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16. Abstract

Researchers examined the impacts of various higher-conspicuity sign materials on traffic operations and driver behavior. A total of eight applications of microprismatic materials were evaluated: fluorescent yellow Chevrons, fluorescent yellow Chevron posts, fluorescent yellow Curve signs, fluorescent yellow Ramp Speed signs, fluorescent yellow Stop Ahead signs, fluorescent red Stop signs, flashing red light emitting diodes Stop signs, and a red border on Speed Limit signs. Researchers installed these signs at locations where it was believed that improving sign conspicuity would provide a statistically significant benefit to safety-related traffic operations. Traffic operations data collected before and after the sign upgrades included vehicle speeds, edge line encroachments, and stopping compliance. Overall, the higher-conspicuity applications produced mostly small changes in traffic operations, although many statistically significant beneficial results occurred. It should be pointed out that no negative driver behavioral impacts were found to be associated with any of the higher-conspicuity sign materials. Based on the findings, the researchers made recommendations pertaining to the application of higher-conspicuity sign materials. Fluorescent yellow Chevrons are recommended for statewide implementation. The other fluorescent yellow signs evaluated in the project are recommended for implementation on an as-needed basis. Microprismatic Stop signs are also recommended for implementation on an as-needed basis. Implementation of the flashing LED Stop sign and red border Speed Limit sign should be limited to an experimental basis, as permission is currently required from FHWA to install these signs. The fluorescent red Stop sign is not commercially available at this time.

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TRAFFIC OPERATIONAL IMPACTS OF HIGHER-CONSPICUITY SIGN MATERIALS

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CHAPTER 1:
INTRODUCTION

Traffic signs provide one of the primary means of communicating vital information to users of the street and highway transportation network in the United States. Signs are one of the three basic types of traffic control devices, the others being pavement markings and signals.

Over the last few decades, advancements have been made in the performance of sign materials, especially sheeting materials. The advancements to sheeting materials have occurred in material retroreflectivity, color, and durability and have been even more recognizable over the past decade with the widespread availability of microprismatic (also referred to simply as "prismatic") and fluorescent materials and in the creation of superior overlay materials. Another recently introduced sign visibility enhancement is the use of light emitting diodes (LEDs) embedded at the corners of the sign. As a result of such improvements, transportation agencies have been provided with new methods of improving sign conspicuity, legibility, and durability. However, these advanced sign materials are considerably more expensive than high intensity sheeting that is currently being used by TxDOT for most sign applications. Therefore, research is needed to determine applications where the benefits of using higher-visibility sign materials justify the additional expense.

ADVANCEMENTS IN THE CONSPICUITY OF SIGN MATERIALS

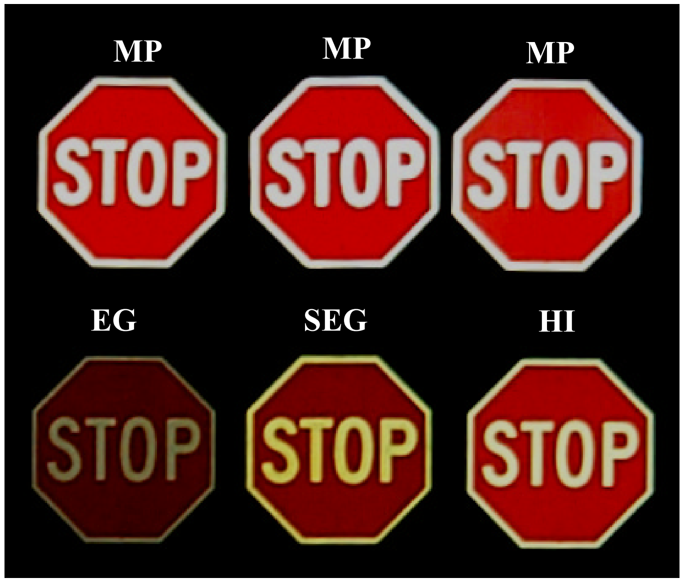
At least three major advancements in the conspicuity of sign materials have occurred over the past decade. The three advancements evaluated in the research performed here are:

- development of microprismatic sheeting materials,
- development of durable fluorescent colored sheeting materials, and
- use of flashing LEDs embedded in corners of the sign.

Each of these advancements has played a role in the improvement of sign conspicuity and/or durability.

Microprismatic Materials

Microprismatic sheeting materials increase the nighttime conspicuity of signs due to the greater retroreflectivity of the material. Nighttime low-beam luminance values for microprismatic sheeting on right side-mounted signs are on the order of five and twelve times those of high intensity and engineering grade sheeting, respectively (*1*). Figure 1 shows a nighttime comparison of Stop signs fabricated with sheeting materials of varying retroreflectivity.



Legend: EG = Engineer Grade
SEG = Super Engineer Grade
HI = High Intensity
MP = Microprismatic

Figure 1. Stop Signs Under Headlamp Illumination.

Fluorescent Materials

Fluorescent sheeting materials have been shown to provide higher-conspicuity under daylight conditions when compared to non-fluorescent colored sheeting, especially for peripheral detection and recognition (*2*). The enhanced performance is due to the increased daytime contrast of fluorescent signs with their surroundings brought on by substantial increases in sign luminance. Increases in daytime luminance of fluorescent sheeting are a result of the conversion of ultraviolet and short wavelength light rays to visible light. These increases are most evident during low-light conditions such as dawn and dusk (*3*). Figure 2 displays a comparison of the visual impact that fluorescent yellow provides vs. standard (i.e., non-fluorescent) yellow for both twilight and full-daylight conditions.

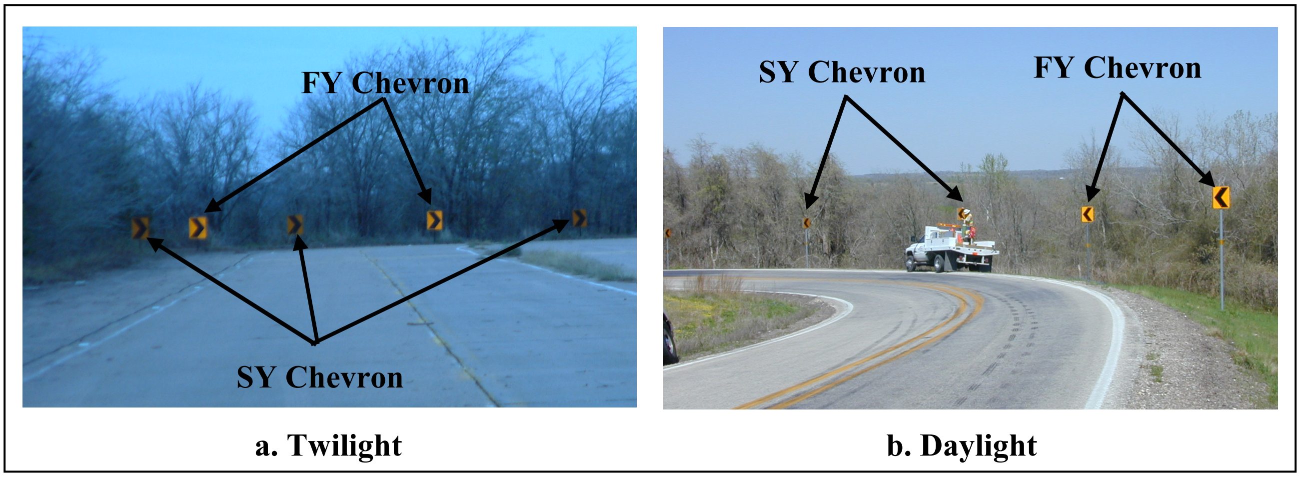


Figure 2. Comparison of Fluorescent vs. Standard Yellow During Twilight and Daylight.

Until recently, fluorescent colors had never achieved widespread acceptance for outdoor sign sheeting applications due to their poor color stability under harsh environmental conditions (*3*,*4*). However, material advancements have vastly improved the color durability of fluorescent sheeting, which has led to acceptance and use for traffic signing applications.

At present, fluorescent colors are available only in microprismatic materials. Used together, microprismatic/fluorescent materials can provide improvements to both daytime and nighttime sign conspicuity. Manufacturers have developed microprismatic sheeting in several fluorescent colors including yellow-green, yellow, and orange all of which are currently approved by the FHWA as an alternative to standard colors. Although fluorescent sheeting colors are only available in prismatic materials, the prismatic materials are also available in standard colors.

Flashing LED Embedded in the Sign

At least one sign manufacturer has begun selling signs with flashing LEDs embedded in the corners of the sign. The flashing LED signs are marketed as a lower cost alternative to flashing stop beacon, as they are cheaper to install and maintain. Because flashing signs are not addressed in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*5*), permission to experiment must be granted by the FHWA prior to installation of the flashing LED signs.

Currently, the embedded LED signs are available for Stop Ahead signs, Stop signs, Pedestrian Crossing signs, Railroad Crossing signs, and portable Stop/Slow paddles. The LEDs are powered by a combination of solar and rechargeable batteries, which allows the LEDs to flash at all times of day. The standard flash rate is approximately one flash per second (although the flash rate can be modified), and the LEDs are highly visible both day and night with a maximum luminous intensity of 600 candelas.

Availability of Higher-Conspicuity Sign Materials

As described in the previous subsections, there are several types of higher-conspicuity sign materials that are currently on the market. To the researchers' current knowledge, the types of advanced materials that are available from manufacturers as of August 2003 are indicated in Table 1. This list is not intended to be all-inclusive, it merely indicates the variety of choices that transportation agencies are faced with and presents materials available for evaluation in this project.

Table 1. List of Manufacturers for Common Higher-Conspicuity Sign Materials.

		Manufacturer[1]				
Type	**Colors**	**3M**	**AD**	**NCI**	**RF**	**TAPCO**
Microprismatic Sheeting Materials	Standard Colors	✓	✓	✓		
	Fluorescent Yellow	✓	✓			
	Fluorescent Yellow-Green	✓	✓			
	Fluorescent Orange[2]	✓	✓	✓	✓	
Flashing LED Signs	Multiple					✓

Notes: [1]Manufacturers listed in alphabetical order. 3M=Minnesota, Mining, and Manufacturing, AD=Avery Dennison, NCI=Nippon Carbide Industries (Nikkalite), RF = Reflexite, TAPCO = Traffic and Parking Control Co.
[2]Includes roll-up signs.

TxDOT and ASTM Sheeting Designations

TxDOT and the American Society of Testing and Materials (ASTM) designate sign sheeting materials differently. TxDOT reflective sheeting material specifications (flat-surface) are defined in DMS 8300. ASTM sheeting material specifications are defined in D 4956.

The major difference between TxDOT and ASTM sheeting specifications is the designation of microprismatic sheeting materials. While the ASTM provides three microprismatic sheeting specifications based on the retroreflective properties (Types VII, VIII, and IX), TxDOT categorizes all microprismatic sheeting materials together, only separating them by non-fluorescent (Type D) and fluorescent (Type E) materials. Table 2 provides a comparison of TxDOT vs. ASTM sheeting designations. This report uses only ASTM sheeting designations.

Table 2. TxDOT vs. ASTM Sign Sheeting Designations.

TxDOT	ASTM	Common Description
A	I	Engineer Grade (EG)
B	II	Super Engineer Grade (SEG)
C	III, IV	High Intensity (HI)
D	VII, VIII, IX (non-fluorescent)	Microprismatic (MP)
E	VII, VIII, IX (fluorescent)	

PROBLEM STATEMENT

The conspicuity of a traffic sign is the most important factor related to whether or not it will be detected (*6*). Under many circumstances, the current high intensity sign sheeting provides adequate conspicuity and legibility for the driving population under both day and night conditions. However, extreme situations exist, such as locations with limited sight distance, where, if a motorist fails to detect a warning or regulatory sign, the potential consequences could be severe. In some of these situations, the day and night conspicuity of signs should be greater under these conditions than for signs used in typical situations.

Transportation agencies have historically employed various methods to increase sign conspicuity, each method displaying varying degrees of effectiveness and cost. The addition of orange overhead flags is an inexpensive method for increasing sign conspicuity. However, they are useful for improving sign detectibility only during daylight hours and have a tendency to fade quickly. Oversized signs often increase the legibility of the sign, but do not necessarily increase the conspicuity of the sign since the color and reflective capabilities of the sign remains unchanged. Flashing beacons have been effective for increasing sign conspicuity, although they are costly to install and maintain and do not improve the legibility or conspicuity of the sign itself.

Fluorescent and prismatic sheeting materials and the use of LEDs embedded in the sign are new methods for improving sign conspicuity. These materials are attractive to engineers because the visual enhancements are made directly to the sign, thereby increasing both the sign conspicuity and legibility and consequently promoting a safer roadway environment for drivers both day and night. However, for a reduction in crashes to occur, the advanced signs must consequently prompt improvements in motorist behavior.

GOAL AND OBJECTIVES

While prior research has found higher-conspicuity materials to have greater visibility characteristics, little research has been done to assess the impact of these higher-conspicuity materials on driver behavior and the resulting impacts on traffic safety. The goal of the research presented herein was to determine specific field applications where the use of microprismatic and fluorescent sign sheeting materials induce changes in driver performance that are related to improved highway safety. Based on this goal, the objectives for this research project were:

- Evaluate the traffic operational effects of microprismatic sheeting materials (nighttime).
- Evaluate the traffic operational effects of fluorescent sheeting materials (daytime/twilight).
- Evaluate the traffic operational effects of flashing LEDs embedded in the corners of Stop signs.
- Based on the research results, develop recommendations for the use of higher-conspicuity sign materials.

RESEARCH APPROACH

The basic approach was to collect and analyze traffic operations data at selected field sites before and after the specified sign treatments were put in place. Sites were selected based largely on safety history and included mostly horizontal curves and stop-controlled intersections. At each site, traffic operations data for the existing standard-colored sign were typically collected first, followed by replacement of the existing sign with the higher-conspicuity sign, followed many days later by collection of traffic operations data in the same manner as before. Typical traffic operations data collected at each site included: vehicular speeds (all sites), edge line encroachments (selected curves), and stopping compliance (selected stop-controlled intersections). To evaluate the relative sign performance at various levels of ambient illumination, data were collected during daytime, twilight (where appropriate), and nighttime periods. Appropriate statistical analysis procedures were then applied to the data allowing the researchers to draw inferences and make recommendations for application of the various higher-conspicuity signs.

CHAPTER 2:
LITERATURE REVIEW

While the higher-conspicuity sign materials described in Chapter 1 are known to offer improved levels of brightness under various conditions (e.g., fluorescence improves daytime luminance, prismatic materials improve nighttime luminance), quantification of field improvements is necessary. The literature provided two common methods for field evaluation of higher-conspicuity sign material applications:

- visibility/conspicuity measures, and
- surrogate crash measures (i.e., traffic operation/driver behavior measures).

Formal crash evaluations involving field applications of higher-conspicuity sign materials were not found in the literature.

VISIBILITY/CONSPICUITY MEASURES

Visibility studies constituted a major portion of the literature involving the benefits of higher-conspicuity sign materials. Many of these studies focused on comparing detection distances (conspicuity) or legibility distances of the advanced materials to those of standard materials. In short, the literature presents conclusive evidence that fluorescent and microprismatic sheeting materials provide substantial improvements to the visibility of signs over standard materials during daytime and nighttime conditions.

Fluorescent Materials

Fluorescent pigments are designed to enhance the detection or conspicuity of a target during daylight hours, especially dawn, dusk, and overcast periods. The literature provides sound evidence suggesting that, during the day, fluorescent materials are detected at greater distances and with fewer misses than their non-fluorescent counterparts. As a result, fluorescent colors are increasingly being used in typical practice for a myriad of traffic control and traffic safety devices, including work zone traffic control devices, construction worker vests, and traffic signs.

Detection distance as a function of fluorescence has been evaluated in a number of studies. A 1996 Norwegian study found that both elderly and younger adults detect fluorescent signs earlier than non-fluorescent signs when viewed from a moving railcar both during the day and at night (*7*). The greatest benefits were associated with the elderly participants. In addition to improved forward detection distances, a Zwahlen and Schnell study found that fluorescent targets are also better detected peripherally during the day than their non-fluorescent counterparts (*8*). Although fluorescent materials are mainly used for their enhancements to sign detectibility during the day, Schnell et al. found that they also provide better daytime legibility distances*,* with improvements of 5.3 to 15.9 percent (*9*). Furthermore, Schnell et al. found that fluorescent yellow-green school zone signs do not lose their "eye catching" quality after drivers become familiar with seeing the more conspicuous fluorescent signs (*10*).

Microprismatic Materials

Microprismatic materials are designed with enhanced retroreflective capabilities making targets brighter under headlamp illumination at night. The literature provides sound evidence suggesting that under headlamp illumination at night, prismatic sign sheeting materials are detected at greater distances, and in many cases, are more legible, than beaded sign sheeting materials, including engineering grade and high intensity. As a result, prismatic sheeting materials are increasingly being used in typical practice for many traffic control and traffic safety devices, including work zone traffic control devices and traffic signs.

Nighttime legibility of ASTM Type VII microprismatic sheeting (e.g., 3M Long Distance Performance – LDP) was evaluated in a TTI study by Carlson et al. This study determined that while prismatic sheeting provides greater nighttime conspicuity of signs, it does not necessarily provide the best nighttime legibility distances. This is because overly bright sheeting materials when used in certain legend/background combinations and with certain stroke widths can have an irradiation or "blooming" effect when viewed at night under normal headlight illumination. The microprismatic materials were found to provide superior legibility distances as the letter stroke widths were increased (*11*).

SURROGATE CRASH MEASURES

While improvements to the visibility and conspicuity of the sign are important to help ensure that drivers will be properly alerted to the sign, determining their effects on driver performance in the field is valuable to assess the impact of the materials on safety. In other words, the increased sign conspicuity must translate to an improvement in motorist behavior in actual driving situations for roadway safety improvements to be realized. As such, the objective of the research described in this report was to identify situations in the field where higher-conspicuity sign materials may offer safety-related traffic operations and driver behavior benefits beyond high intensity. These situations may include horizontal curves, intersection approaches, freeway exit ramps, etc. A detailed discussion of surrogate crash literature for higher-conspicuity sign material applications and other related traffic control device applications was deemed appropriate.

Common surrogate crash measures related to traffic control device research include (*12*):

- speeds,
- acceleration/deceleration,
- initial brake application locations,
- erratic maneuvers,
- traffic conflicts,
- traffic control device compliance,
- lateral placement within lanes, and
- centerline or edge line encroachment.

While surrogate crash measures may be useful in determining implied traffic safety benefits, their direct relationship to crash occurrence has yet to be established. As a result, assigning a monetary value to changes in surrogate crash data is not possible and is a major drawback to this type of analysis.

The literature search produced a number of surrogate measures evaluations that tested the effectiveness of various traffic control devices used in various scenarios, such as horizontal curves and intersections. These evaluations provided valuable guidance to the research that was performed by providing information pertaining to experimental design, field data collection methods, measures of effectiveness (MOEs), data analysis, etc.

Evaluations of Traffic Control Devices at Horizontal Curves

Many evaluations of the effectiveness of various traffic control devices and their impact on driver behavior at horizontal curves have been performed. This includes field studies of surrogate measures for various Curve sign/advisory speed plaque messages, retroreflective raised pavement markers (RRPMs), post-mounted delineators (PMDs), Chevrons, and edge lines.

Alternative Warning Messages for Curves

One means to potentially improve driver behavior on horizontal curves is to provide a more emphatic message on the sign. A study by Lyles in the late 1970s evaluated the effectiveness of Curve signs supplemented by various advisory and regulatory speed signs for controlling speeds at horizontal curves (*13*). Researchers hypothesized that typical Curve signs and Advisory Speed plaques were being overused, overly conservative, and used inconsistently, thereby reducing their effectiveness. Five different Curve sign configurations were evaluated at two separate horizontal curves on rural two-lane highways. Speed data for free-flowing passenger vehicles were collected using piezoelectric sensors spaced evenly along the approach and throughout the curve. Principal dependent variables were:

- initial speed change,
- speed changes in the vicinity of the sign locations,
- speed at the curve itself,
- distance from the entry point to that of minimum speed, and
- speed upon exiting the curve.

The study found that no sign configuration was consistently more effective than another with respect to decreasing the potential hazard at horizontal curves on rural two-lane highways. The author conjectured that the average motorist's respect for the message conveyed by Curve signs and accompanying Advisory Speed plaques had been so lessened by the proliferation of these signs that when a serious horizontal curve exists, Advisory Speed plaques and even more emphatic regulatory speed signs may be ineffective remedies. Findings suggested that further research into the effectiveness of the most emphatic traffic control devices used under the most serious curve situations was needed.

Another means to enhance the conspicuity of a sign message is by using pavement markings to create a supplemental message directly on the pavement surface in the vicinity of the sign and/or hazard. Retting and Farmer evaluated the effectiveness of a curve warning message placed on the pavement surface as a supplement to typical curve signing on a suburban two-lane highway (*14*). The experimental pavement marking message included the word "SLOW" followed by a curve arrow, both of which were bordered by wide transverse markings. All markings included in the message were white. Speed data were collected in the before and after periods using pneumatic road tubes placed on the approach to the curve. Principal dependent variables included:

mean speed,

90th percentile speed, and

percentage of vehicles exceeding given speed thresholds.

The data showed statistically significant reductions in daytime and nighttime speeds at the curve entry point when the curve warning message on the pavement surface was used. Despite these findings, relatively little use has been made of supplemental pavement marking messages for advance warning conditions in the United States.

While the Lyles study made conjectures pertaining to the ineffectiveness of various messages placed on Curve signs and/or Advisory Speed plaques, the effectiveness of improving the conspicuity of the sign was not considered. Additionally, while the Retting/Farmer study showed speed improvements through improved conspicuity of the warning message by using supplemental pavement markings, it did not evaluate the effectiveness of improving the conspicuity of the sign itself. Therefore, it is possible that, when used under similar field conditions, fluorescent and prismatic sign sheeting materials may provide the additional emphasis necessary to properly alert motorists of an upcoming horizontal curve, thereby prompting improved driver behavior.

Improved Conspicuity of Curve Signs

Improved daytime conspicuity of Curve signs through the use of fluorescent sheeting materials was investigated in a recent study by Eccles and Hummer *(6)*. In this study the researchers replaced existing engineer grade or high intensity yellow Curve signs and Advisory Speed plaques with microprismatic fluorescent yellow versions of the same signs at three horizontal curve locations. Speed and/or centerline/edge line encroachment measurements were recorded at each location both before and after sign replacement. Statistically significant beneficial impacts were found at only one of the three locations after the new signs were installed. The authors concluded that fluorescent yellow Curve signs/Advisory Speed plaques appeared to provide the largest benefits at curve locations where the warning information is not reiterated by other features, particularly where view of the curve on the approach is at least partially obstructed.

While the Eccles study evaluated the effectiveness of fluorescent yellow materials to improve Curve sign conspicuity during the day, the nighttime effectiveness of the prismatic materials was not evaluated in this study even though prismatic materials were used. As a result, the impact of the more retroreflective prismatic materials on surrogate measures at night when used for Curve signs/Advisory Speed plaques has yet to be evaluated in the field. Additionally, the impact of fluorescent Curve signs on driver behavior has not been evaluated in the field under lower sunlight conditions such as overcast skies or at dawn and dusk, although fluorescent materials are known to provide the largest conspicuity benefits under these sky conditions. Furthermore, the use of advanced materials for other advisory speed signing, such as at freeway exit ramps, has not been evaluated in the literature. The use of fluorescent and prismatic sheeting materials on Ramp Speed signs may prove to be an effective means to improve safety at these sites, especially for cases where warning of the hazardous condition is not reiterated by other features.

Improved Conspicuity of Curve Delineation

While the Eccles' and Lyles' studies (*6*, *13*) investigated the effectiveness of more emphatic advance warning techniques for curves, they did not evaluate improvements made to the conspicuity of the curve itself. Chevrons, post-mounted delineators, and retroreflective raised pavement markers are all popular devices/methods to increase the conspicuity of horizontal curves, particularly at night.

Jennings and Demetsky investigated the relative effectiveness of Chevrons and PMDs vs. no delineation at horizontal curves (*15*). It was found under both daytime and nighttime conditions that for curves of greater than or equal to seven degrees, Chevrons produced the fewest centerline encroachments, most centralized lateral placement, and better speed control within the curve when compared to no delineation or typical PMD conditions. However, for curves flatter than seven degrees, PMDs were most effective for controlling driver behavior in the same categories, both day and night.

Zador et al. compared the effects of Chevrons, PMDs, and RRPMs on driver behavior when used to supplement typical pavement markings at roadway curves (*16*). Analysis of nighttime lateral placement data showed that vehicles moved away from the centerline when Chevrons were present and moved farther away when RRPMs were used. Conversely, PMDs caused vehicles to move closer to the centerline. They found virtually no change in driver corner-cutting behavior between any of the treatments. RRPMs and PMDs tended to increase curve speeds 1-3 mph on average vs. the standard condition, while Chevrons had little effect on speeds. The overall finding was that while delineation treatments do generally cause drivers to change their behavior while traversing curves, no device was found to be superior to the others. The authors concluded that the primary benefit of creating a more emphatically delineated curve may simply be that it helps drivers to better realize that they are approaching a curve.

Horizontal curve conspicuity at night was examined in a post-mounted delineator vs. retroreflective raised pavement marker study by Krammes et al. (*17*). One of the main study objectives was to evaluate the nighttime operational and safety effectiveness of using RRPMs supplementing the existing painted centerline as an alternative to existing PMDs at horizontal curves on two-lane rural highways. Nighttime speed and lateral placement data were collected using a series of tape-switches spaced evenly on the approach and throughout the curve. Surrogate measures of effectiveness included:

- speed at the midpoint of the curve,
- speed change from the beginning to the midpoint of the curve,
- lateral placement at the midpoint of the curve, and
- number of vehicle encroachments in the opposing lane at the midpoint of the curve.

The findings of the study suggested that the new RRPMs compared favorably to the existing PMDs, both initially and after one year. The results suggested that RRPMs provided better and more consistent lateral placement along with fewer centerline encroachments, although slightly higher speeds (1-3 mph) were observed at the curve midpoint, suggesting improved driver confidence.

While the previously referenced Chevron, RRPM, and PMD studies did not test the effectiveness of fluorescent and/or prismatic sheeting materials, they do indicate that a more conspicuous horizontal curve profile at night does provide better path delineation for drivers. The findings suggest that using higher-conspicuity sign materials on Chevron signs or delineator posts to create a more conspicuous curve profile may elicit favorable driver response.

Evaluations of Traffic Control Devices at Intersections

Some studies have also evaluated the effectiveness of various traffic control devices and their impact on traffic operations at intersections. This includes field surrogate measures studies of Cross Road signs, Stop Ahead signs, and Signal-Ahead signs. Although not every study cited in this report involved higher-conspicuity signs, each provided valuable information to the authors.

Improved Advance Warning Messages for Intersections

Many cases exist in the field where advance warning of intersecting roadways is necessary due to poor sight distance to the intersection or other factors. Lyles evaluated the daytime and nighttime effectiveness of several different sign combinations used to inform motorists of an obstructed intersecting road ahead on rural two-lane roadways (*18*). Six different warning or regulatory sign configurations were evaluated both day and night at the approach to intersections on two separate rural two-lane highways. Speed data for free-flowing passenger vehicles were collected using piezoelectric sensors spaced evenly along the approach to the intersection. Random motorists were also pulled over after passing through the intersection and surveyed regarding their recollection of the signs. Principal dependent variables were:

- spot speeds at various locations on the approach to the intersection,
- changes in speeds,
- distance to point of minimum speed, and
- location of maximum speed change.

Lyles' study found that the regulatory speed-zone configuration and the lighted warning signs were more effective than more traditional unlighted warning signs in reducing motorists' speeds on the approach to the intersection. Additionally, the survey results showed that the regulatory and lighted sign configurations increased motorists' awareness of both the signs and intersection conditions. The author concluded that the regulatory speed/intersection warning sign configuration or the intersection warning sign with continuously flashing beacons should be used to provide a more emphatic warning to motorists of an obstructed intersecting roadway.

While Lyles' intersection warning study showed significant safety benefits associated with increasing the emphasis of the message or providing a flashing beacon, the effectiveness of improving the conspicuity of the sign itself was not considered. When used under similar field conditions, fluorescent and prismatic sign sheeting materials may provide the additional conspicuity necessary to properly alert motorists of an upcoming intersection, thereby prompting improved driver behavior.

Improved Conspicuity of Warning Signs for Intersections

Eccles and Hummer recently investigated the effect of using fluorescent yellow warning signs at intersections on driver behavior during the day (*6*). In this study the researchers replaced existing standard (engineering grade or high intensity) yellow warning signs with fluorescent yellow prismatic versions of the same signs. Three types of warning signs were evaluated, each at a different intersection:

Stop Ahead sign (W3-1a),
signal ahead warning sign (two locations) (W3-3), and
intersection warning sign (W2-1).

Approach speeds, brake light indications, traffic control device compliance, traffic conflicts, and/or traffic events were recorded at the locations both before and after sign replacement. Results varied from location to location, although in most cases the fluorescent yellow materials showed beneficial impacts. Statistically significant beneficial results were found for the fluorescent material when used for Stop Ahead sign application. This included improved compliance with the Stop sign and increased distance from the intersection to the initial brake light indication. In the case of the fluorescent yellow Signal Ahead warning sign, statistically significant reductions in the number of unusual traffic events at the intersection and reduced intersection approach speeds were found. However, the number of traffic conflicts at the intersection did not significantly decrease. When used for intersection ahead warning signs, the fluorescent yellow materials were found to reduce intersection approach speeds. The authors concluded that the use of fluorescent yellow warning signs for advance warning of intersections or intersection traffic control devices appeared to provide the largest benefits at locations where the intersection and/or regulatory traffic control device is obstructed for approaching vehicles.

While the Eccles study evaluated the daytime effectiveness of fluorescent yellow materials to improve advance intersection warning sign conspicuity, the nighttime effectiveness of the prismatic materials was not evaluated in this project, even though prismatic materials were used. As a result, the impact of the more retroreflective prismatic materials on surrogate measures at night when used for advance warning of intersections or intersection traffic control devices has yet to be evaluated in the field. Additionally, the impact of fluorescent yellow intersection warning signs on driver behavior has not been evaluated in the field under lower sunlight conditions such as overcast skies or at dawn and dusk, although fluorescent materials are known to provide the largest conspicuity benefits under these sky conditions.

Improved Conspicuity of Stop Signs

Locations exist in the field where sufficient sight distance to the intersection traffic control device is present, but safety issues still remain. This situation may include cases where view of the intersection itself is at least partially obstructed, the Stop sign has been placed in such a way that sufficient conspicuity is not provided, or the intersection is encountered after long uninterrupted driving conditions. For cases such as these, improving the conspicuity of the Stop sign may provide a significant benefit to the safety of the intersection.

One method for improving the conspicuity of a stop-controlled intersection is through the installation of overhead flashing red beacons, either above the sign or above the intersection. Goldblatt evaluated overhead flashing beacons for intersection traffic control in the late 1970s (*19*). In this study, Stop signs supplemented with both continuously and vehicle-actuated flashing red beacons installed over the intersection were evaluated vs. Stop signs without any beacons. The use of a continuously flashing intersection beacon was found to produce lower approach speeds on the stopped approaches than the vehicle-actuated beacons or non-beacon Stop sign conditions. Hall evaluated the effectiveness of flashing overhead beacons for intersection warning and control for the New Mexico Department of Transportation (*20*). Researchers recommended that intersection warning and control beacons be placed at sites that cannot be improved by using more traditional forms of passive correction.

While the previously mentioned stop-controlled intersection evaluations showed some safety benefits associated with providing a flashing red overhead beacon, the effectiveness of improving the conspicuity of the Stop sign itself was not considered. When used under similar field conditions, higher-conspicuity sign materials may provide the additional conspicuity necessary to properly alert motorists of an upcoming Stop sign, leading to improved intersection safety.

Evaluations of Higher-Conspicuity Sign Materials in Work Zones and School Zones

Beneficial daytime impacts have been found for both fluorescent orange in work zones (*21*) and fluorescent yellow-green in pedestrian crossing areas (*22*). Additionally, these signs provide overwhelming increases in daytime conspicuity. As a result, many state departments of transportation, including TxDOT, have begun to use both fluorescent orange and fluorescent yellow-green sheeting materials extensively for work zone and school zone signing, respectively. It is for these reasons that fluorescent orange work zone sign applications and fluorescent yellow-green school zone applications were not evaluated in the research performed and described in this report.

DIRECT CRASH MEASUREMENT

No published crash analyses were found in the literature. Crash studies, although often difficult to perform from a practical research sense, are the only means by which to determine actual quantifiable benefits to higher-conspicuity sign materials for use in improving traffic safety. Although a detailed crash analysis for higher-conspicuity sign materials would be beneficial to the transportation community, a detailed crash analysis was not performed in the research performed and described in this report due to time constraints and a lack of relevant crash data.

SUMMARY OF LITERATURE REVIEW FINDINGS

The literature search determined many important findings. These findings aided TTI research staff in the development of field evaluation scenarios, experimental plan design, data collection techniques, appropriate measures of effectiveness, and analysis methods. The major findings are as follows:

> Fluorescent signs have been shown in the literature to have a beneficial effect on daytime traffic operations compared to their standard-color counterparts when used for warning of curves, intersections, intersection traffic control devices, pedestrian crossings, and work zones. Daytime effectiveness of fluorescent sign sheeting materials on surrogate safety measures has been well established in the literature, although only a limited number of field scenarios have been evaluated.

None of the surrogate measures studies of higher-conspicuity sign materials were conducted at night. Therefore, traffic operational improvements associated with the use of microprismatic materials have yet to be evaluated and published.

The impact of fluorescent signs on driver behavior has not been evaluated in the field under lower sunlight conditions, such as overcast skies or at dawn and dusk, when the conspicuity benefit over standard colors is the greatest. Therefore, if evaluated under lower sunlight conditions, the materials might show even greater traffic safety benefits.

None of the surrogate measures studies found in the literature involved evaluation of higher-conspicuity sign materials used on curve delineation devices, such as Chevrons or delineator posts. Therefore the impacts on driver behavior of fluorescent and prismatic materials when used to improve the conspicuity of the curve profile have yet to be determined.

Evaluations of higher-conspicuity sign materials for advisory speed signing have investigated only horizontal curves on rural two-lane highways. The effectiveness of fluorescent yellow prismatic materials used for Ramp Speed signing, therefore, has not been established.

The literature review found no studies that evaluated the effectiveness of higher-conspicuity sign materials when used as regulatory signs at intersections. As a result, the effectiveness of higher-conspicuity sign materials for Stop signs has yet to be determined.

No before and after crash studies testing the effectiveness of higher-conspicuity sign materials have been published. While the results of surrogate measures studies are useful in determining implied safety benefits, their direct relationship to crash occurrence has yet to be established. Therefore, findings from surrogate measures studies could be substantiated by a comprehensive crash analysis involving higher-conspicuity sign materials, although a crash analysis was not performed here.

CHAPTER 3: STUDY DESIGN

This chapter documents the design of field evaluations for higher-conspicuity sheeting materials, including:

- overall study approach,
- field evaluation scenarios,
- site selection,
- site characteristics,
- higher-conspicuity sign applications,
- independent variables, and
- dependent variables (i.e., measures of effectiveness).

