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16. Abstract

This report describes a one-year project conducted for the Texas Department of Transportation to identify, evaluate, and recommend traffic control device treatments at two-way stop-controlled intersections. Researchers conducted several research tasks, including surveys of traffic engineers and a diverse sample of the driving population, and field studies to investigate traffic control devices, including supplemental signs, at these types of intersections. Supplemental sign issues that were addressed include placement, shape, color, and legend content. The project developed guidelines to improve driver comprehension and minimize driver confusion of the right of way conditions at two-way stop-controlled intersections. Adoption of the guidelines by TxDOT will provide a consistent treatment across the state and minimize the crash potential and liability exposure that exists at two-way stop-controlled intersections.

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TRAFFIC CONTROL DEVICES AT TWO-WAY STOP-CONTROLLED INTERSECTIONS

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IMPLEMENTATION RECOMMENDATIONS

The results of this project led to the following guidelines for implementation to improve safety and driver understanding of right of way at two-way stop-controlled intersections:

1) The guidelines provide assistance in identifying, studying, and treating such intersections that experience either high/severe crash frequencies and/or driver confusion of right of way conditions;

2) The implementation of the recommendations are achieved through an interim change to Section 2B-4 (Stop Sign) of the Texas Manual on Uniform Traffic Control Devices; and

3) The information provided herein supplements this interim change with respect to providing guidance on identifying intersections for treatment, conducting an engineering study, and implementing traffic control devices at two-way stop-controlled intersections.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. This project was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation, and is NOT INTENDED FOR CONSTRUCTION, BIDDING OR PERMIT PURPOSES. The engineer in charge of the project was H. Gene Hawkins, Jr., P.E. #61509.

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The authors wish to acknowledge several members of the TxDOT Advisory Panel who provided technical assistance for this project.

Project Director

- Ms. Cathy Wood, Fort Worth District, Texas Department of Transportation

Advisory Panel

- Mr. Lewis Rhodes, Traffic Operations Division, Texas Department of Transportation
- Mr. Larry Colclasure, Waco District Office, Texas Department of Transportation
- Mr. Kirk Barnes, Bryan District Office, Texas Department of Transportation
- Mr. Ron Bailey, Austin District Office, Texas Department of Transportation
- Mr. Sam Swan, Brownwood District Office, Texas Department of Transportation
- Mr. John Bassett, Materials and Testing Division, Texas Department of Transportation

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Lastly, the authors wish to acknowledge Mr. Kendall Fogle, Mr. Jesse Guzman, Ms. Melisa Peoples, and Mr. Paul Fread of the Texas Transportation Institute for their contributions in the field and preparing the final report.

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SUMMARY

To improve driver safety and understanding of right of way conditions at two-way stop-controlled (TWSC) intersections, the Texas Transportation Institute (TTI) conducted several evaluations to better understand the current state-of-the-practice and the issues that drivers are confronted with at such intersections. This project involved the completion of six tasks: 1) a literature review; 2) a survey of Texas Department of Transportation (TxDOT) traffic engineers; 3) a survey of state Department of Transportation (DOT) traffic engineers; 4) a driver preference evaluation of supplemental signs at TWSC intersections; 5) a driver behavior evaluation of right of way at TWSC intersections; and 6) a traffic conflict study.

A total of 21 TxDOT Districts, 32 state DOTs, and approximately 2,500 drivers in five different states all contributed to the results and recommendations of the project. The results of the project tasks indicated the following:

- Most traffic engineers expressed the need for guidance in treating TWSC intersections to inform drivers of the right of way conditions;
- A wide disparity of supplemental signs currently exist nationwide, but traffic engineers were divided in opinion — primarily over the question of removing the responsibility of the driver at a TWSC intersection — regarding whether or not a uniform treatment should be adopted;
- Out of over 2,100 drivers, nearly 90 percent preferred the use of a supplemental sign with the legend CROSS TRAFFIC DOES NOT STOP with a horizontal, double-headed "arrow;"
- Most drivers are sure of who has the right of way at TWSC intersections;
- A supplemental sign mounted below the STOP sign significantly improved driver understanding of right of way at a rural TWSC intersection; and
- Traffic conflict studies are an effective tool in evaluating a TWSC intersection, particularly the effects of geometry and traffic operations on driver behavior characteristics.

The results of this project were used to provide guidelines on identifying, studying, and treating TWSC intersections which experience either high/severe crash frequencies and/or driver confusion of right of way conditions. The guidelines are summarized below.

Step 1 - Traffic engineers should first identify the TWSC intersections that would require safety improvements. Several conditions can lead a driver to misinterpret an intersection as being all-way stop-controlled, including a similar volume, speed, and geometry on all approaches. The presence of one or more of these conditions can aid the traffic engineer in identifying problematic intersections.

Step 2 - Secondly, the traffic engineer should conduct a traffic engineering study at these identified intersections to identify volume and conflict levels, the crash history, and existing site characteristics.

Step 3 - After this information has been gathered and if it is obviously determinable that drivers are misinterpreting the right of way conditions at the intersection, a supplemental CROSS TRAFFIC DOES NOT STOP sign should be installed below the STOP signs at each stop-controlled approach.

Step 4 - Lastly, the traffic engineer should conduct a periodic review, every one to two years, of the crashes, conflicts, and other operational characteristics at the intersection to determine if safety and driver understanding of the right of way has improved.

The guidelines for implementation of these recommendations are described in more detail in Chapter 7 of this report, and a TxDOT interim change to the Texas Manual on Uniform Traffic Control Devices is provided in Appendix D.

1.0 INTRODUCTION

According to the *Manual on Uniform Traffic Control Devices* (MUTCD), ". . . a traffic control device should meet five basic requirements: 1) Fulfill a need; 2) Command attention; 3) Convey a clear, simple meaning; 4) Command the respect of road users; and 5) Give adequate time for proper response" (*1*). If a traffic control device (TCD) or a system of TCDs does not meet these basic requirements, the potential for driver error increases. The traffic control scheme at two-way stop-controlled (TWSC) intersections causes safety concerns for many state and local agencies. At four-way or all-way stops (i.e., "multiway"), the use of a 4-WAY or ALL-WAY supplemental plate mounted below the STOP sign is designated as a "should" condition by the MUTCD (*1*). These supplemental plates are intended to inform drivers that traffic at all intersection approaches is required to stop. There is no MUTCD provision, however, for supplemental treatments at two-way stop-controlled intersections.

There is a potential for driver confusion at a four-legged intersection in which two approaches (e.g., minor street) are required to stop and two approaches (e.g., major street) are not required to stop. A lack of understanding of the two-way stop condition could lead a driver on the minor street to enter the intersection under the assumption that an approaching vehicle on the major street will stop, when, in fact, it will not. Some state and local agencies have become concerned about this potential problem and have developed a variety of supplemental word and symbol signs. The supplemental signs inform drivers on the minor street that the major-street traffic has the right of way and does not stop.

1.1 BACKGROUND

At two-way stop-controlled intersections, the use of STOP signs and stop bars are the standard treatment for the minor-street approaches. Some locations also include flashing intersection control beacons and/or STOP sign beacons. The supplemental treatments that have evolved and that are currently used by state and city traffic engineering departments lack consistency in the design of the sign. If a driver is unfamiliar with an intersection, the understanding of the right of way conditions becomes even more critical from a traffic safety standpoint. The responsibilities of a driver deciding to enter an intersection are different for two-way and four-way stop-controlled conditions. If a driver does not clearly understand the type of major-street intersection control, the crash potential increases.

Because of a perceived increase in crash frequency and severity at certain two-way stop-controlled intersections in Texas, the Texas Department of Transportation (TxDOT) has implemented other treatments to improve traffic safety at these intersections. However, due to the lack of research and specific guidelines for traffic engineers to follow, a consistent sign application (including placement, shape, color, and legend content) does not exist within the state of Texas or in most other states. This factor increases the probability that a driver approaching an intersection will be given information that is not uniform, clear, or concise.

Therefore, a detailed evaluation was conducted of existing and alternative treatments for traffic control devices at two-way stop-controlled intersections to improve driver understanding of right of way conditions.

1.2 PROJECT OBJECTIVES

The following objectives were established to evaluate the effectiveness of supplemental treatments at TWSC intersections:

- Identify current practices in use by local and state agencies, as well as identify relevant issues and concerns about supplemental sign treatments;
- Evaluate driver preference, understanding, and behavior of supplemental sign treatments by surveying a diverse sample of the driving population;
- Evaluate driver behavior characteristics at selected TWSC intersections; and
- Develop guidelines for the use of traffic control devices at TWSC intersections.

Issues investigated during the conduct of the research include types and designs of treatments (placement, shape, color, legend content, and letter sizes), as well as driver preference and understanding of the devices. Furthermore, through driver surveys and traffic conflict studies, the project identified signing practices, geometric features, and operational characteristics at TWSC intersections which may improve driver understanding of right of way conditions at such intersections. Based on the findings of the study, researchers developed suggested guidelines for selecting and treating problematic two-way stop-control intersections.

1.3 RESEARCH METHODOLOGY

During the one-year study period, researchers completed six major research tasks to meet the project objectives. An extensive literature review was conducted to provide information on issues related to sign treatments at two-way and four-way stop-controlled intersections. Two surveys were administered to obtain: 1) TxDOT traffic engineers' concerns and difficulties with traffic control devices at TWSC intersections; and 2) state Department of Transportation (DOT) traffic engineers' input on traffic control devices at TWSC intersections. Two additional surveys were administered to obtain information on driver understanding of right of way conditions and preference for sign treatments at TWSC intersections. A traffic conflict study was conducted at selected TWSC intersections in Texas to obtain information on driver behavioral characteristics at such intersections.

1.4 LITERATURE REVIEW

Little research has been done to address supplemental treatments at two-way stop-controlled intersections. Of specific interest in the literature search was the effectiveness in improving driver comprehension of the treatment(s) and driver understanding of the right of way conditions, particularly at intersections with perceived high crash frequencies of right-angle collisions and where intersections have been converted from a multiway stop to a two-way stop-controlled intersection. The concern involves drivers on the stop-controlled approaches not yielding the right of way to drivers on the uncontrolled approaches. Also of interest was the information needs of drivers on a stop-controlled approach at a TWSC intersection.

1.4.1 Federal Research Efforts

An extensive research effort by Ligon, et al. (*2*) for the Federal Highway Administration (FHWA) developed recommended procedures for a city or state traffic agency to follow when converting a multiway stop to a two-way stop. The first task involved obtaining before-and-after crash data at recently converted intersections to determine if supplemental signing was more effective at reducing crashes than at intersections without supplemental signing. While the data, summarized in Table 1, revealed statistical evidence of an overall smaller increase in the number of crashes at treated intersections after the conversion, the results of the analysis were conflicting. Selected intersections with supplemental treatments actually showed a higher increase in crashes compared to selected intersections without supplemental treatments. The authors indicated that geometric and operational characteristics at the study intersections were factors that contributed to the conflicting results (*2*).

Table 1. Summary of Crash Statistics (*2*)

	Crash Frequency		No. of Intersections Where Accidents:		
	Before	After	Increased	Decreased	No Change
With Supplemental Sign	77	101	13	12	32
Without Supplemental Sign	11	43	15	4	96
TOTAL	88	144	28	16	128

Secondly, the authors evaluated eleven different temporary supplemental sign designs to be used below a STOP sign at intersections that were converted from a multiway stop to a two-way stop. Through a series of survey ranking procedures, the 228 participants in the study indicated they preferred a rectangular-shaped sign with the message CAUTION CROSS TRAFFIC DOES NOT STOP, shown in Figure 1(*a*). The word CAUTION is black on a yellow background and the remainder of the message is black on a white background.

Developing the recommended procedure for converting a multiway stop to a two-way stop was the primary goal in this research. In a pre-conversion phase, the study recommends: 1) a traffic engineering study; 2) a public notice of the pending change; and 3) the posting of two "notice" signs, shown in Figures 1(*b*) and 1(*c*), 30 days prior to the conversion. In the conversion phase, the study first recommends the removal of the appropriate STOP signs, Stop Ahead signs, and pavement markings, and installing the "caution" sign and improving sight distance, if possible. Lastly, in the post-conversion phase, the study recommends: 1) a traffic engineering study to monitor volume, speed, crash, and driver behavior characteristics; 2) the use of police enforcement to monitor driver compliance; and 3) the removal of the "caution" sign after 90 days (*2*).

Figure 1. Temporary Sign Treatments Recommended for TWSC Intersection

The study recommends that the three signs shown in Figure 1 be placed below the STOP sign at each stop-controlled approach. The study also recommends the inclusion of these signs in the MUTCD (*2*).

1.4.2 State Research Efforts

A study conducted by Gattis (*3*) for the Arkansas State Highway and Transportation Department evaluated, through survey procedures, the current state-of-practice for supplemental sign messages at two-way stop-controlled intersections. A total of 471 federal, state, and local agencies in the U.S. and Canada and several special-interest organizations were surveyed. Approximately 40 percent (160) of the responding agencies indicated that they used a supplemental treatment at or in advance of a two-way stop-controlled intersection. Approximately 70 percent of these sign legends contained wording similar to CROSS TRAFFIC DOES NOT STOP, CROSS STREET TRAFFIC DOES NOT STOP, or *Roadway Name* DOES NOT STOP (*3*). The various messages are shown in Table 2.

Gattis also conducted a before-and-after crash analysis in which "cross traffic" signs were installed at two-way stop-controlled intersections. Of the seven agencies that provided crash data, three agencies indicated that the supplemental signs had been effective at reducing crashes while the remaining agencies indicated either inconclusive or ineffective results. Gattis noted, however, that the inconclusiveness of the crash data is subject to many driver behavior aspects and intersection factors such as geometry and unusual right of way arrangements (*3*).

A driver survey conducted by the Texas Transportation Institute (TTI) (*4*) for the Texas Department of Transportation compared driver comprehension of several supplemental sign designs below a STOP sign to a "control" treatment, which was a STOP sign only. The supplemental sign designs were developed as a result of several focus groups administered to Texas drivers and a review of several state manuals to identify existing TWSC treatments.

Table 2. Survey Results of Two-Way Supplemental Sign Messages (*3*)

Supplemental Sign Message	Frequency	Percentage
Cross Traffic Does Not Stop	77	
Cross Street Does Not Stop	10	
Name of Roadway Does Not Stop	8	
Name of Roadway Traffic Does Not Stop	6	
Caution Cross Traffic Does Not Stop	5	
Cross Street Traffic Does Not Stop	2	
TOTAL	108	68.8%
Traffic From Left (Right) Does Not Stop	8	
Traffic Left/Right Does Not Stop	1	
To Right/Left	1	
TOTAL	10	6.4%
2(3)-Way	4	
Caution 3-Way	1	
2-Way Stop	1	
Not a 4-Way Stop	1	
All-Way (4-Way)	1	
All Traffic Does Not Stop	1	
TOTAL	9	5.7%
Oncoming Traffic Does Not Stop	5	
Approaching Traffic Does Not Stop	1	
Opposing Left Turn Traffic Does Not Stop	1	
TOTAL	7	4.5%
Stop Except When Turning Right	1	
Yield To All Oncoming Traffic	1	
Signal For Left Turn	1	
Right Turn Permitted Without Stopping	1	
Except Right Turn	1	
Right Turn After Yield	1	
TOTAL	6	3.8%
Side Street Traffic Does Not Stop	2	
Access Road Traffic Does Not Stop	1	
Turning Traffic Does Not Stop	1	
TOTAL	4	2.5%
Other Messages	13	8.3%
TOTAL	**157**	**100%**

Focus group participants were asked to design a sign that would best inform them of the right of way conditions at a TWSC intersection. The most common legend elements that were suggested by the participants included horizontal "arrows" indicating traffic movement through an intersection, the words "cross traffic," and a plan view of a four-legged intersection. In a review of state MUTCDs and sign manuals, five states, including California, Pennsylvania, Minnesota, Illinois, and Wisconsin, were found to have a supplemental sign for use at certain TWSC intersections (*4*). The information discussed in the TTI report is presented below.

California The California Department of Transportation (CalTrans) developed a supplemental word and symbol sign in their state MUTCD (*5*), which is mounted on the same post immediately below the STOP sign. This CROSS TRAFFIC DOES NOT STOP sign (SW1), depicted in Figure 2, "may be used to supplement standard signs and markings that have not proven effective at problem intersections where the minor road is STOP sign controlled" and where the crash history indicates that "motorists on the minor road, after stopping, assume that traffic on the major road will also stop" (*5*). It is also used ("may" condition) for a limited time at intersections that have been converted from a four-way stop to a two-way stop control (*5*).

Figure 2. California Sign for TWSC Intersection

Minnesota The Minnesota Department of Transportation (MnDOT) developed a slightly different alternative for a two-way stop-controlled intersection. The CROSS TRAFFIC DOES NOT STOP sign (R1-X2), depicted in Figure 3, is a word message sign used to warn drivers of the cross-traffic operations. It is intended for use "at those intersections where geometric, topographic or other conditions exist and motorists approaching a STOP sign *may expect* cross traffic to stop" (*6*). Furthermore, the use of the sign "shall" be limited to intersections where driver expectations or an engineering study "indicate a need" (*6*). MnDOT also installs this sign on the same post immediately below the STOP sign.

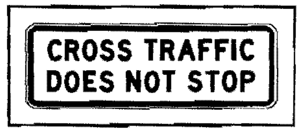


Figure 3. Minnesota Sign for TWSC Intersection

Illinois The Illinois Department of Transportation uses the same CROSS TRAFFIC DOES NOT STOP sign (R1-I100) as MnDOT (*7*).

Pennsylvania The Pennsylvania Department of Transportation uses a word message sign (R1-1B) with the legend OPPOSING TRAFFIC DOES NOT STOP. This sign, depicted in Figure 4, is used when "opposing . . . traffic does not have to stop" (*8*).

Wisconsin Wisconsin uses word message signs (R1-52(A,R,L)) with the legends TRAFFIC ON (INTERSECTED HIGHWAY) DOES NOT STOP, ONCOMING TRAFFIC DOES NOT STOP, or TRAFFIC FROM RIGHT (LEFT) DOES NOT STOP (*9*). These supplemental word message signs are used "sparingly," usually at locations where drivers "believe the intersection may be a four-way" stop-controlled intersection. (*9*).

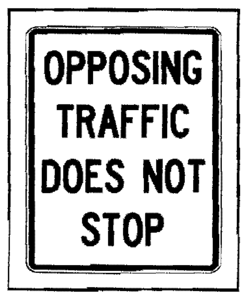
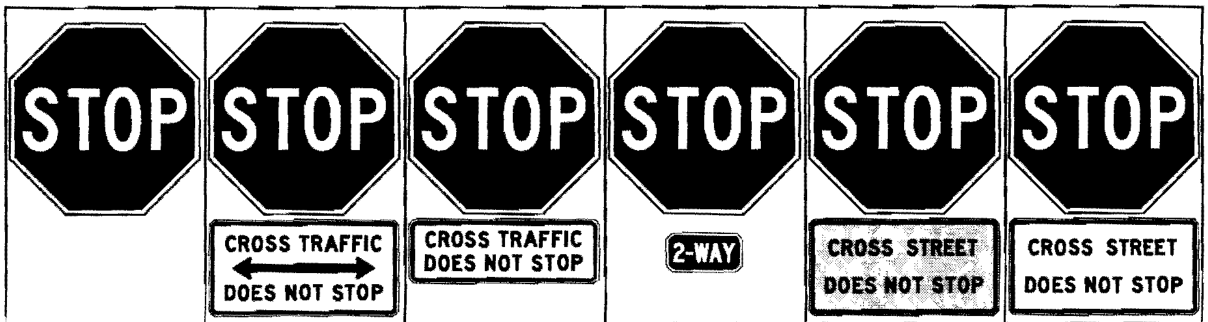


Figure 4. Pennsylvania Sign for TWSC Intersection

After conducting the focus groups and reviewing the state manuals, the TTI researchers developed several alternative sign designs for evaluation. Figure 5 depicts the six alternatives that were evaluated in this study (*4*).

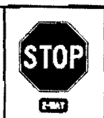


Supplement color	(black on white)	(black on white)	(white on red)	(black on yellow)	(black on white)

Figure 5. Supplemental Sign Treatments Evaluated for TWSC Intersections (*4*)

The study results showed that although no particular "cross traffic" sign message was any more effective than the others, adding a supplemental sign below a STOP sign did significantly improve drivers' understanding that "traffic from the right or left may not stop (at the intersection)" as compared to a STOP sign alone. Furthermore, the use of a STOP sign alone, or a 2-WAY sign below the STOP sign, performed poorly with respect to other alternatives that contained a "cross traffic" message. Approximately 30 percent of the drivers surveyed chose a response indicating that "traffic from all directions must stop (at the intersection)" for the STOP sign and 2-WAY sign treatment; only 10 percent chose the same response for the "cross traffic" sign treatments (*4*). The results from this survey are shown in Table 3.

Table 3. Survey Response to TWSC Intersection Treatments (*4*)

SIGN ALTERNATIVE						QUESTION AND RESPONSES
						What is this sign telling you? Circle ONE answer.
3.3	1.2	4.2	7.1	0.0	3.3	You do not have to stop, you are crossing the int..
37.0	25.2	7.1	10.0	9.9	12.5	Traffic from all directions must stop.
56.5	68.3	87.5	81.4	84.5	83.3	**Traffic from the right or left may not stop.***
3.3	5.4	1.2	1.4	5.6	0.8	I am not sure what this sign means
154	167	168	70	70	120	Sample Size

* Indicates Correct Response

1.5 SURVEY OF STATE TRAFFIC ENGINEERS

The initial survey effort involved addressing the concerns and difficulties that TxDOT and state DOT traffic engineers were experiencing at TWSC intersections. A multi-page survey was sent to the 25 TxDOT District Traffic Engineers and to the State Traffic Engineer in all 49 states (excluding Texas). The goal of each survey was to obtain input from traffic engineering professionals on their use of supplemental treatments, their justification for use (guidelines, warrants, traffic engineering studies, etc.), the effectiveness of any such treatments, and their preference and suggestions on improving driver understanding of right of way conditions. A total of 21 TxDOT Districts and 32 state DOTs responded to the surveys. Chapter 2 and Appendix A describe the results of these two surveys in more detail.

1.6 EVALUATION OF SUPPLEMENTAL SIGN PREFERENCE

An extensive survey effort was conducted to obtain input from a representative sample of drivers in the United States. A one-page survey was mailed to a randomly selected sample of 7,500 drivers in five U.S. states. The goal of the survey was to obtain a general perception of driver understanding of the "right of way" concept at stop-controlled intersections and to provide data on driver preference for supplemental sign treatments at TWSC intersections. The researchers also attempted to learn the general perception of the motoring public on the necessity of supplemental treatments at TWSC intersections. A discussion of the survey development and results are provided in Chapter 3.

1.7 DRIVER ASSESSMENT OF RIGHT OF WAY CONDITIONS

A second driver survey was conducted to obtain an understanding of driver behavior characteristics and what types of visual cues help the drivers understand the right of way conditions at two-way stop-controlled intersections. The survey instrument consisted of a driver simulation video depicting, from a driver's perspective, a vehicle approaching a rural, stop-controlled intersection. Each survey participant viewed one of four different traffic control scenarios depicted in the video. At the conclusion of the video, each participant was asked open-ended questions to determine their perception of the right of way conditions at the intersection. The survey was administered to 436 drivers in four Texas cities. Chapter 4 provides a discussion of the survey and its results.

1.8 TRAFFIC CONFLICT STUDIES AT TWSC INTERSECTIONS

A field study technique utilizing an elevated surveillance camera was conducted to assess driver behavior characteristics at TWSC intersections. The study particularly focused on the interaction of vehicles at the intersections to determine factors that may influence conflict frequency. The data collection effort identified geometric and operational characteristics at the intersections that were possible contributing factors to conflicts and crashes. Researchers evaluated six different TWSC intersections, with 11 hours of videotape at each. Chapter 5 discusses the data collection effort, including the methodology, the results, and the benefits.

1.9 FINDINGS AND RECOMMENDATIONS

Researchers used the results of the project evaluations to develop recommendations for improving driver understanding of right of way at certain two-way stop-controlled intersections. The recommendations provide implementation guidelines for selecting and treating problematic TWSC intersections, as well as factors that TxDOT traffic engineers should consider at such intersections. Chapters 6 and 7 summarize the results of each evaluation and the project recommendations.

2.0 SURVEY OF STATE TRAFFIC ENGINEERS

To address the concerns, difficulties, and traffic control experiences of TxDOT and state DOT traffic engineers with respect to TWSC intersections in their jurisdiction, two different mail-out surveys were conducted. The first survey was mailed to all 25 jurisdictional TxDOT Districts within Texas. The second survey was mailed to the State Traffic Engineers in 49 U.S. states (excluding Texas). These two surveys, similar to the extensive state-of-the-practice surveys conducted by Gattis (*3*), provided technical input on the use and justification of traffic control treatments at TWSC intersections. The surveys also provided an opportunity for the traffic engineers to provide the researchers data on their preferences for supplemental sign design features, such as placement, shape, and color.

This chapter provides a summary of the findings for each survey. A more detailed description of the survey instrument and survey data is provided in Appendix A.

2.1 SURVEY OF TxDOT DISTRICT TRAFFIC ENGINEERS

A total of 21 of the 25 TxDOT Districts completed and returned the survey instrument. Most returned surveys were completed by the Director of Transportation Operations in the respective district; he/she being the one with the most knowledge of existing TWSC treatments in the district. From one participating district, however, nine Area Engineers returned completed surveys. Therefore, a total of 29 surveys were completed and returned. The following sections discuss the results of the surveys, as well as points of interest that the research team utilized in subsequent project tasks. The results of the survey are provided in more detail in Appendix A.

2.1.1 Existing Treatments for Stop-Controlled Intersections

Most districts responding to the survey indicated that they currently use the 3-WAY, 4-WAY, and/or the ALL-WAY (R1-3 and R1-4) supplemental plates at multiway stop-controlled intersections; most prefer the ALL-WAY plate. Furthermore, there was a consensus that the plates should *always* be used at multiway stops. At TWSC intersections (intersection of two state-maintained roadways), however, the respondents indicated a wide disparity of treatments and factors for using these treatments. Of the 29 respondents, 65 percent indicated that they use a supplemental sign mounted below the STOP sign. Nearly all respondents (96 percent) indicated the use of a Stop Ahead sign (W3-1a) in advance of the intersection, and most (81 percent) use flashing intersection control beacons as a treatment alternative.

