Safety Evaluation of Multiple Strategies at Stop-Controlled Intersections

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FOREWORD

The research documented in this report was conducted as part of the Federal Highway Administration's (FHWA) Evaluation of Low-Cost Safety Improvements Pooled Fund Study (ELCSI-PFS). FHWA established this PFS in 2005 to conduct research on the effectiveness of the safety improvements identified by the National Cooperative Highway Research Program *Report 500 Guides* as part of the implementation of the American Association of State Highway and Transportation Officials Strategic Highway Safety Plan.(1) The ELCSI-PFS studies provide a crash modification factor and benefit–cost economic analysis for each of the targeted safety strategies identified as priorities by the pooled fund member States.

This study evaluated multiple low-cost safety improvements at stop-controlled intersections that included basic signing and pavement markings. This strategy is intended to reduce the frequency and severity of crashes at stop-controlled intersections by alerting drivers approaching a stop-controlled intersection. The results indicate reductions for all crash types (i.e., total, fatal and injury, rear-end, right-angle, and nighttime crashes). The economic analysis results suggest that the multiple low-cost treatments at stop-controlled intersections, even with conservative assumptions on cost, service life, and the value of a statistical life, can be cost effective. This report is intended for safety engineers, highway designers, planners, and practitioners at State and local agencies involved with AASHTO Strategic Highway Safety Plan implementation.

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16. Abstract

The Development of Crash Modification Factors program studied the safety performance of various stop-controlled intersections for the Evaluation of Low-Cost Safety Improvements Pooled Fund Study. This study evaluated the safety effectiveness of multiple low-cost treatments at stop-controlled intersections. Improvements included basic signing and pavement markings. This strategy is intended to reduce the frequency and severity of crashes at stop-controlled intersections by alerting drivers to the presence and type of approaching intersection. Geometric, traffic, and crash data were obtained at three- and four-legged, two- and four-lane major road, and urban and rural stop-controlled intersections in South Carolina. To account for potential selection bias and regression to the mean, an empirical Bayesian before–after analysis was conducted, using reference groups of untreated intersections with similar characteristics to the treated sites. The analysis also controlled for changes in traffic volumes throughout time and time trends in crash counts unrelated to the treatments. The aggregate results indicate reductions for all crash types analyzed (i.e., total, fatal and injury, rear-end, right-angle, and nighttime). The reductions are statistically significant at the 95-percent confidence level for all crash types. For all crash types combined, the crash modification factors (CMFs) are 0.917 for all severities and 0.899 for fatal and injury crashes. The CMFs for rear-end, right-angle, and nighttime crashes are 0.933, 0.941, and 0.853, respectively. The benefit–cost ratio estimated with conservative cost and service life assumptions is 12.4 to 1 for total crashes at unsignalized intersections. The results suggest that the multiple low-cost treatments, even with conservative assumptions on cost, service life, and the value of a statistical life, can be cost effective.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS

AADT	annual average daily traffic
B/C	benefit–cost
CMF	crash modification factor
EB	empirical Bayesian
ELCSI-PFS	Evaluation of Low-Cost Safety Improvements Pooled Fund Study
FHWA	Federal Highway Administration
MUTCD	*Manual on Uniform Traffic Control Devices*
NCHRP	National Cooperative Highway Research Program
PDO	property damage only
PE	preliminary engineering
RTM	regression to the mean
SCDOT	South Carolina Department of Transportation
SPF	safety performance function
USDOT	U.S. Department of Transportation

EXECUTIVE SUMMARY

The Federal Highway Administration (FHWA) established the Development of Crash Modification Factors (DCMF) program in 2012 to address highway safety research needs for evaluating new and innovative safety strategies (improvements) by developing reliable quantitative estimates of their effectiveness in reducing crashes. The ultimate goal of the DCMF program is to save lives by identifying new safety strategies that effectively reduce crashes and promote those strategies for nationwide implementation by providing measures of their safety effectiveness and benefit–cost (B/C) ratios through research. State transportation departments and other transportation agencies need to have objective measures for safety effectiveness and B/C ratios before investing in broad applications of new strategies for safety improvements. Forty State transportation departments provided technical feedback on safety improvements to the DCMF program and implemented new safety improvements to facilitate evaluations. These States are members of the Evaluation of Low-Cost Safety Improvements Pooled Fund Study (ELCSI-PFS), which functions under the DCMF program.

This study evaluated multiple low-cost treatments at stop-controlled intersections in South Carolina. Improvements included basic signing and pavement markings. The purpose of this study was to quantify the safety effectiveness of these treatments. The treatments were installed as part of the South Carolina Department of Transportation (SCDOT) systemic intersection improvement program. The results provide evidence for others to consider as they make data-driven decisions about the type of treatments to implement.

Both urban and rural stop-controlled intersections on divided and undivided State-maintained roads (nonfreeways) were selected as locations for treatments. Preliminary study results have shown that, by making improvements such as those listed above, SCDOT was able to achieve a small but statistically significant crash reduction. While the expected crash savings per location were not as large as for some higher cost treatments (e.g., converting conventional intersections to roundabouts), the low cost of these treatments allows many more locations to be treated.

Geometric, traffic, and crash data were obtained at three- and four-legged, two- and four-lane major road, and urban and rural stop-controlled intersections in South Carolina. To account for potential selection bias and regression to the mean (RTM), an empirical Bayesian (EB) before–after analysis was conducted, using reference groups of untreated intersections with similar characteristics to the treated sites. The analysis also controls for changes in traffic volumes throughout time and time trends in crash counts unrelated to the treatments.

The aggregate results indicate reductions for all crash types analyzed (i.e., total, fatal and injury, rear-end, right-angle, and nighttime). The reductions are statistically significant at the 95-percent confidence level for all crash types. For all crash types combined, the crash modification factors (CMFs) are 0.917 for all severities and 0.899 for fatal and injury crashes. The CMFs for rear-end, right-angle, and nighttime crashes are 0.933, 0.941, and 0.853, respectively.

The disaggregate analysis identified those conditions under which the multiple low-cost treatments are most effective. Variables of interest included area type (urban or rural), number of legs (three or four), lane configuration of the mainline and the cross street, traffic volumes, and expected crashes without treatment. The disaggregate analysis indicated larger crash reductions of all types for rural areas, four-legged intersections, and intersections with two-lane major roads. For total entering volume and expected crashes before treatment, the disaggregate analysis indicated the strategy is more effective on average for intersections with lower traffic volumes and fewer expected crashes per year.

Assuming a 3-year service life, conservative costs, and the benefits for total crashes, the B/C ratio is 12.4 to 1. With the U.S. Department of Transportation (USDOT) recommended sensitivity analysis, these values could range from 7.1 to 1 up to 17.5 to 1. Assuming a 7-year service life, and the same conservative costs and benefits for total crashes, the B/C ratio is 25.5 to 1. With the USDOT recommended sensitivity analysis, these values could range from 14.5 to 1 up to 35.9 to 1. These results suggest that the multiple low-cost treatments, even with conservative assumptions on cost, service life, and the value of a statistical life, can be cost-effective in reducing crashes at stop-controlled intersections.

CHAPTER 1. INTRODUCTION

BACKGROUND ON MULTIPLE STRATEGIES AT STOP-CONTROLLED INTERSECTIONS

In recent years, there has been an increased interest in systemic installations of low-cost safety treatments throughout an entire jurisdiction. The South Carolina Department of Transportation (SCDOT) embraced this approach in its intersection safety improvement plan and identified a number of low-cost strategies for implementation at stop-controlled and signalized intersections statewide. Typical low-cost treatments at stop-controlled intersections in South Carolina included improvements to basic signing and pavement markings. Figure 1 illustrates typical improvements at a four-legged, stop-controlled intersection with two-lane major road.

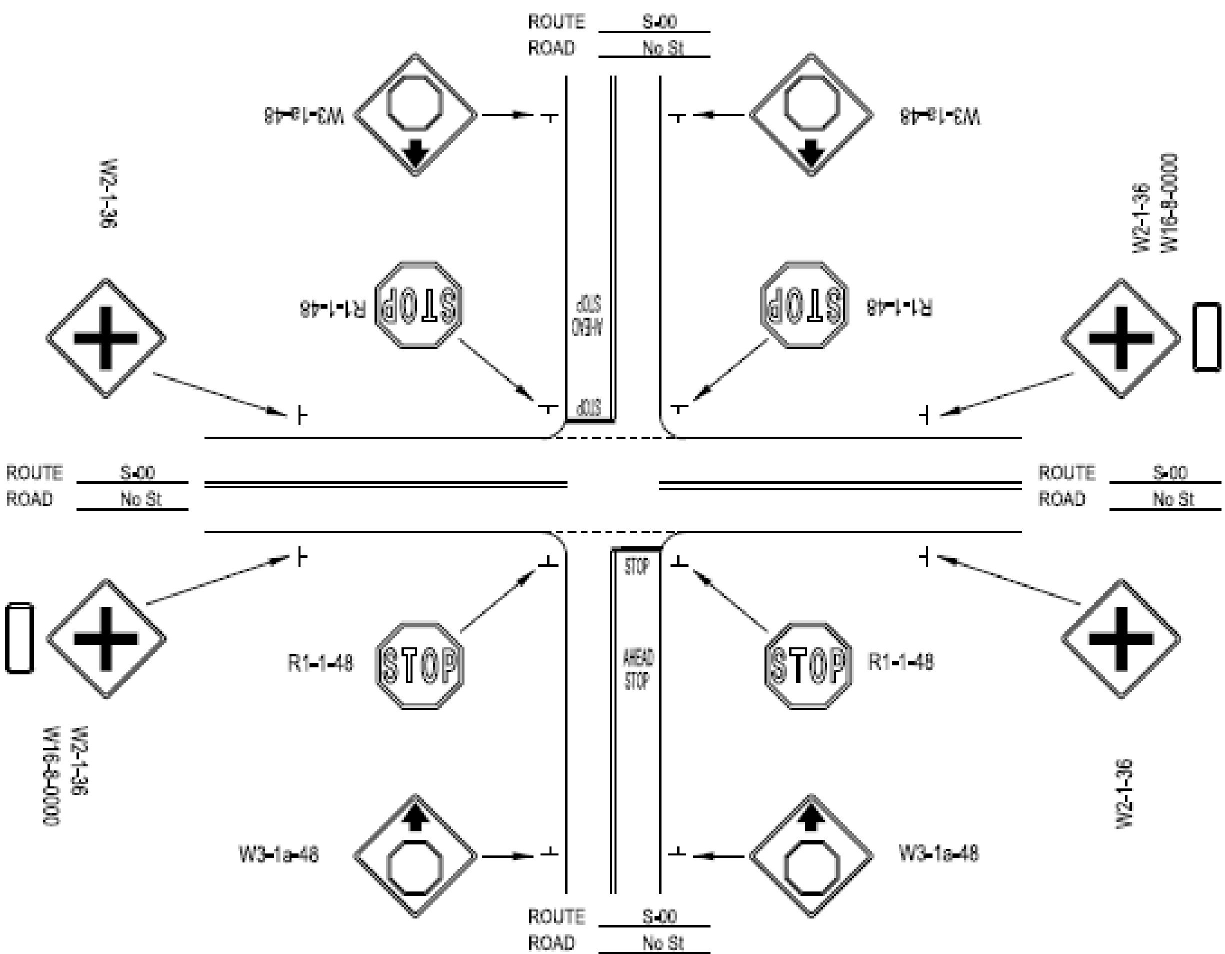


Figure 1. Illustration. Example of stop-controlled intersection improvements.

The following is an overview of the types of basic signing and pavement markings improvements, and the appendix provides further details and considerations. Each treatment was installed when appropriate. Each intersection received a unique package of improvements suited for implementation at that site, which included the following:

- Signing improvements included the following:
    - Double-up (i.e., both right- and left-side, shoulder mounted) 36 inches by 36 inches intersection warning signs (W2-series) on fluorescent yellow sheeting. Figure 1 shows examples of applicable intersection warning signs for stop-controlled intersections.
    - Advance street name plaque (W16-8) on fluorescent yellow sheeting accompanying each right-side intersection warning sign.
    - Double-up (i.e., both right- and left-side, shoulder mounted) 48 inches by 48 inches stop (R1-1) and yield (R1-2) signs.
    - Retroreflective strips on sign posts for the above signs.
- Pavement marking improvements included the following:
    - Stop lines within 4 to 10 ft of the edge of the nearest through lane along the major road.
    - Yield lines at all lanes having yield conditions.
    - Dashed white edge-lines through intersections along major roads.
    - Remarking of all existing stop lines, crosswalks, arrows, and word messages unless:
        - The roadway had been resurfaced within one calendar year and new thermoplastic markings had been applied.
        - Existing markings were uniformly reflective, and the above ground thickness was 90 mm or greater.
        - Otherwise directed by a district representative.
    - Marking of all turn lanes to include the pattern of lane arrows and accompanying word message “ONLY” based on the turn-lane length, in accordance with Standard Drawing 625-410-00.

BACKGROUND ON STUDY

The goal of the Evaluation of Low-Cost Safety Improvements Pooled Fund Study (ELCSI-PFS) is to develop reliable estimates of the effectiveness of the safety improvements that are identified as strategies in the National Cooperative Highway Research Program (NCHRP) *Report 500 Guides*.[1] These estimates are determined by conducting scientifically rigorous evaluations at sites in the United States where these strategies are being implemented. The study has spanned multiple phases. In March 2005, the first Technical Advisory Committee Meeting of the ELCSI-PFS was held at the Turner-Fairbank Highway Research Center. The purpose of the meeting was to discuss the study and applicable strategies from the NCHRP *Report 500 Guides* and to develop a prioritization of those strategies for potential evaluation in the study.(1) Since this initial meeting, several phases have been undertaken to evaluate strategies.

Phase V of the ELCSI-PFS is a "build-to-evaluate" effort in which States have volunteered to install a variety of promising low-cost safety countermeasures and contribute the appropriate data to allow a rigorous crash-based evaluation of their safety effectiveness. This phase has a two-part nature and consists of an implementation part and an evaluation part. The implementation portion (Part 1) defined the before period, including installation data (location and date), roadway data, traffic data, and crash data. The evaluative portion (Part 2) began within 3 years of the conclusion of the installation phase. Four safety strategies were identified for implementation and evaluation in Phase V. Five States volunteered and provided data for the Phase V evaluations. Table 1 shows these safety improvement strategies and the volunteering States.

Table 1. Phase V safety strategies and participating States.

Safety Strategy/Participating State	Combination of Cable Median Barrier and Rumble Strips	Combination of Centerline Rumble Strips and Edge-Line Rumble Strips	Multi-Strategy Improvements at Signalized Intersections	Multi-Strategy Improvements at Stop-Controlled Intersections
Illinois	X	—	—	—
Kentucky	X	X	—	—
Missouri	X	X	—	—
Pennsylvania	—	X	—	—
South Carolina	—	—	X	X

—Not used.

As a volunteering State, SCDOT initiated a project to improve safety at more than 2,200 intersections statewide through low-cost engineering techniques focused primarily on signing and markings in 2009. These intersections—600 of which were classified as rural—comprise only 2 percent of all State-maintained intersections but account for nearly half of all intersection crashes and fatalities. It was envisioned that the project would span 3 years and implement improvements at approximately 700 to 800 intersections each year.

This report documents the safety effectiveness evaluations of multiple strategies at stop-controlled intersections implemented in South Carolina. The evaluation of multiple strategies at signalized intersections can be found in the companion report entitled *Safety Evaluation of Multiple Strategies at Signalized Intersections*.(6)

CHAPTER 2. LITERATURE REVIEW

Literature on the stop-controlled intersection strategies of interest is limited. The following provides a summary of the salient research related to specific strategies. There were very few studies identified that investigated the effects of multiple strategies.

DOUBLING AND OVERSIZING ADVANCE WARNING SIGNS, STOP SIGNS, AND YIELD SIGNS

The Institute of Transportation Engineers published the results of two evaluations concerning doubling stop signs (i.e., placement of a stop sign on the left side of the stop approach road to complement the existing stop sign on right side).(7) The first evaluation was solely for the installation of double stop signs. This countermeasure had an estimated reduction of 11 percent on total crashes. The study neglected to estimate a standard error for this crash reduction. The other evaluation was for a combination of treatments. The combination was adding a centerline, moving the stop line to the extended curb lines, and doubling stop signs. The estimated effect on total crashes was a nine percent decrease, and there was no observed change in right-angle crashes.

Polanis conducted an evaluation of another combination of intersection treatments.(8) The combination was adding a centerline, adding a stop line, and replacing existing 24-inch stop signs with 30-inch stop signs. The results indicate a 55-percent reduction in right-angle crashes with a standard error of 52 percent. Therefore, the reductions were not statistically significant. Not only were the results of Polanis's study statistically insignificant, the design of the study was not rigorous. The study employed a simple before–after methodology, which fails to account for traffic volume changes, RTM, and a host of other potentially confounding factors. Furthermore, only 10 sites were used in the study, and these sites were all from the same municipality in North Carolina: Winston-Salem.(8)

A case study by the Federal Highway Administration (FHWA) further examined the effect of doubling and oversizing stop signs at intersections in Winston-Salem, NC.(9) At four stop-controlled intersections with a history of high crash frequency, stop signs were doubled using 30-inch signs as opposed to the conventional 24-inch variety. Based on a simple before–after comparison, the results estimated a 48-percent reduction in total crashes. As with the Polanis study, this case study employs a weak study methodology (i.e., simple before–after) and uses a small sample size, which lacks geographic diversity. Furthermore, this case study exhibits a clear selection bias, making the regression to the mean (RTM) phenomenon a serious concern.

FLUORESCENT YELLOW SHEETING

There have been multiple studies that examined the use of fluorescent yellow sheeting on warning signs. Eccles and Hummer focused on the use of fluorescent yellow sheeting as an inexpensive method of increasing the conspicuity of signs without violating the provisions contained in the *Manual on Uniform Traffic Control Devices* (MUTCD).(10) Multiple studies confirm the superiority of fluorescent signs in terms of conspicuity. Jenssen et al. conducted a comparative evaluation of fluorescent and nonfluorescent signs on a closed track in Norway.(11) Subjects seated in moving railcars were asked to indicate when they could detect and recognize the size, shape, and content of fluorescent and nonfluorescent signs. The performance of the fluorescent signs proved to be superior because the subjects were able to detect and recognize the fluorescent signs well before they could detect and recognize the nonfluorescent signs. Burns and Johnson studied fluorescent and nonfluorescent materials and found that the photometric properties of fluorescent materials explained their superior visibility and conspicuity.(12)

RETROREFLECTIVE SIGN POSTS

A recent study by the Virginia Department of Transportation directly relates to the retroreflective sign post strategy.(13) This study examined the effectiveness of retroreflective material on stop sign posts with respect to visibility and driver compliance. The authors measured performance with respect to visibility using a video survey in which participants were asked to pinpoint when a stop sign with retroreflective material on the post and another without retroreflective material on the post could be detected. The results indicated that during daytime conditions, the vast majority of participants could detect the stop sign without retroreflective material on the post sooner than the stop sign with retroreflective material on the post. In contrast, during nighttime conditions, the vast majority of participants could detect the stop sign when retroreflective material is on the post sooner than the stop sign without retroreflective material on the post. In terms of compliance, the behavior of drivers approaching a stop sign with retroreflective material on the post was not observed to be different from that of a driver approaching a stop sign without retroreflective material on the post.

REFRESHING EXISTING PAVEMENT MARKINGS

The research team did not identify any existing studies on the safety effects of refreshing existing pavement markings at stop-controlled intersections.

STOP LINES

The installation of a stop line has also been studied in recent years. The installation of a stop line on the minor approach of an unsignalized intersection is intended to address angle crashes in which drivers are unaware of the presence of an intersection or fail to stop at the stop sign. Golembiewski and Chandler estimated that this countermeasure reduced total crashes by 19 percent.(14) This study did not provide an estimate of the standard error of the crash reduction.

The Institute of Transportation Engineers estimated that the installation of stop lines on minor road approaches with short segments of centerline reduced total crashes by 19 percent and reduced right-angle crashes by 47 percent. Once again, the standard errors of these crash reductions were not estimated.(7)

Polanis evaluated the combination of adding a centerline, adding a stop line, and replacing a 24-inch stop sign with a 30-inch stop sign.(8) This combination of treatments was estimated to reduce right-angle crashes by 67 percent with a standard error of 11 percent. Therefore, the reduction is statistically significant.

A FHWA study analyzed the effects of installing stop lines and a short interval of double yellow centerlines at intersections in Winston-Salem, NC.(9) The treatment group consisted of four stop-controlled intersection with a history of high crash frequency. The study used a simple before–

after method to estimate the crash effects on total crash frequency. The results indicated that total crashes decreased by 53 percent. It should be noted that this study employed a weak study design (i.e., simple before–after) and a small sample size.

This strategy is a potentially effective countermeasure at locations with a history of crashes in which drivers are unaware of the presence of the intersection. However, the authors noted that the stop line should be installed in such a way that it can be seen from a significant distance by approaching drivers.[(14)] Aside from its significant crash reduction potential, this countermeasure is appealing because of its relatively low cost.

LIMITATIONS OF PREVIOUS RESEARCH

Literature on the stop-controlled intersection strategies of interest was scarce in some cases and nonexistent in others. In the cases of fluorescent yellowing sheeting, retroreflective sign posts, and refreshing existing pavement markings, the research team did not identify studies that quantify the effect on crashes of implementing the strategies. With regard to the strategy of doubling and oversizing advance warning signs, stop signs, and yields signs, the research team identified several studies that estimate crash effects. However, the studies employed study designs that lacked statistical rigor and frequently neglected to estimate standard errors for the crash reductions. The standard error of a crash reduction enables one to judge the statistical significance of the crash effect. Therefore, the omission of standard errors in these studies poses a major obstacle to a meaningful interpretation of the results. With respect to the strategy of installing stop lines, some of the studies also lacked standard error estimates. Furthermore, none of the previous studies conducted a comprehensive evaluation with regard to crash type and severity. The previous studies generally reported the effect on total crashes or angle crashes, and virtually none estimated the effect on injury crashes. Thus, there is a need for additional research of the stop-controlled strategies of interest that employs rigorous study designs and analyzes a full range of crash types and severities.

CHAPTER 3. OBJECTIVE

This research examined the safety impacts of multiple strategies implemented at stop-controlled intersections throughout South Carolina. The objective was to estimate the safety effectiveness of this strategy as measured by crash frequency. Target crash types included the following:

- Total crashes (all types and severities combined).
- Injury crashes (fatal injury, incapacitating injury, nonincapacitating injury, and possible injury).
- Rear-end crashes (all severities combined).
- Right-angle crashes (all severities combined).
- Nighttime crashes (all severities combined).

A further objective was to address the following questions:

- Do effects vary by area type (i.e., urban versus rural)?
- Do effects vary by approach configuration of intersection (i.e., three-legged versus four-legged)?
- Do effects vary by lane configuration of intersection (e.g., four mainline lanes and two cross-street lanes versus two mainline lanes and two cross-street lanes)?
- Do effects vary by traffic volume?
- Do effects vary by expected crashes?

The evaluation of overall effectiveness included the consideration of the installation costs and crash savings in terms of the benefit–cost (B/C) ratio.

Meeting these objectives placed some special requirements on the data collection and analysis tasks, including the need to do the following:

- Select a large enough sample size to detect, with statistical significance, what may be small changes in safety for some crash types.
- Identify appropriate untreated reference sites.
- Properly account for changes in safety because of changes in traffic volume and other factors unrelated to the strategy.

CHAPTER 4. STUDY DESIGN

The study design involved a sample size analysis and prescription of needed data elements. The sample size analysis assessed the size of sample required to statistically detect an expected change in safety and determined what changes in safety could be detected with available sample sizes.

SAMPLE SIZE ESTIMATION OVERVIEW

When planning a before–after safety evaluation study, it is vital to ensure that enough data are included such that the expected change in safety can be statistically detected. Even though in the planning stage the expected change in safety is unknown, it is still possible to make a rough estimate of how many sites would be required based on the best available information about the expected change in safety. Alternatively, one could estimate, for the number of available sites, the change in safety that could be statistically detected. For a detailed explanation of sample size considerations, as well as estimation methods, see chapter 9 of Hauer.[(15)] The sample size analysis presented here is limited to two cases: (1) how large a sample would be required to statistically detect an expected change in safety; and (2) what changes in safety could be detected with available sample sizes.

For case 1, it was assumed that a conventional before–after study with comparison group design would be used because available sample size estimation methods were based on this assumption. The sample size estimates from this method would be conservative in that the empirical Bayesian (EB) methodology would likely require fewer sites. To facilitate the analysis, it was also assumed that the number of comparison sites was equal to the number of installation sites and the duration of the before and after periods were equal, which, again, was a conservative assumption.

Table 2 provides the crash rate assumptions. It shows the average number of crashes per year per intersection in the before period for each combination of crash type and intersection configuration. The locations of interest for this strategy were three- and four-legged, stop-controlled intersections. Intersection crash rates differ substantially depending on a number of factors (e.g., traffic control, traffic volume, geometric configuration, and area type). Therefore, the intersection crash rates assumed for these computations represented a general estimate based on the reference sites identified for this study. Rates A and B represent rural and urban, four-legged, stop-controlled intersections with two-lane major roads, respectively. Rates C and D represent rural and urban, stop-controlled intersections with four-lane major roads, respectively.