OVERALL STUDY APPROACH

As stated in Chapter 1, the principal research goal was to identify situations in the field where higher-conspicuity sign materials offer safety-related traffic operations benefits beyond the standard-color high intensity sheeting materials (ASTM Type III) currently used by TxDOT. The ultimate measure of effectiveness for the evaluations performed would be the number of collisions prevented by the higher-conspicuity sign materials. However, recognizing that unbiased crash data would be difficult to obtain within the resources and timeframe of this project, the researchers focused on collection of traffic operations data to serve as surrogates for crash data.

Surrogate Crash Measures

Researchers utilize surrogate crash measures of effectiveness for two main reasons:

- because these data are far more readily available than actual crash data, and
- improvements in such measures may correlate to lower crash frequency (*23, 24*).

Furthermore, Eccles stated that surrogate crash evaluations are also helpful in overcoming some of the drawbacks associated with actual crash evaluations because (*25*):

- They require a much shorter time span to perform the evaluation.
- The potential for bias due to history or maturation is reduced.

The potential for regression to the mean is reduced.

Figure 3 illustrates the logical model depicting how installation of new traffic control devices may affect driver behavior and ultimately reduce crashes.

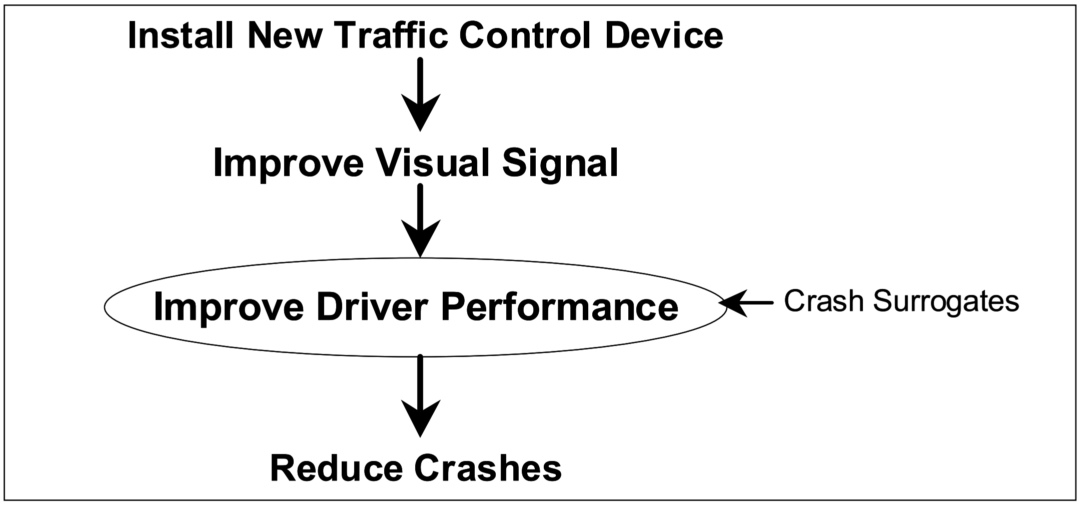


Figure 3. The Effect of Traffic Control Devices on Driver Performance and Crashes.

The general hypothesis for the surrogate crash evaluations performed is stated as follows:

If a causal relationship is found between a particular sign treatment and a change in driver behavior, it is possible that the treatment will have an effect on traffic safety.

For example, a statistically significant reduction in vehicular speeds near a severe curve that can be associated with a specific sign treatment would imply that widespread use of the treatment might reduce speed-related crashes over time at those locations.

Before and After Field Experiments

The basic study approach for the research performed was to collect and evaluate traffic operations data at given field sites with specified sign treatments in place. In nearly every case, the sign treatments evaluated at a given site included, at a minimum, the existing standard-color high intensity sign and its higher-conspicuity counterpart. At some sites, a second alternative sign treatment was also evaluated. The experiments were carried out in typical before and after fashion. The ITE Manual of Transportation Engineering Studies (*12*) recommends before and after experiments both for statistical and practical reasons, including:

eliminating site-to-site variation,

needing fewer sites to draw useful conclusions, and

results make intuitive sense and are easily understood by engineers and non-technical readers alike.

General Field Procedures

For the research described here, a typical data collection effort at a given site was conducted in the following manner:

Covertly collect traffic operations data (i.e., speeds, driver behavior) in the “before” period with the existing TxDOT standard high intensity sign(s) in place.

Replace the existing sign(s) with the alternative sign(s) (the fluorescent colored microprismatic counterpart in most cases).

Allow for a minimum 10-day “warm up” period to allow novelty effects of the new sign to wear off.

Collect traffic operations data in the “after” period in the same manner as in the “before” period.

Restore the sign(s) to the existing conditions.

The data collection effort made every attempt to select sites and design and perform the experiments to minimize biasing factors. With few exceptions, data collection was performed only on Mondays through Thursdays and under clear to partly cloudy weather conditions with dry pavement.

Data were collected during daylight, twilight, and nighttime periods because photometric properties of sign sheeting materials are known to change based on ambient illumination. For a given site, every attempt was made to collect data during the same times of day between the before and after periods and to perform the entire before and after data collection in less than a month. This attempt was made to reduce the potential for extraneous changes within a given site, including changes in the driving population and seasonal changes to the surrounding foliage.

FIELD EVALUATION SCENARIOS

One of the initial research tasks was the development and selection of field scenarios for the higher-conspicuity sign materials.

Scenario Development

The initial task was for TTI research staff to develop a list of potential field evaluation scenarios to present to TxDOT project panel members. During the scenario development process, the researchers first identified the types of signs to be evaluated, higher-conspicuity sign materials for those signs, and field conditions where using the higher-conspicuity signs may provide the greatest benefit to traffic safety. Figure 4 illustrates the development of the general field evaluation scenario.

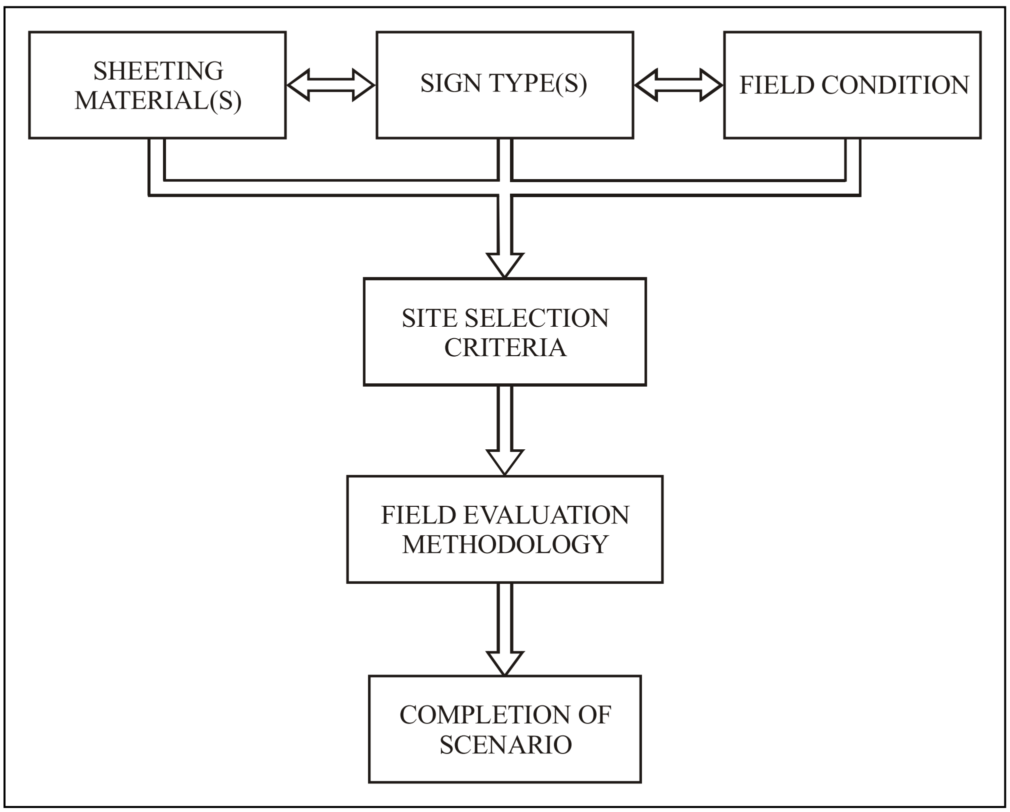


Figure 4. Scenario Development Process.

Scenario Selection

The TTI research team generated a preliminary list of scenarios, which were presented to TxDOT at the initial project meeting in October 2001. From this list, TTI and TxDOT project panel members selected scenarios for evaluation based on those deemed most important to TxDOT. In general, the selected scenarios fell into one of five types of field applications:

fluorescent yellow microprismatic sheeting for curve warning treatments,

fluorescent yellow microprismatic sheeting for Stop Ahead warning signs,

- fluorescent red microprismatic sheeting for Stop signs[1],
- red flashing LEDs embedded in the corners of Stop signs[2], and
- red microprismatic border on Speed Limit signs at entry to a speed zone[2].

Subsequent TTI/TxDOT project team meetings were held approximately once every six months to discuss results of the field evaluations and to further refine the remaining scenarios as needed. At the initial project meeting, TTI and TxDOT project panel members made the decision to not evaluate fluorescent yellow-green signs in school zones or fluorescent orange signs in work zones because:

- Substantial documented field research already existed for both applications (10, 21, 22).
- Many transportation agencies, including TxDOT, already use fluorescent yellow-green and fluorescent orange as the typical sheeting in their respective field applications.

SITE SELECTION

To satisfy the evaluation scenarios, 14 sites were selected and used for field evaluations. These sites included four rural curves, two curves on freeway exit ramps, four urban/suburban stop-controlled intersections, three rural stop-controlled intersections, and one rural speed zone.

A number of criteria were used for selection of sites. The main criterion for site selection was evidence of a hazardous condition that could potentially be remedied through the use of a more conspicuous warning/regulatory sign. The main criteria for hazardous site identification was analysis of crash data, although other measures were used, such as frequency of Chevron or delineator replacement and presence of skid marks. Other site selection criteria included:

- presence of appropriate signing with standard color ASTM Type III sheeting materials,
- long uninterrupted tangent section on approach,
- sign information not reiterated by other features (i.e., flashing beacons, rumble strips, etc.),

[1] 30-in fluorescent red Stop sign manufactured and provided by 3M for research purposes only.
[2] Experimental sign treatment; permission to experiment granted by the FHWA.

ADT of 700 or more,

no evidence of police over-enforcement in the area,

close proximity to TTI headquarters, and

feasibility and ease of data collection.

Researchers developed an initial list of potential sites for each scenario, which were based largely on discussion with TxDOT personnel and analysis of TxDOT crash data. The research team then visited each site to gather additional preliminary data. Final site selection was based on the judgment of the research team.

Tables 3, 4, and 5 display the characteristics for the curve study sites, intersection study sites, and the speed zone study site, respectively. Detailed site descriptions are provided in Appendix A.

Table 3. Characteristics of Horizontal Curve Study Sites.

	Sites					
	FM 1179	**FM 3090**	**FM 244**	**SH 6**	**FM 46**	**FM 60**
Roadway Type	Rural two-lane highway	Rural two-lane highway	Rural two-lane highway	One-lane freeway exit ramp	Rural two-lane highway	One-lane freeway exit ramp
Right or Left Curve	Right	Left	Left	Right	Right	Right
Posted Regulatory Speed (mph)	65	65	70 day/ 65 night	70 day/ 65 night	65	55
Posted Curve Advisory Speed (mph)	35	15	40	None	None	25
Ball Bank Indicator Speed at 10 Degrees (mph)	35	25	40	35	55	25

Table 4. Characteristics of Stop-Controlled Intersection Study Sites.

	Sites						
	Deacon	**Holleman**	**Luther**	**Southwest Parkway**	**FM 2549**	**NB FM 2154**	**SB FM 2154**
Intersection Type	One-way stop ("T")	One-way stop ("T")	One-way stop ("T")	Four-way stop	Two-way stop	Four-way stop	Four-way stop
Development	Suburban	Suburban	Suburban	Suburban	Rural	Rural	Rural
Lighting	Yes	Yes	Yes	Yes	No	No	No
Posted Regulatory Speed (mph)	40	35	45	35	65	70 day/ 65 night	70 day/ 65 night

Table 5. Characteristics of Rural Speed Zone Sites.

	SH 7
Roadway Type	Rural two-lane highway with 10-ft shoulders
Approach	Eastbound, approaching Marlin, Texas
Upstream Posted Speed (mph)	70 day, 65 night
Posted Speed on Treatment Sign (mph)	55

SIGN TREATMENTS AND APPLICATIONS

As stated previously, the evaluations of higher-conspicuity sign sheeting materials were categorized into five types of field applications:

fluorescent yellow microprismatic sheeting curve warning treatments,

fluorescent yellow microprismatic sheeting for Stop Ahead warning signs,

fluorescent red microprismatic sheeting for Stop signs,

red flashing LEDs embedded in the corners of Stop signs, and

red microprismatic border on Speed Limit signs at entry to a speed zone.

Fluorescent Yellow Microprismatic Sign Treatments

Field tests evaluated eight applications of fluorescent yellow microprismatic sheeting. (six curves, two intersections). Table 6 lists the fluorescent yellow microprismatic sign treatments included in each evaluation. Please note that all existing sheeting treatments were standard yellow 3M ASTM Type III (current TxDOT standard material), with the exception of the Chevron posts, which had no existing sheeting treatment.

Table 6. Fluorescent Yellow Microprismatic Sheeting Treatments by Site.

Scenario	Site	Fluorescent Yellow Microprismatic Treatment*						
		Curve Sign	Advisory Speed Plaque	Chevrons	Chevron Posts	Large Arrow	Ramp Speed Sign	Stop Ahead Sign
Curve	FM 1179	3M	3M	3M		3M		
	FM 244	3M	3M	3M				
	FM 3090**			3M	3M			
	SH 6			3M				
	FM 46	3M						
	FM 60						3M	
Inter-section	FM 2154 NB							AD
	FM 2154 SB							AD

Legend: 3M = 3M ASTM Type IX fluorescent yellow
AD = Avery Dennison ASTM Type VIII fluorescent yellow
*All existing sheeting treatments were standard yellow 3M ASTM Type III.
**Curve sign and Advisory Speed plaque were present at FM 3090 but were not upgraded to fluorescent yellow during the evaluation.

Higher-Conspicuity Stop Signs

Various higher-conspicuity red (flashing LED or fluorescent) microprismatic sheeting material treatments were applied and evaluated at five stop-controlled intersections. Table 7 lists the sites where higher-conspicuity Stop signs were evaluated along with the treatment. All Stop signs used in the evaluations were 30 inches in diameter.

Table 7. Higher-Conspicuity Stop Sign Treatments by Site.

Site	Stop Sign Treatment*
FM 2549**	FR, LED***
Deacon	FR
Holleman	FR
Luther	FR
Southwest Parkway	LED***

Legend: FR = Fluorescent red microprismatic 3M ASTM Type IX (experimental color).
LED = Stop sign with flashing LEDs embedded in corners of sign (manufactured by TAPCO).
*All existing sheeting treatments were standard red 3M ASTM Type III.
**Stop Ahead sign, guide signs, and junction marker cluster were present at FM 2549 but were not upgraded during the evaluation.
***Sheeting material on LED Stop sign was 3M Type IX standard red.

Figure 5a displays an installation of the flashing LED Stop sign used in the evaluations. Figure 5b displays a side-by-side comparison of a fluorescent red Stop sign vs. a standard red Stop sign.

a. Flashing LED Stop Sign **b. Fluorescent vs. Standard Red Stop Sign**

Figure 5. Higher-Conspicuity Stop Sign Treatments.

Colored Conspicuity Border on Speed Limit Sign

Speed zones on the TxDOT highway system, such as those approaching cities or municipalities, often begin well outside of the city limits at locations that are unexpected by drivers. In many of these cases, the initial reduction in posted speed limit is unexpected because it occurs prior to any physical indication of a need to slow down. Unexpected changes in speed limit may result in unfavorable traffic operational characteristics such as high speeds, high speed variances, and erratic decelerations, each of which may be associated with higher crash occurrence.

The research team applied a 3-inch red microprismatic border[3] to the 55 mph Speed Limit sign at the entry to a speed zone on eastbound State Highway 7 approaching Marlin, Texas. An

[3] Avery Dennison, ASTM Type VIII (non-fluorescent)

example of the typical 24×30 inch Speed Limit sign (R2-1) with the extended 3-inch red border is shown in Figure 6.

Figure 6. Speed Limit Sign (R2-1) with 3-inch Red Border.

The purpose of the 3-inch red microprismatic border around the perimeter of the initial Speed Limit sign (R2-1) was to increase the conspicuity of the sign, with the intention that it would improve the percentage of drivers complying with the posted speed limit and other speed-related measures.

Selection of red for the border color was based on recommendations of the TTI/TxDOT project team members and the results of two focus groups, which found little potential for driver confusion with the red speed limit border. Please refer to Appendix B for a summary of the focus group findings.

INDEPENDENT VARIABLES

The principal objective of this research project was to assess the effectiveness of various higher-conspicuity sign materials on driver behavior under various field conditions. Therefore, a detailed and unique experiment was devised for each site based on the geometric characteristics and the signs and materials to be evaluated. The following subsections list descriptions of the independent variables.

Sign Treatments (Primary Independent Variable)

The sign treatment condition was the primary independent variable in the data analysis for each site. The following sign conditions were evaluated for a given site:

Existing Sign: The null sign treatment was always the existing sign(s) with TxDOT typical sheeting material, which for every case was the standard-color high intensity (ASTM Type III) sheeting material manufactured by the 3M Corporation.

Higher-Conspicuity Sign: The primary alternative sign treatment was always the identical sign(s) fabricated with the appropriate higher-conspicuity sign materials and placed in the identical location(s) upon removal of the existing signs. See Tables 6 and 7 for the higher-conspicuity sign treatments evaluated at a given site.

Second Alternative Treatment (where applicable): At selected locations, a second alternative sign treatment was also evaluated.

Ambient Lighting Condition

The photometric properties of the sign sheeting materials used in this project are known to change dramatically as a function of the light source. Therefore, researchers were interested in determining the effectiveness of the alternative sign treatments under different ambient lighting conditions. Ambient lighting condition was proxied by time of day. For each sign treatment condition, most data were collected during three time periods:

Daylight: 30 minutes after sunrise to 30 minutes before sunset;

Twilight: 30 minutes before and after sunrise and 30 minutes before and after sunset; and

Night: 30 minutes after sunset to 30 minutes before sunrise.

Speed at Upstream Control Point (Covariate)

It is reasonable to assume that the magnitude of drivers' response to signs, geometric conditions, or intersections varied according to the speed at which they generally chose to drive (i.e., their uninhibited free-flow speed) (*13*). For example, drivers who travel faster on tangent sections will likely travel faster through curves. It can also be assumed that when approaching a stop-controlled intersection, faster drivers will be forced to slow down more than slower drivers.

To provide an explicit measure of uninhibited free-flowing driver behavior, initial spot speed measurements were taken on a tangent section upstream of the project site. Upstream speed measurements served as "control" data for the analysis. Upstream control point speed was included as a covariate in the analysis to account for the impact of individual drivers' uninhibited free-flow speed on speeds at the study site. In addition, the average control point speeds were compared across data collection periods to determine whether or not drivers were behaving similarly prior to entering the project site.

Other Independent Variables as Restraints

Several other independent factors were considered in the evaluations, which were used to further restrain the data and reduce the potential for bias. These restraining factors included:

Day of Week: Data were only collected on Mondays-Fridays, excluding Friday afternoons.

Sky Condition: With few exceptions, data were only collected under clear to partly cloudy sky conditions.

Vehicle Type: With few exceptions, only uninhibited passenger vehicles with headways greater than six seconds were included in the analysis.

Presence of Opposing Vehicle (encroachment and compliance data only): Only unopposed vehicles were included in the encroachment and compliance data.

DEPENDENT VARIABLES (MEASURES OF EFFECTIVENESS)

While improvements to the conspicuity of traffic signs are important to help ensure that drivers are properly alerted to the sign, determining the effect on driver performance in the field is valuable to assess whether the conspicuity improvements translate to improved roadway safety. Before and after crash data were not available for the evaluations performed. As a result, a unique set of traffic operational MOEs were selected for each field evaluation based on the nature of the evaluation and served as surrogates for crash data.

Researchers relied heavily upon a number of previous surrogate crash evaluations to assist in designing the field experiments (*6*,*13*,*26*). The MOEs were designed to detect changes in driver performance that were believed to be related to traffic safety. Available data collection resources were also considered in MOE development. Direct relationships between the MOEs and crash occurrence were not established in the research.

Curve MOEs

Previous research has suggested that reductions in excessive vehicular speeds at horizontal curves may reduce the occurrence of certain crashes, such as single-vehicle run-off-the-road (*27, 28, 29*). Similarly, reductions in centerline/edge line encroachments within curves are also believed to reduce curve-related crashes (*28*, *29*). The traffic operational MOEs for each of the evaluations performed at rural curves were:

- speeds approaching curve (mean),
- speeds at point of curvature (PC) (mean, 85^{th} percentile, percent exceeding safe speed),
- percent of vehicles initiating deceleration prior to passing the Curve sign (Curve sign evaluations only),
- speed variance, and
- centerline/edge line encroachments at midpoint of curve (Chevron evaluations only).

Stop-Controlled Intersection MOEs

The stop-controlled intersection studies utilize similar MOEs. Multiple literature sources have considered speed-related measures (i.e., speeds, decelerations, and speed variance) for vehicles approaching an intersection as appropriate for stop-controlled intersection studies (*28*). Compliance with the Stop sign (stopping vs. non-stopping) is another popular safety-related MOE for stop-controlled intersection studies. The traffic operational MOEs for each of the evaluations performed at stop-controlled intersection were:

- speeds approaching intersection (mean, 85^{th} percentile),
- decelerations approaching intersection (percent exceeding comfortable threshold of 10 ft/s^2 [*12*]),
- speed variance, and
- stopping compliance (Stop sign treatments only).

Rural Speed Zone MOEs

The purpose of the 3-inch red microprismatic border around the perimeter of the initial Speed Limit sign (R2-1) was to improve driver awareness of the posted speed limit by increasing the conspicuity of the sign. Researchers hypothesized that the improved sign conspicuity would improve the percentage of drivers complying with the posted speed limit and other speed-related measures. The traffic operational MOEs for the speed limit border study were:

- speeds in proximity of the treatment sign (mean, 85th percentile),
- percent exceeding speed limit in proximity of the treatment sign, and
- speed variance in proximity of the treatment sign.

CHAPTER 4:
DATA COLLECTION AND ANALYSIS

This chapter documents the field data collection and analytical procedures for the experiments performed in this project, including:

- data collection equipment,
- data collection procedures,
- data screening and formatting, and
- statistical analysis.

TRAFFIC OPERATIONS DATA COLLECTION

Traffic operations data were collected to satisfy the measures of effectiveness for each field evaluation. Speeds of free-flowing (> 6 sec headway) passenger vehicles were measured for every field evaluation and were the basis for a majority of the MOEs. Because the researchers were more interested in the behavior of individual drivers than aggregated spot speeds, speeds of individual vehicles were tracked as they approached and proceeded through the project site. Vehicle tracking allowed speed profiles to be obtained for each vehicle, allowing for a more robust statistical analysis.

Table 8 summarizes the traffic operations data that were collected at the project sites to satisfy the measures of effectiveness described in Chapter 3.

Table 8. Traffic Operations Data Measured at Study Sites.

Curves	Stop-Controlled Intersections	Rural Speed Zone
Vehicle speeds prior to the curve and signs coming into view (control point) Vehicle speeds on the approach to the curve Vehicle speeds at the curve Vehicle encroachment on the edge line or centerline at the curve midpoint (Chevron sites only)	Vehicle speeds prior to intersection or signs coming into view (control point) Vehicle speeds on the approach to the intersection Driver compliance with the Stop sign (Stop sign evaluations only)	Vehicle speeds prior to signs coming into view Vehicle speeds approaching the designated Speed Limit sign Vehicle speeds at the designated Speed Limit sign Vehicle speeds downstream of the designated Speed Limit sign

Data Collection Equipment

Various devices were used to track speeds, including handheld Light Detection and Ranging (LIDAR) units (i.e., police laser) or a series of automated counters connected to either piezoelectric sensors or pneumatic tubes. For each site, the same equipment was used in both the before and after periods. Both stop-compliance data and encroachment data were collected at the sites either manually or with video that was later manually reduced in the office. Appendix C shows detailed information about the various types of speed measurement equipment.

Data Collection Procedures

The data collection procedures for a specific evaluation were based largely on the site characteristics, available staff, equipment, and expected time to collect appropriate sample sizes. The same data collection procedures and equipment were used at a given site for all data collection periods to reduce the potential for data collection bias.

Speed Data Measurement

The relative accuracies of the available speed measurement devices were found to be similar (see Appendix C), and therefore advantages and disadvantages of the various devices were weighed prior to selection of equipment for a given site. Speed measurement with LIDAR generally produced the most robust, reliable, and accurate data set of individual speed profiles, although the manpower requirements were significantly higher than for automated vehicle classifiers. As a result, the decision to use a specific type of equipment was based largely on the expected time and manpower needed to collect a sample of appropriate size, which could usually be determined based on the Average Daily Traffic (ADT) of the roadway.

At low-volume two-lane sites, speeds were measured by using a series of four to seven automated vehicle classifiers, each connected to a pair of pneumatic tubes or piezoelectric sensors placed on the pavement. Spacing of classifiers was uniquely designed for each site based on sight distances and sign locations in an attempt to capture speed-related changes in driver behavior. The layout of the classifiers/sensors was the same for both the before and after periods for a given site.

At medium- to high-volume sites, one or more stationary LIDAR data collectors were used to measure speeds. At sites where LIDAR was used and sight distance was limited by vertical or horizontal curvature, a team of data collectors, each equipped with a LIDAR unit, was often necessary to successfully track a vehicle through the site. LIDAR data collectors placed themselves in the same locations for both the before and after periods.

Encroachment Data Measurement

Encroachment data were collected for the selected Chevron studies by placing an inconspicuous unmanned video camera on the roadside aimed to capture vehicles head-on as they passed through the midpoint of the curve. Encroachment data from the videotapes were later reduced in the office. The researchers defined five levels of encroachment for each representative vehicle passing through the site:

- no encroachment (stayed in lane),
- minor white edge line encroachment (tire touches line but does not entirely cross),
- minor yellow centerline encroachment (tire touches line but does not entirely cross),
- major white edge line encroachment (entire tire crosses line), and
- major yellow centerline encroachment (entire tire crosses line).

Encroachment data were not collected during nighttime periods because the headlamp glare made it impossible to determine from the videotape whether or not the tire had encroached upon the edge line or centerline. Appendix D shows an example of the encroachment data collection tally sheet.

Stopping Compliance Data Measurement

Stopping compliance data were collected for the Stop sign studies either manually or by an unmanned video camera placed inconspicuously at the intersection. Data from videotapes were later reduced in the office using the same procedures as on-site data collection. The researchers defined four levels of stopping compliance for each representative vehicle, as defined by the ITE Manual of Transportation Engineering Studies (*12*):

- voluntary full stop (no conflicting traffic in reasonable sight),
- stopped by traffic from any conflicting approach (not included in the analysis),
- practically stopped (rolling stop, 0-3 mph), and
- non-stopping (i.e., blow-throughs).

Researchers were able to obtain compliance data for all data collection periods, regardless of the ambient lighting condition. Appendix D shows an example of the stopping-compliance data collection tally sheet.

Placement of Data Collection Personnel

The data collectors attempted to locate themselves as inconspicuously as possible without compromising personal safety or the safety of other motorists. At rural sites, data collectors were placed in vehicles that were parked off the roadway, usually in driveways or parking lots. At suburban/urban sites, data collectors were usually placed in vehicles either parked on the edge of the roadway, in a driveway, or in a parking lot, or sat in chairs behind bushes or trees. Data collectors positioned themselves in the same manner for both the before and after periods for a given site.

To minimize cosine error[4], LIDAR data collectors minimized their offset from the path of vehicles during speed measurement. Furthermore, because LIDAR data collectors maintained the same positioning throughout all data collection periods at a given site, any effect of cosine error on speed data was the same for all data collection periods. Therefore, any cosine errors were considered negligible for before and after speed comparisons in this project.

Data Collection Summary

Table 9 shows data collection activities performed at each site along with the equipment used and the time period for which data were collected.

[4] Cosine error is a geometric principle that causes speeds measured with a LIDAR or RADAR unit to be artificially lower than actual. The magnitude of the error increases as the angle between the direction of observation and the true direction of travel increases. While cosine error is nearly impossible to eliminate, it can be reduced to ½ percent or less by maintaining an offset of six degrees or less from the path of vehicles. Six degrees corresponds to a maximum offset on a tangent section of 10 ft for every 100 ft of distance between the observer and the vehicle.

Table 9. Data Collection Activities.

		Speeds			Encroachments	Stop-Compliance
		LIDAR	Classifier - Tubes	Classifier - Piezo	Video	Video
Curves	FM 1179	D,N,T			D	
	FM 244			D,N,T		
	FM 3090			D,N,T		
	SH 6		D,N,T		D	
	FM 46		D,N,T			
	FM 60	D,N,T				
Stop Ahead	FM 2154 NB	D,N,T				
	FM 2154 SB	D,N,T				
Stop Sign	FM 2549		D,N,T			D,N,T
	Deacon Dr.	D,N,T				
	Holleman Dr.	D,N				
	Luther St.	D,N				
	Southwest Parkway	D,N				D,N
Speed Limit Border	SH 7			D,N		

Legend: D = Daytime Data
N = Nighttime Data
T = Twilight Data

Data Screening

The raw speed data measured at the project sites were screened to create a random and unbiased sample of speeds for free-flowing, uninhibited passenger vehicles. The objective of the data screening process was to isolate the effect of the higher-conspicuity materials on driver behavior by identifying and eliminating potentially biased data. Therefore, the main data screening task was to identify anomalous vehicles and exclude them from the final data set.

Definitions of Anomalous and Representative Vehicles

During data collection, the researchers were interested in obtaining data from a sample of free-flowing passenger vehicles that were traveling through the site uninfluenced by other vehicles. However, a certain percentage of vehicles passing through a site during data collection were influenced by factors external to the experiment and deemed anomalous to the experiment. The researchers made every attempt to identify these anomalous vehicles and exclude them from the data set. With few exceptions, for all data collected during the field evaluations, researchers defined anomalous vehicles and representative vehicles by the conditions shown in Table 10.

Table 10. Definitions of Anomalous and Representative Vehicles.

Anomalous Vehicles (Excluded from Data Set)	Representative Vehicles (Included in Data Set)
Non-passenger: – Commercial[1] – Delivery – Bus – Farm equipment Influenced by other vehicles in the site: – Non-free-flowing (≤ 6 second headway) – Traversing through curve when vehicle is present in opposing lane (encroachment data only) – Approaching Stop sign when queue is present (stop-controlled intersection sites only) Turning Towing trailer Motorcycle Erratic behavior Uninhibited upstream speed was deemed excessively slow (e.g., <50 mph for sites with 65-70 mph posted speed limits)	Passenger: – Car – Pickup truck – Sports Utility Vehicle (SUV) – Van Uninfluenced by other vehicles Traversing the entire project site Greater than six-second headway Traveling at an appropriate uninhibited speed upstream of the site (e.g., ≥ 50 mph for sites with 65-70 mph posted speed limits)

Note: [1] Commercial vehicles were included in analysis of the red speed limit border.

Data Formatting

After the speed data had been collected, it was necessary to convert the raw data into a fully formatted data set for statistical analysis. Formatting procedures for the speed data were dependent on the equipment used to collect the data.

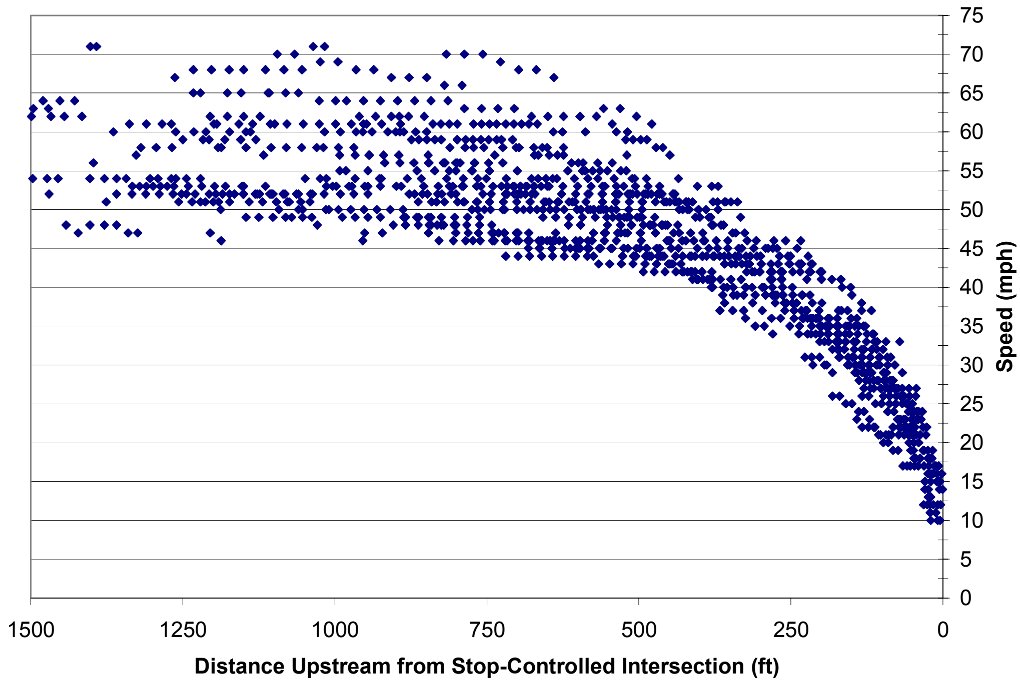
Formatting LIDAR Data

The LIDAR devices were capable of continuously tracking the speed and range of individual vehicles by taking measurements up to four times per second. LIDAR speed and range measurements were instantaneously recorded and stored in a laptop computer using in-house software. The raw LIDAR data was stored as a .txt file, allowing for simple conversion to spreadsheet format. Table 11 shows an example of the raw LIDAR data for a single vehicle approaching a Stop sign.

