IMPACTS OF A CONSPICUITY TREATMENT ON SPEED LIMIT COMPLIANCE

A Thesis

by

ROMA GARG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2006

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	H. Gene Hawkins, Jr.
Committee Members,	Yunlong Zhang
	Michael Sherman
Head of Department,	David Rosowsky

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ABSTRACT

Impacts of a Conspicuity Treatment on Speed Limit Compliance. (May 2006)

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Chair of Committee: Dr. H. Gene Hawkins, Jr.

In reduced speed zones, where no other cues indicate the need to slow down, drivers sometimes fail to notice the standard Speed Limit sign and may be speeding inadvertently. To help reduce inadvertent speeding, a red border was installed around the Speed Limit sign in seven reduced speed areas and the impacts of the increased conspicuity on speed limit compliance were measured.

The general study approach was to collect and compare speed data for a standard sign (before condition) and a red border sign (after condition). The short-term effects of a modified red border sign, which was achieved by replacing the thin black border of the standard sign with a four inch wide red border, were evaluated at four sites. Results of this modified border study indicated that there was a statistically significant reduction in the mean speeds as well as in the 85th percentile speeds for the red border sign conditions, however the reductions were not practically significant. This study also evaluated the effect of using a higher conspicuity sheeting material at two sites. The results indicated that use of higher conspicuity sheeting has some benefits for the standard sign but no additional benefits for the red border sign.

The added border study evaluated the long-term effects (approximately nine to eleven months after the treatment) of adding a three inch wide red border to the standard Speed Limit sign at three sites. The results of this study indicated that impacts of the red border treatment increase with passage of time. The mean speeds decreased by 8.1 percent and the percent of vehicles exceeding the speed limit (55 mph) decreased by 21.7 percent. The decreases in speeds were both statistically and practically significant.

A comparison of the thesis study with other similar studies found in literature shows comparable benefits of the red border sign with other speed management measures. Based on the results for long-term effects, use of the red border Speed Limit sign is recommended in reduced speed zones where inadvertent speeding is common.

DEDICATION

This thesis is dedicated to my mother, Kailash Garg, and to my sister, Dr. Seema Garg. Their love and support were essential for my success in graduate school and will continue to be important in my future professional life.

ACKNOWLEDGEMENTS

The research described in this thesis is an extension of a larger Texas Transportation Institute (TTI) project sponsored through the Texas Department of Transportation (TxDOT). I would like to thank my thesis committee for the support and guidance they provided me throughout the thesis academic process. Dr. H. Gene Hawkins, my committee chair and supervisor, provided me the opportunity to participate in this research and spent many hours working with me to develop my research proposal. As my proposal began to materialize, Dr. Yunlong Zhang and Dr. Michael Sherman further aided in the development of my thesis. Periodically, I sought and received helpful direction from each member of my committee as I collected and analyzed my data. Dr. Hawkins and I worked closely together to refine various drafts of my report prior to submitting a draft to my whole committee. The level of detail and the final quality of my research presented in this document were greatly impacted by my thesis committee.

In general, I would like to thank The Texas A&M University Department of Civil Engineering, TxDOT, and TTI. Each professor that has crossed my path through my academics has played some role in my development as a professional; TxDOT sponsored the very research detailed in this document; and the various professionals within TTI further refined my abilities as a researcher.

Finally, I would like to thank my good friend, Charles Stevens, for his support and help with the statistical analysis software SAS, used for the data analysis.

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ABBREVIATIONS AND TERMINOLOGY

CP	Control point
DS	Downstream point
HI_S	Standard Speed Limit sign with high intensity sheeting
HI_R	Modified Red Border Speed Limit sign with high intensity sheeting
MP_S	Standard Speed Limit sign with microprismatic sheeting
MP_R	Modified Red Border Speed Limit sign with microprismatic sheeting
MOE	Measure of effectiveness
NHTSA	National Highway Traffic Safety Administration
SL	Speed limit
TTI	Texas Transportation Institute
UK	United Kingdom

CHAPTER I

INTRODUCTION

Speeding is a significant safety concern on our highways and contributes to a large number of fatal and non-fatal crashes every year (*1*). The National Highway Traffic Safety Administration (NHTSA) defines speeding as driving too fast for conditions or exceeding the posted speed limit. NHTSA estimates the economic cost to society of speed-related crashes to be approximately $40 billion per year. According to NHTSA, in 2003 speeding was a contributing factor in 31 percent of all fatal crashes and Texas is no exception to national statistics. In fact, speed-related crashes on Texas highways account for 41 percent of all fatal crashes (*1*).

Speed is a major traffic safety issue due to two basic relationships: 1) the velocity of the vehicle and the time available to react to a hazard for the driver of the vehicle, other motorists on the road, bicyclists or pedestrians to avoid a collision; and 2) the law of physics relating mass and speed to energy during impact. In practical terms, the first relationship means that speeding reduces a driver's ability to steer safely around curves or objects in the roadway, and extends the distance required to stop a vehicle in emergency situations. The mass-velocity relationship causes crashes at higher speeds to be more severe than those at lower speeds. Since greater energy is transferred during high-speed crashes, the effectiveness of restraint devices, such as air bags and safety belts, declines. Vehicular construction features, such as crumple zones and side-member beams, and roadside devices like guardrails, are also less effective during high-speed crashes (*2*).

For years researchers have studied the relationship between vehicle speeds and the number and severity of crashes. A majority of these studies indicate that the relationship between absolute speed of the vehicle and the incidence of a crash is

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This thesis follows the style and format of *Transportation Research Record*.

unclear, however crash severity does have a direct and unequivocal relationship with vehicle speed (*2*). Based on the investigations of 50 separate speed-limit changes in Sweden, Nilson derived a series of mathematical functions to explain the relationship between changes in speed limit and traffic safety. Figure 1 illustrates these functions, which predict that a 10 percent increase in vehicle velocity increases the likelihood of fatal crashes by 40 percent, severe-injury crashes by 30 percent, and all-injury crashes by 20 percent (*3*). Finch et al. developed a mathematical model for the change in mean speed and changes in crashes based on the effects of speed limits reported in various international studies. The results of this model indicate that for every 1.0 mph increase in mean speed, the number of injury crashes increases by 5 percent (*4*).

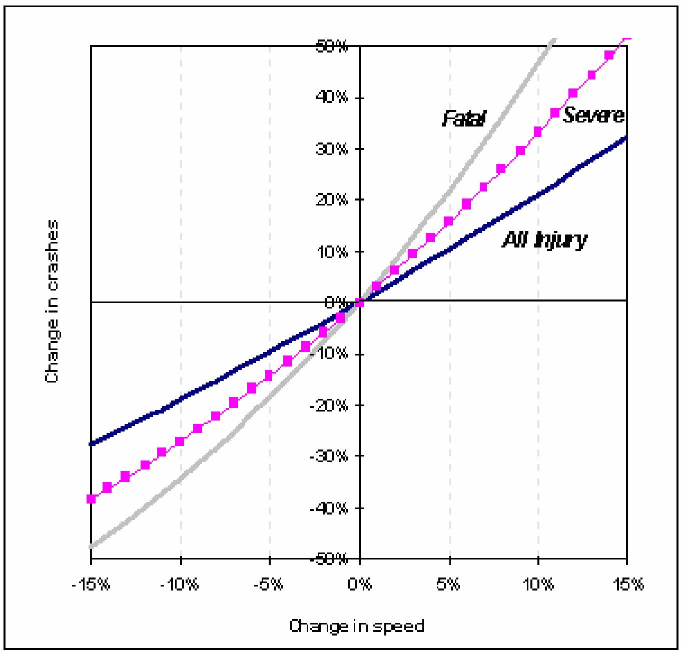

FIGURE 1 Effect of Changes in Speed on Injury and Fatal Crashes (*3*).

All the evidence that speeding increases the incidence and severity of crashes, calls for speed management methods to increase the safety on our highways. Some of the speed management methods are law enforcement, automatic enforcement using speed cameras, radar trailers, signs with flashing lights, pavement markings, and changes to the design and position of Speed Limit signs. Law enforcement and radar trailers encourage compliance with the speed limit, but are effective only when enforcement and trailers are in place. Automatic enforcement is found to be more effective in the long-term, though costly and controversial. Changes to the road geometry, road surface, and Speed Limit signs are the only permanent methods used to reduce the number of speed limit violations. Of these, sign treatments and pavement markings are cost effective measures that improve speed-limit compliance by reducing inadvertent speeding occurrences. A few of the sign treatments used to achieve greater speed compliance are larger speed signs, Reduced Speed Ahead signs, speed signs with orange flags attached to them, speed signs with a colored plaque at the top, overhead positioning of speed signs, and speed feedback signs.

PROBLEM STATEMENT

Reduced speed zones well outside the city limits of most rural communities in Texas usually do not provide any visual clues other than the standard Speed Limit sign or the Reduced Speed Ahead sign to inform motorists of changes in the speed limit. Past research indicates that most drivers choose their speeds based on environmental factors and visual clues, such as changes in road characteristics and roadway surroundings (*2*). As such, in these reduced speed zones where the roadway geometry and surroundings do not change, the standard Speed Limit signs sometimes go unnoticed or unheeded by drivers. Drivers ignore the speed limit for many reasons. Some do not perceive a need to slow down, while others are in a hurry. Most regulatory signs look alike and thus do not capture a driver's attention. Research is needed to determine if changing the design of the Speed Limit sign and making it more conspicuous will attract more attention of drivers entering reduced speed zones and alert them about the reductions in speed limit.

RESEARCH OBJECTIVES

The principle objective of this research was to study the impact of a red border around a Speed Limit sign on speed limit compliance. A secondary objective was to evaluate the impact of sheeting material on speed limit compliance. The specific goals for this research were to:

- Evaluate the short-term impacts of a red border around a Speed Limit sign and/or of different sheeting materials on speed limit compliance by conducting before and after studies at several sites,
- Evaluate the long-term impacts of a similar red border treatment,
- Compare the effectiveness of a red border around a Speed Limit sign with the effectiveness of other speed management measures using results from outside studies, and
- Make recommendations for the use of a red border around Speed Limit signs based on the results of this study.

ORGANIZATION

This thesis is divided into five chapters that document the activities completed to achieve the goals of this study. The first chapter serves as an introduction to the study by providing background information on the subject, presenting the problem statement, and stating the research objectives.

Chapter II presents the literature review undertaken to investigate: 1) the state of practice for countermeasures to speeding on high-speed rural roads; and 2) the rationale for use of the color red for the border around the Speed Limit sign.

Chapter III outlines the methodology followed in the study. In particular, study design, data collection, data reduction, and data analysis procedures are described in detail. The study design describes the experimental treatments evaluated and the study approach used.

Chapter IV presents the results of the modified border and the added border studies. Results of the modified border and the added border studies are presented as separate sections. The results of thesis studies were compared with the results of similar studies found in literature and are presented in this chapter. The final section of this chapter presents potential safety benefits of the red border treatment based on the results of the long-term study.

The fifth chapter presents the findings of the study. In closing, recommendations are made based on the findings of this study.

Finally, Appendix A presents the detailed results for each vehicle group for the modified border study and Appendix B presents the detailed results for the long-term study. Appendix C describes in detail the statistical analyses performed on the data.

CHAPTER II

STATE OF PRACTICE

The literature review investigated the state of practice of speed management methods that have been used worldwide to improve speed limit compliance on high-speed rural roads. There is an abundance of literature on the use of speed management methods. However, for the goals of this study, the following topics were investigated: methods used to improve speed-limit compliance on rural roads; the effect of automatic enforcement using speed cameras on speed-limit compliance; and the rationale for using the color red for a border around a Speed Limit sign.

METHODS TO IMPROVE SPEED LIMIT COMPLIANCE

Literature indicates that a large number of speed management methods are used in practice to achieve better speed limit compliance depending upon the type of highway. Some of these speed management methods, such as law enforcement and radar trailers, are effective only when enforcement and trailers are in place and thus are considered temporary measures. Changes to the road geometry, road surface, and Speed Limit signs are the only permanent methods used to reduce the number of speed limit violations. Of these, sign treatments and pavement markings are cost effective measures that improve speed-limit compliance by reducing inadvertent speeding occurrences. The non-enforcement techniques using signs and automated enforcement techniques using speed cameras are reviewed in this section.

Non-Enforcement Techniques

Wisconsin Traffic Operations and Safety Laboratory studied the effectiveness of overhead mounted regulatory speed signs as a speeding countermeasure at three different locations along the Milwaukee freeway system (*5*). The speed data for this study were obtained from Wisconsin Department of Transportation's automated data collector locations by using the data extracting software. Results showed little change in average operating speeds in the after period. Authors concluded there was no significant evidence to indicate any effect on the operating speeds due to the installation of overhead Speed Limit sign. Figure 2 shows a standard Speed Limit sign mounted overhead instead of mounted on the pavement shoulder.

FIGURE 2 Overhead Speed Limit Sign (*5*).

Another study by Maroney and Dewar (*6*) evaluated the effect of a speed feedback sign on speed compliance. The speed feedback sign informed drivers about the percentage of drivers not speeding the previous day. The 4-by-8-foot sign is shown in Figure 3. The percentage numbers were slots that could be changed everyday. Speed data were collected in four different phases: 1) before the sign was installed in the field; 2) while the percentage slots were blank; 3) while the percentage slots showed values; and 4) after the sign was removed. The speed data were collected 500 meters downstream of the sign location. The results of this study are shown in Table 1. The posted speed limit upstream of the sign was 70 km/hr and downstream of the sign was 50 km/hr.

TABLE 1 Results of Speed Feedback Sign

Study phase	Mean speed (Km/h)	Percent change from phase 1	>50 km/hr		>65 km/hr		>80 km/hr	
			Percent	Percent change	Percent	Percent change	Percent	Percent change
1	61.5	-	89.8	-	25.2	-	3.5	-
2	59.4	3.4	86.2	4	18.7	25.8	2.1	40
3	58.7	4	83.4	7.1	15	40.5	2.1	40
4	59.1	3.9	84.7	5.7	16.4	34.9	2.2	37.1

Source: Reference (*6*)

The results showed a statistically significant reduction in the mean speed (approximately 2.8 Km/h) and extreme speeds, while the sign showed the percentages listed in the slots. After researchers removed the sign from the study site, mean speeds were measured for a period of six weeks. During this six-week period, mean speeds increased, but did not reach previous values. The authors concluded that a speed feedback sign is an effective means of reducing operating speeds.

FIGURE 3 Speed Feedback Sign (*6*).

The Department for Transport in England uses vehicle activated signs at sites which have higher speeding and crash statistics (*7*). When an approaching driver is identified as driving above the speed limit, the sign lights up and flashes the speed limit and "Slow Down." An example of a vehicle-activated Speed Limit sign is shown in Figure 4a. Like all Speed Limit signs in the U.K., the sign has a red, circular border around the posted speed limit. Most Speed Limit signs on European highways have red borders as shown in Figure 4b which is a Speed Limit sign used in France. Figure 4c is an example of an international Speed Limit sign established at the Convention on the Unification of Road Signs held in 1931 (*8*).

a) Vehicle Activated Sign. **b) Speed Limit Sign Used in France.** **c) International Speed Limit Sign.**

FIGURE 4 Examples of Speed Limit Signs with Red Borders in Europe (*7, 8*).

On U.S. highways, the first use of a red border on a Speed Limit sign was made by Gates et al. (*9*) in a study to evaluate the traffic operational impacts of higher conspicuity sign materials. One of the experiments conducted in this study was to evaluate the effect of a 3-inch microprismatic red border around an engineering grade standard Speed Limit sign in a rural speed zone. The Speed Limit sign used for the short-term period in this study is shown in Figure 5.

FIGURE 5 Speed Limit Sign with a Microprismatic Red Border.

The results of this study indicate a statistically significant decrease in the mean speeds of passenger vehicles traveling both during the daytime and at nighttime. The percentage of vehicles exceeding the speed limit also decreased from 80 percent to 65.3 percent, a statistically significant amount. However, this study was completed only at one site. To validate these promising results, the Texas Transportation Institute (TTI) researchers conducted another study in 2004 at four more sites (*10*). This second study used the same experimental treatment used by Gates et al. (*9*), and shown in Figure 5. The basic study approach for this study was to:

- Collect speed data for the existing sign conditions,
- Change the sign to experimental sign,
- Collect speed data for the experimental sign after three weeks of installing the experimental sign, and
- Analyze the speed data for mean speeds, 85th percentile speeds and the percent exceeding speed thresholds of 55 mph, 60 mph, and 65/70 mph.

The results of this study indicated reductions of up to 2.0 mph in the mean speed and up to 3.0 mph in the 85th percentile speed. The study also revealed statistically significant reductions in the percent exceeding speed thresholds of 55 mph, 60 mph and

70 mph. The results were promising and beneficial at three of the four sites but were not conclusive enough to recommend a change in the Speed Limit sign design. Further research at additional sites and the long-term impacts of this treatment were needed to reach definitive conclusions.

Automated Enforcement Techniques

It is well known that police enforcement is an effective countermeasure to speeding. The disadvantage of this measure is that there are not enough police personnel to monitor speeding on a regular basis. Police enforcement results in temporary speed reductions only at the time enforcement is in place. To overcome this problem, automated enforcement programs using cameras at certain locations in the U.K. and some other countries have been implemented. The Department for Transport in England published a report on the results of its safety camera program (*11*). Speed and red light enforcement cameras (collectively known as safety cameras) were employed in eight pilot areas in 2000. This program was then extended to 16 more areas. The program covered 2,300 sites, which included low-speed and high-speed urban areas, low-speed and high-speed rural areas. The data in this report were analyzed by urban and rural areas and then by speed limits. Table 2 shows the results of camera sites according to the speed limit and area type.

Private partnerships were formed to recover the cost of safety camera installation, maintenance and operation of the program. A major drawback of this study is that speed data for this report were provided by the private partnerships and not collected independently.

Researchers in Norway reported similar results of speed camera use to countermeasure speeding (*12*). A before-and-after evaluation of speeds at three speed camera sites in Norway showed a reduction of 4 to 6 km/hr. The reduction was higher in sections with a speed limit of 90 km/hr than in sections with a speed limit of 70 km/hr.

TABLE 2 Results of the Safety Camera Study

Area type	Speed limit (mph)	Number of sites	Change in average speed		Change in 85th percentile speed		Percent change in vehicles exceeding the speed limit	Percent change in vehicles exceeding the speed limit by more than 15 mph
			mph	%	mph	%		
Urban	30	673	-2.4	-8	-3.4	-9	-33	-46
	40	128	-2.8	-7	-3.2	-7	-34	-47
	Total	801	-2.5	-8	-3.3	-9	-33	-46
Rural	50	45	-1.7	-4	-1	-2	-19	-12
	60	152	-2.2	-4	-2.9	-5	-23	-35
	70	21	-2.6	-4	-2.5	-3	-20	-14
	Total	218	-2.1	-4	-2.5	-4	-22	-29

Source: Reference (*11*)

RATIONALE FOR THE USE OF RED BORDER

Some of the factors affecting conspicuity of traffic control signs are angular size, the boldness of internal graphics, the luminance contrast of the sign with its immediate background, the visual complexity of the background, and the angle between the direction of sign and the direction of gaze. "The color of traffic signs and its effect on the conspicuity of the sign at night has not been studied rigorously, rather some trends have emerged as a by-product of the main purposes of the studies. The general trend is that yellow, and probably white, background signs need a higher brightness to achieve the same conspicuity as signs with background colors of red, orange, green and blue" (*13*). Research shows that the search time for colored objects is much less than that for achromatic objects, especially when the color is unique to the target object and is familiar to the observer in advance (*14*).

But the practical consequences of a colored traffic sign are completely different for the abnormal color vision population. O'Brien et al. (*15*) studied the effect of color and defective color vision as factors in conspicuity of signs and signals. The researchers observed that deuteranopes (one type of color vision defect) are less likely to notice color-coded traffic control devices than drivers with normal color vision, with the exception of yellow warning signs and blue parking signs, which have the same conspicuity for both groups of drivers. Overall, researchers observed that color in road traffic devices does contribute to their conspicuity (*15*).

