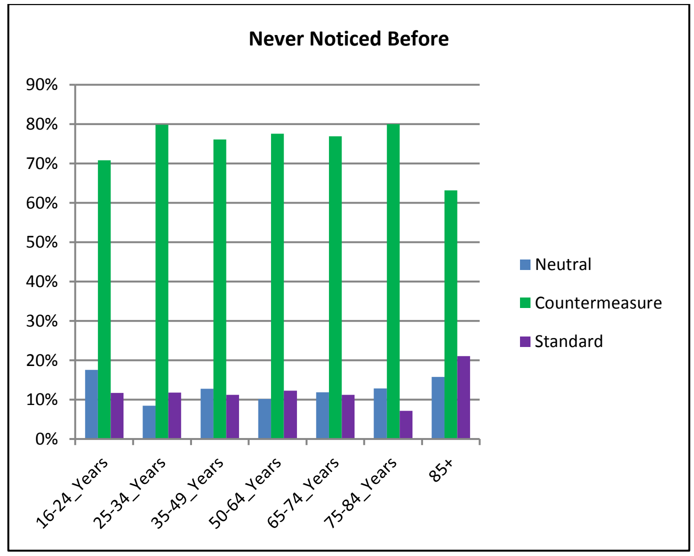
On High Speed Roads



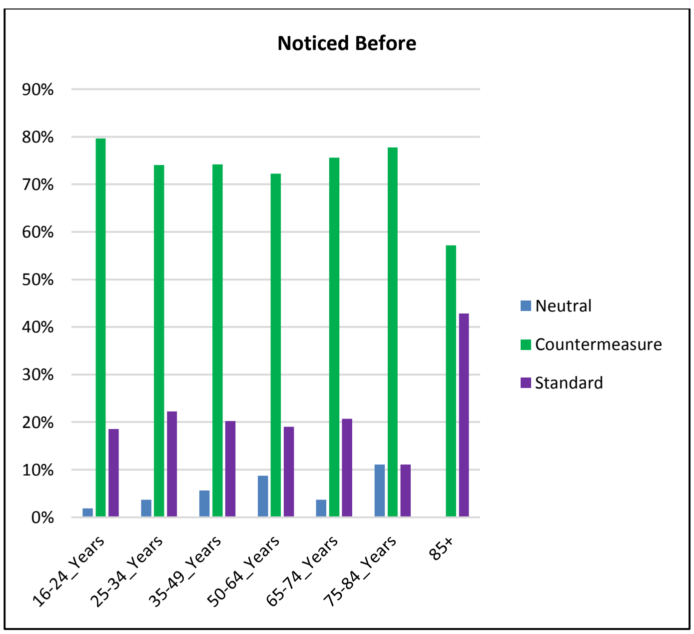


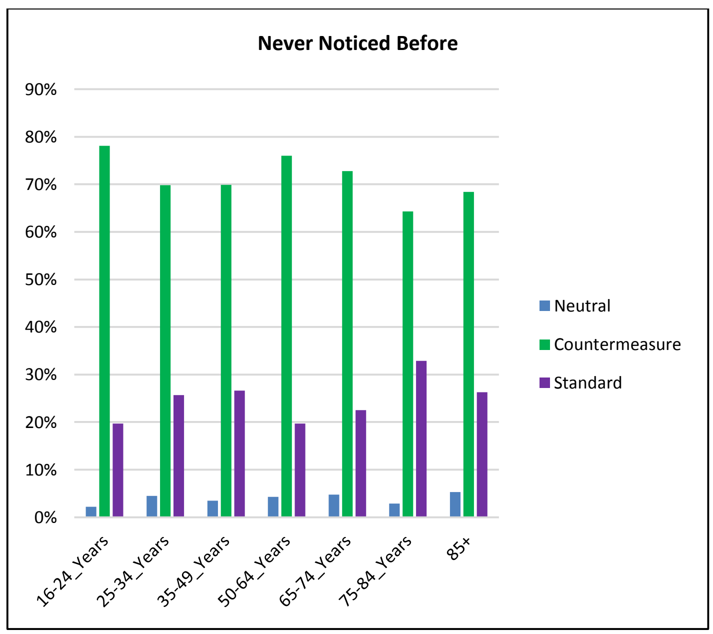
In Inclement Weather





In Nighttime





Countermeasure #5: Lane Use Arrows

<u>Hold pictures in front of participant and proceed with questioning…</u>

#1

#2

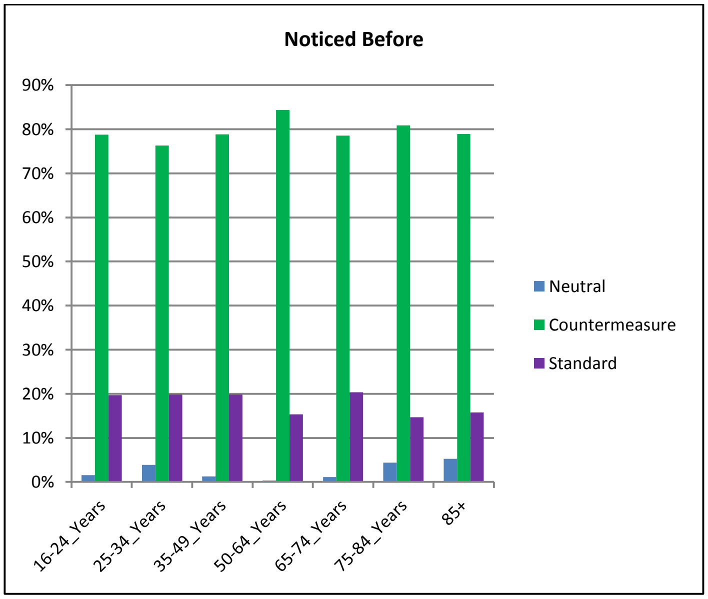