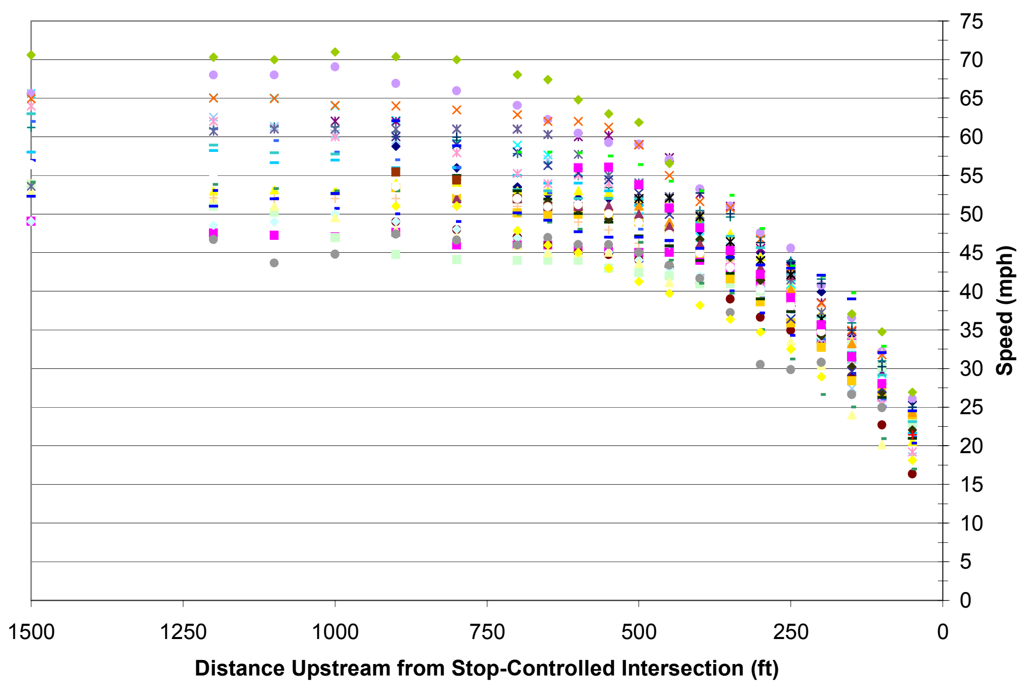
Table 11. Raw LIDAR Data.

Description	Time	Speed	Range
DAT	3:58:12 PM	40	573
DAT	3:58:12 PM	39	556
DAT	3:58:13 PM	38	541
DAT	3:58:13 PM	37	525
DAT	3:58:14 PM	34	465
DAT	3:58:14 PM	34	451
DAT	3:58:15 PM	34	437
DAT	3:58:15 PM	33	423
DAT	3:58:15 PM	32	410
DAT	3:58:16 PM	31	398
DAT	3:58:16 PM	30	385
DAT	3:58:16 PM	29	373
DAT	3:58:17 PM	29	361
DAT	3:58:17 PM	28	349
DAT	3:58:18 PM	22	300
DAT	3:58:19 PM	22	291
DAT	3:58:19 PM	21	283
DAT	3:58:19 PM	20	276
DAT	3:58:20 PM	14	258
DAT	3:58:20 PM	13	252
DAT	3:58:21 PM	13	248
DAT	3:58:21 PM	11	240
REM	car		

LIDAR speed measurement produced far more spot speed measurements for a given vehicle than the automated vehicle classifiers. However, it was impossible for LIDAR speeds to be measured at the exact same spot locations on the roadway for each and every vehicle. LIDAR speed data for each vehicle were therefore converted to specific spot speeds using a parabolic interpolation routine in Microsoft Excel®. Figure 7 displays a comparison of a raw LIDAR data set vs. the formatted spot-speeds measured at a single stop-controlled intersection project site.



a.) Raw LIDAR Data



b.) Formatted LIDAR Data

Figure 7. LIDAR Data.

Formatting Automated Classifier Data

The automated vehicle classifiers often produced a much larger sample of vehicles than LIDAR, but depending on the number of classifiers placed on the roadway, far fewer spot speed measurements were made per individual vehicle. Because the automated classifiers were placed directly on the roadway, spot speeds were measured at the same location for each vehicle. Therefore, unlike the LIDAR data, no interpolation was necessary. The raw classifier data was stored as a .txt file, allowing for simple conversion to spreadsheet format. Once in spreadsheet format, vehicles were "tracked" from counter to counter by comparing the timestamps at successive counters with expected travel times based on speed and distance between the successive counters. Table 12 shows an example of the raw data from a single classifier.

Table 12. Raw Classifier Data.

Date	Time	Vehicle Direction	Quality Verification	FHWA Classification	Speed
25/03/03	11:23:48	+	FFFF	3	42
25/03/03	11:30:16	+	FFFF	2	52
25/03/03	11:36:53	+	FFFF	2	57
25/03/03	11:39:30	+	FFFF	3	54
25/03/03	11:42:36	+	FFFF	5	54
25/03/03	11:44:50	+	FFFF	2	57
25/03/03	11:56:28	+	FFFF	2	64
25/03/03	12:28:55	+	FFFF	2	53
25/03/03	12:29:36	+	FFFF	3	59
25/03/03	12:33:41	+	FFFF	3	59
25/03/03	12:35:22	+	FFFF	2	58
25/03/03	12:44:23	+	FFFF	2	45
25/03/03	12:50:12	+	FFFF	3	52
25/03/03	12:53:23	-	FFFF	2	53
25/03/03	13:04:32	+	FFFF	2	63
25/03/03	13:10:13	+	FFFF	2	47
25/03/03	13:10:40	+	00EE	2	54
25/03/03	13:26:12	+	FFFF	3	55

Figure 8 displays formatted speed data for vehicles approaching a stop-controlled intersection using the automated classifiers.

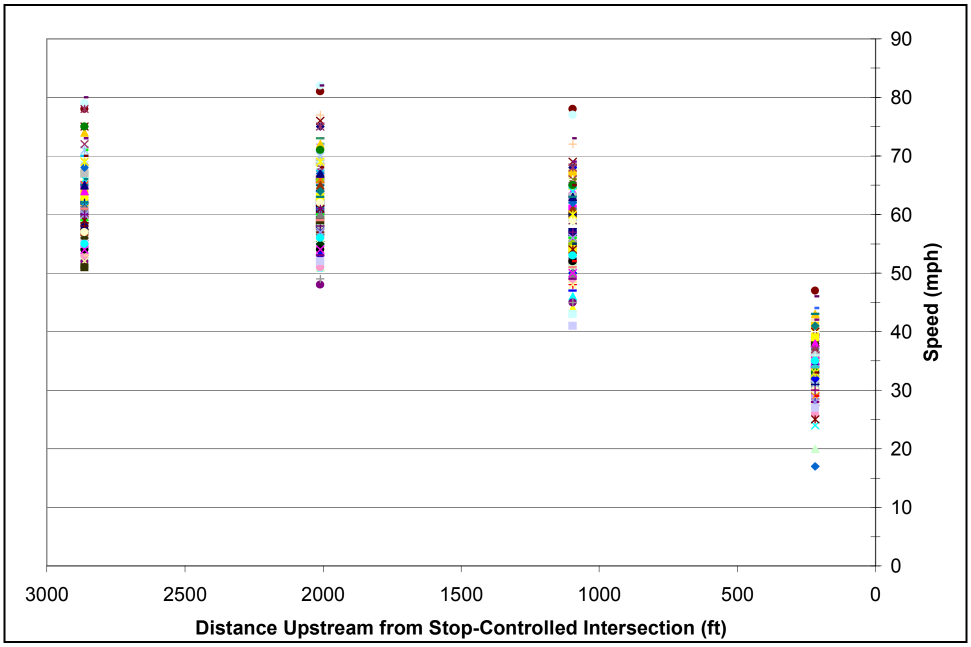


Figure 8. Formatted Speed Data Obtained from Automated Classifiers.

ANALYSIS

Upon completion of the data collection and formatting procedures, the data were analyzed to determine statistically significant correlations between the sign treatments and changes in traffic operational characteristics.

Statistical Procedures

To analyze the relationships between the variables, appropriate statistical tests were selected for each evaluation. The following subsections describe the statistical tests employed in the analyses. Due to the site-to-site differences for the higher-conspicuity material applications, data from each site were analyzed separately.

Analysis of Variance (ANOVA)

Univariate multiple-factor ANOVA was the basic procedure used to test for differences in the means of the speed and deceleration data for each site as functions of the sign treatments. ANOVA was the standard statistical method found in the literature for experiments similar to those performed. ANOVA allows for testing of differences between mean values of multiple populations as a function of the independent variables (i.e., sign treatments, light conditions, etc.)

and interactions between the independent variables. For cases with only one independent variable, one-way ANOVA or t-tests were performed.

The upstream control point speed was entered into the analysis as a covariate for sites where upstream speeds of vehicles were measured. Adding upstream speed as a covariate provides for correction due to vehicles having different speeds prior to entering the project site. For example, vehicles traveling faster upstream of the site are also likely to travel faster through the curve. Covariate analysis accounts for such occurrences.

Hybrid T-test

A hybrid t-test was also developed for testing differences in various speed percentiles as functions of the sign treatments for selected sites. This method allows the analyst to perform a t-like test using double bootstrapping and simulation to compare speed percentiles (1^{st} through 99^{th}) under various sign treatment conditions. Appendix E gives details of this procedure.

Z-Test of Proportions

Z-tests of proportions were used to test for differences in percent exceeding a specified threshold speed or deceleration rate, percent encroaching upon the edge line or centerline, or percent stopping compliance. In every case, the z-test was performed to test if the proportion of vehicles in the defined categories differed as a function of the sign treatment. These tests were useful for testing the effect of a sheeting treatment on the “upper extremities” of the speed and deceleration data.

F-test

F-tests were used to test for differences in speed variance as a function of sign treatment. Speed variance is commonly assumed to be correlated with accident experience. A lower speed variance would indicate a beneficial effect for a given sign.

Sample Size

Sample sizes varied between sites and data collection periods. Data collectors attempted to obtain measurements for a minimum of 30 vehicles per data collection period, although this was not always achieved. Sample sizes were proportional to the length of each data collection period and the traffic volumes on the particular roadway. For the most part, larger samples of vehicular speeds were obtained for those sites where automated classifiers were used vs. LIDAR devices. Chapter 5 and Appendix F report the sample sizes for speed, encroachment, and stop-compliance data.

Summary of Statistical Procedures

Table 13 lists the various measures of effectiveness and the corresponding statistical tests that were applied.

Table 13. Statistical Tests Performed for Each MOE.

	Mean Speed	85^{th} Percentile Speed	Rate Exceeding Threshold Speed or Deceleration	Speed Variance	Mean Deceleration	Encroachment Rate	Compliance Rate
ANOVA or T-test	X				X		
Hybrid T-test		X					
Z-test of proportions		X	X			X	X
F-test				X			

All statistical testing was performed at a confidence level of 95 percent. The software program SPSS[5] version 11.5 was utilized to perform the ANOVA, T-tests, and F-tests. Tests of proportion were performed using Microsoft Excel. Matlab was used for the hybrid t-tests.

[5] Statistical Package for the Social Sciences.

CHAPTER 5: FINDINGS

This chapter describes the findings of the statistical analysis of the traffic operations data. The findings have been organized based on the particular field application, which includes:

- Fluorescent yellow microprismatic curve warning treatments;
  - Fluorescent yellow Chevrons (FM 1179, FM 244, FM 3090, and SH 6).
  - Fluorescent yellow Curve signs (FM 1179, FM 244, and FM 46).
  - Fluorescent yellow reflectorized Chevron posts (FM 3090).
  - Fluorescent yellow Ramp Speed sign (FM 60).
- Fluorescent yellow microprismatic Stop Ahead signs (FM 2154 NB and FM 2154 SB);
- Fluorescent red microprismatic Stop signs (FM 2549, Deacon Dr., Holleman Dr., and Luther St.);
- Red flashing LED Stop signs (FM 2549 and Southwest Parkway); and
- 3-inch red microprismatic border on Speed Limit sign at entry to speed zone (SH 7).

To keep this report as concise as possible, only summaries of the analyses and discussions of the findings are presented here. Detailed site-by-site results of the statistical analyses have been placed in Appendix F. Site descriptions are provided in Appendix A. Recommendations for application of higher-conspicuity sign materials exist in Chapter 6.

FLUORESCENT YELLOW MICROPRISMATIC CURVE WARNING TREATMENTS

Summaries of the changes in speeds associated with installation of various fluorescent yellow microprismatic curve warning treatments are shown in Tables 14 and 15. In each case, the existing sign sheeting treatments were standard yellow high intensity, although no sheeting existed on the Chevron posts prior to fluorescent yellow installation. No other sign attributes were modified between data collection periods.

Overall, mostly small effects on the speed-related MOEs were found, although statistically significant beneficial results were observed for certain applications. Because the fluorescent yellow microprismatic sheeting treatments were found to produce no consistent statistically significant changes in speed variance, speed variance data were omitted from the tables.

Table 14. Effect of Fluorescent Yellow Microprismatic Sheeting on Mean Vehicular Speeds at Horizontal Curves.

Treatment	Site	Time of Day[1]	Overall Sample Size	Mean Speeds Approaching PC (mph)			Mean Speeds at PC (mph)		
				Existing	FY	Change	Existing	FY	Change
Chevrons (W1-8) Only	FM 3090	D	360	45.1	45.1	0.0	36.6	36.9	+0.3
		T	101	46.7	46.2	-0.5	37.1	37.3	+0.2
		N	266	44.8	45.3	+0.5	35.2	35.9	+0.7
	SH 6	D	1148	58.1	57.5	-0.6*	51.3	49.1	-2.2*
		T	222	58.1	56.8	-1.3	49.8	48.5	-1.3
		N	568	57.4	56.3	-1.1*	50.5	48.3	-2.2*
Chevrons and Curve Signs (W1 series)	FM 1179	D	82	57.7	57.8	+0.1	48.3	48.9	+0.6
		T	66	57.2	56.3	-0.9*	47.8	46.6	-1.2
		N	98	56.0	55.8	-0.2	46.4	47.2	+0.8
	FM 244	D	510	59.8	61.1	+1.3*	47.5	47.9	+0.4
		T	268	59.0	61.1	+2.1*	47.7	47.7	0.0
		N	318	58.1	58.3	+0.2*	46.3	44.9	-1.4*
Chevrons and Chevron Posts	FM 3090	D	463	45.1	45.6	+0.5	36.6	36.6	0.0
		T	93	46.7	45.0	-1.7	37.1	36.1	-1.0
		N	208	44.8	43.2	-1.6*	35.2	35.0	-0.2
Curve Sign (W1-2) Only	FM 46	D	747	62.3	61.3	-1.0*	59.2	59.7	+0.5
		T	81	64.4	62.7	-1.7	61.0	60.5	-0.5
		N	143	60.6	61.0	+0.4	57.5	59.2	+1.7
Exit Ramp Advisory (W13-3)	FM 60	D	95	50.5	50.2	-0.3	39.3	41.2	+1.9*
		T	84	50.3	49.4	-0.9	40.0	39.3	-0.7
		N	94	46.4	46.7	+0.3	36.7	37.3	+0.6

Notes: [1] D = Day, T = Twilight, N = Night
*Statistically significant difference at 95% level of confidence

Table 15. Effect of Fluorescent Yellow Microprismatic Sheeting on Excessive Vehicular Speeds at Horizontal Curves.

Treatment	Site	Time of Day[1]	Overall Sample Size	85th Percentile Speeds at PC (mph)			Exceeding Safe Speed at PC (rate of occurrence) [2]		
				Existing	FY	Change	Existing	FY	Change (pct.)
Chevrons (W1-8) Only	FM 3090	D	360	40.1	41.0	+0.9	0.590	0.656	+11.1
		T	101	40.0	41.2	+1.2	0.639	0.577	-9.7
		N	266	39.0	40.0	+1.0	0.508	0.538	+5.9
	SH 6	D	1148	57.0	54.0	-3.0*	0.867	0.782	-9.8*
		T	222	55.0	54.0	-1.0	0.814	0.747	-8.2
		N	568	56.0	53.0	-3.0*	0.833	0.709	-14.9*
Chevrons and Curve Signs (W1 series)	FM 1179	D	82	51.1	52.6	+1.5	0.770	0.667	-13.4
		T	66	52.7	50.4	-2.3	0.638	0.500	-21.6
		N	98	51.5	51.0	-0.5	0.534	0.590	+10.5
	FM 244	D	510	53.0	52.0	-1.0	0.282	0.282	0.0
		T	268	52.0	54.0	+2.0	0.254	0.279	+9.8
		N	318	51.0	50.0	-1.0	0.169	0.124	-26.6
Chevrons and Chevron Posts	FM 3090	D	463	40.1	41.0	+0.9	0.590	0.610	+3.4
		T	93	40.0	39.0	-1.0	0.639	0.614	-3.9
		N	208	39.0	39.9	+0.9	0.508	0.338	-33.5*
Curve Sign (W1-2) Only	FM 46	D	747	66.0	67.0	+1.0	0.163	0.189	+16.0
		T	81	66.6	65.0	-1.6	0.185	0.139	-24.9
		N	143	65.0	65.0	0.0	0.132	0.120	-9.1
Exit Ramp Advisory (W13-3)	FM 60	D	95	44.3	45.1	+0.8	0.744	0.966	+29.8*
		T	84	44.0	45.2	+1.2	0.839	0.750	-10.6
		N	94	40.0	42.0	+2.0	0.536	0.604	+12.7

Notes: [1] D = Day, T = Twilight, N = Night

[2] The maximum safe speed is defined herein as the curve's ball bank indicator speed (at 10 degrees) plus 10 mph. Maximum safe speed: FM 3090 = 35 mph, SH 6 = 45 mph, FM 1179 = 45 mph, FM 244 = 50 mph, FM 46 = 65 mph, FM 60 = 35 mph.

*Statistically significant difference at 95% level of confidence

Chevrons

Fluorescent yellow microprismatic Chevron treatments produced beneficial effects on speeds at most of the installations (Tables 14 and 15). Table 16 summarizes the overall changes in speed-related measures of effectiveness for the four Chevron installations.

Table 16. Overall Effect of Fluorescent Yellow Microprismatic Chevrons on Vehicular Speeds at PC of Curves.

Overall Change in MOE After Implementation of FY Chevrons[1]		
Mean Speed at PC (mph)	**85th Percentile Speed at PC (mph)**	**Exceeding Safe Speed at PC (pct.)**
-1.0	-1.3	-11.1

Note: [1]The total sample size for each MOE was approximately 4000.

Locations where fluorescent yellow Chevrons were implemented experienced a weighted average decrease in mean speeds at the curve PCs of 1.0 mph. An even greater effect was observed for faster drivers as the overall 85th percentile speed at the PC of the curves was reduced by 1.3 mph, and the overall rate of vehicles exceeding safe speeds at the PC of the curves was statistically significantly reduced from 0.63 to 0.56 (11 percent reduction) after implementation. Additionally, two of the four sites where fluorescent yellow Chevrons were implemented experienced a statistically significant decrease in mean speeds at the PC of the curves during at least one of the data collection periods (Table 14).

The fluorescent yellow Chevrons also had a beneficial impact on edge line encroachments during the day at the two locations where encroachment evaluation occurred. Results of the encroachment analysis can be found in Table 17.

Table 17. Daytime Effect of Fluorescent Yellow Chevrons on Edge Line Encroachments in Curves.

Site	Sample Size	Edge Line Encroachments (rate of occurrence)		
		Existing	FY	Change (pct.)
SH 6	255	0.606	0.336	-44.4*
FM 1179	85	0.233	0.286	+22.7
TOTAL	340	0.519	0.323	-37.8*

Note: *Statistically significant difference at 95% level of confidence

Daytime edge line encroachments were statistically significantly reduced by approximately 38 percent overall after installation of fluorescent yellow Chevrons. These impacts indicate that drivers may be better alerted to the curve, thereby adjusting their driving behavior accordingly.

Curve Signs

Fluorescent yellow microprismatic Curve signs, whether used in stand-alone applications or with Chevrons, were found to have small, but beneficial effects on speeds near the curve (Tables 14 and 15). Another measure used by the researchers to detect driver awareness of a Curve sign is the percent of vehicles initiating deceleration prior to passing the sign. A higher percentage of drivers initiating deceleration would indicate better sign detection and improved advance warning of the upcoming curve. Table 18 displays the rate of vehicles initiating their deceleration prior to passing the Curve sign.

Table 18. Effect of Fluorescent Yellow Microprismatic Curve Signs on Point of Initial Deceleration.

Site	Time of Day[1]	Sample Size	Drivers Initiating Deceleration Before Reaching Curve Sign (rate of occurrence)		
			Existing	FY	Change (pct.)
FM 1179[2]	D	80	0.673	0.516	-23.3
	T	69	0.485	0.750	+54.6*
	N	102	0.520	0.780	+50.0*
FM 46	D	747	0.711	0.847	+19.1*
	T	81	0.700	0.720	+2.9
	N	143	0.568	0.640	+12.7
TOTAL	ALL	1089	0.656	0.791	+20.6*

Notes: [1] D = Day, T = Twilight, N = Night
[2] Also includes a 35 mph Advisory Speed plaque directly below the Curve sign
*Statistically significant difference at 95% level of confidence
Please note that FM 244 was not included in this evaluation due to data collection equipment failure.

Table 18 shows that the overall number of vehicles initiating deceleration prior to reaching the Curve sign was increased by approximately 20 percent when the fluorescent yellow Curve sign was in place, indicating a beneficial impact on safety by increasing the awareness of the approaching curve.

Other Curve Treatments

Retroreflectorization of the Chevron posts with fluorescent yellow microprismatic sheeting had mostly beneficial effects on speeds, especially during twilight and nighttime periods (Tables 14 and 15). Fluorescent yellow sheeting had small and inconsistent effects on speeds when used for exit ramp advisory speed signing (Tables 14 and 15).

FLUORESCENT YELLOW MICROPRISMATIC STOP AHEAD SIGNS

Summaries of the changes in mean approach speeds and excessive decelerations associated with installation of fluorescent yellow microprismatic Stop Ahead signs are shown in Table 19. In each case, the sheeting on the existing Stop Ahead sign was standard yellow high intensity. No other sign attributes were modified between data collection periods. Similar to the curve findings, the fluorescent yellow microprismatic sheeting treatments were found to produce no statistically significant changes in speed variance for any of the evaluations.

Table 19. Effect of Fluorescent Yellow Microprismatic Stop Ahead Signs on Mean Vehicular Speeds and Excessive Decelerations.

Site	Time Of Day[1]	Overall Sample Size	Mean Speeds 500 ft Upstream of Stop Sign (mph)			Mean Speeds 250 ft Upstream of Stop Sign (mph)			Vehicles Exceeding Comfortable Deceleration[2] Over Final 500 ft (rate of occurrence)		
			Existing	FY	Δ[3]	Existing	FY	Δ[3]	Existing	FY	Δ%[4]
FM 2154 NB	D	72	43.7	45.4	+1.7	35.4	36.2	+0.8	0.004	0.000	-100
	T	65	45.1	44.4	-0.7	35.2	36.8	+1.6*	0.022	0.002	-90.9
	N	54	45.5	42.0	-3.5*	35.7	34.0	-1.7	0.006	0.008	+33.3
FM 2154 SB	D	73	50.1	50.9	+0.8	39.0	40.3	+1.3	0.022	0.076	+246*
	T	79	48.4	49.6	+1.2	38.4	39.2	+0.8	0.039	0.036	-7.7
	N	77	48.3	45.3	-3.0	40.2	37.8	-2.4	0.073	0.054	-26.0

Notes: [1] D = Day, T = Twilight, N = Night
[2] 10 ft/s^2 is the maximum comfortable deceleration rate used herein (*12*)
[3] Δ = Change
[4] Δ % = Percent Change
*Statistically significant difference at 95% level of confidence

Installations of fluorescent yellow microprismatic sheeting on Stop Ahead signs had an inconsistent effect on driver behavior on approaches to stop-controlled intersections. While relatively large changes in speed were observed between the before and after periods, many of these changes were not statistically significant because of similar changes in before and after driver behavior at the upstream control point, which was factored into the analysis as a covariate (see earlier description of ANOVA with covariate).

Furthermore, inconsistent changes were observed between changes in the daytime/twilight data vs. the nighttime data. For example, it appeared that the fluorescent microprismatic Stop Ahead signs produced increases in driver speeds during the day and twilight while decreases in driver speeds were observed at night. This may indicate that although the fluorescent characteristics had little beneficial effect on driver behavior during the day, the microprismatic characteristics increased the sign brightness enough to produce consistently beneficial nighttime effects on speeds of vehicles approaching the intersection.

FLUORESCENT RED MICROPRISMATIC STOP SIGNS

Summaries of the changes in mean speeds and excessive decelerations associated with installation of fluorescent red microprismatic Stop signs are shown in Table 20. Results of the stopping compliance analysis are presented in Table 21. In each case, the sheeting on the existing Stop sign was standard red high intensity. No other sign attributes were modified between data collection periods. No statistically significant changes in speed variance were found and thus were omitted from Table 20.

Table 20 shows that installations of fluorescent red microprismatic Stop signs had some beneficial effects on vehicular speeds on the approaches to intersections. The signs were especially effective during the daytime periods where half of the sites experienced statistically significant decreases in speeds near the intersection.

Table 21 shows that the rate of vehicles not fully stopping (i.e., blow-throughs and roll-throughs) was also reduced considerably both day and night after installation of the fluorescent red Stop signs, with an overall reduction in vehicles not fully stopping of 23.7 percent. However, the signs had no effect on the overall rate of blow-throughs, which remained a constant 0.13 both before and after installation (not shown in Table 21).

Table 20. Effect of Fluorescent Red Microprismatic Stop Signs on Mean Vehicular Speeds and Excessive Decelerations.

Site	Time of Day[1]	Overall Sample Size	Mean Speeds 500 ft Upstream of Stop Sign (mph)			Mean Speeds 100 ft Upstream of Stop Sign (mph)			Vehicles Exceeding Comfortable Deceleration[2] Over Final 250 ft (rate of occurrence)		
			Existing	FR	Δ[3]	Existing	FR	Δ[3]	Existing	FR	Δ%[4]
Deacon Dr.	D	88	37.9	36.3	-1.6*	27.8	27.1	-0.7	0.070	0.026	-62.9
	T	53	37.1	36.7	-0.4	27.2	26.1	-1.1	0.112	0.014	-87.5*
	N	66	36.4	35.9	-0.5	25.9	25.6	-0.3	0.081	0.020	-75.3
Holleman Dr.	D	92	38.0	37.4	-0.6	27.0	25.7	-1.3*	0.009	0.026	+189
	N	56	34.7	35.1	+0.4	26.6	26.4	-0.2	0.004	0.009	+125
Luther St.	D	61	45.0	45.4	+0.4	27.7	27.7	0.0	0.024	0.052	+117
	N	47	42.3	43.7	+1.4	26.5	27.0	+0.5	0.066	0.037	-43.9
FM 2549[5]	D	262	57.9	57.6	-0.3	34.3	33.4	-0.9*	N/A	N/A	N/A
	T	78	59.1	60.2	+1.1	35.3	33.8	-1.5	N/A	N/A	N/A
	N	59	53.5	54.1	+0.6	32.4	32.3	-0.1	N/A	N/A	N/A

Notes: [1] D = Day, T = Twilight, N = Night
[2] 10 ft/s^2 is the maximum comfortable deceleration rate used herein (*12*)
[3] Δ = Change
[4] Δ % = Percent Change
[5] Speeds reported for FM 2549 were measured approximately 1100 ft and 200 ft from the Stop sign, instead of 500 ft and 100 ft, respectively.
N/A = Data not available
*Statistically significant difference at 95% level of confidence

Table 21. Effect of Fluorescent Red Microprismatic Stop Signs on Stopping Compliance.

Site	Time of Day[1]	Sample Size	Vehicles Not Fully Stopping (rate of occurrence)		
			Existing	FR	Change (pct.)
FM 2549	D	276	0.571	0.414	-27.5*
	N	119	0.578	0.486	-15.9
TOTAL	ALL	395	0.573	0.437	-23.7*

Notes: [1] D = Day, N = Night
*Statistically significant difference at 95% level of confidence

RED FLASHING LED STOP SIGNS

Summaries of the changes in mean speeds and excessive decelerations associated with installation of the red flashing LED Stop signs are shown in Table 22. Table 23 presents the stopping compliance data. In each case, the sheeting on the existing Stop sign was standard red high intensity. No other sign attributes were modified between data collection periods. No changes in speed variance were found.

Table 22. Effect of Red Flashing LED Stop Signs on Mean Vehicular Speeds and Excessive Decelerations.

Site	Time of Day[1]	Overall Sample Size	Mean Speeds 300 ft Upstream of Stop Sign (mph)			Mean Speeds 100 ft Upstream of Stop Sign (mph)			Vehicles Exceeding Comfortable Deceleration[2] Over Final 250 ft (rate of occurrence)		
			Existing	LED	Δ[3]	Existing	LED	Δ[3]	Existing	LED	Δ%[4]
Southwest Parkway	D	60	33.9	34.7	+0.8	27.9	27.9	0.0	0.018	0.011	-38.9
	N	45	33.0	33.7	+0.7	27.8	27.4	-0.4	0.023	0.020	-13.0
FM 2549[5]	D	283	57.9	58.9	+1.0	34.3	34.2	-0.1	N/A	N/A	N/A
	T	88	59.1	59.9	+0.8	35.3	35.0	-0.3	N/A	N/A	N/A
	N	65	53.5	58.0	+4.5	32.4	34.5	+2.1	N/A	N/A	N/A

Notes: [1] D = Day, T = Twilight, N = Night
[2] 10 ft/s^2 is the maximum comfortable deceleration rate used herein (*12*)
[3] Δ = Change
[4] Δ % = Percent Change
[5] Speeds reported for FM 2549 were measured approximately 1100 ft and 200 ft from the Stop sign, instead of 300 ft and 100 ft, respectively.
N/A = Data not available
*Statistically significant difference at 95% level of confidence

Table 23. Effect of Red Flashing LED Stop Signs on Stopping Compliance.

Site	Time of Day[1]	Sample Size	Vehicles Not Fully Stopping (rate of occurrence)			Blow-Throughs (rate of occurrence)		
			Existing	LED	Change (pct.)	Existing	LED	Change (pct.)
Southwest Parkway	D	533	0.357	0.344	-3.6	0.011	0	-100
	N	479	0.484	0.317	-34.5*	0.016	0	-100*
FM 2549	D	359	0.571	0.338	-40.8*	0.151	0.050	-66.9*
	T	135	0.652	0.409	-37.3*	0.145	0.061	-57.9
	N	107	0.578	0.274	-52.6*	0.089	0.065	-27.0
TOTAL	ALL	1613	0.471	0.335	-28.9*	0.051	0.024	-52.9*

Notes: [1] D = Day, T = Twilight, N = Night
*Statistically significant difference at 95% level of confidence

Overall, the use of Stop signs with red flashing LEDs embedded at each corner of the sign had consistent statistically significant beneficial effects on daytime and nighttime stopping compliance. Statistically significant reductions of 34 to 53 percent in the rate of vehicles not-fully stopping (blow-throughs and roll-throughs) were observed during four of the five evaluation periods after installation of the flashing LED Stop sign. Overall, the total rate of vehicles not fully stopping was reduced from 0.471 to 0.335 (28.9 percent reduction) after installation of the flashing LED Stop sign.

The flashing LED Stop sign was particularly effective for reducing the rate of vehicles blowing-through the intersection, as the overall rate of occurrence was reduced from 0.051 to 0.024 (52.9 percent). Although effective towards improving stop-compliance, the flashing red LED signs produced no statistically significant effect on vehicular speeds or decelerations on the approaches to the intersections (Table 22).

RED CONSPICUITY BORDER ON SPEED LIMIT SIGN

Summaries of the changes in mean and 85th percentile speeds, percent of vehicles exceeding the posted speed limit, and the standard deviation of speed associated with installation of the red border on the selected Speed Limit sign at the State Highway 7 site are shown in Tables 24 and 25 for both passenger vehicles and heavy trucks. No statistically significant changes in speed variance were observed. Because the red border was only evaluated at a single location, the results should be viewed with discretion.

Table 24. Effect of 3-inch Red Border on Speeds Upon Entry to Speed Zone.

Vehicle Type	Time of Day[1]	Overall Sample Size	Mean Speeds at Entry to Speed Zone (mph)			85th Percentile Speeds At Entry to Speed Zone (mph)			Exceeding 55 mph Speed Limit at Entry to Speed Zone (rate of occurrence)		
			Existing	With Border	Δ[2]	Existing	With Border	Δ[2]	Existing	With Border	Δ %[3]
Cars	D	799	64.5	62.6	-1.9*	71.0	69.0	-2.0	0.934	0.844	-9.6*
	N	251	60.3	59.3	-1.0	67.7	66.0	-1.7	0.698	0.622	-10.9
Heavy Trucks	D	114	63.2	62.1	-1.1	68.0	68.0	0.0	0.938	0.907	-3.3
	N	46	61.1	60.3	-0.8	65.3	64.2	-1.1	0.840	0.764	-9.0

Notes: [1] D = Day, N = Night
[2] Δ = Change
[3] Δ % = Percent Change
*Statistically significant difference at 95% level of confidence

Table 25. Effect of 3-inch Red Border on Speeds 500 ft Downstream from Entry to Speed Zone.

Vehicle Type	Time of Day[1]	Overall Sample Size	Mean Speeds 500 ft Downstream from Entry to Speed Zone (mph)			85th Percentile Speeds 500 ft Downstream from Entry to Speed Zone (mph)			Exceeding 55 mph Speed Limit 500 ft Downstream from Entry to Speed Zone (rate of occurrence)		
			Existing	With Border	Δ[2]	Existing	With Border	Δ[2]	Existing	With Border	Δ %[3]
Cars	D	728	62.5	60.5	-2.0*	70.0	68.0	-2.0	0.852	0.713	-16.3*
	N	246	58.3	57.5	-0.8*	66.0	64.8	-1.2	0.618	0.500	-19.1
Heavy Trucks	D	83	62.5	58.6	-3.9*	68.0	63.5	-4.5	0.875	0.765	-12.6
	N	61	59.7	59.0	-0.7	65.3	63.9	-1.4	0.689	0.679	-1.5

Notes: [1] D = Day, N = Night
[2] Δ = Change
[3] Δ % = Percent Change
*Statistically significant difference at 95% level of confidence

Overall, the installation of a 3-inch red microprismatic border around the perimeter of the Speed Limit sign at entry to the 55 mph speed zone showed many beneficial effects on speed-related measures for both passenger vehicles and heavy trucks. The red border had the greatest effect on daytime passenger vehicles, which displayed roughly 2 mph decreases for both the mean and 85th percentile speeds both at the entry point to the speed zone and 500 ft after entering. The border had a similar, although slightly weaker, effect on the mean and 85th percentile speeds of passenger vehicles at night. The effect of the red border on speeds of heavy trucks was similar, although only significant during the day where speeds were reduced by approximately 4 mph 500 ft downstream of the speed zone entry point. For all vehicles, the overall rate exceeding the 55 mph speed limit was statistically significantly reduced from 0.800 to 0.653 (18.4 percent) with the red border in place (not shown in Tables 24 or 25).

COST COMPARISON FOR HIGHER-CONSPICUITY SIGN MATERIALS

A critical component to implementation of a traffic control device is consideration of the costs. The researchers gathered current TxDOT cost information for installation of signs with various sheeting materials. Table 26 displays the approximate current (2003) costs for sheeting and installation for various signs[6]. Table 26 clearly displays that while costs of the various

[6] Information obtained from TxDOT Traffic Operations Division on August 6, 2003.

higher-conspicuity sheeting materials are considerably more expensive than their standard color counterparts, the increases in the installed costs of the signs are generally only slightly greater.

Table 26. Application and Installation Costs for Signs of Various Materials.