It is clear from studies reviewed, that color in road traffic devices contributes to their conspicuity, and that red is the brightest, most conspicuous color except for defective color vision drivers. Most defective color vision drivers perceive red as dark yellow which is less conspicuous to them (*16*). To address these issues, Gates et al. evaluated yellow and red as two options for the border color on a Speed Limit sign (*9*). Researchers with the TTI showed two pictures of the Speed Limit sign (one with red border and the other with yellow border) as a warm-up question in seven different focus groups. All of the subjects in these focus groups believed that the color red has a stronger meaning and would stand out during the day, but were concerned about its visibility at night. Two subjects brought up the issue of drivers with abnormal color vision. In addition to the survey results, researchers in the past have found that yellow is a less conspicuous color than red. Also there is a greater chromatic separation between red and white than between yellow and white (*16*). Yellow is associated with school zones and caution, combining it with a regulatory sign would have created an inconsistency in the sign color code. Red is internationally recognized as the color that signifies stop and danger. According to the Manual on Uniform Traffic Control Devices (MUTCD), red is a color for regulatory signs; as such its use on a Speed Limit sign is consistent with the color code. Based on these factors and the results of the survey, Gates et al. decided to use a red border.

The next chapter describes the study design, data collection, data reduction and data analysis procedures.

CHAPTER III

STUDY METHODOLOGY

The primary objective of this study was to evaluate the impact of a red border around a standard Speed Limit sign on speed limit compliance. The short-term and the long-term effects on speed limit compliance were measured in reduced speed limit zones at several sites across Texas. The short-term effects were evaluated 2 to 4 weeks after, and the long-term effects were evaluated 9 to 11 months after the installation of red border sign. This objective was achieved by completing before and after studies at four sites for short-term effects, and separate before and after studies at three sites for long-term effects. This chapter provides a description of the study design, measures of effectiveness (MOE), data collection, data reduction, and data analysis procedures used to fulfill the objectives of this study.

STUDY DESIGN

The basic study design for this research was to collect and evaluate speed data at the study sites with the specified sign treatments in place. In general, at any site, one pair of signs was evaluated. Any one pair of signs included a standard Speed Limit sign and an experimental Speed Limit sign, both of which were made with the same sheeting material. At some sites, two pairs of signs (each pair of different sheeting material) were evaluated. This study used three measures of effectiveness to quantify the impact of experimental sign: the mean speed, the 85^{th} percentile speed, and the percent of vehicles exceeding specific speed thresholds. This section describes the following in detail: experimental treatments; site selection and site description; and the approach used for the modified border and the added border studies.

Experimental Treatments

The research hypothesis was that increasing the conspicuity of the Speed Limit sign would result in increased awareness of the posted speed limit and therefore improve compliance with the speed limit. This study was completed using three Speed Limit sign designs: a standard Speed Limit sign (R2-1); a standard Speed Limit sign with an added red border; and a modified Red Border Speed Limit sign. Each of these signs is shown in Figure 6. A standard Speed Limit sign is the same sign as described in the MUTCD and is shown in Figure 6a. A standard Speed Limit sign with an added red border is a standard Speed Limit sign with a three-inch red border around its perimeter. The red border was achieved by placing a sign blank of red microprismatic sheeting that was 6 inches wider and 6 inches taller behind the existing standard sign. The existing sign was typically 24 x 30 inches, thus resulting in an overall dimension of 30 x 36 inches with the red border. This is shown in Figure 6b. A modified Red Border Speed Limit sign was created by replacing the black border of the standard Speed Limit sign with a four-inch-wide red border while maintaining all other standard layout dimensions, and increasing the width and height of the sign by six inches in both directions. This sign is shown in Figure 6c. The modified border study evaluated the effects of red border two to four weeks after the treatment installation. The added border study evaluated the effects of additional red border in short-term (two to three weeks after the treatment) and in the long-term (nine to 11 months after the treatment). The following sign designs and sheeting combinations were evaluated during this study.

- High intensity standard Speed Limit sign, hereafter designated as HI_S (modified border study),
- Modified high intensity Red Border Speed Limit sign, hereafter designated as HI_R (modified border study),
- Microprismatic standard Speed Limit sign, hereafter designated as MP_S (modified border study),
- Modified microprismatic Red Border Speed Limit sign, hereafter designated as MP_R (modified border study),
- Standard Speed Limit sign with an added red border (added border study), and
- Engineering grade standard Speed Limit sign (added border study).

a) Standard Speed Limit Sign. **b) Standard Speed Limit Sign with an Added Red Border.** **c) Modified Red Border Speed Limit Sign.**

FIGURE 6 Speed Limit Signs Used for Study.

Site Selection and Site Description

Study sites were selected based on specific criteria. All of the study sites have the following common characteristics:

- A 15 mph reduction in speed limit, preferably from 70 mph to 55 mph,
- No apparent reason for the reduction in speed, i.e., roadway cross-section does not change,
- Geometry of the roadway does not change, i.e., there are no sharp horizontal or vertical curves visible that might cause drivers to slow down,
- All other features of the roadway do not change, i.e., no change in land use is visible from the cross section where the Speed Limit sign is located, and

Based on the criteria above, four sites were selected for the modified border study. The three sites used in the added border study were the same as those used in the 2004 TTI study described in Chapter II. Table 3 shows the location, direction of approach, the nearest town, number of lanes and existing sign material for each study site. This table also shows whether the site was selected for the modified border or the added border study.

TABLE 3 Sites for Modified Border and Added Border Studies

Highway designation	Direction of approach	Nearest town	Number of lanes (total)	Existing sign material	Study
SH 7	Eastbound	Marlin	2	HI	Modified border
SH 14	Southbound	Wortham	2	EG	Modified border
FM 39	Northbound	Normangee	2	EG	Modified border
US 79	Northbound	Oakwood	2	EG	Modified border
SH 21	Westbound	Caldwell	4	EG	Added border
SH 36	Northbound	Milano	2	EG	Added border
FM 60	Eastbound	Snook	2	EG	Added border

Modified Border Study Approach

The modified border study evaluated the impact of a modified border sign two to four weeks after the treatment installation. Two or four treatments were evaluated at any given site to fulfill the goals of this study. Treatments were implemented at the same location one after the other. The time gap between treatments was approximately four weeks. Data were collected three to four weeks after placement of the sign in the field. This time gap between sign installation and data collection helps to minimize the novelty effects of the treatment. After the data collection, the previous treatment was replaced by the next treatment. Table 4 shows the sign and sheeting combinations for which data were collected and evaluated at all the sites. To understand and isolate the impact of sign design and sheeting materials, treatments were analyzed in pairs. This also makes it possible to present the results in a before and after study fashion. Table 5 provides site location information about the treatment pairs investigated, and Table 6 shows the schedule for data collection at different sites. The data were collected during weekdays and preferably on the same weekday to capture consistency in traffic patterns, which helped to reduce bias.

TABLE 4 Signs Evaluated during Modified Border Study at Sites

Sign	Site			
	SH 7	**SH 14**	**FM 39**	**US 79**
HI_S	x	x	x	-
HI_R	x	x	x	-
MP_S	-	x	-	x
MP_R	x	x	-	x

TABLE 5 Treatment Pairs Evaluated during Modified Border Study at Sites

Treatment Pair	Site			
	SH 7	**SH 14**	**FM 39**	**US 79**
HI_S - HI_R	x	x	x	-
MP_S - MP_R	-	x	-	x
HI_R - MP_R	x	x	-	-

TABLE 6 Data Collection Schedule for Modified Border Study

Test Sites	Study on Sign			
	HI_S	**HI_R**	**MP_S**	**MP_R**
SH 7	12/1-3/05 Wed - Fri	5/4 - 6/05 Wed - Fri	x x	6/20 - 22/05 Mon - Wed
SH 14	3/23- 25/05 Wed - Fri	5/3 - 5/05 Tue - Thur	7/13 - 15/05 Wed - Fri	6/22- 24/05 Wed - Fri
FM 39	5/10 – 12/05 Tue - Thur	6/6 - 8/05 Mon - Wed	x x	x x
US 79	x x	x x	5/11 - 13/05 Wed - Fri	6/8 - 10/05 Wed - Fri

Added Border Study Approach

As a continuation of the 2004 TTI study (*10*), the researcher evaluated the long-term impacts of a Speed Limit sign that has an additional red border around its perimeter. The short-term findings and the study approach of this research effort are described in Chapter II. The researcher used three of the four study sites from the aforementioned TTI study. The before data for this study were collected on the existing engineering grade standard sign that is shown in Figure 6a. The red border was then installed and the resulting sign is shown in Figure 6b. The short-term data were collected three weeks after the installation of the red border on the existing sign. The standard Speed Limit sign with an added red border was left installed for these sites. The long-term data on this sign were collected nine to 11 months after the addition of the red border as an activity of the thesis study. The data collection schedule for this study is shown in Table 7. The before, the short-term, and the long-term data were then analyzed to quantify the long-term effects of the red border treatment.

TABLE 7 Data Collection Schedule for Added Border Study

Test Sites	Before dates	Short-term dates	Long-term dates
SH 21	6/17 - 6/18/04	7/8 - 7/9/04	4/7 - 4/8/05
	Thur – Fri	Thur – Fri	Thur – Fri
FM 60	7/1 - 7/3/04	7/16 - 7/18/04	4/27 - 4/29/05
	Thur – Sat	Fri – Sun	Wed – Fri
SH 36	6/28 - 6/30/04	7/20 - 7/22/04	6/28 - 6/30/05
	Mon – Wed	Tue – Thur	Tue – Thur

DATA COLLECTION

A series of portable automated vehicle classifiers connected to a pair of pneumatic tubes placed on the pavement were used and output from these classifiers provided vehicle speeds, time stamps, and FHWA vehicle types. Data collection was restricted to weekdays, and data recorded when it was raining were not used for analysis. Tables 6 and 7 show the data collection schedule at each site for the different sign treatments evaluated.

Modified Border Study

For the modified border study, the following data collection procedure was used. Speeds and time stamps were measured using a series of three automated vehicle classifiers connected to a pair of pneumatic tubes placed on the pavement. Figure 7 shows the data collection layout for this study. The location of each classifier was decided based on the following factors:

- Control Point – This classifier was located upstream of the treatment location so that the Speed Limit sign was not visible. Speeds recorded at this point served as control data to determine if traveling speeds for each treatment were comparable. This point was located approximately half a mile upstream of the Speed Limit sign.
- Legibility Point – This classifier was located approximately 250 feet upstream of the Speed Limit sign. At this point, the Speed Limit sign is clearly visible and legible.
- Downstream Point – This classifier was located approximately 500 feet downstream of the Speed Limit sign. Speeds at this point quantified the impact of the treatment.

During review of the 2004 TTI study (*10*), the researcher realized that collecting data at the above mentioned three points will be sufficient for evaluation of the treatment. Considering the time and resource requirements of collecting and reducing data at two additional points, it was decided to collect data only at the three important points.

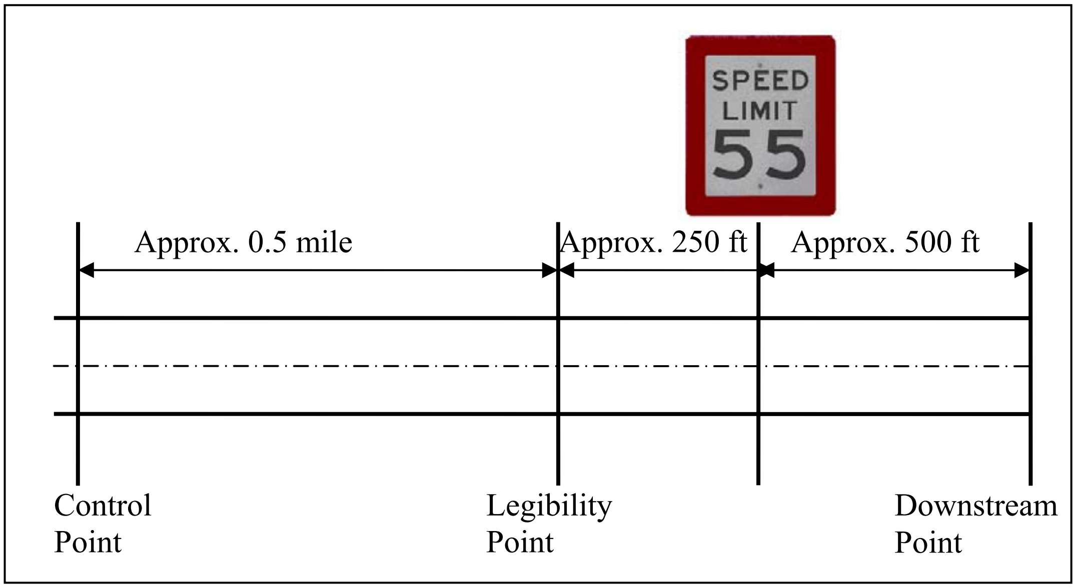

FIGURE 7 Data Collection Layout for Modified Border Study.

Added Border Study

To maintain consistency, the added border study used the same data collection procedure as the 2004 TTI study (*10*). In this procedure, speeds and vehicle types were measured using a series of five automated vehicle classifiers connected to a pair of pneumatic tubes placed on the pavement. Figure 8 shows a schematic of the data collection layout for this study. The location of each classifier was based on following factors:

- Control Point – This classifier was located upstream of the treatment location so that the Speed Limit sign was not visible. Speeds recorded at this point served as control data to determine if traveling speeds for each treatment were comparable. This point was located approximately 0.6 to 0.7 miles upstream of the study Speed Limit sign.
- Threshold Point – This classifier was located at approximately the legibility threshold distance. The legibility threshold distance is the approximate distance at which the motorist can read the sign. For this study, an approximate distance of 600 feet was used as a threshold distance.

- Legibility Point – This point was located midway between the threshold point and the Speed Limit sign. At this point, Speed Limit sign is clearly visible and legible.
- Sign Point – This point was located at the Speed Limit sign location.
- Downstream Point – This classifier was located approximately 300 feet downstream of the Speed Limit sign. Speeds at this point quantified the impact of the treatment.

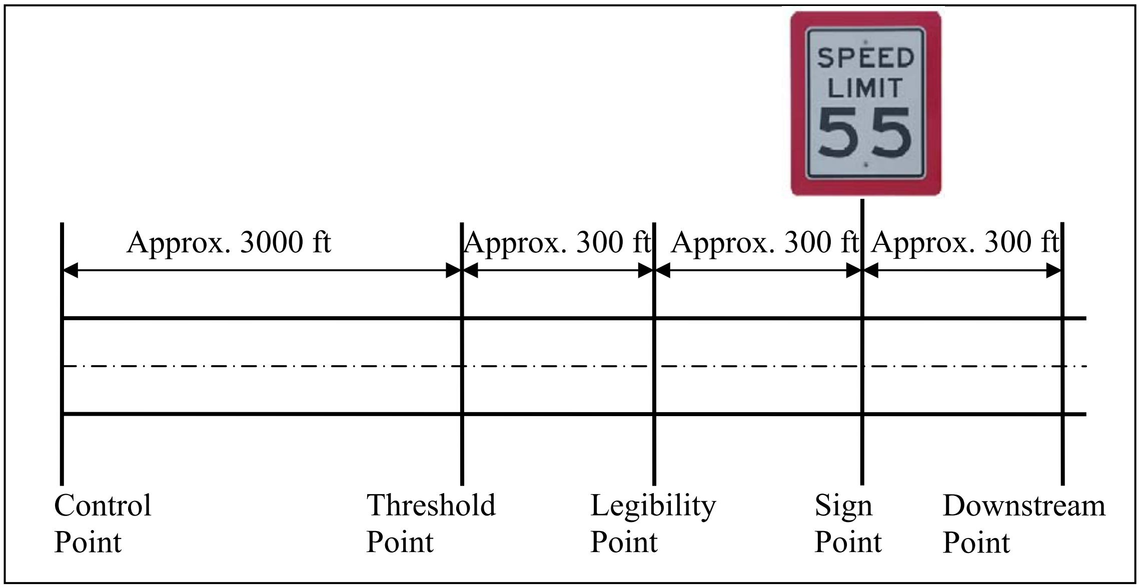

FIGURE 8 Data Collection Layout for Added Border Study.

DATA REDUCTION

The raw data collected at the project sites were screened to create a random and unbiased sample of speeds for free-flowing, uninhibited passenger and heavy vehicles. The objective of the data reduction process was to isolate the effect of the red border and/or sign sheeting conspicuity on driver behavior by identifying and eliminating potentially biased data. Therefore, anomalous vehicles were identified and excluded from the final data set during this process. Anomalous vehicles for this study were defined by the following conditions:

- Non free-flowing i.e. with headways more than 5 seconds,
- Motorcycles,
- Uninhibited upstream speed was deemed excessively slow (e.g., speed is 25 mph or more under the speed limit). For the upstream points, speed limit is 70 mph and for the Speed Limit sign point and the downstream point, speed limit is 55 mph. This is to eliminate any vehicles that have just entered the roadway from a driveway or are in the process of exiting, and
- Vehicles traveling at an unreasonably high speed. For this study, all vehicles traveling above 95 mph were deemed as traveling at unreasonable speeds that will not be affected by the presence or design of a Speed Limit sign.

Data Reduction Procedure at Each Counter Location

Raw data such as that shown in Table 8 were imported in a spreadsheet for each counter location and reduced as described below.

- Delete all the bad hits (the internal control system of the classifiers identified good hits from bad hits and showed in status column of the output).
- Delete all vehicles traveling at 25 mph or more under the speed limit.
- Delete all vehicles traveling at more than 95 mph.
- Delete all vehicles traveling at headways more than 5 seconds. This headway size is based on the free flow headways adopted by other researchers for similar studies (*10, 17*).
- Classify as passenger vehicles and heavy vehicles. Vehicles with FHWA vehicle class 2 (passenger cars with 1- or 2-axle trailers) and class 3 (2-axle, 4-tire single units, pickup or van with 1- or 2-axle trailers) will be

regarded as passenger vehicles and of vehicle class 4 (buses) and higher will be grouped together as heavy vehicles.

TABLE 8 Example of Raw Counter Data

Date	Time	Status	FHWA Vehicle Classification	Speed (mph)
19/07/04	4:51:14	Good	2	55
19/07/04	4:56:16	Good	2	34
19/07/04	4:58:44	Good	5	70
19/07/04	4:59:02	Bad	2	68
19/07/04	4:59:06	Good	2	66

Tracking of Vehicle Profiles

After data were reduced at each counter position, and vehicle profiles were tracked starting from the control point to the downstream point. The objective of this exercise was to isolate vehicles traveling through the entire length of the study section. Vehicle profiles between any two counter locations were established using the following procedure:

- Based on the speeds at point A and point B, and the distance between two points, calculate expected travel time.
- Calculate the actual travel time from difference in time stamps at both locations.
- If the distance between A and B is less than or equal to 750 feet and the absolute difference between the expected and the actual travel time is less than or equal to 2 seconds, the vehicle at point A and B are assumed to be

the same. However a difference of up to 5 seconds will be considered acceptable when the distance between the two points is 2500 feet or more.

- Obtain sunrise and sunset times for data collection days from the webpage of the U.S. Naval Observatory (*18*)
- Group data as day data and night data based on sunrise and sunset times. For this study, data collected after sunrise and before sunset is considered day data and data collected after sunset and before sunrise is considered night data.

DATA ANALYSIS

The data for each site were divided into day and night data, and each analyzed separately. Both the day and the night data were further grouped as passenger vehicles, heavy vehicles, and all vehicles data. Statistical tests were performed for three measures of effectiveness to assess the impact of the red border treatment and higher conspicuity materials. Additional measures of effectiveness, such as 10 mph pace and standard deviation, also were calculated and compared for the before and after conditions for different treatment pairs.

Mean Speeds

The General Linear Model (GLM) Uni-variate procedure was used to compute average speeds and to test for differences in average speeds for different sets of data collected at a site. This procedure provides regression analysis and analysis of variance for one dependent variable (speed in this case) by one or more factors and/or variables. The factor variables divide the population into groups, e.g., passenger vehicles, heavy vehicles. Sign design and/or sheeting material was used as an independent variable. Least significant differences (LSD) or Tamhane’s T2 procedure was used to test for differences in mean speeds for various sign treatments at a site. LSD is used where variances are not significantly different, and Tamhane’s T2 is used where variances between the samples are significantly different. The statistical software SPSS was used to run GLM procedure. In some cases, Q-Q plots indicated that data might not be normally distributed. This doubt about the normality of the sample meant ANOVA might not give correct results for significance between various treatments. To remove this doubt, 95 percent confidence intervals were developed for each treatment data set using the bootstrap procedure. These confidence intervals were then compared for any two sign conditions to establish statistically significant values between the two conditions compared. The bootstrap procedure is described in detail in Appendix C. The values found significant by both the ANOVA and the Bootstrap method are listed as significant in the tabulated results in Chapter IV, and in Appendices A and B.

85th Percentile Speeds

The excel spreadsheet was used to compute 85th percentile speeds for each data set. Since 85th percentile speeds are used to set speed limits and are considered an important measure of driver behavior, it was hypothesized that differences in 85th percentile speeds for the before and after conditions prove a good measure for evaluating the effectiveness of various treatments. Using statistical analysis software (SAS), the Bootstrap procedure was again used to test for statistically significant differences between 85th percentile speeds for the various data sets.