7. Which sign would make it easier to find the lane you want to be in use sign for the following situations, and how would you rate it on a scale of 1 to 3 (1 = low; 2 = medium; 3 = high)?

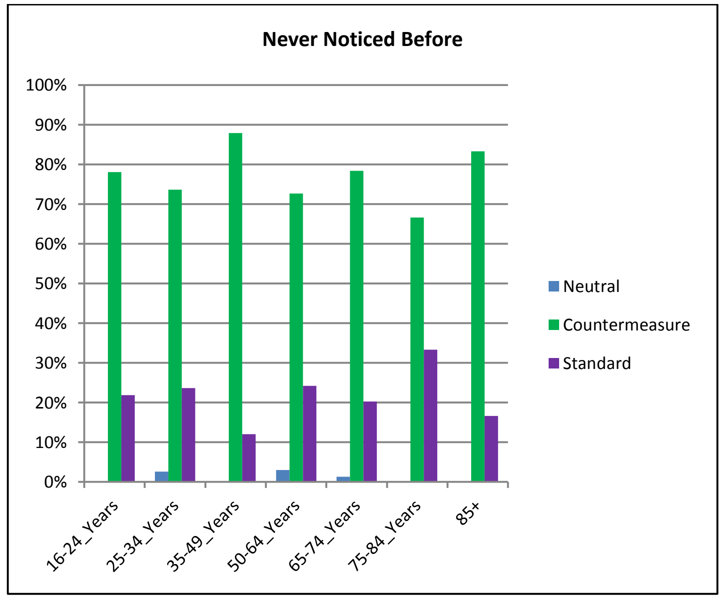
Option #1 (Lane Use Arrows)					*Option #2 (Standard)*			
				Unfamiliar Areas				
NA	3	2	1	Neutral	1	2	3	NA
				Far From the Sign				
NA	3	2	1	Neutral	1	2	3	NA