Sign	Application	Sign Cost[1]	Total Installed Cost[2]
 18-in by 24-in (e.g., Chevron)	Standard Yellow High Intensity	\$3.60	\$335
	Fluorescent Colored Microprismatic	\$12.00	\$343
	Change	333% .	2%.
 48-in by 48-in (e.g., Curve Warning)	Standard Yellow High Intensity	\$19.20	\$350
	Fluorescent Colored Microprismatic	\$64.00	\$395
	Change	333%.	13%.
 48-in Stop	Standard Red High Intensity	\$19.20	\$350
	Standard Red Microprismatic[3]	\$55.50	\$387
	Change	289%.	11%.
 48-in Stop	Standard Red High Intensity	\$19.20	\$350
	Flashing LED Stop Sign	\$895.00 (for completed sign)	\$1226
	Change	4661%.	350%.

Notes: [1]Based on unit prices of \$1.20 per square foot (sf) for standard color high intensity sheeting, \$4.00/sf fluorescent color microprismatic sheeting, and \$3.46/sf for standard color microprismatic sheeting. Cost information obtained from TxDOT Traffic Operations Division on August 6, 2003.
[2]Includes an estimated fixed rate of \$331 for labor and sign support hardware.
[3]Standard red microprismatic Stop signs were not evaluated in the research performed here. Standard red microprismatic Stop signs are recommended due to the unavailability of fluorescent red microprismatic sheeting.

CHAPTER 6:
SUMMARY AND RECOMMENDATIONS

This project examined the effectiveness of various higher-conspicuity traffic control device applications installed under a number of different field conditions. The higher-conspicuity applications included fluorescent yellow microprismatic warning signs, fluorescent red microprismatic Stop signs, Stop signs with red flashing LEDs, and red microprismatic border on the initial Speed Limit sign upon entry to a speed zone.

Fourteen sites were used for the evaluations, including six curves, seven intersections, and one rural speed zone. Researchers hypothesized that the higher-conspicuity sign sheeting treatments would prompt a change in traffic operations that are related to driver behavior. The researchers measured and analyzed the impact on traffic operations of specific applications of higher-conspicuity traffic control device applications. A number of statistical procedures were used to draw inferences from the differences observed in the data.

SUMMARY OF FINDINGS

Overall, the higher-conspicuity applications produced mostly small changes in traffic operations, although many statistically significant beneficial results occurred. It should be pointed out that no negative driver behavioral impacts were found to be associated with any of the higher-conspicuity sign materials. The findings from the analyses are summarized in Table 27.

Table 27. Primary Findings for Higher-Conspicuity Sign Applications.

Sign Treatment	Number of Sites	Primary Finding	Beneficial Impact?
 Fluorescent Yellow Chevron	4	• 38% overall reduction in edge line encroachments • Overall mean and 85th speeds at curve reduced by 1 mph • 11% overall reduction in vehicles exceeding safe speeds at the curves	Yes
 Fluorescent Yellow Chevron Posts	1	• Speeds reduced slightly	Marginal
 Fluorescent Yellow Curve Warning	3	• Speeds reduced slightly • 20% overall increase in vehicles initiating deceleration prior to reaching the sign	Marginal
 Fluorescent Yellow Exit Ramp Advisory	1	• Inconsistent effect on speeds	No
 Fluorescent Yellow Stop Ahead	2	• Approach speeds reduced at night	Marginal
 Flashing LED Stop	2	• 29% overall reduction in vehicles not fully stopping • Blow-throughs reduced by ½	Yes
 Fluorescent Red Stop	5	• 24% overall reduction in vehicles not fully stopping • Daytime approach speeds reduced	Yes
 Red Reflectorized Border	1	• 18% overall reduction in vehicles exceeding 55 mph speed limit shortly after entering speed zone • 2 mph reduction in daytime passenger vehicle speeds shortly after entering speed zone • 4 mph reduction in daytime heavy truck speeds shortly after entering speed zone • Nighttime speeds reduced slightly	Yes

RECOMMENDATIONS

Based on the research findings, the researchers have made a number of recommendations pertaining to the application of higher-conspicuity sign materials. Recommendations have been split into three categories: statewide implementation (maintenance replacement or new installations), spot implementation on an as-needed basis, and optional implementation (either statewide or as-needed).

Fluorescent Yellow Microprismatic Sheeting

The research resulted in mostly beneficial findings associated with the use of fluorescent yellow microprismatic sheeting for warning signs, including improved sign conspicuity, improved driver behavior, and relatively small increased cost for implementation. As a result of the research findings, researchers recommend statewide implementation of fluorescent yellow microprismatic sheeting for fluorescent yellow Chevrons. Researchers also recommended that statewide implementation occur as part of scheduled maintenance replacement, as-needed maintenance replacement (i.e., sign knockdowns), or new installations. Furthermore, if a fluorescent yellow Chevron installation is to occur at a given location, all Chevrons should be upgraded to fluorescent yellow, as mixing standard/fluorescent colored sheeting at a given site is not recommended.

The researchers also recommend the option to implement fluorescent yellow sheeting on an as-needed basis for all other warning signs related to horizontal curves (i.e., Curve signs, Advisory Speed plaques, large arrows, etc.). The use of fluorescent yellow microprismatic materials on Chevron posts or other curve delineators is recommended on an as-needed basis at spot locations where additional delineation is desired. The data showed no undesirable impacts associated with fluorescent yellow. Therefore, fluorescent yellow should be allowed for optional use on any yellow warning sign.

Red Flashing LED Stop Signs

Due to their effectiveness in reducing Stop sign violations, especially blow-throughs, Stop signs with red flashing LEDs embedded in the corners are recommended for implementation on an as-needed basis at spot locations where a high percentage of vehicles do not comply with the Stop sign. Non-compliance with the Stop sign may be especially prevalent at locations where the Stop sign is at least partially obstructed or in an otherwise disadvantaged position, such as extreme lateral offset and the stop condition is not reiterated by other features. It should also be noted that before using a red flashing LED Stop sign, experimental permission must be granted by the FHWA.

Fluorescent Red Microprismatic Sheeting for Stop Signs

Fluorescent red microprismatic sheeting on Stop signs was found to be effective toward improving stopping compliance during the daytime and nighttime periods and also reducing approach speeds during the day. As a result, fluorescent red is recommended as an optional sheeting color for Stop signs at locations where additional daytime conspicuity is desired. However, the fluorescent red sheeting material evaluated in this project was obtained by TTI from the 3M Corporation for experimental purposes only and is not currently available for commercial use. Because these signs were found to be effective at night, the researchers recommend the use of non-fluorescent red microprismatic Stop signs on an as-needed basis at spot locations where increased Stop sign retroreflectivity is desired.

The researchers recommend further research of the impacts of fluorescent red Stop signs before additional recommendations are made.

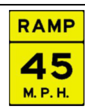
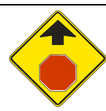
Red Conspicuity Border on Speed Limit Sign

A 3-inch red microprismatic border around the perimeter of a Speed Limit sign had a beneficial daytime and nighttime impact on average and 85^{th} percentile speeds and the percent of vehicles exceeding the speed limit. However, the researchers recommend further research of the impacts of colored speed limit borders before implementation recommendations can be made. It should also be noted that before using a colored border on a Speed Limit sign, experimental permission must be granted by the FHWA.

Summary of Recommendations

Table 28 presents a summary of recommended TxDOT applications for higher-conspicuity sign materials.

Table 28. Summary of Recommendations for Higher-Conspicuity Sign Materials.

Sign Treatment		Implementation Recommendation		
		Statewide	As Special Treatment	As Experimental Device[1]
Fluorescent Yellow Chevron		Yes	---	---
Fluorescent Yellow Chevron Pole		---	Yes, on an as-needed basis.	---
Fluorescent Yellow Curve Warning		---	Yes, on an as-needed basis.	---
Fluorescent Yellow Curve Warning with Advisory Speed Plaque		---	Yes, on an as-needed basis.	---
Fluorescent Yellow Large Arrow		---	Yes, on an as-needed basis.	---
Fluorescent Yellow Exit Ramp Advisory		---	Yes, on an as-needed basis.	---
Fluorescent Yellow Stop Ahead		---	Yes, on an as-needed basis.	---
Flashing LED Stop		---	---	Yes, on an as-needed basis.
Fluorescent Red Stop		---	---	Yes, however, the product is not available commercially. Microprismatic sheeting should be considered for Stop signs.
Microprismatic Stop Sign		---	Yes, based on nighttime results for fluorescent red Stop sign.	---
Red Border		---	---	Yes, where the speed limit is reduced with no apparent change in roadway conditions.

Notes: [1]Permission to experiment must be obtained through the Federal Highway Administration (FHWA).

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APPENDIX A:
SITE DESCRIPTIONS

This appendix provides detailed descriptions of the field evaluations on a site-by-site basis.

CURVES

FM 3090

FM 3090 included evaluation of fluorescent yellow sheeting on both the Chevron signs and the Chevron posts for the northbound approach to the horizontal curve on this rural two-lane highway near Navasota, Texas. The posted speed at the site was 65 mph, while the curve (turn) advisory speed was 15 mph. Speeds of representative vehicles were measured with a series of four piezoelectric sensors both as they approached and traveled through the curve. Speed data were measured in the day, dusk, and nighttime periods both before and after placement of the fluorescent yellow signs. Encroachment data were not collected here due to data collection difficulties.

Data collection in the "before" period occurred on November 14, 15, and 18. Fluorescent yellow Chevron signs were placed on November 21, 2002, and"after" data collection was performed on January 15-17, 2003. With the fluorescent yellow Chevrons in place, 4-in wide by 8-ft tall aluminum panels with fluorescent yellow prismatic sheeting were affixed to the Chevron posts on March 19, 2003. These panels covered the entire length of the Chevron posts and gave the appearance that the sheeting had been directly applied to the posts. Subsequent data were collected on April 8-9, 2003. Figure A-1 displays the FM 3090 study site.

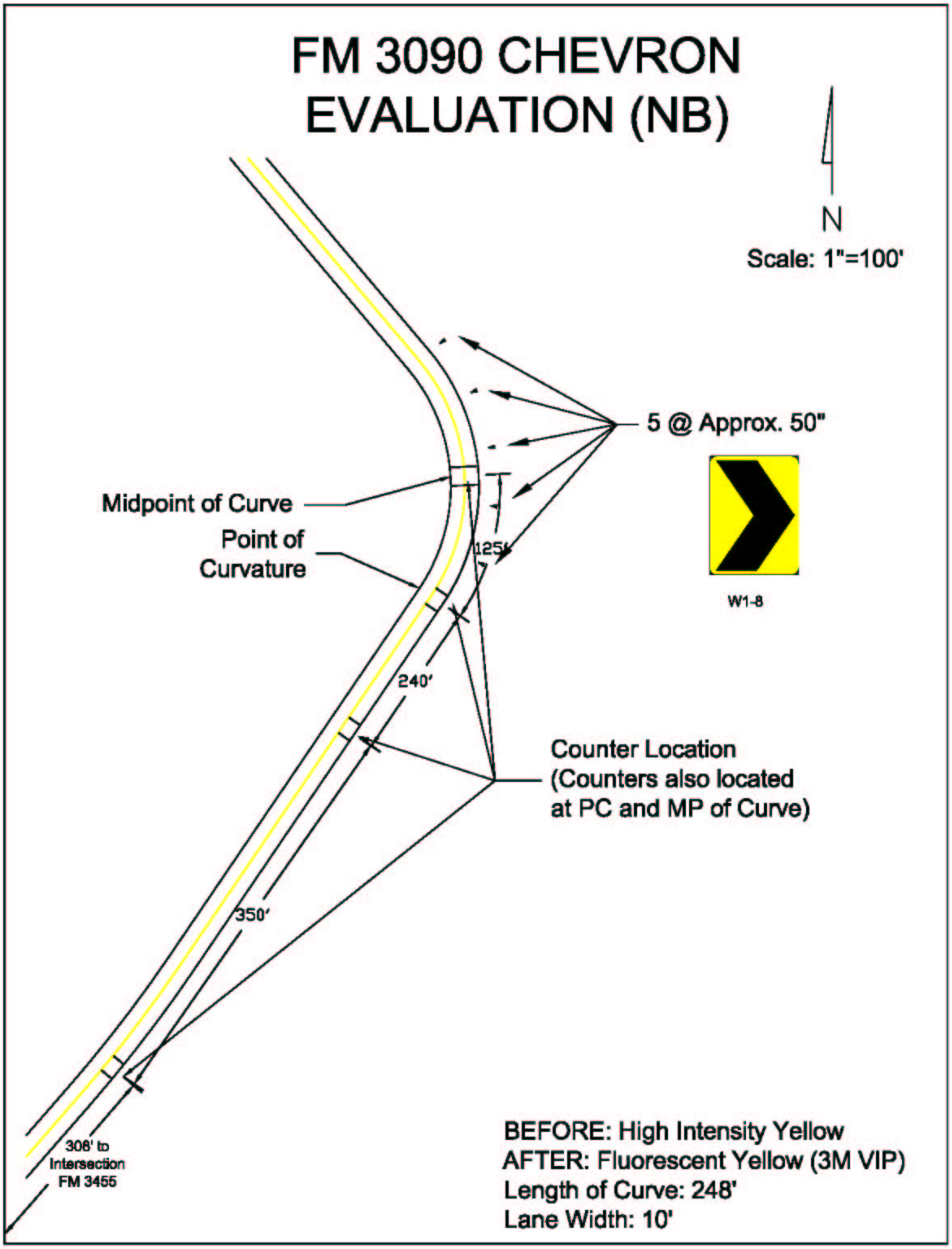

Figure A-1. Plan View of FM 3090 Curve near Navasota, Texas.

State Highway 6

Fluorescent yellow sheeting was evaluated on the Chevrons of the curve at the southbound exit ramp for State Highway 6 to Briarcrest Drive in Bryan, Texas. A series of five pneumatic tube counters was used to measure vehicular speeds both as they approached and traveled through the curve. Encroachment data were captured by a covertly placed video camera.

Speed data were measured in the day, dusk, and nighttime periods both before and after placement of the fluorescent yellow signs, while encroachment data were only measured during the daytime. Data collection in the "before" period occurred on February 20-21, 2002. Signs were replaced in early March 2002, and "after" data collection was performed on April 9-10, 2002. Figure A-2 displays a plan view of the site.

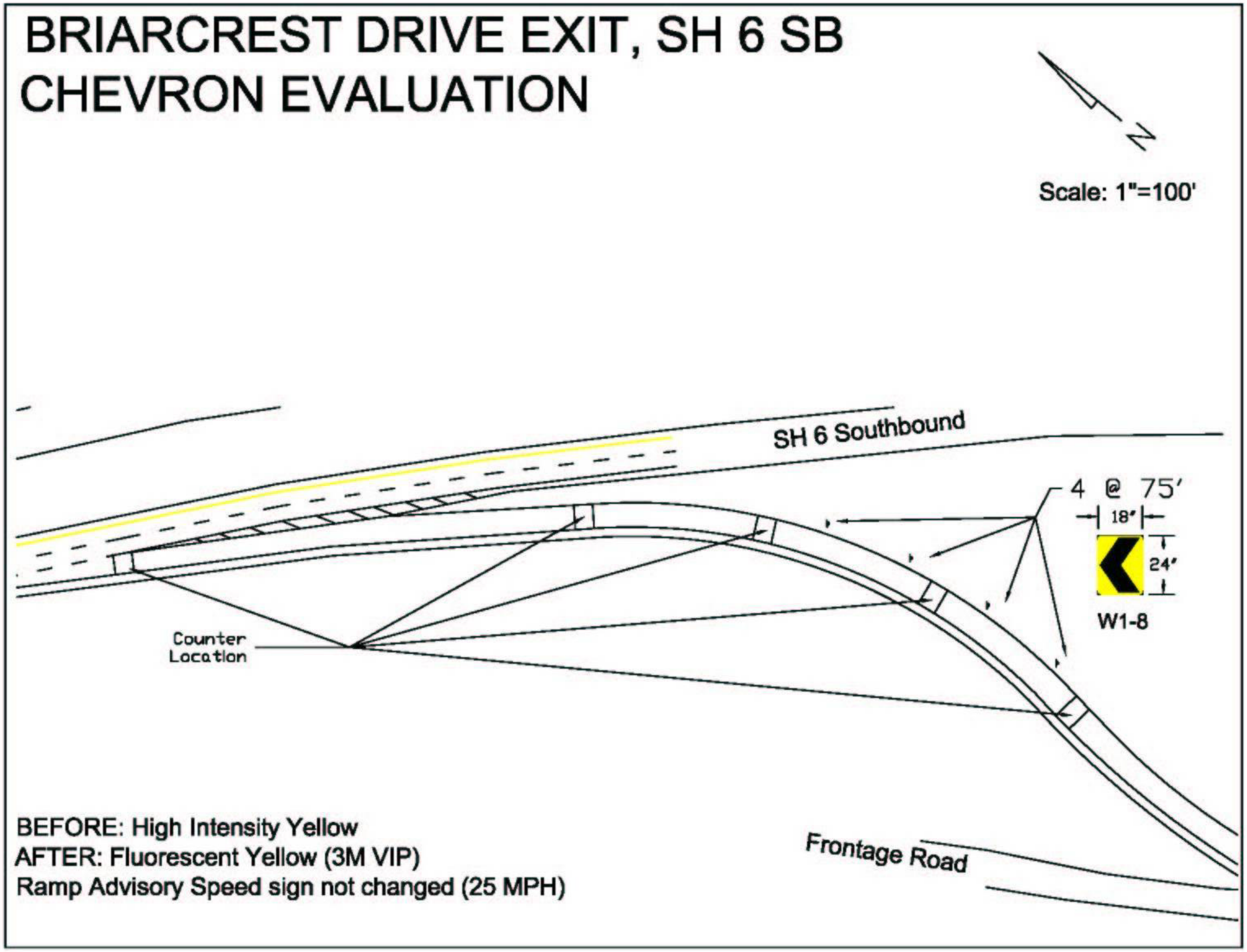

Figure A-2. Plan View of SH 6 Exit to Briarcrest Drive in Bryan, Texas.

FM 1179

FM 1179 included evaluation of fluorescent yellow sheeting on both the Curve signs and the Chevrons at the eastbound approach to the 35 mph horizontal S-curve near Steep Hollow, Texas (near Bryan). The posted speed at the site was 65 mph, while the curve advisory speed was 35 mph. Speeds (LIDAR) and encroachments (video) of representative vehicles were measured both as they approached and traveled through the curve.

Speed data were measured in the day, dusk, and nighttime periods both before and after placement of the fluorescent yellow signs, while encroachment data were only measured during the day. Data collection in the "before" period occurred on November 12, 2002. Signs were replaced on November 21, 2002, and "after" data collection was performed on December 10, 2002. A plan view of the site is shown in Figure A-3.

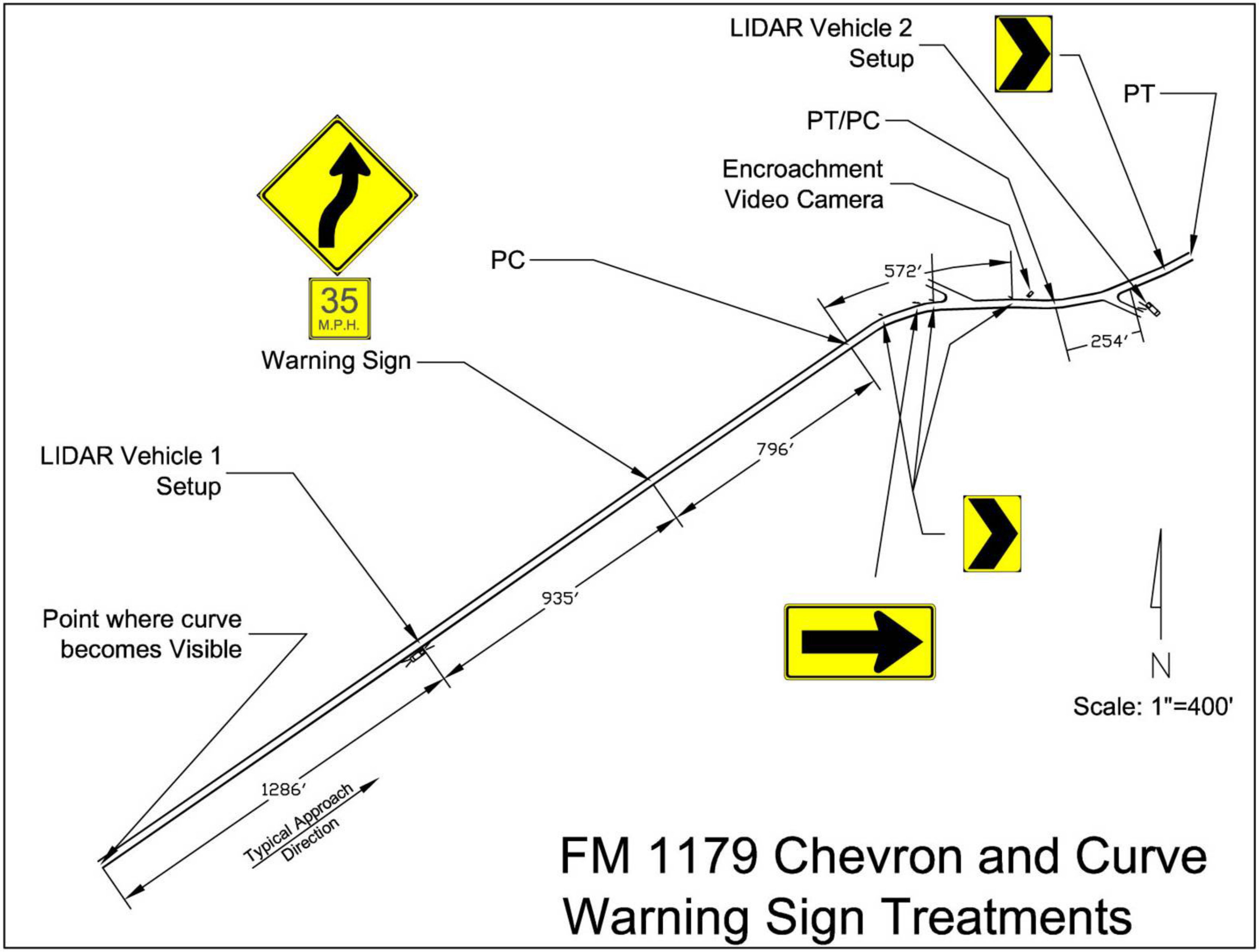

Figure A-3. Plan View of FM 1179 Curve in Steep Hollow, Texas.

FM 244

The FM 244 evaluation included fluorescent yellow sheeting on both the Curve signs and the Chevrons for the horizontal curve on the southbound approach of this rural two-lane highway near Keith, Texas. The posted speed at the site was 65 mph, while the curve advisory speed was 40 mph. Speeds of representative vehicles were measured with a series of four pneumatic tube counters both as they approached and traveled through the curve.

Speed data were measured in the day, dusk, and nighttime periods both before and after placement of the fluorescent yellow signs. Encroachment data were not collected here due to data collection difficulties. Data collection in the “before” period occurred on November 13-14, 2002. Signs were replaced on November 24, 2002, and “after” data collection was performed on January 13-15, 2003. A plan view of the site is shown in Figure A-4.

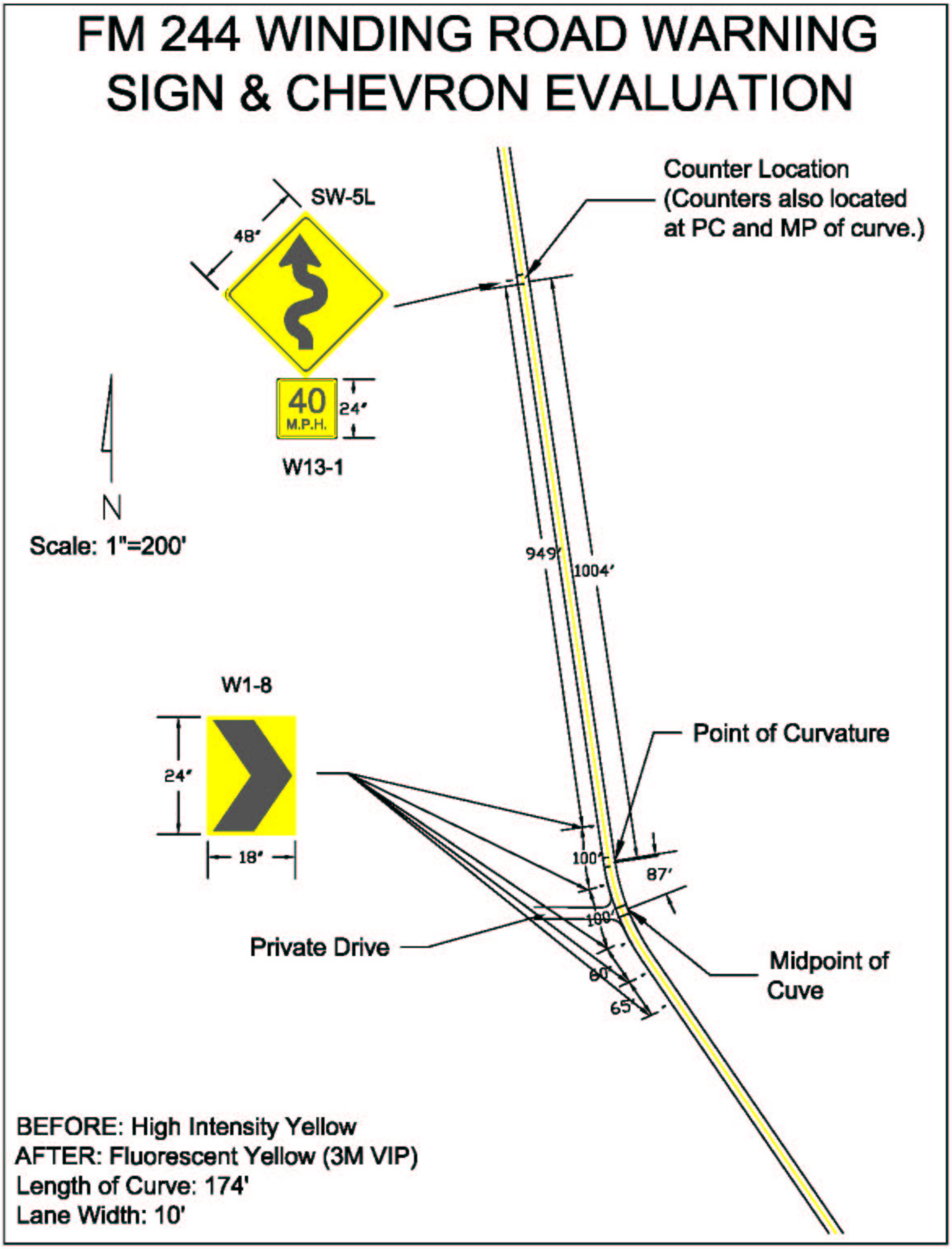

Figure A-4. Plan View of FM 244 Curve near Keith, Texas.

FM 46

FM 46 included evaluation of fluorescent yellow sheeting on the stand-alone Curve sign for the westbound approach to the horizontal curve on this rural two-lane highway near Bremond, Texas. The posted speed at the site was 65 mph, and no advisory speed plaque was present. Speeds of representative vehicles were measured with a series of four pneumatic tube counters both as they approached and traveled through the curve.

Speed data were measured in the day, dusk, and nighttime periods both before and after placement of the fluorescent yellow signs. Data collection in the “before” period occurred on March 6-7, 2003. The Curve sign was replaced on March 18, 2003, and “after” data collection was performed on March 28-30, 2003. Figure A-5 displays a plan view of the site.

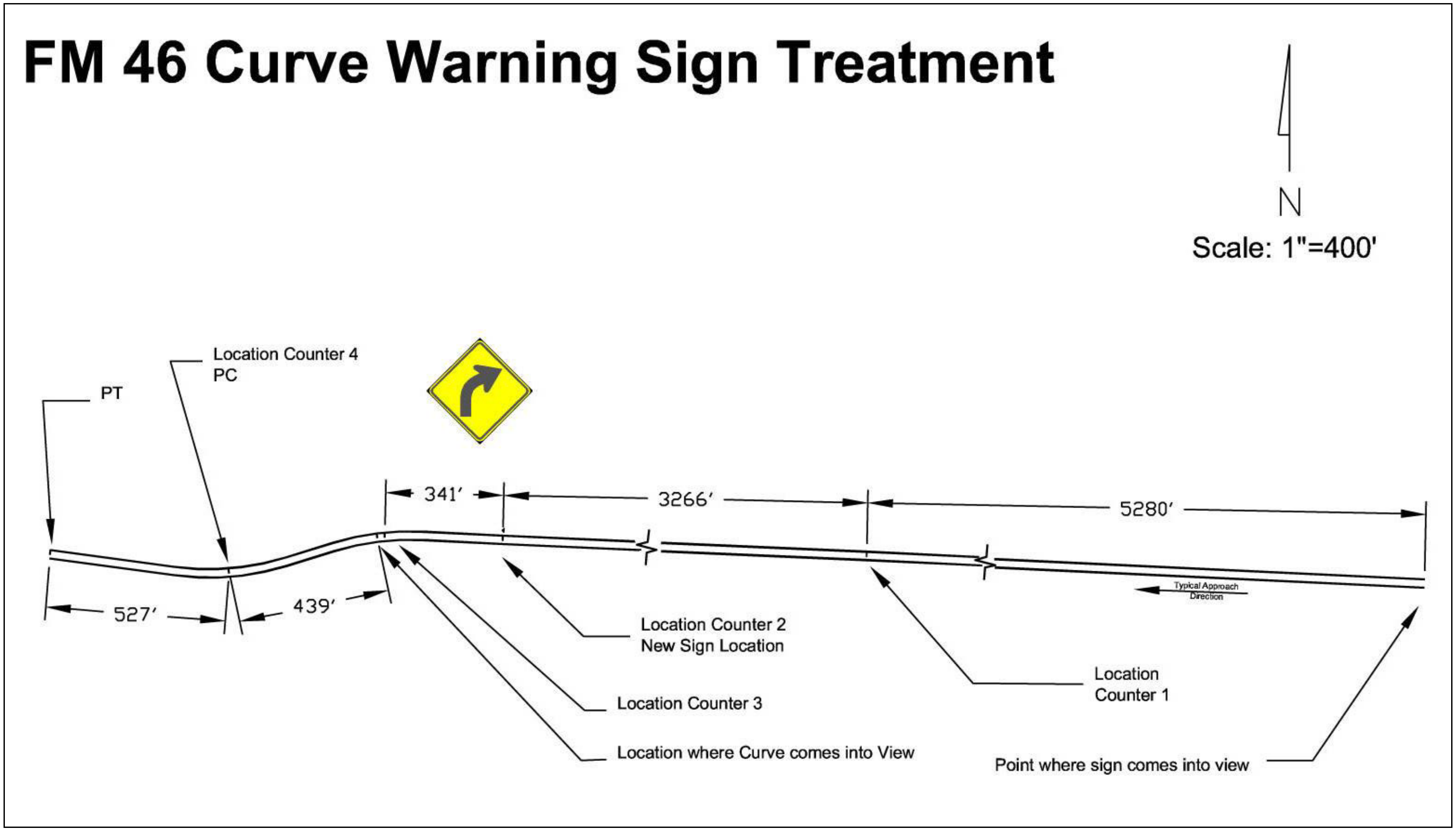

Figure A-5. Plan View of FM 46 Curve near Bremond, Texas.

FM 60

FM 60 included evaluation of fluorescent yellow sheeting on the Advisory Ramp Speed Sign on the eastbound approach at the exit ramp to southbound FM 2818 near College Station, Texas. The posted speed at the site was 55 mph, and the exit ramp advisory speed was 25 mph. Speeds (LIDAR) of representative vehicles were measured both as they approached and traveled through the curve.

Speed data were measured in the day, dusk, and nighttime periods both before and after placement of the fluorescent yellow signs. Data collection in the "before" period occurred on October 29, 2002. The Curve sign was replaced on November 13, 2002, and "after" data collection was performed on December 16, 2002. Figure A-6 displays a plan view of the site.

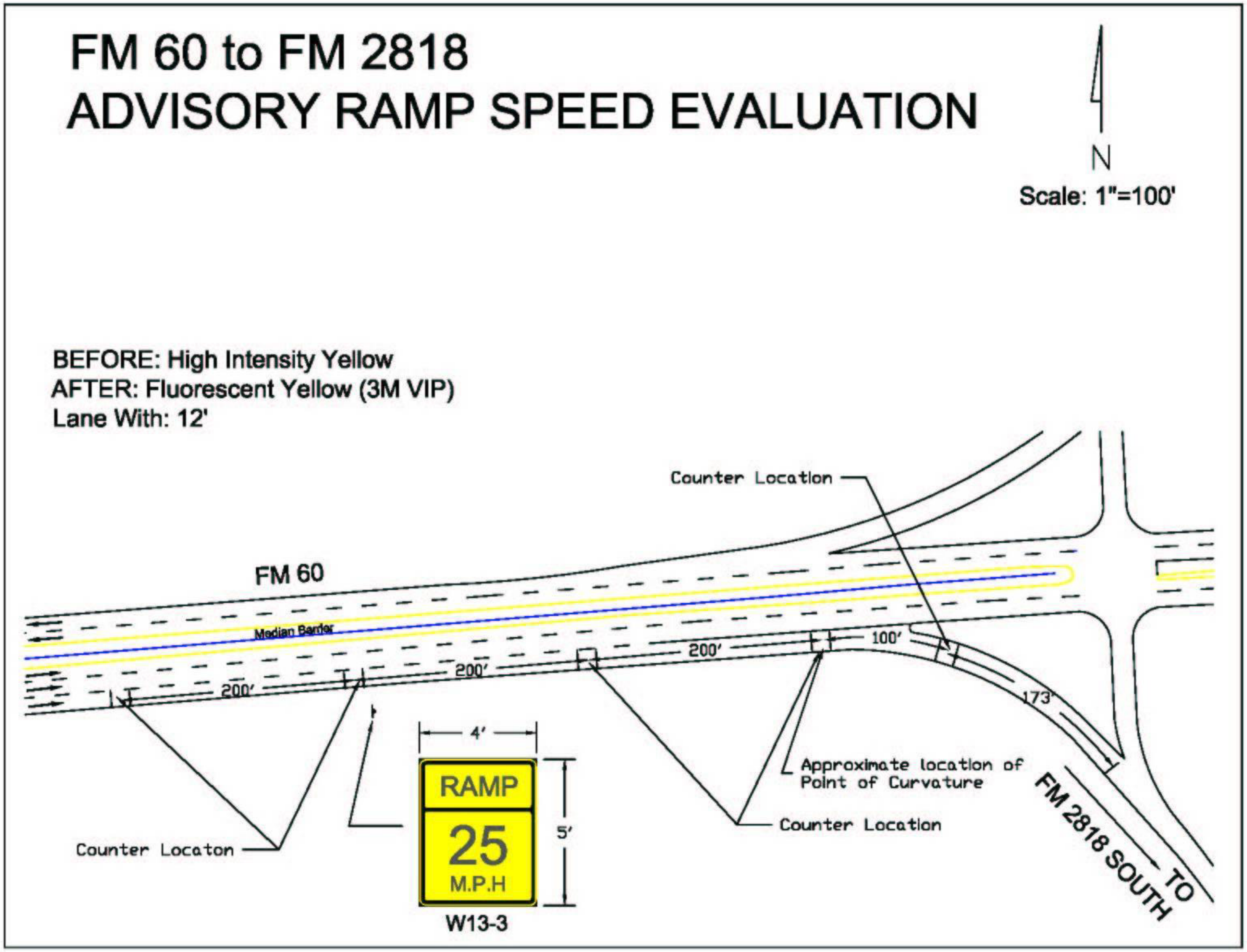

Figure A-6. Plan View of FM 60 Exit to FM 2818 near College Station, Texas.