Percent of Vehicles Exceeding a Specified Speed Threshold

The percent exceeding 55 mph and 70 mph for the daytime and 55 mph and 65 mph for the nighttime vehicles were computed using a spreadsheet. The difference in the percentage of vehicles exceeding specific speed thresholds provides the change in upper extremities of the data. This measure provides insight for variations in the mean speeds in the before and the after conditions. For example, a decrease in the average speed for the after condition and a decrease in the percentage of vehicles exceeding a threshold speed (also for the after condition) would mean faster vehicles decelerated. On the other hand, a decrease in the average speed in the after condition and an increase in the percent vehicles exceeding a specific speed threshold (for the after condition) would mean slower vehicles decelerated more. A ‘Z’ test for binomial proportions was performed to test for statistical significance in the percent of vehicles exceeding a specific speed threshold for any two sign treatments.

The next chapter shows the modified border and the added border study results for all vehicles group. It also presents a comparison of the present study results with other similar studies found in literature. Finally, potential safety benefits of the red border treatment are estimated using graphical models by Nilson (*3*).

CHAPTER IV

RESULTS

The researcher conducted a study at seven sites to determine if placing a red border around a Speed Limit sign will improve driver compliance of the speed limit. At four of the sites (SH 7, SH 14, FM 39, and US 79), the study evaluated the short-term effects on compliance improvement with a modified red border sign compared to a standard sign. At the other three sites (SH 21, FM 60, and SH 36), the researcher evaluated the short-term and the long-term effects on compliance of adding a red border conspicuity enhancement to a standard sign. Automatic classifiers with pneumatic tubes recorded speed data at various points upstream and downstream of the Speed Limit sign. Comparison of the data collected at the downstream point indicated the impact of the treatment. The researcher analyzed the data to compute the mean speeds, the 85th percentile speeds, and the percent of vehicles exceeding specific speed thresholds for the passenger vehicles, heavy vehicles and for all vehicles combined. Appendix A presents the detailed results for the modified border study. Appendix B presents the detailed results for the added border (conspicuity enhancement) study.

The data analysis indicated a statistically significant difference in control point speeds between different study conditions for most cases. Due to this difference in control point speeds, direct comparison of downstream speeds to measure the effectiveness of the red border treatments was not meaningful. Instead, the researcher compared the change from the control point to the downstream point to evaluate the effectiveness of treatments.

This chapter presents the results of the data collected and analyzed at seven study sites. The first part of the chapter describes the various measures of effectiveness used to evaluate the treatments effects. These include changes in mean speeds, deviations of speed from speed limit, and the percent exceeding specified speed thresholds. The second part of the chapter presents the results for the modified border study that evaluated the effect of replacing the thin black border of the Speed Limit sign with a wide red border. The third part of the chapter presents the results for the long-term study, which used a standard Speed Limit sign with an additional red border around its perimeter. This is followed by a comparison of the results of the modified border and the long-term studies with other similar studies found in literature. The last part of this chapter presents the potential safety benefits of a red border treatment based on reductions in speeds.

MEASURES OF EFFECTIVENESS

The researcher hypothesized that the control point speeds have a direct effect on the downstream speeds, i.e., vehicles traveling at higher speeds at the control point will also be traveling at higher speeds at the downstream point. As such, to account for the variations in the control point speeds for various study conditions, the downstream speeds were normalized with respect to the control point speeds. This section describes the normalized measures of effectiveness used to quantify the effect of red border treatment:

Reduction in Mean Speeds from Control Point to Downstream Point

The reduction in the mean speed (Red_{mean}) from the control point to the downstream point is calculated using Equation 1 for each study condition. The control point speed limit is 70 mph and the downstream speed limit is 55 mph.

$$Red_{mean} = \text{Mean Speed}_{control} - \text{Mean Speed}_{downstream} \quad (1)$$

The reduction in speed from the control point to the downstream point indicates the effect of the Speed Limit sign. As such, a higher speed reduction for the red border treatment sign compared to the standard sign indicates a beneficial effect of the red border treatment. The bootstrap procedure was used to determine the statistically significant reductions.

Reduction in Percent Exceeding a Specific Speed Threshold

The researcher computed the percent exceeding the upstream speed limit (70 mph day/ 65 mph night) and also exceeding the downstream speed limit (55 mph day and night) for the control point and the downstream point speed data. The Z test of binomial proportions determined the statistical significance between the various study conditions. The difference (Δ) between the control point and the downstream point percentages, as computed from equations 2, 3 and 4, indicates the Speed Limit sign effect.

$$\Delta_{70} = \text{Percent Exceeding}_{70/CP} - \text{Percent Exceeding}_{70/DS} \quad (2)$$

$$\Delta_{65} = \text{Percent Exceeding}_{65/CP} - \text{Percent Exceeding}_{65/DS} \quad (3)$$

$$\Delta_{55} = \text{Percent Exceeding}_{55/CP} - \text{Percent Exceeding}_{55/DS} \quad (4)$$

A greater value of Δ for the red border treatment condition compared to the standard sign condition indicates that a greater percent of drivers noticed the Speed Limit sign after the treatment. The researcher did not perform any statistical tests to determine significant differences between Δ values for various study conditions.

Deviation of Speeds from the Speed Limit

Deviation from the speed limit consisted of two parameters: the mean deviation from the speed limit (Dev_{mean}), and the 85^{th} percentile deviation from the speed limit (Dev_{85th}). Equation 5 and 6 present mathematical forms for deviation from speed limit.

$$Dev_{mean} = \text{Mean Speed}_{downstream} - \text{Speed Limit (55 mph)} \quad (5)$$

$$Dev_{85th} = 85^{th}\ \text{Speed}_{downstream} - \text{Speed Limit (55 mph)} \quad (6)$$

A smaller value of Dev_{mean} and Dev_{85th} for the red border sign compared to the standard sign signifies improved compliance. The Bootstrap procedure was once again used to determine the statistically significant deviations.

RESULTS FOR THE MODIFIED BORDER STUDY

The researcher conducted a modified border study at four sites to evaluate the short-term effect of the modified Red Border Speed Limit sign, 3 to 4 weeks after its installation in the field. In addition to evaluating the effect of the red border treatment, this study also evaluated the effect of using a higher conspicuity sheeting material. Based on the treatment combinations studied, three treatment pairs shown in Table 5 help in meeting the objectives of this modified border study. The two treatment pairs (HI_S versus HI_R and MP_S versus MP_R) determine the effect of modifying the sign design;

i.e., replacing the thin black border of standard sign with a wide red border. The third treatment pair (HI_R versus MP_R) determines the effect of using a higher conspicuity sheeting material. This section presents the results for each treatment pair.

Results for Treatment Pair HI_S versus HI_R

The researcher evaluated the effect of using a high intensity modified red border sign versus a high intensity standard sign at three sites (FM 39, SH 7, and SH 14). The time gap between the modified red border sign installation and data collection was four weeks at FM 39, five weeks at SH 7, and four weeks at SH 14. Table 9 shows the results for this treatment pair for all vehicles group both for the daytime and the nighttime. The results indicate that the high intensity modified red border sign demonstrated larger reductions in the mean speed from the control point to the downstream point compared to the reductions for the high intensity standard sign. For the daytime vehicles, on an average the reductions were 4.0 mph more for the red border sign. The average deviation of the mean speed from the speed limit also decreased by 2.2 mph for the red border sign compared to the standard sign for the daytime vehicles. This decrease in the deviation signifies better speed limit compliance with the red border sign in place. The reduction in the percent of vehicles exceeding the 55 mph speed limit during the daytime was 11.7 percent more for the red border sign compared to the standard sign. This reduction means that decreases in the mean speed and in the deviations are due to the slowing down of the faster vehicles.

The high intensity modified Red Border Speed Limit sign proved beneficial at all three sites during the daytime. The benefits seen during the daytime continued for the nighttime at two of the three sites studied. At the third site, the red border sign proved beneficial only for the passenger vehicles (not shown in Table 9). Overall, the benefits were greater for passenger vehicles compared to those for heavy vehicles (results for separate vehicle groups are presented in Appendix A) and more so during the daytime than during the nighttime. For this study, the daytime was from sunrise to sunset and the nighttime was from sunset to sunrise.

TABLE 9 Modified Border Study Results for Treatment Pair HI_S versus HI_R

Measure of effectiveness	Site	Daytime			Nighttime		
		HI_S	HI_R	Treatment Impact†	HI_S	HI_R	Treatment Impact†
Reduction in mean speed from CP to DS [Red_{mean}, Eqn. 1]	FM 39	6.0	10.1*	-4.1	6.3	9.9*	-3.6
	SH 7	5.3	10.8*	-5.5	6.1	10.5*	-4.4
	SH 14	8.4	10.8*	-2.4	8.5	9.5*	-1.0
Average reduction in mean speed (mph)		6.6	10.6	-4.0	7.0	10.0	-3.0
Reduction in percent exceeding 70/65 mph from CP to DS point [Δ70 /Δ65, Eqn. 2 /3]	FM 39	31.1	42.2	-11.1	45.7	55.2	-9.5
	SH 7	19.7	50.0	-30.3	31.0	57.7	-26.7
	SH 14	21.0	29.6	-8.6	32.6	36.9	-4.3
Average reduction (%)		23.9	40.6	-16.7	36.4	49.9	-13.5
Reduction in percent exceeding 55 mph from CP to DS point [Δ_{55}, Eqn. 4]	FM 39	7.2	24	-16.8	10.7	32.1	-21.4
	SH 7	13.2	22.2	-9.0	26.7	34.8	-8.1
	SH 14	31.2	40.6	-9.4	51.1	52.0	-0.9
Average reduction (%)		17.2	28.9	-11.7	29.5	39.6	-10.1
Deviation of mean speed from speed limit at DS point [Dev_{mean}, Eqn. 5]	FM 39	8.5	4.7*	3.8	7.1	2.8*	4.3
	SH 7	6.6	5.0*	1.6	3.4	2.8	0.6
	SH 14	2.8*	1.6	1.2	0.1	0.0	0.1
Average deviation of mean speed from speed limit (mph)		6.0	3.8	2.2	3.5	1.9	1.6
Deviation of 85th percentile speed from speed limit at DS point [Dev_{85th}, Eqn. 6]	FM 39	15.8	11.5*	4.3	13.6	9.6*	4.0
	SH 7	13.6	12.3*	1.3	9.9	9.9	0.0
	SH 14	8.8*	7.7	1.1	5.9	6.2	-0.3
Average deviation of 85th percentile speed from speed limit (mph)		12.7	10.5	2.2	9.8	8.6	1.2

* indicates value is statistically significantly different at 95% confidence level compared to the corresponding standard sign value.

† Red border treatment is beneficial for positive values of Dev_{mean} and Dev_{85th} and negative values of Red_{mean}, Δ70 /Δ65, and Δ_{55}.

Results for Treatment Pair MP_S versus MP_R

The effect of using a microprismatic modified red border sign in place of a microprismatic standard sign was evaluated at three sites (US 79, SH 7, and SH 14). The time gap between MP_R sign installation and data collection was 4 weeks at US 79 and 2 weeks at SH 7 and SH 14. Table 10 shows the results for the treatment pair MP_S versus MP_R. Table 10 indicates that the red border treatment provided some benefits at US 79. However, the benefits are small compared to those found for the HI_R sign. At SH 14, the microprismatic modified red border sign showed no beneficial effects compared to the microprismatic standard sign. At SH 7, due to equipment problems, no data were available for the microprismatic standard sign. As such no comparison for the treatment pair MP_S versus MP_R could be made for SH 7. These results for the treatment pair MP_S versus MP_R are unexpected. For US 79, different site characteristics might have caused a lower effect. However at SH 14, the results are confounding and can not be fully explained.

TABLE 10 Modified Border Study Results for Treatment Pair MP_S versus MP_R

Measure of effectiveness	Site	Daytime			Nighttime		
		MP_S	MP_R	Treatment Impact†	MP_S	MP_R	Treatment Impact†
Reduction in mean speed from CP to DS [Red_{mean}, Eqn. 1]	SH 14	9.7	6.9*	2.8	8.7	6.6*	2.1
	US 79	7.9	8.3*	-0.4	7.0	6.9	0.1
Average reduction in mean speed (mph)		8.8	7.6	1.2	7.8	6.8	1.0
Reduction in percent exceeding 70/65 mph from CP to DS point [Δ70 /Δ65, Eqn. 2/3]	SH 14	34.9	32.2	2.7	43	43.4	-0.4
	US 79	23.5	6.5	17.0	34.4	15.9	18.5
Average reduction (%)		29.2	19.4	9.8	38.7	29.7	9.0
Reduction in percent exceeding 55 mph from CP to DS point [Δ_{55}, Eqn. 4]	SH 14	15.7	16.2	-0.5	18.0	21.4	-3.4
	US 79	41.3	35.6	5.7	48.4	49.3	-0.9
Average reduction (%)		28.5	25.9	2.6	33.2	35.3	-2.1
Deviation of mean speed from speed limit at DS point [Dev_{mean}, Eqn. 5]	SH 14	1.6	2.1	-0.5	0.1	-0.2	0.3
	US 79	6.1	5.2*	0.9	6.1	5.0*	1.1
Average deviation of mean speed from speed limit (mph)		3.9	3.7	0.2	3.1	2.4	0.7
Deviation of 85th percentile speed from speed limit at DS point [Dev_{85th}, Eqn. 6]	SH 14	8.1	8.1	0.0	4.8	4.9	-0.1
	US 79	12.8	11.5*	1.3	13.2	11.5*	1.7
Average deviation of 85th percentile speed from speed limit (mph)		10.5	9.8	0.7	9.0	8.2	0.8

* indicates value is statistically significantly different at 95% confidence level compared to the corresponding standard sign value.
† Red border treatment is beneficial for positive values of Dev_{mean} and Dev_{85th} and negative values of Red_{mean}, Δ70 /Δ65, and Δ_{55}.

Results for Treatment Pair HI_R versus MP_R

At SH 7 and SH 14, data were collected for two pairs of signs (HI_S versus HI_R and MP_S versus MP_R). The researcher hypothesized that both the HI_R and the MP_R signs would show similar results during the daytime. However during the nighttime, the microprismatic sign will prove more effective. Table 11 shows the results for the treatment pair of HI_R versus MP_R signs. The results in Table 11 indicate that the microprismatic modified red border sign proved less effective than its high intensity counterpart at both the sites and for both lighting conditions. These results are inconsistent with expectations. Some of the factors that might have caused the results to be inconsistent with expectations are presented in the discussion section.

Summary of Modified Border Study Results

Table 12 presents the summary table for all the treatments evaluated in the modified border study. Figures 9 and 10 show the reductions in mean speeds from the control point to the downstream point at each site for the daytime and the nighttime vehicles respectively. These figures and the average reduction values in Table 12 indicate that during the daytime, both of the modified red border signs were beneficial compared to the high intensity standard sign. However during the nighttime, only the high intensity red border sign was beneficial compared to the standard sign.

TABLE 11 Modified Border Study Results for Treatment Pair HI_R versus MP_R

Measure of effectiveness	Site	Daytime			Nighttime		
		HI_R	MP_R	Treatment Impact†	HI_R	MP_R	Treatment Impact†
Reduction in mean speed from CP to DS [Red_{mean}, Eqn. 1]	SH 7	10.8	6.9*	3.9	10.5	7.4*	3.1
	SH 14	10.8	6.9*	3.9	9.5	6.6*	2.9
Average reduction in mean speed (mph)		10.8	6.9	3.9	10.0	7.0	3.0
Reduction in percent exceeding 70/65 mph from CP to DS point [Δ70 /Δ65, Eqn. 2 /3]	SH 7	50.0	29.0	21.0	57.7	40.9	16.8
	SH 14	29.6	32.2	-2.6	36.9	43.4	-6.5
Average reduction (%)		39.8	30.6	9.2	47.3	42.1	5.2
Reduction in percent exceeding 55 mph from CP to DS point [Δ_{55}, Eqn. 4]	SH 7	22.2	20.5	1.7	34.8	28.7	-6.1
	SH 14	40.6	16.2	24.4	52.0	21.4	30.6
Average reduction (%)		31.4	18.4	13.0	43.4	25.1	18.3
Deviation of mean speed from speed limit at DS point [Dev_{mean}, Eqn. 5]	SH 7	5.0	5.9	-0.9	2.8	3.1	-0.3
	SH 14	1.6	4.0	-2.4	0.0	-0.2	0.2
Average deviation of mean speed from speed limit (mph)		3.3	4.4	-1.1	1.4	1.5	-0.1
Deviation of 85th percentile speed from speed limit at DS point [Dev_{85th}, Eqn. 6]	SH 7	12.3	13.2	-0.9	9.9	10.3	-0.4
	SH 14	7.7	8.8	-1.1	6.2	4.9	1.3
Average deviation of 85th percentile speed from speed limit (mph)		10.0	11.0	-1.0	8.1	7.6	0.5

* indicates value is statistically significantly different at 95% confidence level compared to the corresponding standard sign value.

† Red border treatment is beneficial for positive values of Dev_{mean} and Dev_{85th} and negative values of Red_{mean}, Δ70 /Δ65, and Δ_{55}.

TABLE 12 Summary of Modified Border Study Results for All Vehicles

Measure of effectiveness	Daytime				Nighttime			
	HI_S	HI_R	MP_S	MP_R	HI_S	HI_R	MP_S	MP_R
Average Reduction $_{mean}$	6.6	10.6	8.8	7.4	7.0	10.0	7.8	7.0
Average Δ_{70} / Δ_{65}	23.9	40.6	29.2	22.6	36.4	49.9	38.7	33.4
Average Δ_{55}	17.2	28.9	28.5	24.1	29.5	39.6	33.2	33.1
Average Dev $_{mean}$	6.0	3.8	3.9	4.4	3.5	1.9	3.1	2.6
Average Dev $_{85th}$	12.7	10.5	10.5	10.9	9.8	8.6	9.0	8.9

Red border treatment is beneficial for smaller positive values of Dev_{mean} and Dev_{85th} and larger negative values of Red_{mean}, $\Delta 70$ /$\Delta 65$, and Δ_{55}.

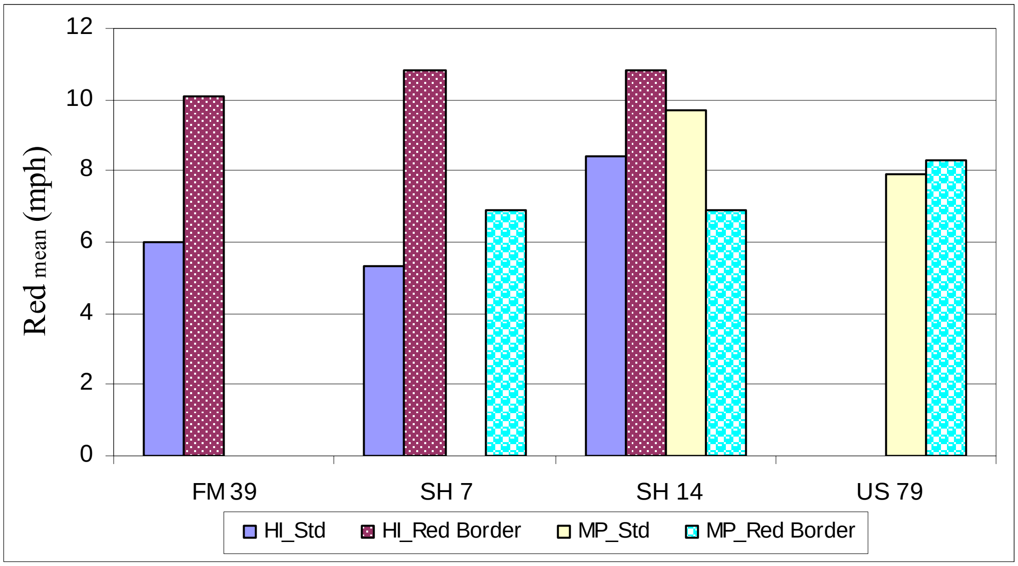

FIGURE 9 Reduction in Mean Speeds from CP to DS Point, Daytime Results for Modified Border Study.