- Remarks: ______________________________________

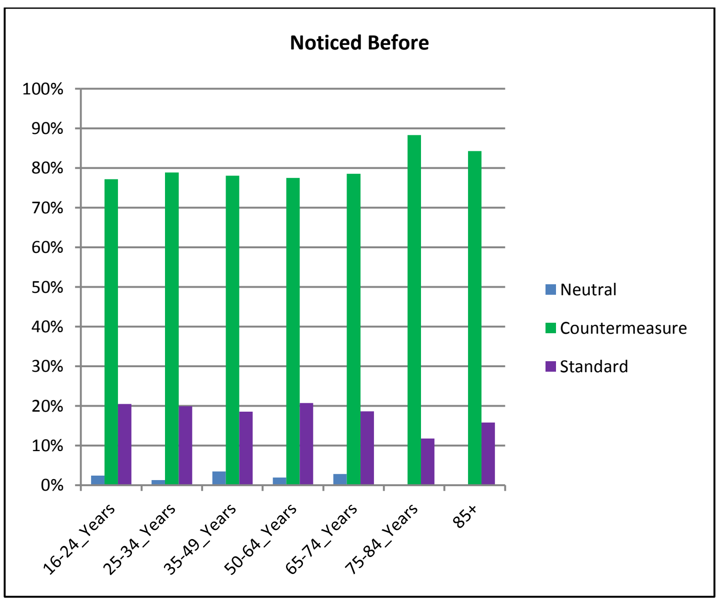
Lane Use Arrows Results

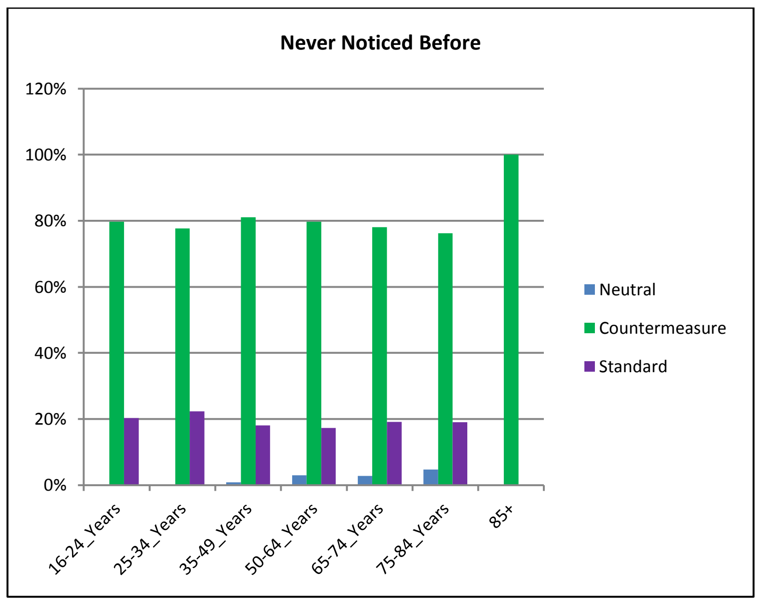
In Unfamiliar Areas





From Far Distance





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

   ☐ No

   ☐ I do not know

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

   ☐ No

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

____

____

10. 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: ____

10.2 Appendix 4.1. Detailed Data Collected

Table 4.A. Example of Crash Data Summary for Arrow-Per Lane Sign for Drivers 65yrs-and-older

Treatment Site Installed	I-96 & I-196 2009	1st Sign Decision Sight Distance				
		Sev.	65-74 Years	75-84 Years	85+ years	All Ages
Before 2004-2008	Crashes	Fat.	0	0	0	0
		Inj.	0	0	0	2
		PDO	0	0	0	7
		Total	0	0	0	9
	Rate (C/mi/Yr)	Fat.	0	0	0	0
		Inj.	0	0	0	1.2
		PDO	0	0	0	4.3
		Total	0	0	0	5.5
After 2010-2013	Crashes	Fat.	0	0	0	0
		Inj.	0	0	0	0
		PDO	0	0	0	8
		Total	0	0	0	8
	Rate (C/mi/Yr)	Fat.	0	0	0	0
		Inj.	0	0	0	0
		PDO	0	0	0	6.2
		Total	0	0	0	6.2
Rate Change	(C/mi/Yr)	Fat.	0	0	0	0
		Inj.	0	0	0	1.2
		PDO	0	0	0	-1.8
		Total	0	0	0	-0.6

Table 4.B. Example Crash Data Summary for Arrow-Per Lane for drivers under 65yrs

Treatment Site	I-96 & I-196	1st Sign Decision Sight Distance		
Installed	2009	Sev.	<59 Years	60-64 Years
Before 2004-2008	Crashes	Fat.	0	0
		Inj.	2	0
		PDO	6	1
		Total	8	1
	Rate (C/mi/Yr)	Fat.	0	0
		Inj.	1.2	0
		PDO	3.7	0.6
		Total	4.9	0.6
After 2010-2013	Crashes	Fat.	0	0
		Inj.	0	0
		PDO	7	1
		Total	7	1
	Rate (C/mi/Yr)	Fat.	0	0
		Inj.	0	0
		PDO	5.4	0.8
		Total	5.4	0.8
Rate Change	(C/mi/Yr)	Fat.	0	0
		Inj.	1.2	0
		PDO	-1.7	-0.2
		Total	-0.5	-0.2

Table 4.C. Detailed Data for Pedestrian Countdown Signals for Pedestrians under 65 years

No	Type Of Crash	Period	Observed Crashes		Treated Sites Statistics			
			Treated Sites	Comparison Group	Mean	Std. Dev.	Min	Max
1	Drivers under-65 (15-24 years) (All Severities)	Before	854	929	3	3.487	0	24
		After	248	885	3	3.916	0	22
2	Drivers under-65 (15-24 years) Fatal and Injury	Before	184	205	1	0.904	0	4
		After	176	180	1	1.042	0	6
3	Drivers under-65 (15-64) (All Severities)	Before	876	989	3	3.538	0	25
		After	770	924	3	3.795	0	19
4	Drivers under-65 (15-64) Fatal and Injury	Before	193	222	1	0.806	0	3
		After	192	184	1	1.159	0	7
5	Total Bike (All Severities)	Before	23	14	0	0.104	0	1
		After	16	14	0	0.227	0	1
6	Total Bike Fatal and Injury	Before	17	10	0	0.104	0	1
		After	11	10	0	0.204	0	1
7	Drivers under-65 (25-64) (All Severities)	Before	1705	1805	6	5.148	0	27
		After	1392	1437	7	6.046	0	29
8	Drivers under-65 (25-64) Fatal and Injury	Before	311	323	1	1.258	0	6
		After	245	278	1	1.279	0	7
9	Pedestrian under-65 (All Severities)	After	90	42				
		Before	61	39				
10	Pedestrian under-65 Fatal and Injury	After	76	36				
		Before	51	28				