Table 2. Before-period crash rate assumptions for four-legged stop-controlled intersections.

Crash Type	Rate A (SC) Rural Stop-Controlled Intersections with 2-Lane Major Roads	Rate B (SC) Urban Stop-Controlled Intersections with 2-Lane Major Roads	Rate C (SC) Rural Stop-Controlled Intersections with 4-Lane Major Roads	Rate D (SC) Urban Stop-Controlled Intersections with 4-Lane Major Roads
Total	1.400	1.966	1.752	2.232
Injury	0.542	0.625	0.669	0.692
Rear-end	0.253	0.633	0.309	0.718
Right-angle	0.460	0.761	0.706	0.927

Crash rate = crashes/intersection/year.

Table 3 to table 6 provide estimates of the required number of before- and after-period intersection-years for total, fatal and injury, rear-end, and right-angle crashes, respectively, at four-legged stop-controlled intersections assuming both 90- and 95-percent confidence levels. Columns labeled “A-95%” and “A-90%” indicate Rate A (rural four-legged, stop-controlled with two-lane major roads) with 95- and 90-percent confidence levels, respectively. Similarly, columns labeled “B-95%,” “C-95%,” and “D-95%” indicate rates B, C, and D at the 95-percent confidence level. Columns labeled “B-90%,” “C-90%,” and “D-90%” indicate rates B, C, and D at the 90-percent confidence level. The minimum sample indicates the amount of data necessary to detect the safety effects with a desirable level of statistical significance. Larger safety effects require less data to achieve the same confidence level. These sample size calculations were based on specific assumptions regarding the number of crashes per intersection and years of available data. Intersection-years were the number of intersections where the strategy was implemented multiplied by the number of years of data before or after implementation. For example, if a strategy was implemented at nine intersections and data were available for three years since implementation, then there would be a total of 27 intersection-years of after period data available for the study. The number of intersection-years was estimated by first estimating the required number of intersection-related crashes and then dividing by the appropriate intersection crash rate.

Table 3. Minimum required before period intersection-years for treated sites—total crashes.

Expected Percent Reduction in Crashes	A-95%	B-95%	C-95%	D-95%	A-90%	B-90%	C-90%	D-90%
10	1,325	944	1,059	831	824	586	658	517
15	420	299	336	263	284	202	227	178
20	199	142	159	125	138	98	110	86
25	111	79	89	70	78	55	62	49

Note: Assumes equal number of site-years for treatment and comparison sites and equal length of before and after periods.

Table 4. Minimum required before period intersection-years for treated sites—fatal and injury crashes.

Expected Percent Reduction in Crashes	A-95%	B-95%	C-95%	D-95%	A-90%	B-90%	C-90%	D-90%
10	3,423	2,968	2,773	2,681	2,127	1,845	1,723	1,666
15	1,085	941	879	850	734	637	595	575
20	515	446	417	403	356	309	288	279
25	288	250	233	225	201	174	163	158

Note: Assumes equal number of site-years for treatment and comparison sites and equal length of before and after periods.

Table 5. Minimum required before period intersection-years for treated sites—rear-end crashes.

Expected Percent Reduction in Crashes	A-95%	B-95%	C-95%	D-95%	A-90%	B-90%	C-90%	D-90%
10	7,332	2,930	6,003	2,584	4,557	1,821	3,731	1,606
15	2,324	929	1,903	819	1,573	629	1,288	554
20	1,103	441	903	389	763	305	625	269
25	617	246	505	217	431	172	353	152

Note: Assumes equal number of site-years for treatment and comparison sites and equal length of before and after periods.

Table 6. Minimum required before period intersection-years for treated sites—right-angle crashes.

Expected Percent Reduction in Crashes	A-95%	B-95%	C-95%	D-95%	A-90%	B-90%	C-90%	D-90%
10	4,033	2,438	2,627	2,001	2,507	1,515	1,633	1,244
15	1,278	773	833	634	865	523	564	429
20	607	367	395	301	420	254	273	208
25	339	205	221	168	237	143	154	118

Note: Assumes equal number of site-years for treatment and comparison sites and equal length of before and after periods.

Case 2 considers the data collected for both the before and after periods. The statistical accuracy attainable for a given sample size is described by the standard deviations of the estimated percent change in safety. From this, *p*-values are estimated for various sample sizes and expected changes in safety for a given crash history. A set of such calculations is shown in Table 7 through table 10. The calculations are based on the methodology in Hauer.[15] The tables indicate the total intersection-years of data available in the before and after period.

Table 7. Sample analysis for crash effects* (rural two-lane intersections).

Crash Type	Intersection-Years in Before Period	Intersection-Years in After Period (Assumes 2-Year After Period for Each Site)	Minimum Percent Reduction p = 0.10**	Minimum Percent Reduction p = 0.05**
Total	3,195	1,278	10	10
Fatal and injury	3,195	1,278	10	15
Rear-end	3,195	1,278	15	15
Right-angle	3,195	1,278	10	15

*Results are to nearest 5-percent interval.
**Minimum percent reduction detectable for crash rate assumption. Crash rate assumption is based on actual crash rate for the before period from table 2.

Table 8. Sample analysis for crash effects* (urban two-lane intersections).

Crash Type	Intersection-Years in Before Period	Intersection-Years in After Period (Assumes 2-Year After Period for Each Site)	Minimum Percent Reduction p = 0.10**	Minimum Percent Reduction p = 0.05**
Total	3,195	1,278	10	10
Fatal and injury	3,195	1,278	10	10
Rear-end	3,195	1,278	10	10
Right-angle	3,195	1,278	10	10

*Results are to nearest 5-percent interval.
**Minimum percent reduction detectable for crash rate assumption. Crash rate assumption is based on actual crash rate for the before period from table 2.

Table 9. Sample analysis for crash effects* (rural four-lane intersections).

Crash Type	Intersection-Years in Before Period	Intersection-Years in After Period (Assumes 2-Year After Period for Each Site)	Minimum Percent Reduction p = 0.10**	Minimum Percent Reduction p = 0.05**
Total	3,195	1,278	10	10
Fatal/injury	3,195	1,278	10	10
Rear-end	3,195	1,278	15	15
Right-angle	3,195	1,278	10	10

*Results are to nearest 5-percent interval.
**Minimum percent reduction detectable for crash rate assumption. Crash rate assumption is based on actual crash rate for the before period from table 2.

Table 10. Sample analysis for crash effects* (urban four-lane intersections).

Crash Type	Intersection-Years in Before Period	Intersection-Years in After Period (Assumes 2-Year After Period for Each Site)	Minimum Percent Reduction p = 0.10**	Minimum Percent Reduction p = 0.05**
Total	3,195	1,278	5	10
Fatal and injury	3,195	1,278	10	10
Rear-end	3,195	1,278	10	10
Right-angle	3,195	1,278	10	10

*Results are to nearest 5-percent interval.
**Minimum percent reduction detectable for crash rate assumption. Crash rate assumption is based on actual crash rate for the before period from table 2.

Another strategy is to estimate the level of significance (i.e., the *p*-value) for which a minimum desired effect can be detected. For instance, assume the minimum desired level of effect is ten percent for total and target crashes. Based on the current knowledge of available data, table 11 indicates the *p*-value associated with a 10-percent change in crashes based on the before period data. These calculations use the crash rates from table 2. Given the existing sample size, it is likely this study can detect moderate treatment effects (e.g., a 10-percent change in total crashes) at the 10-percent level of significance.

Table 11. *p*-value for 10-percent change in crashes.

Crash Type	Rural 2-Lane	Urban 2-Lane	Rural 4-Lane	Urban 4-Lane
Total	0.03	0.02	0.02	0.01
Fatal and injury	0.12	0.10	0.09	0.09
Rear-end	0.27	0.10	0.22	0.09
Right-angle	0.15	0.08	0.09	0.06

REFERENCE GROUP OVERVIEW

A reference group is required for the various intersection groups, including rural and urban, three- and four-legged, stop-controlled intersections with two- and four-lane major roads. Each reference group should consist of untreated sites adjacent to or in the vicinity of the treated sites. The untreated sites in each reference group should have geometric, traffic, and crash data for the same years as treated sites. Each reference group should be similar to its corresponding treatment group—particularly in terms of area type (e.g., urban or rural), geometric configuration (e.g., number of legs and number of through lanes), and annual average daily traffic (AADT)—except that these intersections were not treated during the study period. These sites are used in the calibration of safety performance functions (SPFs). Based on previous experience in similar analyses, the research team determined that at least 30 intersections for each intersection type in reference group would be desirable, as shown in table 12. Where it is impractical or infeasible to obtain the required sample size for one or more intersection groups, it is possible to combine groups and account for the differences through statistical modeling during the development of SPFs.

Table 12. Reference groups and desirable sample sizes.

Number of Legs	Number of Through Lanes on Major Road	Rural	Urban	Total
3	2-lane	30	30	60
3	4-lane	30	30	60
4	2-lane	30	30	60
4	4-lane	30	30	60
—	Total	120	120	240

—Not applicable.

CHAPTER 5. METHODOLOGY

This study employed the EB methodology for observational before–after studies. The EB method was considered rigorous in that it accounted for RTM using a reference group of similar but untreated sites. In the process, SPFs were used for the following reasons:

- They overcome the difficulties of using crash rates in normalizing for volume differences between the before and after periods.
- They can account for time trends. (The final SPFs did not use yearly indicator variables to account for time trend, and more detailed discussions are provided in Before-After Adjustment Factors in chapter 7.)
- They reduce the level of uncertainty in the estimates of safety effect.
- They properly account for differences in crash experience and reporting practice in amalgamating data and results from diverse jurisdictions.
- They provide a foundation for developing guidelines for estimating the likely safety consequences of a contemplated strategy.

In the EB approach, the change in safety (Δ) for a given crash type at a site is given by figure 2.

$$\Delta Safety = \lambda - \pi$$

Figure 2. Equation. Estimated change in safety.

Where:

λ = expected number of crashes that would have occurred in the after period without the strategy.

π = number of reported crashes in the after period.

In estimating λ, the effects of RTM and changes in traffic volume were explicitly accounted for using SPFs, relating crashes of different types to traffic flow and other relevant factors for each jurisdiction based on reference sites. Annual SPF multipliers were calibrated to account for temporal effects on safety (e.g., variation in weather, demography, and crash reporting).

In the EB procedure, the SPF was 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 the one being analyzed (i.e., reference sites). The sum of these annual SPF estimates (P) was then combined with the count of crashes (x) in the before period at a treatment site to obtain an estimate of the expected number of crashes (m) before installation, as shown in figure 3.

$$m = w(P) + (1 - w)(x)$$

Figure 3. Equation. EB estimate of expected crashes.

Where *w* is estimated from the mean and variance of the SPF estimate, as shown in figure 4.

$$w = \frac{1}{1 + kP}$$

Figure 4. Equation. EB weight.

Where *k* is constant for a given model, which is estimated from the SPF calibration process with the use of a maximum likelihood procedure. In that process, a negative binomial distributed error structure is assumed with *k* being the overdispersion parameter of this distribution.

A factor was then applied to *m* to account for the length of the after period and differences in traffic volumes between the before and after periods. This factor was the sum of the annual SPF predictions for the after period divided by *P*, the sum of these predictions for the before period. The result, after applying this factor, was an estimate of λ. The procedure also produced an estimate of the variance of λ.

The estimate of λ was then summed over all treatment sites in a group of interest (to obtain λ_{sum}) and compared with the count of crashes observed during the after period in that group (π_{sum}). The variance of λ was also summed over all sites in the treatment group.

The index of effectiveness (θ) is estimated in figure 5.

$$\theta = \frac{\pi_{sum} / \lambda_{sum}}{1 + \left(Var(\lambda_{sum}) / \lambda_{sum}^2 \right)}$$

Figure 5. Equation. Index of effectiveness.

Where *Var* is variance.

The standard deviation of θ is given in figure 6.

$$StDev(\theta) = \sqrt{\frac{\theta^2 \left(\frac{Var(\pi_{sum})}{\pi_{sum}^2} + \frac{Var(\lambda_{sum})}{\lambda_{sum}^2} \right)}{\left(1 + \frac{Var(\lambda_{sum})}{\lambda_{sum}^2} \right)^2}}$$

Figure 6. Equation. Standard deviation of index of effectiveness.

The percent change in crashes was calculated as $100(1 - \theta)$; thus, a value of $\theta = 0.7$ with a standard deviation of 0.12 indicates a 30-percent reduction in crashes with a standard deviation of 12 percent.

CHAPTER 6. DATA COLLECTION

SCDOT provided the majority of data for this study. The dataset included the following data elements:

- Treatment implementation data: SCDOT provided information related to treatment sites and start and completion dates for each improvement. SCDOT also provided the research team with work orders, drawings, and sketches for these locations. The research team used some of these additional data to verify the intersection configurations.

- Reference site data: SCDOT provided a list of intersections that had not been treated. The research team used these intersections as potential reference sites.

- Traffic data: SCDOT provided a statewide AADT data file for 2014. This file has information for almost all mainline routes and cross streets. The research team obtained additional AADT files for 2006 to 2014 from SCDOT's website. These publicly available files do not have all the details necessary (many AADT for minor routes are missing). The research team used these files to calculate traffic growth factors and estimated AADTs for other years.

- Crash data: SCDOT provided the research team with crash data files for 2005 to 2014.

The research team collected additional data using Google® Earth™ and Google® Maps™.

TREATMENT SITES

SCDOT provided the research team with a list of all intersections under the ground-level contract that includes signing and pavement marking installation (a total of 918 locations.) Because the ground-level contract covers both the improvements at signalized and stop-controlled intersections, the first step was to separate stop-controlled intersections from the file. Key pieces of information from this data file included county, route designations and numbers for both mainline and cross street (e.g., US 25, SC 12), start and completion dates of installation, number of lanes (e.g., two or four lanes on the mainlines, two lanes on the cross street), and area type (i.e., urban, rural). The first step of processing the data was to convert route designation and number for both mainline and cross street into three identification codes as follows:

- Route type code (i.e., US = 2, SC = 4, and S = 7).
- Route number.
- Route auxiliary (i.e., Mainline = 0, Alternate = 2, and Business = 7).

These three identifiers would later be used to link the crash and traffic data files to each intersection. Once crash and traffic data were linked to each intersection, the research team summarized the number of crashes per year by type for each location.

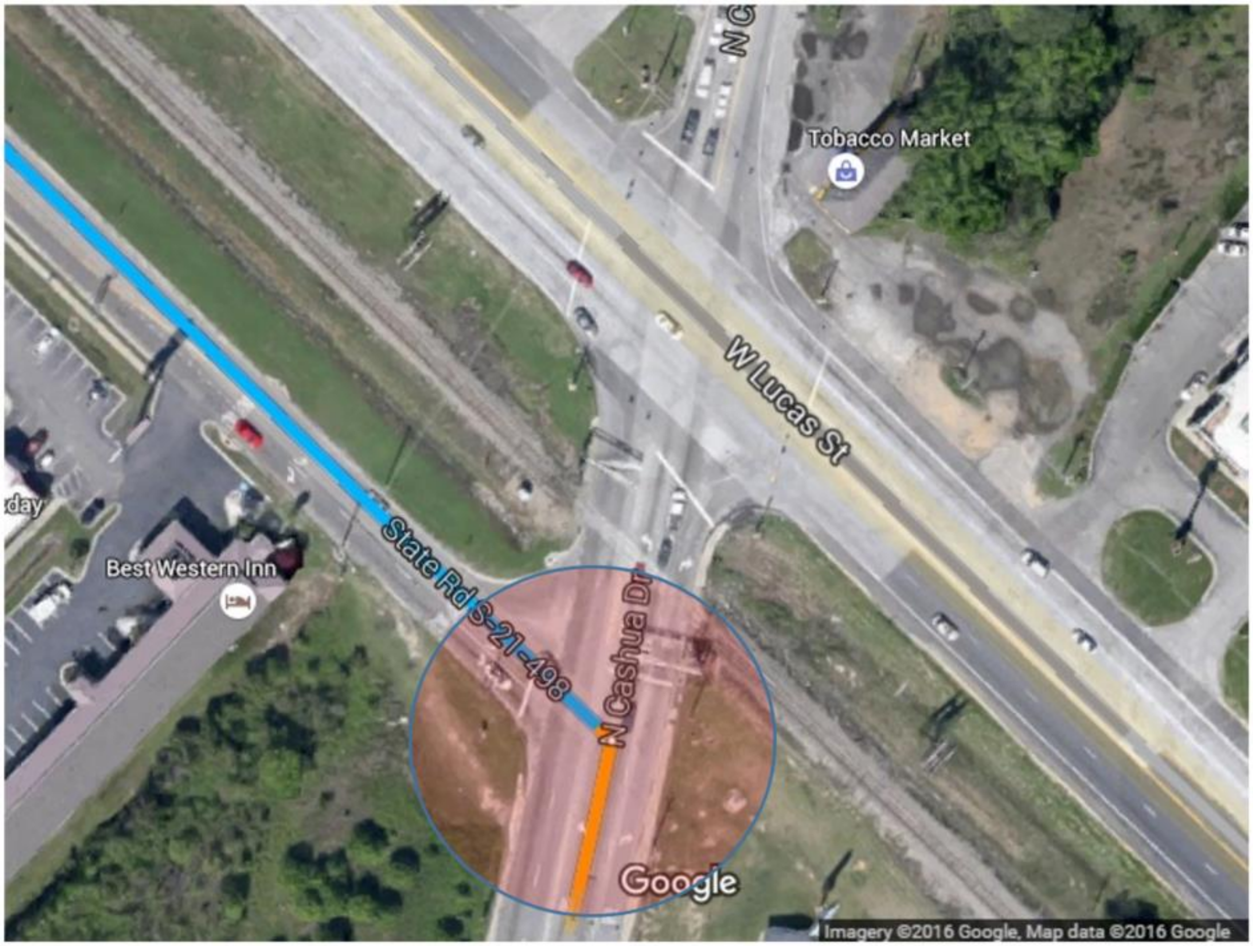
The start and completion dates allowed the team to identify the before and after periods. Before and after periods included complete calendar years during which there was no installation activity. For example, if the work at a given intersection started in December 2009 and was not completed until January 2010, two full calendar years of 2009 and 2010 were considered "installation years" and removed from the dataset. The before period in this research is from 2005 (the first year of available data) to 2008 (the last full year of no construction activity). Similarly, the after period is from 2011 to 2014 (the last year of available data).

The result of this process was a list of stop-controlled intersections with location identifiers in uniform format across different data files. This list included the before and after periods. These intersections were candidates for the treatment group used in the EB evaluation. The research team checked all work orders and work plans to collect number of legs and verify number of lanes for each intersection. The research team conducted a manual process of verifying candidate intersections in Google® Earth™ (i.e., visual verification) to select the final treatment group. The research team flagged intersections—and later dropped treatment sites from the list of candidates—based on the following criteria:

1. The intersection is located close to another intersection or facility (e.g., railroad crossing) and it was not possible to separate crashes and operations, as seen in figure 7. The candidate treatment site is highlighted, however, it is located next to a railroad crossing and what appears to be a major signalized intersection. In this case, the research team determined that it would be difficult to know if a crash occurred because of the intersection of interest or something else. In these cases, the research team dropped the site from the candidate pool.

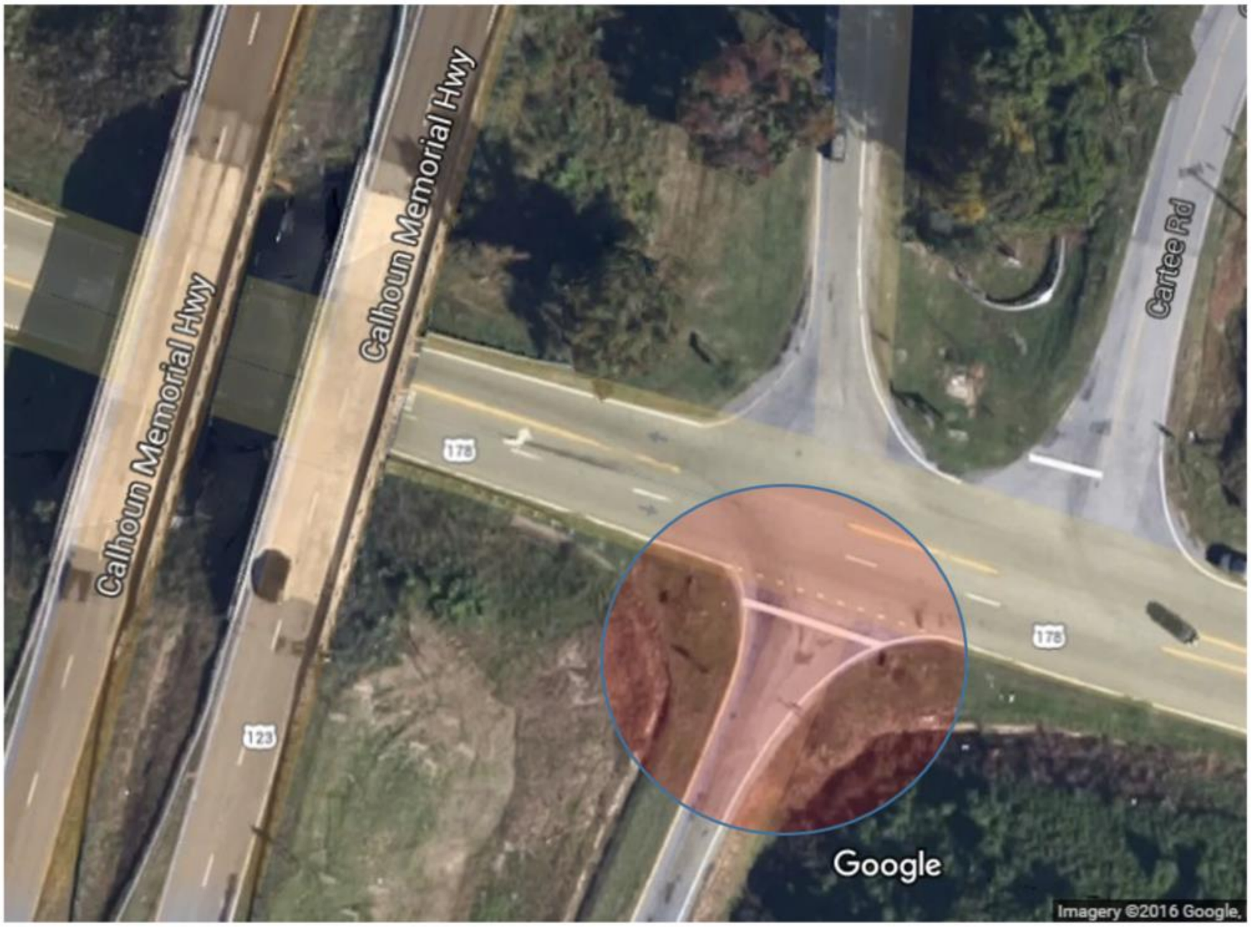
2. The intersection has an abnormal configuration, and the data fail to reflect the anomaly. This is often the case where an intersection has an extreme skew angle or it is an exit ramp from a limited-access highway. Figure 8 and figure 9 are two examples. Both intersections were coded in the installation data file as three-legged, stop-controlled intersections between the surface street and the limited-access highway above (i.e., US 178 and US 123-Calhoun Memorial Hwy, US 378-Sunset Blvd and SC 12-Jarvis Klapman Blvd). There is no indication in the data file that these are exit ramps. The traffic volumes associated with these locations are for the major limited-access highways, not the ramps themselves. All intersections similar to these were flagged and later dropped from the treatment group.

Following SCDOT's advice, the research team decided to exclude all intersections in Beaufort County because there were changes in route names and numbers in this county that could lead to inaccurate matching of traffic and crash data.



Imagery ©2016 Google®, Map data ©2016 Google®.

Figure 7. Screenshot. Example 1 of check and verify treatment site in Google® Earth™ (original image modified with circle around intersection).(16)



Imagery ©2016 Google®, Map data ©2016 Google®.

Figure 8. Screenshot. Example 2 of check and verify treatment site in Google® Earth™ (original image modified with circle around intersection).[(17)]

Imagery ©2016 Google®, Map data ©2016 Google®.

Figure 9. Screenshot. Example 3 check and verify treatment site in Google® Earth™ (original image modified with circle around intersection).(18)

REFERENCE SITES

SCDOT provided the research team with a list of more than 3,000 intersections—both stop-controlled and signalized—for reference sites. Similar to the installation data, this list of intersections included key location identifiers (e.g., county, route designations, and numbers) and intersection characteristics (e.g., number of lanes on the mainline and cross street, area type, and type of traffic control). Therefore, the research team followed similar steps to process the raw data. The route identifiers were converted to a common format to link crash and traffic data for each intersection from different files. However, this data file did not provide number of legs, a key variable for these potential reference sites.

The research team decided to collect number of legs using Google® Earth™ and Google® Maps™. It was infeasible to locate and collect number of legs from Google® Earth™ for every intersection because of resource constraints. Instead, the research team randomly sampled at least 30 intersections for each group from the pool of candidate reference sites, and took the following steps:

1. Separate the pool of stop-controlled intersections into different categories using the available information (e.g., rural intersections with two lanes on the mainline and two lanes on the cross street, urban intersections with four lanes on the mainline).