STOP-CONTROLLED INTERSECTIONS

FM 2154

Researchers evaluated fluorescent yellow Stop Ahead signs for both the northbound and southbound approaches of the rural four-way stop-controlled intersection of FM 2154 and FM 159 in Millican, Texas. The posted speed at the site was 70/65 mph for daytime and nighttime, respectively. Speeds of representative vehicles were measured with LIDAR both upstream and on the approach to the intersection. Speed data were measured in the day, dusk, and nighttime periods both before and after placement of the fluorescent yellow signs.

For the northbound approach, data were collected in the "before" period on September 24 and 26, 2002. The existing Stop Ahead sign was replaced with the fluorescent yellow counterpart on October 11, 2002, and "after" data collection was performed on October 31 and November 6, 2002. Figure A-7 displays a plan view of the northbound approach on FM 2154.

For the southbound approach, data were collected in the "before" period on October 30 and 31, 2002. The existing Stop Ahead sign was replaced with the fluorescent yellow counterpart on November 13, 2002, and "after" data collection was performed on December 12, 2002. Figure A-8 displays a plan view of the southbound approach on FM 2154.

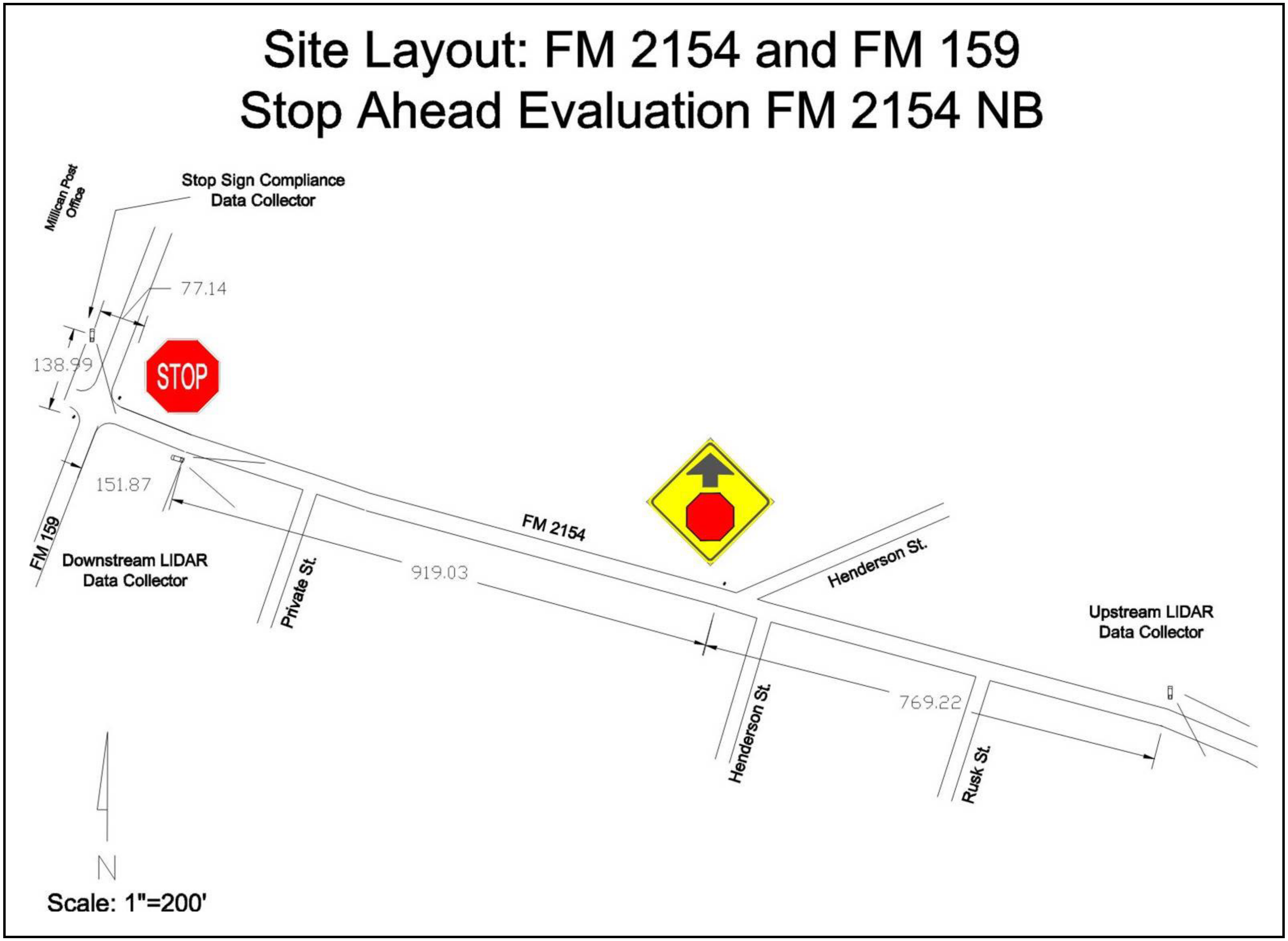

Figure A-7. Plan View of Northbound FM 2154 @ FM 159 in Millican, Texas.

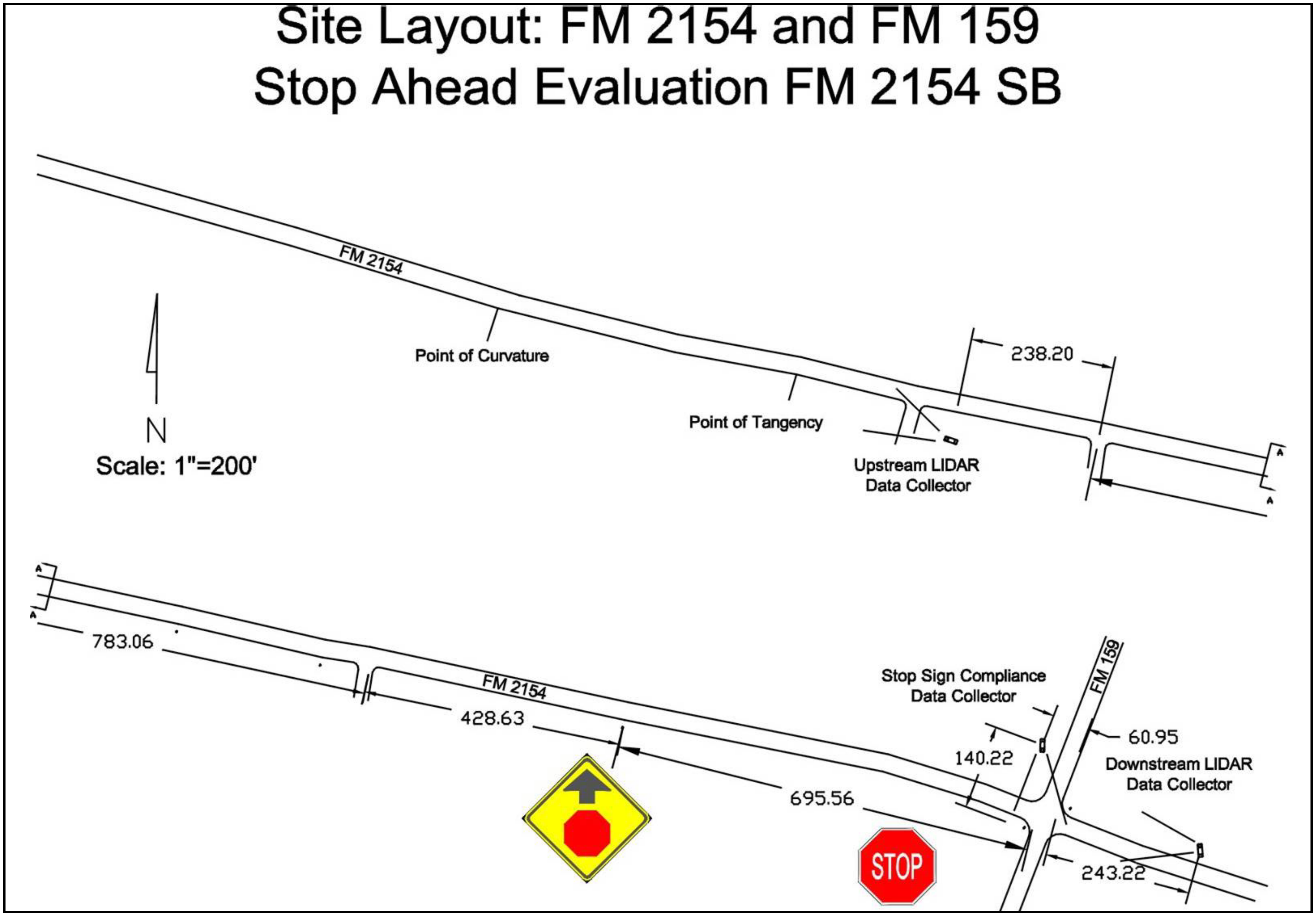

Figure A-8. Plan View of Southbound FM 2154 @ FM 159 in Millican, Texas.

Holleman Dr.

A fluorescent red Stop sign was evaluated at the suburban T-intersection of Holleman Dr. and FM 2818. The posted speed at the site was 35 mph. Speeds (LIDAR) of representative vehicles were measured on the Holleman Dr. approach to the intersection. Speed data were measured in the daytime and nighttime periods both before and after placement of the fluorescent red Stop sign.

Data collection in the "before" period occurred on September 12 and 18, 2002. The existing 30-inch ASTM Type III Stop sign on Holleman was replaced with its 30-inch fluorescent red ASTM Type IX counterpart on September 26, 2002, and"after" data collection was performed on October 29, 2002. Figure A-9 displays a plan view of the Holleman Dr. site.

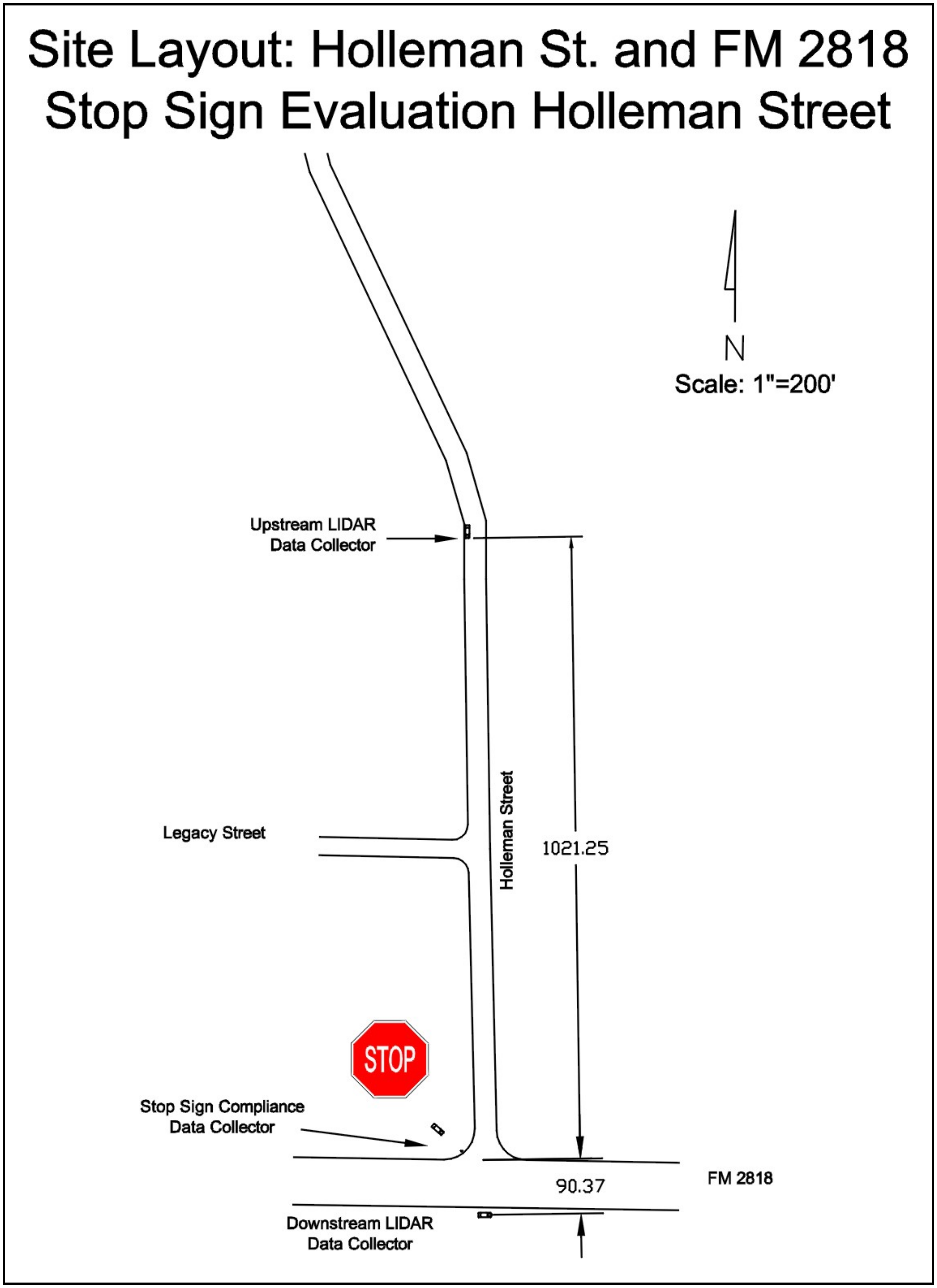

Figure A-9. Plan View of Holleman Dr. @ FM 2818 in College Station, Texas.

Deacon Dr.

A fluorescent red Stop sign was evaluated at the suburban T-intersection of Deacon Dr. and FM 2154 in College Station, Texas. The posted speed at the site was 40 mph. Speeds (LIDAR) of representative vehicles were measured on the Deacon Dr. approach to the intersection. Speed data were measured in the daytime, twilight, and nighttime periods both before and after placement of the fluorescent red Stop sign.

Data collection in the "before" period occurred on October 15, 2002. The existing 30-inch ASTM Type III Stop sign on Deacon Dr. was replaced with its 30-inch fluorescent red ASTM Type IX counterpart on November 1, 2002, and"after" data collection was performed on November 19, 2002. Figure A-10 displays a plan view of the Deacon Dr. site.

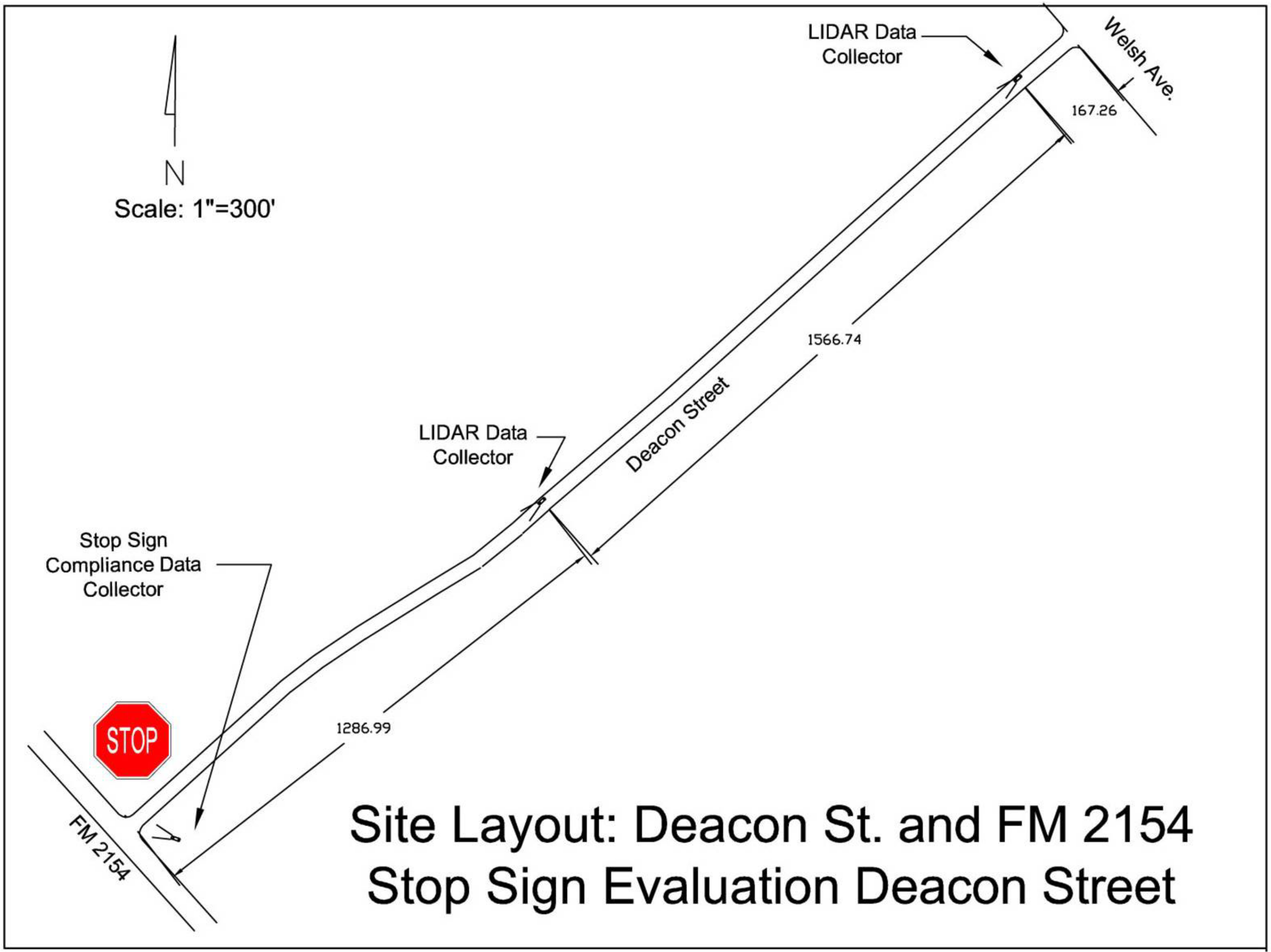

Figure A-10. Plan View of Deacon Dr. @ FM 2154 in College Station, Texas.

Luther St.

A fluorescent red Stop sign was evaluated at the suburban T-intersection of Luther St. and FM 2818 in College Station, Texas. The posted speed at the site was 45 mph. Speeds (LIDAR) of representative vehicles were measured on the Luther St. approach to the intersection. Speed data were measured in the daytime and nighttime periods both before and after placement of the fluorescent red Stop sign.

Data collection in the "before" period occurred on September 11, 2002. The existing 30-inch ASTM Type III Stop sign on Luther St. was replaced with its 30-inch fluorescent red ASTM Type IX counterpart on November 22, 2002, and"after" data collection was performed on January 16, 2003. Figure A-11 displays a plan view of the Luther St. site.

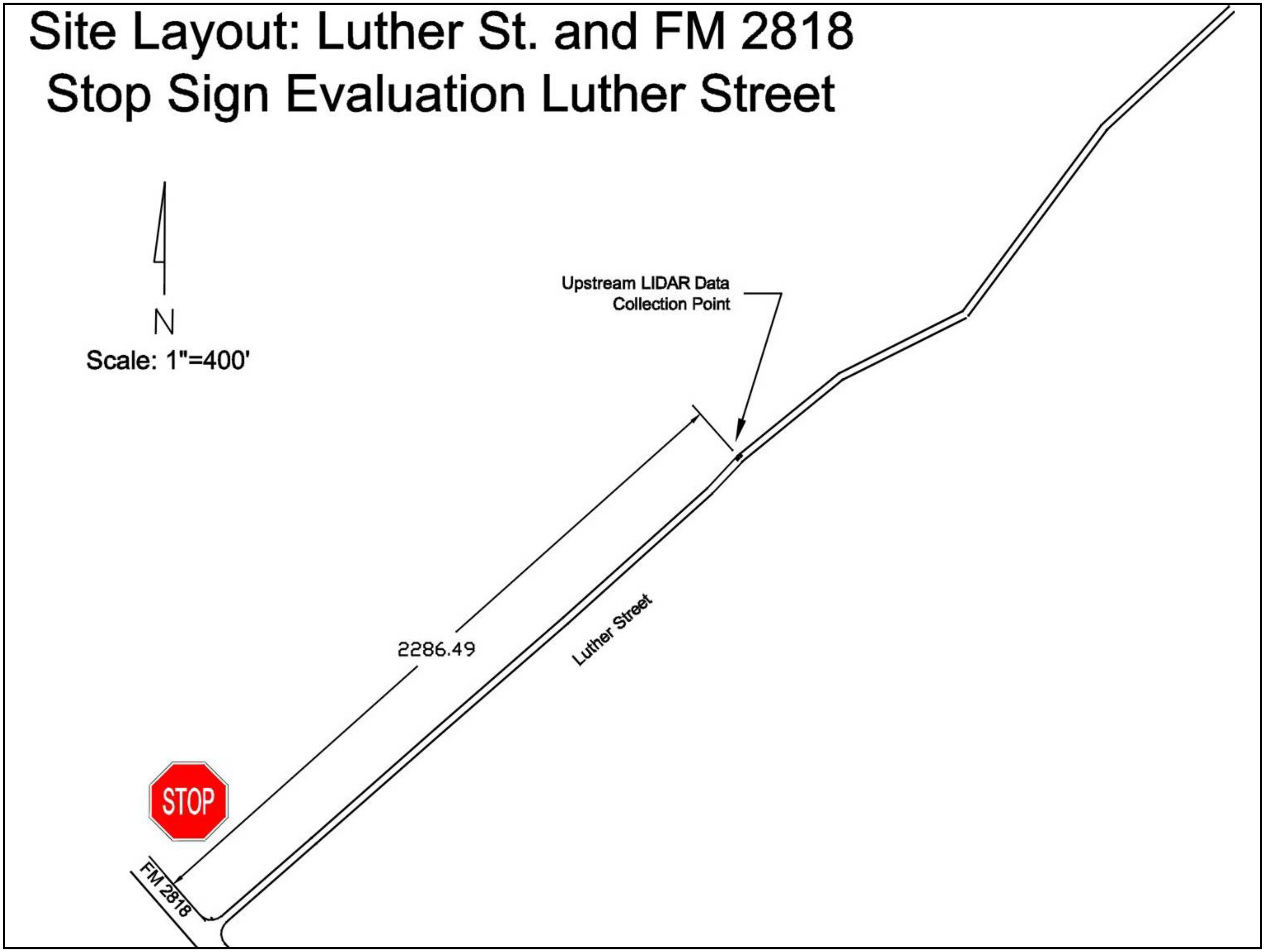

Figure A-11. Plan View of Luther St. @ FM 2818 in College Station, Texas.

FM 2549

The rural intersection of FM 2549 and FM 391 near Hearne, Texas, included evaluation of both a fluorescent red Stop sign and a flashing red LED Stop sign. This intersection was a two-way stop with stop control on FM 2549. The posted speed at the site was 70/65 mph for day and night, respectively. Vehicular speeds were measured with a series of four pneumatic tube counters placed on the eastbound FM 2549 approach to the intersection. Stopping-compliance data were collected with a video camera placed near the intersection, yet out of the view of drivers. All data were measured in the daytime, twilight, and nighttime periods both before and after placement of the flashing LED Stop sign and again after the placement of the fluorescent red Stop sign.

Data collection in the "before" period occurred on March 25-26, 2003. The existing 30-inch ASTM Type III Stop sign on FM 2549 was replaced with its 30-inch flashing red LED counterpart on April 5, 2003, and "after" data collection was performed on April 30 through May 1, 2003. The flashing LED Stop sign was then replaced by a 30-inch fluorescent red Stop sign on May 2, 2003, and "after" data were again collected on June 4-5, 2003. The additional signs at the site were not modified during the evaluation. Figure A-12 displays a plan view of the FM 2549 site.

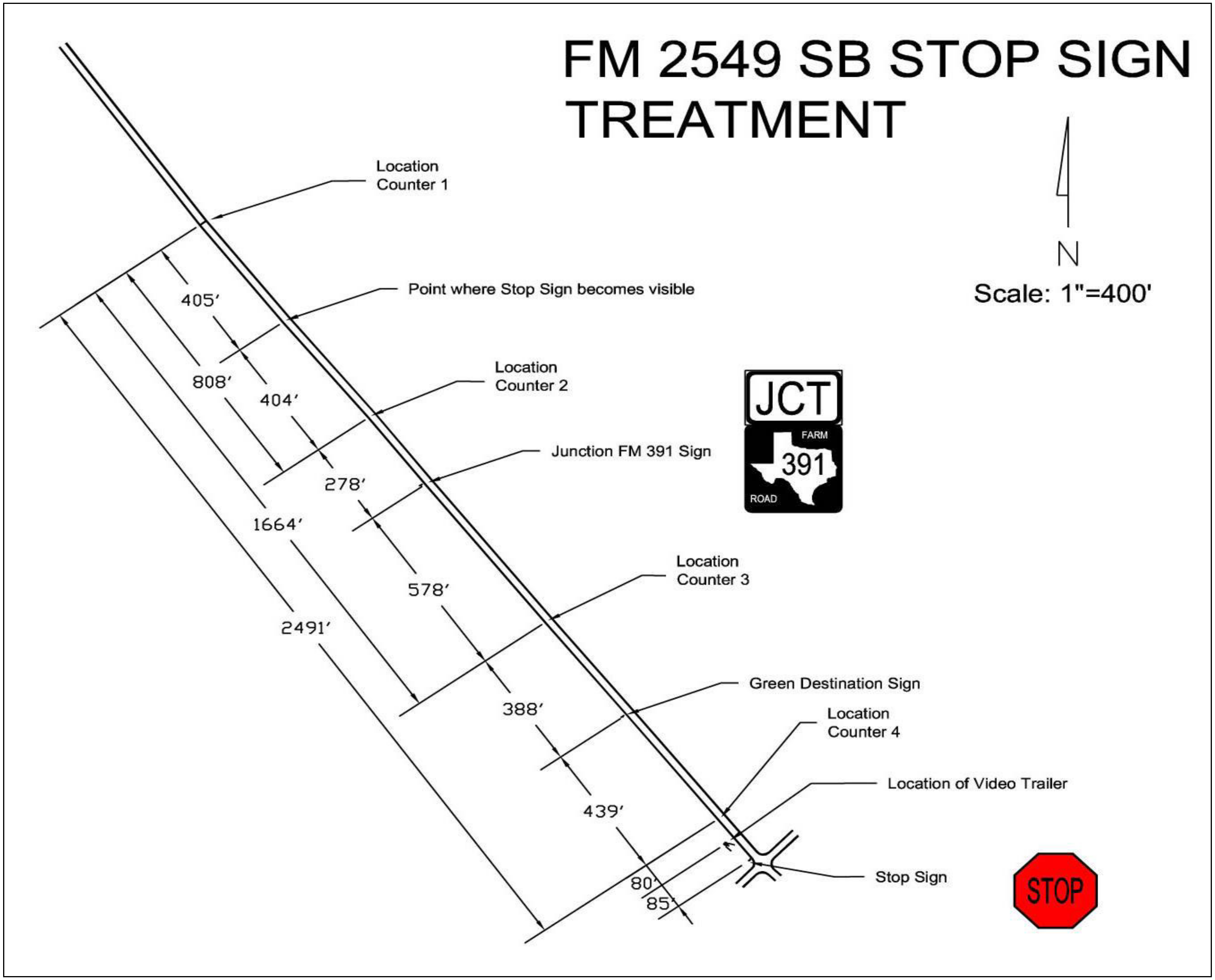

Figure A-12. Plan View of FM 2549 @ FM 391 near Hearne, Texas.

Southwest Parkway

A flashing red LED Stop sign was evaluated at the suburban intersection of Southwest Parkway and Langford St. in College Station, Texas. This intersection was a four-way stop, although Southwest Parkway was the major street at the intersection. The posted speed at the site was 35 mph. The Stop sign on the westbound approach was partially obstructed by a power pole and was not clearly visible to drivers until they were less than 200 ft from the intersection. The flashing LEDs worked to greatly improve the conspicuity of the Stop sign.

Vehicular speeds were measured with LIDAR on the westbound approach on Southwest Parkway. Stopping-compliance data were measured with a covertly placed video camera. Data were measured in the daytime and nighttime periods both before and after placement of the flashing LED Stop sign.

Data collection in the “before” period occurred on July 2, 2003. The existing 30-inch ASTM Type III Stop sign on the westbound approach was replaced with its 30-inch flashing red LED counterpart on July 8, 2003, and “after” data was collected on July 21 and 23, 2003. Figure A-13 displays a plan view of the Southwest Parkway site.

Figure A-13. Plan View of Southwest Parkway @ Langford St. in College Station, Texas.

RURAL SPEED ZONE

State Highway 7

Eastbound State Highway 7 approaching Marlin, Texas, was selected as the site for evaluation of the colored border on a Speed Limit sign. This section of highway 7 was a two-lane cross section with 10 ft shoulders. The posted speed upstream of the speed zone was 70/65 mph for daytime and nighttime, respectively. The posted speed limit on the treatment sign was 55 mph. Eastbound vehicular speeds were measured on approach to the speed zone with a series of six piezoelectric sensors. Speeds of both passenger vehicles and commercial vehicles were included in the analysis. Data were measured in the daytime and nighttime periods both before and after placement of the 3-inch red border on the 55 mph Speed Limit sign.

Data collection in the "before" period occurred on May 6-7, 2003. The 3-inch red border was added to the 55 mph Speed Limit sign on May 14, 2003, and "after" data was collected on June 2-3, 2003. Figure A-14 displays a plan view of the State Highway 7 site.

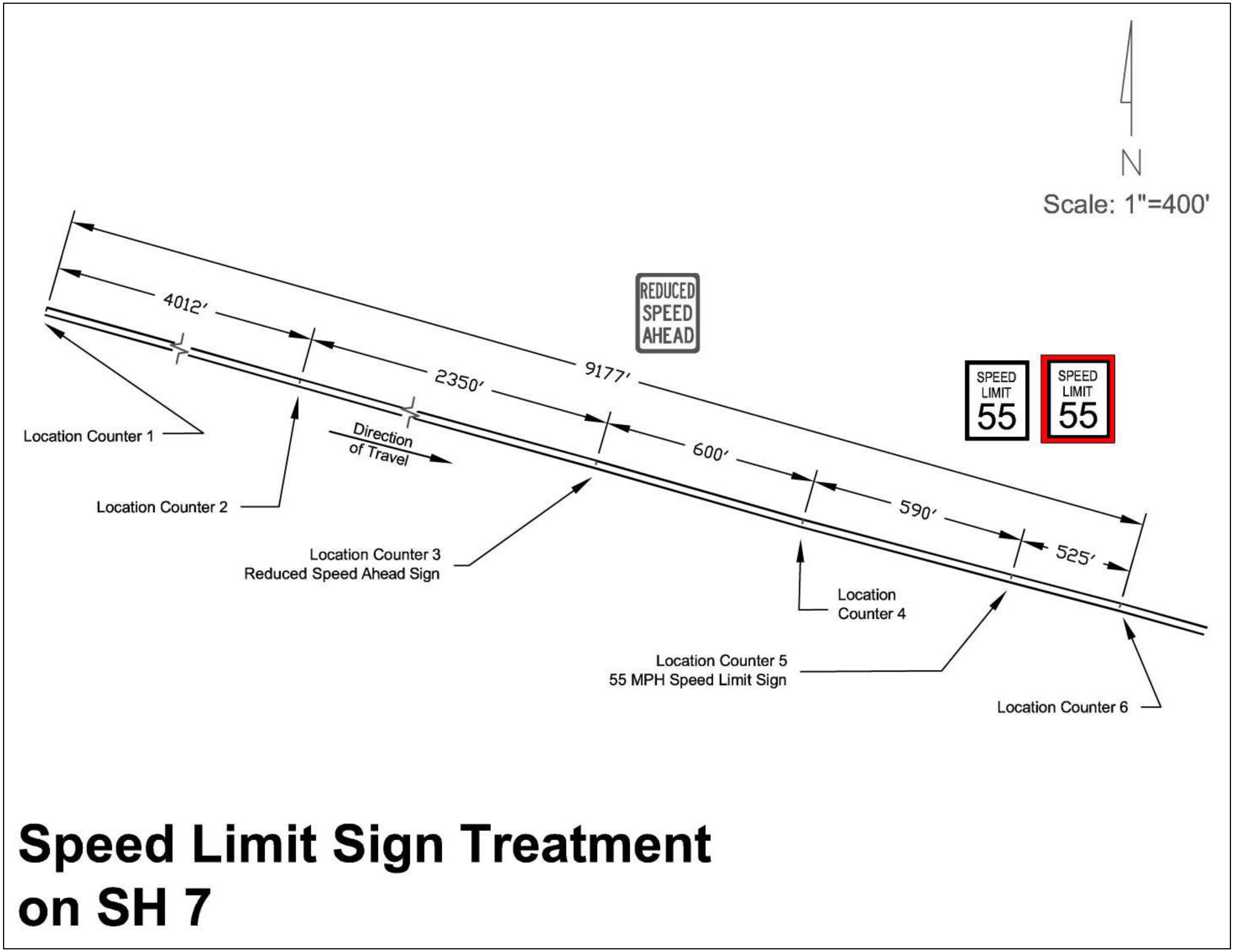

Figure A-14. Plan View of State Highway 7 Approaching Marlin, Texas.

APPENDIX B: SUMMARY OF FOCUS GROUP FINDINGS FOR COLORED SPEED LIMIT BORDER

The subject of the colored speed limit border was included as a warm-up question in seven focus groups that were performed by TTI researchers as part of other research projects. Two pictures depicting a rural road with a 55 mph Speed Limit sign outlined by a colored border were shown to the focus group participants. The first border was red, and the second was yellow. All subjects immediately noticed the changes to the Speed Limit sign.

When asked by the facilitator what the signs meant, almost everyone recognized them as some sort of attention getter to have you adjust your speed to 55 mph. Several believed that it was used on a rural stretch of road, or as you approached a town from a rural area. With further probing, many believed that it represented a change, or more specifically, a drop in the speed limit. Others believed that it might be a cue to slow down because of railroad tracks, animal crossings, traffic signal, or flashing yellow light ahead.

All of the subjects decided that the red border had a stronger meaning and would stand out better during the daytime, but most were concerned about the visibility of the red at night. Two subjects also brought up the issue of people who are colorblind.

When asked, over 50 percent of the subjects stated that they thought the two colored borders had different meanings, but they were unsure of the difference. **The tendency was to think that the red border had a more serious indication such as a warning, and the yellow meant caution.**

Although most recognized that yellow is a color associated with school zones, no one implied that a driver might be confused by the use of yellow. Only one person answered yes when the facilitator asked if the red border could possibly be confused by a driver with a Stop sign. **Other than this concern, there were no concerns that any drivers would misinterpret**

either one of the signs, although several subjects were skeptical if they would produce a reaction from the drivers.

The subjects were asked to think of other options for making drivers aware of a drop in speed as they approached a town. Suggestions included: Reduced Speed Ahead signs, blinking lights, roll bumps, V-flags, and many liked using a fluorescent color for the color of the border.