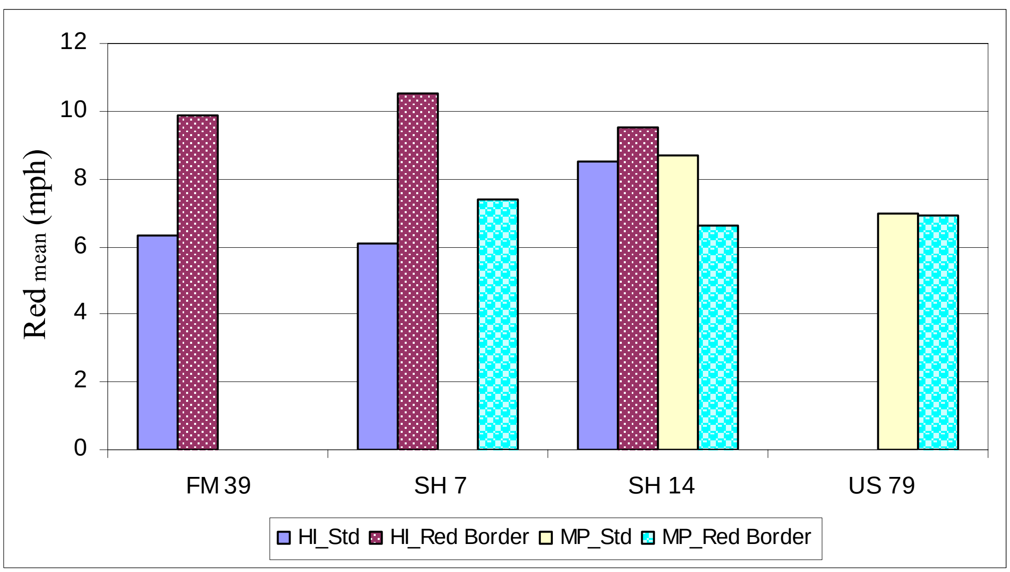

FIGURE 10 Reduction in Mean Speeds from CP to DS Point, Nighttime Results for Modified Border Study.

Figures 11 and 12 show the deviation of mean speeds from the speed limit at the downstream point for the daytime and nighttime vehicles respectively. These figures indicate that the high intensity modified red border sign was beneficial both during the daytime and the nighttime. Average Dev $_{mean}$ values, in Table 12 and in figures 11 and 12, indicate that microprismatic red border sign was beneficial only during the nighttime compared to standard signs. The mean speeds are much closer to the speed limit at all sites for the high intensity red border signs. A comparison of figures 11 and 12 indicate that nighttime results are better than those during the daytime. Another noticeable thing from these figures is that the mean speeds at SH 14 were much closer to the speed limit for the existing standard sign. As such at this site, there was little opportunity for improvement in the mean speeds.

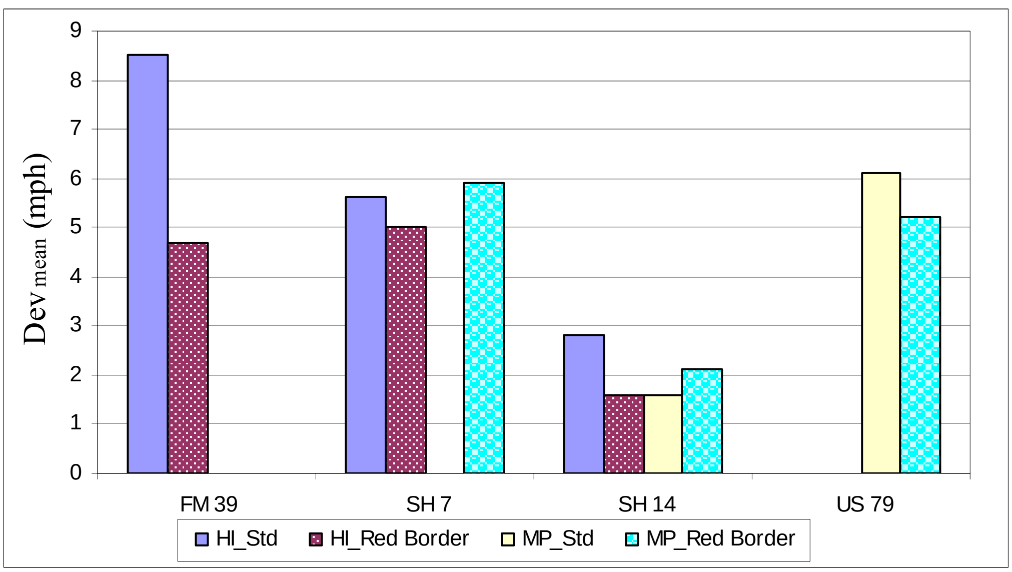

FIGURE 11 Deviation of Mean Speed from Speed Limit, Daytime Results for Modified Border Study.

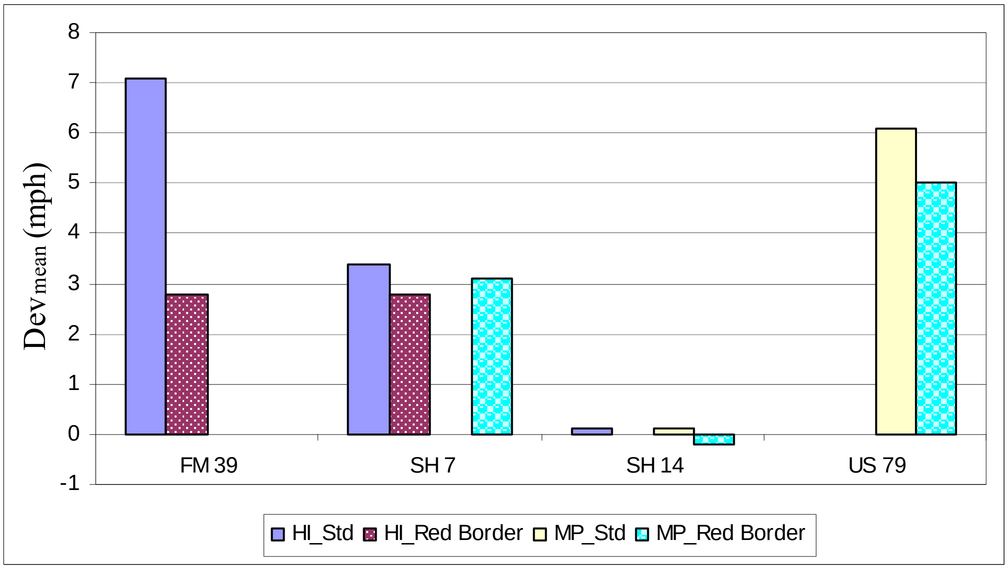

FIGURE 12 Deviation of Mean Speed from Speed Limit, Nighttime Results for Modified Border Study.

Figures 13 and 14 show the deviation of 85^{th} percentile speeds from the speed limit at the downstream point for daytime and nighttime vehicles respectively. These Figures indicate that red border sign proved beneficial at two sites (FM 39 and US 79) and for both lighting conditions. At the other two sites (SH 7 and SH 14), during the daytime, the decrease in deviations for the red border sign compared to the standard sign was not significant. During the nighttime, for these two sites, there was no change in 85^{th} percentile speeds. Table 12 indicates, deviations of 85^{th} percentile speeds from the speed limit were approximately same for the two red border signs, however were smaller compared to the high intensity standard sign.

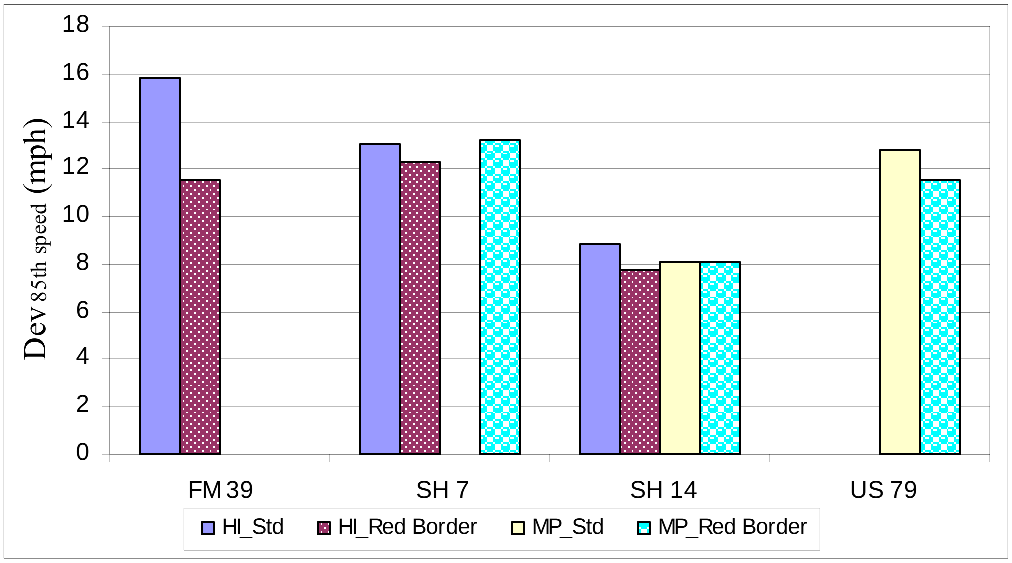

FIGURE 13 Deviation of 85th Percentile Speed from Speed Limit, Daytime Results for Modified Border Study.

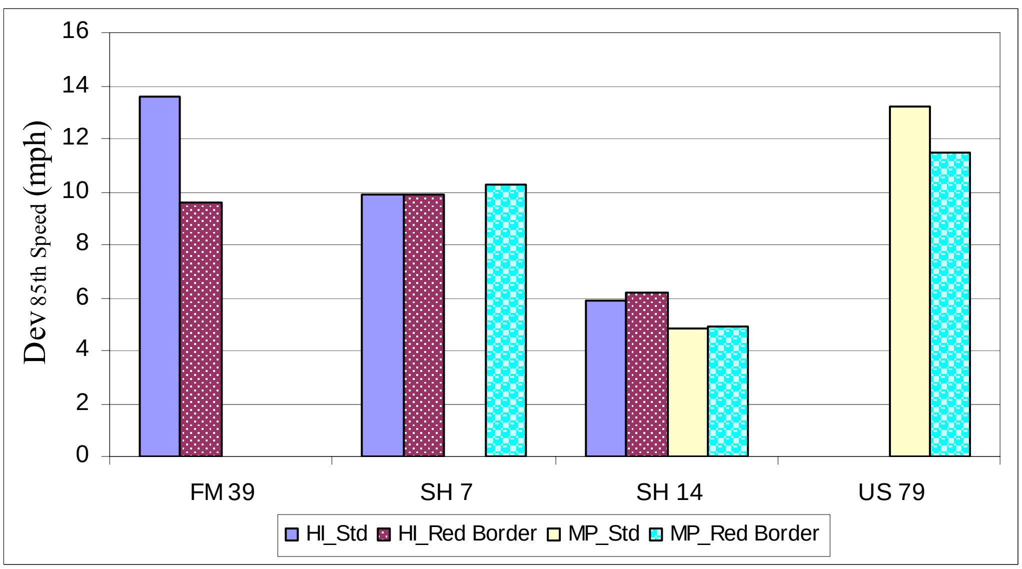

FIGURE 14 Deviation of 85th Percentile Speed from Speed Limit, Nighttime Results for Modified Border Study.

Figures 15 and 16 show the reduction in percent of vehicles that are exceeding the downstream speed limit from the control point to the downstream point during the daytime and nighttime respectively. Ignoring the results for SH 14, since there was not much opportunity for improvement at this site as discussed previously, it is clear from Figure 15 and 16 that red border signs proved beneficial in reducing the percent of vehicles exceeding the speed limit at the downstream point compared to the standard signs.

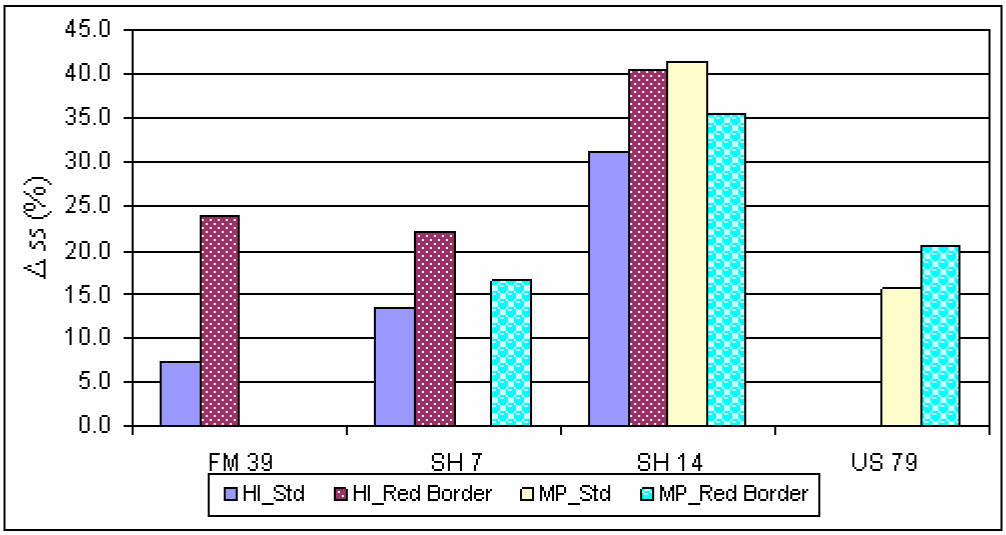

FIGURE 15 Reduction in Percent Exceeding 55 mph from CP to DS Point, Daytime Results for Modified Border Study.

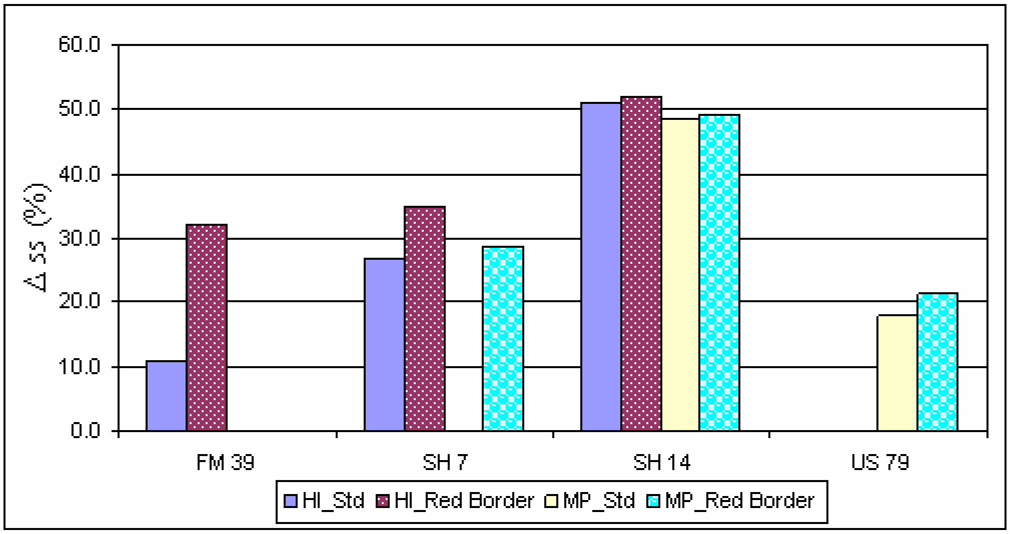

FIGURE 16 Reduction in Percent Exceeding 55 mph from CP to DS Point, Nighttime Results for Modified Border Study.

Table 13 presents the overall performance of the standard Speed Limit sign versus the modified Red Border Speed Limit sign averaged over all sites and for both sheeting materials. Table 13 indicates that for every measure of effectiveness, the modified red border sign proved beneficial in improving the speed limit compliance compared to the standard sign.

Figures 17 and 18 present the mean speed profiles for average daytime and nighttime results for various sign treatments. Looking at these speed profiles, it seems that the high intensity red border sign proved most beneficial. The microprismatic red border sign proved beneficial compared to the high intensity standard sign only. Comparison of high intensity standard sign with microprismatic standard sign shows the benefits of using a higher conspicuity material. However, comparison of both the red border signs did not show any benefit of using a higher conspicuity material.

TABLE 13 Average Results for Standard versus Modified Red Border Sign

MOE	Daytime			Nighttime		
	Standard Speed Limit sign	**Modified red border Speed Limit sign**	**Treatment Impact†**	**Standard Speed Limit sign**	**Modified red border Speed Limit sign**	**Treatment Impact†**
Average Red_{mean}	7.5	9.0	-1.5	7.3	8.5	-1.2
Average Δ_{70} / Δ_{65}	26.0	31.6	-5.6	37.3	41.6	-4.3
Average Δ_{55}	21.7	26.6	-4.9	31.0	36.4	-5.4
Average Dev_{mean}	4.9	4.1	0.8	3.4	2.3	1.1
Average Dev_{85th}	11.7	10.7	1.0	9.5	8.7	0.8

† Red border treatment is beneficial for positive values of Dev_{mean} and Dev_{85th} and negative values of Red_{mean}, $\Delta 70$ /$\Delta 65$, and Δ_{55}.

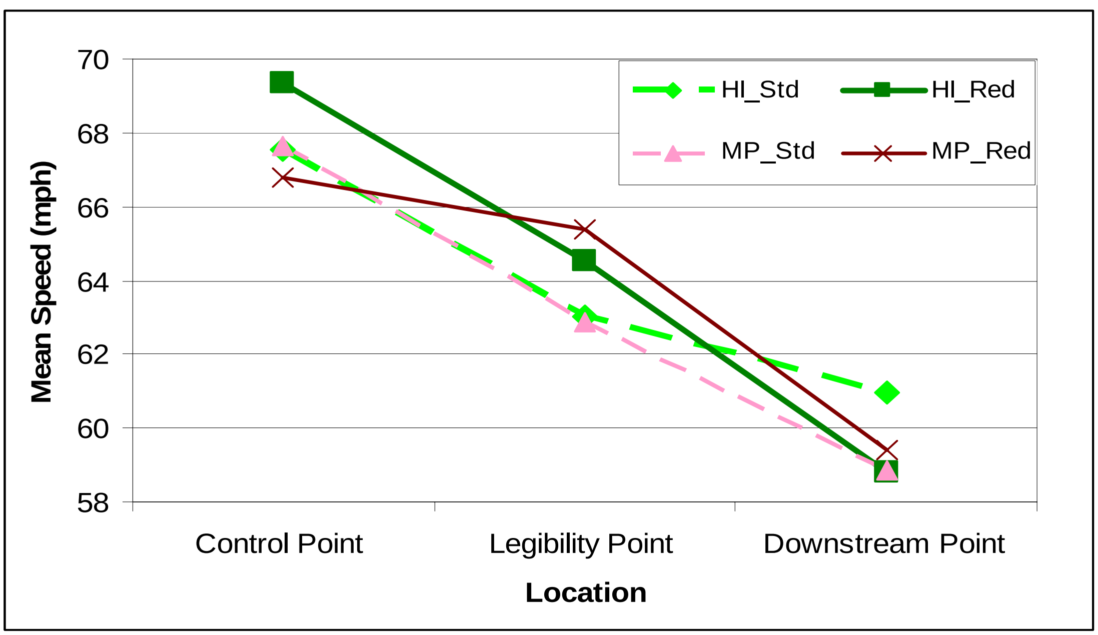

FIGURE 17 Mean Speed Profiles for Average Daytime Results, Modified Border Study.

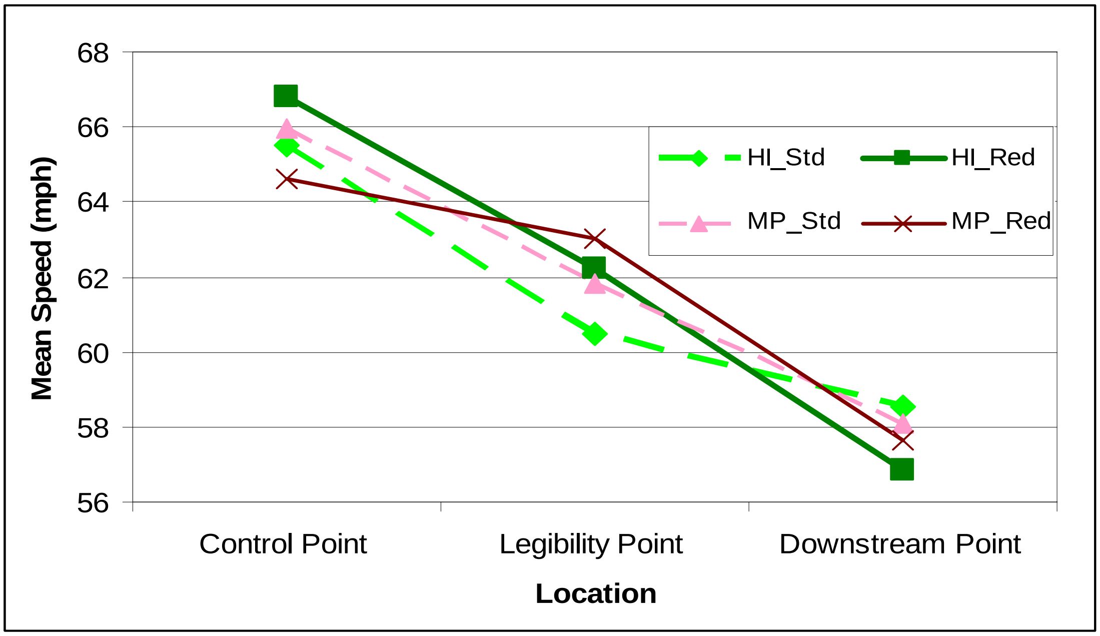

FIGURE 18 Mean Speed Profiles for Average Nighttime Results, Modified Border Study.