2. Randomize the order in each intersection category using a random number generator.

3. Start from the top of the list for each category, locate the intersection in Google® Maps™ and Google® Earth™, and determine the number of legs and verify the number of lanes.

The research team repeated these steps until there were at least 30 sites for each group (e.g., three-legged, rural intersections with two mainline lanes and two cross street lanes). Figure 10 shows a screenshot of a four-legged, rural intersection between US 76 (Garners Ferry Rd) and S-69 (Congress Rd) in Richland County, located in Google® Maps™ in satellite image mode.

Imagery ©2016 Google®, Map data ©2016 Google®.

Figure 10. Example of collecting number of legs for reference site from Google® Earth™.(19)

TRAFFIC DATA

SCDOT provided the research team with a statewide traffic volume data file for 2014. The research team used data in this file and merged with both candidate treatment and reference sites. This data file had more details with AADT information for both mainline and cross street for most intersections. The research team made a request but SCDOT was not able to provide similar data for other years. With SCDOT's advice, the research team downloaded AADT files for 2006 to 2014 publicly available on SCDOT's website. However, these data files were much less detailed than the 2014 file the research team received from SCDOT staff. AADT information from these files was not available for many intersection mainlines and a majority of intersection cross streets. The research team used these data files to create growth factors by county. The research team used the growth factors and the detailed 2014 data file to estimate AADT information for 2006 to 2013. AADT for 2005 was not available from SCDOT's website, so the research team extrapolated 2005 AADT based on data for 2006 to 2008. If AADT for either the mainline or cross street was still missing after the data processing, the research team dropped the intersections from the pools of treatment or reference sites. Note that there were few intersections that fell into this group.

CRASH DATA

SCDOT provided 10 years of crash data (2005 to 2014). A unique accident number identifies each crash in the data files. A combination of the following variables was used to identify the location of each crash:

- County number (e.g., 1 = Abbeville, 2 = Aiken, and 3 = Allendale).
- Route type code (e.g., 2 = US, 4 = SC, and 7 = S).
- Route number.
- Route auxiliary (e.g., 0 = Mainline, 2 = Alternate, and 7 = Business).
- Crossing route type code (e.g., 2 = US, 4 = SC, and 7 = S).
- Crossing route number.
- Crossing route auxiliary (e.g., 0 = Mainline, 2 = Alternate, and 7 = Business).
- Base distance offset from the intersection (e.g., 1 = 0.01 mi, 5 = 0.05 mi, and 10 = 0.1 mi).

Note that the research team used crossing route in this context as a reference point, and the offset determined the distance from that reference point to the crash location. Route and crossing route in crash data files do not necessarily mean the mainline and minor routes in the same context of an intersection. The route indicates the roadway on which the crash occurred, and the crossing route indicates the crossing street at the nearest intersection (reference point). Both can be the mainline or the minor roads of the intersection used as the reference point.

The research team screened crash location information to identify and count crashes at each intersection. The crash data files did not provide a specific code to determine "intersection-related" crashes. Therefore, the process of locating and counting crashes at each intersection relied solely on crash location. The research team considered a crash "intersection-related" and counted it toward the number of crashes at an intersection if the location information indicated the crash occurred within 0.05 mi (264 ft), as was recommended by SCDOT staff.

The research team used number of fatalities and injuries coded for each crash to determine crash severity. Manner of collision determined rear-end and right-angle crashes. Light condition information was also available and identified nighttime crashes.

Table 13 presents the crash type definitions for South Carolina crash data.

Table 13. Definitions of crash types.

Total	Fatal and Injury	Rear-End	Right-Angle	Nighttime
Crashes of all types and severity levels	One of the following conditions: • At least one fatality (fat $\geq$ 1) • At least one injury (inj $\geq$ 1)	Manner of collision coded as "rear-end" (rims_mac = 10)	Manner of collision coded as "Angle 1" (rims_mac = 41), "Angle 2" (rims_mac = 42), or "Angle 3" (rims_mac = 43)	Light Condition coded as anything other than "Daylight" (alc = 1).

TREATMENT COST DATA

SCDOT provided actual construction cost data for improvements at more than 800 unsignalized intersections. Intersection construction costs were separated into subtotal pavement marking and signing treatment costs. Each intersection received a package of those treatments appropriate for implementation at the site out of the list of potential treatments. The treatment costs varied at each intersection based on the unique package of treatments it received. Table 14 summarizes the treatment costs.

Table 14. Treatment cost summary.

Statistic	Pavement Marking	Signing	Total
Minimum	$374.14	$426.05	$430.14
Average	$2,958.10	$3,181.10	$5,874.01
Maximum	$26,524.98	$18,530.21	$33,196.54

Note that some intersections only had pavement marking or signing improvements, but all intersections had at least some of one type of treatment installed.

Maintenance costs are dependent on the countermeasures installed at a given intersection. Without a record of the countermeasures installed at each intersection, it is difficult to estimate maintenance costs and service life. In addition, preliminary engineering (PE) costs were not supplied by SCDOT. For systemic projects, PE costs often represent 10 to 30 percent of the total project costs.

DATA CHARACTERISTICS AND SUMMARY

Table 15 and table 16 provide summary information for the data collected for the treatment and reference sites. The information in table 15 should not be used to make simple before–after comparisons of crashes per site-year since it does not account for factors, other than the strategy, that may cause a change in safety between the before and after periods. Such comparisons are properly done with the EB analysis as presented later.

Table 15. Data summary for treatment sites.

Data Element	Before Period	After Period
Number of sites	434	434
Three-legged, two lanes on the mainline and two lanes on the cross street	126	126
Four-legged, two lanes on the mainline and two lanes on the cross street	131	131
Three-legged, four lanes on the mainline and two lanes on the cross street	116	116
Four-legged, four lanes on the mainline and two lanes on the cross street	60	60
Number of site-years	2,438	1,389
Total crashes	8,514	4,231
Fatal and injury crashes	2,841	1,290
Right-angle crashes	3,538	1,840
Rear-end crashes	2,401	1,472
Nighttime crashes	2,193	915
Max mainline AADT (vehicles per day)	41,731	41,755
Average mainline AADT (vehicles per day)	11,042	10,437
Min mainline AADT (vehicles per day)	641	631
Max minor road AADT (vehicles per day)	8,436	8,400
Average minor road AADT (vehicles per day)	1,453	1,539
Min minor road AADT (vehicles per day)	102	100

Table 16. Data summary for reference sites.

Data Element	Value
Number of sites	568
Number of site-years	5,680
Total crashes	9,095
Fatal and injury crashes	3,122
Right-angle crashes	3,952
Rear-end crashes	2,266
Nighttime crashes	2,382
Max mainline AADT (vehicles per day)	51,589
Average mainline AADT (vehicles per day)	8,495
Min mainline AADT (vehicles per day)	121
Max minor road AADT (vehicles per day)	8,100
Average minor road AADT (vehicles per day)	1,203
Min minor road AADT (vehicles per day)	102

CHAPTER 7. DEVELOPMENT OF SPFS

This section presents the SPFs developed for each crash type. The SPFs support the use of the EB methodology to estimate the safety effectiveness of this strategy.[15] The research team developed negative binomial regression models to predict the number of crashes. In specifying a negative binomial error structure, the dispersion parameter, *k*, was estimated iteratively from the model and the data. For a given dataset, smaller values of *k* indicate relatively better models. The research team developed one SPF for each of the following intersection configurations:

- 3 x 22: Three-legged intersections with two lanes on the mainline and two lanes on the cross street.
- 4 x 22: Four-legged intersections with two lanes on the mainline and two lanes on the cross street.
- 3 x 42: Three-legged intersections with four lanes on the mainline and two lanes on the cross street.
- 4 x 42: Four-legged intersections with four lanes on the mainline and two lanes on the cross street.

The research team developed correlation matrices for variables and used them as guide for the SPF development process. This helped the research team avoid highly correlated variables in the models. The model development followed a process of forward selection for selecting variables with the best fit. The research team started with mainline and cross street traffic volumes and their variants (e.g., natural logarithm, ratio of cross street AADT, and mainline AADT). Other candidate explanatory variables were then added, one by one, to the model. The model was re-estimated and the goodness of fit was reevaluated with each variable addition.

The research team initially included annual adjustment variables (i.e., indicators for years 2005 to 2014) in the SPFs during the first iteration of model development. However, most of these variables did not result in statistically significant parameters or help improve the fit of the SPFs. The inclusion of annual adjustment variables also led to heavily under-predicted crashes for some years (i.e., small coefficients on the negative side and far from being well fit), especially for the later years that cover the after period. The team eventually decided to drop these annual adjustment variables from the models and considered another approach to account for the annual trend (discussed later in this chapter).

In some cases, the research team could not develop an adequate model for a specific crash type. In these cases, the team used the SPF for total crashes and adjusted by the proportion of the number of crashes for the given crash type in total crashes.

The definition of variables included in the final SPFs are as follows:

- $Total_{axbc}$ = the predicted number of total crashes (all types and severity levels) for intersection with "a" legs, "b" lanes on the mainline, and "c" lanes on the cross street (e.g., 3 x 42 for three-legged intersections with four lanes on the mainline and two lanes on the cross street).

- FI_{axbc} = the predicted number of fatal and injury crashes for intersection with "a" legs, "b" lanes on the mainline, and "c" lanes on the cross street.

- $Rear\text{-}End_{axbc}$ = the predicted number of rear-end crashes for intersection with "a" legs, "b" lanes on the mainline, and "c" lanes on the cross street.

- $Right\text{-}Angle_{axbc}$ = the predicted number of right-angle crashes for intersection with "a" legs, "b" lanes on the mainline, and "c" lanes on the cross street.

- $Night_{axbc}$ = the predicted number of nighttime crashes for intersection with "a" legs, "b" lanes on the mainline, and "c" lanes on the cross street.

- *ml_aadt* = AADT on the mainline (vehicles/day).

- *xst_aadt* = AADT on the cross street (vehicles/day).

- *aadt* = *ml_aadt* + *xst_aadt*, total traffic of intersection (vehicles/day).

- *ratio1* = *ln*(*xst_aadt*)/*ln*(*ml_aadt*), with *ln*(*xst_aadt*) being the natural logarithm of AADT on cross street and *ln*(*ml_aadt*) being the natural logarithm of AADT on mainline.

- *ratio2* = *xst_aadt*/*ml_aadt*, with *xst_aadt* and *ml_aadt* being the AADT on cross street and mainline, respectively.

- *ratio3* = *xst_aadt*/(*xst_aadt* + *ml_aadt*), with *xst_aadt* and *ml_aadt* being the AADT on cross street and mainline, respectively.

- *ratio4* = *ln*(*xst_aadt*)/*ln*(*xst_aadt* + *ml_aadt*), with *ln*(*xst_aadt*) being the natural logarithm of AADT on cross street and *ln*(*xst_aadt* + *ml_aadt*) being the natural logarithm of total traffic at intersection.

- *urban* = urban/rural indicator for the intersection (= 1 for urban, = 0 otherwise).

- $\beta_1, \beta_2, \beta_3, \beta_4$ = parameters estimated in the SPF development process using maximum likelihood method.

- k = overdispersion parameter.

SPFs FOR 3 X 22 INTERSECTIONS

The SPF for total crashes at three-legged intersections with two lanes on the mainline and two lanes on the cross street is shown in figure 11.

$$Total_{3\times22} = ml\_aadt^{\beta_1} \times xst\_aadt^{\beta_2} \times e^{(\beta_3 \times urban + \beta_4)}$$

Figure 11. Equation. Total crash SPF for 3 x 22 intersections.

Table 17 presents the total crash SPF parameters for three-legged intersections with two lanes on the mainline and two lanes on the cross street.

Table 17. SPF parameters for total crashes at 3 x 22 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of mainline AADT	0.285	0.049
β_2	Coefficient of cross street AADT	0.081	0.025
β_3	Coefficient for urban/rural indicator	0.270	0.068
β_4	Intercept term	–2.814	0.439
k	Overdispersion parameter	0.128	0.032

The SPF for fatal and injury crashes at three-legged intersections with two lanes on the mainline and two lanes on the cross street is shown in figure 12.

$$FI_{3\times22} = aadt^{\beta_1}e^{\beta_4}$$

Figure 12. Equation. Fatal and injury crash SPF for 3 x 22 intersections.

Table 18 presents the fatal and injury crash SPF parameters for three-legged intersections with two lanes on the mainline and two lanes on the cross street.

Table 18. SPF Parameters for fatal and injury crashes at 3 x 22 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of total intersection AADT (mainline AADT + cross street AADT)	0.329	0.069
β_4	Intercept term	–3.641	0.614
k	Overdispersion parameter	0.125	0.088

The SPF for rear-end crashes at three-legged intersections with two lanes on the mainline and two lanes on the cross street is shown in figure 13.

$$Rear\ End_{3\times22} = ml\_aadt^{\beta_1} \times xst\_aadt^{\beta_2} \times e^{(\beta_3 \times urban\ + \beta_4)}$$

Figure 13. Equation. Rear-end crash SPF for 3 x 22 intersections.

Table 19 presents the rear-end crash SPF parameters for three-legged intersections with two lanes on the mainline and two lanes on the cross street.

Table 19. SPF Parameters for rear-end crashes at 3 x 22 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of mainline AADT	1.033	0.092
β_2	Coefficient of cross street AADT	0.093	0.040
β_3	Coefficient for urban/rural indicator	0.378	0.119
β_4	Intercept term	–10.550	0.844
k	Overdispersion parameter	0.351	0.082

The SPF for right-angle crashes at three-legged intersections with two lanes on the mainline and two lanes on the cross street is shown in figure 14.

$$Right\ Angle_{3\times22} = aadt^{\beta_1} \times e^{(\beta_2 \times ratio\ 1 + \beta_3 \times urban\ + \beta_4)}$$

Figure 14. Equation. Right-angle crash SPF for 3 x 22 intersections.

Table 20 presents the right-angle crash SPF parameters for three-legged intersections with two lanes on the mainline and two lanes on the cross street.

Table 20. SPF parameters for right-angle crashes at 3 x 22 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of intersection AADT	0.264	0.109
β_2	Coefficient for *ratio1* = *ln*(*xst_aadt*)/*ln*(*ml_aadt*)	1.758	0.427
β_3	Coefficient for urban/rural indicator	0.461	0.140
β_4	Intercept term	–5.101	1.015
k	Overdispersion parameter	0.375	0.145

The research team could not develop a statistically significant model for nighttime crashes. The SPF for total crashes was used with an adjustment factor to predict nighttime crashes.

SPFs FOR 4 X 22 INTERSECTIONS

The SPF for total crashes at four-legged intersections with two lanes on the mainline and two lanes on the cross street is shown in figure 15.

$$Total_{4\times22} = ml\_aadt^{\beta_1} \times xst\_aadt^{\beta_2} \times e^{(\beta_3 \times urban\ + \beta_4)}$$

Figure 15. Equation. Total crash SPF for 4 x 22 intersections.

Table 21 presents the total crash SPF parameters for four-legged intersections with two lanes on the mainline and two lanes on the cross street.

Table 21. SPF parameters for total crashes at 4 x 22 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of mainline AADT	0.227	0.030
β_2	Coefficient of cross street AADT	0.082	0.025
β_3	Coefficient for urban/rural indicator	0.081	0.050
β_4	Intercept term	–2.041	0.253
k	Overdispersion parameter	0.169	0.028

The SPF for fatal and injury crashes at four-legged intersections with two lanes on the mainline and two lanes on the cross street is shown in figure 16.

$$FI_{4\times 22} = ml\_aadt^{\beta_1} \times xst\_aadt^{\beta_2} \times e^{(\beta_3 \times urban\ + \beta_4)}$$

Figure 16. Equation. Fatal and injury crash SPF for 4 x 22 intersections.

Table 22 presents the fatal and injury crash SPF parameters for four-legged intersections with two lanes on the mainline and two lanes on the cross street.

Table 22. SPF Parameters for fatal and injury crashes at 4 x 22 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of mainline AADT	0.106	0.048
β_2	Coefficient of cross street AADT	0.086	0.042
β_3	Coefficient for urban/rural indicator	–0.165	0.079
B_4	Intercept term	–2.005	0.398
k	Overdispersion parameter	0.240	0.078

The SPF for rear-end crashes at four-legged intersections with two lanes on the mainline and two lanes on the cross street is shown in figure 17.

$$Rear\ End_{4\times 22} = ml\_aadt^{\beta_1} \times xst\_aadt^{\beta_2} \times e^{\beta_3}$$

Figure 17. Equation. Rear-end crash SPF for 4 x 22 intersections.

Table 23 presents the rear-end crash SPF parameters for four-legged intersections with two lanes on the mainline and two lanes on the cross street.

Table 23. SPF Parameters for rear-end crashes at 4 x 22 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of mainline AADT	1.133	0.080
β_2	Coefficient of cross street AADT	0.130	0.057
β_3	Intercept term	–11.721	0.731
k	Overdispersion parameter	0.869	0.172

The SPF for right-angle crashes at four-legged intersections with two lanes on the mainline and two lanes on the cross street is shown in figure 18.

$$Right\ Angle_{4\times22} = aadt^{\beta_1} \times e^{(\beta_2 \times ratio\ 4 + \beta_3 \times urban\ + \beta_4)}$$

Figure 18. Equation. Right-angle crash SPF for 4 x 22 intersections.

Table 24 presents the right-angle crash SPF parameters for four-legged intersections with two lanes on the mainline and two lanes on the cross street.

Table 24. SPF parameters for right-angle crashes at 4 x 22 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of intersection AADT (Mainline AADT + Cross street AADT)	0.166	0.044
β_2	Coefficient for *ratio4* = (*xst_aadt*)/(*ml_aadt*)	1.397	0.329
β_3	Coefficient for urban/rural indicator	0.172	0.066
β_4	Intercept term	–2.817	0.470
k	Overdispersion parameter	0.266	0.051

The SPF for nighttime crashes at four-legged intersections with two lanes on the mainline and two lanes on the cross street is shown in figure 19.

$$Night\ Time_{4\times22} = ml\_aadt^{\beta_1} \times xst\_aadt^{\beta_2} \times e^{(\beta_3 \times urban\ + \beta_4)}$$

Figure 19. Equation. Nighttime crash SPF for 4 x 22 intersections.

Table 25 presents the nighttime crash SPF parameters for four-legged intersections with two lanes on the mainline and two lanes on the cross street.

Table 25. SPF Parameters for nighttime crashes at 4 x 22 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient for natural mainline AADT	0.153	0.058
β_2	Coefficient of cross street AADT	0.100	0.050
β_3	Coefficient for urban/rural indicator	–0.217	0.095
β_4	Intercept term	–2.784	0.481
k	Overdispersion parameter	0.459	0.119

SPFs FOR 3 X 42 INTERSECTIONS

The SPF for total crashes at three-legged intersections with four lanes on the mainline and two lanes on the cross street is shown in figure 20.

$$Total_{3\times42} = aadt^{\beta_1} \times e^{(\beta_2 \times ratio\ 3 + \beta_4)}$$

Figure 20. Equation. Total crash SPF for 3 x 42 intersections.

Table 26 presents the total crash SPF parameters for three-legged intersections with four lanes on the mainline and two lanes on the cross street.

Table 26. SPF parameters for total crashes at 3 x 42 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of intersection AADT (mainline AADT + cross street AADT)	0.356	0.056
β_2	Coefficient for *ratio3* = *xst_aadt*/(*xst_aadt* + *ml_aadt*)	1.164	0.294
β_4	Intercept term	–2.950	0.548
k	Overdispersion parameter	0.185	0.032

The research team could not develop a statistically significant model for fatal and injury crash SPF at three-legged intersections with four lanes on the mainline and two lanes on the cross street. The SPF for total crashes was used with an adjustment factor to predict the number of fatal and injury crashes.

The SPF for rear-end crashes at three-legged intersections with four lanes on the mainline and two lanes on the cross street is shown in figure 21.

$$Rear\ End_{3\times 42} = aadt^{\beta_1} \times e^{(\beta_3 \times urban\ + \beta_4)}$$

Figure 21. Equation. Rear-end crash SPF for 3 x 42 intersections.

Table 27 presents the rear-end crash SPF parameters for three-legged intersections with four lanes on the mainline and two lanes on the cross street.

Table 27. SPF parameters for rear-end crashes at 3 x 42 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of intersection AADT (mainline AADT + cross street AADT)	0.345	0.115
β_3	Coefficient for urban/rural indicator	0.289	0.121
β_4	Intercept term	–4.325	1.076
k	Overdispersion parameter	0.799	0.162

The SPF for right-angle crashes at three-legged intersections with four lanes on the mainline and two lanes on the cross street is shown in figure 22.

$$Right\ Angle_{3\times 42} = aadt^{\beta_1} \times e^{(\beta_2 \times ratio\,3 + \beta_3 \times urban\ + \beta_4)}$$

Figure 22. Equation. Right-angle crash SPF for 3 x 42 intersections.

Table 28 presents the right-angle crash SPF parameters for three-legged intersections with four lanes on the mainline and two lanes on the cross street.

Table 28. SPF parameters for right-angle crashes at 3 x 42 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of intersection AADT (mainline AADT + cross street AADT)	0.428	0.095
β_2	Coefficient for *ratio3* = (*xst_aadt*)/(*xst_aadt* + *ml_aadt*)	2.582	0.439
β_3	Coefficient for urban/rural indicator	0.180	0.092
β_4	Intercept term	–4.815	0.914
k	Overdispersion parameter	0.411	0.084

The research team could not develop a statistically significant model for nighttime crashes. The SPF for total crashes was used with an adjustment factor to predict nighttime crashes.

SPFs FOR 4 X 42 INTERSECTIONS

The SPF for total crashes at four-legged intersections with four lanes on the mainline and two lanes on the cross street is shown in figure 23.

$$Total_{4\times 42} = ml\_aadt^{\beta_1} \times xst\_aadt^{\beta_2} \times e^{(\beta_3 \times urban\ + \beta_4)}$$

Figure 23. Equation. Total crash SPF for 4 x 42 intersections.

Table 29 presents the total crash SPF parameters for four-legged intersections with four lanes on the mainline and two lanes on the cross street.

Table 29. SPF parameters for total crashes at 4 x 42 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of mainline AADT	0.149	0.039
β_2	Coefficient of cross street AADT	0.147	0.024
β_3	Coefficient for urban/rural indicator	0.157	0.054
β_4	Intercept term	–1.878	0.402
k	Overdispersion parameter	0.197	0.029

The SPF for fatal and injury crashes at four-legged intersections with four lanes on the mainline and two lanes on the cross street is shown in figure 24.

$$FI_{4\times 42} = ml\_aadt^{\beta_1} \times xst\_aadt^{\beta_2} \times e^{\beta_4}$$

Figure 24. Equation. Fatal and injury crash SPF for 4 x 42 intersections.

Table 30 presents the fatal and injury SPF parameters for four-legged intersections with four lanes on the mainline and two lanes on the cross street.

Table 30. SPF parameters for fatal and injury crashes at 4 x 42 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of mainline AADT	0.100	0.055
β_2	Coefficient of cross street AADT	0.089	0.037
β_4	Intercept term	–1.949	0.579
k	Overdispersion parameter	0.272	0.075

The SPF for rear-end crashes at four-legged intersections with four lanes on the mainline and two lanes on the cross street is shown in figure 25.

$$Rear\ End_{4\times42} = mlaadt^{\beta_1} \times e^{(\beta_2 \times ratio\ 3 + \beta_3 \times urban\ + \beta_4)}$$

Figure 25. Equation. Rear-end crash SPF for 4 x 42 intersections.

Table 31 presents the rear-end SPF parameters for four-legged intersections with four lanes on the mainline and two lanes on the cross street.

Table 31. SPF parameters for rear-end crashes at 4 x 42 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of mainline AADT	0.521	0.093
β_2	Coefficient for *ratio3* = *xst_aadt*/(*xst_aadt* + *ml_aadt*)	1.430	0.412
β_3	Coefficient for urban/rural indicator	0.538	0.111
β_4	Intercept term	–6.372	0.880
k	Overdispersion parameter	0.262	0.109

The SPF for right-angle crashes at four-legged intersections with four lanes on the mainline and two lanes on the cross street is shown in figure 26.

$$Right\ Angle_{4\times42} = aadt^{\beta_1} \times e^{(\beta_2 \times ratio\ 4 + \beta_3 \times urban\ + \beta_4)}$$

Figure 26. Equation. Right-angle crash SPF for 4 x 42 intersections.

Table 32 presents the right-angle SPF parameters for four-legged intersections with four lanes on the mainline and two lanes on the cross street.

Table 32. SPF parameters for right-angle crashes at 4 x 42 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of intersection AADT (mainline AADT + cross street AADT)	0.123	0.067
β_2	Coefficient *ratio4* = (*xst_aadt*)/(*ml_aadt*)	1.660	0.324
β_3	Coefficient for urban/rural indicator	0.205	0.077
β_4	Intercept term	–2.620	0.714
k	Overdispersion parameter	0.375	0.065

The SPF for nighttime crashes at four-legged intersections with four lanes on the mainline and two lanes on the cross street is shown in figure 27.

$$Night\ Time_{4\times 42} = aadt^{\beta_1} \times e^{(\beta_2 \times ratio\ 3 + \beta_3 \times urban\ + \beta_4)}$$

Figure 27. Equation. Nighttime crash SPF for 4 x 42 intersections.