Based on the focus group findings, TTI researchers selected red as the color for the speed limit border evaluation conducted for this project.

APPENDIX C:
COMPARISON OF PORTABLE SPEED MEASUREMENT EQUIPMENT

LIDAR

LIDAR devices measure the speed and range of a moving object by sending out hundreds of invisible infrared laser light pulses per second. The laser beams are reflected off the object and directed back to the device. An internal algorithm is then used to derive the speed of the moving target from a successive number of range calculations[1]. LIDAR devices are capable of measuring speeds of both approaching and departing objects up to a maximum range of 4500 ft. The use of a LIDAR unit is very similar to that of radar, but with an infinitely narrower beam width.

When continuously tracking the speeds of a moving object, the LIDAR device is capable of up to four speed measurements per second, displaying both the speed and range of the object. By connecting the LIDAR device to a laptop computer via serial cable, LIDAR speed and distance measurements were instantaneously recorded and stored. A DOS-based computer program was used to capture and store the data sent from the LIDAR device to the computer. This program was developed by TTI specifically for purposes of automated LIDAR data recording and storage. Use of the LIDAR/laptop equipment provides for a much larger sample of speeds for each individual vehicle than automated counters.

AUTOMATED VEHICLE CLASSIFIERS

Portable automated vehicle classifiers were also used for speed measurement in this project. Portable automated vehicle classifiers are the most common vehicle measurement devices used by transportation agencies nationwide and allow for a much larger sample of vehicles with far less manpower than LIDAR. These devices are placed on the roadside and connected to a pair of sensors (pneumatic tubes, piezoelectric sensors, etc.) affixed to the pavement surface. The device records information for each axle that passes over the sensors. Using internal algorithms, the device then computes desired information about each vehicle, including speed and classification.

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[1] *Pro Laser III Reference Manual.* Revision 1. Kustom Signals, Inc., Chanute, KS, 1999.

Speeds of individual vehicles were also tracked with the portable automated vehicle classifiers. This tracking was accomplished by placing a number of the devices in succession at specific locations throughout the study site. Time clocks were synchronized for all devices. Individual vehicles were later tracked during the data reduction phase by tracking time stamps and classifications among successive counters.

EQUIPMENT COMPARISON

The TTI research team had various types of data collection equipment available for use in this study. When the project began, however, the researchers were unsure of the relative accuracies of the speeds measured by the various devices. Therefore, as part of the research activities, the researchers performed an experiment in which the accuracies of speeds measured by the following devices were compared in a controlled setting:

- pneumatic tubes connected to automated vehicles classifier,
- piezoelectric sensors connected to automated vehicle classifier,
- tape switch sensors connected to laptop computer,
- radar, and
- LIDAR.

Only a summary of the findings and conclusions of the equipment comparison are reported here. The following conclusions were made based on the findings of the speed measurement comparison between devices:

- All devices perform equally well at lower speeds.
- LIDAR and radar are the most accurate and precise at higher speeds.
- For the most part, only relatively small errors (< ± 1.5 mph) occur for all devices.
- With the exception of radar, all devices become slightly less accurate and less precise at higher speeds.
- Overall, there was little difference in the performance among on-pavement devices at any speed level.
- Inaccuracies observed in on-pavement equipment were likely due to:
  - slight measurement errors during placement of the sensors and
  - movement of the sensors resulting from repeated tire hits.

Unexplainable equipment failures were encountered for one tube setup and one piezo setup reducing the reliability of these devices.

Although LIDAR and radar were overall found to be the most accurate and precise devices, the most significant finding from this experiment is that for all devices, if deviations from the "true" speed occurred, they were relatively small ($< \pm 1.5$ mph) in nature. Based on these findings, the researchers selected portable speed measurement equipment to suit the characteristics of a given field evaluation.

APPENDIX D:
DATA COLLECTION FORMS

Centerline and Edgeline Encroachment - Field Sheet

Data Collector: ______________________

Location: __________________________

Study Approach: ___________________

Data Collection Date: ______________________________

Time: ___________ to ____________

Weather: ___________________________

	Count
Major White Edgeline Encroachment	
Minor White Edgeline Encroachment	
Stayed in Lane	
Minor Yellow Centerline Encroachment	
Major Yellow Centerline Encroachment	

Notes:
1. Only count passenger vehicles without trailers (cars, pickups, SUVs, vans). No commercial vehicles, RVs, farm vehicles.
2. Only count vehicles when no opposing vehicles are present in the curve (+- 5 sec either direction from midpoint)
3. Only count non-platooned vehicles approaching when no queue is present (6 sec headway)
4. Do not count any vehicle that you think is acting out of the ordinary (U-turn, reversing, etc.)

Driver Observance of Stop Signs - Field Sheet

Data Collector: ______________________

Location: ___________________________

Study Approach: ______________________

Date: ______________________________

Time: _____________ to _____________

Weather: ___________________________

	Turned Left	Went Straight	Turned Right
Non Stopping			
Practically Stopped (Rolling Stop: 0 - 3 mph)			
Stopped by Traffic (from any conflicting approach)			
Voluntary Full Stop (no conflicting traffic in reasonable sight)			

Notes: 1. Only count passenger vehicles without trailers (cars, pickups, SUVs, vans). No commercial vehicles, RVs, farm vehicles.
2. Only count non-platooned vehicles approaching when no queue is present
3. Do not count any vehicle that you think is acting out of the ordinary (U-turn, reversing, etc.)

APPENDIX E:
HYBRID T-TEST FOR COMPARISON OF 85TH PERCENTILE SPEEDS

Comparing samples from two or more populations is among the most common statistical tasks that engineers and scientists perform. Typically a t-test or one-way ANOVA is used to compare the means of different populations. When differences are detected it is not uncommon for post-hoc tests such as Fisher's least significant difference, Tukey's, or Scheffé's multiple comparison procedure to be applied to determine which means are different among the collection of populations. See Mason et al.[1] for additional methods and descriptions. While these tests are useful for describing differences in means for various populations, they are of limited use for comparison of other population parameters, such as percentiles.

Percentiles (i.e., quantiles) are important parameters in many engineering and scientific studies and are especially important to the traffic engineering profession. For example, an experiment could be performed to determine the most effective sign treatment for alerting drivers to an approaching speed zone. Suppose that we find that the mean speeds are significantly different for the signs. Are they different due to slower traffic driving slower, faster traffic driving slower, or both? There is value to determining the answer to the previous question because higher speeds are well correlated to higher crash severity. Therefore, a sign found to reduce the speeds of faster drivers could warrant its use, but if the sign affects speeds of only slower drivers, then there may be no safety reason for making a sign change.

But in a statistical sense, how are differences in percentiles between two populations determined? Since the population and sample means are functions of the population and sample quantiles, it follows that if the means of two populations are different, then their quantiles must be different. The equality of probability distributions may be tested directly using tests such as the Kolmogrov-Smirnov test, although this does not provide a direct comparison of specific quantiles. This paper describes a procedure for direct comparison of quantiles (i.e., percentiles) of two sample populations.

[1] Mason, R.L., R.F. Gunst, and J.L. Hess. *Statistical Design and Analysis of Experiments: With Applications to Engineering and Science.* Chapter 16. Wiley, New York, New York, 1989.

DESCRIPTION OF PROBLEM

A main obstacle to identifying differences among quantiles (percentiles) is calculating a reasonable estimate of the standard error for each estimated quantile. Several statistical software packages output quantiles in their list of summary statistics, for example SAS, JMP, MINITAB, and SPSS etc. Except for the median, however, it is unusual for statistical packages to give confidence intervals or standard errors for the estimated quantiles. The reasons for this are multiple, with a major reason being that nonparametric intervals tend to work best for percentiles that are not in the tails of the distribution. In addition, finding 95 percent or 99 percent confidence intervals using order statistics is typically not feasible (see work by Lothar[1] and the references contained therein). Parametric confidence intervals may not be useful because they assume a fixed shape for the statistical probability distribution, and in many engineering studies there is no firm assurance a parametric model is reasonable. So it is likely that some part of the differences or similarities found among percentiles will be due to the failure of a parametric model. Indeed, one reason for checking quantiles is to check if the treatments changed the shape of the population differently in different regions of the anticipated experimental response. This reasoning is explained more fully in the example section.

Presented herein are procedures for a bootstrapping method to provide uncertainty statements for confidence intervals and tests for quantiles from two or more populations. The extension to more than two populations is by the Bonferonni multiple comparisons method (see Mason et al.[2]). It is recommended that one-way ANOVA or t-test is performed initially, since they are simple, yet powerful tests. If the means are found to be significantly different, then proceed to determine the quantiles that are different. Other more robust and general tests are available but are used less frequently[3].

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[1] Lothar, S. and Z. Reynarowych (Translator). *Applied Statistics: A Handbook of Techniques*. Springer Series in Statistics, New York, New York, 1982.

[2] Mason.

[3] Tukey, J.W. *Exploratory Data Analysis.* Addison Wesley, Reading, Massachusetts, 1977.

METHODOLOGY

Quantile Development

We start by defining quantiles in both sample populations. The authors recognize that there is some variation and non-uniqueness in how the quantiles are defined. For the purpose of this paper we ignore these difficulties.

Let $f(x)$ denote the theoretical density for a population under study. The p-th quantile, $q(p)$, is defined by the integral equation:

$$\int_{-8}^{q(p)} f(x)dx = p \tag{1}$$

Assuming that $f(x)$ is everywhere positive where observations are anticipated (i.e., no gaps in regions where observations are anticipated) then the population quantiles are uniquely defined. Next, the sample quantiles are defined. It is noted that there are many ways to define sample quantiles. For example, if a sample size were 20, any value between the 10th and 11th smallest observation would be considered a median. Typically the average of the 10th and 11th observation is used. Other definitions may have a theoretical advantage, but we believe there is no evidence that they would have a practical advantage. Thus to consider other definitions in this paper would add to the technical complexity and would be of questionable practical value.

Let a random sample from a population be denoted by $X_1, \quad ,X_n$. We will calculate the order statistics from this sample and denote the ordered values by using a bracket subscript. The order statistics are $X_{(1)} = X_{(2)} = \quad = X_{(n)}$. In order to define the p-th sample quantile, find i such that $\frac{i}{n+1} = p = \frac{i+1}{n+1}$, $i = 0, \quad ,n$. Then the p-th sample quantile $\hat{q}(p)$ is defined by the equation:

$$\hat{q}(p) = ((i+1) - (n+1)p)X_{(i)} + ((n+1)p - i)X_{(i+1)} \tag{2}$$

Equation 2 defines an interpolant between the i-th and (i+1)-st order statistics. The reader can verify that the usual definition of the sample median agrees with this equation.

The main obstacle to providing confidence intervals and tests for quantiles is calculating reasonable estimates of variances for the sample quantiles that are far from the median. In traffic engineering, the 85th is a commonly used percentile in setting posted speed limits for roadways or for measuring the efficacy of a specific traffic control device. Asymptotic formulas typically need large samples to function for percentiles such as the 85th, severely limiting their usefulness for small-scale traffic engineering studies. As an alternative to asymptotic formulas, doubly bootstrapped confidence intervals are suggested.

Double Bootstrapping Procedure

A nonparametric bootstrap procedure is described in work by Efron and Tibshirani[1]. Simply defined, a nonparametric bootstrap is a simulation method based upon resampling of existing data. This is contrasted with old fashioned, but sometimes still effective, simulation of data from a normal population or other parametric family. The first bootstrap experiment produces estimates of standard errors for the desired quantiles. The second layer of bootstrap simulations is used to get the threshold cutoff values for the test of hypothesis or confidence interval. That is, instead of using 1.96 as a 95 percent cutoff value for a test of hypothesis, the cutoff value is calculated using a second bootstrap experiment. The procedures are as follows:

1. Put both samples in one column, the order does not matter. Let n_1 samples exist in population 1 and n_2 samples exist in population 2. Thus, in one column we have $n = n_1 + n_2$ samples.
2. With replacement from the single column formed in step 1 draw random samples of size n_1 and n_2.
3. Compute the percentiles (from 1 percent to 99 percent) for each sample.
4. Repeat steps 2 and 3 multiple times (>100 is suggested).
5. Form a t-like statistic for each of the percentiles (from 1 percent to 99 percent) using the following equation:

$$\frac{|\hat{q}_1(p) - \hat{q}_2(p)|}{\sqrt{\hat{\sigma}_1^2 + \hat{\sigma}_2^2}} \tag{3}$$

Now we proceed with the second bootstrap experiment:

[1] Efron, B., and R. Tibshirani. *An Introduction to the Bootstrap*. Chapman and Hall, New York, New York, 1993.

6. Repeat steps 2 through 5 multiple times (> 100) and compute the percentiles of the simulated t-like statistic.
7. Based on the percentiles computed in step 6, use an appropriate level of confidence (i.e., 95 percent) to determine a threshold cutoff value for the t-like statistic.
8. Compute the t-like statistics for the original data using the percentiles of the original data sets along with the variances generated in the first bootstrap run.
9. Take the ratio of the t-like statistics computed in step 8 to the cutoff value for each percentile. A statistically significant difference exists between the two populations if this ratio is greater than one. If desired, use the cutoff values to form a confidence interval.

EXAMPLE

To provide an example, the researchers performed the double bootstrap technique on actual speed data collected in the field.

Hypothesis

Drivers do not always realize that they have entered a zone with a lower speed limit, especially at locations with minimal speed-reduction cues. Researchers were interested in the effect that a 3-inch reflectorized red border[1] around the perimeter of a Speed Limit sign had on speeds of passenger vehicles upon entry to a speed zone approaching a municipality where violations were common. Researchers hypothesized that by improving the conspicuity of the Speed Limit sign with the red border, drivers would be better alerted of posted speed conditions and the mean and 85th percentile speeds would be reduced. The red reflectorized border treatment used in this project is shown in Figure E-1.

[1] Because the red reflectorized border is not an approved traffic control device per the Texas Manual on Uniform Traffic Control Devices, permission to experiment with the red border was sought and granted by the FHWA.

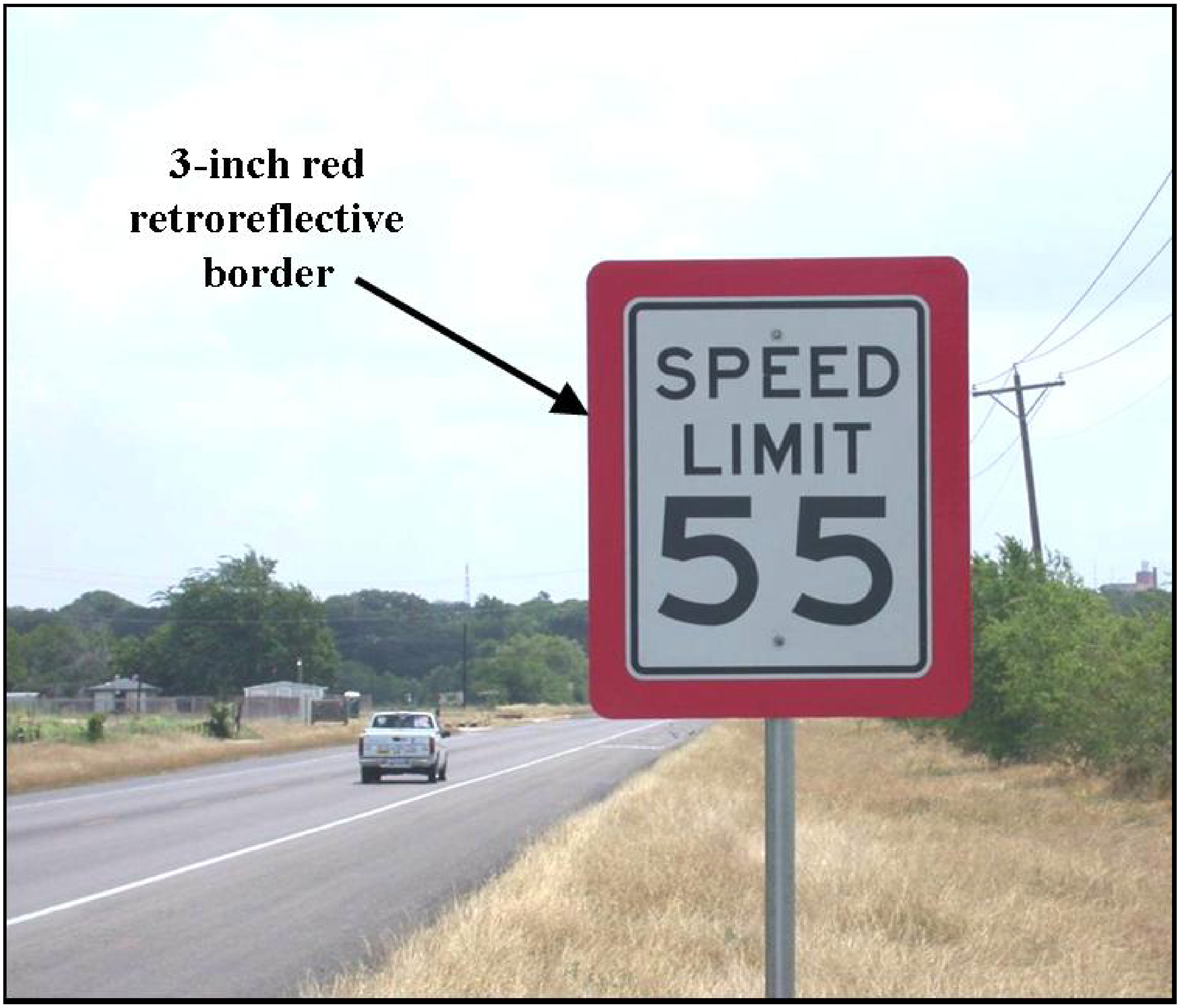

Figure E-1. Experimental Sign Treatment.

Speed Measurement

Researchers measured speeds of passenger vehicles using piezoelectric sensors connected to automated counters on a two-lane state highway approaching the city of Marlin in rural Texas. The posted speed limit upstream of the site was 70 mph/65 mph for daytime and nighttime, respectively. The posted speed limit on the entry to the speed zone was 55 mph. The 55 mph Speed Limit sign served as the treatment sign for the red border.

Speeds were measured at the 55 mph Speed Limit sign. Speeds were measured in the same manner both with the standard 55 mph Speed Limit sign in place (existing condition) and two-weeks after placement of the 3-inch red reflectorized border around the Speed Limit sign.

Each data collection period lasted for approximately 24 hours. Relevant descriptive statistics from the data collection efforts are shown in Table E-1.

Table E-1. Passenger Vehicle Speeds at 55 mph Speed Limit Sign.

		Sample Size	Mean (mph)	Std. Dev. (mph)	15th Percentile (mph)	Median (mph)	85th Percentile (mph)
Day	Before	319	64.5	6.1	58	65	71
	After	480	62.6	6.6	55	63	69
Night	Before	130	60.3	7.7	53	60	67.65
	After	121	59.3	7.1	52	59	66

Initial Analysis

The before and after spot speed data were first analyzed using standard pooled t-tests[1]. Table E-2 shows the results of these tests.

Table E-2. Pooled T-test for Mean Speeds Before and After Placement of Red Border.

	Mean Before (mph)	Mean After (mph)	Change (mph)	P-value	Significant at 95% Confidence?
Day	64.5	62.6	-1.9	<0.0001	Yes
Night	60.3	59.3	-1.0	0.289	No

The t-tests showed that the mean speed at the sign was significantly reduced during the day and insignificantly reduced at night with the red border in place. But were these reductions in the mean speeds due to faster drivers driving slower, slower drivers driving slower, or both? Furthermore, are positive effects on faster drivers being masked by contrasting effects on slower drivers? The double bootstrapping procedure described herein allows for comparison of the quantiles between the two populations, thereby allowing researchers to better describe the effect of the sign across the entire distribution of speeds, rather than simply on the measures of central tendency.

Quantile Comparison

Using the speed data collected at the site, the double bootstrapping procedure was performed comparing the Speed Limit sign with the red border to the existing sign condition,

[1] One-way ANOVA should be used for analyses with greater than two treatments.

with separate analyses performed for day and night data. The first bootstrap (200 simulations) was used to generate a variance for each quantile, allowing for computation of the t-like statistic for each quantile. The second bootstrap (500 simulations) allowed for determination of the corresponding threshold cutoff value for each t-like statistic. Figure E-2 displays the cutoff values for the t-like statistic for the daytime data.

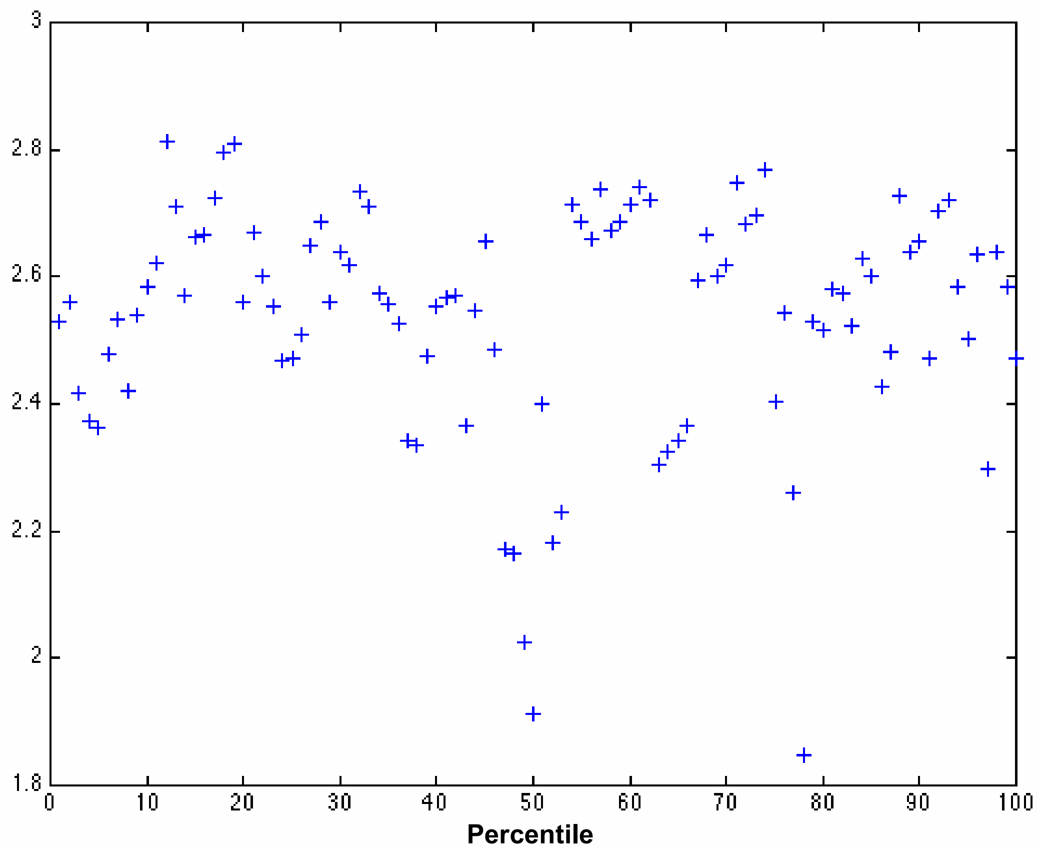

Figure E-2. Cutoff Values of T-like Statistic (Daytime).

Finally, for each quantile, a ratio was computed of each t-like statistic (based on the original data) to the simulated cutoff value. Statistically significant differences existed if the ratio was greater than 1. These ratios are shown for each quantile in Figures E-3 and E-4 for daytime and nighttime, respectively.

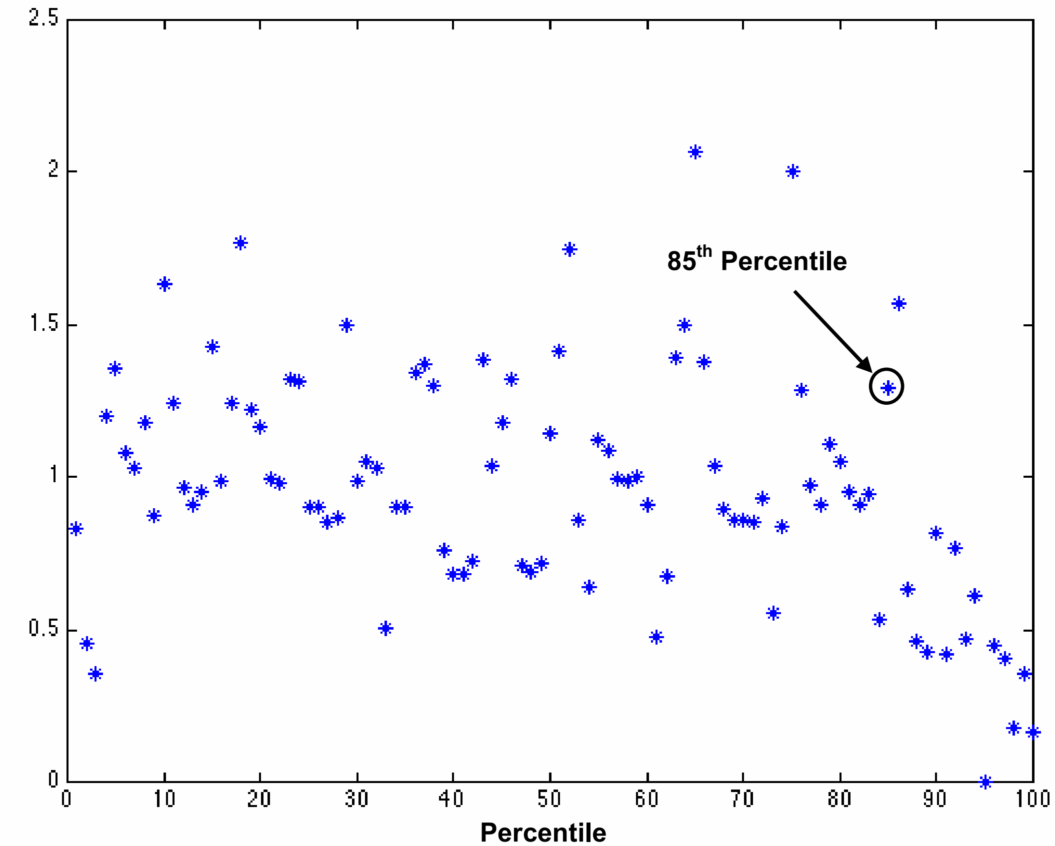

Figure E-3. Ratio of T-like Statistic to Simulated Cutoff Value (Daytime).

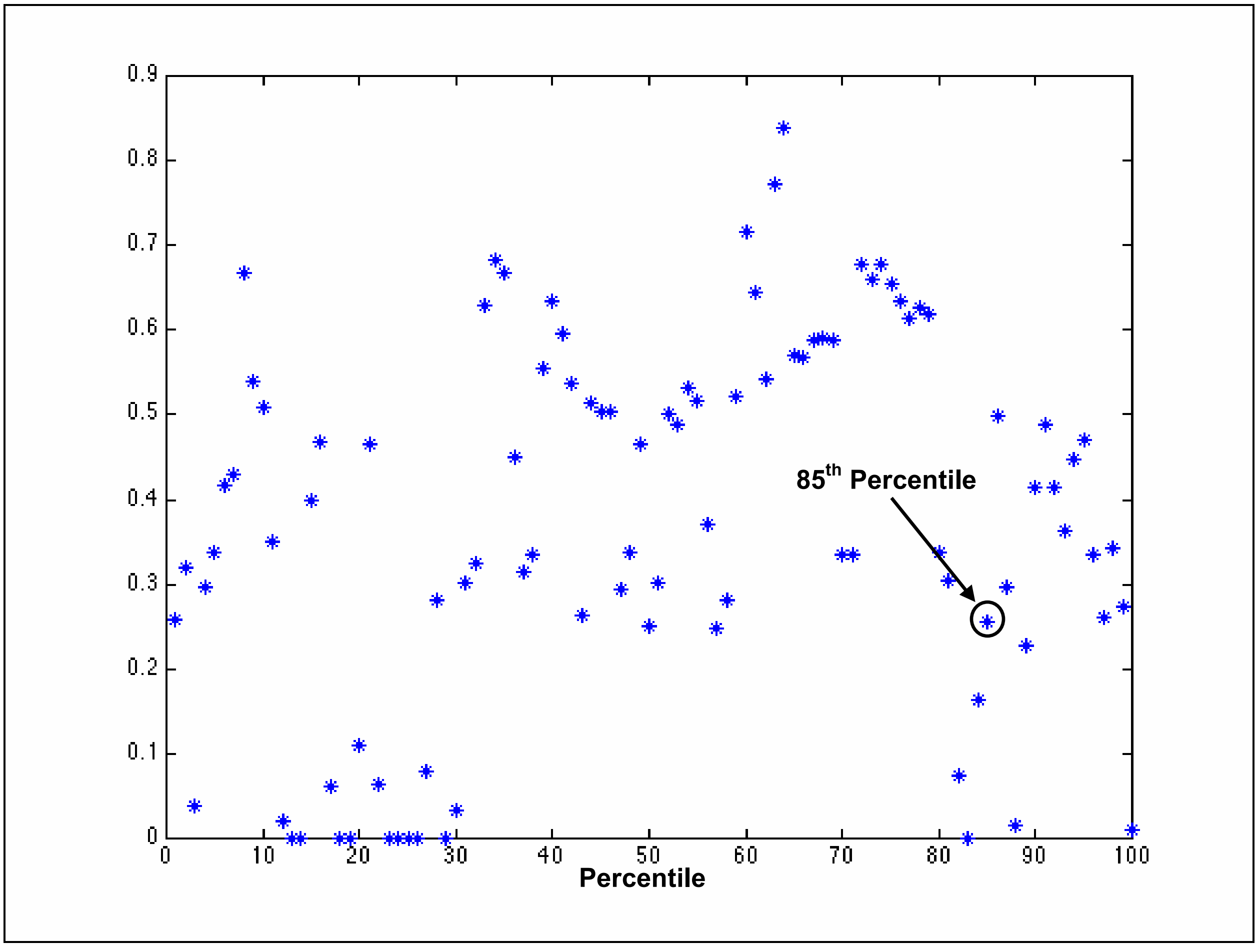

Figure E-4. Ratio of T-like Statistic to Simulated Cutoff Value (Nighttime).

Examination of Figure E-3 shows that approximately one-half of the percentiles have t-ratios greater than one, meaning that significant differences were detected between the two sample populations. Examination of Figure E-4 shows no significant differences between any of the quantiles for the nighttime data. Comparison of the quantile results with the ANOVA results shows that the results of the double bootstrapping procedure mirror the ANOVA results for both day and night (i.e., daytime – significant, nighttime – insignificant).

The direction and magnitude of the percentile differences for the daytime data were determined through examination of the corresponding cumulative frequency plot shown in Figure E-5.

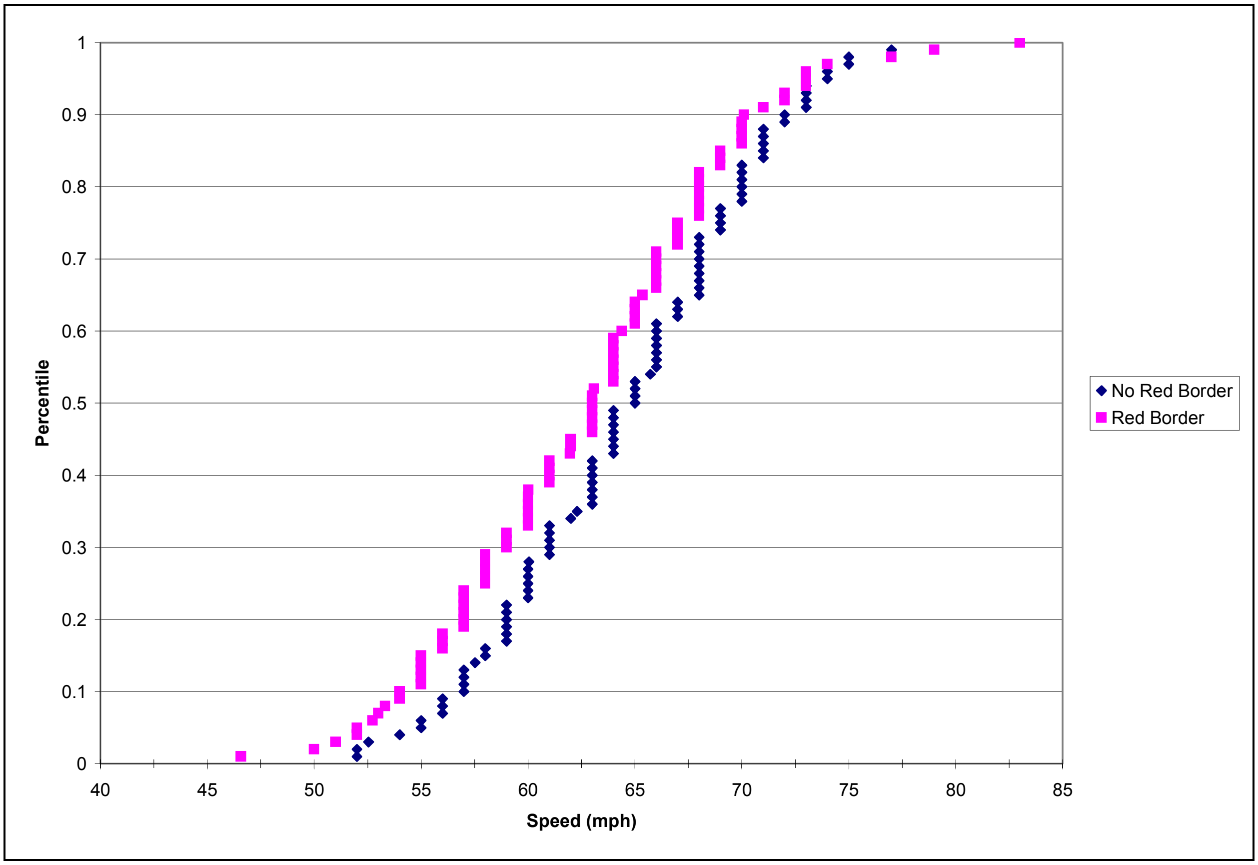

Figure E-5. Cumulative Frequency of Daytime Speed Data.

Figure E-5 shows that the speeds at nearly every percentile were lower after installation of the red conspicuity border. Therefore, any significant reductions in speed detected through the bootstrapping procedure (Figure E-3) occurred after installation of the red border.

As stated earlier, the effect of the sign on the faster drivers was of particular interest for safety-related inferences to be drawn. The 85th percentile speed was reduced by 2 mph (71 mph to 69 mph) after installation of the red conspicuity border (Table E-1). While statistical procedures such as ANOVA would not allow for an inference to be drawn as to the statistical validity of this 2 mph reduction, the double bootstrapping procedure allows for statistical inference to be made. Thus, it can be observed in Figure E-3 that the 2 mph reduction in the 85th percentile speed was significant (t-like statistic > 1). As a result, the red conspicuity border was deemed effective at reducing not only the mean speeds, but the speed of the 85th percentile driver, as well.

Summary

Presented in this paper is a discussion of a double bootstrapping procedure for comparison of quantiles (i.e., percentiles). The procedure is useful to traffic engineers because it allows for direct statistical inferences to be drawn on differences between the percentiles of two or more sample populations.