2.1.2 Factors For Using a Supplemental Treatment at TWSC Intersections

With respect to the supplemental sign, the primary factor for usage (65 percent) is when the traffic engineer believes that drivers at either of the stop-controlled approaches may expect traffic from all directions to stop. Related to the driver expectancy issue is the crash frequency at the intersection over a given period of time. Over half of TxDOT engineers indicated that crash frequency, as well as geometry of the intersection, were factors that were considered prior to installing a supplemental sign. The traffic engineers indicated a typical crash frequency range of at least three to five crashes per year as an indicator for installing a supplemental treatment.

2.1.3 Justification for Using a Supplemental Treatment

When asked for the justification, or basis, for using a certain supplemental treatment at a TWSC intersection, a significant percentage of the respondents (82 percent) indicated that their decision was based on an engineering judgement, on a case-by-case basis. A smaller percentage (55 percent) also indicated that their decision was based on an engineering study, primarily an evaluation of crashes at the intersection of interest.

2.1.4 Alternatives to Supplemental Signs at TWSC Intersections

TxDOT engineers were asked if other traffic control treatments were considered *if* a supplemental sign was not effective in conveying the intended meaning (i.e., crashes do not decrease and/or drivers do not understand). A majority of the respondents indicated that they install intersection control beacons (75 percent), while approximately 40 percent either install traffic signals or physically redesign the intersection (improve sight distance, modify approach grades, and/or widen the roadway). Prior to conducting the surveys, the researchers hypothesized that supplemental signs were generally installed as a "last resort" effort prior to signalization. The results of this question, however, seem to indicate that TxDOT engineers first attempt to address problematic intersections by installing a supplemental sign, a more cost-effective measure than beacons or signals. Furthermore, installing unwarranted beacons or signals, which likely creates a public perception of a safety improvement, only breeds disrespect toward the devices.

2.1.5 TxDOT Preference for An MUTCD Standard for TWSC Intersections

A higher percentage of survey respondents (46 percent) indicated that the MUTCD should adopt a uniform treatment for TWSC intersections, compared to 36 percent who indicated that no standard is necessary and 18 percent who were not sure on the issue. Based on their comments, however, both respondents who favored and opposed the adoption of a standard expressed their concern of having to use the standard treatment at *all* TWSC intersections, as well as city and county agencies adhering to new standards outside of TxDOT's jurisdiction. The respondents indicated that a more uniform treatment should be adopted for only problematic, or "specialized," intersections, where high crash frequencies are prevalent and/or where drivers may expect all directions to stop.

2.1.6 TxDOT Preference for Supplemental Sign Design

TxDOT engineers were also asked to provide their preference for a supplemental sign design, including placement, shape, and legend/background color, for a TWSC intersection.

The message of the legend was not considered in this part of the survey. A majority of the respondents indicated that they preferred a rectangular-shaped sign (92 percent), with black letters on either a white background (50 percent) or yellow background (23 percent), or red letters on a white background (23 percent). Most (89 percent) preferred that the supplemental sign be mounted below the stop sign on each stop-controlled approach. Even though a wide disparity of legend messages exists throughout the TxDOT Districts, nearly all supplemental signs in use are rectangular-shaped and mounted below the STOP sign.

A complete summary of the Districts that are currently using supplemental signs at TWSC intersections is documented in Table 4. The table provides the design (shape, color, and legend content) of the sign, the primary factors for usage, and the justification for usage.

2.2 SURVEY OF STATE DOT TRAFFIC ENGINEERS

A total of 32 of the 49 state Departments of Transportation completed and returned the survey instrument. Most returned surveys were completed by an engineer in an administrative department of the DOT. The following sections discuss the results of the surveys. A more detailed presentation of the survey data is provided in Appendix A.

2.2.1 Existing Treatments for Stop-Controlled Intersections

Similar to the question asked of TxDOT traffic engineers, the state DOTs were asked to provide information on the usage of multiway plates and other treatments at stop-controlled intersections. Again, as expected, most states use the 3-WAY, 4-WAY, and ALL-WAY supplemental plates in the MUTCD at multiway stop-controlled intersections. Concerning TWSC intersections, nearly 40 percent indicated the use of a specific device or treatment to distinguish a two-way stop from a four-way stop, most being a supplemental sign mounted below the STOP sign. Again, the researchers observed a wide disparity of supplemental sign designs and factors for using these signs.

2.2.2 Factors For Using a Supplemental Treatment at TWSC Intersections

With respect to specific treatments for TWSC intersections, the state DOTs indicated that crash frequency (88 percent) was the primary factor that influenced their decision to install a supplemental sign. Also considered is 1) the perception that drivers may expect all directions to stop (60 percent), and 2) the geometry of the intersection (53 percent) that could lead a driver to believe that the intersection is a multiway stop-controlled intersection.

Table 4. Summary of TxDOT District Supplemental Treatments

TxDOT District No./Name	Supplemental Sign	Color Scheme	Primary Factors for Usage							Justification			
			Conversion	Driver Expects	Crash Frequency	Fatalities	Geometry	Volumes	Sight Distance	District Std.	Engr. Study	Engr. Judge	Other
1/Paris	CROSS TRAFFIC DOES NOT STOP	Black/White	✓	✓	✓							✓	
	SH 39 DOES NOT STOP	Black/White	✓	✓	✓							✓	
3/Wichita Falls	CROSS STREET TRAFFIC DOES NOT STOP	Black/Yellow	✓	✓	✓						✓	✓	
8/Abilene	2-WAY	White/Red		✓	✓	✓	✓		✓			✓	
	CROSS TRAFFIC DOES NOT STOP	Black/Yellow		✓	✓	✓	✓		✓			✓	
9/Waco	CROSS STREET DOES NOT STOP	Black/Yellow		✓	✓		✓	✓			✓	✓	
10/Tyler	CROSS TRAFFIC DOES NOT STOP	Black/Yellow		✓		✓			✓			✓	
	US 96 TRAFFIC DOES NOT STOP	Black/White		✓		✓			✓			✓	
11/Lufkin	US 96 TRAFFIC DOES NOT STOP	Black/Yellow			✓	✓	✓				✓		✓

Table 4. Summary of TxDOT District Supplemental Treatments (continued)

TxDOT District No./Name	Supplemental Sign	Color Scheme	Primary Factors for Usage:							Justification			
			Conversion	Driver Expects	Crash Frequency	Fatalities	Geometry	Volumes	Sight Distance	District Std.	Engr. Study	Engr. Judge	Other
17/Bryan	CROSS TRAFFIC DOES NOT STOP	Black/Yellow		✓	✓	✓	✓		✓		✓	✓	
	US 96 TRAFFIC DOES NOT STOP	Black/Yellow		✓	✓	✓	✓		✓		✓	✓	
18/Dallas Area 7	CROSS TRAFFIC DOES NOT STOP	Black/White		✓								✓	
Area 8	CROSS TRAFFIC DOES NOT STOP	Black/White	✓									✓	
Area 1	CROSS TRAFFIC DOES NOT STOP	Black/White					✓						
Area 2	US 96 TRAFFIC DOES NOT STOP	Black/White			✓	✓		✓	✓		✓	✓	
20/Beaumont	CROSS STREET TRAFFIC DOES NOT STOP	Black/Yellow	✓	✓	✓							✓	
25/Childress	2-WAY	White/Red	✓	✓	✓	✓	✓				✓	✓	
	CROSS STREET TRAFFIC DOES NOT STOP	Black/White	✓	✓	✓	✓	✓				✓	✓	
Total			7	14	13	10	9	2	7	0	8	16	1

2.2.3 State DOT Preference for An MUTCD Standard for TWSC Intersections

Unlike the TxDOT respondents, a higher percentage of state DOT engineers (71 percent) indicated that the MUTCD should not include a standard that identifies an intersection as a TWSC intersection. Only 13 percent indicated that the MUTCD should provide a standard, and 16 percent were unsure. The data, however, comes primarily from administrative personnel who may not want to fully endorse a standard treatment until further research can provide the necessary guidance for treating such intersections. In the TxDOT survey, the respondents represented personnel who had first-hand knowledge of the problems at TWSC intersections and who desire a more immediate solution to treating the intersection.

A complete summary of the states that are currently using supplemental signs at TWSC intersections is presented in Table 5. The table provides the design (shape, color, and legend content) of the sign and the primary factors for usage.

2.3 FINDINGS OF TRAFFIC ENGINEERS' SURVEYS

Findings from both previously discussed surveys were utilized in subsequent research tasks and in the development of recommendations for this project. From the TxDOT survey, a large percentage (65 percent) of the traffic engineers who responded to the survey were currently using supplemental sign treatments at TWSC intersections. Since there are no established guidelines for treating the existing TWSC intersections, most traffic engineers were basing their usage of supplemental signs solely on engineering judgement. Furthermore, most supplemental signs in use are rectangular-shaped, contain a black legend on either a white (50 percent) or yellow (25 percent) background, and are mounted below the STOP sign.

According to the results of both surveys, the traffic engineering community remains divided on whether or not the MUTCD should provide a standard sign or treatment for TWSC intersections. Many of the TxDOT traffic engineers favored the inclusion of such a treatment at "specialized" locations; traffic engineers with other DOTs, however, were more opposed to supporting the inclusion in the MUTCD. Most of the traffic engineers, regardless of favoring or opposing an MUTCD standard, expressed concern about widely utilizing such a treatment at all locations, especially since many TWSC intersections are out of their jurisdiction and under city or county jurisdiction.

Table 5. Summary of State DOT Supplemental Treatments

State	Supplemental Sign	Color Scheme	Primary Factors for Usage:					
			Driver Expects	Crash Frequency	Fatalities	Geometry	Volumes	Sight Distance
Arkansas	CAUTION CROSS TRAFFIC DOES NOT STOP	Black/Yellow Black/White	✓			✓		
Idaho	CROSS TRAFFIC DOES NOT STOP	Black/Yellow	✓	✓		✓	✓	✓
Indiana	CROSS TRAFFIC ⟷ DOES NOT STOP	Black/White	✓	✓				
Kansas	→ US 81 ← DOES NOT STOP	Black/White	✓	✓	✓	✓	✓	✓
Kentucky	CROSS TRAFFIC DOES NOT STOP	Black/White	✓	✓		✓		
Mississippi	CROSS TRAFFIC DOES NOT STOP	Black/Yellow (Advance)[1]	✓			✓	✓	
	NOT A 4-WAY STOP	Black/White	✓			✓	✓	
Nebraska	CROSS TRAFFIC DOES NOT STOP	Black/Yellow	✓	✓	✓	✓	✓	✓
	HWY. XX TRAFFIC DOES NOT STOP	Black/White	✓	✓	✓	✓	✓	✓
Ohio	CROSS TRAFFIC ⟷ DOES NOT STOP	Black/White	✓					
Oregon	SIDE STREET TRAFFIC DOES NOT STOP	Black/White		✓	✓			
Total			10	7	4	8	6	4

Note: [1] Sign used in advance of the intersection.

3.0 EVALUATION OF SUPPLEMENTAL SIGNS

The primary purpose of this evaluation was to evaluate driver understanding of the "right of way" concept at a two-way stop-controlled intersection and then to determine which supplemental sign message(s) best informed the drivers that traffic on the major-street approaches has the "right of way." The objectives were achieved by conducting a mail-out survey of 7,500 drivers in five different states. Three of these states have this type of supplemental sign message included in their respective state MUTCD.

The survey evaluated driver understanding of the "right of way" concept and how often they are confused about who has to yield the "right of way" at a two-way stop-controlled intersection. The survey included nine different supplemental sign messages that were divided equally into word, symbol, or word/symbol message designs. Participants were asked which message in each category best described the right of way conditions at a two-way stop-controlled intersection and which was preferred overall. Demographic data for the survey sample were also collected.

3.1 SURVEY OBJECTIVE

The objectives of this survey were to evaluate driver understanding of the "right of way" concept at TWSC intersections, their preference for a supplemental sign design, and their opinion on the actual need for a supplemental sign at such an intersection. To achieve the objectives, the following tasks were conducted:

- Develop supplemental sign designs for evaluation;
- Evaluate driver understanding of right of way conditions and preference for supplemental signs at a TWSC intersection; and
- Summarize the survey data.

3.2 SURVEY METHODOLOGY

The research team, with technical assistance from the TxDOT Advisory Panel, developed a mail-out survey instrument that would address fundamental aspects of right of way conditions at TWSC intersections, including a preference evaluation for supplemental signs. Many of the supplemental signs currently in use state a message that suggests that the major street traffic does not have to stop at the intersection. These sign messages do not imply who *has to yield*, but rather, who *does not stop* at the intersection. Therefore, the researchers took this approach for the questions in the mail-out survey. To evaluate a large, diverse sample of drivers, a mail-order company was contracted to provide a random sample of 7,500 persons in five different U.S. states.

3.3 SURVEY INSTRUMENT DESIGN

The research team carefully designed a survey instrument to provide answers to right of way assumptions and to provide solutions to improve safety at TWSC intersections. The survey was pilot tested to not only assure that the concept of "right of way" was well understood by the survey respondents, but to also refine the questions and response choices. Afterwards, the refined survey was administered and the results were analyzed. A copy of the final survey instrument is provided in Appendix B.

3.3.1 Survey Instrument Development

The survey presented nine different supplemental sign designs to the participants. Three of the designs were word message signs, three were symbol signs, and three were a combination of words and symbol(s). The participants were asked to choose the preferred sign in each category that best conveyed the right of way conditions at a two-way stop-controlled intersection. The sign alternatives developed were based on previous research, surveys of traffic engineers conducted prior to the administration of this survey (see Chapter 2), and input from the TxDOT Advisory Panel.

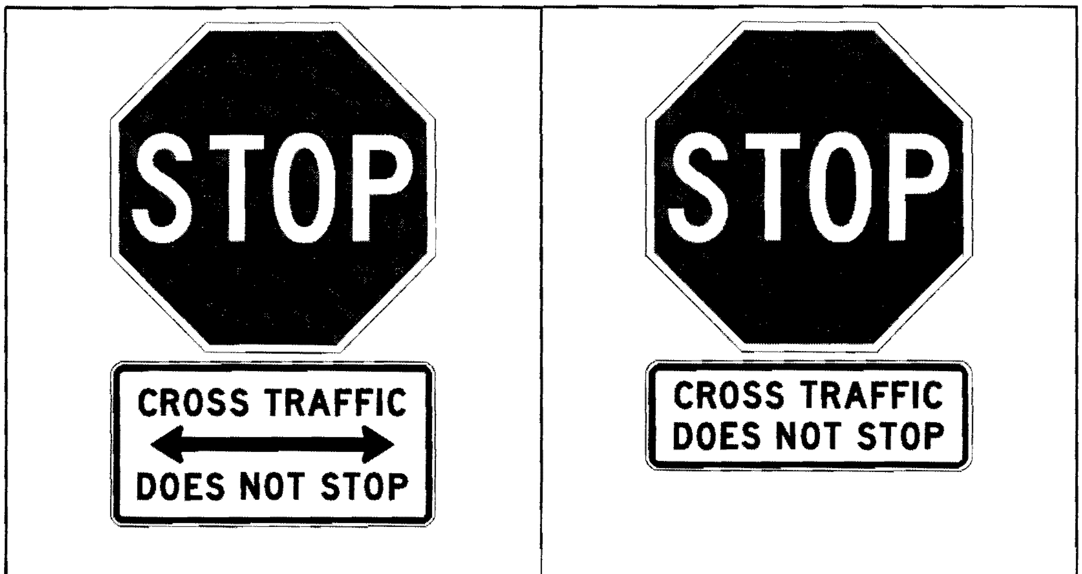
In a previous research project (*4*), TTI conducted several focus group evaluations of licensed drivers. The focus group participants were asked to design a traffic control treatment at a TWSC intersection that best conveyed the message that the intersecting roadway traffic is not required to stop. The sign elements that appeared the most frequently in the designs were:

- A plan view of the intersection that depicted approaching traffic stopping and cross street traffic continuing through the intersection; and
- A horizontal, left/right or double-headed "arrow" intended to show that the cross traffic is a continuous movement and does not stop.

In conjunction with the focus group evaluations, the study included a review of several state MUTCDs and Sign Manuals to identify existing supplemental signs in use at TWSC intersections (*4*). Several states, including California and Minnesota, have adopted such a treatment (see Figure 6) and guidelines to implement the treatment (*5*, *6*). These two states have indicated in their state MUTCD that the sign should only be used "if the standard signs and markings have not proven effective at problem intersections where the minor road is STOP sign controlled" (*5*) and/or based on an "engineering judgement that the crash history indicates where traffic on the minor road may expect traffic on the major road to also stop" (*5*, *6*). Other state and local agencies have adopted similar supplemental signs and have taken similar approaches to their justification for use (*3*).

Prior to administering the survey, the researchers conducted other surveys of TxDOT and other state DOT traffic engineers (see Chapter 2). The respondents were asked to identify supplemental sign designs that their state or jurisdiction had implemented in the field. Similar to Gattis' results (*3*), a large percentage of the respondents indicated that supplemental sign messages contained legends such as CROSS (STREET) TRAFFIC DOES

NOT STOP and *Highway Name* DOES NOT STOP. Most of these supplemental treatments were either white or yellow rectangular-shaped signs mounted below the STOP sign.



California Standard Sign Manual (*5*) | Minnesota MUTCD (*6*)

Figure 6. Supplemental Sign Treatments in California and Minnesota

With the assistance of the Advisory Panel, the results of the previous research and the traffic engineers' surveys were combined to develop the nine alternatives evaluated in this survey. These alternatives are illustrated in Figure 7. Two of the three word message supplemental signs (Figures 7(*a*) and (*b*)) represent the most commonly used legends. The 2-WAY sign alternative (Figure 7(*c*)) has been evaluated in previous studies (*2*, *4*) and was included for this evaluation. The three symbol supplemental signs, illustrated in Figures 7(*d*), (*e*), and (*f*), represent a composite of designs that focus group participants indicated would best convey the message that the intersecting roadway is not required to stop. The horizontal "arrow" and the intersection plan view were the two most common symbol elements found in the focus group designs (*4*) and were used in these three alternatives. The final three alternatives, illustrated in Figures 7(*g*), (*h*), and (*i*), were a combination of words and symbols from the six previous alternatives, derived from the focus group results (*4*), and from Advisory Panel input.

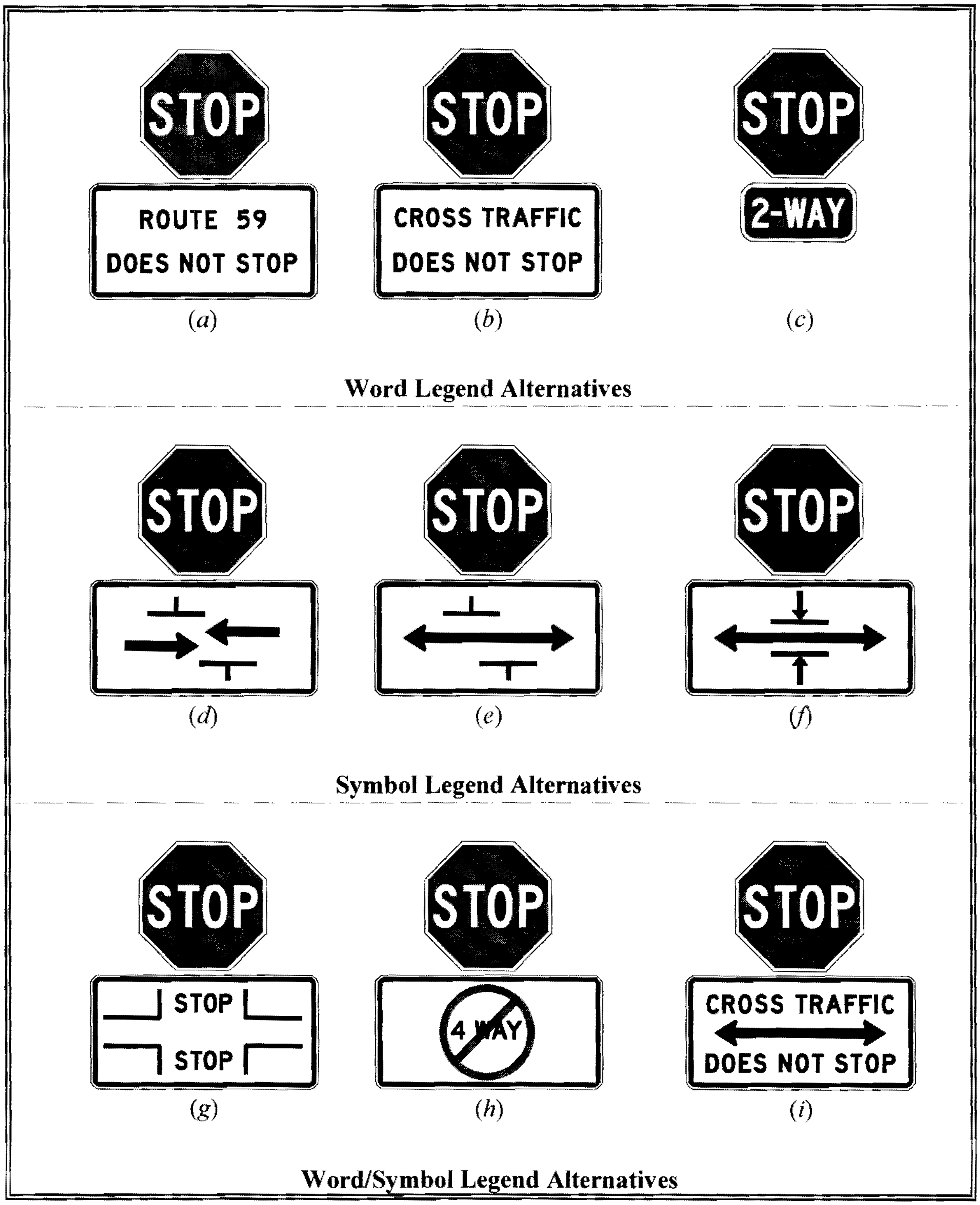


Figure 7. Supplemental Sign Message Designs

3.3.2 Survey Format

Researchers determined supplemental sign design preference by asking a series of eight "technical" questions related to two-way stop-controlled intersections. The eight questions included:

- Two questions that addressed the drivers' perception of "right of way" at an intersection drawing depicted in the survey;
- Five questions that addressed the sign design that best conveyed the right of way conditions at a two-way stop-controlled intersection; and
- One question that addressed the issue of whether drivers believe that a supplemental sign is necessary at such an intersection.

Additionally, four demographic questions were asked to establish the distribution of the survey participants. Each of the questions is described in more detail in the following paragraphs.

"Technical" Questions

Question 1 Question 1 addressed driver understanding of the term "right of way." Since "right of way" is a term commonly used in the traffic engineering profession, it was important to establish whether survey participants understood the meaning of the term. Also, as discussed earlier, since most existing supplemental signs imply that the major street traffic *does not stop* rather than the minor street traffic has to *yield*, the question was asked: "*Which vehicle at the intersection has the right of way*?" The question also referred the respondent to the image shown in Figure 8.

Question 2 Question 2 addressed how often drivers feel unsure of which vehicle has the right of way at intersections such as the one shown in Figure 8. The question provided data on how frequently drivers are confused as to which vehicles are required to stop at such an intersection. The data may serve as an indicator of the perceived need for a supplemental sign. This question referred to Figure 8 and asked, "*At an intersection like this, how often are you unsure of who has to stop*?"

Questions 3, 4, and 5 Questions 3, 4, and 5 addressed the actual sign messages on the supplemental sign designs. Three different supplemental sign messages were shown for the word, symbol, and word/symbol combination designs. All nine designs are shown in Figure 7. For Questions 3, 4, and 5, the survey participants were asked the following based on the Figure 8 drawing: "*If you were in Vehicle A, which WORD SIGN (SYMBOL SIGN or WORD/SYMBOL SIGN) best tells you that Vehicle B has the right of way*?"