10.3 Appendix 5.1. SPFs for drivers under 65 years old

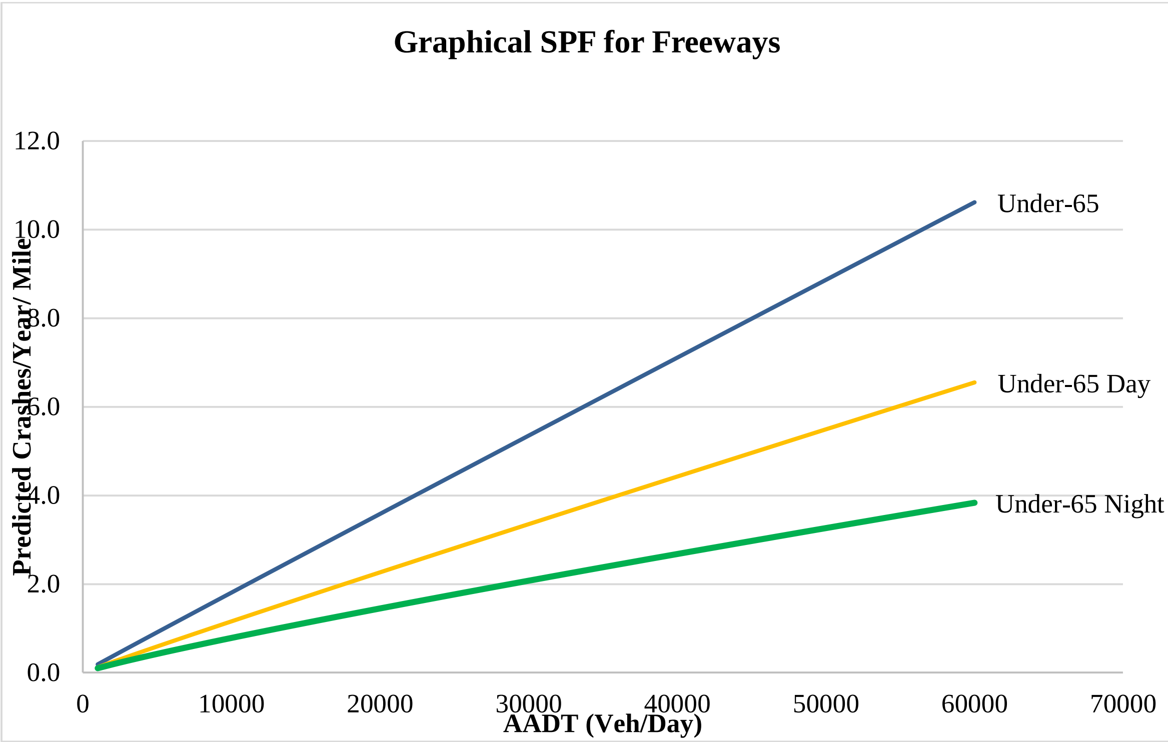
SPFs for Freeways for Drivers Under 65

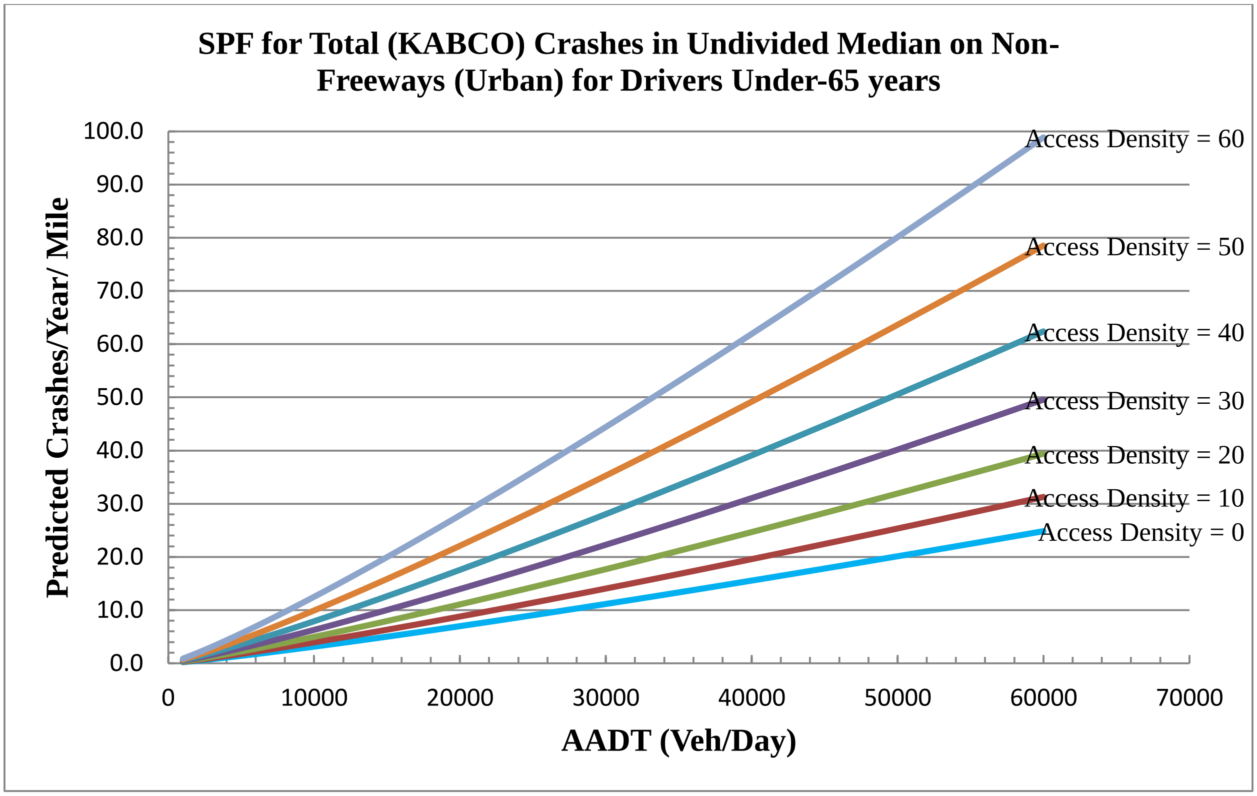
Crash Category	β_1 (std. error)	β_2 (std. error)	β_0	c