Table 33 presents the nighttime SPF parameters for four-legged intersections with four lanes on the mainline and two lanes on the cross street.

Table 33. SPF parameters for nighttime crashes at 4 x 42 intersections.

Parameter	Description	Estimated Value	Standard Error
β_1	Coefficient of intersection AADT (mainline AADT + cross street AADT)	0.554	0.087
β_2	Coefficient for *ratio3* = *xst_aadt*/(*xst_aadt* + *ml_aadt*)	1.167	0.386
β_3	Coefficient for urban/rural indicator	–0.233	0.097
β_4	Intercept term	–6.062	0.825
k	Overdispersion parameter	0.240	0.105

BEFORE–AFTER ADJUSTMENT FACTORS

SPFs may include annual factors to account for potential time trends, as discussed in the first section of chapter 5. In this study, however, the SPFs did not include yearly indicator variables because after numerous attempts, the research team could not achieve a reasonable level of statistical significance for these individual variables. The research team decided to account for the time trend by using an aggregate before-to-after adjustment factor. Instead of using annual adjustment factors (i.e., one for each year), the research team used a single adjustment factor to account for the difference (i.e., crash trend) between the before and after periods. Because SCDOT did not install the treatment at all sites in the same year, the installation periods varied. For this reason, the team calculated one adjustment factor for each installation period (i.e., all intersections for which treatments were implemented in 2009–2010 have the same adjustment factor). Using these adjustment factors, the assumption is that all safety effects of unknown or immeasurable factors (e.g., weather) do not differ among reference and treatment sites or across intersection configurations. These factors were calculated based on the observed and predicted crashes at all reference sites. Figure 28 shows the equation used to calculate the before-after adjustment factors.

$$Adj\_Factor = \frac{\frac{Obs_{after}}{Pred_{after}}}{\frac{Obs_{before}}{Pred_{before}}}$$

Figure 28. Equation. Before–after adjustment factor calculation.

Where:

Adj_Factor = the factor for adjusting the difference between the before and after period.

$Obs_{\_before}$ = observed number of crashes at reference sites during the before period.

$Pred_{before}$ = predicted number of crashes at reference sites during the before period (calculated by SPF).

$Obs_{\_after}$ = observed number of crashes at reference sites during the after period.

$Pred_{after}$ = predicted number of crashes at reference sites during the after period (calculated by SPF).

Table 34 to table 38 present the before–after adjustment factors for each installation time frame and crash type.

Table 34. Before–after adjustment factor for total crashes.

Installation Year(s)	Observed Crashes—Before	Observed Crashes—After	Predicted Crashes—Before	Predicted Crashes—After	Adjustment Factor
2009	3,894	4,321	3,648	4,540	0.892
2009–2010	3,894	3,426	3,648	3,634	0.883
2010	4,774	3,426	4,552	3,634	0.899
2010–2011	4,774	2,641	4,552	2,724	0.925
2011	5,669	2,641	5,458	2,724	0.934
2011–2012	5,669	1,759	5,458	1,814	0.934
2012	6,454	1,759	6,368	1,814	0.957

Table 35. Before–after adjustment factor for fatal and injury crashes.

Installation Year(s)	Observed Crashes—Before	Observed Crashes—After	Predicted Crashes—Before	Predicted Crashes—After	Adjustment Factor
2009	1,346	1,462	1,251	1,559	0.872
2009–2010	1,346	1,124	1,251	1,248	0.837
2010	1,660	1,124	1,562	1,248	0.848
2010–2011	1,660	871	1,562	936	0.876
2011	1,998	871	1,874	936	0.873
2011–2012	1,998	557	1,874	623	0.838
2012	2,251	557	2,186	623	0.868

Table 36. Before–after adjustment factor for rear-end crashes.

Installation Year(s)	Observed Crashes—Before	Observed Crashes—After	Predicted Crashes—Before	Predicted Crashes—After	Adjustment Factor
2009	912	1,144	909	1,119	1.019
2009–2010	912	943	909	895	1.050
2010	1,122	943	1,132	895	1.063
2010–2011	1,122	727	1,132	668	1.098
2011	1,323	727	1,356	668	1.115
2011–2012	1,323	487	1,356	440	1.133
2012	1,539	487	1,583	440	1.137

Table 37. Before–after adjustment factor for right-angle crashes.

Installation Year(s)	Observed Crashes—Before	Observed Crashes—After	Predicted Crashes—Before	Predicted Crashes—After	Adjustment Factor
2009	1,695	1,887	1,585	1,974	0.894
2009–2010	1,695	1,512	1,585	1,580	0.895
2010	2,065	1,512	1,979	1,580	0.917
2010–2011	2,065	1,171	1,979	1,185	0.947
2011	2,440	1,171	2,373	1,185	0.961
2011–2012	2,440	772	2,373	789	0.951
2012	2,781	772	2,768	789	0.974

Table 38. Before–after adjustment factor for nighttime crashes.

Installation Year(s)	Observed Crashes—Before	Observed Crashes—After	Predicted Crashes—Before	Predicted Crashes—After	Adjustment Factor
2009	1,049	1,096	956	1,188	0.841
2009–2010	1,049	857	956	951	0.821
2010	1,286	857	1,193	951	0.836
2010–2011	1,286	652	1,193	713	0.849
2011	1,525	652	1,430	713	0.858
2011–2012	1,525	416	1,430	475	0.822
2012	1,730	416	1,669	475	0.846

CHAPTER 8. BEFORE–AFTER EVALUATION RESULTS

AGGREGATE ANALYSIS

Table 39 provides the estimates of expected crashes in the after period without treatment, the observed crashes in the after period, and the estimated crash modification factor (CMF) and its standard error for each crash type considered in this study. The results in table 39 indicate reductions for all crash types analyzed in this study. The reductions are statistically significant at the 95-percent confidence level for all crash types. For all crash types combined, the CMFs are 0.917 for all severities and 0.899 for fatal and injury crashes. The crash type with the smallest CMF (which translates to the greatest reduction) is nighttime crashes with a CMF of 0.853 (or 14.7-percent reduction). The CMFs for rear-end and right-angle crashes are 0.933 and 0.941, respectively.

Table 39. Aggregate results for EB before–after study.

Statistic	Total	Fatal and Injury	Rear-End	Right-Angle	Nighttime
EB estimate of crashes expected in the after period without the systemic improvement	4,614	1,434	1,577	1,955	1,072
Count of crashes observed in the after period	4,231	1,290	1,472	1,840	953
Estimated CMF	0.917*	0.899*	0.933*	0.941*	0.853*
Standard error of the estimated CMF	0.017	0.028	0.030	0.026	0.031

*Statistically significant results at the 95-percent confidence level.

DISAGGREGATE ANALYSIS

The disaggregate analysis identified specific CMFs by crash type and different conditions. The process also revealed those conditions under which the multiple low-cost treatments are more effective. The research team identified several variables of interest, including: area type (urban or rural), number of legs (three or four), lane configuration of the mainline and the cross street, traffic volumes, and expected crashes without treatment. All of these variables are likely correlated, and caution should be exercised in interpreting and applying the disaggregate analysis results. The team did not conduct a disaggregate analysis on individual treatments or groups of treatments because no detailed information on type of treatment that each intersection received was available. Although we knew these intersections received at least some or all of the treatments, we did not know exactly what treatments were applied.

Table 40 presents the disaggregate results by area type (urban or rural), indicating the sample size (number of sites), CMF, and standard error of the CMF (in parentheses) by group for each crash type considered in this study. For the 188 urban intersections, the results in table 40 indicate increases in all crash types analyzed in this study. Specifically, the CMFs for total and fatal and injury crashes are 1.066 and 1.095, respectively, which are statistically significant at the 95-percent confidence level. The CMFs for rear-end, right-angle, and nighttime crashes are 1.006, 1.025, and 1.013, respectively, which are not statistically significant at the 95-percent confidence level. For the 245 rural intersections, the results in table 40 indicate reductions for all crash types analyzed in this study, which are all statistically significant at the 95-percent confidence level. Based on the disaggregate analysis by area type, it appears this strategy is highly effective at rural intersections, but there is the potential to increase crashes at urban intersections. However, as noted above, this effect may be due to other correlated variables.

Table 40. Disaggregate results by area type.

Statistic	Urban	Standard Error	Rural	Standard Error
Number of intersections	188	N/A	245	N/A
Total CMF	1.066	0.025	0.748*	0.022
Fatal and injury CMF	1.095	0.047	0.734*	0.034
Rear-end CMF	1.006	0.040	0.811*	0.044
Right-angle CMF	1.025	0.037	0.833*	0.037
Nighttime CMF	1.013	0.051	0.718*	0.039

*Statistically significant results at the 95-percent confidence level.

Table 41 presents the disaggregate results by number of legs, indicating the sample size (number of sites), CMF, and standard error of the CMF (in parentheses) by group for each crash type considered in this study. For the 242 three-legged intersections, the results in table 41 indicate reductions in all crash types analyzed in this study. The CMFs for total, fatal and injury, rear-end, and right-angle crashes are not statistically significant at the 95-percent confidence level. The CMF for nighttime crashes is 0.902 and is statistically significant at the 95-percent confidence level. For the 191 four-legged intersections, the results in table 41 indicate reductions for all crash types analyzed in this study, which are all statistically significant at the 95-percent confidence level. Based on the disaggregate analysis by number of legs, it appears this strategy is more effective at four-legged intersections than three-legged intersections. However, as noted above, this effect may be due to other correlated variables.

Table 41. Disaggregate results by number of legs.

Statistic	3-Legged	Standard Error	4-Legged	Standard Error
Number of intersections	242	N/A	191	N/A
Total CMF	0.958	0.022	0.854*	0.025
Fatal and injury CMF	0.949	0.039	0.836*	0.041
Rear-end CMF	0.962	0.036	0.862*	0.052
Right-angle CMF	0.977	0.037	0.902*	0.037
Nighttime CMF	0.902*	0.041	0.780*	0.048

*Statistically significant results at the 95-percent confidence level.

Table 42 presents the disaggregate results by number of lanes, indicating the sample size (number of sites), CMF, and standard error of the CMF (in parentheses) by group for each crash type considered in this study. For the 257 intersections with two-lane major roads, the results in table 42 indicate reductions in all crash types analyzed in this study, which are all statistically significant at the 95-percent confidence level. For the 176 intersections with four-lane major roads, the results in table 42 indicate reductions in total, rear-end, right-angle, and nighttime crashes, and an increase in fatal and injury crashes. None of the CMFs associated with four-lane major roads are statistically significant at the 95-percent confidence level. Based on the disaggregate analysis by number of lanes, it appears this strategy is more effective at two-lane major road intersections than four-lane major road intersections. However, as noted above, this effect may be due to other correlated variables.

Table 42. Disaggregate results by number of lanes.

Statistic	2 Mainline Lanes and 2 Cross Street Lanes	Standard Error	4 Mainline Lanes and 2 Cross Street Lanes	Standard Error
Number of intersections	257	N/A	176	N/A
Total CMF	0.879*	0.022	0.960	0.025
Fatal and injury CMF	0.814*	0.035	1.013	0.047
Rear-end CMF	0.919*	0.041	0.948	0.043
Right-angle CMF	0.925*	0.037	0.956	0.037
Nighttime CMF	0.806*	0.040	0.916	0.050

*Statistically significant results at the 95-percent confidence level.

Table 43 presents the disaggregate results by number of legs and number of lanes, indicating the sample size (number of sites), CMF, and standard error of the CMF (in parentheses) by group for each crash type considered in this study.

For the 126 three-legged intersections with two-lane major roads, the results in table 43 indicate reductions in all crash types analyzed in this study. The CMFs for total, fatal and injury, and nighttime crashes are 0.902, 0.811, and 0.828, respectively, which are statistically significant at the 95-percent confidence level. The CMFs for rear-end and right-angle crashes are not statistically significant at the 95-percent confidence level. For the 116 three-legged intersections with four-lane major roads, none of the CMFs are statistically significant at the 95-percent confidence level.

For the 131 four-legged intersections with two-lane major roads, the results in table 43 and table 44 indicate reductions in all crash types analyzed in this study. The CMFs for total, fatal and injury, right-angle, and nighttime crashes are 0.854, 0.816, 0.892, and 0.779, respectively, which are statistically significant at the 95-percent confidence level. The CMF for rear-end crashes is not statistically significant at the 95-percent confidence level, but is statistically significant at the 90-percent confidence level.

For the 60 four-legged intersections with four-lane major roads, the results in table 43 indicate reductions in all crash types analyzed in this study. The CMFs for total, rear-end, and nighttime crashes are 0.854, 0.838, and 0.780, respectively, which are statistically significant at the 95-percent confidence level. The CMFs for fatal and injury and right-angle crashes are not statistically significant at the 95-percent confidence level.

Based on the disaggregate analysis by number of legs and number of lanes, it appears this strategy is effective for most combinations of legs and lanes. It is least effective at three-legged intersections with four-lane major roads (i.e., 3 x 42). It is most effective at four-legged intersections with two-lane major roads (i.e., 4 x 22). However, as noted above, this may be due to other correlated variables.

Table 43. Disaggregate results for three-legged intersections by number of lanes.

Statistic	3-Legged with 2 Mainline Lanes and 2 Cross Street Lanes	Standard Error	3-Legged with 4 Mainline Lanes and 2 Cross Street Lanes	Standard Error
Number of intersections	126	N/A	116	N/A
Total CMF	0.902*	0.032	1.003	0.031
Fatal and Injury CMF	0.811*	0.050	1.082	0.059
Rear-end CMF	0.940	0.051	0.982	0.052
Right-angle CMF	0.990	0.066	0.970	0.045
Nighttime CMF	0.828*	0.054	0.979	0.063

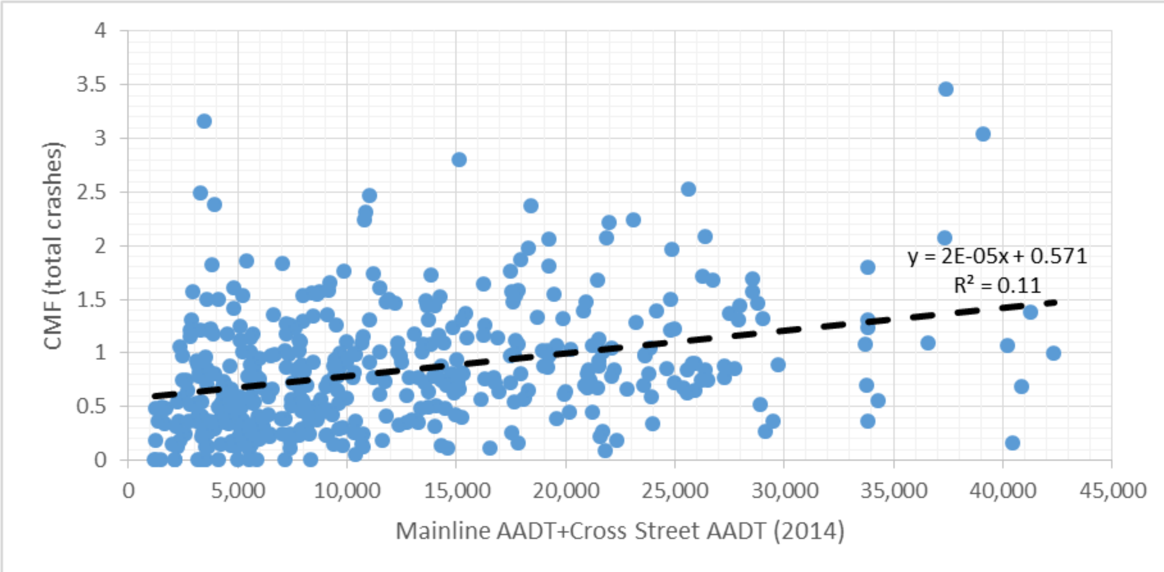
*Statistically significant results at the 95-percent confidence level.

Table 44. Disaggregate results for four-legged intersections by number of lanes.

Statistic	4-Legged with 2 Mainline Lanes and 2 Cross Street Lanes	Standard Error	4-Legged with 4 Mainline Lanes and 2 Cross Street Lanes	Standard Error
Number of intersections	131	N/A	60	N/A
Total CMF	0.854*	0.032	0.854*	0.043
Fatal and injury CMF	0.816*	0.049	0.878	0.074
Rear-end CMF	0.875	0.069	0.838*	0.078
Right-angle CMF	0.892*	0.044	0.924	0.064
Nighttime CMF	0.779*	0.060	0.780*	0.081

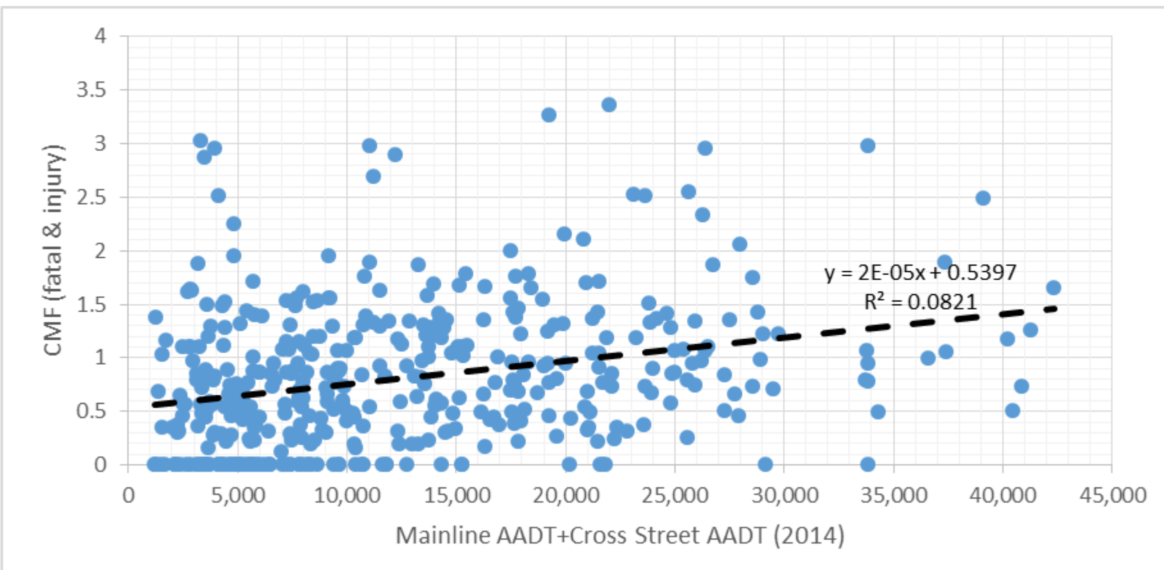
*Statistically significant results at the 95-percent confidence level.

Figure 29 and figure 30 show the individual CMFs for total crashes and fatal and injury crashes, respectively, for each treatment site compared to the total entering traffic volume associated with the intersection. The linear trend line suggests the multiple low-cost treatments are more effective on average for intersections with lower traffic volumes, and the effectiveness decreases (i.e., CMF increases) as traffic volume increases. The CMFs in both figure 29 and figure 30 appear to cross 1.0 when AADT is around 20,000. This suggests that the crash reduction potential is better for intersections with total entering AADT under 20,000. Again, the perceived relationship may also be due to correlations with other variables.



Source: FHWA.

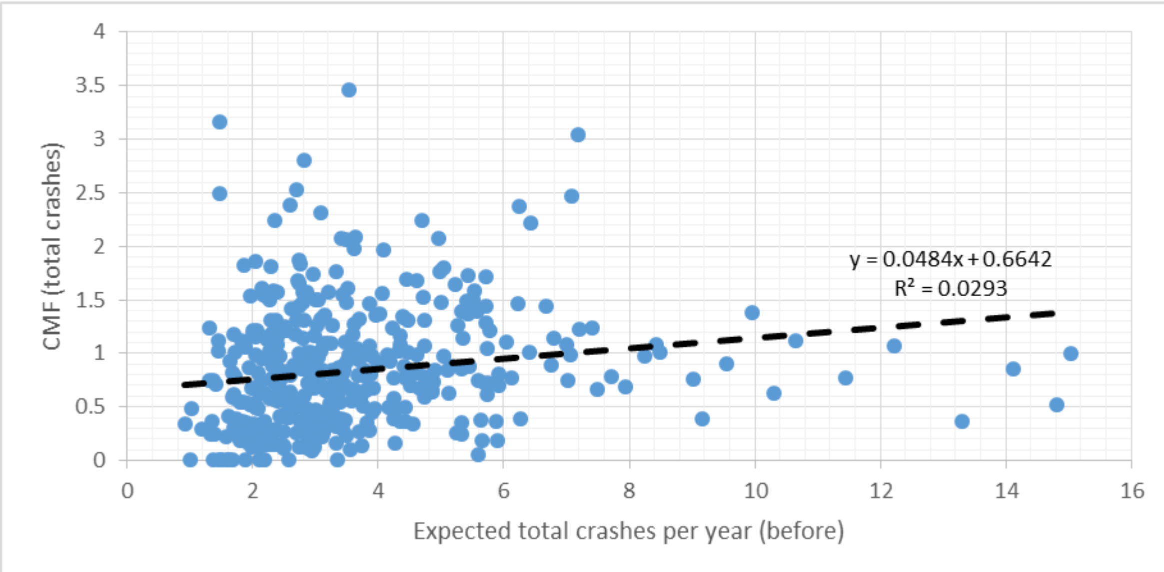
Figure 29. Chart. Relationship between CMF (total crashes) and total intersection AADT.



Source: FHWA.

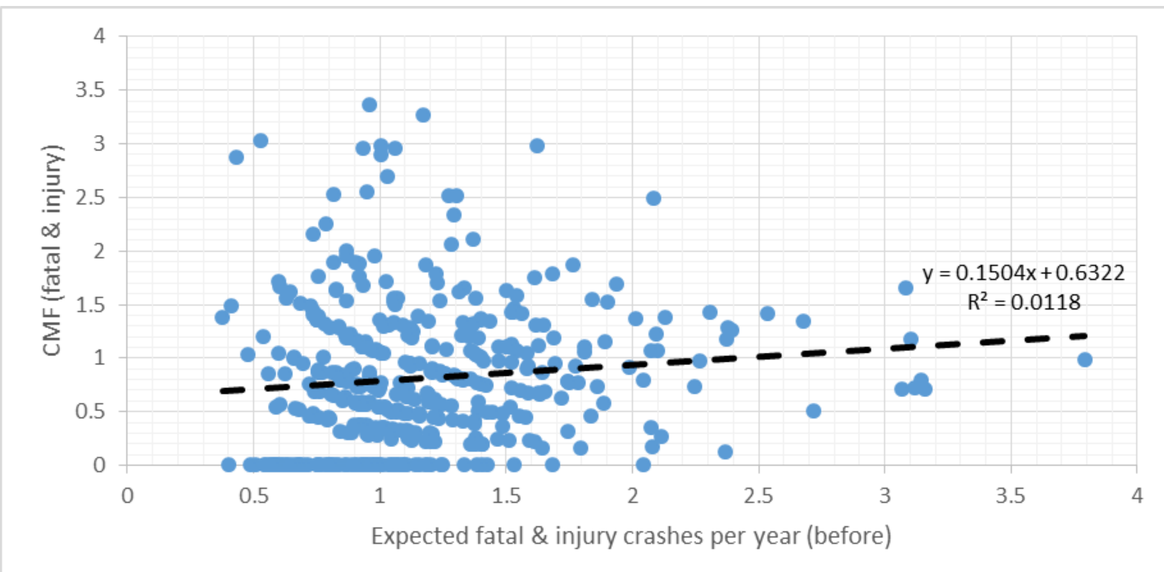
Figure 30. Chart. Relationship between CMF (fatal and injury crashes) and total intersection AADT.

Figure 31 and figure 32 show the individual CMFs for total crashes and fatal and injury crashes, respectively, for each treatment site compared to the expected crashes per year in the before period. The linear trend line suggests the multiple low-cost treatments are more effective on average for intersections with fewer expected crashes per year in the before period, and the effectiveness decreases (i.e., CMF increases) as expected crashes increase. Note that this trend is consistent with the relationship for traffic volume as shown in figure 29 and figure 30, which makes sense because expected crashes increase as traffic volume increases. This confirms the need for caution when interpreting the results of the univariate analyses. Specifically, the net effect of the multiple correlations among variables investigated is a negligible effect on the expected number of crashes, which collectively captures the effects of those variables.



Source: FHWA.

Figure 31. Chart. Relationship between CMF (total crashes) and expected total crashes per year during before period.



Source: FHWA.

Figure 32. Chart. Relationship between CMF (fatal and injury crashes) and expected fatal and injury crashes per year during before period.

CHAPTER 9. ECONOMIC ANALYSIS

An economic analysis was conducted to estimate the B/C ratio for implementing various low-cost pavement marking and signing improvements at stop-controlled intersections. The statistically significant aggregate reduction in total crashes was used to calculate the benefits for an average intersection. The research team performed the economic analysis of total crashes as a conservative estimate of the economic benefit.