Question 6 Question 6 addressed which of the three signs chosen in Questions 3, 4, and 5 was preferred overall by the participants for best conveying the right of way conditions. The question was used to compare the preferences among the three categories of message types and to determine which type was most effective. This question asked, "*Of the signs in the previous three questions, which one do you prefer the most?*"

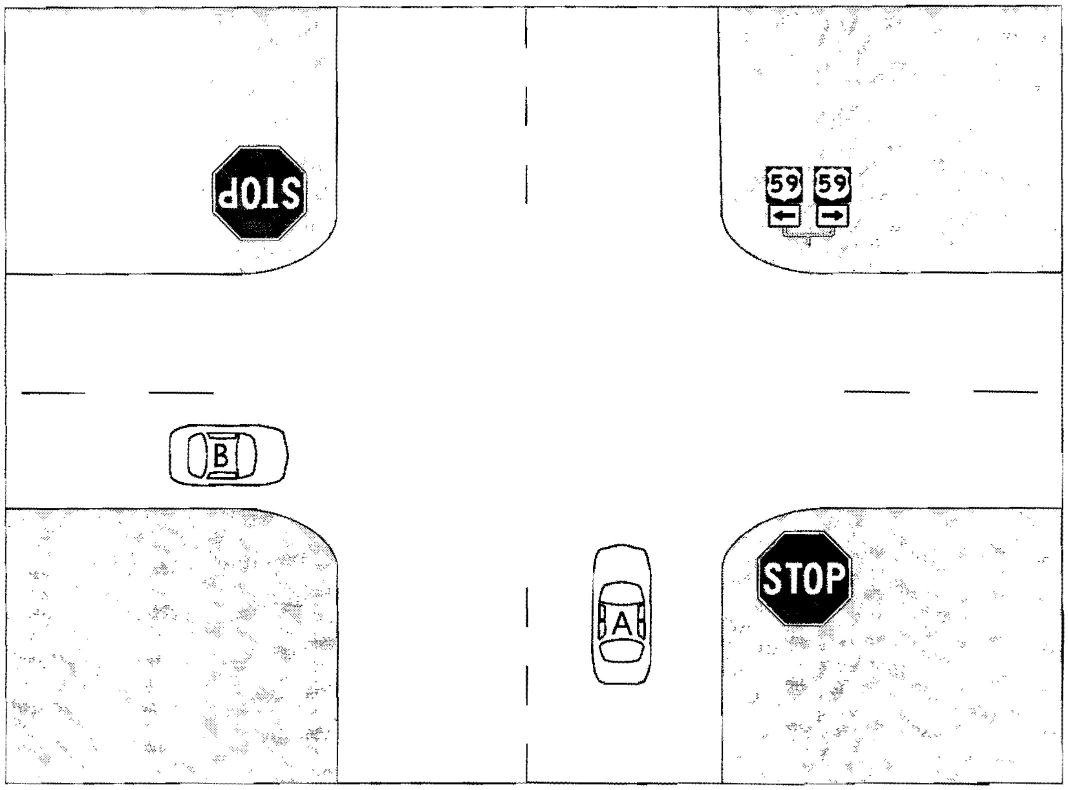


Figure 8. Intersection Drawing Presented in Mail-Out Survey

Question 7 Question 7 was asked to determine if the participants believed a supplemental sign was needed to inform drivers that the crossing traffic has the right of way. In the absence of an MUTCD standard, opinion in the traffic engineering profession is widely split on whether the need for a supplemental sign exists. There is a belief, held by many, that an additional supplemental sign at a two-way stop-controlled intersection violates driver expectancy. At a multiway stop, the use of ALL-WAY signs below the STOP sign implies that all directions are required to stop. In the absence of a sign, however, drivers should assume that the intersection is not a multiway stop. Furthermore, the use of a supplemental sign at all two-way stop-controlled intersections is impractical, and drivers may expect them at all such intersections. Furthermore, in Texas and in most states, the driver education and licensing process teaches drivers that they should be responsible and know that the STOP sign means to ". . . stop at a clearly marked line or before entering the intersection . . ." (*10*). Many agencies are also concerned about liability because of the nonstandard supplemental treatment (*3*). This survey question asked the participants, based on the drawing in Figure 8: "*Do you think a sign in addition to the STOP sign is needed to tell you that Vehicle B has the right of way?*"

Question 8 Question 8 was asked to determine if the participant could suggest a message that was more effective than those shown in Questions 3, 4, and 5. An enlarged STOP sign and blank supplemental sign were shown to allow the participant to illustrate his or her message. This question asked, "*Can you suggest a better sign that would best tell drivers*

Vehicle B has the right of way at the intersection?" The participants were then instructed to "*Fill in the sign below with words and/or symbols.*"

Demographic Questions

Questions 9, 10, 11, and 12 Questions 9 through 12 addressed the gender, age, ethnicity, and education level of the survey participants. The following categories were used for each question:

- Gender: Male or Female;
- Age: 16 to 24, 25 to 54, 55 to 64, or Over 65;
- Ethnicity: African-American, American Indian, Anglo, Asian, Hispanic, or Other; and
- Education: Less than High School, High School or equivalent, Some College, or College Graduate.

3.4 SURVEY ADMINISTRATION

A random sample of 1,500 drivers in each of five states (California, Minnesota, Mississippi, Pennsylvania, and Texas) were sent surveys. The sample size was based on an anticipated questionnaire return rate of 10 percent to ensure a statistical precision at a 90 percent confidence interval. The five states were selected because they are in geographically diverse regions of the United States and because each was known to have supplemental sign treatments in use at certain two-way stop-controlled intersections. It was believed that the drivers in these states had at least been exposed to a supplemental sign treatment and would be more accustomed to the purpose of the survey and the meaning of the signs.

3.5 DISCUSSION OF RESULTS

The survey was mailed to 7,500 drivers in the five states. The drivers were randomly selected by a mail listing company that provides national consumer databases for general mail-order businesses. A total of 2,129 anonymous surveys (28 percent) were returned, with an average of approximately 425 returns per state. With the higher-than-expected return rate, the researchers were able to place more confidence in the survey results. A standard normal *z-test* was used to statistically analyze the data. The response percentages discussed below are based on a 99 percent confidence interval and have a ±2 percent precision for the overall sample and a ±4 percent precision for the sample in each state.

3.5.1 Survey Demographics

Table 6 summarizes the demographic characteristics of the initial sample size ("Initial") and of the sample population that returned the surveys ("Return"). A majority of the initial database surveyed, as well as the returned sample, consisted of male Anglos between the ages of 25 and 54. The over-representation of male drivers in the random sample was likely due to the mail listing company's listing of consumers by home ownership, which is typically listed under the male's surname. Ethnicity and educational background were not initially available from the mail listing company.

Table 6. Demographic Characteristics of Mail-Out Survey Sample

Characteristics		Percent by State					Overall Percent	
		CA	MN	MS	PA	TX	Initial	Return
Gender	Male	68.2	66.7	64.4	68.4	67.5	69.8	67.2
	Female	31.8	33.3	35.6	31.4	32.5	30.2	32.8
Age	16 to 24	1.1	1.7	2.1	1.9	1.5	1.5	1.6
	25 to 54	51.1	67.8	53.2	62.2	58.1	58.7	59.4
	55 to 64	19.6	14.3	17.3	17.0	17.1	15.8	16.8
	65+	28.2	16.2	27.4	18.9	23.3	24.1	22.2
Ethnicity	African-American	2.6	0.4	12.1	2.6	3.1	n/a	3.4
	American Indian	0.8	0.9	0.3	0.5	0.6		0.7
	Anglo (white)	81.2	96.5	86.2	94.1	85.3		89.3
	Asian	6.9	0.4	0.3	0.2	1.6		1.8
	Hispanic	5.6	1.1	0.0	0.5	6.3		2.8
	Other	2.9	0.7	1.0	2.1	3.1		2.0
Education	Less than H.S.	3.4	2.0	6.9	4.4	4.9	n/a	4.1
	H.S. Graduate	13.4	24.5	24.1	24.7	16.3		20.6
	Some College	29.7	34.6	31.7	28.7	33.2		31.8
	College Graduate	53.5	38.9	37.2	42.2	45.6		43.5
Total Sample		382	538	290	428	491	7,500	2,129

3.5.2 Survey Results

Tables 7 and 8 summarize the "technical" preference characteristics, and Table 9 provides a listing of the "improved" suggestions for a sign message from Question 8 of the survey. Table 7 shows that a majority of drivers (90 to 95 percent) understand the term and concept of "right of way." Likewise, 70 to 75 percent of the drivers indicated that they are "never" unsure of who has the right of way at a two-way stop-controlled intersection. Approximately 21 to 23 percent of the drivers indicated that they were "sometimes" unsure of who has the right of way at this type of intersection.

Table 8 shows that the overall sample preferred the sign with the legend CROSS TRAFFIC DOES NOT STOP for the word message sign (65 percent), but there was some variance among the states. For example, only 40 percent of the drivers in Mississippi preferred this message while 74 and 86 percent of the drivers from California and Minnesota, respectively, preferred this message. For the symbol sign preference, 63 percent of all drivers surveyed preferred the symbol shown in Figure 7(*f*); 84 percent preferred the word/symbol combination sign shown in Figure 7(*i*). The variance among the five states was statistically the same for the symbol sign preference in Question 4, but California and Minnesota drivers again showed statistically higher responses (86 and 95 percent, respectively) for their preference for the word/symbol sign in Question 5. It is worth noting that the preferred word/symbol sign in Question 5 is a combination of the most preferred word message sign and symbol sign in Questions 3 and 4, respectively.

Table 7. Right of Way Characteristics of Survey Sample

QUESTION 1. Right of Way Conditions						
Survey Location & Percent Response						**Question and Responses**
CA	MN	MS	PA	TX	All	Which vehicle at the intersection has the right of way?
0.5	0.0	0.7	1.6	0.6	0.7	Neither Vehicle
0.0	0.2	0.3	0.2	0.0	0.1	Both Vehicles
6.0	1.7	3.1	1.4	3.3	3.0	Vehicle A
93.5	98.1	95.5	94.5	95.9	96.1	***Vehicle B***
0.0	0.0	0.3	0.2	0.2	0.1	Not Sure
382	538	290	428	491	2,129	Sample Size
QUESTION 2. How often are you unsure of who has to stop?						
CA	MN	MS	PA	TX	All	At an intersection like this, how often are you unsure of who has to stop?
73.8	72.9	74.6	69.4	70.4	72.0	Never
21.1	21.9	20.9	23.1	22.2	21.9	Sometimes
5.1	5.2	4.6	7.5	7.4	6.1	Always
370	534	283	425	490	2,102	Sample Size

As a follow-up question to Questions 3, 4, and 5, the survey participants were asked to choose the most preferred sign out of the three they previously selected. The results indicated that 58 percent of all drivers preferred the word/symbol combination sign over the word sign (37 percent) and symbol sign (5 percent) previously chosen. The results among the states were similar as well, except for equally high preferences by the Mississippi drivers for the word message and word/symbol message signs.

The final multiple-choice "technical" question pertained to the necessity of a sign in addition to the STOP sign to communicate the right of way conditions at a two-way stop-controlled intersection. Approximately 50 percent of the overall sample indicated "NO," that an additional sign was *not* necessary, while 44 percent indicated "YES" and 6 percent indicated "*Not Sure*." Similar statistical differences existed among the results in California, Mississippi, and Pennsylvania. Drivers in Minnesota and Texas, however, were evenly split between the "YES/NO" response.

Table 8. Sign Message Preferences from Survey Sample

QUESTION 3. Which WORD SIGN is more effective?						
CA	MN	MS	PA	TX	All	If you are in Vehicle A, which WORD SIGN best tells you that Vehicle B has the right of way?
12.4	6.6	21.2	20.1	20.1	15.5	Route 59 Does Not Stop
13.7	7.4	38.9	24.1	20.6	19.2	2-Way
74.0	86.0	39.9	55.8	59.2	65.4	Cross Traffic Does Not Stop
380	542	288	428	491	2,129	Sample Size
QUESTION 4. Which SYMBOL SIGN is more effective?						
CA	MN	MS	PA	TX	All	If you are in Vehicle A, which SYMBOL SIGN best tells you that Vehicle B has the right of way?
22.2	22.8	27.1	28.3	24.7	24.8	A
11.4	12.0	13.9	13.4	13.0	12.6	B
66.5	65.2	59.0	58.3	62.3	62.6	C
370	526	288	410	478	2,072	Sample Size
QUESTION 5. Which WORD/SYMBOL SIGN is more effective?						
CA	MN	MS	PA	TX	All	If you are in Vehicle A, which WORD/SYMBOL SIGN best tells you that Vehicle B has the right of way?
10.5	3.1	18.0	15.4	12.8	11.2	A
3.7	1.5	11.4	5.0	5.3	4.8	B
85.8	95.4	70.6	79.7	81.9	84.1	C
380	542	289	423	491	2,125	Sample Size
QUESTION 6. Which sign type is preferred?						
CA	MN	MS	PA	TX	All	Of the signs chosen in the previous three questions, which **ONE** do you prefer the most?
30.9	37.2	46.8	36.3	38.4	37.5	Question 3
3.8	2.4	5.3	6.6	7.0	5.0	Question 4
65.3	60.3	47.9	57.1	54.6	57.6	Question 5
372	537	282	424	485	2,100	Sample Size
QUESTION 7. Is an additional sign necessary?						
CA	MN	MS	PA	TX	All	Do you think a sign in addition to the STOP sign is needed to tell you that **Vehicle B** has the right of way?
41.1	48.8	40.5	41.6	46.8	44.4	Yes
53.6	45.5	54.2	52.0	48.7	50.1	No
5.3	5.8	5.3	6.4	4.5	5.5	Not Sure
375	539	284	423	489	2,110	Sample Size

3.5.3 Sign Message Suggestions From Survey Sample

The survey participants were asked, based on the intersection drawing in Figure 7, to illustrate a sign to indicate that *Vehicle B* had the right of way (the vehicle on the uncontrolled approach). Of the 2,129 participants, 514 provided an illustration for this question. Approximately 35 percent of these illustrations included the words "cross traffic" in the sign design, in combination with "arrows" and/or with the words "does not stop," "caution," or "has the right of way." Approximately 25 percent of the illustrations contained a message with a plan view of the intersection and/or horizontal, left/right "arrows" indicating the crossing traffic. A summary of the suggestions is provided in Table 9. Numerous "creative" designs were illustrated by the participants, but many were impractical from an implementation standpoint. Such messages as STOP HERE NOW, GO SLOWLY, GIVE WAY, BEWARE, and ENTER AT YOUR OWN RISK were some of the many messages classified under "miscellaneous."

Table 9. Supplemental Sign Message Suggestions

Supplemental Sign Suggestion	Frequency	Percentage
CROSS TRAFFIC DOES NOT STOP (w/arrows)	53	10%
CROSS TRAFFIC DOES NOT STOP	45	9%
Intersection Drawing and/or Arrows	41	8%
CROSS TRAFFIC HAS RIGHT OF WAY	38	7%
2-WAY	30	6%
YIELD TO CROSS TRAFFIC	22	4%
Flashing lights/beacons	20	4%
STOP 2-WAY/ CROSS TRAFFIC	15	3%
LOOK BOTH WAYS	14	3%
ROUTE 59 DOES NOT STOP/ RIGHT OF WAY	13	3%
THRU TRAFFIC	12	2%
CAUTION CROSS TRAFFIC DOES NOT STOP	11	2%
WATCH FOR CROSS TRAFFIC	11	2%
NOT 4 WAY STOP/ NO 4 WAY STOP	9	2%
CAUTION CROSS TRAFFIC DOES NOT STOP (w/arrows)	8	2%
DANGER	8	2%
PROCEED WITH CAUTION/ WHEN CLEAR	7	1%
YIELD (others)	7	1%
WARNING	6	1%
Other Miscellaneous	144	28%
TOTAL	514	100%

3.6 SURVEY CONCLUSIONS

The survey results indicated that, if supplemental signs are used at TWSC intersections, most drivers understand and prefer the design with the message CROSS TRAFFIC DOES NOT STOP with a double-headed, horizontal "arrow." This design is shown in Figure 9. However, approximately half of the drivers believed that an additional sign at such an intersection is not necessary in conveying the right of way conditions. This conclusion may be based on the driver's perception that too many signs already exist and that drivers should accept the responsibility in determining the right of way conditions at a TWSC intersection. In other words, a STOP sign means "to stop and then proceed when it is safe to do so." The question was also asked with respect to *all* two-way stop-controlled intersections; the survey participants, much like the traffic engineers who participated in the previous surveys (see Chapter 2), more than likely recognize that supplemental signs are not necessary at all locations, but only at certain intersections where they may be confused about the right of way conditions.

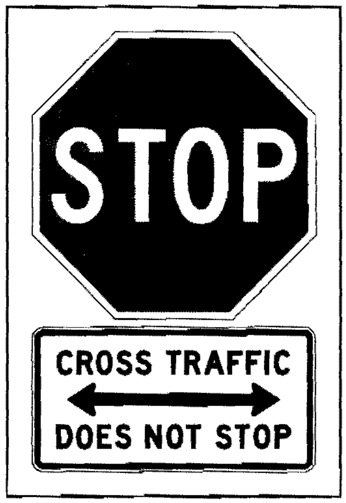


Figure 9. Most Preferred Supplemental Sign

Further study of the supplemental sign was conducted for this project. The results of the sign preference evaluation were used in developing a survey instrument to evaluate driver behavior at TWSC intersections. The driver behavior survey is discussed in Chapter 4.

4.0 DRIVER ASSESSMENT OF RIGHT OF WAY

The purpose of this evaluation was to determine the effectiveness of current and proposed traffic control devices used at two-way stop-controlled intersections to inform drivers of right of way conditions. In particular, this survey examined driver understanding of right of way conditions of four traffic control treatments at such an intersection: a STOP sign alone; a STOP sign with beacons; a STOP sign with stop bar pavement markings; and a STOP sign with a supplemental CROSS TRAFFIC DOES NOT STOP sign.

A video survey of the four traffic control treatments was developed and administered to 436 participants at selected Department of Public Safety (DPS) locations in Texas. Each survey participant was given only one of the four treatments to view and upon completion was asked to answer a few questions pertaining to the right of way conditions at the intersection. Each video scenario was 90 seconds long and was filmed from the perspective of a driver approaching a TWSC intersection.

4.1 SURVEY OBJECTIVE

The objective of this survey was to evaluate driver understanding of right of way conditions and their response to the traffic control devices and other visual cues at a TWSC intersection. To achieve the objectives, the following tasks were conducted:

- Establish TWSC treatments (scenarios), specifically:
  1) STOP sign with overhead flashing beacons;
  2) STOP sign with a stop bar;
  3) STOP sign alone; and
  4) STOP sign with a supplemental sign mounted below with the legend CROSS TRAFFIC DOES NOT STOP;
- Evaluate driver understanding of right of way conditions for each scenario through a video survey instrument; and
- Summarize the survey data.

4.2 SURVEY METHODOLOGY

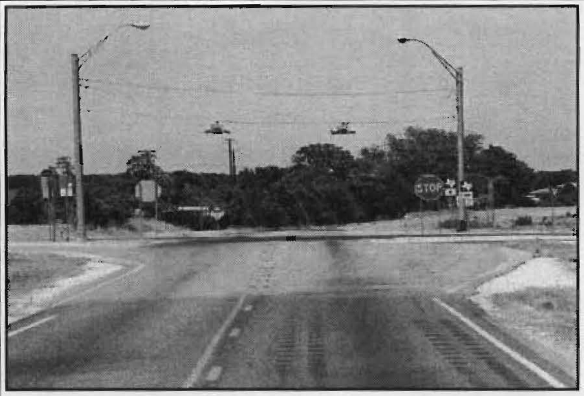
A video survey was developed that depicted a "driver" approaching a TWSC intersection. The survey participant viewing the video was asked to play the role of the "driver" and to answer questions pertaining to the right of way conditions at the intersection.

The first task was to establish the traffic control treatments to evaluate at a TWSC intersection. Since the MUTCD (*1*) does not provide any specific treatments at a TWSC intersection other than either a STOP sign or a STOP sign and a stop bar for each stop-controlled approach, these two scenarios were chosen for evaluation. Where volume or accident warrants may indicate, overhead flashing intersection control beacons may also be used. This scenario was also chosen for evaluation. In previous surveys, the use of certain supplemental signs below a STOP sign was shown to improve driver understanding of right of way conditions at TWSC intersections. Therefore, the fourth and final scenario included the use of a supplemental sign below the STOP sign. Figure 10 depicts the four scenarios.

The supplemental sign chosen for Scenario 4 was based on the results of the three mail-out surveys previously discussed in Chapters 2 and 3. Two of the surveys sent to Texas and state DOT traffic engineers showed that a majority of supplemental sign designs currently in use at TWSC intersections were rectangular-shaped, mounted below the STOP sign, and contained a black legend on either a white or yellow background (see Chapter 2). A mail-out survey sent to drivers in five U.S. states resulted in a preferred supplemental sign message with the legend CROSS TRAFFIC DOES NOT STOP and a horizontal "arrow" symbol (see Chapter 3). Thus, the supplemental sign design chosen for Scenario 4 was a rectangular-shaped sign with the legend CROSS TRAFFIC DOES NOT STOP and "arrow" symbol. The research team and the Advisory Panel decided to experiment with the black legend on a yellow high-intensity sheeting background. The design of this sign, which was manufactured by the TxDOT Waco District for this study, is shown in Figure 11. The design was adapted from the California *Traffic Manual* (*5*). A 600-mm (24-inch) by 1200-mm (48-inch) sign design was chosen to maximize the size of the 100-mm (4-inch) letters in the sign legend.

4.3 SURVEY INSTRUMENT DESIGN

A video survey instrument was developed to evaluate driver understanding of different traffic control devices used at TWSC intersections. The video consisted of four scenarios, each 90 seconds in length, taped from a driver's perspective as a vehicle traveled toward a TWSC intersection. The video showed the traffic control devices (i.e., STOP sign, stop bar, beacons, etc.) as the vehicle approached the intersection. The video then panned left and right, simulating the looking behavior of a driver checking for traffic. While panning left, the video showed a white-colored vehicle approaching from a distance; however, a person viewing the video who is unfamiliar with the project would not be able to determine if the approaching vehicle would stop or not. The intent was to force the person viewing the video to make a decision based only on what was *perceived* in the video. This decision was ascertained through the administration of prepared questions after viewing the video.



SCENARIO 1
(Survey Set A)

Condition: 1200-mm (48-inch) STOP Sign with Overhead Flashing Beacons

SCENARIO 2
(Survey Set B)

Condition: Existing conditions with 1200-mm (48-inch) STOP sign and stop bar.

SCENARIO 3
(Survey Set C)

Condition: 1200-mm (48-inch) STOP sign alone with stop bars covered on each approach.

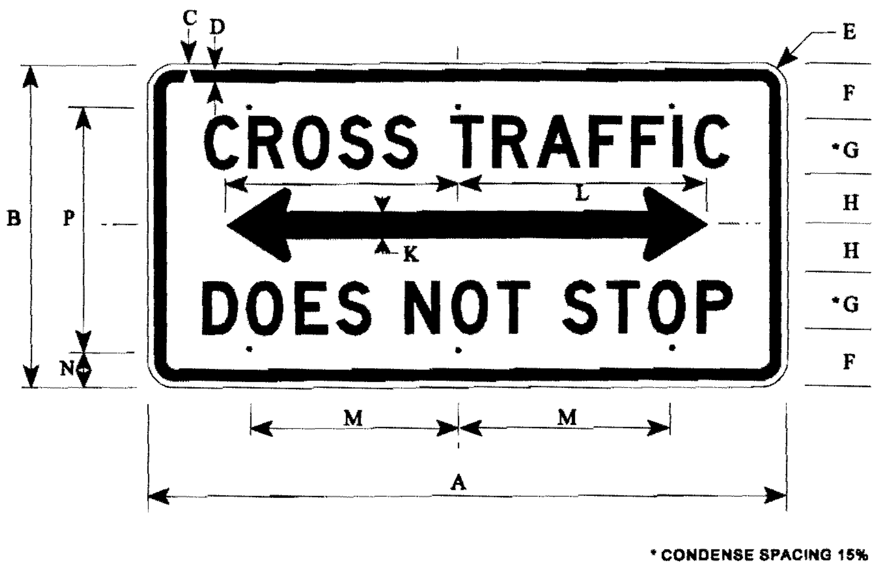
Note: Stop bars uncovered after study.

SCENARIO 4
(Survey Set D)

Condition: 1200-mm (48-inch) STOP sign with CROSS TRAFFIC DOES NOT STOP sign mounted below (no stop bars).

Note: Sign removed after study.

Figure 10. Four Intersection Scenarios Evaluated in Driver Behavior Survey



Sign	Dimensions (Inches)													
	A	B	C	D	E	F	G	H	J	K	L	M	N	P
Special	36	18	3/8	5/8	1½	3	3D	3	3½	1½	13½	-	2½	13
Special	48	24	3/8	5/8	1½	4	4D	4	5¼	2	18	16	3	20

COLORS
BORDER, LEGEND & SYMBOL - BLACK
BACKGROUND - YELLOW (Refl)

Figure 11. Supplemental Sign Design Used for Scenario 4

4.3.1 Site Selection for Video Shoot

In the next procedure, one site was selected for filming the two-way stop-controlled intersection with beacons (Scenario 1) and a similar site was chosen for filming the remaining three scenarios. The first site was at the intersection of Farm-to-Market Road (FM) 2818 and FM 1687 near Bryan, Texas. The second site was at the intersection of FM 391 and FM 2549 near Hearne, Texas. This second site had an existing STOP sign and a stop bar on each stop-controlled approach; therefore, the existing conditions were used for the third scenario. For the second scenario, only a STOP sign was desired at each stop-controlled approach; therefore, the stop bars were covered. For the fourth and last scenario, the supplemental CROSS TRAFFIC DOES NOT STOP sign was attached below the STOP sign (and subsequently removed upon completion of the study).

The video was filmed from a convertible vehicle with the assistance of a TTI camera crew. Traffic control personnel were used to stop traffic from all four directions during videotaping. The camera was placed in the center of the vehicle and the field of view was slightly above the top of the convertible's windshield. When the video was viewed, the field of view approximated a driver's perspective. The goal was to make the video appear as a realistic driving situation.

4.3.2 Survey Questionnaire

The remaining element of the survey instrument was a questionnaire developed for the survey participants to answer upon the completion of watching the video. Three questions were asked that pertained to the participant's understanding of the right of way conditions at the intersection shown in the video. The three questions are shown in Figure 12. Question 1 was used as the primary indication of the participant's understanding of the right of way conditions. Question 2 was an open-ended question used by the researchers to determine *why* the participant chose a particular answer in Question 1. Question 3 was treated as supplemental information to Questions 1 and 2 to verify the participant's understanding of the scenario. The wording of each of the questions was carefully considered prior to administering the surveys. The *Texas Drivers' Handbook* (*10*) was referenced for terms that drivers could identify with some familiarity.

VIDEO SURVEY

1. If the white car doesn't turn off, will it hit you? (please check ✓ only one answer)
   - ❑ No
   - ❑ Yes
   - ❑ Not sure

2. What led you to this conclusion? (please **print** your answer)

   ____

   ____

   ____

3. How many roadway directions have to stop? (please check ✓ only one answer)
   - ❑ One
   - ❑ Two
   - ❑ Three
   - ❑ Four
   - ❑ Not sure

Figure 12. Survey Questions Pertaining to Right of Way Conditions

4.4 SURVEY ADMINISTRATION

The survey was administered at selected Texas Department of Public Safety (DPS) locations in Houston, Lufkin, Temple, and Waco. Approximately 100 surveys per scenario (400 total) were anticipated for statistical purposes. The total number of surveys administered was 436. Typical participants were patrons waiting in line to renew their license, patrons waiting for their turn to take a driving test, and persons waiting on a family member or friend.

Prior to taking the survey, each participant was instructed with the following information:

> "You are going to watch a video. Pretend you are driving the car you see in the video. As you are driving along, you will approach an intersection. When you get to the intersection, you will see a white car approaching from the left side."

Each participant was given only one scenario to view and then was asked to answer seven questions. The first three questions, shown in Figure 12 above (two multiple-choice and one open-ended essay-type question), were specifically related to the right of way conditions at the intersection shown in the video. The remaining four questions inquired about demographic information such as age, gender, years of driving experience, and educational background. A copy of the complete survey is provided in Appendix B. Completing the survey, including watching the video, took approximately five minutes. Each survey participant was compensated for their time with a free Texas highway travel map.

4.5 DISCUSSION OF RESULTS

A sample size of 400 was desired for the survey (100 per scenario), and 436 drivers actually participated. The drivers represented a diverse sample of age, ethnicity, educational background, and driving environments.