Under 65yrs Drivers	0.223 (0.050)	0.989 (0.111)	-8.742	-0.084
Under 65yrs Drivers Day	0.174 (0.057)	0.966 (0.124)	-8.923	0.152
Under 65yrs Drivers Night	0.259 (0.060)	0.885 (0.134)	-8.652	0.416

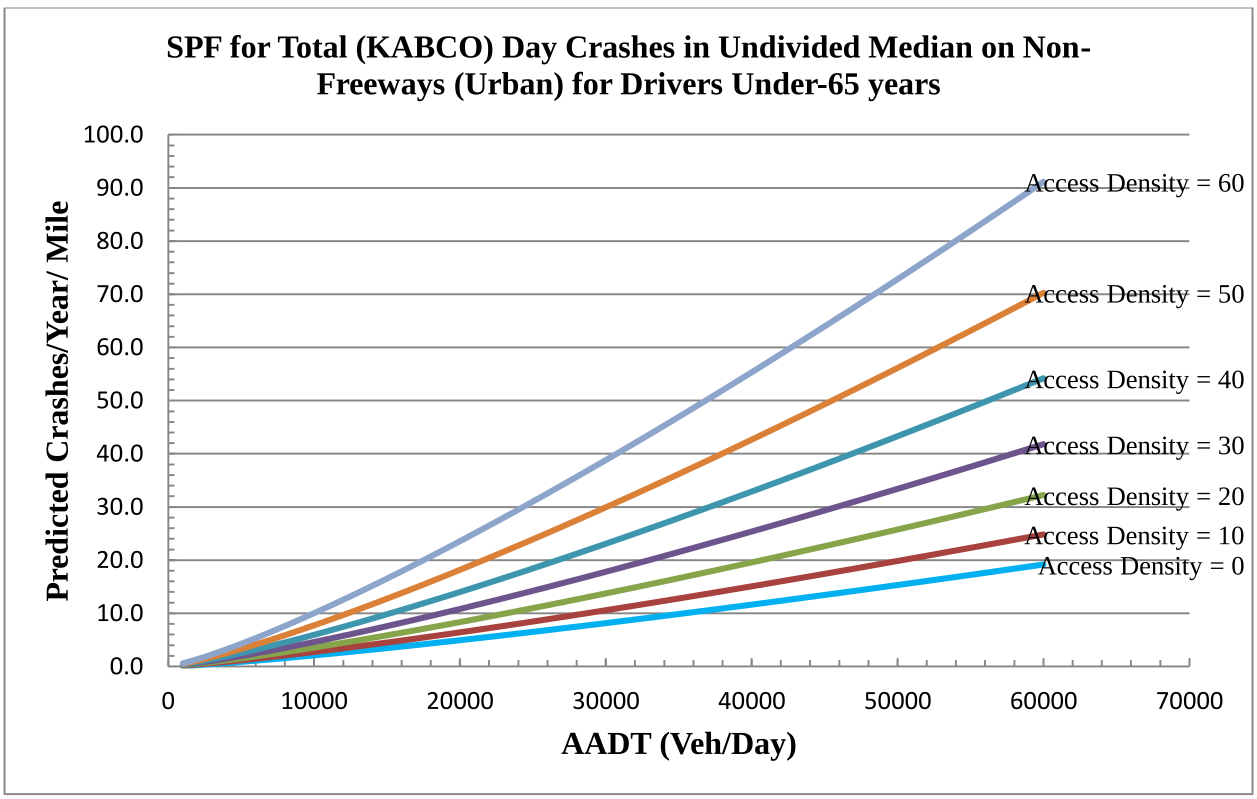
SPFs for Urban Non-Freeways for Drivers Under 65