APPENDIX F:
RESULTS OF FIELD EVALUATIONS

Appendix F provides detailed results of the field evaluations on a site-by-site basis. Detailed descriptions and drawings of each study site are presented in Appendix A.

FM 3090

FM 3090 included evaluation of fluorescent yellow microprismatic sheeting on both the Chevrons (After #1) and Chevron posts (After #2) versus standard yellow high intensity sheeting on the Chevrons (Before). Tables F-1, F-2, and F-3 present the results of the daytime, twilight, and nighttime evaluations, respectively.

Table F-1. FM 3090 Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After #1	Aft#1-Before	Significant @ 95% Confidence?	After #2	Aft#2-Before	Significant @ 95% Confidence?
Control Point (at crest of hill 575 ft upstream from PC)	Mean Speed (mph)	676	46.89	47.86	+0.97	NO	48.44	**+1.55**	**YES**
	85th Speed (mph)	676	52.0	54.0	+2.0	NO	54.0	+2.0	NO
	Std. Dev. (mph)	676	5.00	5.13	+0.13	NO	5.95	+0.95	NO
215 ft Upstream from PC	Mean Speed (mph)*	676	45.14	45.16	+0.02	NO	45.61	+0.47	NO
	85th Speed (mph)	676	50.0	50.0	0.0	NO	50	0.0	NO
	Std. Dev. (mph)	676	4.84	4.56	-0.28	NO	4.72	-0.12	NO
Point of Curvature (PC)	Mean Speed (mph)*	676	36.55	36.92	+0.37	NO	36.59	+0.04	NO
	85th Speed (mph)	676	40.1	41.0	+0.9	NO	41.0	+0.9	NO
	Pct. Exceeding 35 mph**	676	59.0	65.6	+6.6	NO	61.0	+2.0	NO
	Std. Dev. (mph)	676	4.11	3.71	-0.40	NO	4.05	-0.06	NO

*Control point speed included in the analysis as a covariate
**35 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-2. FM 3090 Results, Twilight.

Location	Measure of Effectiveness	Overall Sample Size	Before	After #1	Aft#1-Before	Significant @ 95% Confidence?	After #2	After#2-Before	Significant @ 95% Confidence?
Control Point (at crest of hill 575 ft upstream from PC)	Mean Speed (mph)	146	48.56	48.66	+0.10	NO	47.44	-1.12	NO
	85th Speed (mph)	146	53.0	55.2	+2.2	NO	53.0	0.0	NO
	Std. Dev. (mph)	146	5.76	5.81	+0.05	NO	5.00	-0.76	NO
215 ft Upstream from PC	Mean Speed (mph)*	146	46.71	46.19	-0.52	NO	44.98	-1.73	NO
	85th Speed (mph)	146	51.95	52.00	+0.05	NO	49.0	**-2.95**	**YES**
	Std. Dev. (mph)	146	5.06	5.79	+0.73	NO	4.17	-0.89	NO
Point of Curvature (PC)	Mean Speed (mph)*	146	37.08	37.30	+0.22	NO	36.11	-0.97	NO
	85th Speed (mph)	146	40.0	41.2	+1.2	NO	39.0	-1.0	NO
	Pct. Exceeding 35 mph**	146	63.9	57.7	-6.2	NO	61.4	-2.5	NO
	Std. Dev. (mph)	146	3.92	4.71	+0.79	NO	3.40	-0.52	NO

*Control point speed included in the analysis as a covariate
**35 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-3. FM 3090 Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After #1	After#1-Before	Significant @ 95% Confidence?	After #2	After#2-Before	Significant @ 95% Confidence?
Control Point (at crest of hill 575 ft upstream from PC)	Mean Speed (mph)	341	47.27	48.30	+1.03	NO	46.41	-0.86	NO
	85th Speed (mph)	341	52.0	54.0	+2.0	NO	52.0	+0.0	NO
	Std. Dev. (mph)	341	5.23	5.15	-0.08	NO	5.16	-0.07	NO
215 ft Upstream from PC	Mean Speed (mph)*	341	44.80	45.29	+0.49	NO	43.21	-1.59	NO
	85th Speed (mph)	341	49.0	50.0	+1.0	NO	48.0	-1.0	NO
	Std. Dev. (mph)	341	4.39	4.82	+0.43	NO	4.82	+0.43	NO
Point of Curvature (PC)	Mean Speed (mph)*	341	35.23	35.89	+0.66	NO	35.03	-0.20	NO
	85th Speed (mph)	341	39.0	40.0	+1.0	NO	39.9	+0.9	NO
	Pct. Exceeding 35 mph**	341	50.8	53.8	3.0	NO	33.8	**-17.0**	**YES**
	Std. Dev. (mph)	341	3.71	4.00	+0.29	NO	4.65	+0.94	NO

*Control point speed included in the analysis as a covariate
**35 mph = ball bank indicator speed at 10 degrees plus 10 mph

SH 6 EXIT TO BRIARCREST

Fluorescent yellow microprismatic sheeting (After) was evaluated versus standard yellow high intensity sheeting (Before) on the Chevrons of the curve at the exit ramp for southbound

State Highway 6 to Briarcrest Drive. Tables F-4, F-5, and F-6 present the results for daytime, twilight, and nighttime, respectively.

Table F-4. SH 6 Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
385 ft Upstream from PC	Mean Speed (mph)	1148	58.11	57.45	**-0.66**	**YES**
	85^{th} Speed (mph)	1148	63.00	62.45	-0.55	NO
	Std. Dev. (mph)	1148	5.18	5.07	-0.11	NO
Point of Curvature (PC)	Mean Speed (mph)	1148	51.26	49.14	**-2.12**	**YES**
	85^{th} Speed (mph)	1148	57.00	54.00	**-3.00**	**YES**
	Std. Dev. (mph)	1148	4.94	4.87	-0.07	NO
	Pct. Exceeding 45 mph*	1148	86.7	78.2	**-8.5**	**YES**
150 ft Downstream from PC	Mean Speed (mph)	1148	44.50	43.01	**-1.49**	**YES**
	85^{th} Speed (mph)	1148	49.00	48.00	**-1.00**	**YES**
	Std. Dev. (mph)	1148	4.52	4.50	-0.02	NO
300 ft Downstream from PC	Mean Speed (mph)	1148	41.59	39.66	**-1.93**	**YES**
	85^{th} Speed (mph)	1148	46.00	44.00	**-2.00**	**YES**
	Std. Dev. (mph)	1148	4.45	4.49	+0.04	NO
	Pct. Edge Line Encroachment	255	60.6	33.6	**-27.0**	**YES**
450 ft Downstream from PC	Mean Speed (mph)	1148	40.19	40.39	+0.20	NO
	85^{th} Speed (mph)	1148	45.00	45.00	0.00	NO
	Std. Dev. (mph)	1148	4.66	4.41	-0.25	NO

*45 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-5. SH 6 Results, Twilight.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
385 ft Upstream from PC	Mean Speed (mph)	222	58.08	56.79	-1.29	NO
	85^{th} Speed (mph)	222	63.00	62.00	-1.00	NO
	Std. Dev. (mph)	222	5.24	4.91	-0.33	NO
Point of Curvature (PC)	Mean Speed (mph)	222	49.83	48.46	-1.37	NO
	85^{th} Speed (mph)	222	55.00	54.00	-1.00	NO
	Std. Dev. (mph)	222	4.98	4.62	-0.36	NO
	Pct. Exceeding 45 mph*	222	81.4	74.7	-6.7	NO
150 ft Downstream from PC	Mean Speed (mph)	222	42.72	42.59	-0.13	NO
	85^{th} Speed (mph)	222	47.00	47.75	+0.75	NO
	Std. Dev. (mph)	222	4.30	4.12	-0.18	NO
300 ft Downstream from PC	Mean Speed (mph)	222	40.17	40.12	-0.05	NO
	85^{th} Speed (mph)	222	44.00	44.00	0.00	NO
	Std. Dev. (mph)	222	4.17	4.28	+0.11	NO
450 ft Downstream from PC	Mean Speed (mph)	222	38.97	39.89	+0.92	NO
	85^{th} Speed (mph)	222	43.00	45.00	+2.00	NO
	Std. Dev. (mph)	222	4.19	4.56	+0.37	NO

*45 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-6. SH 6 Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
385 ft Upstream from PC	Mean Speed (mph)	568	57.43	56.28	**-1.15**	**YES**
	85th Speed (mph)	568	63.00	62.00	-1.00	NO
	Std. Dev. (mph)	568	5.13	5.67	+0.54	NO
Point of Curvature (PC)	Mean Speed (mph)	568	50.51	48.32	**-2.19**	**YES**
	85th Speed (mph)	568	56.00	53.00	**-3.00**	**YES**
	Std. Dev. (mph)	568	5.06	5.48	+0.42	NO
	Pct. Exceeding 45 mph*	568	83.3	70.9	**-12.4**	**YES**
150 ft Downstream from PC	Mean Speed (mph)	568	43.55	42.45	**-1.10**	**YES**
	85th Speed (mph)	568	48.00	47.00	**-1.00**	**YES**
	Std. Dev. (mph)	568	4.76	4.94	+0.18	NO
300 ft Downstream from PC	Mean Speed (mph)	568	41.10	40.49	-0.61	NO
	85th Speed (mph)	568	46.00	45.00	-1.00	NO
	Std. Dev. (mph)	568	4.62	4.54	-0.08	NO
450 ft Downstream from PC	Mean Speed (mph)	568	40.13	40.42	+0.29	NO
	85th Speed (mph)	568	45.00	45.00	0.00	NO
	Std. Dev. (mph)	568	4.61	4.55	-0.06	NO

*45 mph = ball bank indicator speed at 10 degrees plus 10 mph

FM 1179

FM 1179 included evaluation of fluorescent yellow microprismatic sheeting (After) versus standard yellow high intensity sheeting (Before) on both the Curve signs and the Chevrons at the eastbound approach to the horizontal S-curve at Steep Hollow. Tables F-7, F-8, and F-9 present the results of the daytime, twilight, and nighttime evaluations, respectively.

Table F-7. FM 1179 Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (2800 ft Upstream from PC)	Mean Speed (mph)	84	60.08	60.81	+0.73	NO
	85^{th} Speed (mph)	84	66.00	65.75	-0.25	NO
	Std. Dev. (mph)	84	4.70	6.06	**+1.36**	**YES**
Warning Sign (800 ft Upstream from PC)	Mean Speed (mph)*	80	58.97	60.19	+1.22	NO
	85^{th} Speed (mph)	80	63.11	65.12	+2.01	NO
	Std. Dev. (mph)	80	3.87	5.06	+1.19	NO
	Pct. Began Decelerating	80	67.3	51.6	-15.7	NO
500 ft Upstream from PC	Mean Speed (mph)*	82	57.72	57.83	+0.11	NO
	85^{th} Speed (mph)	82	61.96	62.89	+0.93	NO
	Std. Dev. (mph)	82	3.73	5.22	**+1.49**	**YES**
250 ft Upstream from PC	Mean Speed (mph)*	66	54.72	54.98	+0.26	NO
	85^{th} Speed (mph)	66	58.16	61.56	+3.40	NO
	Std. Dev. (mph)	66	3.91	5.27	+1.36	NO
100 ft Upstream from PC	Mean Speed (mph)*	53	51.05	51.77	+0.72	NO
	85^{th} Speed (mph)	53	54.44	55.93	+1.49	NO
	Std. Dev. (mph)	53	3.84	4.82	+0.98	NO
Point of Curvature (PC)	Mean Speed (mph)*	52	48.27	48.90	+0.63	NO
	85^{th} Speed (mph)	52	51.07	52.61	+1.54	NO
	Pct. Exceeding 45 mph**	52	77.0	66.7	-10.3	NO
	Std. Dev. (mph)	52	3.31	4.79	+1.48	NO
Midpoint (250 ft Downstream from PC)	Mean Speed (mph)*	47	43.31	44.82	+1.51	NO
	85^{th} Speed (mph)	47	47.07	48.10	+1.03	NO
	Std. Dev. (mph)	47	3.82	4.66	+0.84	NO
	Pct. Edge Line Encroachments	85	23.3	28.6	+5.3	NO

*Control point speed included in the analysis as a covariate
**45 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-8. FM 1179 Results, Twilight.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (2800 ft Upstream from PC)	Mean Speed (mph)	69	58.81	59.12	+0.31	NO
	85th Speed (mph)	69	64.00	63.20	-0.80	NO
	Std. Dev. (mph)	69	4.96	4.85	-0.11	NO
Warning Sign (800 ft Upstream from PC)	Mean Speed (mph)*	70	58.39	57.68	-0.71	NO
	85th Speed (mph)	70	63.73	63.05	-0.68	NO
	Std. Dev. (mph)	70	5.15	5.47	+0.32	NO
	Pct. Began Decelerating	70	48.5	75.0	**+26.5**	**YES**
500 ft Upstream from PC	Mean Speed (mph)*	67	57.15	56.33	**-0.82**	**YES**
	85th Speed (mph)	67	62.42	61.48	-0.94	NO
	Std. Dev. (mph)	67	5.19	4.65	-0.54	NO
250 ft Upstream from PC	Mean Speed (mph)*	62	54.56	52.91	-1.65	NO
	85th Speed (mph)	62	60.78	57.19	-3.59	NO
	Std. Dev. (mph)	62	4.88	4.22	-0.66	NO
100 ft Upstream from PC	Mean Speed (mph)*	57	50.64	49.73	-0.91	NO
	85th Speed (mph)	57	55.51	53.08	-2.43	NO
	Std. Dev. (mph)	57	4.55	4.14	-0.41	NO
Point of Curvature (PC)	Mean Speed (mph)*	46	47.81	46.57	-1.24	NO
	85th Speed (mph)	46	52.71	50.39	-2.32	NO
	Pct. Exceeding 45 mph**	46	63.8	50.0	-13.8	NO
	Std. Dev. (mph)	46	4.62	3.96	-0.66	NO
Midpoint (250 ft Downstream from PC)	Mean Speed (mph)*	46	42.63	41.15	-1.48	NO
	85th Speed (mph)	46	47.02	43.48	-3.54	NO
	Std. Dev. (mph)	46	4.90	2.19	**-2.71**	**YES**

*Control point speed included in the analysis as a covariate
**45 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-9. FM 1179 Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (2800 ft Upstream from PC)	Mean Speed (mph)	107	58.69	59.19	+0.50	NO
	85th Speed (mph)	107	63.10	64.00	+0.90	NO
	Std. Dev. (mph)	107	4.97	4.73	-0.24	NO
Warning Sign (800 ft Upstream from PC)	Mean Speed (mph)*	102	57.88	57.33	**-0.55**	**YES**
	85th Speed (mph)	102	62.00	63.18	+1.18	NO
	Std. Dev. (mph)	102	4.78	4.89	+0.11	NO
	Pct. Began Decelerating	102	52.0	78.0	**+26.0**	**YES**
500 ft Upstream from PC	Mean Speed (mph)*	98	56.01	55.77	-0.24	NO
	85th Speed (mph)	98	60.10	61.42	+1.32	NO
	Std. Dev. (mph)	98	5.05	4.49	-0.56	NO
250 ft Upstream from PC	Mean Speed (mph)*	90	53.00	52.79	-0.21	NO
	85th Speed (mph)	90	58.02	57.78	-0.24	NO
	Std. Dev. (mph)	90	5.03	4.45	-0.58	NO
100 ft Upstream from PC	Mean Speed (mph)*	85	49.49	49.48	-0.01	NO
	85th Speed (mph)	85	54.67	53.32	-1.35	NO
	Std. Dev. (mph)	85	5.08	4.19	-0.89	NO
Point of Curvature (PC)	Mean Speed (mph)*	78	46.42	47.23	+0.81	NO
	85th Speed (mph)	78	51.52	51.03	-0.49	NO
	Pct. Exceeding 45 mph**	78	53.4	59.0	+5.6	NO
	Std. Dev. (mph)	78	4.99	3.77	-1.22	NO
Midpoint (250 ft Downstream from PC)	Mean Speed (mph)*	81	41.68	41.97	+0.29	NO
	85th Speed (mph)	81	45.20	46.18	+0.98	NO
	Std. Dev. (mph)	81	3.59	4.06	+0.47	NO

*Control point speed included in the analysis as a covariate
**45 mph = ball bank indicator speed at 10 degrees plus 10 mph

FM 244

The FM 244 evaluation included fluorescent yellow microprismatic sheeting (After) versus standard yellow high intensity sheeting (Before) on both the Curve signs and the Chevrons for the horizontal curve on this rural two-lane highway. Tables F-10, F-11, and F-12 present the results for daytime, twilight, and nighttime, respectively.

Table F-10. FM 244 Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (930 ft Upstream from PC)	Mean Speed (mph)	510	62.90	62.09	-0.81	NO
	85th Speed (mph)	510	70.0	69.0	**-1.0**	**YES**
	Std. Dev. (mph)	510	7.13	6.46	-0.67	NO
465 ft Upstream from PC	Mean Speed (mph)*	510	59.84	61.13	**+1.29**	**YES**
	85th Speed (mph)	510	66.0	68.0	+2.0	NO
	Std. Dev. (mph)	510	6.46	6.55	+0.09	NO
Point of Curvature (PC)	Mean Speed (mph)*	510	47.49	47.85	+0.36	NO
	85th Speed (mph)	510	53.0	52.0	-1.0	NO
	Pct. Exceeding 50 mph**	510	28.2	28.2	+0.0	NO
	Std. Dev. (mph)	510	4.50	4.42	+0.08	NO
Midpoint (95 ft Downstream from PC)	Mean Speed (mph)*	496	46.90	47.18	+0.28	NO
	85th Speed (mph)	496	51.0	52.0	+1.0	NO
	Std. Dev. (mph)	496	4.39	4.47	+0.08	NO

*Control point speed included in the analysis as a covariate
**50 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-11. FM 244 Results, Twilight.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (930 ft Upstream from PC)	Mean Speed (mph)	268	61.98	61.95	-0.03	NO
	85th Speed (mph)	268	68.0	68.0	0.0	NO
	Std. Dev. (mph)	268	5.64	5.99	+0.35	NO
465 ft Upstream from PC	Mean Speed (mph)*	268	59.01	61.05	**+2.04**	**YES**
	85th Speed (mph)	268	64.0	67.0	**+3.0**	**YES**
	Std. Dev. (mph)	268	5.64	6.92	**+1.28**	**YES**
Point of Curvature (PC)	Mean Speed (mph)*	268	47.68	47.73	+0.05	NO
	85th Speed (mph)	268	52.0	54.0	+2.0	NO
	Pct. Exceeding 50 mph**	268	25.4	27.9	+2.5	NO
	Std. Dev. (mph)	268	4.15	5.06	**+0.91**	**YES**
Midpoint (95 ft Downstream from PC)	Mean Speed (mph)*	192	46.24	47.23	+0.99	NO
	85th Speed (mph)	192	50.65	52.00	+1.35	NO
	Std. Dev. (mph)	192	4.18	4.83	+0.65	NO

*Control point speed included in the analysis as a covariate
**50 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-12. FM 244 Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (930 ft Upstream from PC)	Mean Speed (mph)	318	60.92	59.86	-1.06	NO
	85th Speed (mph)	318	67.0	66.0	-1.0	NO
	Std. Dev. (mph)	318	5.50	6.03	+0.53	NO
465 ft Upstream from PC	Mean Speed (mph)*	318	58.09	58.33	**+0.24**	**YES**
	85th Speed (mph)	318	64.0	64.0	0.0	NO
	Std. Dev. (mph)	318	5.72	5.56	-0.16	NO
Point of Curvature (PC)	Mean Speed (mph)*	318	46.31	44.92	**-1.39**	**YES**
	85th Speed (mph)	318	51.0	50.0	-1.0	NO
	Pct. Exceeding 50 mph**	318	16.9	12.4	-4.5	NO
	Std. Dev. (mph)	318	4.24	4.31	+0.07	NO
Midpoint (95 ft Downstream from PC)	Mean Speed (mph)*	251	44.64	44.43	-0.21	NO
	85th Speed (mph)	251	49.0	49.0	0.0	NO
	Std. Dev. (mph)	251	3.98	4.10	+0.12	NO

*Control point speed included in the analysis as a covariate
**50 mph = ball bank indicator speed at 10 degrees plus 10 mph

FM 46

FM 46 included evaluation of fluorescent yellow microprismatic sheeting (After) versus standard yellow high intensity sheeting (Before) on the stand-alone Curve sign for the horizontal curve on this rural two-lane highway. Tables F-13, F-14, and F-15 present the results for daytime, twilight, and nighttime, respectively.

Table F-13. FM 46 Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (3465 ft Upstream from PC)	Mean Speed (mph)	774	67.26	67.95	+0.69	NO
	85^{th} Speed (mph)	774	75.0	76.0	+1.0	NO
	Std. Dev. (mph)	774	7.41	8.44	+1.03	NO
665 ft Upstream from PC (at Curve sign)	Mean Speed (mph)*	774	65.22	64.27	**-0.95**	**YES**
	85^{th} Speed (mph)	774	72.85	72.0	-0.85	NO
	Std. Dev. (mph)	774	7.74	8.28	+0.54	NO
	Pct. Began Decelerating	774	71.1	84.7	**+13.6**	**YES**
365 ft Upstream from PC (shortly after curve becomes visible)	Mean Speed (mph)*	774	62.35	61.34	**-1.01**	**YES**
	85^{th} Speed (mph)	774	69.0	69.0	0.0	NO
	Std. Dev. (mph)	774	7.62	8.3	+0.68	NO
Point of Curvature (PC)	Mean Speed (mph)*	747	59.24	59.69	+0.45	NO
	85^{th} Speed (mph)	747	66.0	67.0	+1.0	NO
	Pct. Exceeding 65 mph**	747	16.3	18.9	+2.6	NO
	Std. Dev. (mph)	747	6.71	7.21	+0.5	NO

*Control point speed included in the analysis as a covariate
**65 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-14. FM 46 Results, Twilight.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (3465 ft Upstream from PC)	Mean Speed (mph)	85	69.0	68.57	-0.43	NO
	85^{th} Speed (mph)	85	77.00	75.55	-1.45	NO
	Std. Dev. (mph)	85	7.95	7.55	-0.4	NO
665 ft Upstream from PC (at Curve sign)	Mean Speed (mph)*	85	67.41	65.77	-1.64	NO
	85^{th} Speed (mph)	85	72.00	71.55	-0.45	NO
	Std. Dev. (mph)	85	8.19	6.35	-1.84	NO
	Pct. Began Decelerating	85	70.0	72.0	+2.0	NO
365 ft Upstream from PC (shortly after curve becomes visible)	Mean Speed (mph)*	85	64.44	62.66	-1.78	NO
	85^{th} Speed (mph)	85	70.0	68.0	-2.0	NO
	Std. Dev. (mph)	85	7.72	5.82	-1.9	NO
Point of Curvature (PC)	Mean Speed (mph)*	81	60.95	60.48	-0.47	NO
	85^{th} Speed (mph)	81	66.6	65.0	-1.6	NO
	Pct. Exceeding 65 mph**	81	18.5	13.9	-4.6	NO
	Std. Dev. (mph)	81	7.19	5.42	-1.77	NO

*Control point speed included in the analysis as a covariate
**65 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-15. FM 46 Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (3465 ft Upstream from PC)	Mean Speed (mph)	149	64.27	66.41	+2.14	NO
	85th Speed (mph)	149	73.3	74.0	+0.7	NO
	Std. Dev. (mph)	149	7.59	8.34	+0.75	NO
665 ft Upstream from PC (at Curve sign)	Mean Speed (mph)*	149	62.98	64.11	+1.13	NO
	85th Speed (mph)	149	71.0	70.0	-1.0	NO
	Std. Dev. (mph)	149	7.15	7.11	-0.04	NO
	Pct. Began Decelerating	149	56.8	64.0	+7.2	NO
365 ft Upstream from PC (shortly after curve becomes visible)	Mean Speed (mph)*	149	60.64	61.01	+0.37	NO
	85th Speed (mph)	149	69.3	67.3	-2.0	NO
	Std. Dev. (mph)	149	6.92	7.31	+0.39	NO
Point of Curvature (PC)	Mean Speed (mph)*	143	57.48	59.2	+1.72	NO
	85th Speed (mph)	143	65.0	65.0	0.0	NO
	Pct. Exceeding 65 mph**	143	13.2	12.0	-1.2	NO
	Std. Dev. (mph)	143	6.64	6.52	-0.12	NO

*Control point speed included in the analysis as a covariate
**65 mph = ball bank indicator speed at 10 degrees plus 10 mph

FM 60 EXIT TO FM 2818

FM 60 included evaluation of fluorescent yellow microprismatic sheeting (After) versus standard yellow high intensity sheeting (Before) on the Ramp Advisory Speed sign at the eastbound exit ramp to southbound FM 2818. Tables F-16, F-17, and F-18 present the results for daytime, twilight, and nighttime, respectively.

Table F-16. FM 60 Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
350 ft Upstream from PC (at exit ramp advisory sign)	Mean Speed (mph)	111	55.44	54.37	-1.07	NO
	85^{th} Speed (mph)	111	59.47	59.16	-0.31	NO
	Std. Dev. (mph)	111	4.56	3.78	-0.78	NO
200 ft Upstream from PC	Mean Speed (mph)	107	50.54	50.20	-0.34	NO
	85^{th} Speed (mph)	107	55.26	53.79	-1.47	NO
	Std. Dev. (mph)	107	4.64	3.17	**-1.47**	**YES**
100 ft Upstream from PC	Mean Speed (mph)	98	45.71	45.87	+0.16	NO
	85^{th} Speed (mph)	98	51.13	50.90	-0.23	NO
	Std. Dev. (mph)	98	4.75	3.82	-0.93	NO
Point of Curvature (PC)	Mean Speed (mph)	95	39.34	41.2	**+1.86**	**YES**
	85^{th} Speed (mph)	95	44.30	45.11	+0.81	NO
	Pct. Exceeding 35 mph*	95	74.4	96.6	**+22.2**	**YES**
	Std. Dev. (mph)	95	4.52	3.4	-1.12	NO

*35 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-17. FM 60 Results, Twilight.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
350 ft Upstream from PC (at exit ramp advisory sign)	Mean Speed (mph)	97	54.62	53.93	-0.69	NO
	85^{th} Speed (mph)	97	58.7	60.25	+1.55	NO
	Std. Dev. (mph)	97	3.86	5.59	+1.73	NO
200 ft Upstream from PC	Mean Speed (mph)	102	50.26	49.44	-0.82	NO
	85^{th} Speed (mph)	102	54.48	54.85	+0.37	NO
	Std. Dev. (mph)	102	4.05	5.01	+0.96	NO
100 ft Upstream from PC	Mean Speed (mph)	99	45.29	45.07	-0.22	NO
	85^{th} Speed (mph)	99	48.53	50.03	+1.5	NO
	Std. Dev. (mph)	99	3.96	5.27	+1.31	NO
Point of Curvature (PC)	Mean Speed (mph)	84	40.02	39.33	-0.69	NO
	85^{th} Speed (mph)	84	43.98	45.21	+1.23	NO
	Pct. Exceeding 35 mph*	84	83.9	75.0	-8.9	NO
	Std. Dev. (mph)	84	4.19	4.61	+0.42	NO

*35 mph = ball bank indicator speed at 10 degrees plus 10 mph

Table F-18. FM 60 Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
350 ft Upstream from PC (at exit ramp advisory sign)	Mean Speed (mph)	104	50.33	50.88	+0.55	NO
	85th Speed (mph)	104	55.16	55.97	+0.81	NO
	Std. Dev. (mph)	104	4.89	5.25	+0.36	NO
200 ft Upstream from PC	Mean Speed (mph)	106	46.4	46.72	+0.32	NO
	85th Speed (mph)	106	51.29	51.95	+0.66	NO
	Std. Dev. (mph)	106	4.78	5.06	+0.28	NO
100 ft Upstream from PC	Mean Speed (mph)	104	42.5	42.61	+0.11	NO
	85th Speed (mph)	104	46.9	46.87	-0.03	NO
	Std. Dev. (mph)	104	4.24	5.15	+0.91	NO
Point of Curvature (PC)	Mean Speed (mph)	94	36.7	37.33	+0.63	NO
	85th Speed (mph)	94	40	41.95	+1.95	NO
	Pct. Exceeding 35 mph*	94	53.6	60.4	+6.8	NO
	Std. Dev. (mph)	94	3.52	5.14	+1.62	NO

*35 mph = ball bank indicator speed at 10 degrees plus 10 mph

FM 2154

Researchers evaluated fluorescent yellow microprismatic sheeting (After) versus standard yellow high intensity sheeting (Before) installed on the Stop Ahead signs for both the northbound and southbound approaches of the rural four-way stop-controlled intersection of FM 2154 and FM 159. Tables F-19, F-20, and F-21 present the results for daytime, twilight, and nighttime, respectively, for data collected on the *northbound* approach. Tables F-22, F-23, and F-24 present the results for daytime, twilight, and nighttime, respectively, for data collected on the *southbound* approach.

Table F-19. FM 2154 NB Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (3000 ft upstream from intersection)	Mean Speed (mph)	76	65.33	64.61	-0.72	NO
	85th Speed (mph)	76	72.00	70.89	-1.11	NO
	Std. Dev. (mph)	76	6.32	6.16	-0.16	NO
800 ft Upstream from Intersection (shortly after Stop Ahead sign)	Mean Speed (mph)*	63	48.82	51.12	+2.30	NO
	85th Speed (mph)	63	54.28	56.85	+2.57	NO
	Std. Dev. (mph)	63	5.34	5.96	+0.62	NO
	Pct. Began Decelerating	54	100	99.6	-0.4	NO
500 ft Upstream from Intersection	Mean Speed (mph)*	72	43.65	45.4	+1.75	NO
	85th Speed (mph)	72	49.95	50.1	+0.15	NO
	Std. Dev. (mph)	72	4.77	6.38	+1.61	NO
	Pct. Decelerating > 10 ft/s^2 over final 500 ft.	70	0.4	0.0	-0.4	NO
350 ft Upstream from Intersection	Mean Speed (mph)*	72	38.87	39.56	+0.69	NO
	85th Speed (mph)	72	43.36	44.36	+1.00	NO
	Std. Dev. (mph)	72	4.56	5.05	+0.49	NO
250 ft Upstream from Intersection	Mean Speed (mph)*	72	35.41	36.18	+0.77	NO
	85th Speed (mph)	72	39.04	41.94	+2.90	NO
	Std. Dev. (mph)	72	4.74	4.96	+0.22	NO

*Control point speed included in the analysis as a covariate

Table F-20. FM 2154 NB Results, Twilight.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (3000 ft upstream from intersection)	Mean Speed (mph)	68	65.72	64.02	-1.7	NO
	85th Speed (mph)	68	70.85	71.00	+0.15	NO
	Std. Dev. (mph)	68	5.52	7.45	+1.93	NO
800 ft Upstream from Intersection (shortly after Stop Ahead sign)	Mean Speed (mph)*	57	49.72	49.88	+0.16	NO
	85th Speed (mph)	57	55.37	56.20	+0.83	NO
	Std. Dev. (mph)	57	6.66	5.78	-0.88	NO
	Pct. Began Decelerating	53	100.0	100.0	0.0	NO
500 ft Upstream from Intersection	Mean Speed (mph)*	65	45.04	44.39	-0.65	NO
	85th Speed (mph)	65	51.33	50.07	-1.26	NO
	Std. Dev. (mph)	65	6.61	5.43	-1.18	NO
	Pct. Decelerating > 10 ft/s^2 over final 500 ft.	65	2.2	0.2	-2.0	NO
350 ft Upstream from Intersection	Mean Speed (mph)*	65	39.65	40.61	+0.96	NO
	85th Speed (mph)	65	43.92	46.38	+2.46	NO
	Std. Dev. (mph)	65	6.54	6.23	-0.31	NO
250 ft Upstream from Intersection	Mean Speed (mph)*	53	35.2	36.8	**+1.6**	**YES**
	85th Speed (mph)	53	38.98	41.48	+2.50	NO
	Std. Dev. (mph)	53	4.98	5.22	+0.24	NO

*Control point speed included in the analysis as a covariate

Table F-21. FM 2154 NB Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (3000 ft upstream from intersection)	Mean Speed (mph)	62	63.1	63.5	+0.4	NO
	85th Speed (mph)	62	68.01	67.90	-0.11	NO
	Std. Dev. (mph)	62	4.67	7.11	+2.44	NO
800 ft Upstream from Intersection (shortly after Stop Ahead sign)	Mean Speed (mph)*	52	48.13	47.33	-0.80	NO
	85th Speed (mph)	52	52.48	52.02	-0.46	NO
	Std. Dev. (mph)	52	4.9	5.81	+0.91	NO
	Pct. Began Decelerating	44	100.0	100.0	0.0	NO
500 ft Upstream from Intersection	Mean Speed (mph)*	54	45.45	41.98	**-3.47**	**YES**
	85th Speed (mph)	54	49.03	45.86	-3.17	NO
	Std. Dev. (mph)	54	3.56	5.07	+1.51	NO
	Pct. Decelerating > 10 ft/s^2 over final 500 ft.	53	0.6	0.8	+0.2	NO
350 ft Upstream from Intersection	Mean Speed (mph)*	61	40.06	37.41	**-2.65**	**YES**
	85th Speed (mph)	61	43.20	42.46	-0.74	NO
	Std. Dev. (mph)	61	4.13	4.98	+0.85	NO
250 ft Upstream from Intersection	Mean Speed (mph)*	57	35.72	33.95	-1.77	NO
	85th Speed (mph)	57	40.03	39.5	-0.53	NO
	Std. Dev. (mph)	57	4.12	5.06	+0.94	NO

*Control point speed included in the analysis as a covariate

Table F-22. FM 2154 SB Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (3000 ft upstream from intersection)	Mean Speed (mph)	77	65.55	67.16	+1.61	NO
	85^{th} Speed (mph)	77	71.45	72	+0.55	NO
	Std. Dev. (mph)	77	6.17	4.87	-1.3	NO
1500 ft Upstream from Intersection (at Stop Ahead sign)	Mean Speed (mph)*	44	58.27	59.43	+1.16	NO
	85^{th} Speed (mph)	44	65.14	65.97	+0.83	NO
	Std. Dev. (mph)	44	6.23	5.49	-0.74	NO
	Pct. Began Decelerating	44	100	100	0	NO
800 ft Upstream from Intersection	Mean Speed (mph)*	65	55.01	55.99	+0.98	NO
	85^{th} Speed (mph)	65	60.32	62.49	+2.17	NO
	Std. Dev. (mph)	65	6.08	6.42	+0.34	NO
500 ft Upstream from Intersection	Mean Speed (mph)*	73	50.09	50.87	+0.78	NO
	85^{th} Speed (mph)	73	54.02	57.52	+3.5	NO
	Std. Dev. (mph)	73	5.1	5.7	+0.6	NO
	Pct. Decelerating > 10 ft/s^2 over final 500 ft.	71	2.2	7.6	**+5.4**	**YES**
350 ft Upstream from Intersection	Mean Speed (mph)*	70	44.54	45.76	+1.22	NO
	85^{th} Speed (mph)	70	49.69	51.36	+1.67	NO
	Std. Dev. (mph)	70	3.98	5.13	+1.15	NO
250 ft Upstream from Intersection	Mean Speed (mph)*	72	39	40.28	+1.28	NO
	85^{th} Speed (mph)	72	43	45.14	+2.14	NO
	Std. Dev. (mph)	72	3.92	4.73	+0.81	NO
100 ft Upstream from Intersection	Mean Speed (mph)*	70	28.09	28.19	+0.1	NO
	85^{th} Speed (mph)	70	31.89	31.42	-0.47	NO
	Std. Dev. (mph)	70	3.38	3.9	+0.52	NO

*Control point speed included in the analysis as a covariate

Table F-23. FM 2154 SB Results, Twilight.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (3000 ft upstream from intersection)	Mean Speed (mph)	87	64.27	64.19	-0.08	NO
	85^{th} Speed (mph)	87	69.99	69.34	-0.65	NO
	Std. Dev. (mph)	87	6.77	4.98	-1.79	NO
1500 ft Upstream from Intersection (at Stop Ahead sign)	Mean Speed (mph)*	55	57.87	56.61	-1.26	NO
	85^{th} Speed (mph)	55	63.74	61.67	-2.07	NO
	Std. Dev. (mph)	55	5.62	4.96	-0.66	NO
	Pct. Began Decelerating	55	100	100	0	NO
800 ft Upstream from Intersection	Mean Speed (mph)*	72	52.26	53.33	+1.07	NO
	85^{th} Speed (mph)	72	58.99	58.75	-0.24	NO
	Std. Dev. (mph)	72	5.24	5.58	+0.34	NO
500 ft Upstream from Intersection	Mean Speed (mph)*	79	48.44	49.61	+1.17	NO
	85^{th} Speed (mph)	79	55.09	55.24	+0.15	NO
	Std. Dev. (mph)	79	5.12	5.45	+0.33	NO
	Pct. Decelerating > 10 ft/s^2 over final 500 ft.	76	3.9	3.6	-0.3	NO
350 ft Upstream from Intersection	Mean Speed (mph)*	76	43.61	44.79	+1.18	NO
	85^{th} Speed (mph)	76	47.79	51.46	+3.67	NO
	Std. Dev. (mph)	76	4.39	5.33	+0.94	NO
250 ft Upstream from Intersection	Mean Speed (mph)*	78	38.44	39.21	+0.77	NO
	85^{th} Speed (mph)	78	42.37	43.88	+1.51	NO
	Std. Dev. (mph)	78	4.17	4.88	+0.71	NO
100 ft Upstream from Intersection	Mean Speed (mph)*	79	27.05	27.86	+0.81	NO
	85^{th} Speed (mph)	79	30.05	31.93	+1.88	NO
	Std. Dev. (mph)	79	2.91	4.23	+1.32	NO

*Control point speed included in the analysis as a covariate

Table F-24. FM 2154 SB Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (3000 ft upstream from intersection)	Mean Speed (mph)	84	65.76	63.62	**-2.14**	**YES**
	85^{th} Speed (mph)	84	70.04	68.88	-1.16	NO
	Std. Dev. (mph)	84	4.46	4.97	+0.51	NO
1500 ft Upstream from Intersection (at Stop Ahead sign)	Mean Speed (mph)*	67	59.72	56.41	-3.31	NO
	85^{th} Speed (mph)	67	65.01	62.64	-2.37	NO
	Std. Dev. (mph)	67	5.4	6.02	+0.62	NO
	Pct. Began Decelerating	67	97.2	84.9	-12.3	NO
800 ft Upstream from Intersection	Mean Speed (mph)*	74	53.53	50.58	-2.95	NO
	85^{th} Speed (mph)	74	59.08	54.99	-4.09	NO
	Std. Dev. (mph)	74	6.09	5.2	-0.89	NO
500 ft Upstream from Intersection	Mean Speed (mph)*	77	48.28	45.25	-3.03	NO
	85^{th} Speed (mph)	77	53.93	49.96	-3.97	NO
	Std. Dev. (mph)	77	6.44	5.71	-0.73	NO
	Pct. Decelerating > 10 ft/s^2 over final 500 ft.	76	7.3	5.4	-1.9	NO
350 ft Upstream from Intersection	Mean Speed (mph)*	78	44.3	41.58	-2.72	NO
	85^{th} Speed (mph)	78	50.49	47.27	-3.22	NO
	Std. Dev. (mph)	78	6.12	5.91	-0.21	NO
250 ft Upstream from Intersection	Mean Speed (mph)*	78	40.2	37.77	-2.43	NO
	85^{th} Speed (mph)	78	45.61	43.65	-1.96	NO
	Std. Dev. (mph)	78	5.35	5.5	+0.15	NO
100 ft Upstream from Intersection	Mean Speed (mph)*	78	29.11	28.51	-0.6	NO
	85^{th} Speed (mph)	78	34.46	33.21	-1.25	NO
	Std. Dev. (mph)	78	4.3	4.44	+0.14	NO

*Control point speed included in the analysis as a covariate

Holleman Dr.