4.5.1 Survey Demographics

Table 10 summarizes the demographic characteristics of the sample of participants, as well as the statewide characteristics for the general population and driving population for some categories. A majority of the participating drivers were Anglos between the ages of 25 and 54.

4.5.2 Categorical Analysis

The first step in the data analysis involved categorizing the answers of the first three questions to determine why participants chose particular answers. Because Question 2 was open-ended and important in establishing the reason for their answer to Question 1, each survey was individually examined and several categories were established for similar answers. The following information in Table 11 identifies the 11 categories that were established *after* individually reviewing all survey responses.

A "YES" answer to Question 1 indicated that the driver understood the right of way conditions at the intersection. A "NO" answer indicated that the driver was mistaken about the right of way conditions. A "NOT SURE" answer indicated that the participant was unsure either because of his/her lack of attention while watching the video or that limitations of the video did not allow him/her to make a judgement.

In addition, demographic data was analyzed to compare driver comprehension level among the different age groups, years of driving experience, family background, metropolitan area, and educational background.

Table 10. Demographic Characteristics of Driver Behavior Evaluation

Characteristics		Survey		Texas Population	
		Number	Percent	General	Driving
Gender	Male	205	47.0	49.3	51.5
	Female	231	53.0	50.7	48.5
Age	Less than 25	120	27.5	18.9	15.2
	25 to 54	248	56.9	57.4	62.4
	55 to 65	31	7.1	10.2	10.4
	Over 65	37	8.5	13.6	12.0
Years Driving	Less than 1 year	29	6.7		
	1 to 5 years	79	18.3		
	6 to 50 years	299	69.4		
	More than 50 years	24	5.6		
Ethnicity	African-American (Black)	43	9.9	11.6	
	Anglo (White)	307	70.6	60.6	
	Asian	17	3.9		
	Hispanic	57	13.1	25.6	
	Other	11	2.5	2.2	
Education	Less Than High School	50	11.5	28.1	
	High School Graduate	134	30.7	25.9	
	Some College	138	31.7	27.8	
	College Graduate	114	26.1	18.1	
Total Sample		436	100		

4.5.3 Statistical Analysis

Once the data was categorized, the standard normal *z-test* was used to statistically analyze the results. A precision level for each category was established for a 90 percent confidence interval; an increase in the response percentage and sample size increased the precision for that response. The level of precision for each category is provided in the "Survey Results" section of this chapter.

Table 11. Categories of Answers to Survey Questions 1, 2, and 3

Question 1 Response	Question 2 & 3 Categorized Response	Category Explanation
Yes	STOP Sign	Driver indicated that the intersection was a two-way STOP because he/she had a STOP sign and the crossing roadway did not have one.
	Two-Way Implied	Driver did not specifically mention that the intersection was a two-way STOP, but by his response, he understood the traffic control conditions.
	Supplemental Sign	Driver indicated that the other vehicle had the right of way because of the presence of the supplemental sign below the STOP sign.
	Speed/Distance	Driver indicated that because of the high speed and/or short distance of the approaching vehicle, he knew it was a two-way STOP.
	Other	Other miscellaneous responses
No	Speed/Distance	Driver indicated that because of the speed and/or distance of the approaching vehicle, it was going to stop at the intersection (incorrect assumption).
	Four-Way Stop	Driver assumed the intersection was a four-way STOP (incorrect assumption).
	Other	Other miscellaneous responses.
Not Sure	Speed/Distance	Driver was unsure of the right of way conditions because of the uncertainty of the speed and/or distance of the approaching vehicle.
	Two-Way Stop	Driver indicated that even though he understood the intersection was a two-way STOP (directly or indirectly), he was unsure if the approaching vehicle would collide with him.
	Four-Way Stop	Driver indicated that the intersection was a four-way stop but was unsure if the approaching vehicle would collide with him.

4.5.4 Survey Results

The overall survey results for each of the categories previously established are provided in Table 12. With the assumption that "YES, the car will hit you" (Question 1) is the correct survey response, Set D (with the supplemental CROSS TRAFFIC DOES NOT STOP sign) demonstrated higher correct response rates over all other sets, with statistical significance over Sets A and B. The statistical significance suggests that the supplemental sign provides a higher level of understanding of the right of way conditions at a TWSC intersection. An important finding that supports this notion was the fact that no drivers who participated in Set D misunderstood the intersection to be four-way stop-controlled, and Set D demonstrated the lowest percentage (statistically significant) of "NO" and "NOT SURE" answers when compared to the other three scenarios.

Table 12. Participants' Responses to Right of Way Questions

Question 1 (Answer)	Question 2 & 3 (Categorized)	Survey Set (Percent Responding)			
		A (Beacon)	B (Stop bar)	C (STOP sign)	D (Suppl. Sign)
YES	STOP Sign	25.7	35.2	43.9	22.2
	2-Way Implied	21.2	19.4	15.0	24.1
	Suppl. Sign	0.0	0.0	0.0	27.8
	Speed/Distance	22.1	16.7	15.0	12.0
	Other	2.7	4.6	5.6	2.8
NO	Four-Way Stop	6.2	7.4	3.7	0.0
	Speed/Distance	9.7	3.7	1.9	2.8
	Other	0.9	0.9	0.9	2.8
NOT SURE	Two-Way Stop	5.3	7.4	6.5	2.8
	Four-Way Stop	3.5	2.8	4.7	0.9
	Speed/Distance	2.7	0.5	2.8	1.9

Notes: Question 1: If the white car does not turn off, will it hit you? Correct Answer - Yes.
Question 2: What led you to this conclusion? (See Table 11).
Question 3: How may roadway directions have to stop? (See Table 11).

The scenario with beacons (Set A) scored the poorest among all scenarios. The intersection chosen for this scenario was geometrically a high-type intersection (shoulders, turn bays) and survey participants may have had more difficulty understanding the traffic control conditions at this intersection as compared to the low-type intersection (isolated, two-lane, no shoulders) used for the other three scenarios.

Results of drivers in the four age groups and years of driving experience are presented in Tables 13 and 14. Drivers in the "Over 65" age group and "Over 50" years driving group had lower correct response rates and were more unsure about the right of way conditions than the other age/driving groups. The uncertainty could be due to the diminished mental alertness and slower reaction of older drivers.

There is no statistically significant difference found between ethnicity and comprehension level, as shown in Table 15. The "Hispanic" group did score lower than the other groups, likely due to a small percentage of the Hispanic participants not being fluent in the English language. Because of the significant proportion of Hispanic drivers in Texas and of drivers that speak Spanish as their primary language, a Spanish-version of the questionnaire would have been beneficial.

Table 13. Survey Response Rates with Respect to Survey Set and Age

ANSWER	SURVEY SET (% Responding)				AGE (% Responding)			
	A	B	C	D	Less than 25	25 to 54	55 to 65	Over 65
YES	71.7	76.0	79.5	88.8	80.8	81.0	74.2	62.2
NO	16.8	12.0	6.5	5.6	10.8	7.7	16.1	21.6
NOT SURE	11.5	12.0	14.0	5.6	8.4	11.3	9.7	16.2
Sample Size	113	108	107	108	120	248	31	37
% Precision	±7.0	±6.8	±6.4	±5.0	±5.9	± 4.1	±12.9	±13.1

Table 14. Survey Response Rates with Respect to Survey Set and Years Driving

ANSWER	SURVEY SET (% Responding)				YEARS DRIVING (% Responding)			
	A	B	C	D	Less than 1	1 to 5	6 to 50	Over 50
YES	71.7	76.0	79.5	88.8	82.8	78.5	80.9	58.3
NO	16.8	12.0	6.5	5.6	13.8	10.1	9.4	16.7
NOT SURE	11.5	12.0	14.0	5.6	3.4	11.4	9.7	25.0
Sample Size	113	108	107	108	29	79	299	24
% Precision	±7.0	±6.8	±6.4	±5.0	±11.5	±4.6	±3.7	±16.6

Table 15. Survey Response Rates with Respect to Survey Set and Ethnicity

ANSWER	SURVEY SET (% Responding)				ETHNICITY (% Responding)				
	A	B	C	D	Anglo (White)	African-American	Asian	Hispanic	Other
YES	71.7	76.0	79.5	88.8	78.8	83.7	88.2	73.7	81.8
NO	16.8	12.0	6.5	5.6	9.1	9.3	11.8	15.8	9.1
NOT SURE	11.5	12.0	14.0	5.6	12.1	7.0	0.0	10.5	9.1
Sample Size	113	108	107	108	307	43	17	57	11
% Precision	±7.0	±6.8	±6.4	±5.0	±3.8	±9.3	±12.9	±9.6	±19.1

In comparison between educational background and comprehension level, the results in Table 16 indicate that the correct response rates for the educational level of less than high school, high school or equivalent, some college, and college graduate were 78 percent, 78 percent, 83 percent, and 75 percent, respectively. One might expect survey participants with a higher educational background to have a higher correct response rate. People, however, are often not completely honest about their educational background in such a survey. No statistical difference existed among the four educational groups and no conclusive results can be drawn from this data.

Table 17 shows participants in Houston and Waco had lower correct response rates than participants in Lufkin and Temple. The traffic conditions and traffic control designs for larger cities and towns such as Houston and Waco are different from those of the smaller towns like Lufkin and Temple. The TWSC intersection portrayed in the video survey was a rural intersection; therefore, rural drivers in Lufkin and Temple might have been more familiar with such an intersection and would appear to have a higher comprehension level than the urban drivers.

Table 16. Survey Response Rates with Respect to Survey Set and Education

ANSWER	SURVEY SET (% Responding)				EDUCATION (% Responding)			
	A	B	C	D	Less than High School	High School or Equivalent	Some College	College Graduate
YES	71.7	76.0	79.5	88.8	78.0	77.6	83.3	75.4
NO	16.8	12.0	6.5	5.6	10.0	11.9	8.7	10.5
NOT SURE	11.5	12.0	14.0	5.6	12.0	10.5	8.0	14.1
Sample Size	113	108	107	108	50	134	138	114
% Precision	±7.0	±6.8	±6.4	±5.0	±9.6	±5.9	±5.2	±6.6

Table 17. Survey Response Rates with Respect to Survey Set and Metropolitan Area

ANSWER	SURVEY SET (% Responding)				METROPOLITAN AREA (Population) (% Responding)			
	A	B	C	D	Houston (1,600,000)	Lufkin (30,000)	Temple (50,000)	Waco (110,000)
Yes	71.7	76.0	79.5	88.8	77.0	85.5	83.5	73.4
	16.8	12.0	6.5	5.6	12.9	2.6	7.2	14.5
	11.5	12.0	14.0	5.6	10.1	11.9	9.3	12.1
Sample Size	113	108	107	108	139	76	97	124
% Precision	±7.0	±6.8	±6.4	±5.0	±5.9	±6.6	±6.2	±6.5

4.6 LIMITATIONS OF BEHAVIOR EVALUATION

The discussion of the results would not be complete without considering the limitations of this behavior evaluation. An ideal method of conducting this research would be to have each participant actually drive through a setup course and approach an intersection such as the one portrayed in the video. Since neither funding nor time permitted such an evaluation, the purpose of a video survey of this type was to simulate, as close as possible, the real world driving condition and to collect a statistically sufficient amount of data. The main limitation in this research was that the video can simulate but not duplicate exact real world driving conditions. For example, the video camera's panning action is much slower than the actual human eye movements of the driver scanning for traffic. The camera's view is also limited and cannot exactly simulate the wide range of peripheral vision of a driver.

4.7 SURVEY CONCLUSIONS

The primary objective of this survey was to evaluate driver understanding of existing and proposed traffic control devices at TWSC intersections and to evaluate the types of driver visual cues that are present at an intersection. A review of the survey participants' answers and open-ended responses revealed a list of specific visual cues that drivers recognize at an intersection to assist them in understanding the right of way conditions. Table 11 presents these cues, or reasons, that were indicated by the participants. The "STOP sign" category pertains to those participants that indicated that they understood the right of way conditions by first observing the presence of a STOP sign. The "Two-Way Implied" category represents those participants who understood the right of way conditions by indirectly stating it was a two-way stop because the major street did not have STOP signs or that they were only required to proceed when no vehicles were approaching on the major street. The "Supplemental Sign" category pertains to the participants who indicated that the CROSS TRAFFIC DOES NOT STOP sign is what led them to understand the right of way conditions. The "Speed/Distance" category pertains to the participants who indicated that the speed (and/or distance) of the white, crossing vehicle was too fast or slow (and/or was too close or too far away) to hit them if they proceeded into the intersection.

Many drivers were able to recognize the supplemental CROSS TRAFFIC DOES NOT STOP sign (in Scenario 4) and its implication to the right of way condition at the TWSC intersection. With a correct response rate of 89 percent to "YES the car will hit you," this visual cue had the highest driver understanding of the right of way condition in comparison to the remaining three scenarios. Thus, the survey results indicated that the use of the STOP sign with the supplemental CROSS TRAFFIC DOES NOT STOP sign was the most effective treatment, as compared to the other alternatives, in explaining the right of way conditions that were present.

5.0 TRAFFIC CONFLICT STUDIES

An attempt was made to observe and quantify driver performance at two-way stop-controlled intersections through a series of pilot field studies. Six TWSC intersections, both with and without supplemental signs, were chosen through a selection process consisting of surveys and phone calls to TxDOT engineers and site visits. Due to the limited amount of documented research of driver behavior at TWSC intersections, the entire data collection and reduction process was largely experimental in nature.

5.1 STUDY OBJECTIVES

The original objective of the pilot field studies was to observe driver performance with respect to different supplemental sign shapes, colors, and legend contents. This objective, however, was determined to be infeasible due to the difficulty of quantifying performance differences between signs. The pilot field studies were modified to observe driver behavior at six TWSC intersections, three intersections with no supplemental signs ("control" sites) and three intersections with supplemental signs ("study" sites). The supplemental sign commonly used in Texas was found to be rectangular-shaped with a black legend CROSS TRAFFIC DOES NOT STOP message on a yellow or white background (see Chapter 2). This sign was found to be generally mounted below the STOP sign, but other sign locations exist, including next to the STOP sign (Waco District), on the opposite intersection quadrant of the STOP sign (Tyler District), and above the roadway in advance of the STOP sign (Yoakum District).

5.2 MEASURES OF EFFECTIVENESS

Two measures of effectiveness (MOEs) were identified in the proposal: erratic vehicle maneuvers and driver looking behavior. To evaluate these MOEs, two portable telescoping pole units were utilized that allowed video surveillance from an elevated position. The telescoping poles could be raised to a height of nine meters with an 8-mm video camera mounted on top, producing a complete view of all four intersection approaches with one camera. This point-of-view was thought to be optimal for viewing erratic maneuvers at TWSC intersections. Erratic maneuvers were classified as traffic conflicts, a technique already developed by previous research and described in subsequent sections. A ground-mounted camera was required to view driver looking behavior since drivers could not be seen at the distance and elevation of the telescoping pole unit. Driver looking behavior was defined as the head movements to the left and right made by a driver checking for an available gap in the major-street traffic. In the initial stages of developing this data collection technique, the ground-mounted camera was positioned on the opposite stop-controlled approach of vehicles under observation.

5.3 BACKGROUND

The following sections document the procedure in which the appropriate data collection technique was developed, the pilot field studies were conducted, and the data were quantified. To explain the data collection technique, a brief introduction to the concept of traffic conflicts and the standard method of classifying and quantifying conflict data is provided in the following section. The methodology employed to select site locations and conduct the field studies is documented next. A discussion of the results is presented followed by the conclusions drawn from both the data and the effectiveness of this technique for the purposes of this project. Finally, recommendations are made regarding the potential factors that influence safety and driver performance at the six sites included in the field study.

5.3.1 Traffic Conflict Studies

Erratic maneuvers observed at the study sites were classified as traffic conflicts. Traffic conflict studies have been identified by both the Federal Highway Administration and the Institute of Transportation Engineers (ITE) as an effective surrogate measure of traffic safety *(11, 12)*. This measure was determined to be the most feasible means of quantifying driver performance and intersection safety at the study sites. A traffic conflict study is an observation of the interaction of vehicles at a specific location over a period of time ranging from a few hours to a few days. Guidelines for conducting conflict studies at intersections are outlined in *Traffic Conflict Techniques for Safety and Operations*, published in January 1989 by the FHWA *(11)*. The manual represents the most current and practical guide in the United States regarding the appropriate use of conflict studies, data collection procedures, and analysis of the results. The FHWA manual was the basis for the procedures developed for the pilot field studies. A traffic conflict is defined as follows:

> *"A traffic conflict is an event involving the interaction of two or more road users, usually motor vehicles, where one or both drivers take evasive action such as braking or weaving to avoid a collision (11)."*

Fourteen intersection conflict situations are possible, but only six of these types are relevant to this project. The relevant conflicts are those in which an action by a vehicle on the minor-street (stop-controlled) approach causes a vehicle on the major-street (non-stopping) approach to perform an evasive maneuver. The six types of conflicts are classified by the relative directions of travel and the turning movement of the vehicle on the minor-street approach. These conflicts are shown graphically in Figure 13. Traditionally, the study is performed by a trained observer(s) stationed along one (or more) of the intersection approaches. The observer determines if a situation can be classified as a conflict and then records the event on a data sheet. The observer only records conflicts on a single approach since he/she is not generally in a position to witness conflicts on other approaches. If only one observer is recording conflicts, he/she alternates between approaches for each observation period.

A possible alternative means of collecting conflict data is to replace the observer with a video camera to record vehicle maneuvers on videotape. The portable telescoping units were found to offer several significant benefits over the traditional technique for the field studies. Unlike the observer-based method, potential conflict situations are identified on the tape by a single technician and then reviewed by several persons to determine if each questionable event should either be labeled as a traffic conflict or omitted from consideration. If an event remains questionable, it can be reviewed repeatedly or a frame-by-frame analysis can be conducted. The video-based method further allows the project engineer(s), who may otherwise only spend a nominal amount of time in the field, to gain more insight into the geometric and operating conditions at the intersection and how these conditions affect the observed conflicts. The observer-based method relies upon on-the-spot judgement; the accuracy of classifications depends on observer training and conflict frequency.

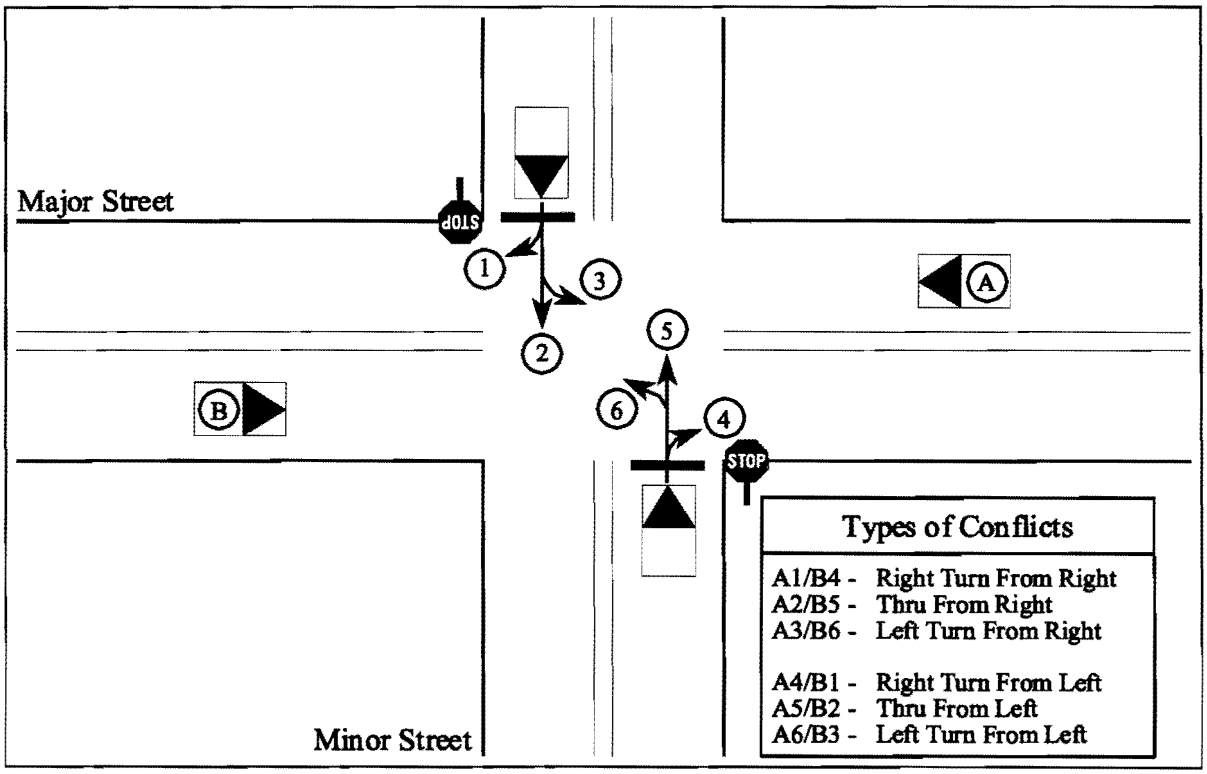


Figure 13. Traffic Conflicts Observed at TWSC Intersections

Additionally, the entire intersection can be viewed continuously by a single observer in the office. In the traditional method, an observer must be positioned on each approach or alternate between approaches. Any conflicts that occur while the observer is viewing another approach or taking a break are missed. The number of conflicts observed on an individual approach before the non-observation period are averaged with the number in the subsequent period to estimate the number of conflicts over a continuous period. Since traffic conflicts of interest for this type of study generally occurred infrequently (zero to two per hour), an estimation during non-observation periods may produce inaccurate values.

5.3.2 Justification for Conducting a Traffic Conflict Study

It is not generally practical to conduct a traffic conflict study at every location. The method may be applicable, however, to "problematic" intersections that have been identified by a high crash frequency, police notification, or citizen complaints (*11*). The FHWA manual notes that a traffic conflict study should be conducted when any of the following conditions exist:

- Crash data indicate the intersection is hazardous, but an analysis of the crash reports does not identify specific causal factors;
- There is a need to determine the effectiveness of corrective action taken at a hazardous intersection without having to wait years before an accident-based evaluation can be conducted; and
- An accident analysis cannot be conducted to identify hazards because the data are either not available or not of an acceptable quality (*11*).

Conversely, traffic conflict studies should not be conducted when any of the following conditions exist:

- During periods of forced flow when congestion creates stop-and-go conditions;
- To justify safety or operational treatments that are not related to an abnormally high conflict pattern. Unless the treatment(s) are implemented to reduce higher than expected daily conflict counts, there is little chance, if any, that a conflict study will indicate that the treatment is warranted; and
- At low-volume intersections where the number of vehicle interactions is limited. While no standards have been developed, a general guideline is when the sum of entering volumes is less than 1,000 vehicles per day (*11*).

Conflict data should be collected when traffic volumes are heaviest, since the frequency of vehicle interaction is increased. Thus, peak morning, midday, and afternoon periods should be included during the times of observation. However, periods of congestion, where stop-and-go conditions exist, should be avoided due to the low vehicle speeds, as noted above. A standard day is defined as the 11-hour period from 7:00 a.m. to 6:00 p.m. Traditionally, observation occurs on weekdays, during daylight hours, and on a dry pavement (*11*).

5.3.3 Time Duration for Conducting a Traffic Conflict Study

The number of hours of observation depends on the types of conflicts applicable to the study, traffic volumes, the traffic control device at the intersection, and the precision required (*11*). Observation time also depends on the level of statistical significance and accuracy desired, the mean number of conflicts per hour, and the variance of the counts, based on previous research. The FHWA manual presents the following equation to estimate the number of observation hours needed to compute the mean number per hour of traffic conflicts of a specific type:

$$n = \left(100\frac{t}{p}\right)^2 \left(\frac{\sigma_e^2}{\bar{Y}^2}\right) \tag{1}$$

where:

n	=	number of hours of observation required;
t	=	statistic from the normal distribution defined by α, the level of significance;
p	=	percent of the hourly mean (e.g., if the hourly mean is 6 conflicts and p is 50 percent, the precision of the estimate is 6 ± 50 percent, or 3 to 9 conflicts per hour);
σ_e^2	=	hourly variance from previous conflict studies; and
$\bar{Y}$	=	hourly mean number of conflicts of a specific type.

5.3.4 Summarizing Conflict Data

The types of conflicts observed depends on the operational problem under investigation; in this study, only cross-traffic conflicts were considered. Once the number of required hours of observation is determined, the data are collected at the site(s). Conflict type and time are recorded as they are witnessed by an observer, or later in the office as they are reviewed on video tape. Conflicts are summarized by approach for each observation period. The conflicts recorded by approach are then summed to produce intersection totals. Conflict types may be combined into a single group if each is an indicator of the operational problem under investigation. For example, each of the six cross-traffic conflict types may result from driver misunderstanding of the right of way conditions at the intersection. The next step is to determine daily conflict counts for the standard 11-hour day which may include several non-observation periods. Conflict frequencies for non-observation periods are estimated by averaging the number of conflicts observed in the period immediately before, with the number observed in the period subsequent to the non-observation time (*11*).

The final step is to determine if the number of observed conflicts represents an abnormally high value. A set of mean conflict values for intersections were established in the mid-1980s by Glauz, et al. (*13*). For that study, 46 intersections were each observed for four standard days. The study sites were categorized according to traffic control (signalized and unsignalized), and traffic volume (low, medium, high). Low volume intersections were designated as locations with 2,500 to 10,000 vehicles per day. The intersection criteria included the following characteristics:

- Four-leg approaches;
- Minimal pedestrian traffic;
- No unusual sight distance restrictions;
- No appreciable grade; and
- No turn restrictions or one-way streets.

Once the mean and variance values for each conflict type were determined, the data set was fit to the gamma probability distribution. Conflict counts were established at the 90th and 95th percentile of the distribution to represent abnormally high values. The classification of an abnormally high conflict count, however, is left to the judgement of the engineer. Table 18 lists the values for each of the six cross-traffic conflict types for the low volume, unsignalized intersection category (*13*).

Table 18. Mean and Abnormal Daily Conflict Counts for TWSC Intersections (*13*)

Total Volume: 2,500 to 10,000 Vehicles Per Day				Abnormally High Conflict Count	
Conflict Type		Mean Conflict Count	Variance	90th Percentile	95th Percentile
1	Right-Turn from Right	5.546	12.1	10.0	12.0
2	Right-Turn from Left	0.567	0.828	*	*
3	Thru from Right	5.228	11.6	10.0	12.0
4	Thru from Left	6.698	42.0	15.0	19.0
5	Left-Turn from Right	4.993	72.7	16.0	23.0
6	Left-Turn from Left	3.366	7.790	7.0	9.0

Note: * Blanks indicate conflict types so rare than any number observed should be considered abnormal.