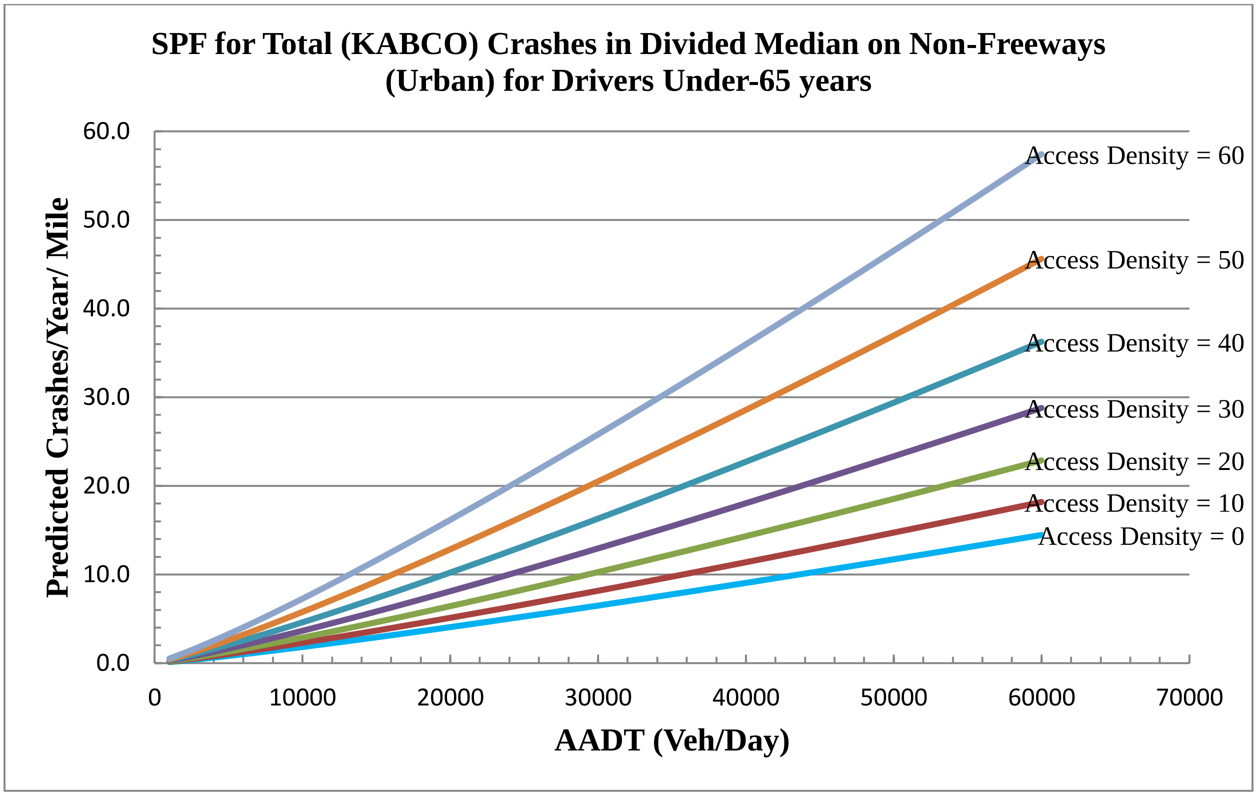
Crash Category	B_1 (std. error)	B_2 (std. error)	B_3 (std. error)	B_4 (std. error)	β_0	c
Under 65yrs Drivers	1.154 (0.160)	0.376 (0.117)	0.026 (0.009)	0.543 (0.209)	-10.402	-0.148
Under 65yrs Drivers Day	1.231 (0.181)	0.311 (0.129)	0.029 (0.010)	0.486 (0.232)	-11.388	-0.055
Under 65yrs Drivers Night	No reliable SPF					