Based on work order cost data for over 800 unsignalized intersections provided by SCDOT, the economic analysis assumed an average total construction cost of $5,900. In addition, annual maintenance and operations costs were not available and are assumed to be zero (i.e., these costs will not be incurred within the service life). PE, project management, and other general costs were not provided; however, a large portion of project planning was completed by State forces, and other costs for two contractors would have been split across all intersections if the costs were available. In future economic analyses of similar projects, all of these preliminary costs should be added to the construction costs.

The analysis assumed the useful service life for safety benefits was approximately 7 years. Pavement markings were assumed to last roughly 4 years and signs roughly 10 years for an approximate average of 7 years for the overall project. A conservative analysis using a service life of 3 years was also conducted.

The FHWA Office of Safety Research and Development suggested using the Office of Management and Budget *Circular A-4* as a resource for the real discount rate of seven percent to calculate the present value benefits and costs of the treatment over the service life.[20] With this information, the capital recovery factor was computed for all intersection types as 2.62 for a service life of 3 years and 5.39 for a service life of 7 years.

For the benefit calculations, the most recent FHWA mean comprehensive crash costs disaggregated by crash severity and location type were used as a base.[21] These costs were developed based on 2001 crash costs and the unit cost (in 2001 dollars) was $158,177 for fatal and injury crashes and $7,428 for property damage only (PDO) crashes. This was updated to 2015 dollars by applying the ratio of the USDOT 2015 value of a statistical life of $9.4 million to the 2001 value of $3.8 million.[21,22] Applying this ratio of 2.474 to the unit costs for fatal and injury and PDO crashes yields values of $391,280 and $18,375, respectively. The research team then weighted the values at approximately 30 percent fatal and injury crashes in the after period, which resulted in a total crash cost of $132,071 in 2015 dollars.

All project costs were brought forward to 2015 dollars for consistency with crash cost values based on the same 7-percent discount rate, assuming original project costs are in 2011 dollars.

The total crash reduction was calculated by subtracting the actual crashes in the after period from the expected crashes in the after period had the intersection treatments not been implemented. The total crash reduction was then divided by the average number of after period years per site to compute the total crashes saved per year. The treatments saved 119.7 crashes per year for the sample sites, or an average reduction of 0.3 crashes per site per year across the 434 treatment sites. Similarly, the treatments reduced fatal and injury crashes by 45 crashes per year across the sample sites, or an average reduction of 0.1 fatal and injury crashes reduced per site per year.

The annual economic benefits were calculated by multiplying the crash reduction per site per year by the cost of a crash. Total crash reduction and total crash cost were used in the calculation. The B/C ratio was calculated as the ratio of the present value of benefits to the present value of all costs. USDOT recommended a sensitivity analysis be conducted assuming values of a statistical life of 0.57 and 1.41 times the recommended 2015 value.(22) These factors can be applied directly to the estimated B/C ratios to obtain a lower and upper bound of the B/C ratios. Table 45 presents the resulting B/C ratios.

Table 45. B/C ratios.

Service Life	Lower Bound	Average B/C	Upper Bound
3 years	7.1	12.4	17.5
7 years	14.5	25.5	35.9

These results suggest that the unsignalized intersection treatments, even with conservative assumptions of service life and the value of a statistical life, can be cost effective in reducing total crashes at stop-controlled intersections.

CHAPTER 10. SUMMARY AND CONCLUSIONS

The objective of this study was to undertake a rigorous before–after evaluation of the safety effectiveness, as measured by crash frequency, of systemic low-cost improvements at stop-controlled intersections. The study used data from South Carolina to examine the effects for the specific crash types total, fatal and injury, rear-end, right-angle, and nighttime crashes. Based on the aggregate results, table 46 presents the recommended CMFs for the various crash types.

Table 46. Recommended CMFs.

Variable	Total	Fatal and Injury	Rear-End	Right-Angle	Nighttime
CMF	0.917	0.899	0.933	0.941	0.853
Standard Error	0.017	0.028	0.030	0.026	0.031

The disaggregate analysis sought to identify those conditions under which the multiple low-cost treatments are most effective. Variables of interest included area type (urban or rural), number of legs (three or four), lane configuration of the mainline and the cross street, traffic volumes, and expected crashes without treatment. The disaggregate analysis indicated larger crash reductions of all types for rural areas, four-legged intersections, and intersections with two-lane major roads. For total entering volume and expected crashes before treatment, the disaggregate analysis indicated the strategy is more effective on average for intersections with lower traffic volumes and fewer expected crashes per year. However, it is important to cautious in interpreting and applying the results of the other univariate comparisons, which are likely confounded my multiple correlative effects.

The B/C ratio, estimated with conservative costs and 3-year service life, considering the benefits for total crashes, is 12.4 to 1. With the USDOT recommended sensitivity analysis, these values could range from 7.1 to 1 up to 17.5 to 1. These results suggest that the multiple low-cost treatments, even with conservative assumptions on cost, service life, and the value of a statistical life, can be cost effective in reducing crashes at stop-controlled intersections.

This research demonstrates the potential effect of a systemic intersection improvement program by evaluating a systemic program where each site received an individualized version of a package of intersection treatments with some differences in application at each individual intersection. Although information regarding the exact treatments installed at each site was not available to the research team, such data would have value in future evaluations of multiple-strategy improvement projects. Agencies should consider how to best document and track the improvements at each site to facilitate more complete and rigorous disaggregate analyses. However, the approach used in this research is able to quantify the overall effects of an improvement program and suggests the expected effectiveness of similar future programs.

APPENDIX. ADDITIONAL INSTALLATION DETAILS

This appendix provides a description and examples of the general work completed by SCDOT to implement the multiple-strategy improvements at signalized intersections and illustrations of the SCDOT Standard Drawings used in the project. The appendix concludes with a list of general notes related to standard review guidelines, field notes, final plans, and submissions. Most of the following text is excerpted from SCDOT project guidelines. For explanatory purposes, the authors of this report added the text in brackets.

EXAMPLE OF DOCUMENTS USED DURING THE LOW-COST INTERSECTION IMPROVEMENT PROJECT(19)

[SCDOT used the following documents during the project:]

- **General Signing & Pavement Marking Notes for all Intersections.** SCDOT included this document in each work order sent to the contractors. It contains general notes and instructions that pertain to all intersections.

- **SCDOT Standard Drawing 625-305-00.** This document shows the standard pavement markings for intersections.

- **SCDOT Standard Drawing 625-310-00.** This document shows the standard pavement markings for turn lanes.

- **SCDOT Standard Drawing 625-410-00.** This document shows the standard pavement markings for arrows and the word message "Only."

- **Additional Sign Inventory for Replacement.** SCDOT decided to replace additional warning and regulatory signs (in addition to the typical) from this table to include signs near the intersection that were considered to have notable safety impacts.

- **Unsignalized Intersection Design.** This document shows general pavement marking and sign installation information for unsignalized intersections.

- **SCDOT Traffic Engineering Guideline 20.** SCDOT Traffic Engineering designed this document to provide information on the installation of retroreflective sign post panels.

- **SCDOT Guidelines for Advance Placement of Warning Signs.** SCDOT revised this document from the Table 2C-4 from the 2009 MUTCD to show suggested placement of advanced warning signs. Proper staking has been one of the biggest issues to date so this document was used to serve as a guideline. 100 feet was added to Condition B (0) to provide additional advance notice needed for the added street name sign.

- **Intersection Typicals.** These documents are examples of intersection typicals provided to the contractor by SCDOT. They include typicals for a signalized intersection, a four-way stop controlled intersection, a cross-type stop controlled intersection, and a t-type stop controlled intersection. These typicals are revised after field inspection to create a final plan.

- **Street Name Sign Typical.** This document is an example of the SignCADD layout provided with each intersection typical.

- **Placement Dimensions for Stop Ahead.** [This document shows dimensions for placement of rumble strips preceding a Stop sign.]

GENERAL SIGNING AND PAVEMENT MARKING NOTES FOR ALL INTERSECTIONS[19]

[SCDOT used the following guidance for signing and pavement marking for all intersections.]

Remark all existing stop lines, crosswalks, arrows and word messages unless:

- The roadway has been resurfaced within one calendar year and new thermoplastic markings have been applied.

- Existing markings are uniformly reflective and above ground thickness is $\geq$ 90 mils.

- Otherwise directed by a district representative.

Individual typicals in work orders may not show all desired markings; therefore, all turn lanes shall be marked to include the pattern of lane arrows and accompanying word message "ONLY" based on the turn lane length, in accordance with Standard Drawing 625-410-00.

As referenced in Standard Drawing 625-410-00 for signalized intersections, combination Straight and Left or Right Turn arrows shall be added on all shared usage lanes where there are two or more through lanes (exclusive or shared). For example, if an approach has an exclusive through lane AND a shared through/right turn lane, the shared lane shall have two through/right turn arrows installed in accordance with Standard Drawing 625-410-00.

Additional pavement marking details for intersections shall be followed in accordance with Standard Drawing 625-305-00 and 625-310-00. Note that all turn bays should be delineated with an extended dashed edgeline as shown in the standard drawings.

If existing lane markings and word messages are in good condition but not compliant with the typical, retain the existing marking scheme and do not install the typical layout.

For fabrication of D series signs, utilize appendix C of the blue MUTCD with 8" capital letters for 4-lane divided roadways and 6" capital letters for all other roadways.

Opposite side signs should be placed adjacent to the existing sign within a 30' tolerance.

If "STOP" pavement marking is used, place 8' letters approximately 10' in advance of stop limit line.

Install retroreflective sign post panels only on signs as indicated on Traffic Engineering Guideline TG-20 that are shown on the original typicals. Additional signs will not require sign post panels.

Do not replace Junction signs with blue border and lettering.

For electric sign mounted flashers, contact the RCE for disconnect of electric power to convert to solar flasher.

Replace all other existing signs within 500’ of the intersection that are included in the attached table entitled “Additional Sign Inventory for Replacement.”

Reinstall all pavement markings to match the existing field markings unless otherwise noted, i.e., TWLT markings should not be remarked as double yellow, dashed edge lines should not be installed for single turn lanes, etc.

STANDARD MARKINGS FOR INTERSECTIONS[19]

[The following text is transcribed from SCDOT Standard Drawing 625-305-00. Excerpts of details from the standard drawing are included as figures.]

Application of Markings at Intersections

1. Stop lines are to be applied at all signalized intersections.

2. At non-signalized intersections, the roadways which must stop are to have stoplines if centerlines are present.

3. Where stoplines are used, lane lines and center lines will terminate at the stopline. They do not extend across stoplines nor do they terminate prior to stoplines. Location of stoplines should be determined prior to marking longitudinal lines.

4. Lane lines terminating at a stopline should not be less than 10 ft in length, however they may be longer. The last lane line will be 10 to 40 ft long. The following procedure will aid in this determination:

    a. Mark a spot 50 ft in advance of stopline of each lane line approach.

    b. If a line is being applied when the spot is crossed, the striper operator permits automatic cut-off and the following 30 gap. When the next line begins, the striper operator will manually override the automatic cut-off and will extend the line to the stopline.

    c. If a line is not being applied when the spot is crossed, when the next line begins the striper operator will manually override the automatic cut-off and will extend the line to the stopline.

5. At all intersections, lane lines will normally be omitted within the intersection area where turning vehicles must maneuver.

[Figure 33 shows a detail of standard markings for intersections.]

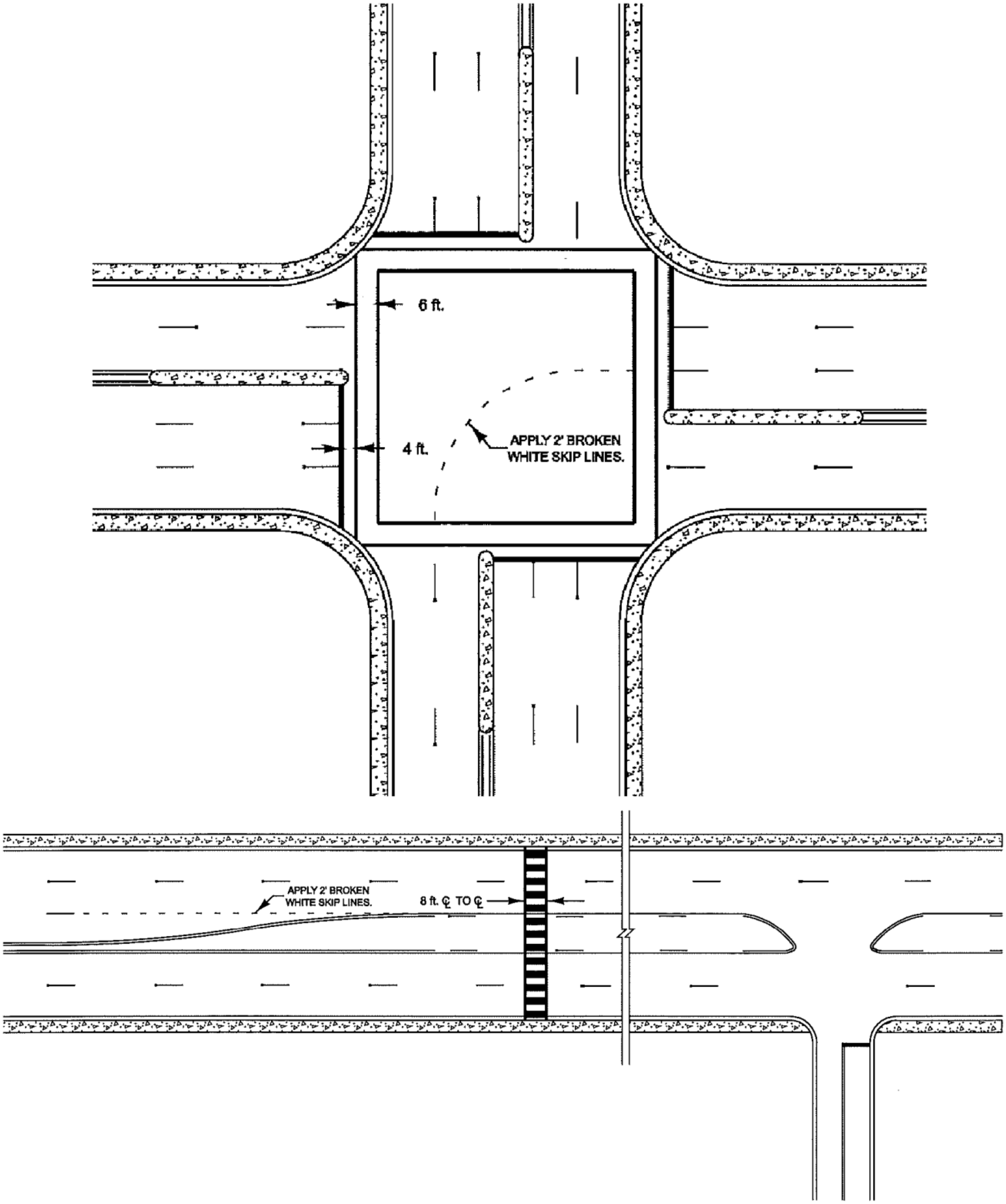


Figure 33. Illustration. SCDOT Standard Drawing 625-305-00 excerpts for application of markings at intersections.

Arrows and Word Messages

Arrows and word messages are not typical at all turn lanes and will be placed only at locations shown on the plans or where directed by the engineer. In the absence of a marked crosswalk the stopline should be placed at a distance of no less than 4 ft and no more than 30 ft from the where arrows supplement signs to prohibit a movement that would otherwise be legal from that lane, the arrow must be accompanied by the word ‘only.’ All arrows and word messages shall be as indicated on standard drawings 625-410-00.

Additional Guidance through Intersections

[Figure 34 shows guidelines for applying dashed-line pavement markings through intersections.]

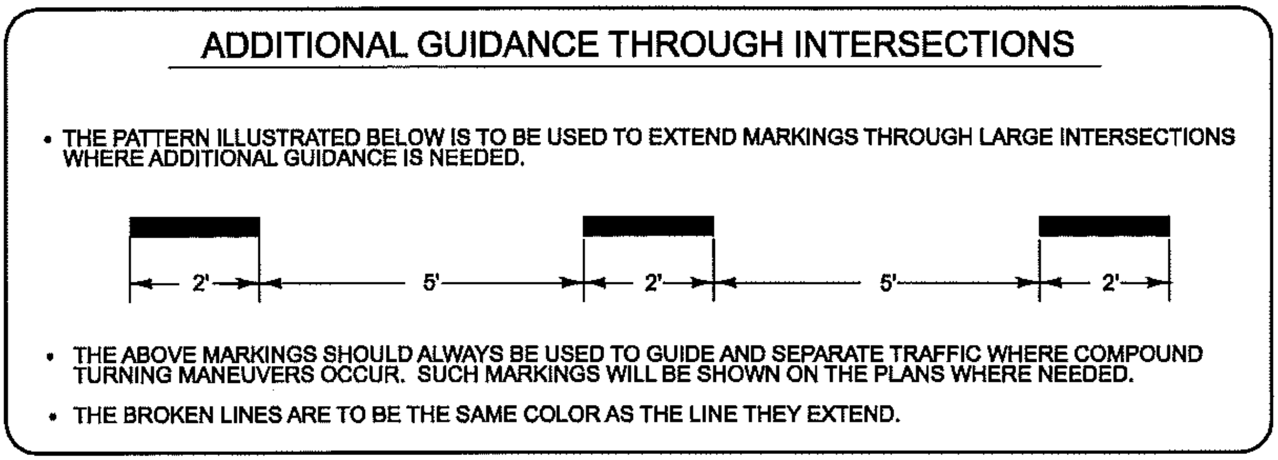


Figure 34. Illustration. SCDOT Standard Drawing 625-305-00 excerpt for guidance through intersections.

Crosswalks

All crosswalks are to be marked with 8” solid white lines. Crosswalk lines are to be spaced not less than 6 feet apart. [Figure 35 shows standards for an unsignalized school crosswalk.]

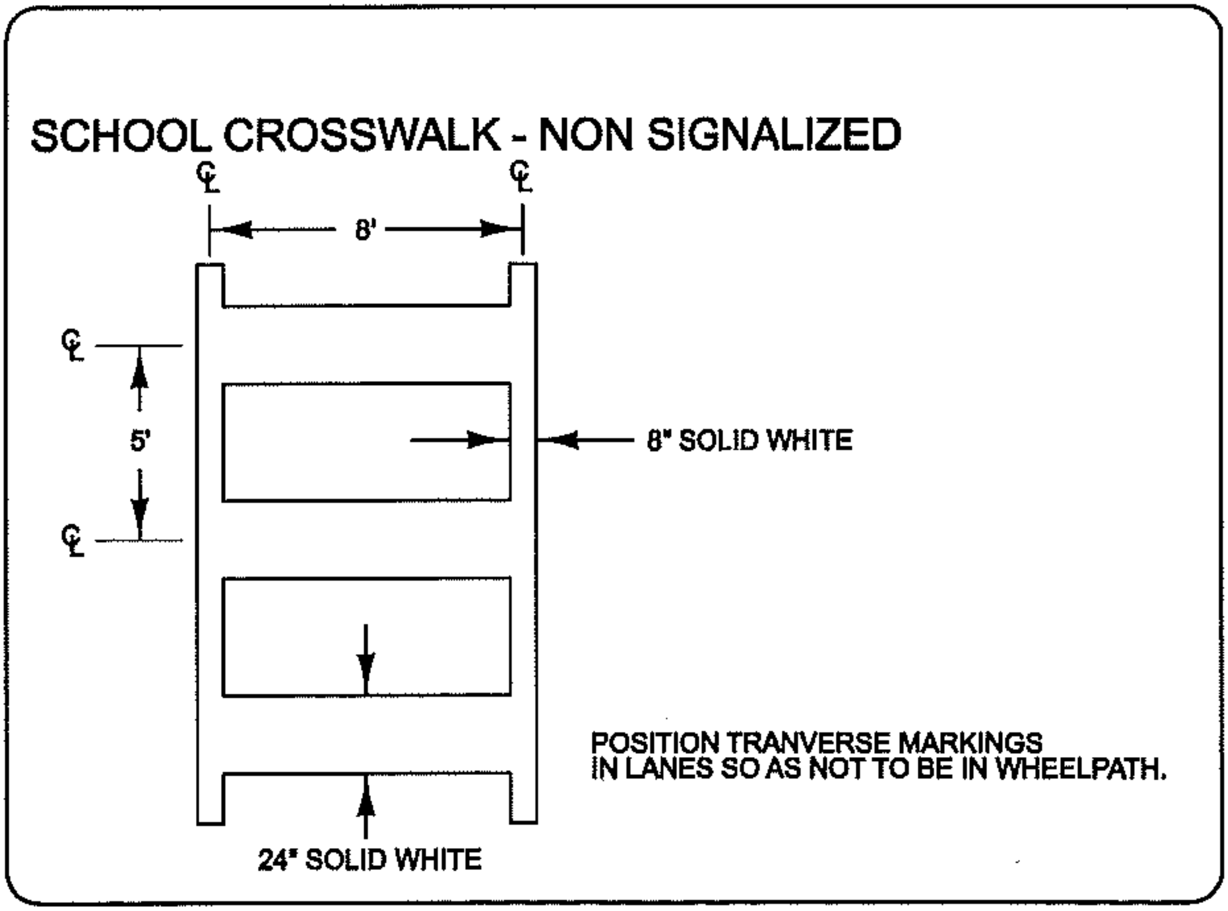


Figure 35. Illustration. SCDOT Standard Drawing 625-305-00 excerpts for crosswalk markings.

TYPICAL MARKINGS FOR TURN LANE INSTALLATIONS[19]

[The following text is transcribed from SCDOT Standard Drawing 625-310-00. Excerpts of details from the standard drawing are included as figures.]

Notes

[The following notes relate to installing typical markings for turn lanes:]

1. Length of tapers and chevrons vary. See plan sheets for dimensions.
2. Apply arrows, see Standard Drawing number 625-410-00.
3. Apply ‘only’ copy, see Standard Drawing number 625-410-00.
4. No raised markers are to be applied on chevrons.

5. Stoplines shown on mainline are to be applied only at signalized intersections.

[Figure 36 through figure 39 show details for turn lane markings from SCDOT Standard Drawing 625-310-00.]

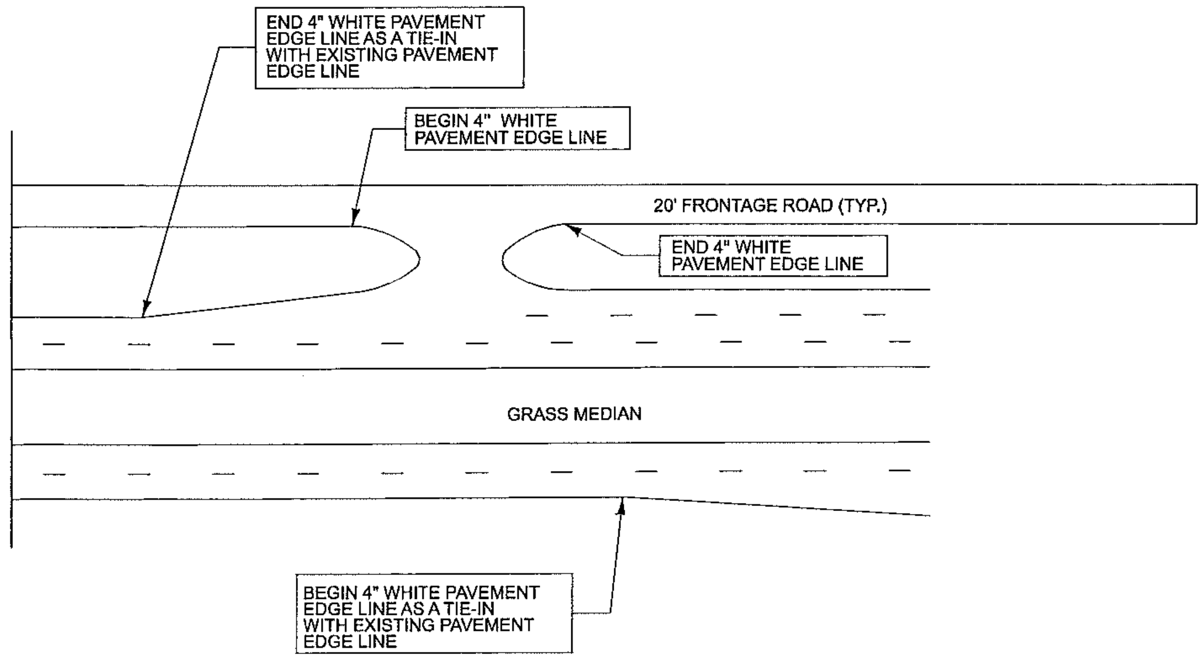


Figure 36. Illustration. SCDOT Standard Drawing 625-310-00 excerpts for turn lane installations (part 1).