5.4 STUDY METHODOLOGY

Two MOEs were identified in the proposal to evaluate driver performance: erratic maneuvers and driver looking behavior. The next step was to determine how to quantify these measures and relate them to driver understanding of the right of way condition. The best field measure of erratic maneuvers was found be an observation of traffic conflicts at each of the six TWSC intersections chosen for evaluation. A driver entering the intersection from the minor-street approach who makes the false assumption that vehicles on the major-street approach have to stop, may fail to yield the right of way, and thus cause a conflict. It was found from the TxDOT surveys (see Chapter 2) that supplemental signs are often placed after a series of crashes in which failure to yield right of way is a contributing factor. A crash is basically a conflict in which the vehicle on the major-street approach did not react in time to perform the necessary evasive maneuver (*11*). Therefore, a conflict study was deemed the most appropriate measure of driver performance and intersection safety for this research. Data for the traffic conflict study were to be collected using a portable telescoping pole unit located along the major-street approach. Since conflicts were expected to occur infrequently with relatively long observation times required at each site, video surveillance was expected to improve accuracy while resulting in a feasible data reduction time.

Driver looking behavior was initially included as the second MOE of driver performance and would be quantified by observing the number of head movements made by a driver before his/her vehicle enters the intersection at one of the stop-controlled approaches. These data would be collected using a ground level camera located on the opposite approach, allowing a view of driver head movement as he/she scans for approaching vehicles before entering the intersection. However, due to the difficulty of correlating the data to driver understanding of the right of way conditions, this MOE was not examined further. Increased driver looking behavior was found to be a function of approach volumes, vehicle speeds, desired movement (right, left, or thru) into the intersection, and familiarity with the intersection. No correlation to understanding of right of way conditions could be made by measuring the number of driver head movements made before entering the intersection.

5.5 DATA COLLECTION PROCEDURES

5.5.1 Equipment Testing and Configuration

The camera trailer, with the telescoping mast extended, is shown in Figure 14. This unit was placed at various distances from the intersection to determine the optimal location for recording cross-traffic conflicts. Vehicles on the major-street approach may be traveling at speeds as high as 90 to 100 kilometers per hour and may begin deceleration to avoid an imminent collision as far 75 meters upstream of the intersection. To achieve the wide field-of-view necessary to capture these conflicts, the proper location of the portable telescoping pole unit was determined to be a distance of 90 to 120 meters from the intersection along the major-street approach. The camera trailer was then situated in the clear zone of the right of way. The graphic in Figure 15 illustrates the position of the unit at each study site and the field-of-view obtained by the elevated camera.

The location of the sun was found to influence the camera trailer location since views to the east or west could produce poor video quality. Appropriate countermeasures were taken to prevent this, by ensuring that the vertical field-of-view was just below the horizon and/or by moving the camera to the opposite major-street approach. Other environmental conditions such as rain and wind were not problematic. The equipment was not exposed to these elements since conflict studies are generally conducted only during favorable weather and dry pavement conditions. Analysis of the video quality revealed that it was possible to view vehicle brake lights along one approach. Brake lights, however, cannot be the sole basis for conflict determination because some drivers may intentionally decelerate on intersection approaches. Furthermore, the brake lights for vehicles traveling toward the camera cannot be seen.

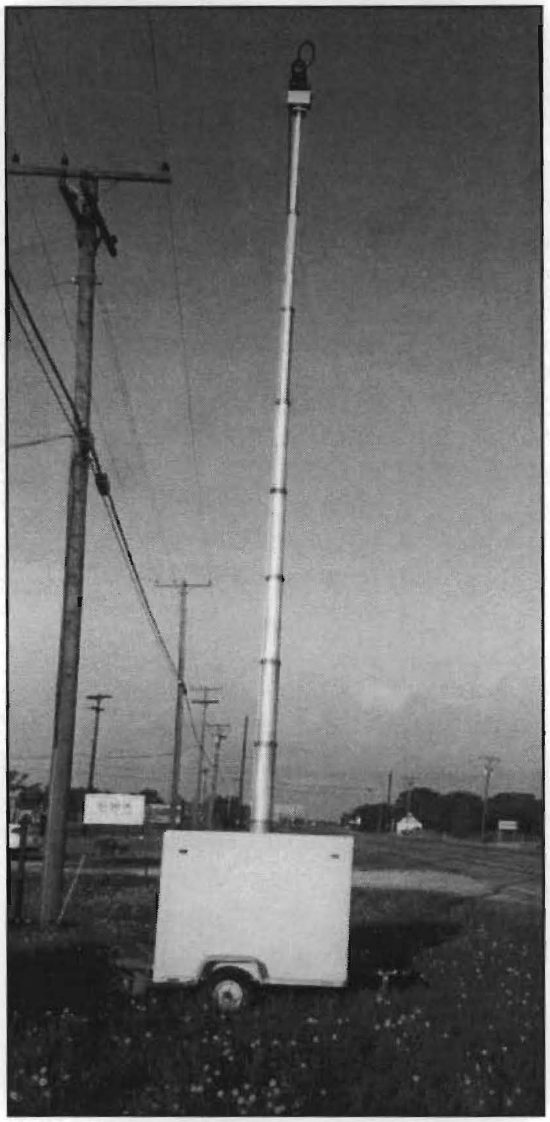


Figure 14. Portable Telescoping Camera Unit

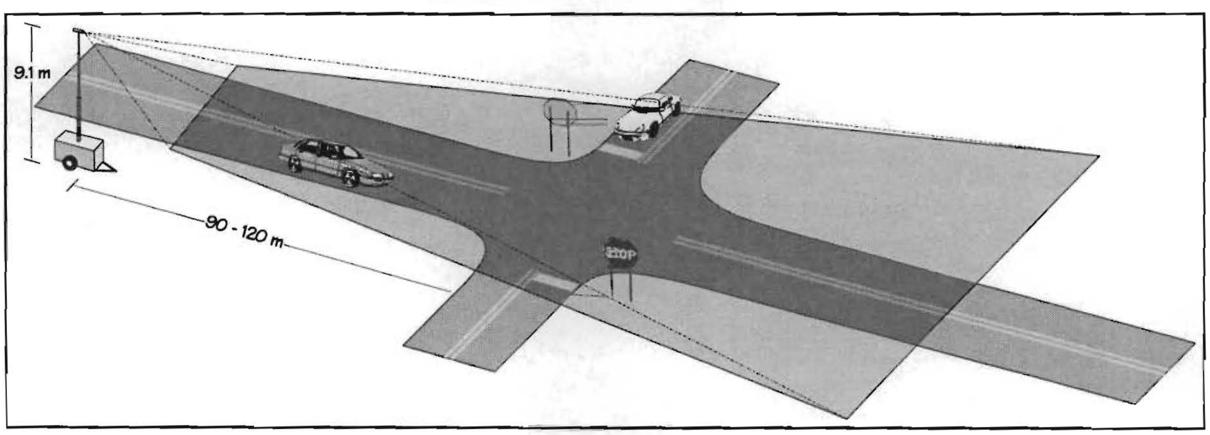


Figure 15. Location of Portable Telescoping Unit and Field-of-View Obtained

5.5.2 Site Criteria and Identification

The first step toward establishing general guidelines for the selection of six study sites was to determine the characteristics of current locations where a supplemental sign had been installed. Researchers would study a maximum of six sites based on the expected amount of observation time at each intersection and the duration of this study. The first potential locations were determined through phone calls to TxDOT traffic engineers. The only criteria were locations where a supplemental treatment had been applied. This guideline was purposely not specific as to geometry or volume in the hopes of acquiring a number of potential sites from this survey. A limited number of sites were obtained in this manner. Several potential locations were received, however, from the Waco, Yoakum, and Lufkin Districts. The camera trailer was taken to a site in the Lufkin District for a four-hour pilot data collection period. The results of this pilot observation enabled the research team to gain insight as to the geometric characteristics and volume levels that would be ideal for the study. These criteria are as follows:

- Intersection of two state roadways, Farm-to-Market (FM) or higher classification;
- Ninety-degree intersection with similar geometry on both roadways (i.e., same number of lanes on each approach);
- 80 kilometer (50 mile) per hour posted speed limit or higher on major-street approach;
- Acceptable sight distance for given approach speeds; and
- The intersection is a perceived high-accident location.

These criteria compare favorably to the intersection characteristics that were prevalent in the traffic conflict research by Glauz, et al. (*13*), described in the previous section. Additional efforts to locate potential study sites involved follow-up correspondence with TxDOT personnel and reviewing traffic volume maps to pinpoint intersections that had the desired approach volumes. Based on the pilot data collection effort in the Lufkin District and previous research from the literature, it was determined that the total intersection average daily traffic (ADT) should be 10,000 to 20,000 vehicles. Further, the ADT should be 5,000 to 10,000 on each of the major-street approaches and 1,500 to 3,000 on the minor-street approaches. Based on volumes and road classification only, several sites were identified in each district. The Area Engineer was contacted to determine the existing traffic control devices present at the intersection of interest. The majority of these intersections consisted of grade separations, signalized intersections, or four-way stop-controlled intersections; a few, however, were found to be TWSC intersections.

The site identification effort generated a list of approximately 15 potential study sites. It was determined that the majority of these intersections had received overhead intersection control beacons; therefore, this criteria was added to the list in an attempt to maximize uniformity between the sites. The next step was to visit each site, determine its suitability based on the above criteria, and observe vehicle interactions for 15 to 20 minutes. From this data, the researchers selected six intersections which best fit the criteria. The intersections chosen for evaluation are listed in Table 19. The table provides the jurisdictional TxDOT jurisdictional TxDOT District, the major and minor streets, and the volume and traffic control characteristics for each site.

Table 19. Location and Characteristics of Pilot Field Study TWSC Intersections

Location				Volume			Traffic Control		
Site/City	TxDOT District	Major Street	Minor Street	Entering Volume (7am-6pm)	% Trucks	1995 ADT	Suppl. Sign	Suppl. Sign Location	Beacons
Control Sites (No Supplemental Signs)									
Hungerford	Yoakum	SH 60	FM 1161	3,681	8	5,300		N/A	✓
Bastrop	Austin	SH 21	FM 812	5,202	8	7,250		N/A	✓
Crockett	Lufkin	Loop 304	FM 2022	4,409	4	5,500		N/A	✓
Study Sites (Supplemental Signs)									
Waco	Waco	Loop 340	FM 3400	9,775	20	12,100	✓	Below	✓
Lorena	Waco	FM 2113	FM 2837	4,942	1	6,500	✓	Below	✓
Port Lavaca	Yoakum	SH 35	FM 2433	4,416	6	5,650	✓	Advance	

Three of the intersections were classified as "control" sites and did not contain any supplemental signs at or near the intersection that indicated the right of way conditions. The remaining three intersections, classified as "study" sites, did have supplemental signs at or near the intersection, as indicated in Table 19. All intersections, except the "study" site in Port Lavaca, contained overhead intersection control beacons.

5.5.3 Data Collection

With the identification of the sites completed, the next phase was to collect data at each location. The number of hours of observation became the final decision before the data were collected at each of the sites. In conformance with the FHWA Manual (*11*), Equation (1) was used to estimate the number of hours of observation required at each site. However, due to the infrequency of the types of conflicts at the volume levels typical of TWSC intersections, the computed number of hours ranged from 10 hours to two weeks. This amount of observation time was not feasible due to the short duration of this project. Therefore, the data collection time was planned to encompass one standard day (7:00 a.m.-6:00 p.m.) at each of the sites. One standard day containing each of the peak periods was thought to provide the research team a basic insight to the operational characteristics of the intersection and prevalent types of conflicts. The actual statistical significance of the data would be noted with the results. Data were only to be collected on either Tuesday, Wednesday, or Thursday under favorable weather and dry pavement conditions. Additionally, turning-movement counts would be performed for comparative purposes for each of the study sites.

A typical one-day period of data collection proceeded in the following manner: the technicians arrived at the site at approximately 6:40 a.m. so that the equipment could be set up and operating by 7:00 a.m. A site along the major-street approach in the right-of-way was chosen for the trailer camera location. This location depended upon the width and topography of the clear zone, the location of residential property near the intersection, and, as noted above, the location of the sun. Once the location for the portable telescoping unit was established, the crew mounted the camera on the mast and extended the pole to its maximum height of nine meters. A ground-level TV monitor was used to allow camera adjustment and appropriate field-of-view.

Technicians were instructed to perform turning movement counts with a digital counter with a category reserved for trucks. Passenger car and truck volume counts are included in Appendix C. The field crew was also instructed to identify potential conflicts and note the time, vehicle descriptions, and respective turning or through movements. During break or lunch periods, a member of the crew would walk into the camera picture and signal to denote a break in the count. Later in the office, the technician viewing the video could perform the counts for the periods missed in the field. The power source for all equipment was a 3500-watt portable gas generator that required refueling near midday. At 6:00 p.m., the observation period ended and the technicians removed the equipment from the site and traveled to the next location.

5.5.4 Data Reduction

Data reduction occurred in the office where a technician was assigned to observe traffic conflicts recorded on videotape. Any situation that may be defined as a conflict was recorded by time, involved vehicles, direction of travel, and turning movement. The 11 hours of data could be reduced in five to six hours by playing the tape back at two to three times normal speed. As potential conflicts were observed, the tape could be replayed at slower speeds for verification that a conflict occurred. The possible conflict times recorded in the field were given special attention while the tape was reviewed. It should be noted that the technicians were not required to remain at the site at all times; the equipment could be secured at the site in their absence. Therefore, there were additional conflicts observed on the tape that were not marked by the field crew and required analysis in the office. Once a list of possible conflict times was completed for each site, other members of the research team viewed the tape and ruled each situation either a conflict or no conflict, based on the definition found in the FHWA manual (*11*).

5.6 DISCUSSION OF RESULTS

As previously mentioned, the pilot field studies were largely experimental in nature. Since neither funding nor time permitted an extensive TWSC intersection evaluation, only six intersections were evaluated for one day (11 hours) each, with the primary objective to study erratic vehicle maneuvers (i.e., conflicts). This section presents a summary of the conflict frequencies and conflict rates at each of the six sites, and a discussion of the results between the "control" sites and "study" group sites.

5.6.1 Conflict Frequency

Once the set of conflicts had been established for each of the study sites, researchers categorized the conflicts by the types shown in Figure 13. The conflict types were summarized for each intersection to obtain a value in units of conflicts per standard day. Table 20 shows these results. Abnormally high conflicts were determined to be those which exceed the 90th percentile value given in the FHWA manual (*11*). An abnormally high frequency of the left-turn from left conflict type was found at two locations. This conflict type occurred eight times at the Waco site and 13 times at the Port Lavaca site, exceeding the 90th percentile frequency of seven. All other conflict types did not exceed the 90th percentile values at any of the six sites. This comparison, however, is not likely to be statistically acceptable since the required observation time is much longer than 11 hours.

The values shown in Table 20 indicate a wide range of conflict type frequencies at each site. The highest number of conflicts, 25, was observed at the Waco site. The lowest number was observed at the Lorena site, with only seven conflicts observed in the entire 11-hour data collection period. The most commonly observed conflict type was the left-turn from left conflict, followed by the right-turn from right conflict. The right-turn from left conflict was not observed at any of the sites. This type of conflict is the extremely rare case when a right-turning vehicle from the minor approach, while executing the turn, encroaches across the centerline or into the lane of a vehicle on the opposing major approach.

Equation (1) was used to calculate the number of hours required based on the observed number of each type of conflict (the results are given in Appendix Table C-1). The required number of hours ranged from eight to more than 1,000. Since the mean-conflict-frequency per hour is in the denominator of Equation (1) and squared, the result is calculated to be a significantly high observation time. The required number of conflict types per day which result in observation times of less than 11 hours is shown in Appendix Table C-2.

Generally, each type of conflict must be observed, on the average, of one per hour to result in feasible observation times. At the TWSC intersections studied, however, the mean number observed per hour was significantly much less than one. Although the 11-hour period may not have been statistically acceptable, this amount of time allowed the research team to gain valuable insight as to the operational characteristics and potential accident problems which exist at each of the sites.

Table 20. Observed Number of Conflicts Per 11-Hour Day by Type

Conflict Type	Control Group Sites			Study Group Sites			90th Percentile[1]
	Hungerford	Bastrop	Crockett	Waco	Lorena	Port Lavaca	
Right-Turn from Right	4	2	3	8	4	2	10.0
Right-Turn from Left	0	0	0	0	0	0	[2]
Thru from Right	4	2	2	7	0	3	10.0
Thru from Left	0	1	1	2	0	0	15.0
Left-Turn from Right	2	1	4	0	1	2	16.0
Left-Turn from Left	5	3	7	8	2	13	7.0
Total	15	9	17	25	7	20	

Note: [1] From Table 7 (*11*).
[2] Any number observed should be considered abnormal (*11*).

5.6.2 Conflict Rate

Conflict frequency (per day or per hour) is generally the manner in which values are reported, since mean, variance, and percentile values (90th and 95th) have been established by previous research. Frequency values, however, do not express the differences which may result from increased volumes. The conflict rate per 1,000 entering vehicles expresses each conflict type as a function of the volume of vehicles that are exposed. For example, the number of vehicles that may be exposed to a right-turn from right conflict consists of the major-street approach through volume and the minor-street approach right-turn volume. The FHWA traffic conflict manual (*11*) states that the volume exposed equals the square root of the product of these two numbers. Since a right-turn from right conflict can occur in the opposite direction of the major approach, the same calculation is performed and the square root values summed. Conflict rates were computed for this study based on the traffic volume counts performed and are shown in Table 21. Turning movement data for each of the six sites is given in Appendix C. The main disadvantage of conflict rates is that there are no standard values in the literature for comparison and, therefore, difficult to define an abnormally high conflict rate.

Table 21. Observed Conflict Rate Per 1,000 Entering Vehicles

Conflict Type	Conflicts per 1,000 Entering Vehicles					
	Control Group Sites			Study Group Sites		
	Hungerford	Bastrop	Crockett	Waco	Lorena	Port Lavaca
Right-Turn from Right	4.61	3.66	3.54	3.54	3.55	2.80
Right-Turn from Left	[1]					
Thru from Right	5.43	1.02	1.90	3.00		2.52
Thru from Left		0.51	0.95	0.86		
Left-Turn from Right	2.91	1.04	4.07		1.25	2.08
Left-Turn from Left	7.41	3.21	7.13	5.97	2.50	13.49
Total/1,000 Vehicles	4.07	1.73	3.86	2.56	1.42	4.53

Note: [1] Blanks indicate conflict types not observed.

5.6.3 Conflict Frequencies and Rates at Control/Study Group Sites

Conflict frequencies and rates at the control and study group sites were statistically compared to determine if the study group exhibited a significantly different conflict rate than the control group. The conflict values shown in Tables 20 and 21 were totaled for a pooled conflict frequency and rate for each site. A Wilcoxon Rank Sum test was performed to determine any statistical difference between the pooled values for the control group site and the study group site. This statistical test is optimal for small sample sizes where the assumption of a normal distribution is not required (*14*). The results of the test gave insufficient evidence to reject the hypothesis that the populations are identical at the 90 percent level of confidence. Thus, neither conflict frequencies nor conflict rates were significantly different between the control and study group populations.

5.6.4 Correlation Between Conflicts and Crashes

For the six intersections evaluated, Schuckel (*15*) provides a detailed discussion of the conflict frequencies/rates at these six intersections, the statistical tests that were used, the available crash data for each site, and the correlation between conflicts and crashes. A potential relationship would be the correlation between a high cross traffic conflict frequency and a high number of cross traffic accidents. The occurrence of conflicts at an intersection can directly correlate with the intersection's crash frequency. As shown in Figure 16, a positive correlation can be observed between conflicts and accidents for four of the six sites that were evaluated. The crash data for the Lorena site was discarded because the supplemental sign was only recently installed, and the Bastrop data was not included in the correlation due to a crash frequency and rate that was nearly double the values from the remaining four sites. With the Bastrop data excluded, a correlation coefficient, r, was computed to be 0.95, suggesting a good fit to a positive linear relationship. The intercept on the vertical axis of near 10 conflicts (see Figure 16) suggests that a minimum number of conflicts will occur even at intersections experiencing a mean accident frequency approaching zero (*15*).

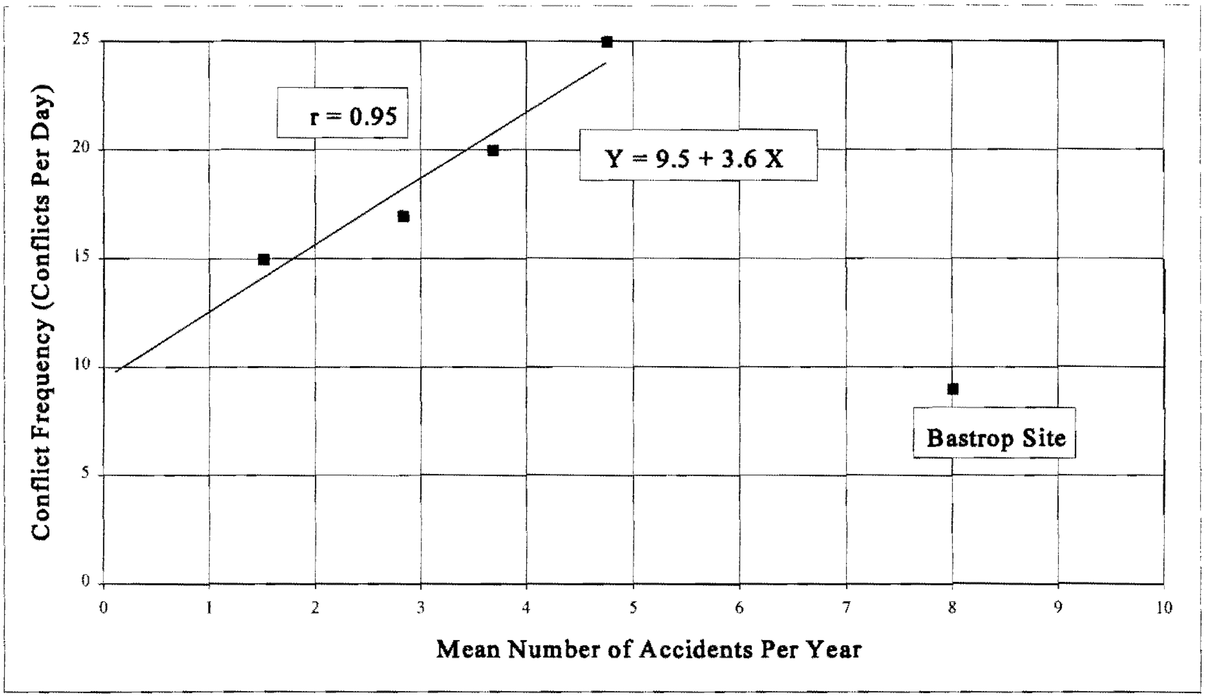


Figure 16. Correlation Between Conflict and Accident Frequency (*15*)

5.7 CONCLUSIONS

5.7.1 Contributing Factors to Observed Traffic Conflicts

Although the required number of observation hours for statistical precision was not met for nearly all conflict types, a data collection period of one standard day was beneficial to the objectives of this study. The observation period allowed the research team to gain considerable insight as to the operational features and potential problems which exist at each site. Possible sources for traffic conflicts (and possibly accidents) were classified into five categories: driver behavior characteristics, geometric features, traffic characteristics, traffic control characteristics, and environmental factors.

Driver Behavior Characteristics

One hypothesis formulated by the research team was that driver impatience may be a contributing factor to conflict occurrence. When a driver has to wait for a significant amount of time for an available gap in the major-street traffic, he or she may become impatient and accept a smaller gap to avoid being further delayed at the intersection. Using the video to review each of the conflict situations, the wait time was measured for each of the vehicles on the stop-controlled approach which caused a conflict. This time was measured from the instant the vehicle comes to a stop at the intersection, including the time the vehicle waited in a queue. The results shown in Table 22 indicate that nearly two-thirds of the conflicts were caused by drivers who had to wait less than 10 seconds to proceed into or across the major street. Thus, wait time was not observed to be significant in a majority of the conflicts and this hypothesis was not developed further. If major-street volumes were increased, the average delay per vehicle on the minor-street approach would be higher and driver impatience may be a factor. A significant number of conflicts were caused by drivers accepting minimal gaps in the major-street traffic that were not adequate for merging or crossing without impeding the major-street traffic movement. Conflicts were also caused even when larger gaps were accepted; the driver choosing the larger gap either selected an improper time to proceed relative to the presence of approaching major-street vehicles or did not accelerate sufficiently, causing the major-street vehicle to decelerate.

Table 22. Conflicts Per 11-Hour Day and Corresponding Minor-Street Delay

Vehicle Delay (sec)[1]	Control Group Sites			Study Group Sites			Total
	Hungerford	Bastrop	Crockett	Waco	Lorena	Port Lavaca	
0-5	9	5	10	10	3	12	49
5-10	1	2	4	3	3	2	15
10-20	2	2	2	4	1	5	16
20-30	3	0	0	5	0	0	8
30-45	0	0	1	3	0	1	5
45+	0	0	0	0	0	0	0
Total	15	9	17	25	7	20	93

Note: [1] Delay ranges adapted from *Highway Capacity Manual* (*16*).

Geometric Features

The geometry of the intersection (high-type at Waco, low-type for remaining sites) was observed to contribute to a number of conflicts. The presence of wide shoulders (2.5 to 3 meters) and left-turn bays on the major street were found to have the most profound impact on operations. Wide shoulders were present at the Waco, Port Lavaca, and Bastrop sites. Left-turn bays were present at the Waco site only. Shoulders created a de facto acceleration lane for vehicles, especially large trucks turning right or left onto the major street. Many vehicles would accept smaller gaps by using the shoulder to accelerate and allowing approaching major-street vehicles to pass. Additionally, a wide shoulder was used as a deceleration lane for major-street right-turning vehicles, or as a "fly-by" lane when a left-turning vehicle was present and no turn bays were present. A right-turn from right conflict or a left-turn from left conflict occurred several times when a minor-street vehicle moved from the shoulder to the main lane before accelerating to a sufficient speed, or was not sufficiently off the major-street lane to avoid interference with the through vehicle. The presence of left-turn bays in Waco was observed to result in a "screening effect" in two conflict situations. A large truck, or other high-profile vehicle, in the left- or right-turn bay would impede the vision of drivers on the minor-street approach who were scanning for traffic on the major-street approach.