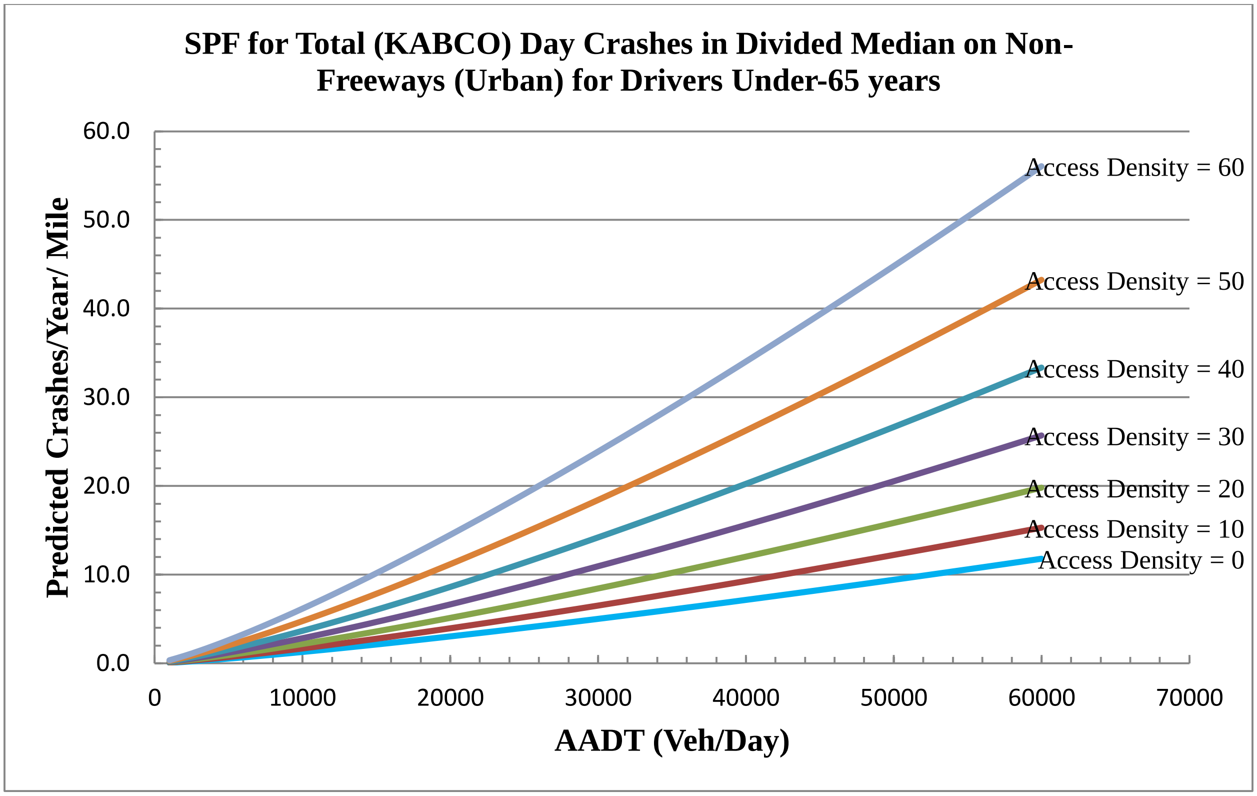
Graphical SPFs for Drivers Under 65




SPF for Total (KABCO) Crashes in Undivided Median on Non-Freeways (Urban) for Drivers Under-65 years
Predicted Crashes/Year/ Mile
AADT (Veh/Day)
100.0
90.0
80.0
70.0
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 (KABCO) Day Crashes in Undivided Median on Non-Freeways (Urban) for Drivers Under-65 years
Predicted Crashes/Year/ Mile
AADT (Veh/Day)
100.0
90.0
80.0
70.0
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 (KABCO) Crashes in Divided Median on Non-Freeways (Urban) for Drivers Under-65 years
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 (KABCO) Day Crashes in Divided Median on Non-Freeways (Urban) for Drivers Under-65 years
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