Discussion of Modified Border Study Results

The high intensity modified red border sign at FM 39 and SH 7 proved to be the most beneficial. At SH 14, the effect of the red border treatment was small compared to the effect at other two sites. One reason for this small effect could be that the traveling speeds in the existing condition were very close to the posted speed limit of 55 mph. As such there was very little room for improvement at this site. The microprismatic modified red border sign showed some beneficial effects at US 79. However, even for this site, the benefits were not as much as were seen for the high intensity modified red border sign at other sites. This difference could be due to different site characteristics or random. At the other two sites i.e., at SH 7 and SH 14 where the microprismatic modified red border sign was evaluated, no or very little benefits were seen. Overall, the results for the microprismatic modified red border sign were inconsistent with the expectations. The following issues might have contributed to the unexpected results for the MP_R sign.

- At SH 7 and SH 14, four different signs were replaced one after the other in the following order: HI_S, HI_R, MP_S, MP_R, and again MP_S. The data were collected in the following order: HI_S, HI_R, MP_R, and MP_S. Thus, at these sites, the MP_S sign was in the field for four weeks, replaced by the MP_R sign, data collected on the MP_R sign after two weeks. The sign was replaced again by the MP_S sign and the data were collected on the MP_S sign after three weeks. This frequent replacement of the sign might have affected the way motorists would perceive the importance of red border.
- The time gap between sign installation and data collection might have affected the results. The data on HI_R were collected after 4 to 5 weeks of installation, whereas data on microprismatic red border sign were collected only after 2 weeks of installation. From the long-term results of the added border study (described later in this chapter), it is clear that effect of red border increases with time. However, it is unknown as to after how long the treatment shows benefits. Thus there is possibility that the red border treatment becomes effective after a time gap of 4 weeks or longer.
- At SH 7 and SH 14, the high intensity red border sign was replaced by the microprismatic standard sign for the study on the second treatment pair of MP_S versus MP_R. Here this is important, since it is not known as to how long the effects of red border treatment last, after it is replaced by the standard Speed Limit sign. Thus there is a possibility, that data for MP_R sign has the spillover effect from the MP_S and vice-versa.

RESULTS FOR ADDED BORDER STUDY

The objective of the added border study was to evaluate the long-term effect (nine to 11 months after its installation) of adding a red border around a standard Speed Limit sign at three different sites. The researcher analyzed the before, the short-term, and the long-term data to quantify the effects of treatment in the long-term period. A comparison of the before study and long-term study would indicate if the red border treatment had any effect on driver behavior, and a comparison of the short-term study and the long-term study would indicate the effect of the red border treatment with passage of time. Appendix B presents the detailed results for each site. The roadway geometry did not change during this one-year period at any of the sites in a way that might have affected the results.

The first part of this section presents the results for all vehicles group at each site separately. The section following this presents the summary and discussion of the results for each measure of effectiveness and across all three sites.

Results at SH 21 - Westbound Traffic Approaching Caldwell

At this site, the before, the short-term, and the long-term data were collected on Thursday and Friday. The short-term data were collected three weeks after the installation of the red border and the long-term data were collected 42 weeks after the installation of the red border treatment.

Table 14 and 15 present the daytime and the nighttime results respectively for all vehicles group at this site. Treatment impact (short-term) indicates the impact of treatment in the short-term period (3 weeks after the addition of the red border to the standard sign). Treatment impact (long-term) indicates the effect of the red border treatment in the long-term period compared to the standard sign. For the daytime vehicles, Table 14 indicates that driver compliance of the speed limit started improving in the short-term period and continued with time. Long-term impact of the treatment is approximately double of the short-term impact. Table 15 indicates that the beneficial effects of the treatment in the long-term period continued during the nighttime and are consistent for all measures of effectiveness. However, the speed reductions during nighttime are less than those during the daytime. The results were also statistically significant for all measures of effectiveness. The passenger vehicles showed more reductions in speed during the daytime and at nighttime compared to the heavy vehicles (Detailed results for passenger vehicles and heavy vehicles are tabulated in Appendix B).

TABLE 14 Added Border Study Results for Daytime Vehicles at SH 21

Measure of effectiveness	Before	Short-term	Long-term	Treatment Impact (short-term)†	Treatment Impact (long-term)†
Sample size	1285	1182	2259	-	-
Reduction in mean speed from CP to DS [Red_{mean} , Eqn. 1]	6.0*	8.2*	11.0	-2.2	-5.0
Reduction in percent exceeding 70/65 mph from CP to DS point [Δ70 /Δ65, Eqn. 2 /3]	22.8	41.7	48.5	-18.9	-25.7
Reduction in percent exceeding 55 mph from CP to DS point [Δ_{55} , Eqn. 4]	12.8	15.5	29.5	-2.7	-16.7
Deviation of mean speed from speed limit at DS point [Dev_{mean} , Eqn. 5]	8.0*	7.0*	4.4	1.0	3.6
Deviation of 85th percentile speed from speed limit at DS point [Dev_{85th} , Eqn. 6]	16.0*	14.0*	12.0	2.0	4.0

* Indicates value is statistically significantly different at 95% confidence level compared to long-term study.

† Red border treatment is beneficial for positive values of Dev_{mean} and Dev_{85th} and negative values of Red_{mean}, Δ70 /Δ65, and Δ_{55}.

TABLE 15 Added Border Study Results for Nighttime Vehicles at SH 21

Measure of effectiveness	Before	Short-term	Long-term	Treatment Impact (short-term) †	Treatment Impact (long-term)†
Sample size	377	253	741		
Reduction in mean speed from CP to DS [Red_{mean}, Eqn. 1]	5.4*	7.9*	9.8	-2.5	-4.4
Reduction in percent exceeding 70/65 mph from CP to DS point [Δ70 /Δ65, Eqn. 2 /3]	26.5	46.3	55.3	-19.8	-28.8
Reduction in percent exceeding 55 mph from CP to DS point [Δ_{55}, Eqn. 4]	20.5	28.2	38.2	-7.7	-17.7
Deviation of mean speed from speed limit at DS point [Dev_{mean}, Eqn. 5]	5.2*	3.4	2.7	1.8	2.5
Deviation of 85th percentile speed from speed limit at DS point [Dev_{85th}, Eqn. 6]	12.0*	11.0*	9.0	1.0	3.0

* Indicates value is statistically significantly different at 95% confidence level compared to long-term study.
† Red border treatment is beneficial for positive values of Dev_{mean} and Dev_{85th} and negative values of Red_{mean}, Δ70 /Δ65, and Δ_{55}.

Results at FM 60 - Eastbound Traffic Approaching Snook

At this site, the heavy vehicle data sample for the short-term condition was too small to analyze separately. As such, the results presented in Appendix B do not include the short-term study results for heavy vehicles for this site. The short-term data at this site were collected two weeks after the installation of the red border and the long-term data were collected 43 weeks after the installation of the red border treatment.

Tables 16 and 17 present the daytime and the nighttime results for all vehicles group at this site. A comparison of the before and the short-term data at this site shows that decreases in the mean speeds and the 85th percentile speeds were small in the short-term period. However, the long-term results for daytime indicate large decreases in the mean speeds, 85th percentile speeds, and in the percent of vehicles exceeding specific speed thresholds. These decreases were also present for nighttime. Once again, the benefits during the nighttime were less than those during the daytime. At this site, the benefits of the red border treatment found during the long-term study are even more important, since very little benefits were realized during the short-term study. Here it should be noted that data for short-term study at this site were collected only two weeks after the installation of red border treatment which points to the premise that probably red border treatment does not show immediate benefits. The mean speeds in the long-term study are very close to the speed limit.

At this site, the before and the short-term data were collected during the weekend and the long-term data were collected on weekdays. Due to this difference in data collection days, the control point speeds for the long-term data were statistically significantly lower (by 3.0 mph less compared to the before period). As such there is a possibility that the reduction in the downstream speeds could be due to the lower speeds at the control point for the long-term period. However a closer look at the results shows, reductions in mean speeds of approximately 7.5 mph for the long-term condition compared to the before condition. As such the researcher believes the reduction in downstream speeds is not entirely due to the lower control point speeds, but is also due to the red border treatment.

TABLE 16 Added Border Study Results for Daytime Vehicles at FM 60

Measure of effectiveness	Before	Short-term	Long-term	Treatment Impact (short-term) †	Treatment Impact (long-term)†
Sample size	1558	349	1701	x	x
Reduction in mean speed from CP to DS [Red_{mean}, Eqn. 1]	5.1*	6.0*	9.6	-0.9	-4.5
Reduction in percent exceeding 70/65 mph from CP to DS point [$\Delta 70$ /$\Delta 65$, Eqn. 2 /3]	27.5	35.8	26.4	-8.3	1.1
Reduction in percent exceeding 55 mph from CP to DS point [Δ_{55}, Eqn. 4]	5.6	7.5	33.1	-1.9	-27.5
Deviation of mean speed from speed limit at DS point [Dev_{mean}, Eqn. 5]	10.0*	9.9*	2.5	0.1	7.5
Deviation of 85th percentile speed from speed limit at DS point [Dev_{85th}, Eqn. 6]	17.0*	17.0*	8.8	0.0	8.2

* Indicates value is statistically significantly different at 95% confidence level compared to long-term study.

† Red border treatment is beneficial for positive values of Dev_{mean} and Dev_{85th} and negative values of Red_{mean}, $\Delta 70$ /$\Delta 65$, and Δ_{55}.

TABLE 17 Added Border Study Results for Nighttime Vehicles at FM 60

Measure of effectiveness	Before	Short-term	Long-term	Treatment Impact (short-term)†	Treatment Impact (long-term)†
Sample size	498	189	655		
Reduction in mean speed from CP to DS [Red_{mean}, Eqn. 1]	6.1*	8.1	9.6	-2.0	-3.5
Reduction in percent exceeding 70/65 mph from CP to DS point [Δ70 /Δ65, Eqn. 2 /3]	36.7	49.2	43.2	-12.5	-6.5
Reduction in percent exceeding 55 mph from CP to DS point [Δ_{55}, Eqn. 4]	22.9	21.7	44.2	1.2	-21.3
Deviation of mean speed from speed limit at DS point [Dev_{mean}, Eqn. 5]	5.8*	5.2*	1.1	0.6	4.7
Deviation of 85th percentile speed from speed limit at DS point [Dev_{85th}, Eqn. 6]	13.0*	11.8*	7.3	1.2	5.7

* Indicates value is statistically significantly different at 95% confidence level compared to long-term study.
† Red border treatment is beneficial for positive values of Dev_{mean} and Dev_{85th} and negative values of Red_{mean}, Δ70 /Δ65, and Δ_{55}.

Results at SH 36 - Northbound Traffic Approaching Milano

At this site, the before, the short-term, and long-term data were collected on the weekdays. The short-term-data were collected three weeks after the installation of the red border and the long-term data were collected 49 weeks after the installation of the red border treatment. Tables 18 and 19 show the long-term study results for the daytime vehicles and the nighttime vehicles, respectively. The results at this site are similar to those found at the other two sites. The red border treatment proved highly beneficial in the long-term period, even though the short-term study results had shown only small benefits of the treatment.

TABLE 18 Added Border Study Results for Daytime Vehicles at SH 36

Measure of effectiveness	Before	Short-term	Long-term	Treatment Impact (short-term) †	Treatment Impact (long-term)†
Sample size	518	480	1570	x	x
Reduction in mean speed from CP to DS [Red_{mean} , Eqn. 1]	5.0*	7.2*	11.6	-2.2	-6.6
Reduction in percent exceeding 70/65 mph from CP to DS point [Δ70 /Δ65, Eqn. 2 /3]	25.1	44.6	53.4	-19.5	-28.3
Reduction in percent exceeding 55 mph from CP to DS point [Δ_{55} , Eqn. 4]	6.3	6.5	25.5	0.2	-19.2
Deviation of mean speed from speed limit at DS point [Dev_{mean} , Eqn. 5]	10.0*	9.9*	4.4	0.1	5.6
Deviation of 85th percentile speed from speed limit at DS point [Dev_{85th} , Eqn. 6]	17.0*	16.2*	10.7	0.8	6.3

* Indicates value is statistically significantly different at 95% confidence level compared to long-term study.

† Red border treatment is beneficial for positive values of Dev_{mean} and Dev_{85th} and negative values of Red_{mean}, Δ70 /Δ65, and Δ_{55}.

TABLE 19 Added Border Study Results for Nighttime Vehicles at SH 36

Measure of effectiveness	Before	Short-term	Long-term	Treatment Impact (short-term) †	Treatment Impact (long-term)†
Sample size	238	71	463		
Reduction in mean speed from CP to DS [Red_{mean} , Eqn. 1]	5.8*	7.6*	10.0	-1.8	-4.2
Reduction in percent exceeding 70/65 mph from CP to DS point [Δ70 /Δ65, Eqn. 2 /3]	42.4	59.1	63.1	-16.7	-20.7
Reduction in percent exceeding 55 mph from CP to DS point [Δ_{55} , Eqn. 4]	15.5	11.3	33.9	4.2	-18.4
Deviation of mean speed from speed limit at DS point [Dev_{mean} , Eqn. 5]	6.6*	6.5*	2.8	0.1	3.8
Deviation of 85th speed from speed limit at DS point [Dev_{85th} , Eqn. 6]	13.0*	12.0*	9.0	1.0	4.0

* Indicates value is statistically significantly different at 95% confidence level compared to long-term study.
† Red border treatment is beneficial for positive values of Dev_{mean} and Dev_{85th} and negative values of Red_{mean}, Δ70 /Δ65, and Δ_{55}.

Summary and Discussion of Added Border Study Results

Figures 19 and 20 show the reduction in mean speeds from the control point to the downstream point for various study conditions at all three sites for the daytime and the nighttime vehicles, respectively. These figures indicate that reductions in the long-term period were twice the reductions in the before period. Comparison of Figure 19 with 20 shows that speed reductions during the nighttime were less than during the daytime.

FIGURE 19 Reduction in Mean Speeds Between CP and DS Point, Daytime Results for Added Border Study.

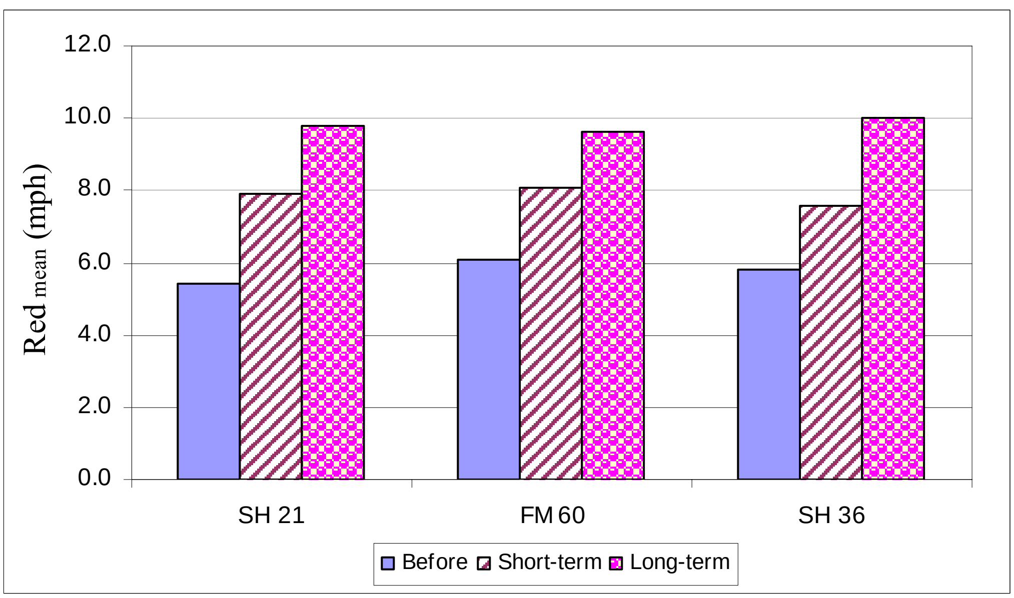

FIGURE 20 Reduction in Mean Speeds Between CP and DS Point, Nighttime Results for Added Border Study.

Figures 21 and 22 show the deviations of mean speeds from the speed limit for the daytime and the nighttime vehicles respectively. Figure 21 indicates that during the daytime, deviations in the short-term decreased only at SH 21. However, in the long-term, there is large decrease in the deviations from the speed limit at all three sites irrespective of the short-term impacts of the treatment. From Figure 22, it can be seen that during the nighttime, short-term impacts of the red border treatment were better for this measure of effectiveness. In the long-term, decreases in deviations continued with time and mean speeds are much closer to the speed limit at all three sites compared to the before period and short-term period.

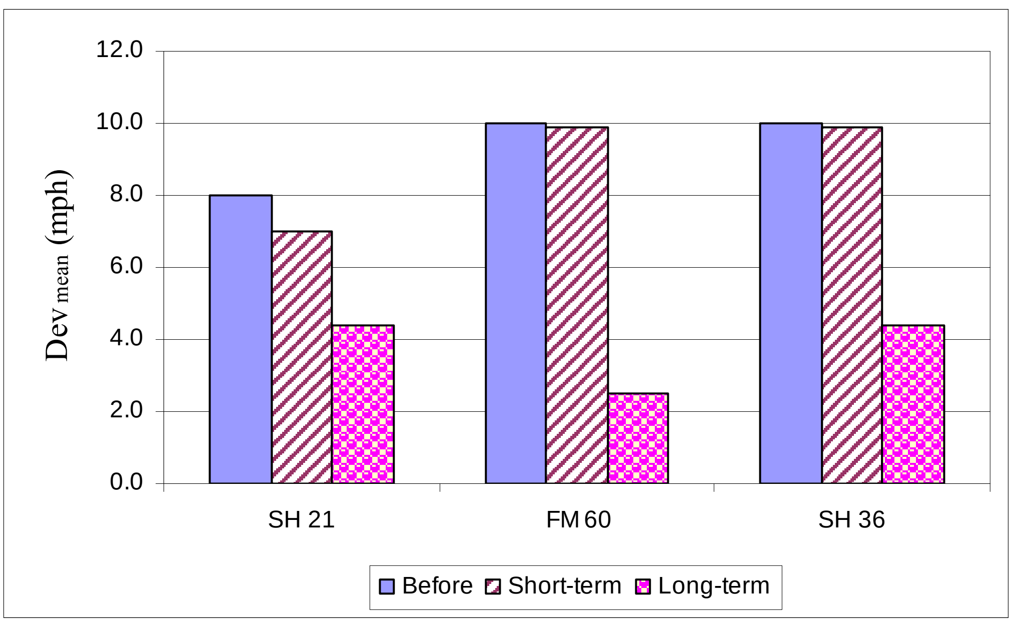

FIGURE 21 Deviation of Mean Speed from Speed Limit, Daytime Results for Added Border Study.

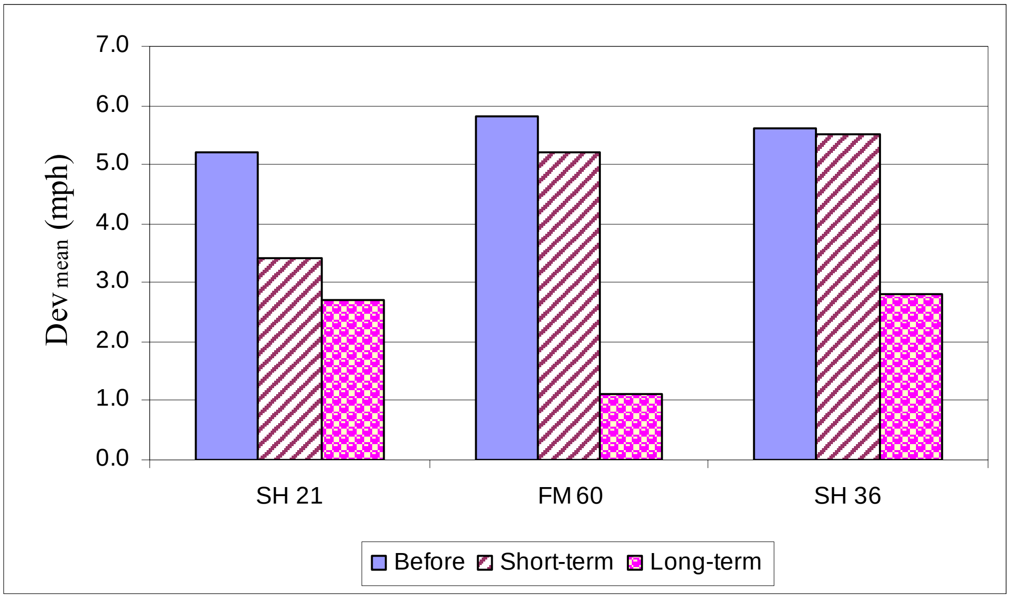

FIGURE 22 Deviation of Mean Speed from Speed Limit, Nighttime Results for Added Border Study.