Traffic Characteristics

With the exception of the Waco site, each of the study intersections had comparable total intersection volumes. The increased volume at the Waco location (nearly twice that of the other sites), was found to increase conflict frequency due to increased vehicle interaction. When the conflict frequency was converted into a rate per 1,000 entering vehicles, the effect of increased volume was reduced, and a more suitable comparison could be made. A significant percentage of truck volume was also observed to increase conflicts due to the reduced acceleration capabilities of heavy trucks. Traffic at the Waco site was observed to consist of 20 percent heavy trucks, while 40 percent of the conflicts involved these types of vehicles. Truck traffic was 8 percent or less at each of the remaining sites, and thus, was not observed to be a significant factor in conflict frequency elsewhere. The fluctuation of volume during the course of the day was also found to influence the conflict rate. Sites with a significant fluctuation in volume during peak periods (Waco, Lorena, Port Lavaca, and Bastrop) experienced an increased number of conflicts during these times.

Traffic Control Characteristics

The use of traffic control devices at intersections in a system should be consistent to meet driver expectations. If a TWSC intersection is located along a roadway system where other intersections of state-maintained roadways are signalized or are four-way stop-controlled intersections, driver expectancy may be violated. This factor may have influenced the traffic operations at the Crockett site. Nearly all intersections on Loop 304 around Crockett are four-way stop-controlled with red flashing intersection control beacons. At the study site, however, approximately 20 vehicles on Loop 304 (major street) were observed during the 11-hour period to completely stop at the intersection.

Environmental Conditions

A final contributing factor to conflict frequency is environmental conditions, such as the location of the sun or adverse weather conditions. The sun may be a crucial factor, especially where the major street runs in an approximate East-West direction. At sunrise or sunset, the sun may be low in the horizon in the direction drivers are scanning for approaching vehicles. A quantification of this effect, however, was beyond the scope of this study. An additional factor, the weather condition, was not examined since the conflict study design was formulated to collect data only during favorable weather conditions.

5.7.2 Advantages/Disadvantages of Study Design

The use of video for collecting the traffic conflict data was found to have a number of benefits on the accuracy of the data and the extent to which it could be analyzed. The video enabled the research team to conduct the study over a continuous period of time without having to estimate conflict frequency for non-observation times. Estimation may result in inaccurate values due to the infrequent occurrence of cross-traffic conflicts. Additionally, questionable conflict situations could be reviewed in the office to verify or reject the event as an actual conflict. The video also enabled each member of the research team to gain insight as to the operational characteristics of each site without having to leave the office to observe the site for an extended period of time. The calculation of the minor-street approach delay for vehicles causing conflicts (see Table 22) would not have been feasible with field observers because they could not know in advance that a conflict was about to occur.

Statistical precision was difficult to obtain based on the infrequent nature of cross-traffic conflicts. A required observation period of more than two days is not likely to be feasible for an operational study. In one standard day of data collection, however, the results enabled the research team to gain valuable insight into the potential problems that may exist. As previously noted, the standard values, developed by Glauz, et al., allow a determination of abnormal conflict values (*13*). The operational characteristics of the intersections in that study may not correspond well to those of the study sites in this study, due to differences in volumes, speeds, geometry, and truck traffic. Noting these limitations, this data is the only such available, and considered adequate enough to be included in an FHWA manual (*11*). Finally, a traffic conflict study may not correlate directly with driver understanding of the right of way conditions. Other factors undoubtedly are the cause of many of the observed conflicts, including inadequate gap acceptance and poor judgement of major-street vehicle distances and speeds. This study design, however, may enable traffic engineers to discover and eliminate other sources of safety problems identifiable through video or field analysis.

5.8 RECOMMENDATIONS

The traffic conflict study cannot be used as a direct measure of driver understanding about the right of way condition, but it can be used to identify the source of a number of other potential safety problems. Viewing the intersection of interest for one standard day will enable the traffic engineer to obtain valuable information that may allow him/her to properly diagnose a high-accident TWSC intersection. Factors that should be considered in a safety evaluation at TWSC intersections are:

- *Driver Behavior*: Impatience may cause drivers who are delayed for significant amounts of time to accept shorter gaps to avoid further delay;

- *Geometry*: Wide shoulders may be used as acceleration, deceleration, or "fly-by" lanes by a significant proportion of vehicles. This may create operational problems since drivers are likely to accept smaller gaps when using the shoulder as an acceleration lane. The presence of high-profile vehicles in left-turn bays on the major-street approach may cause a visual screen for drivers on the minor street scanning for approaching vehicles on the major street;

- *Traffic Characteristics*: A high percentage of trucks may result in an increased number of conflicts. Additionally, conflict frequency will increase during peak periods. Calculation of conflict rates may be a more suitable indicator when a comparison is made between two or more intersections with different volumes;

- *Traffic Control Characteristics:* The use of traffic control schemes along a roadway system can influence driver behavior characteristics. Driver expectancy may be violated if a TWSC intersection immediately proceeds or follows a series of signalized or four-way stop-controlled intersections; and

- *Environmental Conditions*: The location of the sun at dusk or dawn and weather conditions should be considered in an intersection safety evaluation, especially if the crash frequency is notable during a specific time of day or during wet pavement conditions.

A standard 11-hour day of video analysis at a TWSC intersection is not likely to allow a statistically precise determination of the mean conflict rates. Additionally, the observation period represents operational conditions under favorable weather conditions from 7:00 a.m. to 6:00 p.m. A disproportionate number of accidents may be occurring at night or under adverse weather conditions. The 11-hour day of video, however, will allow a determination of the source of many other potential operational problems. There were many benefits noted in this chapter that were derived from using the video equipment to collect conflict data. The observation, however, could be conducted in the field with trained observers, but with some limitations. Further efforts to collect conflict data would allow an improved estimation of conflict frequency for TWSC intersections at a more narrow range of volumes.

6.0 SUMMARY OF RESULTS

This chapter provides an overall discussion and summary of the results for each of the tasks conducted for this project. A more detailed discussion of the data and results can be found in the respective chapters for the tasks summarized below, or in the appendices. The following information in Table 23 is a summary of the research tasks for this project.

Table 23. Summary of Project Research Tasks

Task	Description	Chapter
1	Literature Review	1
2	Survey of TxDOT District Traffic Engineers	2
3	Survey of State DOT Traffic Engineers	2
4	Sign Preference Evaluation	3
5	Driver Assessment of Right of Way Conditions	4
6	Traffic Conflict Studies	5

6.1 LITERATURE REVIEW

Limited research evaluating driver understanding of right of way conditions at two-way stop-controlled intersections has been conducted. Previous studies (*2*, *3*, *4*) have suggested temporary treatments for converting a four-way stop-controlled intersection to a two-way stop-controlled intersection, discussed the nationwide state-of-practice regarding the use of supplemental sign treatments, and presented findings of driver comprehension studies.

6.2 TxDOT SURVEY RESULTS

TxDOT traffic engineers were surveyed to provide their input and professional experience with traffic control devices at two-way stop-controlled intersections. All 25 TxDOT Districts were surveyed, and 21 provided responses. In general, 70 percent of the respondents currently use a supplemental sign below or next to the STOP sign to warn drivers of the right of way conditions in their district. Overhead flashing intersection control beacons are also widely used. The main factors considered when installing a supplemental sign include situations where drivers may expect all traffic to stop at the intersection and/or where the crash frequency indicates problems.

With few guidelines to follow, most traffic engineers base their decision to use a supplemental sign on engineering judgement. Even though a wide disparity of legend messages exists in Texas, with respect to a supplemental sign design, most traffic engineers preferred the use of a rectangular-shaped sign, with a black legend on either a white or yellow background, mounted below the STOP sign at TWSC intersections. Furthermore, over half of the respondents prefer to have a standard treatment adopted in the MUTCD (*1*).

6.3 STATE DOT SURVEY RESULTS

Similar to the TxDOT survey, 49 U.S. state DOTs were asked to provide input on the use of supplemental signs in their state. Of the 31 respondents, nearly 40 percent indicated the use of a specific device or treatment to distinguish a two-way stop from a four-way stop. Nearly all specific treatments are supplemental signs mounted below the STOP sign. Similar to the TxDOT respondents, most of the states consider the crash frequency and driver expectation issue as factors for installing a specific treatment. Unlike the TxDOT respondents, however, more than 70 percent indicated that the MUTCD should not include a standard that distinguishes an intersection as a TWSC intersection.

6.4 EVALUATION OF SUPPLEMENTAL SIGN PREFERENCE

In a comprehensive driver survey of more than 2,100 drivers in five different states, 84 percent of the respondents preferred the use of the CROSS TRAFFIC DOES NOT STOP sign containing a horizontal, double-headed "arrow." When answering questions pertaining to driver understanding of right of way conditions at TWSC intersections, more than 70 percent indicated that they were never unsure of who has the right of way. Furthermore, the respondents were split in their opinion on whether or not a supplemental sign is actually necessary at all TWSC intersections.

6.5 DRIVER ASSESSMENT OF RIGHT OF WAY CONDITIONS

In a video survey that evaluated driver behavior characteristics, drivers indicated that they utilize specific visual cues at an intersection to help them determine the right of way conditions. In response to the primary question that pertained to their understanding of the right of way conditions at a TWSC intersection, 75 percent of the respondents were correct in their assumption of who had the right of way. This percentage directly correlates to the 70 percent in the sign preference evaluation who indicated that they were never unsure of who has the right of way at a TWSC intersection. In response to the different traffic control treatments at a TWSC intersection, a significantly high percentage (89 percent) of the respondents correctly assumed the right of way conditions when a CROSS TRAFFIC DOES NOT STOP supplemental sign was mounted below the STOP sign.

The visual cues and characteristics that assisted the driver in determining the right of way conditions include the presence of STOP signs on the stop-controlled approaches, the absence of STOP signs on the uncontrolled approach, the perceived speed and/or distance of the vehicles approaching on the major street, the presence of a supplemental sign below the STOP sign, and the looking behavior of the driver in determining the presence or absence of vehicles on the major-street approach.

6.6 TRAFFIC CONFLICT STUDIES

Based on what the researchers learned during the conduct of the traffic conflict studies, several factors can influence the traffic operations, driver behavior characteristics, and driver understanding of the right of way conditions at TWSC intersections. Traffic conflicts are quantifiable indicators of the crash potential at intersections. Possible sources for traffic conflicts (and possibly crashes) were classified into five categories:

- *Driver behavior characteristics* - A driver at a stop-controlled approach becomes impatient, making a poor decision to proceed into the intersection, causing a conflict;
- *Geometric features* - Shoulders and left- and right-turn lanes can increase the presence of conflicts at a TWSC intersection, especially when a high-profile vehicle shields the view of major-street through movements from drivers on the stop-controlled approaches and when large trucks use the shoulders for acceleration purposes. A significant difference in conflict frequency was noted between high-type intersections and low-type intersections;
- *Traffic characteristics* - A high percentage of large trucks in the traffic stream can increase conflict frequency, especially when acceleration/deceleration movements are made;
- *Traffic control characteristics* - A system of roadway intersections should be consistent with respect to traffic control schemes. Driver expectancy can be violated if adjacent intersections are not controlled with a similar design; and
- *Environmental factors* - The location of the sun with respect to the major- and minor-street approaches and the weather conditions are factors that can influence driver behavior characteristics. Traffic engineers should consider these factors during a safety evaluation.

7.0 GUIDELINES FOR IMPLEMENTATION

This chapter provides recommendations and guidelines for the project, based on a culmination of the results from all research tasks. Guidelines are provided for selecting and treating problematic TWSC intersections in the hopes of improving driver understanding of right of way conditions at these intersections. The guidelines can be summarized as follows:

Step 1 - Identify Intersection for Treatment;
Step 2 - Conduct Traffic Engineering Study;
Step 3 - Implement Traffic Control Treatment; and
Step 4 - Conduct Periodic Safety Review.

7.1 IDENTIFY INTERSECTION FOR TREATMENT

Many two-way stop-controlled intersections continuously experience frequent and/or severe right-angle crashes. The problem may be related to a misinterpretation of the right of way where drivers believe the intersection to be all-way stop-controlled. This misinterpretation can lead to increased traffic conflicts, crashes, and fatalities.

Based on the results of this study, most traffic engineers expressed the need for guidance in treating certain four-legged, TWSC intersections to inform drivers of the right of way conditions. There is a general consensus that, if used, supplemental signing at such intersections should be restricted only to specialized intersections where an engineering study *obviously* suggests that drivers misinterpret the intersection as an all-way stop (including during a four-way to two-way conversion phase).

At an existing four-legged, two-way stop-controlled intersection (with or without intersection control beacons), one or more of the following conditions may lead a driver to misinterpret the intersection to be all-way stop-controlled. Any of these conditions can justify a supplemental sign treatment:

1) The intersection of two single-jurisdictional roadways (e.g., two state-maintained roadways) in a rural or isolated area;

2) Average daily traffic (ADT) volumes on all approaches are similar but less than the minimum volumes which would warrant the installation of a traffic signal. Typical volumes ranging from 5,000 to 10,000 ADT will likely not meet signal warrants but could justify a supplemental treatment;

3) Although difficult to define an abnormally high conflict frequency and rate, the results of this study suggest that 20 to 25 conflicts per day (all conflicts combined) or a rate of at least 4 conflicts per 1,000 entering vehicles could justify a supplemental treatment;

4) Right-angle crash frequency in the range of three to five (or more) per year. (Such a condition may not necessarily meet traffic signal warrants);

5) A system of roadway intersections (at-grade) that are not consistent with respect to traffic control schemes (including TWSC frontage road/cross road intersections);

6) Similar, high speeds on all approaches (greater than 80 kilometers per hour); and

7) Similar cross-sectional elements (number/width of lanes/shoulders, grades, and drainage) on all approaches;

7.2 CONDUCT TRAFFIC ENGINEERING STUDY

Prior to implementing any traffic control improvements, a traffic engineering study should be conducted to determine, at a minimum, the crash history, the types and frequency of conflicts during a 10- to 12-hour period of a typical day, the average daily approach volumes (including turning movements), approach speeds, the number/width of through/turn lanes (and shoulders, if any), pavement conditions, and cross-section elements. Recommendations for this safety evaluation are discussed below.

7.1.1 Review Design/Traffic Control Plans

It is recommended that traffic engineers evaluate the existing design and traffic control plans of the intersection to familiarize themselves with specific geometric and traffic control features in existence, historical volume levels, and traffic control warrants, not only at the study site, but also at adjacent intersections along the same roadway.

7.1.2 Conduct Traffic Study

The traffic engineer should conduct a study to determine existing volume levels (ADT, peak-hour, turning movements, and major/minor volume splits) and approach speeds, as well as existing geometric conditions, such as the number/width of through/turn lanes and shoulders, existing pavement conditions, cross-section elements, and unique horizontal/vertical alignment features at or near the intersection. By conducting this study, the engineer may be able to better understand factors related to the cause of conflicts and crashes.

7.1.3 Conduct Crash Study

An investigation of the crash history at the intersection is recommended. The engineer should pay special attention to the types of crashes (which movements are involved), the frequency (and its relation to intersection improvements), the time of day of crashes, and the weather conditions present during the crash. If obtainable, the traffic engineer should also review crash narratives to determine if any unique factors may have caused the crash.

7.1.4 Conduct Traffic Conflict Study

A traffic conflict study utilizing either a video-based method (an elevated camera) or an observer-based method should be conducted for a 10- to 12-hour period to better understand the geometric and operational effects on driver behavior at the intersection. Viewing the intersection for 10 to 12 hours in a typical day will enable the traffic engineer to obtain valuable information that may allow him/her to properly diagnose a problematic TWSC intersection. Factors that should be considered in a conflict study at TWSC intersections, and ones that can contribute to conflicts, include driver behavior and traffic flow characteristics, the effects of geometric features, traffic control characteristics, and environmental factors. The study results indicated that traffic conflicts may be a result of the misunderstanding of the right of way conditions. The conflict study (and video analysis, if available) will allow a determination of this, as well as the source of many other potential operational problems.

7.3 IMPLEMENT TRAFFIC CONTROL TREATMENT

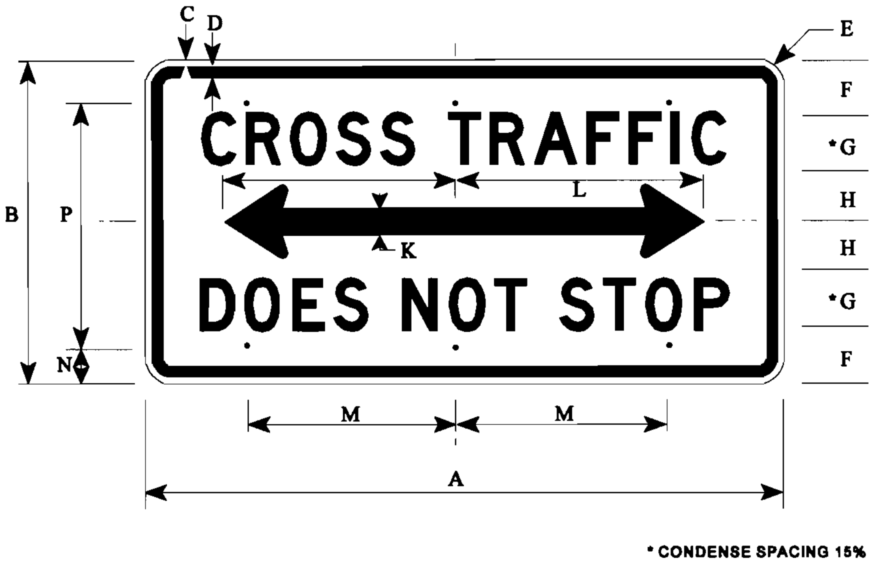
Being less restrictive, a supplemental sign treatment may serve as an intermediate upgrade to beacon or traffic signal installations. It is also less costly than installing beacons or signals. If used, the supplemental sign should be uniform with respect to placement, shape, color, and legend content. The recommended design of this supplemental sign is presented in Figure 17 and is discussed below.

7.3.1 Placement of Supplemental Treatments

Based on previous studies (*3*, *4*) and on the results of the two traffic engineer surveys discussed in this report, supplemental signs, if used, are recommended to be placed below the STOP sign at both stop-controlled approaches of a four-legged, TWSC intersection.

7.3.2 Shape, Color, and Size of Supplemental Treatments

Supplemental signs should be uniform with respect to shape, color, and size. Some states have already adopted a regulatory sign in their respective state MUTCDs, with most indicating that the sign is intended to *inform* drivers of the right of way conditions that may not be apparent. Being designated as a regulatory sign, drivers would expect a rectangular-shaped sign with black letters on a white background. Most signs in use have such features, but for many reasons, a wide disparity of shapes and colors have been implemented in the field. Even though a yellow background is frequently used (likely for conspicuity purposes or for the warning-type message that is intended), a white background is recommended. A rectangular-shaped sign (with the longer dimension horizontal), the same width as the STOP sign it is to be placed under, is recommended (see Figure 17).



Sign	Dimensions (Inches)													
	A	B	C	D	E	F	G	H	J	K	L	M	N	P
Special	36	18	3/8	5/8	1½	3	3D	3	3½	1½	13½	-	2½	13
Special	48	24	3/8	5/8	1½	4	4D	4	5¼	2	18	16	3	20

Sign	Dimensions (mm)													
	A	B	C	D	E	F	G	H	J	K	L	M	N	P
Special	900	450	9	15	35	75	75D	75	85	35	335	-	60	325
Special	1200	600	9	15	35	100	100D	100	130	50	450	400	75	500

COLORS
BORDER, LEGEND & SYMBOL - BLACK
BACKGROUND - WHITE (Refl)

Figure 17. Recommended Supplemental Sign Design for TWSC Intersections

7.3.3 Legend Content

Previous research has indicated that "cross traffic," "cross street," and "does not stop" were legend phrases that are present in a majority (70 percent) of existing supplemental signs at TWSC intersections (*3*). Further research involving more than 1,000 drivers in Texas (*4*) and, as discussed in Chapter 3, more than 2,100 drivers in five different states, has indicated that the best understood and most preferred sign legend was one that contained the words CROSS TRAFFIC DOES NOT STOP and a horizontal, double-headed "arrow" symbol. The size of these letters should be either 75 or 100 millimeters (Letter Series C or D), depending upon the size of the supplemental sign (See Figure 17).

7.3.4 Other Traffic Control Devices

The use of larger STOP signs at TWSC intersections should be approached carefully. Although limited data supports the notion, some TxDOT Districts/Areas did indicate that the use of 1200-mm (48-inch) STOP signs, combined with certain geometric features (e.g., channelized right turns on all approaches) may, in fact, provide a false sense of security for some drivers in that they would interpret the intersection to be all-way stop-controlled. No one solution can solve this problem, but regardless of sign size, the presence of visible, adequately maintained stop bars on each stop-controlled approach is recommended.

Lastly, the use of a white-on-red 2-WAY plate mounted below a STOP sign is highly discouraged at TWSC intersections. Previous research results indicated that drivers frequently associated the 2-WAY plate under a STOP sign with an intersection in which "traffic from all directions must stop" (*4*).

7.4 CONDUCT PERIODIC SAFETY REVIEW

At the selected TWSC intersections, the traffic engineer should conduct a periodic review (every one to two years) of crashes, conflicts, and other operational characteristics (volumes and speeds) to determine if the installation of the supplemental sign treatment has improved the safety and driver understanding of the right of way conditions. If frequent and/or severe crashes still persist, the engineer should fully investigate traffic signal warrants for that intersection.

7.5 RECOMMENDED TxDOT PRACTICE

Based on the results of this study, the TxDOT Traffic Operations Division distributed a memorandum to all District Engineers recommending a preferred design "if supplemental signs are used" at two-way stop-controlled intersections. The memorandum is also considered an interim change to the *Texas Manual on Uniform Traffic Control Devices* (*17*). A copy of this memorandum and detail sheets of the preferred design is provided in Appendix D.

8.0 REFERENCES

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APPENDIX A

SUMMARY OF TRAFFIC ENGINEERS SURVEY

This appendix provides a summary of the responses from both the TxDOT traffic engineers' survey, summarized in the first section of this chapter, and the state DOT survey, summarized in the second section. Each section provides a sample of the survey instrument and a summary of the answers and comments. Both surveys were mailed to the traffic engineers in their respective jurisdictions. The results of both surveys were utilized by the researchers to develop subsequent driver surveys.

SURVEY OF TxDOT DISTRICT TRAFFIC ENGINEERS

The Texas Department of Transportation is jurisdictionally divided into 25 Districts in the state. Each district, further divided into area jurisdictions, maintains the highways in their districts, including roadway construction, maintenance, and improvements. Furthermore, each district or area designs, installs, and maintains all traffic control devices under their jurisdiction. The engineer responsible for the design, installation, and maintenance of traffic control devices in each district or area is the Director of Transportation Operations and/or the Area Engineer. The researchers first contacted the District Engineer and asked each one to distribute the survey to the engineer responsible for traffic control devices.

Survey Instrument Design

The research team, with the assistance of the Advisory Panel, developed a 14-question survey that addressed the use of traffic control devices at two-way stop-controlled intersections. Eight of the questions pertained to the district's use and justification for devices at TWSC intersections, three of the questions pertained to their preference for supplemental signs, and three pertained to intersection locations in their district that would be ideal for study locations. A copy of the survey instrument is provided on the following pages.

Texas Transportation Institute

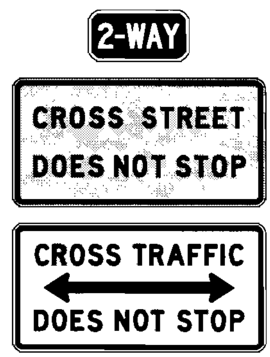
STOP SIGN SURVEY

Texas Department of Transportation

The Texas Transportation Institute (TTI) is conducting a one-year research project for the Texas Department of Transportation to evaluate potential traffic control treatments for distinguishing between two-way and four-way stop-controlled intersections. The objectives of the project are as follows:

- Identify existing supplemental treatments at two-way and four-way stop-controlled intersections;
- Evaluate the effectiveness of various treatments through motorist surveys and field evaluations of driver behavior; and
- Recommend a uniform treatment at stop-controlled intersections in Texas that best conveys to the driver the right-of-way conditions that are present for all approaching traffic.

Supplemental plaques, such as the ones to the right, are sometimes used at intersections where motorists approaching the STOP Sign may expect the cross street traffic to also stop. Other State DOT's have developed various standards for the use of supplemental plaques, but TxDOT has not. Various treatments are in existence around the state, and you, as a practicing engineer, may have knowledge of existing treatments in your district which can offer insight into developing a more uniform treatment that improves safety at these types of intersections.



If you have any questions or comments, please feel free to contact the person at the address or phone number below. The completed survey can be returned in the enclosed envelope and mailed to the address below. Thank you in advance for your time and assistance.

Texas Transportation Institute
Texas A&M University
College Station, Texas 77843-3135
FAX (409) 845-9761

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Go to Next Page ☞

Please answer each question to the best of your knowledge. If a question is not applicable to your district, please check **NOT SURE** or **N/A**, and feel free to make additional comments. Thank you.

1. Does your district currently have one or more specific devices or treatments that distinguish a two-way stop from a four-way stop?

   ❑ Yes **(Go to Question #2)** ❑ No **(Skip to Question #8)** ❑ Not Sure **(Go to Question #2)**

2. Please indicate which devices or treatments that have been and/or are currently used in your district. Please check (✓) any appropriate boxes.

   STANDARD MUTCD DEVICE: ❑ 4-WAY ❑ 3-WAY ❑ ALL WAY

   ALTERNATIVE TREATMENTS:

   ❑ Supplemental sign below a STOP sign, intended to alert drivers that all traffic does not stop
   ❑ Secondary sign mounted separately next to a STOP sign, intended to alert drivers that all traffic does not stop
   ❑ Stop Ahead sign
   ❑ Other advance warning or regulatory sign
   ❑ Flashing intersection control beacons
   ❑ Pavement markings
   ❑ Special STOP sign post (*i.e., different color, reflective material, etc.*)
   ❑ None of the above
   ❑ Not sure
   ❑ Other (*briefly describe*) ____________________
   *Comments:*____________________

3. What are the primary factors that influenced your district's decision to install a device or treatment to warn drivers that all approaches at an intersection are not required to stop? Please check (✓) any appropriate boxes.