SPFs for intersection (Box Span Signal) for Drivers Under 65 years

Significance Testing of Variables

	Major AADT	Minor AADT	Major thru lanes	Minor thru lanes	Major LT Lane	Minor LT Lane	Major LT Phase	Minor LT Phase	3-leg	4-leg	Wide Median
Drivers <65 years											
Total Crashes	✓	✓		✓		✓		✓			
FI Crashes	✓	✓				✓		✓			✓
Angle Crashes		✓									

SPFs for Box Span Signals for Drivers under 65 years

Model	**α**	**β1** Major AADT	**β2** Minor AADT	**β3** Minor LT Lane	**β4** Minor LT Phase	**β5** Wide Median	**k**
Intersection Total Crashes	-8.66	0.50	0.63	0.44	-	-	0.68
Intersection FI Crashes	-8.49	0.44	0.49	0.48	0.32	0.38	2.90
Angle Crashes	No reliable SPF						

10.4 Appendix 6.1. CMFs for Drivers Under 65 Years

10.4.1 Clearview Font and Fluorescent Yellow Sheeting on Freeways

Crash and Countermeasure Type	% Reduction	CMF	Standard Error	Significant?
Total Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting	24.06%	0.759	0.0312	YES
Total Crashes - Presence of Fluorescent Yellow Sheeting only	15.45%	0.846	0.047	YES
Day Crashes- Crashes Presence of Clearview Font and Fluorescent Yellow Sheeting	19.32%	0.807	0.042	YES
Day Crashes- Presence of Fluorescent Yellow Sheeting only	12.77%	0.872	0.0612	YES
Night Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting	27.21%	0.728	0.0463	YES
Night Crashes - Presence of Fluorescent Yellow Sheeting only	9.77%	0.902	0.0786	YES

10.4.2 Clearview Font and Fluorescent Yellow Sheeting on Urban Non-Freeways

Crash and Countermeasure Type	% Reduction	CMF	Standard Error	Significant?
Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting	29.25%	0.707	0.0422	YES
Crashes - Presence of Fluorescent Yellow Sheeting only	10.47%	0.895	0.0412	YES
Day Crashes- Crashes Presence of Clearview Font and Fluorescent Yellow Sheeting	28.03%	0.72	0.0496	YES
Day Crashes- Presence of Fluorescent Yellow Sheeting only	12.45%	0.875	0.0481	YES
Night Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting	7.09%	0.929	0.0262	YES
Night Crashes - Presence of Fluorescent Yellow Sheeting only	1.11%	0.989	0.0145	NO

10.4.3 Clearview Font and Fluorescent Yellow Sheeting on Rural Non-Freeways

Crash and Countermeasure Type	% Reduction	CMF	Standard Error	Significant?
Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting	13.20%	0.868	0.0115	YES
Crashes - Presence of Fluorescent Yellow Sheeting only	8.40%	0.916	0.00815	YES
Day Crashes- Crashes Presence of Clearview Font and Fluorescent Yellow Sheeting	22.75%	0.772	0.0193	YES
Day Crashes- Presence of Fluorescent Yellow Sheeting only	15.18%	0.848	0.0151	YES
Night Crashes - Presence of Clearview Font and Fluorescent Yellow Sheeting	7.67%	0.923	0.0241	YES
Night Crashes - Presence of Fluorescent Yellow Sheeting only	5.32%	0.947	0.016	YES

10.4.4 Pedestrian Countdown Signals

Type Of Crash	CMF	Std. Error	% Reduction/ Increase	Significant?
Drivers under-65 (15-24 years) (All Severities)	0.304	0.026	69.619	YES
Drivers under-65 (15-24 years) Fatal and Injury	1.072	0.155	-7.236	NO
Drivers under-65 (15-64) (All Severities)	0.938	0.063	6.22	NO
Drivers under-65 (15-64) Fatal and Injury	1.182	0.166	-18.239	NO
Total Bike (All Severities)	1.022	0.052	-2.219	NO
Total Bike Fatal and Injury	0.906	0.106	9.368	NO
Drivers under-65 (25-64) (All Severities)	0.586	0.247	41.361	YES
Drivers under-65 (25-64) Fatal and Injury	0.514	0.241	48.598	YES
Pedestrian under-65 (All Severities)	0.688	0.18	31.18	YES
Pedestrian under-65 Fatal and Injury	0.801	0.231	19.86	NO

10.4.5 Arrow-Per Lane

Statistical Significance Summary for Combined Full Length Locations

Crash Type	% Reduction	CMF	Significance
Total Crashes, All Severities, <65 Years	37.8%	0.622	YES
Sideswipe Crashes, All Severities, <65 Years	-19.5%	1.195	NO

10.4.6 Box Span Signal Configuration

Crash Type	% Reduction	CMF	Standard Error	Significance
Total Crashes	3.5	0.965	0.044	NO
FI Crashes	8.9	0.911	0.090	NO