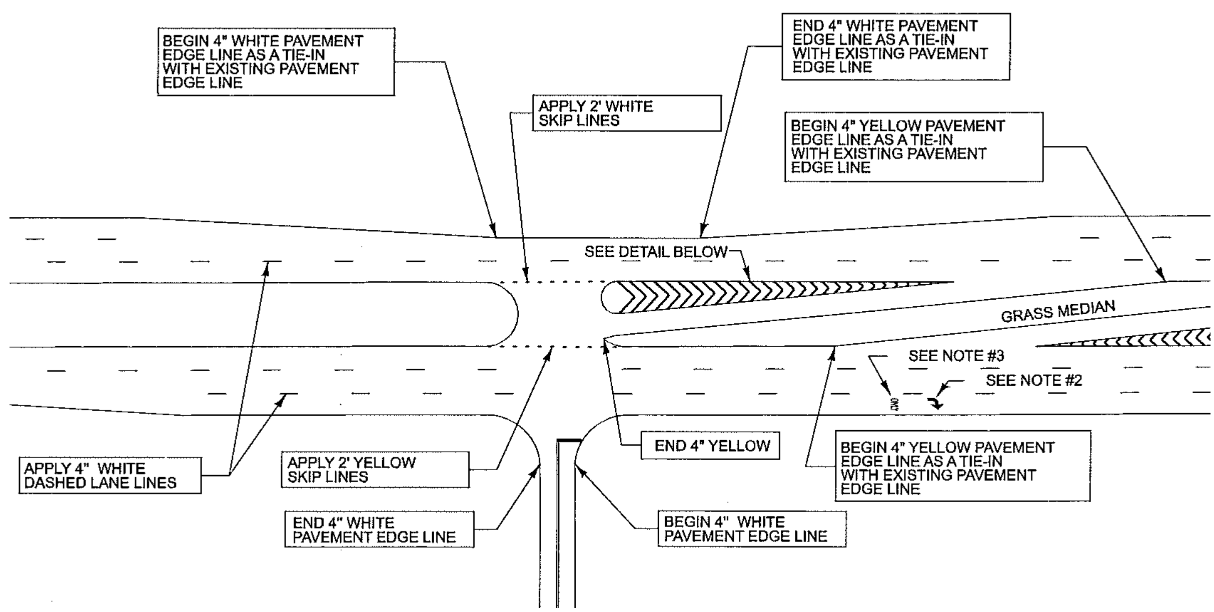


Figure 37. Illustration. SCDOT Standard Drawing 625-310-00 excerpts for turn lane installations (part 2).

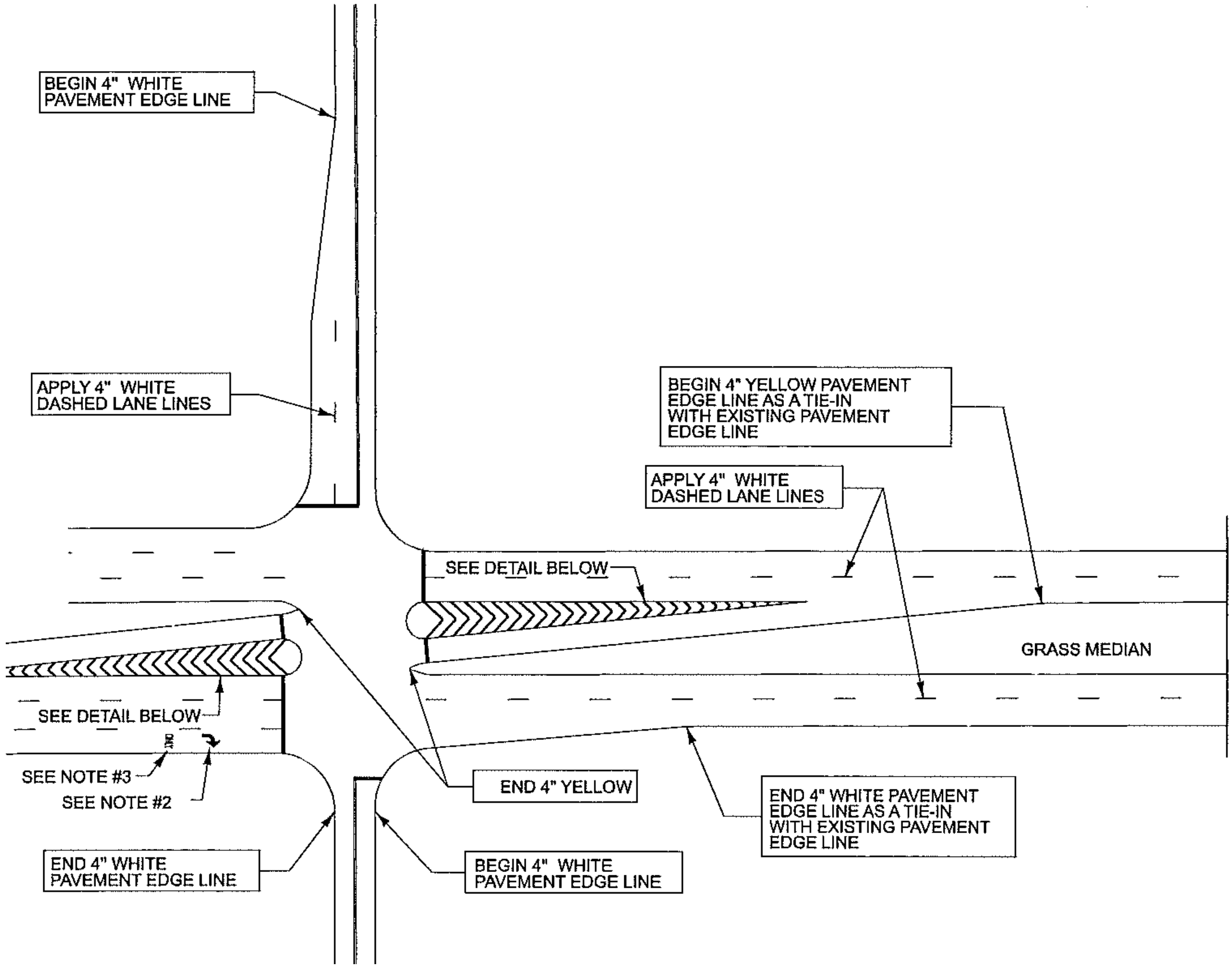


Figure 38. Illustration. SCDOT Standard Drawing 625-310-00 excerpts for turn lane installations (part 3).

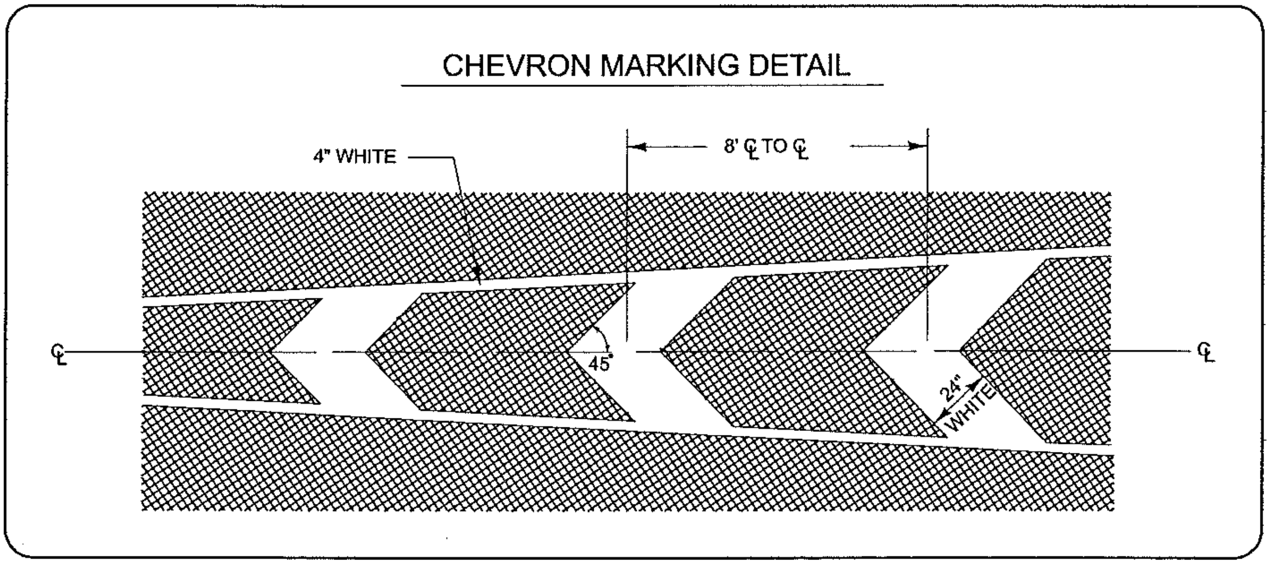


Figure 39. Illustration. SCDOT Standard Drawing 625-310-00 excerpts for chevron marking details.

STANDARD PAVEMENT MARKINGS[19]

[Figure 40 through figure 44 are excerpts of details from SCDOT Standard Drawing 625-410-00.]

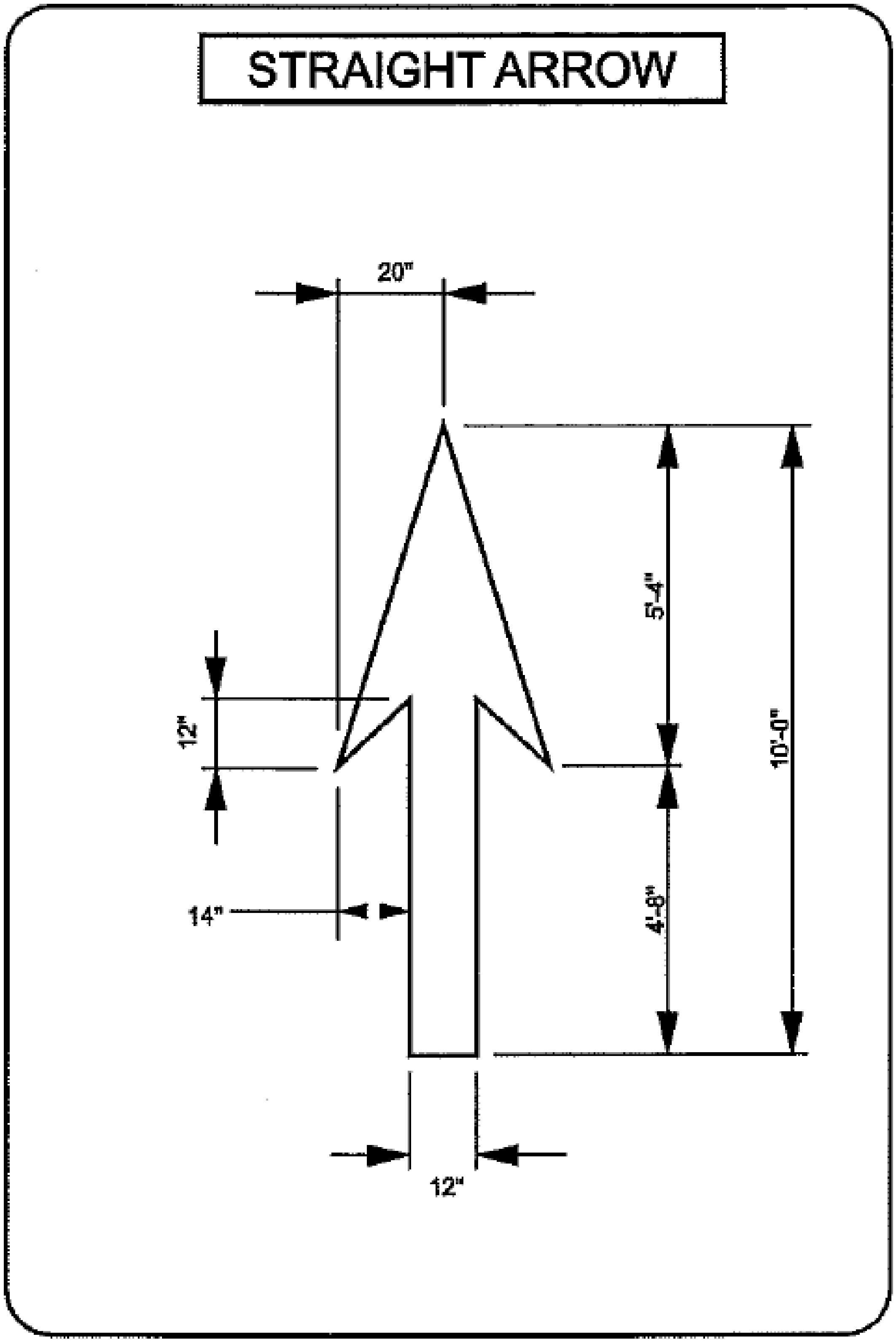


Figure 40. Illustration. SCDOT Standard Drawing 625-410-00 excerpt for straight arrow standard pavement marking.

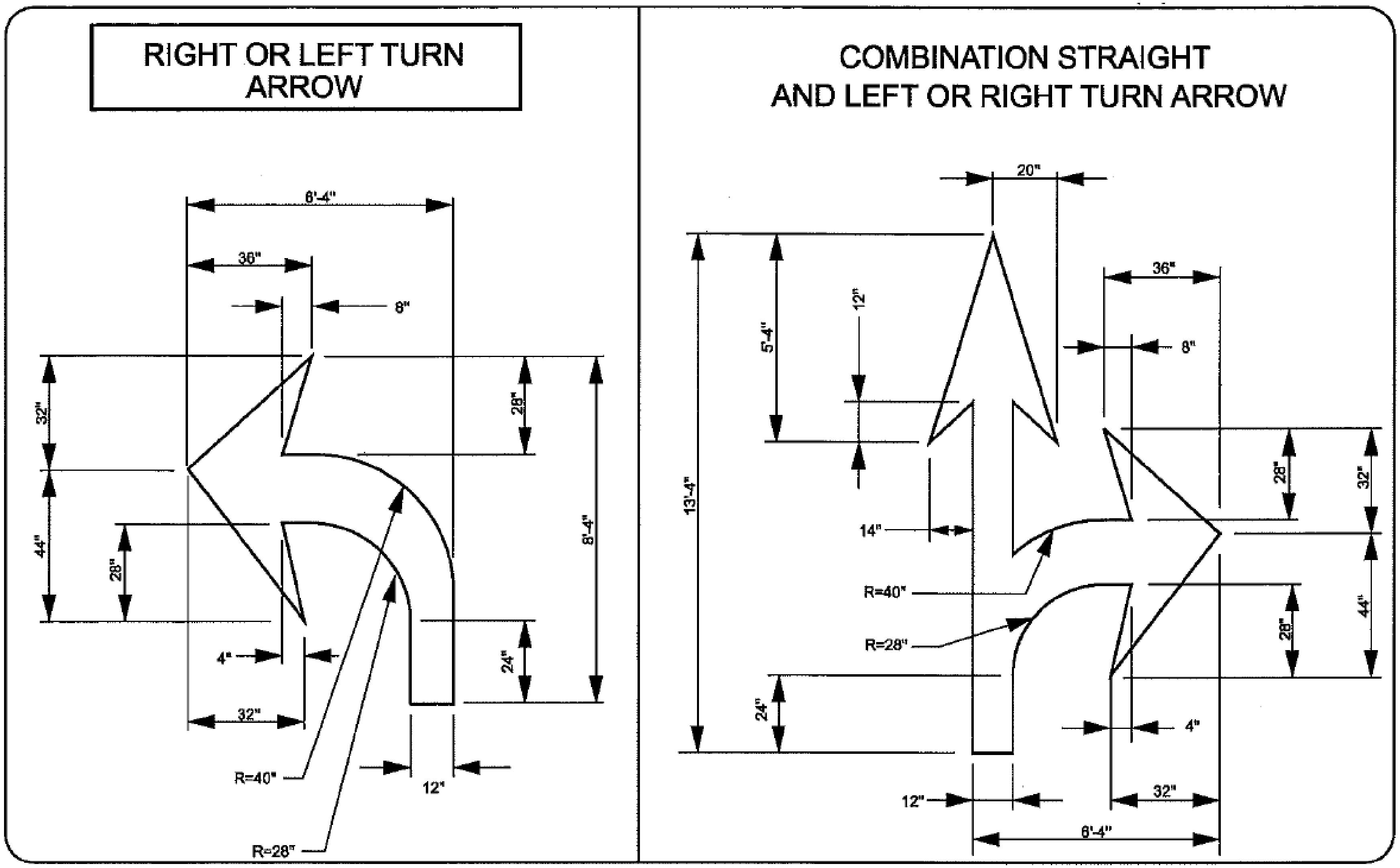


Figure 41. Illustration. SCDOT Standard Drawing 625-410-00 excerpt for right or left turn arrow and combination straight and left or right turn arrow standard pavement marking.

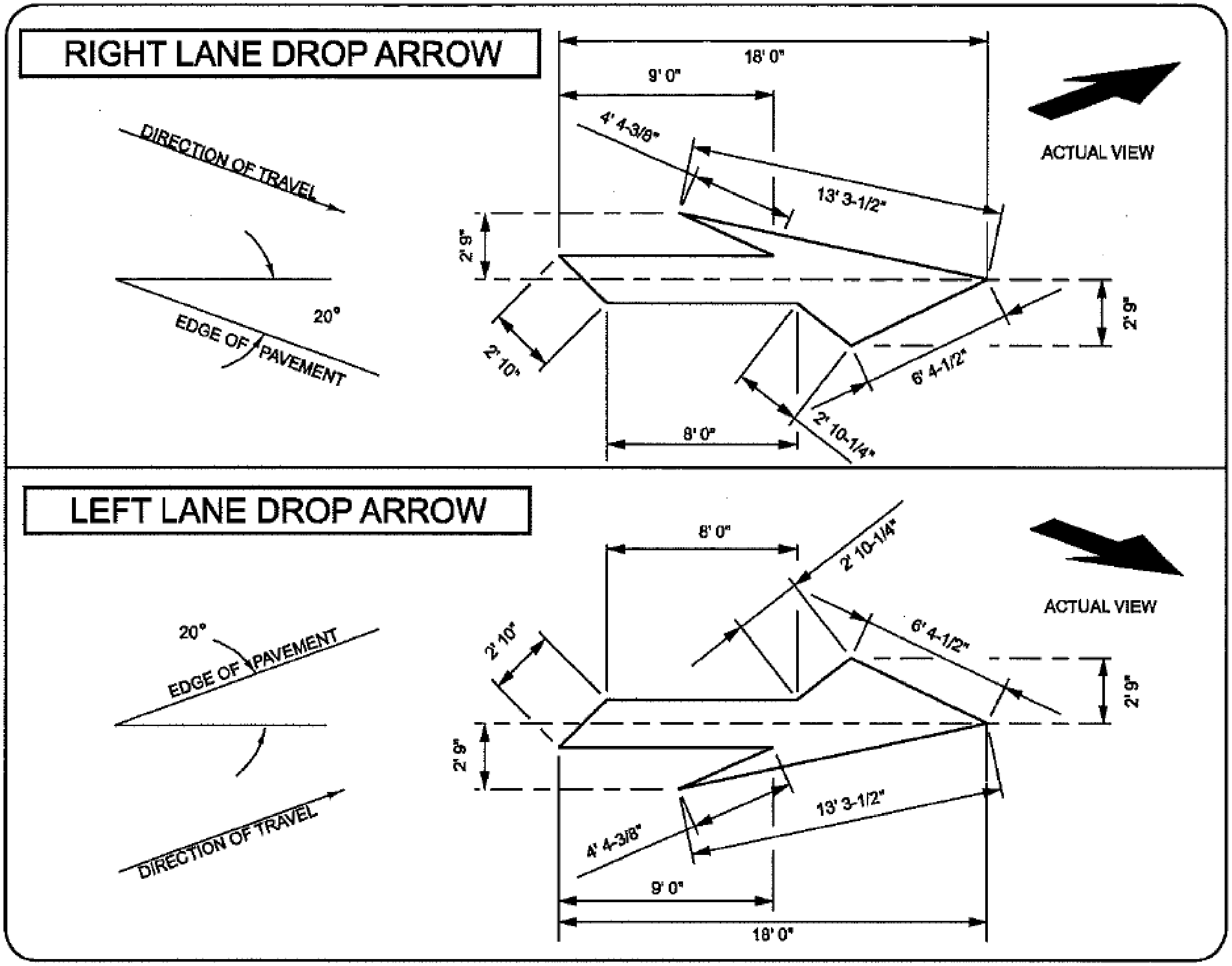


Figure 42. Illustration. SCDOT Standard Drawing 625-410-00 excerpt for right lane drop arrow and left lane drop arrow standard pavement marking.

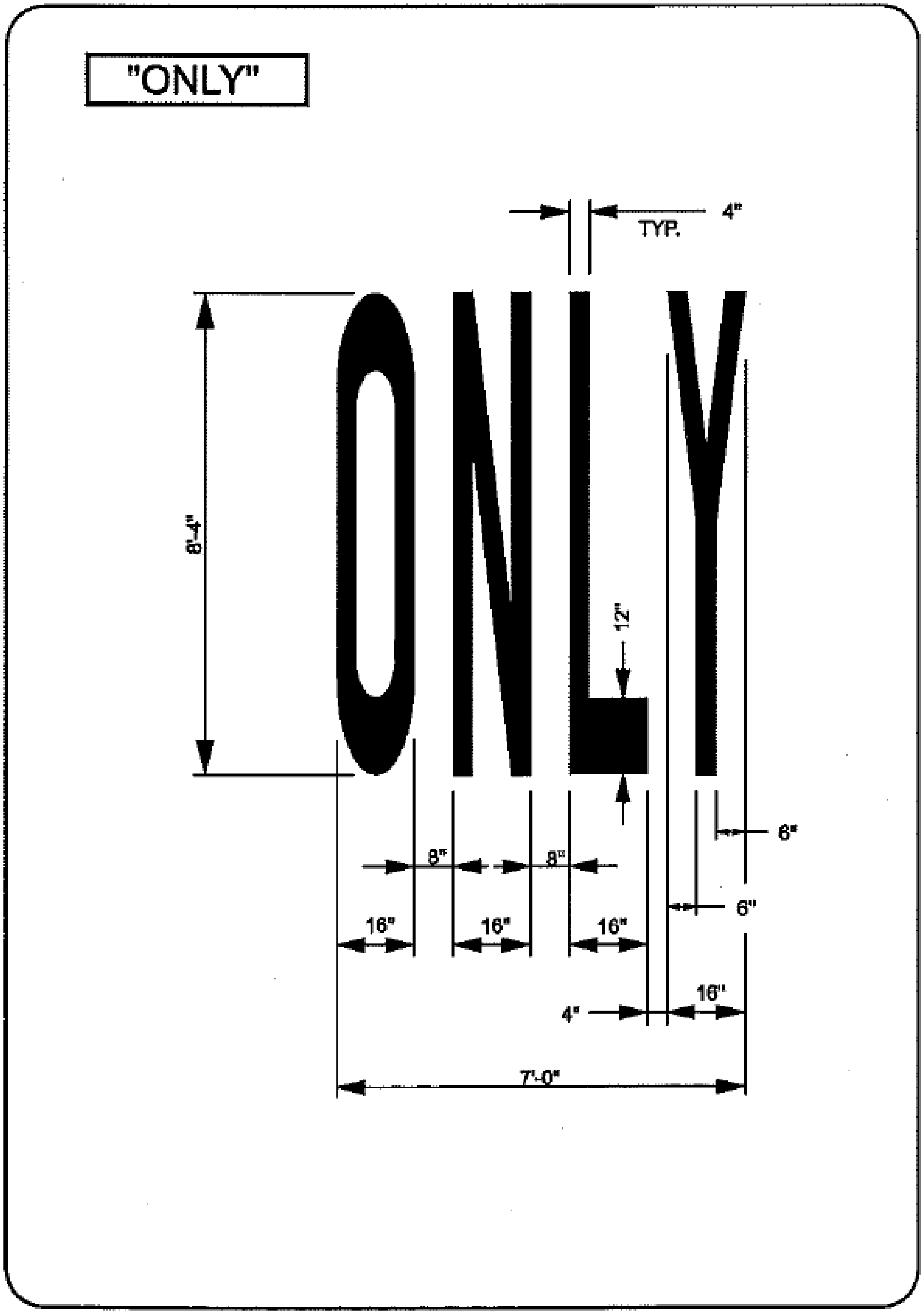


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Figure 43. Illustration. SCDOT Standard Drawing 625-410-00 excerpt for "ONLY" standard pavement marking.