   ❑ When converting a four-way to a two-way stop
   ❑ Drivers may expect all traffic to stop at the intersection
   ❑ Accident frequency How many? _____ per Year
   ❑ Fatalities How many? _____ per Year
   ❑ Lawsuit against the State
   ❑ Geometry of the intersection: *Please indicate:* ❑ Geometry is similar on both roadways ❑ Geometry is different on both roadways
   ❑ Traffic volumes on intersection roadways: *Please indicate:* ❑ Low volumes on both roadways ❑ High volumes on both roadways ❑ One roadway had significantly higher volume
   ❑ Sight distance is limited on one/both of the roadways
   ❑ Other____________________

4. Is this a temporary or permanent treatment? ❑ Temporary ❑ Permanent ❑ Not Sure
   *Comments*____________________

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5. Please provide a sketch of any device or treatment that has been and/or is currently being used in your district to distinguish a two-way stop from a four-way stop intersection.

1	2
Type (*sign, marking, etc.*) ______ Size: ______ Shape: ______ Color: ______ Location: ❑ Below STOP sign ❑ Next to STOP sign ❑ Advance of STOP sign ❑ Other ______ Accident Decrease? ❑ Yes ❑ No ❑ Not Sure *Comments:* ______	Type (*sign, marking, etc.*) ______ Size: ______ Shape: ______ Color: ______ Location: ❑ Below STOP sign ❑ Next to STOP sign ❑ Advance of STOP sign ❑ Other ______ Accident Decrease? ❑ Yes ❑ No ❑ Not Sure *Comments:* ______
3	4
Type (*sign, marking, etc.*) ______ Size: ______ Shape: ______ Color: ______ Location: ❑ Below STOP sign ❑ Next to STOP sign ❑ Advance of STOP sign ❑ Other ______ Accident Decrease? ❑ Yes ❑ No ❑ Not Sure *Comments:* ______	Type (*sign, marking, etc.*) ______ Size: ______ Shape: ______ Color: ______ Location: ❑ Below STOP sign ❑ Next to STOP sign ❑ Advance of STOP sign ❑ Other ______ Accident Decrease? ❑ Yes ❑ No ❑ Not Sure *Comments:* ______

If additional space is required, please use next page.

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5. *(continued from previous page)*

1	2
Type (*sign, marking, etc.*) ________ Size: ________ Shape: ________ Color: ________ Location: ❑ Below STOP sign ❑ Next to STOP sign ❑ Advance of STOP sign ❑ Other ________ Accident Decrease? ❑ Yes ❑ No ❑ Not Sure *Comments:* ________	Type (*sign, marking, etc.*) ________ Size: ________ Shape: ________ Color: ________ Location: ❑ Below STOP sign ❑ Next to STOP sign ❑ Advance of STOP sign ❑ Other ________ Accident Decrease? ❑ Yes ❑ No ❑ Not Sure *Comments:* ________
3	4
Type (*sign, marking, etc.*) ________ Size: ________ Shape: ________ Color: ________ Location: ❑ Below STOP sign ❑ Next to STOP sign ❑ Advance of STOP sign ❑ Other ________ Accident Decrease? ❑ Yes ❑ No ❑ Not Sure *Comments:* ________	Type (*sign, marking, etc.*) ________ Size: ________ Shape: ________ Color: ________ Location: ❑ Below STOP sign ❑ Next to STOP sign ❑ Advance of STOP sign ❑ Other ________ Accident Decrease? ❑ Yes ❑ No ❑ Not Sure *Comments:* ________

If additional space is required, use a separate sheet.

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6. What is the justification for these types of treatments? Check (✓) all that applies.

   - ❑ District standard (*established procedure, specification, district memorandum*)
   - ❑ Traffic engineering study (*accidents, volumes, speeds, etc.*)
   - ❑ Engineering judgement (*case-by-case basis*)
   - ❑ Other ______________________________

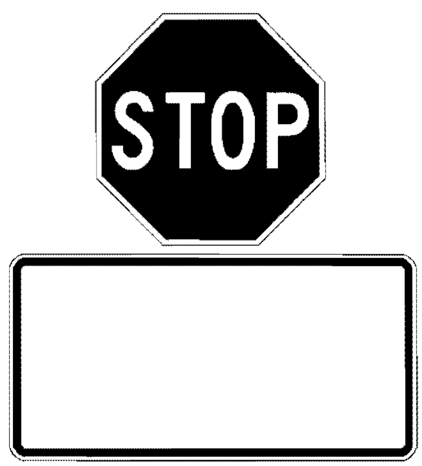
   Comments: ______________________________

7. If the treatment is not effective in conveying the intended meaning (*accidents do not decrease, drivers do not understand, etc.*), what other alternatives are considered?

   - ❑ No alternatives considered; treatment left in place
   - ❑ Remove treatment; return to original traffic control
   - ❑ Install intersection control beacons
   - ❑ Install traffic signals
   - ❑ Physically redesign the intersection: *Please indicate:* ❑ Improve sight distance ❑ Modify approach grades ❑ Widen roadway
   - ❑ Other ______________________________

   Comments: ______________________________

8. In your experience, what is the most effective message on a supplemental plaque to inform drivers that the intersection is a two-way stop. Please indicate this message using <u>words</u> and/or <u>symbols</u>.



Note: Not to scale

Recommended Letter Height: ____ Inches

Plaque Size: Width: ____ Inches
Height: ____ Inches

Background Color: ______________

Legend Color: ______________

What should be the legibility distance? ____ Feet

- ❑ Legibility is not a concern <u>at</u> a STOP sign
- ❑ Not Sure

Comments: ______________________________

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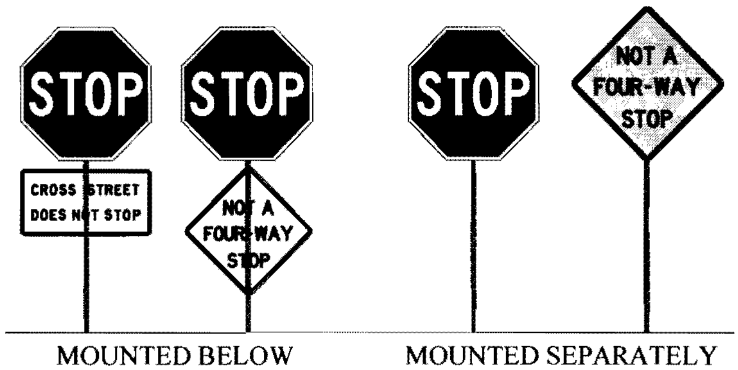
9. In your opinion, should a standard sign, plaque, or other treatment be adopted in the Texas MUTCD that identifies an intersection as a two-way stop-controlled intersection? ❑ Yes ❑ No ❑ Not Sure

Comments: ______________________________

Please answer QUESTIONS #10 and #11 based on the TWO drawings provided below.



10. Where should the device be mounted?

❑ Below ❑ Separately ❑ Advance of Intersection ❑ Not Sure ❑ Other__________

11. What color and shape combinations are the most appropriate?

COLOR
❑ Red Legend on White Background
❑ Black Legend on White Background
❑ Black Legend on Yellow Background
❑ Other______________________

SHAPE
❑ Square
❑ Rectangular
❑ Diamond
❑ Circular

Comments: ______________________________

The Texas Transportation Institute will be conducting an evaluation of several different treatments around the state. We need assistance in identifying the location of these treatments. Ideal locations are rural intersections that are either two-way or four-way stop-controlled that have unusually high accident frequencies and/or where it is perceived that drivers may be confused about the right-of-way requirements at the intersection.

12. Is there a location in your district that would be ideal for this evaluation? ❑ Yes ❑ No ❑ Not Sure

13. Is this location: ❑ Two-Way with Supplemental Treatment
❑ Two-Way Stop
❑ Four-Way Stop ❑ Other______________

14. Can we contact you for further information about this location(s)? ❑ Yes ❑ No

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Please provide the following information:

Name: ____________________

Title: ____________________

District: ____________________

Address: ____________________

____

____

Telephone Number: ____________________

FAX Number: ____________________

A return label has been provided for your response. Please return the survey by **March 1, 1996**.

THANK YOU IN ADVANCE FOR YOUR ASSISTANCE

End of Survey

Participating Districts

A total of 21 out of the 25 TxDOT Districts were represented in the sample of completed surveys. From one of the participating districts, nine Area Engineers returned completed surveys, which brought the total number of 29 completed surveys. The following information in Table A-1 summarizes the TxDOT Districts and Areas that participated in the survey.

Table A-1. TxDOT Districts and Areas Participating in Survey

District Number	District	District Number	District
01	Paris	13	Yoakum
03	Wichita Falls	15	San Angelo
04	Amarillo	16	Corpus Christi
05	Lubbock	17	Bryan
06	Odessa	18	Dallas (9 Areas)
07	San Angelo	19	Atlanta
08	Abilene	20	Beaumont
09	Waco	21	Pharr
10	Tyler	24	El Paso
11	Lufkin	25	Childress
12	Houston		
TOTAL RETURNS: 29			

Survey Results

The following sections summarize the answers and responses for each of the survey questions. Each question, response choices, percentage of responses, and comments are provided in Figures A-1 through A-9.

QUESTION:	Does your district currently have one or more specific devices or treatments that distinguish a two-way stop from a four-way stop?	
ANSWER:	97%	Yes
	3%	No
	0%	Not Sure

Figure A-1. TxDOT Question Pertaining to Existence of TWSC Treatments

QUESTION: Please indicate which devices or treatments that have been and/or are currently used in your district. Please check (✓) any appropriate boxes.

ANSWER: **Standard MUTCD Device:**

73%

62%

85%

Alternative Treatments:

65%	Supplemental sign <u>below</u> a STOP sign, intended to alert drivers that all traffic does not stop
4%	Secondary sign mounted separately <u>next</u> to a STOP sign, intended to alert drivers that all traffic does not stop
96%	Stop Ahead Sign
30%	Other advance warning or regulatory sign
81%	Flashing intersection control beacons
52%	Pavement markings
4%	Special STOP sign post (i.e., different color, reflective material, etc.)
0%	None of the above
0%	Not sure
4%	Other

Comments:
- We use various treatments at different locations depending on situation.
- Other: In advance of the STOP sign and at the far side of the intersection.
- We use "ALL WAY" at all locations that all traffic must stop.
- We have several high accident locations; we have added supplemental signs at both. One reads "CROSS STREET DOES NOT STOP" and the other reads "SH 7 (or FM 39 or US 79) DOES NOT STOP."
- Also flashing red beacon on STOP sign support as shown on pg. 4E 2.2 of MUTCD.

Figure A-2. TxDOT Question Pertaining to Existing Intersection Treatments

QUESTION:	What are the primary factors that influenced your district's decision to install a device or treatment to warn drivers that all approaches at an intersection are <u>not</u> required to stop? Please check (✓) any appropriate boxes.		
ANSWER:	23%	When converting a four-way to a two-way stop	
	65%	Drivers may expect all traffic to stop at the intersection	
	54%	Accident frequency	2 to 5 How many? ____ per Year
	38%	Fatalities	1 to 2 How many? ____ per Year
	8%	Lawsuit against the State	
	50%	Geometry of the intersection:	
		55%	Geometry is similar on both roadways
		45%	Geometry is different on both roadways
	31%	Traffic volumes on intersection roadways:	
		30%	Low volumes on both roadways
		50%	High volumes on both roadways
		40%	One roadway had significantly higher volume
	42%	Sight distance is limited on one/both of the roadways	
	12%	Other	

Comments:
- Public complaints.
- Accident frequency: Any, where there had previously been none.
- Accident frequency: No set number.
- These are all on one intersection - FM 1171 and US 377.
- Other: Not sure.

Figure A-3. TxDOT Question Pertaining to Factors for Using a TWSC Treatment

QUESTION:	Is this a temporary or permanent treatment?	
ANSWER:	4%	Temporary
	88%	Permanent
	8%	Not Sure

Comments:
- Temporary, but it sometimes turns into a permanent treatment.
- Generally will be permanent until design of road is modified.
- We have one intersection where we had spanned wire flashing beacons, and we also added 12" flashers above the 48" STOP sign, along with the CROSS-STREET DOES NOT STOP sign.

Figure A-4. TxDOT Question Pertaining to Permanence of TWSC Treatment

QUESTION:	What is the justification for these types of treatments? Check (✓) all that applies.	
ANSWER:	14%	District standard (*established procedure, specification, district memorandum*)
	55%	Traffic engineering study (*accidents, volumes, speeds, etc.*)
	82%	Engineering judgement (*case-by-case basis*)
	9%	Other

Comments:
- Other: Request from law enforcement.
- Other: To inform and warn the drivers.

Figure A-5. TxDOT Question Pertaining to the Justification for TWSC Treatment

QUESTION:	If the treatment is not effective in conveying the intended meaning (*accidents do not decrease, drivers do not understand, etc.*), what other alternatives are considered?	
ANSWER:	8%	No alternatives considered; treatment left in place
	0%	Remove treatment; return to original traffic control
	75%	Install intersection control beacons
	42%	Install traffic signals
	38%	Physically redesign the intersection:
		86% Improve sight distance
		57% Modify approach grades
		86% Widen roadway
	4%	Other

Comments:
- Other: We ask the news media to make a public service broadcast.
- Each intersection treated on individual basis.
- Construct grade separation.
- These are considerations; there are no standards; each intersection is looked at individually.
- Other: 4-way stop.
- Isolated rural traffic signals could pose as much of a accident problem as the 2-way stopped intersection.
- Other: Possible All-way stop.
- We've looked at removing or relocating existing signs that might be viewed from the backside as some type of traffic control sign. We've moved DO NOT ENTER signs since some STOP signs are mounted on the back sides.
- Other: Larger signs and/or additional signs.
- Other: Turn bays.

Figure A-6. TxDOT Question Pertaining to Alternative TWSC Treatments

QUESTION:	In your opinion, should a standard sign, plaque, or other treatment be adopted in the Texas MUTCD that identifies an intersection as a two-way stop-controlled intersection?
ANSWER:	46% Yes 36% No 18% Not Sure
	Comments: • Too many signs at or near intersections as it is. Each additional requirement removes from drivers their "responsibility" and places more "liability" on Dept. To be responsible for driver's actions. • Supplemental plaques should be considered if the intersection has a moderate to high accident frequency. • This type of sign should only be used when the geometry of an intersection, or other considerations, would cause the driving public to believe it to be a 4-way stop. • Because this isn't necessary at all locations. If you don't do it all the time, it would be confusing. • This would be okay but should remain the responsibility of the engineer. • We already have a treatment for two-way stop control, there should be a supplemental plaque on all stop signs to convey if all approaches stop or all approaches do not stop. • If we adopt a new sign, will we be required to install this sign at all two-way stop intersections? Will cities and counties install these new signs? • As a "may" condition. • Division personnel have recommended the CROSS STREET DOES NOT STOP sign. • This treatment should only be applied at specialized locations; not all locations.

Figure A-7. TxDOT Question Pertaining to an Adopted MUTCD Standard

QUESTION:	Where should a (supplemental) device be mounted?
ANSWERS:	89% Below 4% Separately 11% Advance of Intersection 0% Not Sure 4% Other
QUESTION:	What color and shape combination are the most appropriate?

ANSWER:

COLOR		SHAPE	
23%	Red Legend on White Background	0%	Square
50%	Black Legend on White Background	92%	Rectangular
23%	Black Legend on Yellow Background	8%	Diamond
8%	Other	0%	Circular

Comments:
- Other Mounting Location: Over roadway if feasible.
- Other Color: White legend on green background.
- Other Color: White legend.
- Other Mounting Location: On the far side of the intersection.
- Prefer the CROSS STREET DOES NOT STOP sign.
- Do not support the diamond shaped sign listed above.

Figure A-8. TxDOT Question Pertaining to Supplemental TWSC Sign Design

QUESTION: Is there a location in your district that would be ideal for further evaluation?		
ANSWER:	48%	Yes
	11%	No
	41%	Not Sure
QUESTION:	Is this location:	
ANSWER:	79%	Two-Way with Supplemental Treatment
	7%	Two-Way Stop
	7%	Four-Way Stop
	14%	Other
QUESTION:	Can we contact you for further information?	
ANSWER:	89%	Yes
	11%	No

Figure A-9. TxDOT Question Pertaining to Participation in Project Tasks

SURVEY OF STATE DOT TRAFFIC ENGINEERS

All 49 State Traffic Engineers (excluding Texas) were contacted to participate in the survey. Three other concurrent projects on traffic control devices also required a survey of each state Department of Transportation; therefore, a four-part survey (four different projects) was sent to each State Traffic Engineer. Each was asked to distribute each part of the survey to the appropriate person within their organization. The survey for this project was Part III of IV.

Survey Instrument Design

Similar to the TxDOT survey, the research team developed a questionnaire with the assistance of the Advisory Panel. This questionnaire contained only seven questions, as compared to the 14-question survey sent to TxDOT personnel. The effort to shorten the survey questionnaire was primarily to keep each part of the four DOT surveys to a minimum and to only include the primary questions on the use and justification of traffic control devices at TWSC intersections under the state's jurisdiction. All seven questions pertained to devices currently in use at TWSC intersections. A copy of the survey instrument is provided on the following pages.

PART III OF IV - TREATMENTS FOR TWO-WAY AND FOUR-WAY STOP-CONTROLLED INTERSECTIONS

The Texas Transportation Institute is conducting a research project for the Texas Department of Transportation to evaluate potential treatments for distinguishing between two-way and four-way stop-controlled intersections. Some state agencies have developed such treatments, but Texas has not. Your state's experiences with this situation will help with the development of treatments for Texas. Please answer each of the following questions about your state's practices regarding treatments for two-way and four-way stop-controlled intersections.

Name: ______________________________
Position: ______________________________
State: ______________________________
Phone: ______________________ Fax: ______________________

1. Has your state conducted any evaluations of treatments that are used to distinguish a two-way stop-controlled intersection from a four-way stop-controlled intersection?

   ❑ Yes - (please describe or provide copy) ❑ No

   Comments: ______________________________

2. Please indicate which, if any, of the following supplemental plaques from the National MUTCD are used in your state.

   ❑ 4-WAY ❑ 3-WAY ❑ ALL WAY

   Comments: ______________________________

3. Does your state currently have one or more specific treatments or devices that distinguish a two-way stop from a four-way stop?

   ❑ Yes ❑ No ❑ Not sure

   If Yes, please sketch or describe on the next page

   Comments: ______________________________

If your state currently uses a supplemental treatment or device at stop-controlled intersections, would you please provide the Texas Transportation Institute the following documentation?

- A copy of the specific mention of the treatment in your state manual, MUTCD supplement, and/or the state sign design manual.
- Any other relevant documentation that would assist in this effort.

4. Please provide a sketch of any treatment or device that is currently being used in your state to distinguish a two-way stop-controlled intersection from a four-way stop-controlled intersection.

1	2
Type (*sign, marking, etc*): ________ Size: ________ Shape: ________ Color: ________ Location: ❑ Below Stop Sign ❑ Next to Stop Sign ❑ Advance of Stop Sign ❑ Other ________ Accident decrease? ❑ Yes ❑ No ❑ Not Sure In state manual/supplement: ❑ Yes ❑ No *Comments:* ________	Type (*sign, marking, etc*): ________ Size: ________ Shape: ________ Color: ________ Location: ❑ Below Stop Sign ❑ Next to Stop Sign ❑ Advance of Stop Sign ❑ Other ________ Accident decrease? ❑ Yes ❑ No ❑ Not Sure In state manual/supplement: ❑ Yes ❑ No *Comments:* ________
3	4
Type (*sign, marking, etc*): ________ Size: ________ Shape: ________ Color: ________ Location: ❑ Below Stop Sign ❑ Next to Stop Sign ❑ Advance of Stop Sign ❑ Other ________ Accident decrease? ❑ Yes ❑ No ❑ Not Sure In state manual/supplement: ❑ Yes ❑ No *Comments:* ________	Type (*sign, marking, etc*): ________ Size: ________ Shape: ________ Color: ________ Location: ❑ Below Stop Sign ❑ Next to Stop Sign ❑ Advance of Stop Sign ❑ Other ________ Accident decrease? ❑ Yes ❑ No ❑ Not Sure In state manual/supplement: ❑ Yes ❑ No *Comments:* ________

5. What are the primary factors that would influence your decision to install a treatment or device to warn drivers that all approaches at an intersection are not required to stop. Check all that apply.

- ❑ Driver expects all traffic to stop
- ❑ Accident frequency - How many? ____ per year
- ❑ Fatalities - How many? ____ per year
- ❑ Geometry of intersection roadways
  - ❍ Geometry is similar on both roadways
  - ❍ Geometry is different on both roadways
- ❑ Traffic volumes on intersecting roadways
  - ❍ Low volumes on both roadways
  - ❍ High volumes on both roadways
  - ❍ One roadway had significantly higher volume
- ❑ Sight distance is limited on one/both roadways

6. Has your agency been involved in a lawsuit where confusion over whether the intersection had a two-way or four-way stop control that was cited as a factor?

- ❑ Yes
- ❑ No
- ❑ Not sure
- ❑ Information not available.

If yes, what was the primary source of complaint against the state? Check any that apply.

- ❑ Non-standard supplemental plaque on minor roadway
- ❑ Driver confusion over stop-control conditions on minor roadway
- ❑ Driver confusion over stop-control conditions on major roadway
- ❑ No warning of cross traffic conditions on major roadway
- ❑ Other, *please explain:* ______________________________

____

7. In your opinion, should the National MUTCD include a sign or plaque that identifies an intersection as a two-way stop-controlled intersection?

- ❑ Yes
- ❑ No
- ❑ Not sure

Comments: ______________________________

____

Please return the survey to the following address:

Texas Transportation Institute
Texas A&M University System
College Station, TX 77843-3135
FAX: (409) 845-9761

Participating States

A total of 32 states returned surveys. The following information in Table A-2 summarizes these states that participated.

Table A-2. State Departments of Transportation Participating in Survey

State	State	State	State
Alaska	Kansas	New Hampshire	Pennsylvania
Arkansas	Kentucky	New Mexico	Rhode Island
Colorado	Maryland	New York	South Carolina
Connecticut	Michigan	North Carolina	Utah
Delaware	Minnesota	North Dakota	Virginia
Idaho	Mississippi	Ohio	Washington
Indiana	Missouri	Oklahoma	West Virginia
Iowa	Nebraska	Oregon	Wyoming
TOTAL RETURNS: 32			

Survey Results

The following section summarizes the answers and responses for each of the survey questions. Each question, response choices, percentage of responses, and comments are provided in Figures A-10 through A-15.

QUESTION: Has your state conducted any evaluations of treatments that are used to distinguish a two-way stop-controlled intersection from a four-way stop-controlled intersection?

ANSWER:
7% Yes
93% No

Comments:
- 3-way and 4-way are very infrequently used in NC.

Figure A-10. State DOT Question Pertaining to Evaluation of TWSC Intersections

QUESTION: Please indicate which, if any, of the following supplemental plaques from the National MUTCD are used in your state.

ANSWER:

4-WAY	3-WAY	ALL WAY
91%	75%	75%

Comments:
- Depends on geometrics of location.
- 4-way most common. Others used on special conditions.
- NCDOT has 14 operational divisions. The one division polled that has utilized multi-way stop indicated they use "3-way" and "4-way" panels. Since "ALL-WAY" is in the MUTCD, it would also be appropriate and may be used in some divisions.
- Normally, the 4-way sign is used, however, some cities have installed the "ALL-WAY" plaque.
- All of these signs are in the Ohio MUTCD.
- These are used more by cities than by the state.
- 3- or 4-way plaque preferable. All-way plaque is least desirable.

Figure A-11. State DOT Question Pertaining to Existing Intersection Treatments

QUESTION: Does your state currently have one or more specific treatments or devices that distinguish a two-way stop from a four-way stop?

ANSWER:

39% Yes
61% No

Comments
- Supplemental signing for Stop Signs, attached.
- CROSS TRAFFIC DOES NOT STOP.
- CROSS TRAFFIC DOES NOT STOP is under evaluation, but not generally used.
- CROSS TRAFFIC DOES NOT STOP used in high accident locations.
- See attached detail, CROSSROAD WARNING SIGN.
- Tabs used on all multiway stops...not used on 2-way stops.
- 4-way plaques.
- CROSS TRAFFIC DOES NOT STOP, NOT A 4-WAY STOP.
- ALL-WAY signs are used at intersections which have 4-way stop sign controls. The omission of the sign means one or more approaches does not have a stop sign.
- The absence of the supplemental "X-WAY" plaque on two-way stop condition indicated it is not a multiway stop condition.
- A "Cross Traffic Does Not Stop" sign is used on a limited basis at locations where motorists have, or it is anticipated that they will have a problem recognizing that the cross street traffic does not stop.
- We use 4-way and All-way plaques under stop signs at 4-way stops but no additional signs are used at 2-way stops.
- Normally, the 4-way sign is installed below the STOP sign.

Figure A-12. State DOT Question Pertaining to Existence of TWSC Treatments

QUESTION:	What are the primary factors that would influence your decision to install a treatment or device to warn drivers that all approaches at an intersection are not required to stop. Check all that apply.	
ANSWERS:	59%	Driver expects all traffic to stop
	88%	Accident frequency - How many? ____ per year
	35%	Fatalities - How many? ____ per year
	53%	Geometry of intersection roadways
		100% Geometry is similar on both roadways
		50% Geometry is different on both roadways
	41%	Traffic volumes on intersecting roadways
		22% Low volumes on both roadways
		33% High volumes on both roadways
		67% One roadway had significantly higher volume
	41%	Sight distance is limited on one/both roadways
	Comments: • Accident frequency - five per year. • Experimental locations based on accident reports that people said they thought it was a 4-way stop.	