Figures 23 and 24 show the deviations of 85th percentile speeds from the speed limit for the daytime and the nighttime vehicles respectively. Findings are similar to those for the deviations in mean speeds. The long-term period shows extended benefits of the red border treatment at all sites. The long-term benefits of the treatment were most at FM 60 even when the short-term benefits were insignificant at this site. The nighttime benefits for this measure of effectiveness are same as for the daytime.

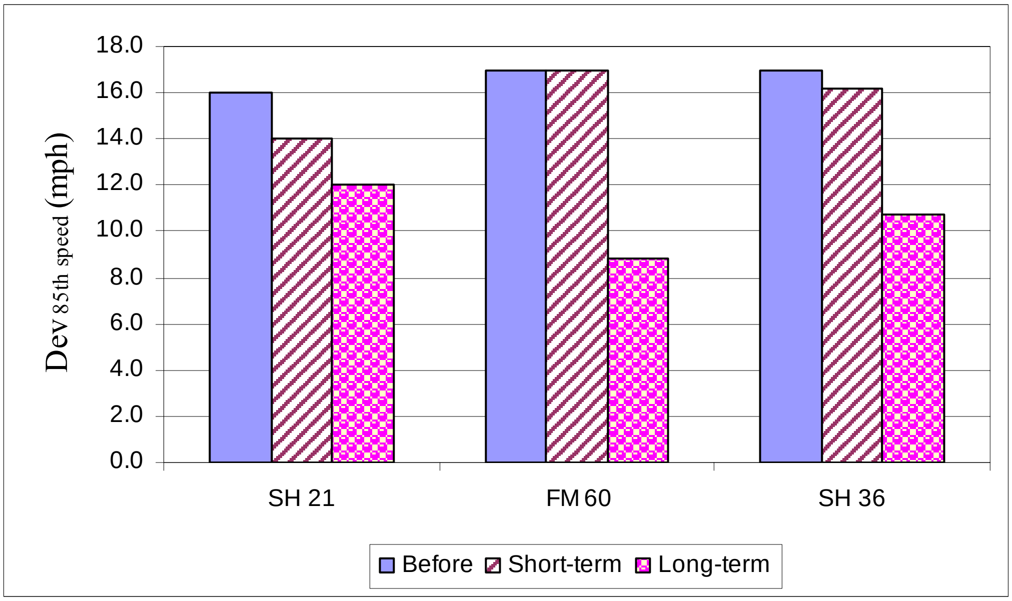

FIGURE 23 Deviation of 85th Percentile Speed from Speed Limit, Daytime Results for Added Border Study.

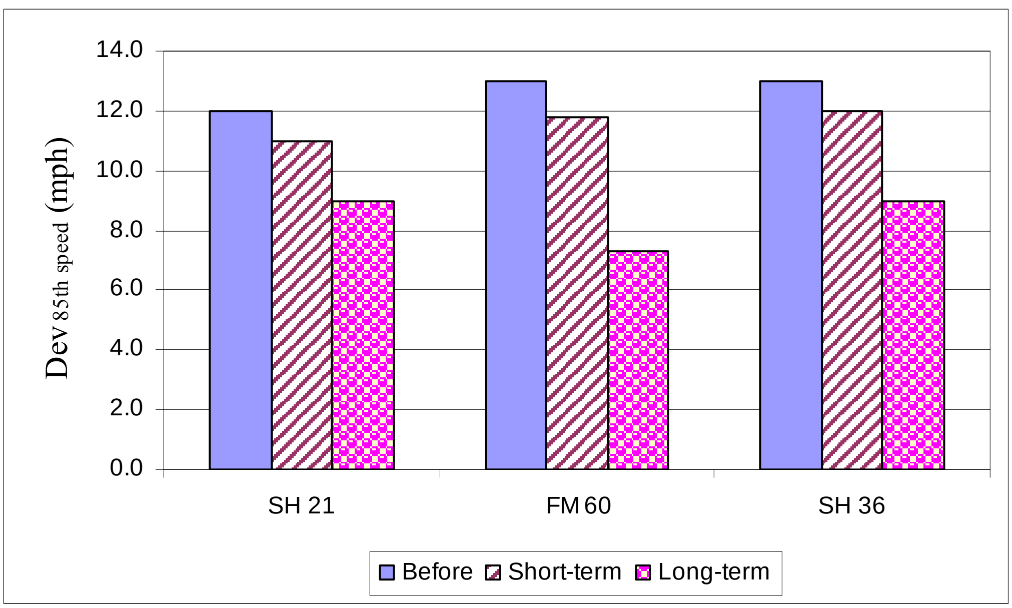

FIGURE 24 Deviation of 85th Percentile Speed from Speed Limit, Nighttime Results for Added Border Study.

Figure 25 and 26 show reductions in the percent of vehicles exceeding the upstream speed limit during the daytime and the nighttime respectively. These figures are a graphical representation of the results in Tables 14 through 19. From these figures, it seems that the treatment impact for FM 60 in the long-term period is smaller compared to the short-term period. However, a closer look at the data (Table B-9 in Appendix B) shows that the percent exceeding the 70 mph were smaller in the long-term study (28.1 percent at the control point and 1.7 percent at the downstream point) compared to the before study (45.2 percent at the control point and 17.7 percent at the downstream point). Also looking at the percent exceeding 55 mph, it is clear that percent of vehicles traveling faster than 55 mph decreased much more in the long-term study compared to the before study. As such, the apparently small impact in the long-term is due to the smaller percent exceeding the upstream speed limit at the control point.

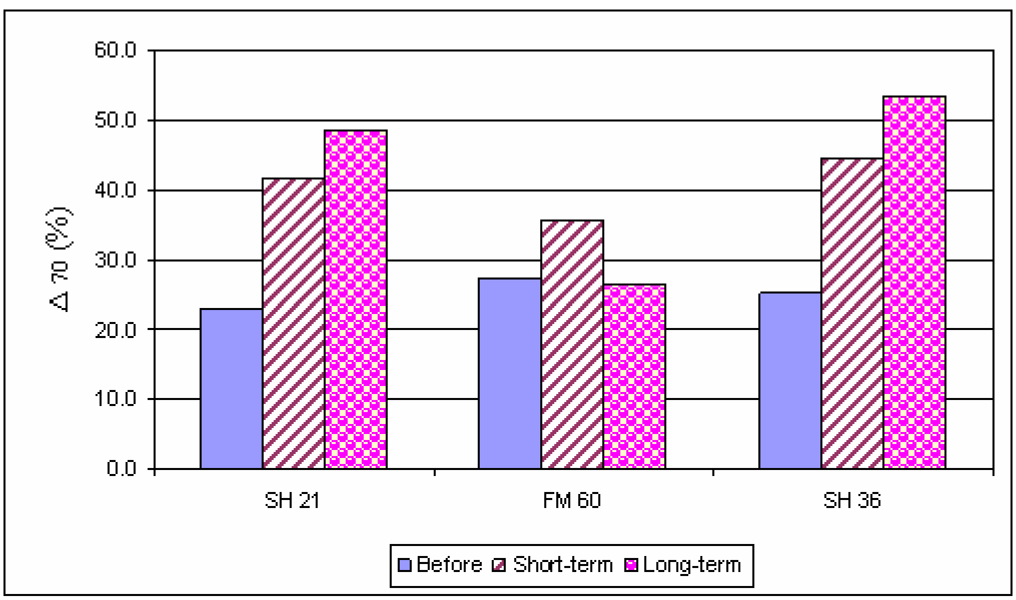

FIGURE 25 Reduction in Percent Exceeding 70 mph between CP and DS Point, Daytime Results for Added Border Study.

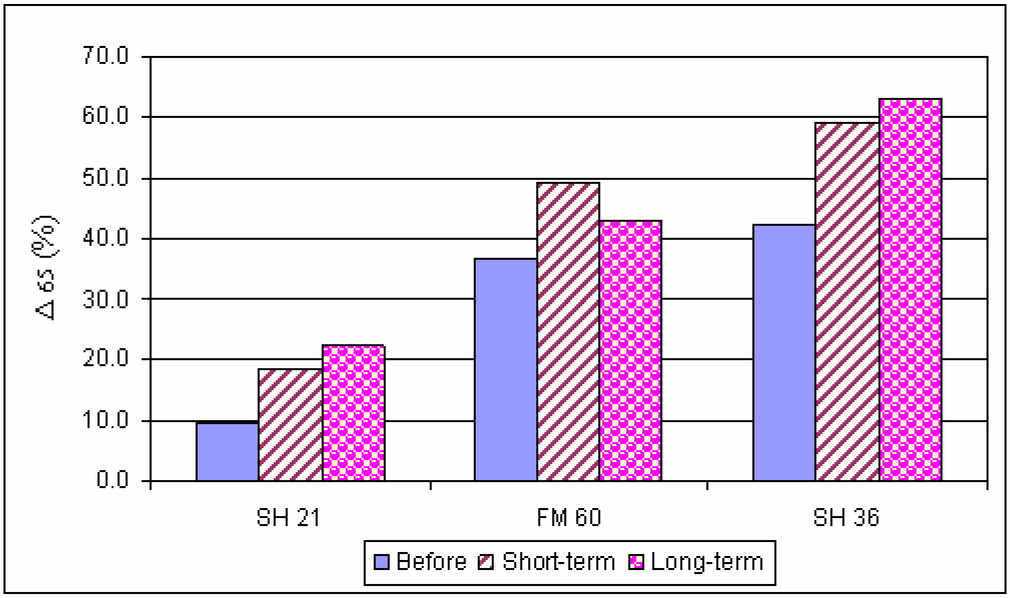

FIGURE 26 Reduction in Percent Exceeding 65 mph between CP and DS Point, Nighttime Results for Added Border Study.

Figure 27 and 28 show the percent of vehicles exceeding the speed limit (55 mph) for the daytime and the nighttime vehicles, respectively. These figures indicate that the red border treatment impact in short-term period was insignificant except for SH 21 during the nighttime. However, the treatment impact in the long-term period is statistically significant at all sites and for both lighting conditions. During the daytime, the average reduction in the percent exceeding the speed limit for the long-term period was approximately three times compared to the before period and the short-term period. During the nighttime, the reductions were twice in the long-term period compared to the before period.

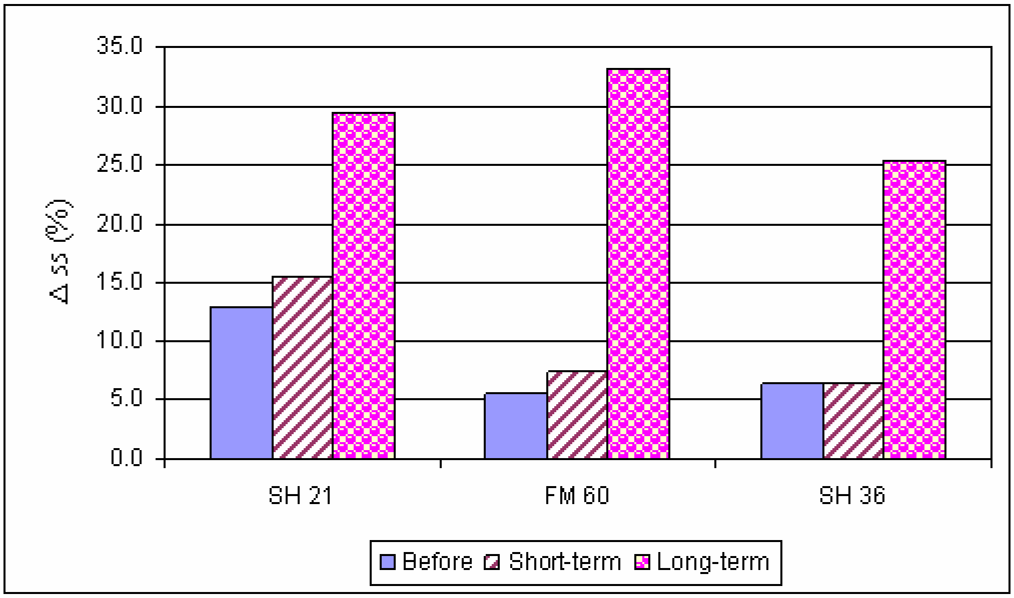

FIGURE 27 Reduction in Percent Exceeding 55 mph between CP and DS Point, Daytime Results for Added Border Study.

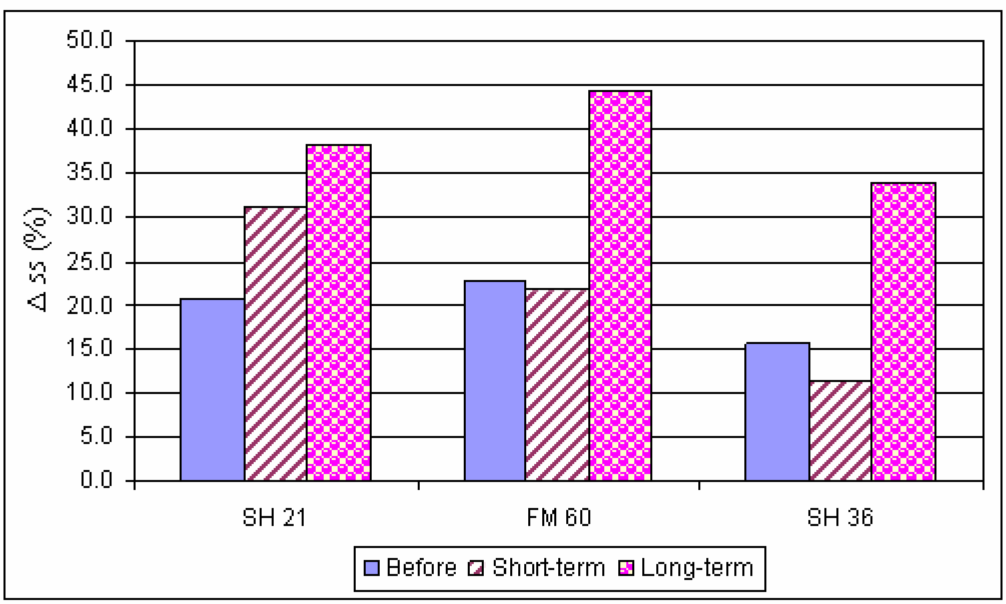

FIGURE 28 Reduction in Percent Exceeding 55 mph between CP and DS Point, Nighttime Results for Added Border Study.

Table 20 shows added border study results averaged for all three sites. This table indicates that in long-term, the average reduction in the mean speed from the control point to the downstream point was 5.3 mph more during the daytime and 4.0 mph more during the night as compared to the before condition. Deviations of mean speeds from the speed limit were less than 4.0 mph, whereas in the before study, the deviations were as high as 9.3 mph. The percent of vehicles slowing down below the 70 mph threshold increased approximately by 18 percent for both lighting conditions. A similar increase is evident in the percent of vehicles slowing down below 55 mph threshold. This finding indicates that slowing down by the faster moving vehicles has caused the reduction in mean speeds. The benefits were consistent for all measures of effectiveness, under all lighting conditions, across different sites, and were also found to be statistically significant. Further, benefits were of similar amount irrespective of the results of the short-term study.

Table 20 indicates that though the average impact of the red border treatment in short-term was small, still the treatment had a large beneficial impact in the long-term period. This finding is important for making recommendations for the use of red border sign. Comparison of the average short-term effects in modified border study (Table 13) with the average short-term effects in the added border study (Table 20), indicates that the modified Red Border Speed Limit sign had similar or better effects compared to the standard Speed Limit sign with an added red border. Based on the above finding and findings for long-term treatment impact, it can be assumed that the modified Red Border Speed Limit sign will also show similar or better beneficial effects in the long-term. The finding that benefits of the red border treatment increase with time is plausible, since most of the driver population at these study sites is familiar.

TABLE 20 Summary of Added Border Study Results for All Vehicles

Measure of effectiveness	Light	Before	Short-term	Long-term	Treatment Impact (short-term)†	Treatment Impact (long-term)†
Average reduction in mean speed from CP to DS [Avg. Red_{mean}]	Daytime	5.4	7.1	10.7	-1.7	-5.3
	Nighttime	5.8	7.9	9.8	-2.1	-4.0
Average Reduction in percent of vehicles exceeding 70/65 mph from CP to DS point [Avg. Δ70 /Δ65]	Daytime	25.1	40.7	42.8	-15.6	-17.7
	Nighttime	35.2	51.5	53.9	-16.3	-18.7
Average Reduction in percent of vehicles exceeding 55 mph from CP to DS point [Avg. Δ55]	Daytime	8.2	9.8	29.4	-1.6	-21.2
	Nighttime	19.6	20.4	38.8	-0.8	-19.2
Average Deviation of mean speed from speed limit at DS point [Avg. Dev_{mean}]	Daytime	9.3	8.9	3.8	0.4	5.5
	Nighttime	5.9	5.0	2.2	0.9	3.7
Average Deviation of 85th percentile speed from speed limit at DS point [Avg. Dev_{85th}]	Daytime	16.7	15.7	10.5	1.0	6.2
	Nighttime	12.7	11.6	8.4	1.1	4.3

† Red border treatment impact is beneficial for positive values of Dev_{mean} and Dev_{85th} and negative values of Red_{mean}, Δ70 /Δ65, and Δ_{55}.

Figures 29 and 30 show the mean speed profiles for average daytime and nighttime results through the study section. Looking at the mean speeds at the threshold point in Figure 29, it is clear that benefits of the red border treatment start as soon as the sign is visible to the motorist. The mean speed at the downstream point are significantly lower for the long-term study compared to the before and the short-term study and for both lighting conditions.

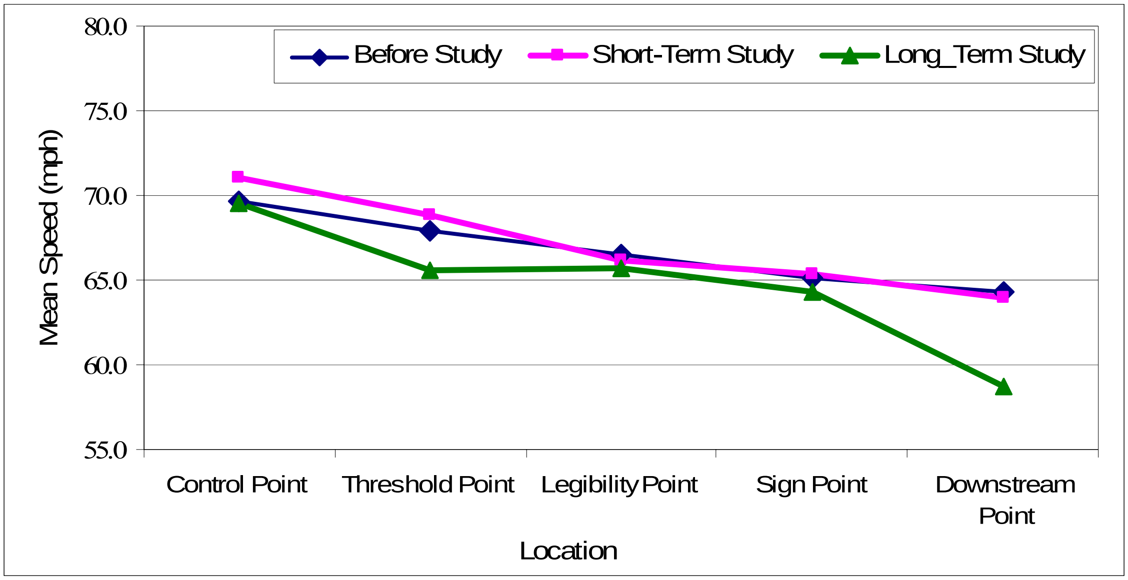

FIGURE 29 Mean Speed Profiles for Average Daytime Results, Added Border Study.