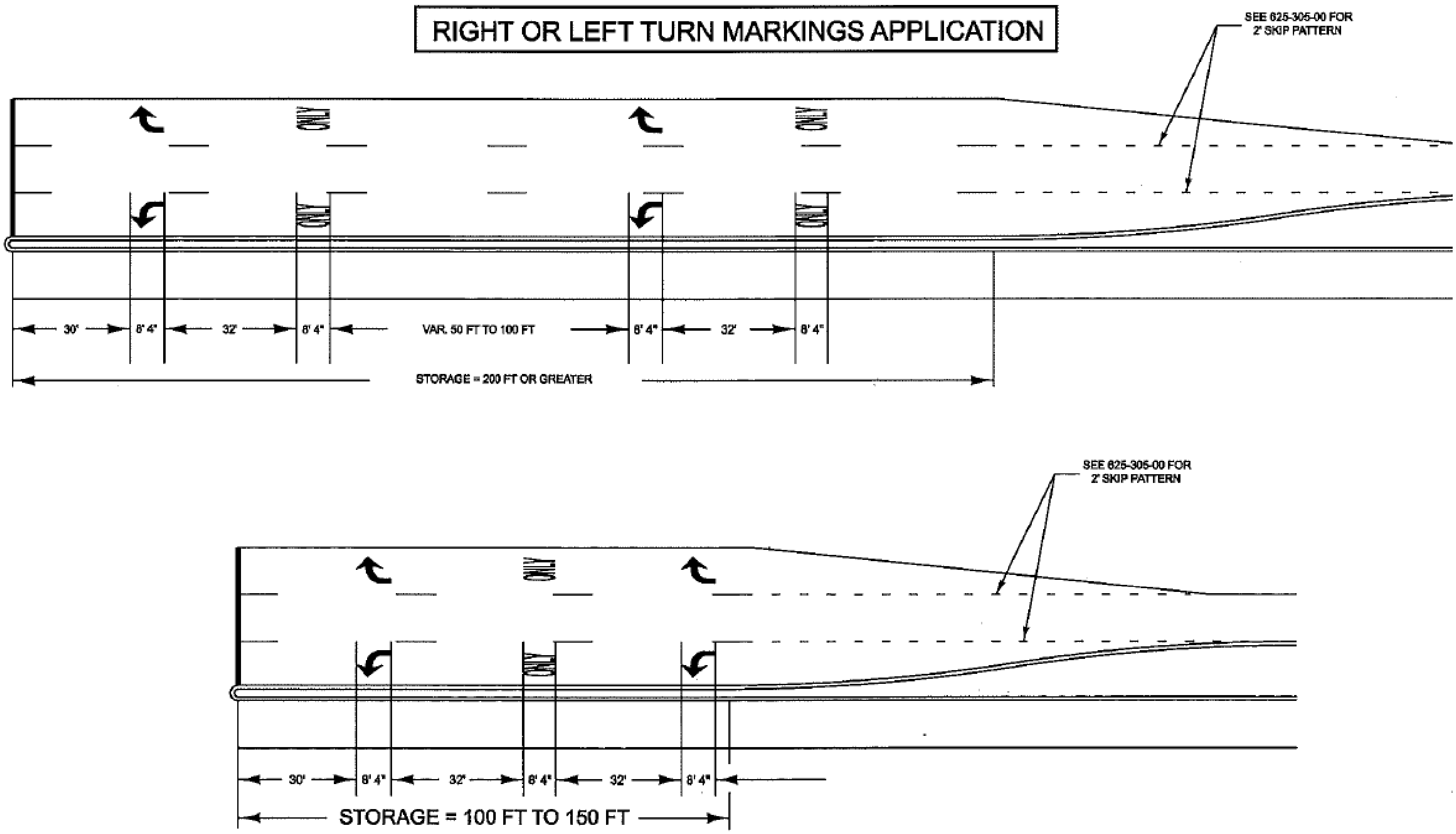


Figure 44. Illustration. SCDOT Standard Drawing 625-410-00 excerpt for right or left turn markings application.

ADDITIONAL SIGN INVENTORY FOR REPLACEMENT(19)

[SCDOT replaced additional warning and regulatory signs (in addition to the typical) shown in figure 45 through figure 48, including signs near the intersection that were considered to have notable safety impacts.]

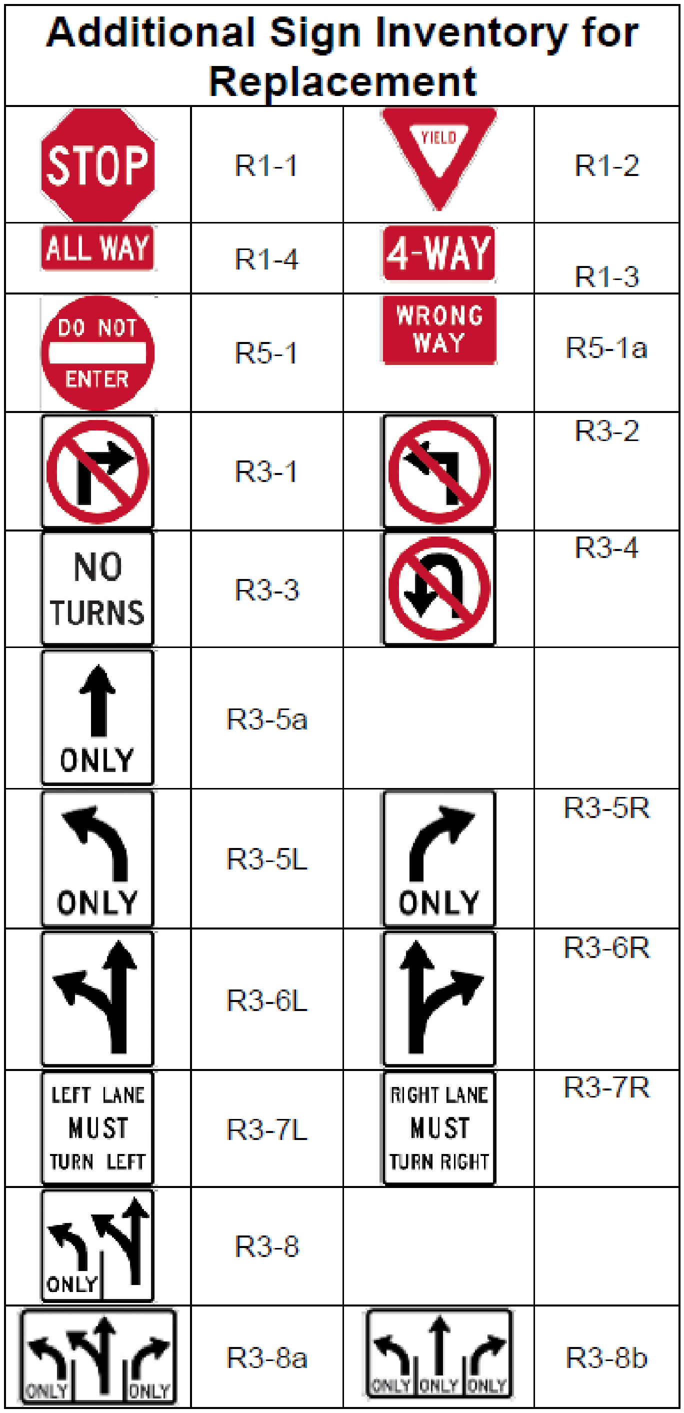


Figure 45. Illustration. Additional sign inventory for replacement (part 1).

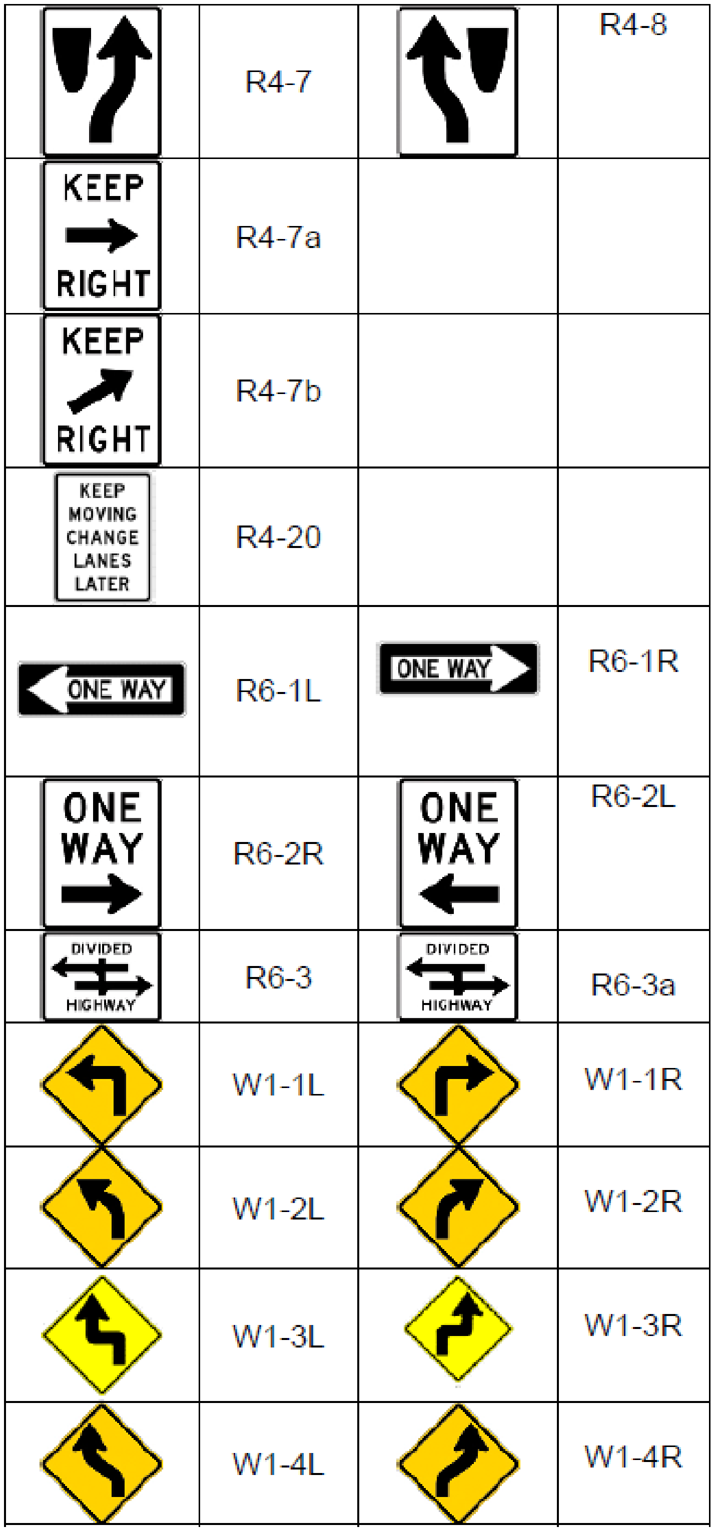


Figure 46. Illustration. Additional sign inventory for replacement (part 2).

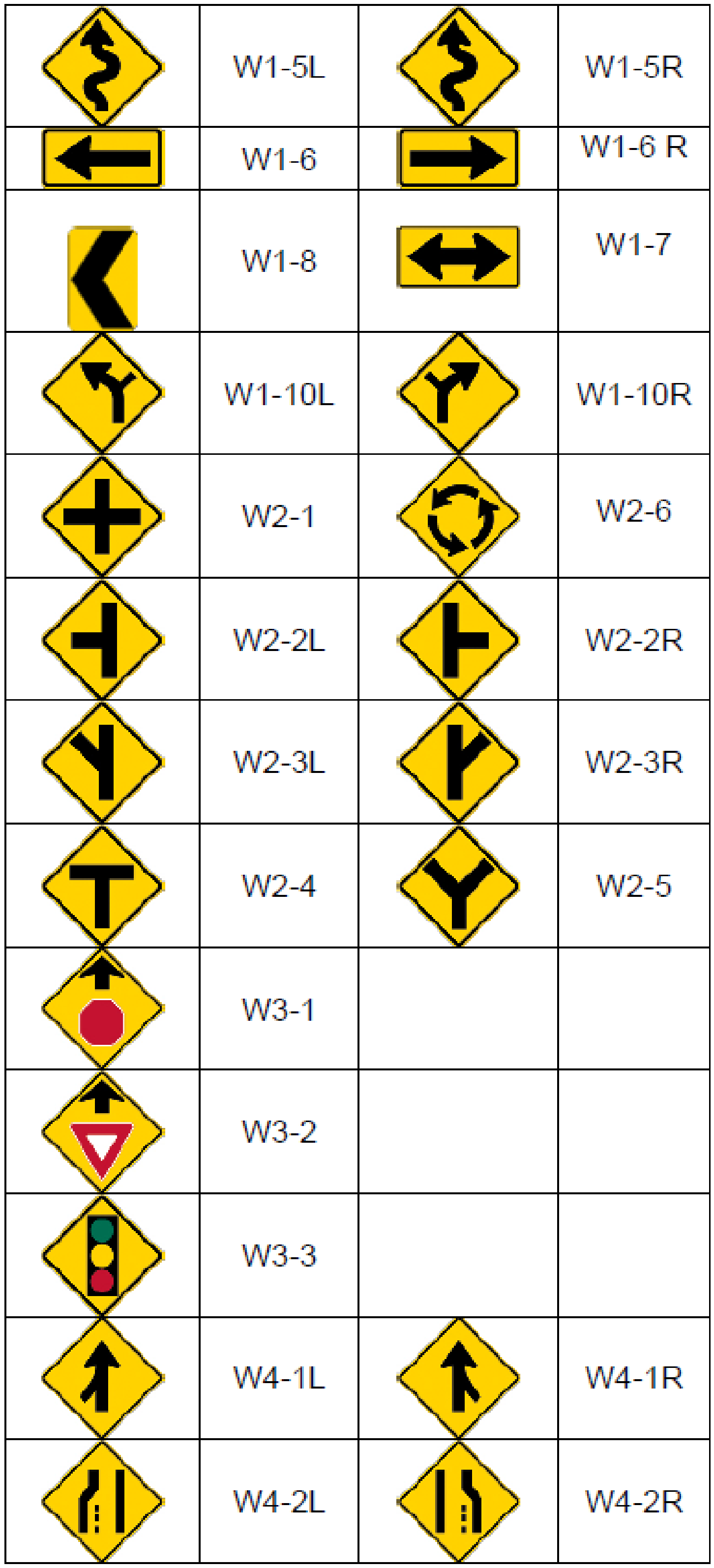


Figure 47. Illustration. Additional sign inventory for replacement (part 3).

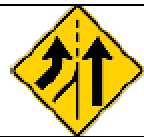
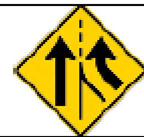
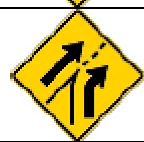
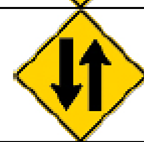
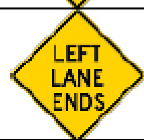
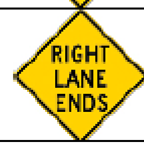
	W4-3L		W4-3R
	W4-6R		W6-3
	W9-2L		W9-2R
	W13-1		
	W16-8		

Figure 48. Illustration. Additional sign inventory for replacement (part 4).

[Table 47 shows the advance placement distance at different posted speed limits or 85th-precentile speeds.]

This chart is intended as a reference with adjustments expected due to field conditions and engineering judgment.

Table 47. Advance placement distance for signal ahead, stop, or intersection warning signs.

Posted or 85th-Percentile Speed (mi/hr)	Multilane Approach* (ft)	Single Lane Approach** (ft)
20	225	200
25	325	200
30	460	200
35	565	200
40	670	225
45	775	275
50	885	350
55	990	425
60	1,100	500
65	1,200	575
70	1,250	650
75	1,350	750

Note: * These values reflect condition A from table 2C-4 of the 2009 MUTCD and should be used as a reference for designated signs on multilane approaches.
** These values reflect condition B from table 2C-4 of the 2009 MUTCD plus 100 ft due to the chart representing minimum guidelines and the additional advance notice needed due to the supplemental street name signs added to these sign assemblies.

RETROREFLECTIVE SIGN POST PANELS[19]

[The following guidelines on the use of retroreflective signpost panels were signed and approved by South Carolina's Director of Traffic Engineering on June 24, 2008:]

Number:	TG-20
Subject:	Retroreflective Sign Post Panels
Background:	Section 2A.21 of the MUTCD provides guidance on the use of Retroreflective Sign Post Panels. This section states that these panels can be applied to regulatory and warning signs where engineering judgment indicates a need for additional target enhancement during nighttime conditions. Therefore, these panels will generally be applied where crash history indicates a relatively high percentage of nighttime crashes.
Guideline:	The panels shall be constructed of a nonmetallic composite or 3mm aluminum composite material approved by the SCDOT covered with

a 3-inch wide type III sheeting. The panel shall be placed for the full length of the support from the sign except that the color for the "Yield" and "Do Not Enter" signs shall be red. If there are two posts supporting the sign, panels should be added to both posts.

To avoid excessive use of the Retroreflective Sign Post Panel, it is suggested that panels only be applied when needed to the regulatory signs below:

- **Red Regulatory Signs.** Stop, Yield, Do Not Enter, and Wrong Way signs—Red Panels.
- **Horizontal Alignment Signs.** Chevrons, Curve, Turn, and Large Arrow signs—Yellow Panels.
- **Advance Traffic Control Signs.** Stop Ahead, Yield Ahead, and Signal Ahead signs—Yellow Panels.
- **Intersection Warning Signs.** Cross Road, Side Road, and Two-Direction Large Arrow signs—Yellow Panels.
- **Pedestrian Signs and School Area Signs.** W11-2 and S1 Series—Fluorescent Yellow Green Panels.

[Figure 49 and figure 50 show standards for pavement marking and rumble strip placement at unsignalized intersections.]

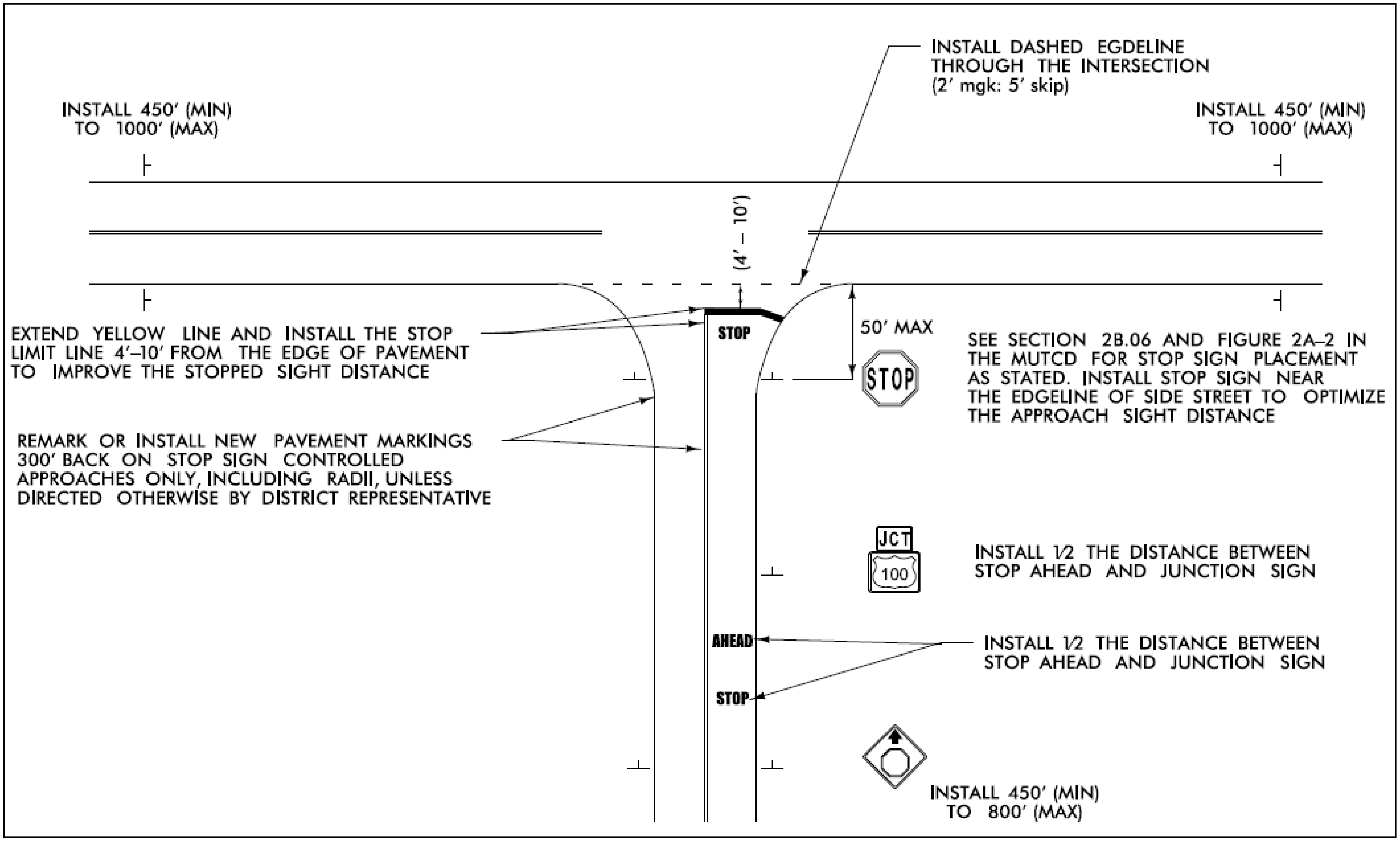
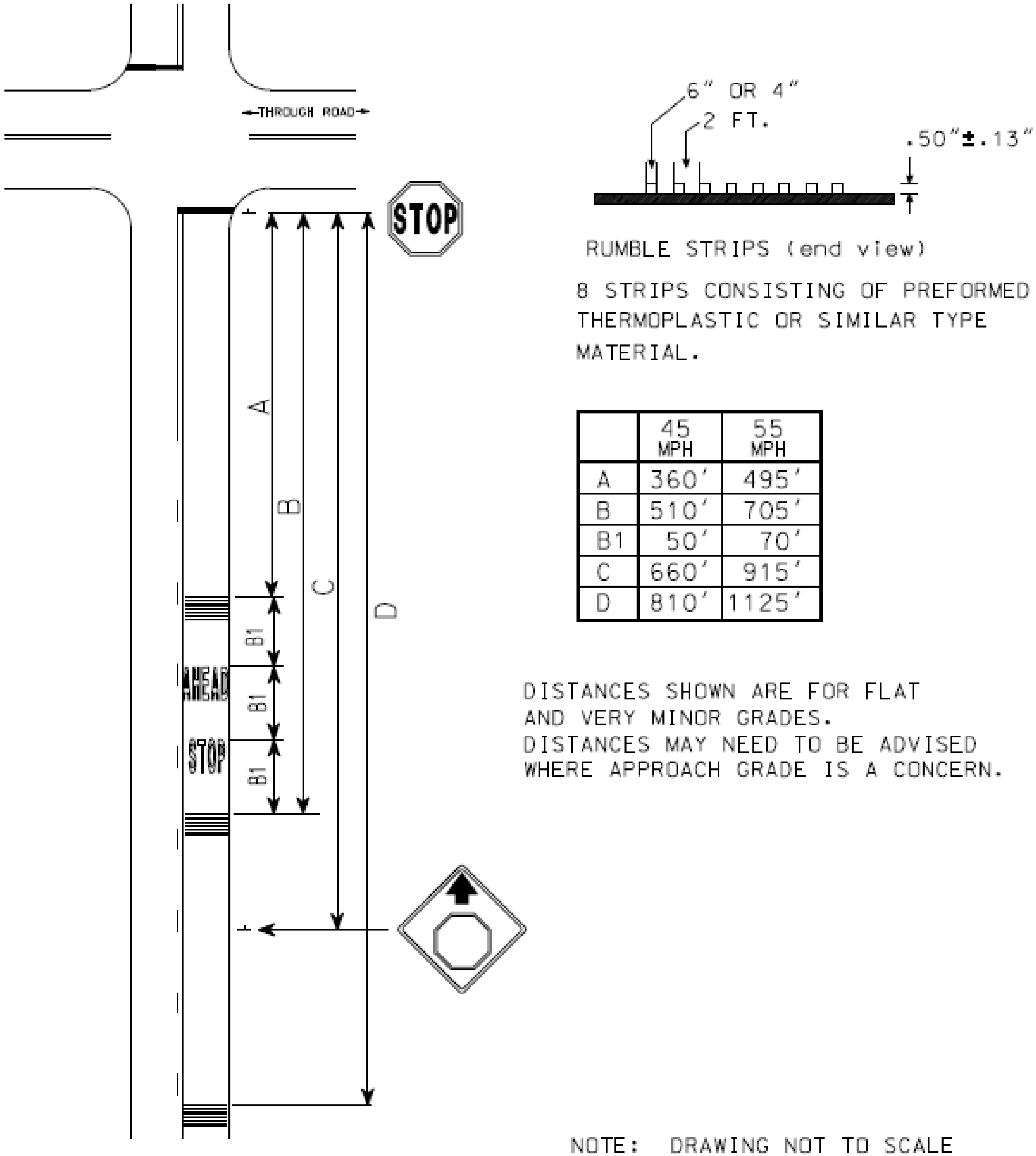


Figure 49. Illustration. SCDOT nonsignalized intersection design for pavement marking and sign installations.



	45 MPH	55 MPH
A	360'	495'
B	510'	705'
B1	50'	70'
C	660'	915'
D	810'	1125'

Figure 50. Illustration. SCDOT traffic engineering rumble strip typical.

[Figure 51 through figure 54 are examples of intersection typicals that SCDOT provided to the contractor, including a signalized intersection, a four-way stop-controlled intersection, a cross-type controlled intersection, and a t-type strop-controlled intersection.]