A fluorescent red microprismatic Stop sign (After) was evaluated versus its standard red high intensity counterpart (Before) at the suburban T-intersection of Holleman Dr. and FM 2818. Tables F-25 and F-26 present the results for daytime and nighttime, respectively.

Table F-25. Holleman Dr. Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (600 ft upstream from intersection)	Mean Speed (mph)	93	37.91	37.51	-0.40	NO
	85^{th} Speed (mph)	93	41.70	42.56	+0.86	NO
	Std. Dev. (mph)	93	3.80	4.35	+0.55	NO
500 ft Upstream from Intersection	Mean Speed (mph)*	92	38.05	37.39	-0.66	NO
	85^{th} Speed (mph)	92	41.98	41.49	-0.49	NO
	Std. Dev. (mph)	92	3.91	4.29	+0.38	NO
	Pct. Began Decelerating	92	56.0	61.2	+5.2	NO
350 ft Upstream from Intersection	Mean Speed (mph)*	92	37.37	36.54	-0.83	NO
	85^{th} Speed (mph)	92	40.00	40.04	+0.04	NO
	Std. Dev. (mph)	92	3.49	4.24	+0.75	NO
250 ft Upstream from Intersection	Mean Speed (mph)*	92	35.83	34.79	-1.04	NO
	85^{th} Speed (mph)	92	38.43	38.5	+0.07	NO
	Std. Dev. (mph)	92	2.84	3.63	+0.79	NO
	Pct. Decelerating > 10 ft/s^2 over final 250 ft.	92	0.9	2.6	+1.7	NO
150 ft Upstream from Intersection	Mean Speed (mph)*	88	31.01	30.07	-0.94	NO
	85^{th} Speed (mph)	88	33.24	32.63	-0.61	NO
	Std. Dev. (mph)	88	2.52	2.93	+0.41	NO
100 ft Upstream from Intersection	Mean Speed (mph)*	85	27.01	25.74	**-1.27**	**YES**
	85^{th} Speed (mph)	85	29.45	28.95	-0.5	NO
	Std. Dev. (mph)	85	3.00	2.86	-0.14	NO
50 ft Upstream from Intersection	Mean Speed (mph)*	77	21.08	19.45	**-1.63**	**YES**
	85^{th} Speed (mph)	77	24.24	21.98	**-2.26**	**YES**
	Std. Dev. (mph)	77	3.03	2.59	-0.44	NO

*Control point speed included in the analysis as a covariate

Table F-26. Holleman Dr. Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (600 ft upstream from intersection)	Mean Speed (mph)	56	34.97	34.78	-0.19	NO
	85th Speed (mph)	56	38.04	37.00	-1.04	NO
	Std. Dev. (mph)	56	2.91	3.31	+0.40	NO
500 ft Upstream from Intersection	Mean Speed (mph)*	56	34.73	35.07	+0.34	NO
	85th Speed (mph)	56	38.66	37.00	-1.66	NO
	Std. Dev. (mph)	56	3.46	3.17	-0.29	NO
	Pct. Decelerating	56	57.1	57.8	+0.7	NO
350 ft Upstream from Intersection	Mean Speed (mph)*	56	34.69	35.03	+0.34	NO
	85th Speed (mph)	56	38.41	38.86	+0.45	NO
	Std. Dev. (mph)	56	3.25	3.41	+0.16	NO
250 ft Upstream from Intersection	Mean Speed (mph)*	56	33.71	33.66	-0.05	NO
	85th Speed (mph)	56	36.85	37.16	+0.31	NO
	Std. Dev. (mph)	56	3.12	3.44	+0.32	NO
	Pct. Decelerating > 10 ft/s^2 over final 250 ft.	56	0.4	0.9	+0.5	NO
150 ft Upstream from Intersection	Mean Speed (mph)*	55	30.26	29.98	-0.28	NO
	85th Speed (mph)	55	33.05	33.0	-0.05	NO
	Std. Dev. (mph)	55	3.22	3.18	-0.04	NO
100 ft Upstream from Intersection	Mean Speed (mph)*	54	26.57	26.43	-0.14	NO
	85th Speed (mph)	54	28.52	29.27	+0.75	NO
	Std. Dev. (mph)	54	2.84	3.45	+0.61	NO
50 ft Upstream from Intersection	Mean Speed (mph)*	48	20.83	20.64	-0.19	NO
	85th Speed (mph)	48	23.28	23.41	+0.13	NO
	Std. Dev. (mph)	48	2.86	3.02	+0.16	NO

*Control point speed included in the analysis as a covariate

Deacon Dr.

A fluorescent red Stop sign (After) was evaluated versus its standard red high intensity counterpart (Before) at the suburban T-intersection of Deacon Dr. and FM 2154. Tables F-27, F-28, and F-29 present the results for daytime, twilight, and nighttime, respectively.

Table F-27. Deacon Dr. Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
600 ft Upstream from Intersection	Mean Speed (mph)	84	37.64	35.91	**-1.73**	**YES**
	85^{th} Speed (mph)	84	42.6	39.3	**-3.3**	**YES**
	Std. Dev. (mph)	84	3.96	3.16	-0.80	NO
500 ft Upstream from Intersection	Mean Speed (mph)	88	37.90	36.28	**-1.62**	**YES**
	85^{th} Speed (mph)	88	41.95	39.37	-2.58	NO
	Std. Dev. (mph)	88	4.26	3.26	-1.00	NO
350 ft Upstream from Intersection	Mean Speed (mph)	88	37.28	36.65	-0.63	NO
	85^{th} Speed (mph)	88	41.0	40.0	-1.0	NO
	Std. Dev. (mph)	88	4.00	2.90	-1.10	NO
250 ft Upstream from Intersection	Mean Speed (mph)	90	35.97	35.40	-0.57	NO
	85^{th} Speed (mph)	90	39.76	38.94	**-0.82**	**YES**
	Std. Dev. (mph)	90	3.93	2.81	-1.12	NO
	Pct. Decelerating > 10 ft/s^2 over final 250 ft.	90	7.00	2.60	-4.4	NO
150 ft Upstream from Intersection	Mean Speed (mph)	88	32.32	31.64	-0.68	NO
	85^{th} Speed (mph)	88	35.28	34.90	-0.38	NO
	Std. Dev. (mph)	88	3.28	2.56	-0.72	NO
100 ft Upstream from Intersection	Mean Speed (mph)	85	27.81	27.06	-0.75	NO
	85^{th} Speed (mph)	85	30.15	28.98	-1.17	NO
	Std. Dev. (mph)	85	3.17	2.11	-1.06	NO
50 ft Upstream from Intersection	Mean Speed (mph)	86	20.01	20.16	+0.15	NO
	85^{th} Speed (mph)	86	22.57	22.72	+0.15	NO
	Std. Dev. (mph)	86	3.00	2.40	-0.6	NO

Table F-28. Deacon Dr. Results, Twilight.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
600 ft Upstream from Intersection	Mean Speed (mph)	50	36.81	36.58	-0.23	NO
	85th Speed (mph)	50	39.85	39.85	0	NO
	Std. Dev. (mph)	50	6.55	2.90	**-3.65**	**YES**
500 ft Upstream from Intersection	Mean Speed (mph)	53	37.13	36.66	-0.47	NO
	85th Speed (mph)	53	41.26	39.92	-1.34	NO
	Std. Dev. (mph)	53	6.37	2.76	**-3.61**	**YES**
350 ft Upstream from Intersection	Mean Speed (mph)	53	37.31	36.70	-0.61	NO
	85th Speed (mph)	53	42.51	39.63	**-2.88**	**YES**
	Std. Dev. (mph)	53	6.20	2.42	**-3.78**	**YES**
250 ft Upstream from Intersection	Mean Speed (mph)	54	36.03	35.04	-0.99	NO
	85th Speed (mph)	54	41.14	37.04	**-4.10**	**YES**
	Std. Dev. (mph)	54	5.01	2.26	**-2.75**	**YES**
	Pct. Decelerating > 10 ft/s^2 over final 250 ft.	54	11.20	1.40	-9.8	NO
150 ft Upstream from Intersection	Mean Speed (mph)	52	31.75	30.60	-1.15	NO
	85th Speed (mph)	52	35.66	32.35	**-3.31**	**YES**
	Std. Dev. (mph)	52	4.52	2.45	**-2.07**	**YES**
100 ft Upstream from Intersection	Mean Speed (mph)	48	27.24	26.09	-1.15	NO
	85th Speed (mph)	48	32.26	28.41	**-3.85**	**YES**
	Std. Dev. (mph)	48	4.17	2.61	**-1.56**	**YES**
50 ft Upstream from Intersection	Mean Speed (mph)	44	19.47	18.17	-1.3	NO
	85th Speed (mph)	44	22.50	21.14	-1.36	NO
	Std. Dev. (mph)	44	3.62	3.18	-0.44	NO

Table F-29. Deacon Dr. Results, Night.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
600 ft Upstream from Intersection	Mean Speed (mph)	48	36.46	35.19	-1.27	NO
	85^{th} Speed (mph)	48	41.34	39.25	-2.09	NO
	Std. Dev. (mph)	48	4.04	3.74	-0.30	NO
500 ft Upstream from Intersection	Mean Speed (mph)	50	36.36	35.87	-0.49	NO
	85^{th} Speed (mph)	50	40.77	40.00	-0.77	NO
	Std. Dev. (mph)	50	4.03	3.73	-0.30	NO
350 ft Upstream from Intersection	Mean Speed (mph)	49	35.45	35.38	-0.07	NO
	85^{th} Speed (mph)	49	39.27	39.05	-0.22	NO
	Std. Dev. (mph)	49	3.94	3.40	-0.54	NO
250 ft Upstream from Intersection	Mean Speed (mph)	49	33.70	33.62	-0.08	NO
	85^{th} Speed (mph)	49	36.04	36.59	+0.55	NO
	Std. Dev. (mph)	49	4.06	2.92	-1.14	NO
	Pct. Decelerating > 10 ft/s^2 over final 250 ft.	49	8.10	2.00	-6.1	NO
150 ft Upstream from Intersection	Mean Speed (mph)	40	29.67	29.80	+0.13	NO
	85^{th} Speed (mph)	40	31.93	32.31	+0.38	NO
	Std. Dev. (mph)	40	4.22	2.74	-1.48	NO
100 ft Upstream from Intersection	Mean Speed (mph)	32	25.94	25.57	-0.37	NO
	85^{th} Speed (mph)	32	28.27	27.60	-0.67	NO
	Std. Dev. (mph)	32	3.26	2.10	-1.16	NO

Luther St.

A fluorescent red Stop sign (After) was evaluated versus its standard red high intensity counterpart (Before) at the suburban T-intersection of Luther St. and FM 2818. Tables F-30 and F-31 present the results for daytime and nighttime, respectively.

Table F-30. Luther St. Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (1500 ft upstream from intersection)	Mean Speed (mph)	64	47.27	48.09	+0.82	NO
	85^{th} Speed (mph)	64	52.14	51.87	-0.27	NO
	Std. Dev. (mph)	64	4.76	3.90	-0.86	NO
800 ft Upstream from Intersection	Mean Speed (mph)*	80	46.88	46.94	+0.06	NO
	85^{th} Speed (mph)	80	51.29	52.00	+0.71	NO
	Std. Dev. (mph)	80	4.69	4.68	-0.01	NO
	Pct. Decelerating	64	44.4	56.2	+11.8	NO
500 ft Upstream from Intersection	Mean Speed (mph)*	79	44.99	45.42	+0.43	NO
	85^{th} Speed (mph)	79	48.55	50.57	+2.02	NO
	Std. Dev. (mph)	79	4.61	4.81	+0.2	NO
350 ft Upstream from Intersection	Mean Speed (mph)*	77	42.32	43.37	+1.05	NO
	85^{th} Speed (mph)	77	45.98	49.2	+3.22	NO
	Std. Dev. (mph)	77	4.09	5.01	+0.92	NO
250 ft Upstream from Intersection	Mean Speed (mph)*	71	39.16	39.72	+0.56	NO
	85^{th} Speed (mph)	71	42.85	44.52	+1.67	NO
	Std. Dev. (mph)	71	3.60	4.74	+1.14	NO
	Pct. Decelerating > 10 ft/s^2 over final 250 ft.	71	2.4	5.2	+2.8	NO
150 ft Upstream from Intersection	Mean Speed (mph)*	63	33.05	32.96	-0.09	NO
	85^{th} Speed (mph)	63	36.76	36.21	-0.55	NO
	Std. Dev. (mph)	63	3.71	4.14	+0.43	NO
100 ft Upstream from Intersection	Mean Speed (mph)*	58	27.69	27.73	+0.04	NO
	85^{th} Speed (mph)	58	31.04	32.99	+1.95	NO
	Std. Dev. (mph)	58	3.59	4.28	+0.69	NO

*Control point speed included in the analysis as a covariate

Table F-31. Luther St. Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (1500 ft upstream from intersection)	Mean Speed (mph)	49	44.91	47.28	**+2.37**	**YES**
	85^{th} Speed (mph)	49	48.33	50.60	+2.27	NO
	Std. Dev. (mph)	49	4.00	3.43	-0.57	NO
800 ft Upstream from Intersection	Mean Speed (mph)*	57	44.34	44.45	**+0.11**	**YES**
	85^{th} Speed (mph)	57	48.97	49.00	+0.03	NO
	Std. Dev. (mph)	57	4.32	4.15	-0.17	NO
	Pct. Decelerating	49	50.0	55.0	+5.0	NO
500 ft Upstream from Intersection	Mean Speed (mph)*	57	42.28	43.65	+1.37	NO
	85^{th} Speed (mph)	57	48.00	45.85	-2.15	NO
	Std. Dev. (mph)	57	4.69	4.16	-0.53	NO
350 ft Upstream from Intersection	Mean Speed (mph)*	57	39.73	41.58	+1.85	NO
	85^{th} Speed (mph)	57	45.89	44.04	-1.85	NO
	Std. Dev. (mph)	57	5.18	3.81	-1.37	NO
250 ft Upstream from Intersection	Mean Speed (mph)*	54	37.12	37.86	+0.74	NO
	85^{th} Speed (mph)	54	42.09	41.04	-1.05	NO
	Std. Dev. (mph)	54	4.36	4.41	+0.05	NO
	Pct. Decelerating > 10 ft/s^2 over final 250 ft.	54	6.6	3.7	-2.9	NO
150 ft Upstream from Intersection	Mean Speed (mph)*	51	31.22	32.53	+1.31	NO
	85^{th} Speed (mph)	51	35.24	36.37	+1.13	NO
	Std. Dev. (mph)	51	3.73	4.21	+0.48	NO
100 ft Upstream from Intersection	Mean Speed (mph)*	47	26.50	26.99	+0.49	NO
	85^{th} Speed (mph)	47	29.46	29.73	+0.27	NO
	Std. Dev. (mph)	47	3.40	3.55	+0.15	NO

*Control point speed included in the analysis as a covariate

FM 2549

The rural intersection of FM 2549 and FM 391 included evaluation of both a fluorescent red Stop sign (After #1) and a flashing red LED Stop sign (After #2) versus the standard red high intensity counterpart (Before). Tables F-32, F-33, and F-34 present the results for daytime, twilight, and nighttime, respectively.

Table F-32. FM 2549 Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After #1	Aft#1-Before	Significant @ 95% Confidence?	After #2	Aft#2-Before	Significant @ 95% Confidence?
Control Point (2800 ft upstream from intersection)	Mean Speed (mph)	441	62.48	63.61	+1.13	NO	62.96	+0.48	NO
	85th Speed (mph)	441	70.0	70.0	0		70.0	0	
	Std. Dev. (mph)	441	7.00	6.87	-0.13	NO	6.51	-0.49	NO
2000 ft (shortly after intersection appearing)	Mean Speed (mph)*	441	62.59	62.04	**-0.55**	**YES**	62.18	-0.41	NO
	85th Speed (mph)	441	69.75	69.0	-0.75		69.0	-0.75	
	Std. Dev. (mph)	441	7.27	6.82	-0.45	NO	6.68	-0.59	NO
1100 ft (at Stop Ahead sign)	Mean Speed (mph)*	441	57.86	57.62	**-0.24**	**YES**	58.94	+1.08	NO
	85th Speed (mph)	441	65.0	65.5	+0.50		66.0	+1.00	
	Std. Dev. (mph)	441	7.31	7.51	+0.20	NO	6.52	-0.79	NO
200 ft Upstream from Intersection	Mean Speed (mph)*	431	34.28	33.37	**-0.91**	**YES**	34.18	-0.10	NO
	85th Speed (mph)	431	39.0	38.0	-1.00		38.80	-0.20	
	Std. Dev. (mph)	431	4.78	4.66	-0.12	NO	4.77	-0.01	NO
At Intersection	Pct. Vehicles Coming to a Voluntary Full Stop	635	57.1	41.4	**-15.7**	**YES**	33.8	**-23.3**	**YES**

*Control point speed included in the analysis as a covariate

Table F-33. FM 2549 Results, Twilight.

Location	Measure of Effectiveness	Overall Sample Size	Before	After #1	Aft#1-Before	Significant @ 95% Confidence?	After #2	Aft#2-Before	Significant @ 95% Confidence?
Control Point (2800 ft upstream from intersection)	Mean Speed (mph)	120	62.78	63.59	+0.81	NO	64.19	+1.41	NO
	85^{th} Speed (mph)	120	68.0	70.7	+2.70		69.0	+1.00	
	Std. Dev. (mph)	120	6.58	7.20	+0.62	NO	8.06	+1.48	NO
2000 ft (shortly after intersection appearing)	Mean Speed (mph)*	120	63.35	63.41	+0.06	NO	64.19	+0.84	NO
	85^{th} Speed (mph)	120	68.25	70.0	+1.75		71.0	+2.75	
	Std. Dev. (mph)	120	6.48	7.16	+0.68	NO	7.55	+1.07	NO
1100 ft (at Stop Ahead sign)	Mean Speed (mph)*	120	59.13	60.16	+1.03	NO	59.86	+0.73	NO
	85^{th} Speed (mph)	120	65.25	67.35	+2.10		67.0	+1.75	
	Std. Dev. (mph)	120	6.91	8.14	+1.23	NO	7.37	+0.46	NO
200 ft Upstream from Intersection	Mean Speed (mph)*	120	35.30	33.78	-1.52	NO	34.98	-0.33	NO
	85^{th} Speed (mph)	120	39.0	38.35	-0.65		39.85	+0.85	
	Std. Dev. (mph)	120	4.49	5.20	+0.71	NO	4.67	+0.18	NO
At Intersection	Pct. Vehicles Coming to a Voluntary Full Stop	135	65.2	N/A	N/A		40.9	**-24.3**	**YES**

*Control point speed included in the analysis as a covariate

Table F-34. FM 2549 Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After #1	Aft#1-Before	Significant @ 95% Confidence?	After #2	Aft#2-Before	Significant @ 95% Confidence?
Control Point (2800 ft upstream from intersection)	Mean Speed (mph)	94	60.27	61.59	+1.32	NO	62.60	+2.33	NO
	85^{th} Speed (mph)	94	66.65	69.8	+3.15		70.0	+3.35	
	Std. Dev. (mph)	94	6.23	7.73	+1.50	NO	7.80	+1.57	NO
2000 ft (shortly after intersection appearing)	Mean Speed (mph)*	94	59.67	60.48	+0.81	NO	62.23	+2.56	NO
	85^{th} Speed (mph)	94	66.65	69.0	+2.35		69.0	+2.35	
	Std. Dev. (mph)	94	7.04	7.16	+0.12	NO	8.39	+1.35	NO
1100 ft (at Stop Ahead sign)	Mean Speed (mph)*	94	53.47	54.07	+0.60	NO	57.97	**+4.50**	**YES**
	85^{th} Speed (mph)	94	61.6	61.0	-0.60		67.0	+5.40	
	Std. Dev. (mph)	94	8.20	6.71	-1.49	NO	8.84	+0.64	NO
200 ft Upstream from Intersection	Mean Speed (mph)*	94	32.43	32.31	-0.12	NO	34.46	+2.03	NO
	85^{th} Speed (mph)	94	38.3	36.8	-1.50		39.0	+0.70	
	Std. Dev. (mph)	94	4.86	4.69	-0.17	NO	4.75	-0.11	NO
At Intersection	Pct. Vehicles Coming to a Voluntary Full Stop	226	57.8	48.6	-9.2	NO	27.4	**-30.4**	**YES**

*Control point speed included in the analysis as a covariate

Southwest Parkway

A flashing red LED Stop sign (After) was evaluated versus its standard red high intensity counterpart (Before) at the suburban four-way stop intersection at Southwest Parkway and Langford St. Tables F-35 and F-36 present the results for daytime and nighttime, respectively.

Table F-35. Southwest Parkway Results, Daytime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
300 ft Upstream from Intersection	Mean Speed (mph)	60	33.94	34.73	+0.79	NO
	85^{th} Speed (mph)	60	36.00	37.36	+1.36	NO
	Std. Dev. (mph)	60	2.90	2.64	-0.26	NO
250 ft Upstream from Intersection	Mean Speed (mph)	63	33.48	34.71	+1.23	NO
	85^{th} Speed (mph)	63	35.68	37.21	**+1.53**	**YES**
	Std. Dev. (mph)	63	2.84	2.68	-0.16	NO
	Pct. Decelerating > 10 ft/s^2 over final 250 ft.	60	1.8	1.1	-0.7	NO
150 ft Upstream from Intersection	Mean Speed (mph)	61	31.75	31.76	+0.01	NO
	85^{th} Speed (mph)	61	33.66	33.27	-0.39	NO
	Std. Dev. (mph)	61	5.88	2.89	-2.99	NO
100 ft Upstream from Intersection	Mean Speed (mph)	61	27.89	27.93	+0.04	NO
	85^{th} Speed (mph)	61	30.21	29.69	-0.52	NO
	Std. Dev. (mph)	61	2.49	2.95	+0.46	NO
50 ft Upstream from Intersection	Mean Speed (mph)	60	21.59	21.26	-0.33	NO
	85^{th} Speed (mph)	60	23.48	24.00	+0.52	NO
	Std. Dev. (mph)	60	2.13	2.50	+0.37	NO
At Intersection	Pct. Vehicles Coming to a Voluntary Full Stop	533	35.7	34.4	-1.3	NO

Table F-36. Southwest Parkway Results, Nighttime.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
300 ft Upstream from Intersection	Mean Speed (mph)	46	33.03	33.66	+0.63	NO
	85th Speed (mph)	46	36.24	36.89	+0.65	NO
	Std. Dev. (mph)	46	2.72	2.78	+0.06	NO
250 ft Upstream from Intersection	Mean Speed (mph)	54	33.32	33.32	0	NO
	85th Speed (mph)	54	36.91	36.15	-0.76	NO
	Std. Dev. (mph)	54	3.21	3.11	-0.10	NO
	Pct. Decelerating > 10 ft/s^2 over final 250 ft.	43	2.3	2.0	-0.3	NO
150 ft Upstream from Intersection	Mean Speed (mph)	56	30.93	30.48	-0.45	NO
	85th Speed (mph)	56	34.49	33.01	-1.48	NO
	Std. Dev. (mph)	56	3.40	3.13	-0.27	NO
100 ft Upstream from Intersection	Mean Speed (mph)	56	27.80	27.37	-0.43	NO
	85th Speed (mph)	56	30.09	30.27	+0.18	NO
	Std. Dev. (mph)	56	2.87	3.23	+0.36	NO
50 ft Upstream from Intersection	Mean Speed (mph)	43	20.86	19.78	-1.08	NO
	85th Speed (mph)	43	22.76	21.91	-0.85	NO
	Std. Dev. (mph)	43	2.44	2.15	-0.29	NO
At Intersection	Pct. Vehicles Coming to a Voluntary Full Stop	479	48.4	31.7	**-16.7**	**YES**

State Highway 7

A 3-inch red microprismatic border affixed to the perimeter of the 55 mph Speed Limit sign (After) was evaluated versus the same sign without the border (Before) at the entrance to the speed zone approaching Marlin, Texas, from the west on State Highway 7. Tables F-37 and F-38 present the results for passenger vehicles daytime and nighttime, respectively. Tables F-39 and F-40 present the results for heavy trucks daytime and nighttime, respectively.

Table F-37. State Highway 7 Results, Daytime Passenger Vehicles.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (7500 ft upstream from sign)	Mean Speed (mph)	1209	67.89	67.44	-0.45	NO
	85^{th} Speed (mph)	1209	73.0	73.0	0.0	NO
	Std. Dev. (mph)	1209	6.70	6.00	-0.70	NO
2000 ft upstream of the sign (where sign is visible)	Mean Speed (mph)*	926	67.53	66.43	**-1.10**	**YES**
	85^{th} Speed (mph)	926	73.0	73.0	0.0	NO
	Std. Dev. (mph)	926	6.03	6.27	0.24	NO
600 ft upstream of the sign (where sign is legible)	Mean Speed (mph)*	1007	65.70	64.79	**-0.91**	**YES**
	85^{th} Speed (mph)	1007	71.0	71.0	0.0	NO
	Std. Dev. (mph)	1007	5.99	6.33	0.34	NO
	Percent Exceeding 55 mph	1007	95.0	92.8	-2.2	NO
At 55 treatment sign	Mean Speed (mph)*	799	64.53	62.61	**-1.92**	**YES**
	85^{th} Speed (mph)	799	71.0	69.0	-2.0	NO
	Std. Dev. (mph)	799	6.13	6.64	0.51	NO
	Percent Exceeding 55 mph	799	93.4	84.4	**-9.0**	**YES**
500 ft downstream of sign	Mean Speed (mph)*	728	62.50	60.51	**-1.99**	**YES**
	85^{th} Speed (mph)	728	70.0	68.0	-2.0	NO
	Std. Dev. (mph)	728	6.65	7.35	0.70	NO
	Percent Exceeding 55 mph	728	85.0	71.3	**-13.7**	**YES**

*Control point speed included in the analysis as a covariate

Table F-38. State Highway 7 Results, Nighttime Passenger Vehicles.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (7500 ft upstream from sign)	Mean Speed (mph)	268	65.77	66.66	0.89	NO
	85th Speed (mph)	268	73.0	73.0	0.0	NO
	Std. Dev. (mph)	268	6.82	7.70	0.88	NO
2000 ft upstream of the sign (where sign is visible)	Mean Speed (mph)*	262	63.51	63.04	-0.47	NO
	85th Speed (mph)	262	70.2	70.0	-0.2	NO
	Std. Dev. (mph)	262	7.02	7.33	0.31	NO
600 ft upstream of the sign (where sign is legible)	Mean Speed (mph)*	260	62.32	61.32	**-1.00**	**YES**
	85th Speed (mph)	260	69.45	68.00	-1.45	NO
	Std. Dev. (mph)	260	6.85	7.04	0.19	NO
	Percent Exceeding 55 mph	260	80.0	77.1	-2.9	NO
At 55 treatment sign	Mean Speed (mph)*	251	60.29	59.30	-0.99	NO
	85th Speed (mph)	251	67.65	66.00	-1.65	NO
	Std. Dev. (mph)	251	7.70	7.09	-0.61	NO
	Percent Exceeding 55 mph	251	69.8	62.2	-7.6	NO
500 ft downstream of sign	Mean Speed (mph)*	246	58.26	57.48	**-0.78**	**YES**
	85th Speed (mph)	246	66.0	64.8	-1.2	NO
	Std. Dev. (mph)	246	7.15	7.39	0.24	NO
	Percent Exceeding 55 mph	246	62.0	50.0	-12.0	NO

*Control point speed included in the analysis as a covariate

Table F-39. State Highway 7 Results, Daytime Heavy Trucks.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (7500 ft upstream from sign)	Mean Speed (mph)	180	67.09	65.71	-1.38	NO
	85th Speed (mph)	180	71.0	71.0	0.0	NO
	Std. Dev. (mph)	180	4.47	5.49	1.02	NO
2000 ft upstream of the sign (where sign is visible)	Mean Speed (mph)*	132	66.41	64.69	-1.72	NO
	85th Speed (mph)	132	70.0	70.0	0.0	NO
	Std. Dev. (mph)	132	4.66	5.06	0.40	NO
600 ft upstream of the sign (where sign is legible)	Mean Speed (mph)*	145	64.71	63.56	-1.15	NO
	85th Speed (mph)	145	70.0	68.0	-2.0	NO
	Std. Dev. (mph)	145	5.42	4.80	-0.62	NO
	Percent Exceeding 55 mph	145	99.0	95.6	-3.4	NO
At 55 treatment sign	Mean Speed (mph)*	114	63.20	62.14	-1.06	NO
	85th Speed (mph)	114	68.0	68.0	0.0	NO
	Std. Dev. (mph)	114	4.75	5.19	0.44	NO
	Percent Exceeding 55 mph	114	93.8	90.7	-3.1	NO
500 ft downstream of sign	Mean Speed (mph)*	83	62.49	58.56	**-3.93**	**YES**
	85th Speed (mph)	83	68.00	63.45	-4.55	NO
	Std. Dev. (mph)	83	5.37	3.96	-1.41	NO
	Percent Exceeding 55 mph	83	88.0	76.5	-11.5	NO

*Control point speed included in the analysis as a covariate

Table F-40. State Highway 7 Results, Nighttime Heavy Trucks.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (7500 ft upstream from sign)	Mean Speed (mph)	80	64.65	65.39	0.74	NO
	85^{th} Speed (mph)	80	68.00	69.95	1.95	NO
	Std. Dev. (mph)	80	4.77	3.62	-1.15	NO
2000 ft upstream of the sign (where sign is visible)	Mean Speed (mph)*	71	62.76	63.04	0.28	NO
	85^{th} Speed (mph)	71	66.25	67.40	1.15	NO
	Std. Dev. (mph)	71	3.90	4.08	0.18	NO
600 ft upstream of the sign (where sign is legible)	Mean Speed (mph)*	70	62.18	61.62	-0.56	NO
	85^{th} Speed (mph)	70	66.0	65.0	-1.0	NO
	Std. Dev. (mph)	70	4.38	3.90	-0.48	NO
	Percent Exceeding 55 mph	70	92.0	100.0	8.0	NO
At 55 treatment sign	Mean Speed (mph)*	46	61.08	60.30	-0.78	NO
	85^{th} Speed (mph)	46	65.25	64.15	-1.10	NO
	Std. Dev. (mph)	46	4.51	4.58	0.07	NO
	Percent Exceeding 55 mph	46	84.0	76.4	-7.6	NO
500 ft downstream of sign	Mean Speed (mph)*	61	59.70	59.00	-0.70	NO
	85^{th} Speed (mph)	61	65.25	63.90	-1.35	NO
	Std. Dev. (mph)	61	5.53	4.69	-0.84	NO
	Percent Exceeding 55 mph	61	69.0	67.9	-1.1	NO

*Control point speed included in the analysis as a covariate