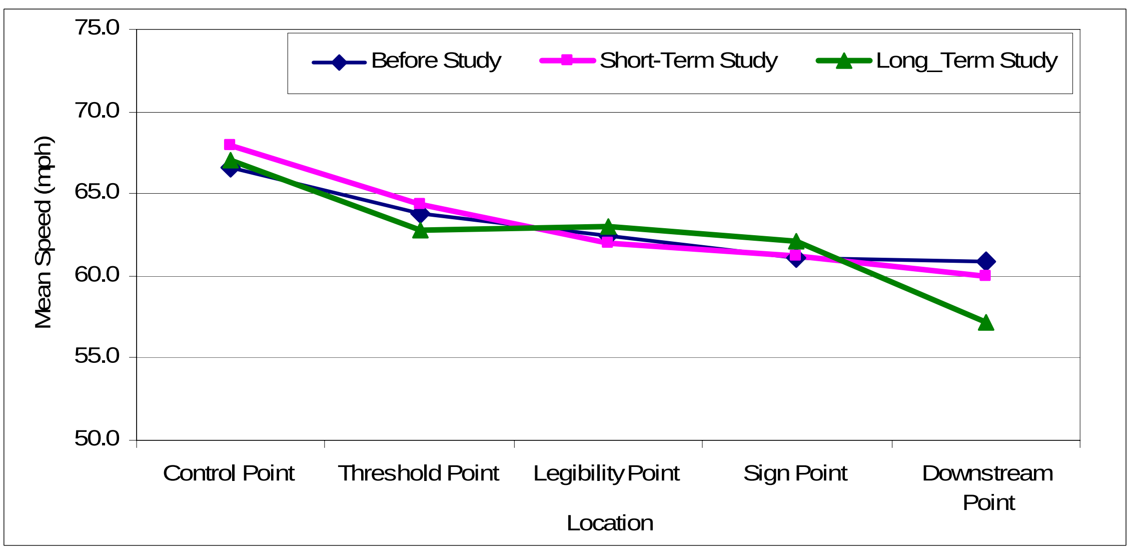

FIGURE 30 Mean Speed Profiles for Average Nighttime Results, Added Border Study.

COMPARISON WITH OTHER STUDIES

One of the objectives of this study was to compare its results to those of other methods used to improve speed-limit compliance. Most speed management techniques are implemented in urban areas and work zones. The author found few studies in which speeding on rural high-speed roads was addressed. The study by Maroney and Dewar (*6*) using a speed feedback sign compares most closely with the present study. This study was also conducted in a reduced speed zone where speeds dropped from 70 km/hr to 50 km/hr (approximately 50 mph to 35 mph). Maroney and Dewar's study tracked only short-term results. As such, only the short-term results of the thesis study could be compared with the results of Maroney and Dewar's study. Table 21 shows the results from Maroney and Dewar's study and the thesis study. The results presented in Table 21 are the average results across all sites for both lighting conditions and are computed from the results shown in Table 13 and Table 20. The lower changes for the short-term study could be due to the following factors:

- Averaging across all sites. As discussed previously in the short-term study results, at one of the sites (SH 14), the speeds in before condition were also very close to the speed limit. As such, red border treatment had negligible impact at this site. If this site is excluded from the study, change in the mean speed is 3.3 percent and change in percent exceeding the speed limit is 6.4 percent.
- Another factor is the unexpected results for microprismatic red border sign at two sites (SH 7 and SH 14). If the results for microprismatic red border sign at SH 7 and all results for SH 14 are excluded from the study, change in the mean speed is 4.2 percent and change in percent exceeding the speed limit is 8.8 percent. Ignoring the bias due to frequent replacement of sign and due to special site characteristics, the results for the thesis study are comparable to the results of Maroney and Dewar's study.

TABLE 21 Comparison of Short-Term Effects for Non-Enforcement Techniques

Measure of effectiveness	Maroney and Dewar's speed feedback sign study†	Thesis modified border study		Thesis added border study
		Only HI sheeting	Average of HI and MP sheeting	
Mean speed (Percent change)	-4.0 %	-3.2 %	-2.3 %	-1.0 %
Percent exceeding speed limit (Change)	-7.1 %	-10.3 %	-5.1 %	-1.2 %

† indicates study by Maroney and Dewar (*6*)

For the long-term effects, no similar studies were found in literature. However, the Department for Transport in the England reported the long-term results of its automatic enforcement program using speed cameras after one year of implementation (*11*). A valid comparison can not be made between an enforcement program and a non-enforcement study effort. Even so, Table 22 shows the results of this comparison for the sake of completion. For the safety camera study, no control point speed was available; as such the control point speed for the long-term study was ignored for this comparison.

TABLE 22 Comparison of Long-Term Effects with Safety Camera Study

Study	Speed limit (mph)	Number of sites	Change in mean speed		Change in 85th percentile speed		Percent exceeding the SL (change)	Percent traveling at >SL +15 (change)
			mph	Percent	mph	Percent		
Safety camera study	50	45	-1.7	-4.0	-1.0	-2.0	-19.0	-12.0
Thesis long-term study	55	3	-5.2	-8.1	-5.8	-8.1	-21.7	-12.3

SL stands for Speed Limit.

POTENTIAL SAFETY BENEFITS OF THE RED BORDER TREATMENT

The primary purpose of setting and enforcing the speed limits is to reduce the number and severity of incidents on our highways. The author of this study did not collect and analyze any crash data to evaluate the safety benefits of the red border treatment. However, the benefits of red border treatment in terms of injury and fatal crashes were estimated using the graphical relationship (Figure 1) developed by Nilson (*3*). The results of the long-term study show that a red border treatment will result in approximately eight percent reduction in mean speeds. From Figure 1, for an eight percent decrease in speeds, all injury crashes decrease by more than 10 percent and fatal crashes decrease by more than 20 percent. Another relationship developed by Finch et al. predicts that number of injury crashes decrease by 5 percent for every 1 mph decrease in speed (*4*). Based on this relationship and for a reduction in mean speed of 5.2 mph (results of added border study for long-term effects), it is estimated that red border treatment would result in 25 percent fewer injury crashes.

The above mentioned mathematical and graphical relationships between changes in speed and number of crashes are not based on the US speed limit changes and have not been validated by the US studies. The author of this thesis did not find any relationship for change in travel speed versus change in crashes specifically developed for the US highways and as such decided to use the models developed by Nilsson (*3*) and Finch et al. (*4*). Studies conducted for speed limit changes in the US also indicate increases in crashes with increase in speed and a few of them are summarized below for comparison with the results of Figure 1. Two of these studies, one by NHTSA and another by McKnight, Kleinand and Tippetts found that fatal crashes increased by approximately 21 percent, when speed limits in the US were raised from 55 mph to 65 mph, i.e. an 18 percent increase (*2*). The Insurance Institute of Highway Safety evaluated the safety effects of a second round of speed limit increases from 65 mph to 70/75 mph (a 7.7/15 percent increase) in 22 states in the mid 1990s. The results of this study indicated an average increase of 15 percent in fatal crashes in the 22 states where speed limits were raised (*19*). Comparison of results from Figure 1 and the results of US studies indicates that the change in crashes for US highways is lower than that predicted by this figure. However, it should be noted that Figure 1 represents the change in travel speed and not the change in speed limit.

CHAPTER V

SUMMARY OF FINDINGS AND RECOMMENDATIONS

This study was conducted to evaluate the short-term and the long-term impacts of placing a red border around a Speed Limit sign on speed limit compliance. The research hypothesis was that motorists sometimes fail to notice the standard Speed Limit sign and thus speed inadvertently. This occurrence is especially true in reduced speed zones outside the city limits of a rural community where there are no other indications to suggest a reduction in speed is needed. The researcher hypothesized that a red border will attract more attention to the Speed Limit sign and the color red would heighten the perceived need to slow down. Positive results for the modified border and the added border study indicate that red border does help in making the sign more conspicuous and help drivers notice the change in speed limits.

The researcher evaluated the short-term effects of a modified red border sign in the modified border study at four sites, and of adding a red border to the standard Speed Limit sign in the added border study at three additional sites. The long-term effects (nine to 11 months after treatment installation) of adding a red border to the standard Speed Limit sign on driver compliance of the speed limit were evaluated at three sites. The results of the modified border and the added border study are summarized in this chapter.

SUMMARY OF FINDINGS FOR MODIFIED BORDER STUDY

- The modified high intensity Red Border Speed Limit sign resulted in better speed limit compliance for all measures of effectiveness at all three sites in comparison to the high intensity standard Speed Limit sign. The improvement was for both passenger vehicles as well as heavy vehicles and under both lighting conditions. Specifically, mean speeds reduced by 4.0 mph more during daytime and by 3.0 mph more during night time for the red border sign. Percent of vehicles exceeding the speed limit reduced by 11.7 percent during day time and by 10.1

percent during night time. For the red border sign, deviation of the mean speed from the speed limit was smaller at all three sites.

- The microprismatic modified Red Border Speed Limit sign proved beneficial only at one site. At the other two sites, the MP_R sign failed to repeat the positive benefits found for the high intensity modified red border sign. The results for the microprismatic modified red border sign were inconsistent with expectations and difficult to explain.
- The red border treatment for the microprismatic sign showed no or little benefits when the time gap between sign installation and data collection was only two weeks.
- Frequent switching of the standard Speed Limit sign and the red border treatment sign showed mixed effects of the treatment. At two sites, where two sheeting materials were evaluated, these mixed effects were seen for the microprismatic pair of signs.
- At SH 14, actual mean speeds for the existing condition were close to the speed limit. This fact resulted in smaller benefits of the red border treatment for both high intensity as well as microprismatic sheeting signs.
- Overall comparison of the standard Speed Limit sign with the modified Red Border Speed Limit sign across all four sites showed benefits of the red border treatment. The average reduction in speed from the control point to the downstream point was 1.5 mph more for the modified red border sign compared to the standard sign. Similar benefits for other measures of effectiveness were also seen.
- Microprismatic standard sign resulted in better speed limit compliance compared to the high intensity standard sign. However, microprismatic red border sign did not show better compliance in comparison to high intensity red border sign.

SUMMARY OF FINDINGS FOR ADDED BORDER STUDY

- The short-term benefits of adding a red border to the standard Speed limit sign were statistically significant at one site. However, at the other two sites, short-term effects of the treatment on driver compliance of the speed limit were insignificant or none.
- The long-term benefits of red border treatment increase with time. In the long-term period, the mean speeds and the 85th percentile speeds showed an average reduction of 8.1 percent compared to the before period. The percent exceeding the speed limit (55 mph) decreased by 21.7 percent and the percent exceeding 70 mph decreased by 12.3 percent more with the red border sign compared to the standard sign. The decreases in speeds were both statistically and practically significant.
- The beneficial effects of the red border treatment in the long-term study were consistent across all sites. The benefits were approximately the same for all three sites. In the long-term study condition, mean speeds were found very close to the speed limit in all cases.
- In the long-term period, approximately the same benefits were realized for all three sites irrespective of the nature and amount of benefits found in the short-term period.
- In all cases, the benefits were greater for passenger vehicles compared to those for heavy vehicles and more so during the daytime than at nighttime.
- Results for the long-term effects are consistent with the results found by other researchers using other speed management measures such as safety cameras.
- Based on the long-term results and the mathematical models by Nilson (*3*), the red border treatment has the potential of reducing fatal crashes by 20 percent and injury crashes by 10 percent. Since Nilsson's model has not been validated by any U.S. data, these potential safety benefits may or may not be true for U.S. highways.

RECOMMENDATIONS

Based on the consistent beneficial results of the added border study for the long-term effects, it is recommended that the added red border sign be used in reduced speed zones and in areas where incidents of inadvertent speeding are common. Based on the results of the added border study for the short-term and the long-term effects, the researcher believes that the modified red border sign will also provide similar long-term benefits.

As a follow-up to the current study, the safety benefits of the red border treatment may be validated using actual crash data. This follow-up study can also validate the previously developed mathematical models for predicting crashes in terms of change in travel speeds. Evaluating the impact of the red border treatment for a Reduced Speed Ahead sign can be another follow-up to the current study.

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APPENDIX A

MODIFIED BORDER STUDY RESULTS

The modified border study was completed at four sites to evaluate the short-term effects of a modified red border sign. The speed data were collected at three points for specified sign treatments at each site. The data were analyzed to compute: the mean speeds, 85th percentile speeds, the 10 mph pace values, the percent exceeding upstream and downstream speed limits. The data for daytime and nighttime vehicles were analyzed separately. The results for each lighting condition were further grouped as passenger vehicles, heavy vehicles and all vehicles combined. This appendix presents these detailed results for the modified border study. Tables are organized by results for treatment pairs: HI_S versus HI_R, MP_S versus MP_R, and HI_R versus MP_R. For each treatment pair, the daytime results are followed by the nighttime results. The daytime and the nighttime results show separate tables for passenger vehicle, heavy vehicle and finally for all vehicles combined. The asterisk (*) next to a value indicates that the two values compared were statistically significantly different at a 95% confidence level.

TABLE A-1 Daytime Results for Treatment Pair HI_R versus HI_S, Passenger Vehicles

Location	Measure of Effectiveness	FM 39 - Normangee			SH 7 - Marlin			SH 14 - Wortham		
		HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S
	Sample Size	1284	1133	x	1895	1695	x	944	1071	x
Control Point	Mean Speed (mph)	70.1	70.0	-0.1	67.0	70.8	3.8*	66.7	67.7	1.0*
	85th Speed (mph)	75.8	75.2	-0.6	72.2	76.8*	4.6	72.2	73.2*	1.0
	10 mph pace (mph)	65-75	66-76	1	62-72	66-76	4	62-72	63-73	1
	Percent Exceeding 70 mph	53.2	51.1	-2.1	30.3	57.9*	27.6	28.8	35.6*	6.8
	Percent Exceeding 55 mph	98.0	98.7	0.7	96.8	98.5*	1.7	97.1	97.5	0.4
	Std. Dev.	6.3	5.8	-0.5	5.6	6.6	1	5.7	5.6	-0.1
Legibility Point	Mean Speed (mph)	63.0	59.6	-3.4*	64.4	72.3	7.9*	62.5	61.7	-0.8*
	85th Speed (mph)	70.4	65.8*	-4.6	70.4	80.2*	9.8	68.6	68.2	-0.4
	10 mph pace (mph)	55-65	55-65	0	59-69	67-77	8	58-68	56-66	-2
	Percent Exceeding 70 mph	15.1	4.3*	-10.8	17.6	60.9*	43.3	10.5	9.5	-1.0
	Percent Exceeding 55 mph	89.5	77.8*	-11.7	94.4	99.4*	5.0	89.6	85.4*	-4.2
	Std. Dev.	6.7	5.9	-0.8	5.9	7.2	1.3	6.1	6.3	0.2
Downstream Point	Mean Speed (mph)	63.9	59.7	-4.2*	61.6	59.8	-1.8*	58.1	56.5	-1.5*
	85th Speed (mph)	71.3	66.5*	-4.8	69.0	66.9*	-2.1	64.4	62.7*	-1.7
	10 mph pace (mph)	56-66	53-63	-3	54-64	53-63	-1	52-62	50-60	-2
	Percent Exceeding 70 mph	19.7	7.3*	-12.4	9.9	7.5*	-2.4	4.3	3.2	-1.1
	Percent Exceeding 55 mph	90.7	74.8*	-15.9	83.0	74.6*	-8.4	65.5	55.2*	-10.3
	Std. Dev.	7.2	6.5	-0.7	6.5	6.7	0.2	6.4	6.0	-0.4

* Indicates value is statistically significant at 95% confidence level.

TABLE A-2 Daytime Results for Treatment Pair HI_R versus HI_S, Heavy Vehicles

Location	Measure of Effectiveness	FM 39 - Normangee			SH 7 - Marlin			SH 14 - Wortham		
		HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S
	Sample Size	287	128	-	259	332	-	288	285	-
Control Point	Mean Speed (mph)	67.0	68.0	1	66.1	70.9	4.8*	64.7	66.3	1.6*
	85th Speed (mph)	71.8	73.2	1.4	71.5	76.3*	4.8	69.5	70.8*	1.3
	10 mph pace (mph)	61-71	62-72	1	61-71	66-76	5	60-70	61-71	1
	Percent Exceeding 70 mph	27.9	34.4	6.5	23.9	58.1*	34.2	10.1	20.4*	10.3
	Percent Exceeding 55 mph	98.3	97.7	-0.6	95	99.4*	4.4	93.4	97.9*	4.5
	Std. Dev. (mph)	6.1	6.2	0.1	5.8	5.6	-0.2	5.2	5.2	0
Legibility Point	Mean Speed (mph)	60.8	58.8	-2.0*	64.3	73.6	9.3*	60.9	61.3	0.5
	85th Speed (mph)	65.3	64.6	-0.7	69.9	80.2*	10.3	65.3	66.1	0.8
	10 mph pace (mph)	55-65	56-66	1	59-69	70-80	11	56-66	57-67	1
	Percent Exceeding 70 mph	4.9	3.9	-1	13.5	71.4*	57.9	2.4	2.1	-0.3
	Percent Exceeding 55 mph	87.8	68.8*	-19	93.4	99.4*	6	85.8	90.5	4.7
	Std. Dev. (mph)	5.2	6.1	0.9	5.4	6.4	1	5.1	5.2	0.1
Downstream Point	Mean Speed (mph)	62.0	59.4	-2.6*	62.1	61.2	-0.9	57.0	56.8	-0.2
	85th Speed (mph)	67.8	65.7	-2.1	68.6	67.9	-0.7	62.3	62.0	-0.3
	10 mph pace (mph)	56-66	53-63	-3	54-64	55-65	1	51-61	50-60	-1
	Percent Exceeding 70 mph	7.7	6.3	-1.4	9.3	9.9	0.6	0.3	1.4	1.1
	Percent Exceeding 55 mph	91.3	72.7*	-18.6	86.5	85.5	-1	63.9	63.9	0.0
	Std. Dev. (mph)	5.6	6.3	0.7	5.8	6.3	0.5	5.0	5.0	0.0

* Indicates value is statistically significant at 95% confidence level.

TABLE A-3 Daytime Results for Treatment Pair HI_R versus HI_S, All Vehicles

Location	Measure of Effectiveness	FM 39 - Normangee			SH 7 - Marlin			SH 14 - Wortham		
		HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S
	Sample Size	1571	1261	-	2154	2027	-	1232	1356	-
Control Point	Mean Speed (mph)	69.5	69.8	0.3*	66.9	70.8	3.9*	66.2	67.4	1.2*
	85th Speed (mph)	75.2	75.2	0	72.2	76.8*	4.6	71.8	72.7*	0.9
	10 mph pace (mph)	64-74	66-76	2	62-72	66-77	4	62-72	62-72	0
	Percent Exceeding 70 mph	48.6	49.4	0.8	29.5	57.9*	28.4	24.4	32.4*	8
	Percent Exceeding 55 mph	98.0	98.6	0.6	96.6	98.6*	2	96.3	97.6	1.3
	Std. Dev. (mph)	6.4	5.9	-0.5	5.6	6.4	0.8	5.6	5.6	0
Legibility Point	Mean Speed (mph)	62.6	59.5	-3.1*	64.4	72.5	8.1*	62.1	61.6	-0.5
	85th Speed (mph)	69.5	65.7*	-3.8	70.4	80.2*	9.8	68.2	67.8*	-0.4
	10 mph pace (mph)	55-65	55-65	0	59-69	67-77	8	56-66	57-67	1
	Percent Exceeding 70 mph	13.2	4.3*	-8.9	17.1	62.7*	45.6	8.6	8.0	-0.6
	Percent Exceeding 55 mph	89.2	76.8*	-12.4	94.3	99.4*	5.1	88.7	86.5	-2.2
	Std. Dev. (mph)	6.5	5.9	-0.6	5.9	7.1	1.2	5.9	6.1	0.2
Downstream Point	Mean Speed (mph)	63.5	59.7	-3.8*	61.6	60.04	-1.6	57.8	56.6	-1.2*
	85th Speed (mph)	70.8	66.5*	-4.3	68.6	67.3*	-1.3	63.8	62.7*	-1.1
	10 mph pace (mph)	56-66	53-63	-3	54-64	54-64	0	52-62	50-60	-2
	Percent Exceeding 70 mph	17.5	7.2*	-10.3	9.8	7.9*	-1.9	3.4	2.8	-0.6
	Percent Exceeding 55 mph	90.8	74.6*	-16.2	83.4	76.4*	-7	65.1	57.0*	-8.1
	Std. Dev. (mph)	6.9	6.5	-0.4	6.4	6.69	0.29	6.1	5.8	-0.3

* Indicates value is statistically significant at 95% confidence level compared to HI_S.