Figure A-13. State DOT Question Pertaining to Factors for Using a TWSC Treatment

QUESTION:	Has your agency been involved in a lawsuit where confusion over whether the intersection had a two-way or four-way stop-control that was cited as a factor?	
ANSWERS:	3%	Yes
	57%	No
	35%	Not sure
	10%	Information not available
	If yes, what was the primary source of complaint against the state? Check any that apply.	
	50%	Non-standard supplemental plaque on minor roadway
	100%	Driver confusion over stop-control conditions on minor roadway
	50%	Driver confusion over stop-control conditions on major roadway
	50%	No warning of cross traffic conditions on major roadway
	Comments: • Yes, with old style CROSS TRAFFIC DOES NOT STOP WITHOUT ARROWS. Driver said she didn't need to stop because she was going across the road and not turning. • Red/red and red/yellow beacons are used and may confuse drivers. • At first sign of trouble.	

Figure A-14. State DOT Question Pertaining to State Liability

QUESTION:	In your opinion, should the National MUTCD include a sign or plaque that identifies an intersection as a two-way stop-controlled intersection?
ANSWERS:	13% Yes 71% No 16% Not Sure **Comments:** • People do get confused at those intersections. • State opinion split, majority say no. • It is generally understood that if the 4-way supplemental plaque isn't installed, then it is a 2-way stop. • High % of int are 2-way. Special treatment not needed is not needed on all. • In the absence of the plaque, the driver should assume that the stop is a 2-way stop. • Local agencies use this now. If necessary, signing of this nature can be used without the sign being included in the MUTCD. • Should be left to the discretion of the governmental entity. • This issue needs further review. • Unless 3- or 4-way plaques are present, drivers should assume that traffic on a main road does not stop. I feel they would tend to confuse the 2-way with a 3- or 4-way panel, and pull out in front of oncoming traffic. • Consideration should be given to installing a sign or plaque for a limited time period when converting a multi-stop to a 2-way stop. • We are not aware of a problem of this type in this area.

Figure A-15. State DOT Question Pertaining to an Adopted MUTCD Standard

APPENDIX B

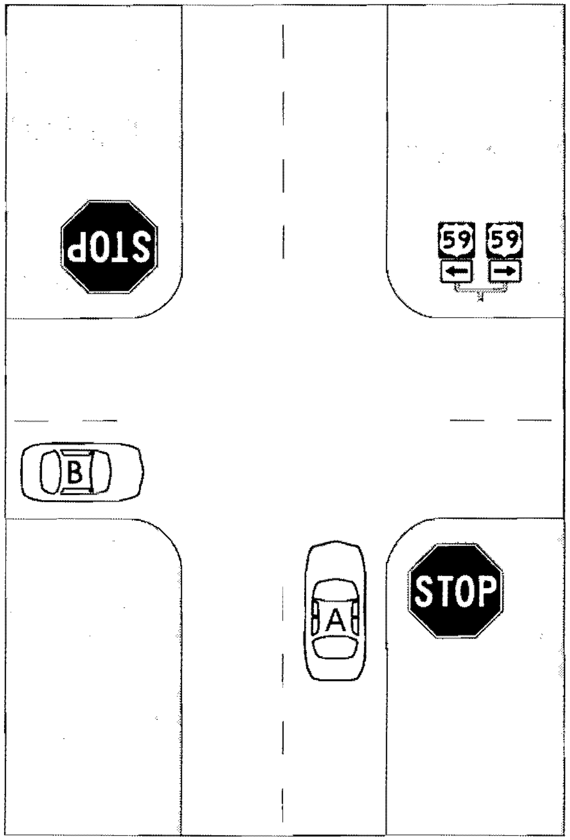
DRIVER SURVEY INSTRUMENTS

This appendix provides samples of two survey instruments; one was utilized for the sign preference evaluation and the other for the driver behavior evaluation. Each survey was administered separately and was developed with the assistance of the TxDOT Advisory Panel. The development, administration, and results of the sign preference evaluation and the driver behavior evaluation are provided in Chapter 3 and 4, respectively.

A copy of each survey instrument is provided on the following pages. The sign preference survey instrument is presented first, followed by the driver behavior survey instrument.

You have been randomly selected to assist in a research study to improve the safety at intersections where stop signs are used.

Your input is extremely important. Please take a few minutes to complete this survey and return it in the postage-paid envelope.



Based on the drawing above, please answer the twelve questions that begin in Column 2:

1. Which vehicle at the intersection has the right-of-way? Please ✓ only **ONE** answer.

❑ Neither Vehicle ❑ Vehicle A
❑ Both Vehicles ❑ Vehicle B
❑ Not Sure

2. At an intersection like this how often are you unsure of who has to stop? Please ✓ only **ONE** answer.

❑ Never ❑ Sometimes ❑ Always

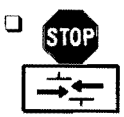
3. If you are in **Vehicle A**, which WORD-SIGN best tells you that **Vehicle B** has the right-of-way? Please ✓ only **ONE** answer.

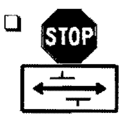
❑ 

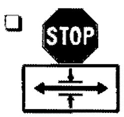
❑ 

❑ 

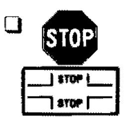
4. If you are in **Vehicle A**, which SYMBOL-SIGN best tells you that **Vehicle B** has the right-of-way? Please ✓ only **ONE** answer.

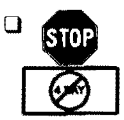
❑ 

❑ 

❑ 

5. If you are in **Vehicle A**, which SYMBOL/WORD-SIGN best tells you that **Vehicle B** has the right-of-way? Please ✓ only **ONE** answer.

❑ 

❑ 

❑ 

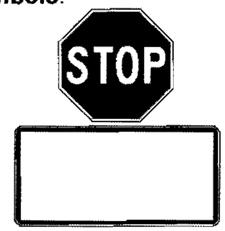
6. Of the signs chosen in the previous three questions, which **ONE** do you prefer the most? Please ✓ only **ONE** answer.

❑ Question 3 ❑ Question 4 ❑ Question 5

7. Do you think a sign in addition to the STOP sign is needed to tell you that **Vehicle B** has the right-of-way?

❑ Yes ❑ No ❑ Not Sure

8. Can you suggest a **better** sign that would best tell drivers **Vehicle B** has the right-of-way at the intersection? Fill in the sign below with **words** and/or **symbols**.



9. What is your sex?

❑ Male
❑ Female

10. What is your Age?

❑ 16 - 24
❑ 25 - 54
❑ 55 - 64
❑ 65+

11. What is your family background?

❑ African-American (black)
❑ American Indian
❑ Anglo (white)
❑ Asian
❑ Hispanic
❑ Other (please indicate)________________

12. What is the highest level of school you completed?

❑ Less than high school
❑ High school graduate (or equivalent)
❑ Some college
❑ College graduate

Thank You For Your Help. Please Return In the Postage-Paid Envelope by March 30, 1996.

TEXAS TRANSPORTATION INSTITUTE

VIDEO SURVEY

1. If the white car doesn't turn off, will it hit you? (please check only one answer)
   - No
   - Yes
   - Not sure

2. What lead you to this conclusion? (please **print** your answer)

3. How many roadway directions have to stop? (please check only one answer)
   - One
   - Two
   - Three
   - Four
   - Not sure

4. Why are you here today?
   - Obtain a driver's license
   - Renew your driver's license
   - Replace lost/stolen driver's license
   - Obtain Identification card
   - Waiting for someone else
   - Change personal information
   - Other ____________________

5. What is your age?
   - Less than 24
   - 25 to 54
   - 55 to 64
   - Over 65

6. How long have you been driving?
   - Less than 1 year
   - 1 to 5 years
   - 6 to 50 years
   - More than 50 years

7. What is your gender (sex)?
   - Male
   - Female

8. What is your family background?
   - Anglo (White)
   - African American (Black)
   - American Indian
   - Asian
   - Hispanic
   - Other ____________________

9. What is the highest level of school you have completed?
   - Less than high school
   - High school or equivalent
   - Some college
   - College graduate

Thank you for your participation in helping to make our roads safer!

APPENDIX C

TRAFFIC CONFLICT STUDIES

This appendix provides a more detailed discussion of the statistical procedure for determining required observation times for a conflict study. Sample calculations are included with the discussion. This appendix also provides a tabulated summary of the turning-movement counts that were conducted during the conduct of the traffic conflict studies.

CALCULATION OF REQUIRED OBSERVATION TIME

The required observation time is directly related to the frequency at which conflicts are observed to occur. Therefore, the duration must be estimated in advance of the actual data collection by using values from previous research. The number of hours required for conflict observation is calculated using Equation C-1 (*11*).

$$n = \left(100\frac{t}{p}\right)^2 \left(\frac{\sigma_e^2}{\bar{Y}^2}\right) \qquad \text{(C-1)}$$

where:

- n = number of hours of observation needed;
- t = 1.65 (statistic from the normal distribution defined by α, the level of significance);
- p = 50 percent (percent of the hourly mean; e.g., if the hourly mean is 6 conflicts and p is 50 percent, the precision of the estimate is 6 ± 50 percent, or 3 to 9 conflicts per hour);
- σ_e^2 = hourly variance from previous conflict studies (see Table 18); and
- $\bar{Y}$ = hourly mean number of conflicts of a specific type (see Table 20).

The statistical level of significance, α, was chosen to be 0.10, resulting in a *t-statistic* equal to 1.65. The precision of the estimate of the hourly mean, p, was selected as 50 percent. The variance for each conflict type, σ_e^2, was established by previous research and given in Table 18. The hourly mean number of conflicts was obtained through this study and was shown in Table 20. These variables are inserted into Equation (C-1) to complete Table C-1.

Table C-1. Hours of Required Observation Time for a Traffic Conflict Study

Conflict Type	Estimated Hourly Variance[1]	Number of Hours					
		Waco	Lorena	Hungerford	Port Lavaca	Bastrop	Crockett
Right-Turn from Right	1.11	23	91	91	366	366	163
Right-Turn from Left	Not listed	[2]					
Thru from Right	0.35	9		29	51	115	115
Thru from Left	0.42	138				553	553
Left-Turn from Right	0.78		1028	257	257	1028	64
Left-Turn from Left	1.01	21	333	53	8	148	27

Note: [1] From Table 2 (*11*).
[2] Blanks indicate conflict types not observed.

The right-turn from left conflict was not observed at any of the sites, and therefore, is omitted from Table C-1. This conflict type occurs when a right-turning vehicle encroaches into the oncoming major street as the vehicle makes the turn. The denominator of Equation (C-1), the mean number of conflicts per hour squared, results in a large observation time if the value is much less than 1.0. This is the reason infrequent conflict types result in long observation times. To reduce the required observation period to less than one standard day, Table C-2 lists the minimum conflict frequency that must be observed.

Table C-2. Minimum Conflict Frequency Required for One Day of Observation

Conflict Type	Estimated Hourly Variance[1]	Conflict Frequency (number/day)	Hours of Observation Required
Right-Turn from Right	1.11	12	10.2
Thru from Right	0.35	7	9.4
Thru from Left	0.42	8	8.6
Left-Turn from Right	0.78	10	10.3
Left-Turn from Left	1.01	11	11.0

Note: [1] From Table 2 (*11*).

SAMPLE CALCULATION

<u>Site</u>:	Waco
<u>Traffic Conflict Type</u>:	Right-Turn from Right
<u>Variance</u>:	1.11
<u>Mean Number of Conflicts Observed</u>:	8
<u>Mean Number of Conflicts per Hour</u>:	0.7273 (8/11)

$$n = \left(\frac{100 \times 1.65}{50}\right)^2 \left(\frac{1.11}{(8/11)^2}\right) = (10.89)\ (2.10) \qquad \text{(C-2)}$$

$$n = 22.9 \approx 23 \text{ hours} \qquad \text{(C-3)}$$

TURNING MOVEMENT COUNTS

Turning movement counts for all vehicles, including trucks, were conducted at each of the study sites. The counts were conducted in the field and, during non-observation periods, by reviewing the video tapes for each respective site. The data are tabulated in Tables C-3 through C-14.

Table C-3. Turning Movement Counts at Hungerford Intersection

	From: 1161 West			From: 60 North			From: 1161 East			From: 60 South			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	16	15	20	10	127	29	25	6	11	6	63	9	337
8:00	10	12	17	9	103	21	15	10	11	6	70	12	296
9:00	12	12	16	15	87	15	14	3	3	10	62	8	257
10:00	7	11	13	8	86	17	16	5	6	8	72	8	257
11:00	9	5	10	17	93	9	17	10	5	5	86	9	275
12:00	14	8	15	9	88	13	14	6	6	6	82	11	272
1:00	10	5	7	13	88	14	20	4	6	8	91	11	277
2:00	14	5	8	10	96	14	16	4	10	3	75	12	267
3:00	7	12	9	18	136	28	18	6	8	8	76	12	338
4:00	12	18	9	22	128	25	23	13	11	9	107	13	390
5:00	17	11	8	22	141	21	39	10	3	11	112	17	412
Total	128	114	132	153	1173	206	217	77	80	80	896	122	3378

Table C-4. Large Vehicle Counts at Hungerford Intersection

	From: 1161 West			From: 60 North			From: 1161 East			From: 60 South			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	0	8	0	13	1	1	0	0	0	0	3	0	26
8:00	0	1	1	9	6	3	3	0	0	0	6	0	29
9:00	0	0	0	13	4	4	1	0	0	0	4	0	26
10:00	0	8	1	11	11	2	1	1	0	0	3	0	38
11:00	0	4	0	3	4	2	1	1	0	0	6	0	21
12:00	0	3	0	8	8	3	1	1	0	0	4	0	28
1:00	0	11	0	8	2	4	2	2	0	0	6	0	35
2:00	0	7	0	7	7	0	1	2	0	0	6	0	30
3:00	0	3	1	2	14	1	3	2	0	0	10	0	36
4:00	0	2	1	2	8	3	0	0	0	0	5	0	21
5:00	1	1	0	1	3	3	0	1	0	0	3	0	13
Total	1	48	4	77	68	26	13	10	0	0	56	0	303

Table C-5. Turning Movement Counts at Bastrop Intersection

	From: SH 21 West			From: FM 812 North			From: SH 21 East			From: FM 812 South			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	1	69	7	4	28	15	118	69	5	5	247	5	573
8:00	2	64	5	1	23	24	52	100	5	6	98	6	386
9:00	1	69	4	10	30	15	42	86	2	1	53	0	313
10:00	4	70	3	1	26	22	28	88	6	4	53	3	308
11:00	2	73	0	5	33	24	25	91	6	8	56	4	327
12:00	3	73	3	6	40	26	29	96	4	4	57	3	344
1:00	0	75	3	3	56	31	24	90	3	2	47	1	335
2:00	3	86	10	5	71	33	23	120	6	5	58	1	421
3:00	1	97	7	1	99	50	27	116	4	5	52	3	462
4:00	5	117	8	11	172	99	29	119	9	14	43	4	630
5:00	4	122	8	9	234	130	20	106	8	8	44	2	695
Total	26	915	58	56	812	469	417	1081	58	62	808	32	4794

Table C-6. Large Vehicle Counts at Bastrop Intersection

	From: SH 21 West			From: FM 812 North			From: SH 21 East			From: FM 812 South			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	1	15	0	0	1	0	0	13	0	0	1	0	31
8:00	0	29	1	1	2	4	0	17	0	0	0	0	54
9:00	0	15	1	1	0	1	2	20	0	1	0	0	41
10:00	0	27	1	0	0	1	1	18	1	0	0	0	49
11:00	0	30	1	0	0	1	0	17	0	0	0	0	49
12:00	0	21	0	0	1	0	0	19	0	0	0	0	41
1:00	0	21	0	0	0	1	2	17	0	0	0	0	41
2:00	0	11	0	1	0	0	1	13	0	1	1	0	28
3:00	2	7	1	0	1	2	0	12	0	0	1	0	26
4:00	0	14	1	1	2	0	0	3	0	0	1	1	23
5:00	1	12	0	3	3	1	0	4	0	0	1	0	25
Total	4	202	6	7	10	11	6	153	1	2	5	1	408

Table C-7. Turning Movement Counts at Crockett Intersection

	From: Loop 304 West			From: FM 2022 North			From: Loop 304 East			From: FM 2022 South			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	6	139	3	8	38	36	12	101	9	15	5	12	384
8:00	5	117	4	9	35	31	13	87	18	18	14	7	358
9:00	6	84	6	5	22	28	25	96	16	19	9	6	322
10:00	3	108	5	5	15	29	23	81	21	14	18	5	327
11:00	8	107	5	8	15	20	33	120	13	24	26	6	385
12:00	7	118	7	8	20	32	36	140	28	23	16	7	442
1:00	7	104	14	9	15	30	28	122	16	18	10	9	382
2:00	6	109	6	7	13	20	26	109	16	18	15	10	355
3:00	8	98	10	12	23	22	25	123	26	10	22	14	393
4:00	14	111	7	6	13	28	50	136	28	31	24	13	461
5:00	7	117	10	2	19	20	44	115	16	19	36	8	413
Total	77	1212	77	79	228	296	315	1230	207	209	195	97	4222

Table C-8. Large Vehicle Counts at Crockett Intersection

	From: Loop 304 West			From: FM 2022 North			From: Loop 304 East			From: FM 2022 South			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	0	5	2	0	0	0	0	4	0	0	0	0	11
8:00	0	4	0	0	0	2	0	5	0	0	0	0	11
9:00	0	19	0	0	0	0	1	8	0	1	0	0	29
10:00	0	4	1	0	0	0	2	12	0	1	0	0	20
11:00	0	11	0	0	0	0	0	10	0	0	0	0	21
12:00	0	5	0	0	0	0	0	5	0	0	0	0	10
1:00	0	8	0	0	0	0	0	8	0	0	0	0	16
2:00	0	10	0	0	0	0	0	11	0	0	0	0	21
3:00	0	12	0	0	0	0	0	9	0	0	0	0	21
4:00	0	9	0	0	0	0	0	6	0	0	0	0	15
5:00	0	5	0	0	0	0	0	7	0	0	0	0	12
Total	0	92	3	0	0	2	3	85	0	2	0	0	187

Table C-9. Turning Movement Counts at Waco Intersection

	From: FM 3400 North			From: Loop 340 East			From: FM 3400 South			From: Loop 340 West			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	40	15	6	4	445	18	30	55	26	21	345	102	1107
8:00	36	20	1	2	205	14	10	29	13	11	192	51	584
9:00	18	30	7	6	187	9	11	35	15	9	178	30	535
10:00	23	19	2	4	170	12	7	24	20	12	194	23	510
11:00	40	23	2	1	183	5	7	24	9	11	156	30	491
12:00	32	35	7	6	177	9	12	29	10	10	195	36	558
1:00	30	27	5	6	194	12	5	30	14	13	177	30	543
2:00	32	29	5	6	211	17	12	33	7	13	213	22	600
3:00	44	39	6	7	230	8	4	33	13	17	289	46	736
4:00	52	52	5	7	329	23	19	26	21	15	398	41	988
5:00	99	48	10	9	356	12	14	25	15	29	502	42	1161
Total	446	337	56	58	2687	139	131	343	163	161	2839	453	7813

Table C-10. Large Vehicle Counts at Waco Intersection

	From: FM 3400 North			From: Loop 340 East			From: FM 3400 South			From: Loop 340 West			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	1	1	0	0	63	2	21	6	5	15	29	0	143
8:00	1	9	0	0	68	6	3	8	1	0	61	1	158
9:00	6	4	1	0	71	24	14	8	2	7	69	5	211
10:00	6	4	1	0	77	13	19	8	3	3	82	7	223
11:00	11	8	0	0	72	11	15	7	2	4	67	11	208
12:00	10	4	0	0	61	13	6	7	2	0	46	9	158
1:00	5	5	1	0	74	11	12	6	1	3	74	7	199
2:00	7	5	1	1	86	13	8	5	16	11	65	10	228
3:00	7	4	2	0	70	13	13	3	14	10	53	4	193
4:00	3	3	1	1	58	2	7	1	14	13	40	12	155
5:00	4	0	0	0	19	0	8	3	1	13	33	5	86
Total	61	47	7	2	719	108	126	62	61	79	619	71	1962

Table C-11. Turning Movement Counts at Lorena Intersection

	From: FM 2837 North			From: FM 2113 East			From: FM 2837 South			From: FM 2113 West			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	12	124	28	14	56	77	70	79	25	103	193	51	832
8:00	10	19	10	10	42	24	37	32	16	18	99	19	336
9:00	10	19	7	7	36	25	35	34	10	7	65	13	268
10:00	10	18	4	8	46	23	19	20	8	10	49	9	224
11:00	10	30	6	9	74	33	28	19	10	8	52	12	291
12:00	24	18	6	12	57	31	25	19	10	17	65	12	296
1:00	14	12	9	15	61	34	37	9	15	7	59	12	284
2:00	18	24	13	11	55	45	26	27	8	17	48	13	305
3:00	26	39	22	21	107	50	95	79	48	21	59	17	584
4:00	53	51	17	33	146	72	57	46	30	29	101	22	657
5:00	58	73	19	38	204	108	51	67	36	37	95	28	814
Total	245	427	141	178	884	522	480	431	216	274	885	208	4891

Table C-12. Large Vehicle Counts at Lorena Intersection

	From: FM 2837 North			From: FM 2113 East			From: FM 2837 South			From: FM 2113 West			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	0	2	0	0	3	0	0	0	0	1	1	0	7
8:00	0	0	0	1	0	0	0	0	0	0	0	0	1
9:00	0	1	0	1	2	0	0	0	1	0	1	0	6
10:00	0	1	0	0	1	1	0	1	0	1	0	0	5
11:00	0	2	0	0	2	0	0	1	0	0	1	0	6
12:00	0	1	0	0	2	0	0	0	0	0	0	0	3
1:00	1	0	0	0	2	0	0	2	1	1	3	0	10
2:00	1	0	0	0	1	0	0	1	0	0	1	0	4
3:00	0	0	0	0	0	0	0	1	0	1	2	1	5
4:00	0	0	0	0	0	0	0	1	0	0	1	0	2
5:00	0	0	0	0	1	0	0	0	1	0	0	0	2
Total	2	7	0	2	14	1	0	7	3	4	10	1	51

Table C-13. Turning Movement Counts at Port Lavaca Intersection

	From: 2433 East			From: 35 South			From: 2433 West			From: 35 North			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	10	7	25	17	179	3	9	38	33	16	142	19	498
8:00	8	14	12	8	118	5	4	13	10	13	87	12	304
9:00	7	9	10	12	114	7	5	3	10	10	93	12	292
10:00	4	13	17	6	112	10	4	2	16	9	90	0	283
11:00	20	2	3	7	132	6	2	2	11	12	109	9	315
12:00	12	2	14	8	111	6	12	2	13	9	120	18	327
1:00	11	5	8	5	110	8	7	10	9	13	116	17	319
2:00	3	15	19	4	115	2	9	12	10	15	106	4	314
3:00	5	11	12	12	115	4	3	10	12	18	95	6	303
4:00	11	41	15	27	222	13	2	11	19	32	164	12	569
5:00	16	32	13	22	273	14	2	25	20	21	188	8	634
Total	107	151	148	128	1601	78	59	128	163	168	1310	117	4158

Table C-14. Large Vehicle Counts at Port Lavaca Intersection

	From: 2433 East			From: 35 South			From: 2433 West			From: 35 North			
	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Total
7:00	0	10	0	0	0	0	0	5	0	0	0	1	16
8:00	0	11	1	0	1	0	1	4	0	0	1	0	19
9:00	0	9	0	0	0	1	2	14	1	2	1	0	30
10:00	2	3	0	0	1	0	0	14	0	0	3	3	26
11:00	0	13	0	1	0	0	0	11	0	0	0	1	26
12:00	2	14	1	0	2	0	0	11	0	1	3	2	36
1:00	0	8	0	0	0	0	0	10	1	2	0	0	21
2:00	0	8	1	0	2	1	0	11	0	0	1	1	25
3:00	0	8	0	0	1	0	1	10	1	0	1	0	22
4:00	2	8	0	0	2	0	0	10	0	0	1	1	24
5:00	0	3	0	0	0	0	0	10	0	0	0	0	13
Total	6	95	3	1	9	2	4	110	3	5	11	9	258

APPENDIX D

TxDOT INTERIM CHANGE TO THE MUTCD

This appendix contains a memorandum from the Traffic Operations Division of the Texas Department of Transportation. The memorandum addresses that if supplemental signing is to be used at two-way stop-controlled intersections in Texas, the preferred design for this supplement is shown in the memorandum's attachment.

Texas Department of Transportation

Memorandum

TO: All District Engineers

DATE: April 24,1997

FROM: David T. Newbern, P.E.

Originating Office:
Traffic Operations - TE

SUBJECT: 1980 Texas Manual on Uniform Traffic Control Devices

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A research study titled *Traffic Control Devices At Two-way Stop-Controlled Intersections* (Research Study Number 0-1374) conducted by the Texas Transportation Institute (Texas A&M - College Station) evaluated the effectiveness of supplemental plaques for stop signs at two-way stop-controlled intersections. The study indicated that if supplemental signs are used, most drivers understand and prefer the design attached.

We plan to add the following section and the attached CROSS TRAFFIC DOES NOT STOP plaque to the *Texas Manual on Uniform Traffic Control Devices* (TMUTCD) during the next revision.

2B-4.1Cross Traffic Does Not Stop Plaque (R1-5)

CROSS TRAFFIC DOES NOT STOP plaques may be used to supplement STOP signs on approaches to two-way stop-controlled intersections where an engineering study indicates drivers frequently misinterpret the intersection as an ALL-WAY or 4-WAY stop condition.

This memorandum may be considered to be an interim change to the TMUTCD.

If there are any questions, please call Mr. Dan Maupin at (512) 416-3128 or me at (512) 416-3200.

Tom Newbern

DM:dm
Attachment

A-4.1

R1-5R(L)

R1-5B

* reduce spacing 15%

SIGN NUMBER	SIGN	DIMENSIONS (MM)								
		A	B	C	D	E	F	G	H	J
R1-5	STD.	900	450	15	25	75	75D	335	35	35
SR1-5	SPECIAL	1200	600	15	25	100	100D	450	50	35

COLORS

LEGEND - BLACK (NON-REFL)
BACKGROUND - WHITE (REFL)

(Metric)

A-4.1

R1-5R(L)

R1-5B

* reduce spacing 15%

SIGN NUMBER	SIGN	DIMENSIONS (INCHES)								
		A	B	C	D	E	F	G	H	J
R1-5	STD.	36	18		1	3	3D	13½	1½	1½
SR1-5	SPECIAL	48	24		1	4	4D	18	2	1½

COLORS

LEGEND - BLACK (NON-REFL)
BACKGROUND - WHITE (REFL)

(Rev. No. 4)