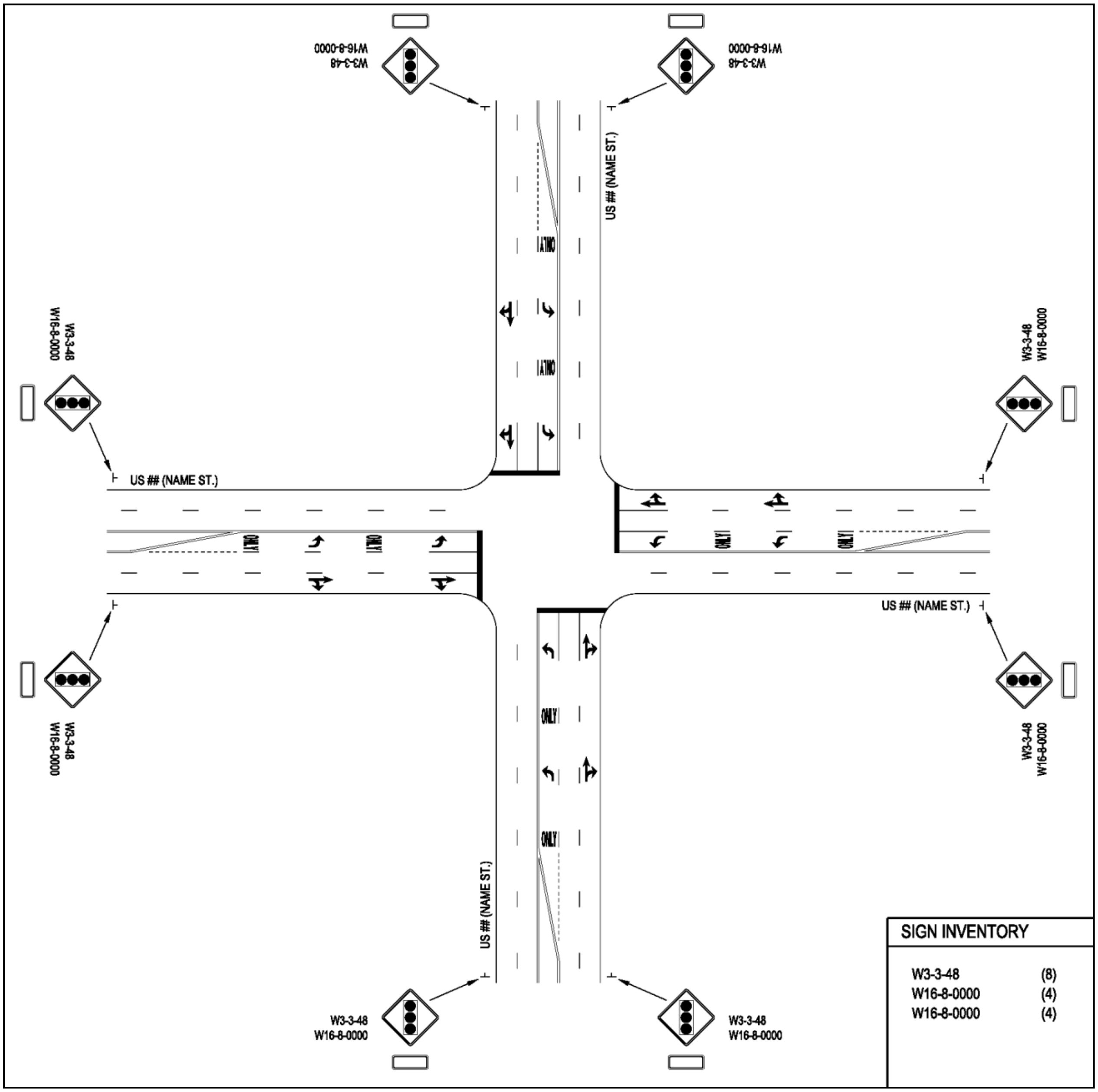


Figure 51. Illustration. SCDOT typical for a signalized intersection.

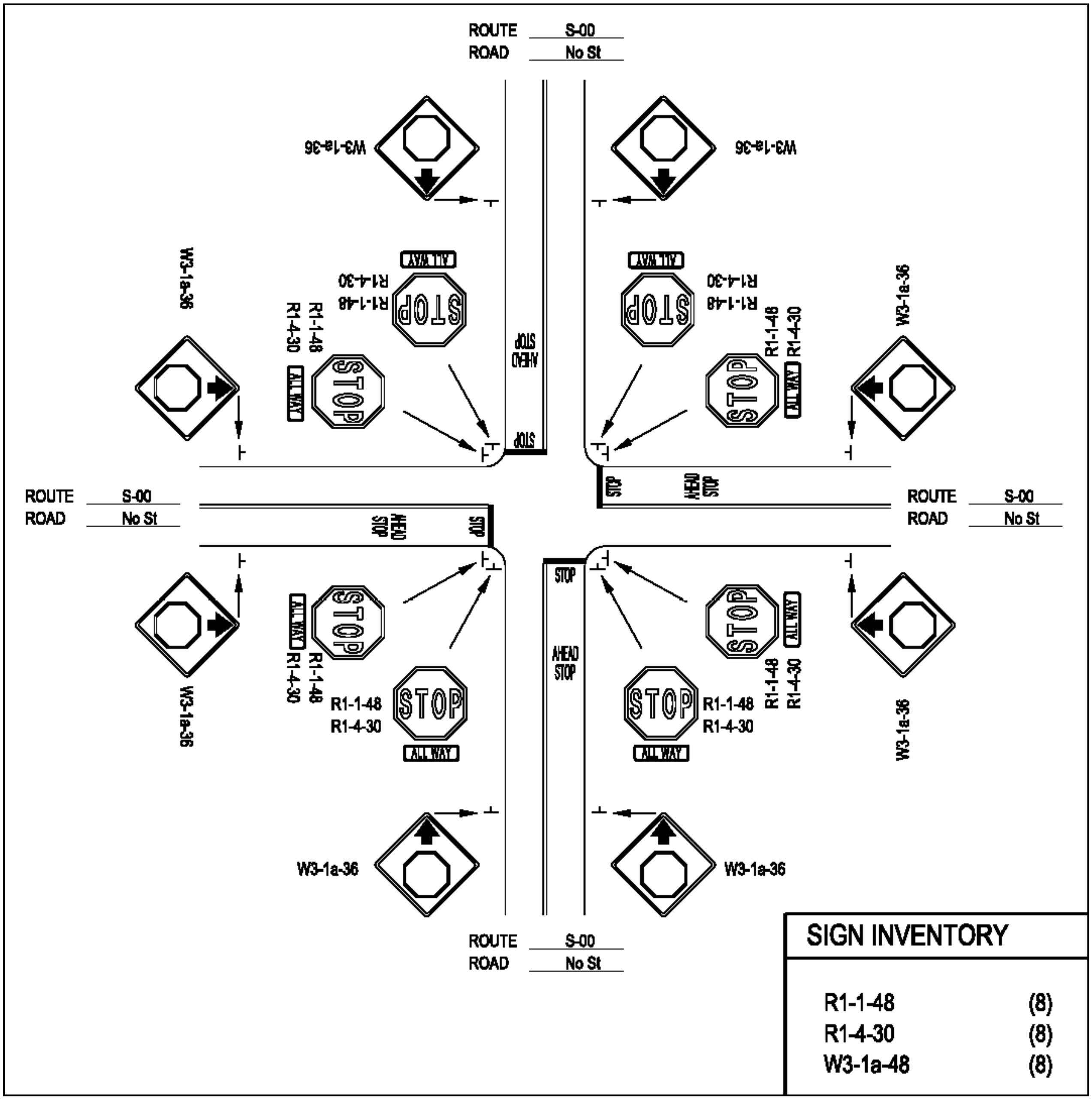


Figure 52. Illustration. SCDOT typical for a four-way stop controlled intersection.

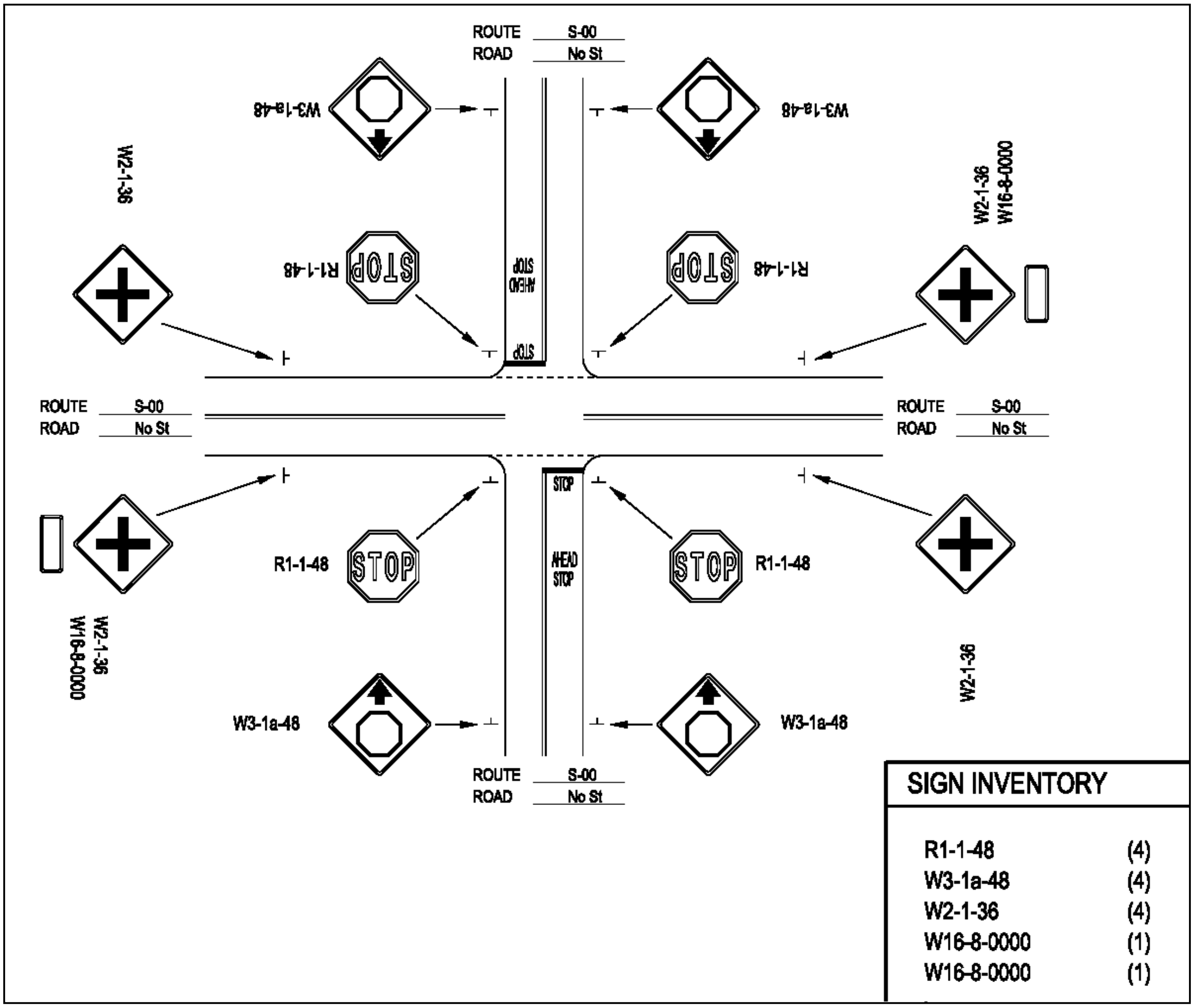


Figure 53. Illustration. SCDOT typical for a cross-type stop controlled intersection.

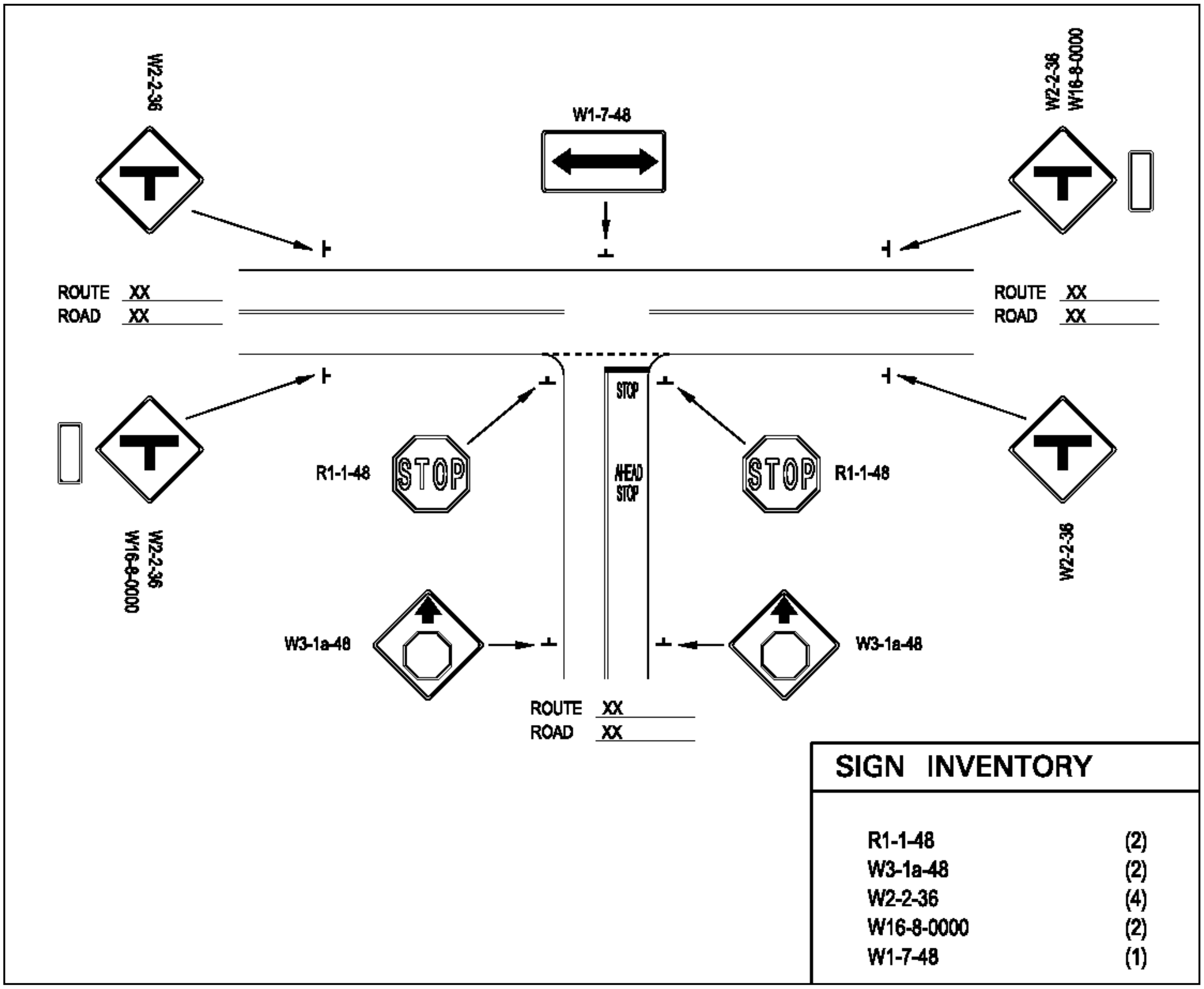


Figure 54. Illustration. SCDOT typical for a t-type stop controlled intersection.

[Figure 55 shows a street name sign typical layout.]

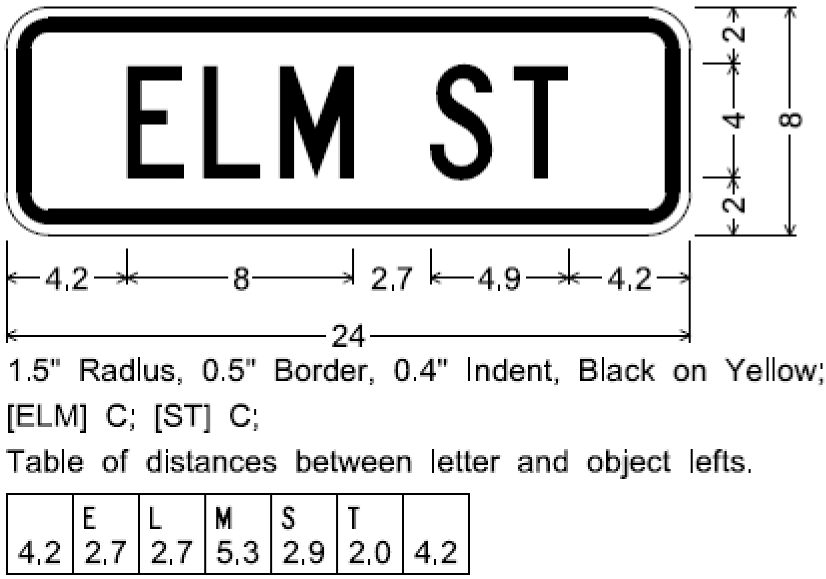


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Figure 55. Illustration. SCDOT street name sign typical.

STANDARD REVIEW GUIDELINES[20]

[The following is an excerpt from an internal SCDOT document containing standard review guidelines for reviewing installations of the treatments in this project.]

General Notes

- Speed limit signs are not to be replaced as part of this project.
- Additional Advisory Speed plaques (such as speed plaques on “Trucks Entering Hwy” sign, etc.) will not be addressed as a part of this project.
- Do not list info for retroreflective sign post panels on the plans.
- Left Turn arrow Pavement Markings shall be installed in TWLTL’s.
- Show all signs as proposed; do not shade anything to represent existing conditions.
- Any non-standard intersections, i.e., free flow interchanges or roundabouts should be sent to SCDOT Safety Office for verification and instruction.
- No Pavement Markings or signs shall be applied to routes that are not state maintained.
- All Illumination shall be upgraded to LED.
- Yield conditions shall receive yield line and skip line pavement markings.
- Place note “retain existing” for all non-MUTCD signs.

- A photo of the current street name signs in the field trumps all spelling of the street name.
- No signs should be placed in paved radii.
- Limit sign placement for dead ends, short routes, grid systems, etc.
- Engineering judgment should be used when placing all warning signs.
  - Under urban grid conditions cross road warning signs (or signal ahead signs) should not be placed.
  - Signs should not be placed near driveways (where it would obstruct sight distance) or in citizen's front yard.
  - Signs should not be placed when an object would obscure their view (i.e., a large tree, shrubs, bridge columns, etc.).
  - Use caution when placing signs in historic districts.
  - Use caution when placing signs on interchange entrance and exit ramps.
- Guidelines for placing opposite side intersections (or signal) warning signs.
  - Do not place on roadways with more than three-lanes (three-lanes meaning two through lanes and a paved median).
  - On four-lane divided highways signs should be placed in the median.
- We will not be making upgrades to existing ramps at crosswalks.

Non-Signalized Locations

- Include estimated quantities for crosswalk, stop lines, yield lines, and skip lines on final sheet for non-signalized locations.
- Left turn Arrows and ONLY's:
  - Less than 250' – arrow ONLY arrow.
  - 250' or more – arrow ONLY arrow ONLY.
- D-Signs – Make a note of the size of the letters on the signs:
  - Only need to note of existing 8" letters on 4-lane divided.
- Do not show junction signs unless they are attached to a D-sign that is being moved or replaced.
- Skip lines and yield lines must be shown at all yields.
- Overhead Flashers at a stop intersection should be treated as a signalized location and have plans made for both pavement markings/signs and signals. All flashers will be replaced with LED casings and modules. NOTE: this does not include pole-mounted flashers on a Stop sign, Stop Ahead sign or intersection warning sign.

- No NEW Flashers will be installed on Stop controlled intersections.

- All Signal Ahead, Stop Ahead, Yield and Stop signs shall be 48". Stop and Yield signs in the median or in exclusive turn lanes can be 30". Use engineering judgment to determine.

- Intersection warning signs shall be 36".

- Guidelines for placing street name signs on intersection warning signs:

  - On all undivided roadways street name signs should be placed on only the right side intersection warning sign (no opposite side sign placement).
  - On four-lane divided highways street name signs should be placed on both the right side and opposite side intersection warning signs (if they are both used).
  - Word messages (such as "STOP" and "STOP AHEAD") should be used sparingly. Only when currently in the field or engineering judgment warrants their placement (i.e., no warning signs or opposite side signs can be placed).

Signalized Locations

- **All** signal ahead signs must have street names.

- Yield and stop lines must be behind crosswalk. Indicate on plans that the stop lines/yield lines need to be eradicated and new ones installed to accommodate the crosswalk.

- Show piano lines in crosswalk **only** if they currently exist.

- Ramps will be counted as 2 if crosswalks don't connect at the corner and 1 if they do.

- Left Turn Yield on Green (ball) sign - only installed when protected/permissive left turn (5-signal face, dog-house style head).

- There should be one 3-signal face head located in the center of each thru lane, as a minimum. A 5-signal face PT/PM head counts as one thru lane signal.

- Skip lines and yield lines must be shown at all yields.

- No NEW flashers will be installed at signalized locations.

- At intersections where Ped Heads are currently installed, if the "Walk" symbol appears automatically, then no Push Buttons are required.

- All Ped Heads shall be Countdown.

- If Ped Heads are present, propose crosswalks.

- If Push Buttons are present a crosswalk is not required.

- If a crosswalk is required, show ramps. If ramps cannot be installed mark on field notes why (i.e., catch basin).

- If ped BUTTONS are present (or proposed) = cross walks are not required.

- If ped HEADS are present (or proposed) = cross walks are required.

- If cross walks are present (or proposed) = ped heads should be present.

- Quantities for pedestrian equipment will be estimated based on the number of NEW pedestrian equipment installed.

- Number of signal heads: With permitted/protected left - 1 signal head per thru lane (5 signal face, dog-house style counts as one). With protected only left - 4 signal face, red arrows for left lane + 1 signal face per thru lane.

Field Notes

- Location information (Street names, county, etc.)

- Indicate reasons for not following regular guidelines so we know that it was not just overlooked… ped treatments, crosswalk, ramps, signs, etc.

- Any information or recommendations that may be helpful that you happen to notice while you are in the field.

- If “Signal Ahead” or “Stop Ahead” signs are determined not to be necessary, put note on field sheet as to why.

- On field notes, make mention of conflicting signs. For example, a Stop controlled intersection located between a signalized intersection and its coordinating “Signal Ahead” sign. Locations of the proposed intersection warning signs should be discussed with SCDOT.

- On field notes, note if JCT signs are black or blue.

- Note on field sheets any landscaped areas where proposed signs are to be located as well as any historic districts.

- Note on field sheets if medians or islands are pavement markings or raised. If raised, note if it is earthen or concrete.

- Street name signs on Mast Arms and Span Wire to be noted in field notes but not to be replaced.

Final Plans

- Name the intersections as they are in the list given by SCDOT.

- Consultant Company logos.

- Note NOT TO SCALE.

- Speeds from each approach.

- North arrow.

- Any changes that are made to a signalized location must be called out with an arrow pointing and a note indicating a change, i.e., Install new ped treatments (with arrows to new ped treatments only), Install NEW near-side head (with arrows to new near-side heads only), Install NEW ramp (…), Install NEW overhead signs (…), Install NEW red arrow LED head (…), etc.).

- These changes may or may not require a new PE'd plan. At a minimum, they will require an update to the signal plan if one exists. Please supply a list of signalized locations that will require a new plan to be drawn and which additions there were to the plan. (See checklist for submitting packets.)

- Example list:

    - US1 @ SC12 – nearside head, ped treatments.
    - US1 @ S-35 – ped treatments, ramps.
    - US1 @ S-1298 – additional thru lane head, ramps.

- Small maps are not necessary on Final plans (per example plan set for LCSI letting.pdf).

- Right of way does not need to be shown on plans.

- Signal Equipment box is not necessary on the Final plans.

Submissions

- Round 2 and 3 signals and stops can be submitted at the same time to cover the area all at once.

- Submit packets of approximately 50 locations at a time.

- If at all possible, do not split up a single county into two different submittals; it's best to have all locations in each county together.

- Submittals should include two packets:

    - Signal group – this packet will go to the signal group for review and contain all necessary documents spelled out below.
    - Safety group – this packet will go to the safety group for review and contain all necessary documents spelled out below.

Checklist for Submitting Packets

Initial Signal Group:

_____ Final plan – electronic version printout, may have pavement markings and signs on them

_____ Field notes plan – can be hand drawn plan or notes handwritten on electronic print, make notes for all decisions that are not following the standard recommendations (i.e., no signal ahead sign because signal nearby, no sidewalk ramp because gutter under curb, no double up on signal ahead because of somebody's beautiful garden, etc.)

_____ Quantities form – can be hand written from field as long as legible, include color of signal head/ped head casing, whether there are mast arms or not

_____ Electronic photos or ftp

_____ Electronic plans on disk or ftp

_____ Electronic list of locations needing updated signal plan

Final Signal Group Construction Packet:

_____ Coversheet

_____ Quantity sheets

_____ Drawing for each location

_____ Construction specifications with specific location information for the district

Safety Group:

_____ Electronic Documents (submitted on CD is fine) - Microstation file for each location, PDF of field notes and quantities sheet, PDF of final plan and any photos taken during the site review

_____ Cover sheet – this should include a list of all locations included in the packet (along with their signalized or stop controlled status) and all locations omitted from the packet along with the reason for omission (current project, interchange, etc.). Please also note the locations where overhead flashers (mounted on span wire or mast arms) are present. These will need to be included in both the signalized and safety packets.

_____ For signalized locations: include a hard copy of the final signing and marking plan (without signal information), a copy of the field notes and a copy of the quantities sheet.

_____ For stop controlled locations: include a hard copy of the final signing and marking plan, a copy of the field notes and a copy of the quantities sheet.

_____ For stop controlled locations with overhead flashers: include a hard copy of the final signing and marking plan (include flasher information on both the safety and signal copies for overhead flashers only), a copy of the field notes and a copy of the quantities sheet.

ACKNOWLEDGEMENTS

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