TABLE A-4 Nighttime Results for Treatment Pair HI_R versus HI_S, Passenger Vehicles

Location	Measure of Effectiveness	FM 39 - Normangee			SH 7 - Marlin			SH 14 - Wortham		
		HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S
	Sample Size	236	221	-	716	371	-	402	275	-
Control Point	Mean Speed (mph)	69.1	68.0	-1.1	64.5	68.1	3.6*	63.8	64.6	0.8
	85th Speed (mph)	75.2	74.2	-1	69.5	74.5*	5	69	70.4*	1.4
	10 mph pace (mph)	64-74	64-74	0	59-69	64-74	5	59-69	59-69	0
	Percent Exceeding 70 mph	76.3	71.0	-5.3	45.5	70.1*	24.6	39.3	44.0	4.7
	Percent Exceeding 55 mph	99.2	97.3	-1.9	95.7	96.2	0.5	94.8	93.5	-1.3
	Std. Dev. (mph)	6.1	6.4	0.3	5.5	6.9	1.4	5.8	6.1	0.3
Legibility Point	Mean Speed (mph)	61.4	57.9	-3.5*	61.3	68.9	7.6*	59.0	59.3	0.3
	85th Speed (mph)	67.3	64.6*	-2.7	67.3	77.4*	10.1	65.7	66.1	0.4
	10 mph pace (mph)	56-66	55-65	-1	56-66	62-72	6	55-65	55-65	0
	Percent Exceeding 70 mph	27.5	11.8*	-15.7	26	68.5*	42.5	17.2	17.5	0.3
	Percent Exceeding 55 mph	85.6	67.4*	-18.2	82.8	96.2*	13.4	70.4	71.3	0.9
	Std. Dev. (mph)	6.5	5.9	-0.6	6.2	7.9	1.7	6.4	6.6	0.2
Downstream Point	Mean Speed (mph)	62.1	57.8	-4.3*	58.4	57.5	-0.9	55.1	54.8	-0.3
	85th Speed (mph)	68.6	64.9*	-3.7	64.9	65.3	0.4	61.3	60.6	-0.7
	10 mph pace (mph)	54-64	52-62	-2	52-62	50-60	-2	48-58	48-58	0
	Percent Exceeding 70 mph	27.1	13.6*	-13.5	14.5	15.6	1.1	6.7	7.6	0.9
	Percent Exceeding 55 mph	87.3	63.3*	-24	68.2	58.5*	-9.7	43.3	41.1	-2.2
	Std. Dev. (mph)	7	6.5	-0.5	6.5	7.3	0.8	6.2	6.5	0.3

* Indicates value is statistically significant at 95% confidence level compared to HI_S.

TABLE A-5 Nighttime Results for Treatment Pair HI_R versus HI_S, Heavy Vehicles

Location	Measure of Effectiveness	FM 39 - Normangee			SH 7 - Marlin			SH 14 - Wortham		
		HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S
	Sample Size	101	47	-	105	95	-	105	75	-
Control Point	Mean Speed (mph)	66.8	66.2	-0.6	64.6	68.7	4.1*	62.9	64.3	1.5
	85th Speed (mph)	70.8	70.6	-0.2	69.0	73.2*	4.2	67.3	68.5	1.2
	10 mph pace (mph)	60-70	59-69	-1	58-68	64-74	6	59-69	57-67	-2
	Percent Exceeding 70 mph	66.3	53.2	-13.1	43.8	81.1*	37.3	37.1	46.7	9.6
	Percent Exceeding 55 mph	100.0	100.0	0	95.2	98.9	3.7	91.4	97.3	5.9
	Std. Dev. (mph)	4.8	5.0	0.2	5.3	5.1	-0.2	5.0	5.8	0.8
Legibility Point	Mean Speed (mph)	60.9	58.1	-2.8*	61.2	70.56	9.4*	59.1	59.8	0.8
	85th Speed (mph)	65.7	62.1*	-3.6	65.5	76.3*	10.8	64	66.4	2.5
	10 mph pace (mph)	55-65	55-65	0	56-66	66-76	10	55-65	55-65	0
	Percent Exceeding 70 mph	26.7	6.4*	-20.3	19.0	78.9*	59.9	11.4	20.0	8.6
	Percent Exceeding 55 mph	88.1	72.3*	-15.8	85.7	98.9*	13.2	74.3	84	9.7
	Std. Dev. (mph)	5.8	4.2	-1.6	5.3	6.1	0.8	5.1	5.5	0.4
Downstream Point	Mean Speed (mph)	62.1	57.9	-4.2*	58.6	58.95	0.4	55.0	55.7	0.7
	85th Speed (mph)	68.6	62.8*	-5.8	64.9	64.16	-0.7	59.2	61.3	2.1
	10 mph pace (mph)	54-64	52-62	-2	55-65	53-63	-2	49-59	48-58	-1
	Percent Exceeding 70 mph	28.7	8.5*	-20.2	12.4	10.5	-1.9	4.8	8.0	3.2
	Percent Exceeding 55 mph	92.1	76.6*	-15.5	74.3	75.8	1.5	41.9	46.7	4.8
	Std. Dev. (mph)	6.3	5.0	-1.3	5.7	5.66	-0.04	5.2	5.5	0.3

* Indicates value is statistically significant at 95% confidence level compared to HI_S.

TABLE A-6 Nighttime Results for Treatment Pair HI_R versus HI_S, All Vehicles

Location	Measure of Effectiveness	FM 39 - Normangee			SH 7 - Marlin			SH 14 - Wortham		
		HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S	HI_S	HI_R	HI_R-HI_S
	Sample Size	337	268	-	821	466	-	507	350	-
Control Point	Mean Speed (mph)	68.4	67.7	-0.7	64.5	68.25	3.8*	63.6	64.5	0.9
	85th Speed (mph)	74.7	74.2	-0.5	69.5	74.2*	4.7	68.6	70.4*	1.8
	10 mph pace (mph)	62-72	62-72	0	59-69	64-74	5	59-69	59-69	0
	Percent Exceeding 70 mph	73.3	67.9	-5.4	45.3	72.3*	27	38.9	44.6	5.7
	Percent Exceeding 55 mph	99.4	97.8	-1.6	95.6	96.8	1.2	94.1	94.3	0.2
	Std. Dev. (mph)	5.8	6.2	0.4	5.5	6.6	1.1	5.6	6.1	0.5
Legibility Point	Mean Speed (mph)	61.2	58.0	-3.2*	61.3	69.2	7.9*	59.0	59.4	0.4
	85th Speed (mph)	66.9	64.2*	-2.7	67.3	76.8*	9.5	65.3	66.1	0.8
	10 mph pace (mph)	55-65	55-65	0	56-66	62-72	6	55-65	55-65	0
	Percent Exceeding 70 mph	27.3	10.8*	16.5	25.1	70.6*	45.5	16.0	18.0	2.0
	Percent Exceeding 55 mph	86.4	68.3*	-18.1	83.2	96.8*	13.6	71.2	74.0	2.8
	Std. Dev. (mph)	6.3	5.7	-0.6	6.1	7.6	1.5	6.2	6.4	0.2
Downstream Point	Mean Speed (mph)	62.1	57.8	-4.3*	58.4	57.8	-0.6	55.1	55.0	-0.1
	85th Speed (mph)	68.6	64.6*	-4	64.9	64.9	0	60.9	61.2	0.2
	10 mph pace (mph)	54-64	52-62	-2	52-62	50-60	-2	48-58	48-58	0
	Percent Exceeding 70 mph	27.6	12.7*	-14.9	14.3	14.6	0.3	6.3	7.7	1.4
	Percent Exceeding 55 mph	88.7	65.7*	-23	68.9	62.0	-6.9	43.0	42.3	-0.7
	Std. Dev. (mph)	6.8	6.2	-0.6	6.4	7.1	0.7	6	6.3	0.3

* Indicates value is statistically significant at 95% confidence level compared to HI_S.

TABLE A-7 Daytime Results for Treatment Pair MP_R versus MP_S, Passenger Vehicles

Location	Measure of Effectiveness	US 79 - Oakwood			SH 14 - Wortham		
		MP_S	MP_R	MP_R-MP_S	MP_S	MP_R	MP_R-MP_S
	Sample Size	954	2191	-	1072	1192	-
Control Point	Mean Speed (mph)	69.7	69.1	-0.6*	66.6	64.4	-2.2*
	85th Speed (mph)	74.2	73.7*	-0.5	72.2	69.2*	-3.0
	10 mph pace (mph)	64-74	64-74	0	62-72	59-69	-3
	Percent Exceeding 70 mph	27.7	11.1*	-16.6	48.4	43.6*	-4.8
	Percent Exceeding 55 mph	96.5	95.2	-1.3	99.2	99.5	0.3
	Std. Dev. (mph)	5.4	4.9	-0.5	6.0	5.2	-0.8
Legibility Point	Mean Speed (mph)	66	65.9	-0.1	60.4	61.7	1.3*
	85th Speed (mph)	71.8	71.8	0.0	67.3	69*	1.7
	10 mph pace (mph)	60-70	62-72	2	55-65	55-65	0
	Percent Exceeding 70 mph	5.9	9.8*	3.9	24.4	23.2	-1.2
	Percent Exceeding 55 mph	77.5	81.5*	4.0	96.8	96.9	0.1
	Std. Dev. (mph)	6.0	5.9	-0.1	6.5	6.5	0.0
Downstream Point	Mean Speed (mph)	61.4	60.7	-0.7*	56.7	57.1	0.4
	85th Speed (mph)	68.2	67.3*	-0.9	63.4	63.4	0.0
	10 mph pace (mph)	55-65	53-63	-2	50-60	50-60	0
	Percent Exceeding 70 mph	2.9	3.3	0.4	8.9	6.7*	-2.2
	Percent Exceeding 55 mph	54.8	58.5	3.7	83.3	80.4*	-2.9
	Std. Dev. (mph)	6.3	6.2	-0.1	6.3	6.0	-0.3

* Indicates value is statistically significant at 95% confidence level compared to MP_S.

TABLE A-8 Daytime Results for Treatment Pair MP_R versus MP_S, Heavy Vehicles

Location	Measure of Effectiveness	US 79 - Oakwood			SH 14 - Wortham		
		MP_S	MP_R	MP_R-MP_S	MP_S	MP_R	MP_R-MP_S
	Sample Size	341	701	-	216	275	-
Control Point	Mean Speed (mph)	67.1	66.7	-0.4	64.9	62.2	-2.7*
	85th Speed (mph)	71.3	70.8*	-0.5	70.4	66.9*	-3.5
	10 mph pace (mph)	62-72	62-72	0	59-69	56-66	-3
	Percent Exceeding 70 mph	16.7	3.3*	-13.4	25.8	19.4*	-6.4
	Percent Exceeding 55 mph	96.8	94.9	-1.9	98.8	99.4	0.6
	Std. Dev. (mph)	5.2	4.4	-0.8	5.4	4.7	-0.7
Legibility Point	Mean Speed (mph)	64.0	63.5	-0.5	59.5	60.5	1.0
	85th Speed (mph)	68.6	68.2	-0.4	64.9	66.0	1.1
	10 mph pace (mph)	59-69	59-69	0	54-64	55-65	1
	Percent Exceeding 70 mph	2.3	2.9	0.6	10.6	7.7	-2.9
	Percent Exceeding 55 mph	79.2	84.4	5.2	95.3	94.9	-0.4
	Std. Dev. (mph)	4.8	4.9	0.1	5.6	5.2	-0.4
Downstream Point	Mean Speed (mph)	60.1	58.8	-1.3	56.4	57.2	0.8
	85th Speed (mph)	65.3	63.8*	-1.5	62.0	62.0	0.0
	10 mph pace (mph)	54-64	53-63	-1	51-61	50-60	-1
	Percent Exceeding 70 mph	0.0	2.2*	2.2	3.8	2.1	-1.7
	Percent Exceeding 55 mph	57.9	64.4	6.5	83.6	74.9*	-8.7
	Std. Dev. (mph)	5.2	5.1	-0.1	5.6	5.1	-0.5

* Indicates value is statistically significant at 95% confidence level compared to MP_S.

TABLE A-9 Daytime Results for Treatment Pair MP_R versus MP_S, All Vehicles

Location	Measure of Effectiveness	US 79 - Oakwood			SH 14 - Wortham		
		MP_S	MP_R	MP_R-MP_S	MP_S	MP_R	MP_R-MP_S
	Sample Size	1295	2892	-	1288	1467	-
Control Point	Mean Speed (mph)	69	68.5	-0.5*	66.3	64.0	-2.3*
	85th Speed (mph)	73.7	73.2*	-0.5	72.2	69.0*	-3.2
	10 mph pace (mph)	63-73	63-73	0	62-72	59-69	-3
	Percent Exceeding 70 mph	25.9	9.6*	-16	42.5	37.8*	-4.7
	Percent Exceeding 55 mph	96.6	95.2	-1.4	99.1	99.5	0.4
	Std. Dev. (mph)	5.4	4.9	-0.5	5.9	5.2	-0.7
Legibility Point	Mean Speed (mph)	65.5	65.3	-0.2	60.2	61.4	1.2*
	85th Speed (mph)	71.3	71.3	0	66.9	68.0*	1.1
	10 mph pace (mph)	59-69	59-69	0	55-65	55-65	0
	Percent Exceeding 70 mph	5.3	8.5*	3.2	20.8	19.4	-1.4
	Percent Exceeding 55 mph	77.8	82.1*	4.3	96.4	96.4	0
	Std. Dev. (mph)	5.8	5.7	-0.1	6.3	6.3	0
Downstream Point	Mean Speed (mph)	61.1	60.2	-0.9*	56.6	57.1	0.5
	85th Speed (mph)	67.8	66.5*	-1.3	63.1	63.1	0
	10 mph pace (mph)	54-64	53-63	-1	50-60	50-60	0
	Percent Exceeding 70 mph	2.4	3.1	0.7	7.6	5.6*	-2
	Percent Exceeding 55 mph	55.3	59.6*	4.3	83.4	79.0*	-4.4
	Std. Dev. (mph)	6.1	6.0	-0.1	6.2	5.9	-0.3

* Indicates value is statistically significant at 95% confidence level compared to MP_S.

TABLE A-10 Nighttime Results for Treatment Pair MP_R versus MP_S, Passenger Vehicles

Location	Measure of Effectiveness	US 79 - Oakwood			SH 14 - Wortham		
		MP_S	MP_R	MP_R-MP_S	MP_S	MP_R	MP_R-MP_S
	Sample Size	266	505	-	212	217	-
Control Point	Mean Speed (mph)	68.5	67.4	-1.1*	63.7	61.7	-2.0*
	85th Speed (mph)	74.2	72.2*	-2	69.0	66.1*	-2.9
	10 mph pace (mph)	64-74	62-72	-2	59-69	56-66	-3
	Percent Exceeding 70 mph	41.5	24.4*	-17.1	75.9	66.3*	-9.6
	Percent Exceeding 55 mph	93.4	90.8	-2.6	99.2	98.8	-0.4
	Std. Dev. (mph)	5.5	5.3	-0.2	5.8	5.0	-0.8
Legibility Point	Mean Speed (mph)	65.9	65.2	-0.7	57.9	57.7	-0.2
	85th Speed (mph)	71.8	71.3	-0.5	64.2	63.6	-0.6
	10 mph pace (mph)	59-69	59-69	0	55-65	55-65	0
	Percent Exceeding 70 mph	9.9	10.6	0.7	56.8	51.5	-5.3
	Percent Exceeding 55 mph	60.4	60.8	0.4	95.5	94.1	-1.4
	Std. Dev. (mph)	5.9	6.3	0.4	6.3	5.9	-0.4
Downstream Point	Mean Speed (mph)	61.2	60.3	-0.9	54.6	54.4	-0.2
	85th Speed (mph)	68.2	66.9	-1.3	59.0	59.6	0.6
	10 mph pace (mph)	55-65	54-64	-1	49-59	49-59	0
	Percent Exceeding 70 mph	5.2	3.2	-2	30.1	23.2*	-6.9
	Percent Exceeding 55 mph	40.6	38.2	-2.4	82.0	77.6	-4.4
	Std. Dev. (mph)	6.7	6.8	0.1	6.0	5.5	-0.5

* Indicates value is statistically significant at 95% confidence level compared to MP_S.

TABLE A-11 Nighttime Results for Treatment Pair MP_R versus MP_S, Heavy Vehicles

Location	Measure of Effectiveness	US 79 - Oakwood			SH 14 - Wortham		
		MP_S	MP_R	MP_R-MP_S	MP_S	MP_R	MP_R-MP_S
	Sample Size	134	284	-	79	85	-
Control Point	Mean Speed (mph)	67.2	66.2	-1.0	64	60.5	-3.5*
	85th Speed (mph)	71.3	69.9	-1.4	69.2	64.2*	-5.0
	10 mph pace (mph)	61-71	61-71	0	59-69	56-66	-3
	Percent Exceeding 70 mph	32.9	5.9*	-27.0	61.9	58.1	-3.8
	Percent Exceeding 55 mph	94.9	90.6	-4.3	100.0	99.6	-0.4
	Std. Dev. (mph)	5.4	4.0	-1.4	4.7	3.8	-0.9
Legibility Point	Mean Speed (mph)	65.3	64.4	-0.9	58.5	59.1	0.6
	85th Speed (mph)	70.4	69.0	-1.4	62.8	65*	2.2
	10 mph pace (mph)	61-71	59-69	-2	55-65	55-65	0
	Percent Exceeding 70 mph	5.1	8.2	3.1	47.0	44.4	-2.6
	Percent Exceeding 55 mph	73.4	70.6	-2.8	98.5	97.2	-1.3
	Std. Dev. (mph)	5.9	4.9	-1.0	4.7	5.0	0.3
Downstream Point	Mean Speed (mph)	60.9	59.5	-1.4	56.4	55.7	-0.8
	85th Speed (mph)	67.3	64.9	-2.4	62.0	60.6	-1.4
	10 mph pace (mph)	54-64	54-64	0	52-62	50-60	-2
	Percent Exceeding 70 mph	3.8	3.5	-0.3	24.6	14.4*	-10.2
	Percent Exceeding 55 mph	58.2	49.4	-8.8	80.6	77.8	-2.8
	Std. Dev. (mph)	6.9	5.7	-1.2	5.0	4.5	-0.5

* Indicates value is statistically significant at 95% confidence level compared to MP_S.

TABLE A-12 Nighttime Results for Treatment Pair MP_R versus MP_S, All Vehicles

Location	Measure of Effectiveness	US 79 - Oakwood			SH 14 - Wortham		
		MP_S	MP_R	MP_R-MP_S	MP_S	MP_R	MP_R-MP_S
	Sample Size	400	789	-	291	302	-
Control Point	Mean Speed (mph)	68.1	66.9	-1.2*	63.8	61.4	-2.4*
	85th Speed (mph)	73.2	71.3*	-1.9	69.0	66.1*	-2.9
	10 mph pace (mph)	63-73	62-72	-1	59-69	56-66	-3
	Percent Exceeding 70 mph	39.2	19.2*	-20	71.3	63.4*	-7.9
	Percent Exceeding 55 mph	93.8	90.7	-3.1	99.5	99.1	-0.4
	Std. Dev. (mph)	5.5	4.9	-0.6	5.5	4.7	-0.8
Legibility Point	Mean Speed (mph)	65.7	64.9	-0.8*	58.0	58.1	0
	85th Speed (mph)	71.3	70.4	-0.9	63.8	65.0	1.2
	10 mph pace (mph)	59-69	59-69	0	55-65	55-65	0
	Percent Exceeding 70 mph	8.6	9.9	1.3	53.5	48.9	-4.6
	Percent Exceeding 55 mph	63.9	63.6	-0.3	96.5	95.2	-1.3
	Std. Dev. (mph)	5.9	5.9	0	5.9	5.7	-0.2
Downstream Point	Mean Speed (mph)	61.1	60.0	-1.1*	55.1	54.8	-0.3
	85th Speed (mph)	68.2	66.5*	-1.7	59.8	59.9	0.1
	10 mph pace (mph)	54-64	54-64	0	49-59	49-59	0
	Percent Exceeding 70 mph	4.8	3.3	-1.5	28.3	20.0*	-8.3
	Percent Exceeding 55 mph	45.4	41.4	-4	81.5	77.7	-3.8
	Std. Dev. (mph)	6.8	6.4	-0.4	5.8	5.3	-0.5

* Indicates value is statistically significant at 95% confidence level compared to MP_S.

TABLE A-13 Daytime Results for Treatment Pair MP_R versus HI_R, Passenger Vehicles

Location	Measure of Effectiveness	SH 7 - Marlin			SH 14 - Wortham		
		HI_R	MP_R	MP_R-HI_R	HI_R	MP_R	MP_R-HI_R
	Sample Size	1695	1712	-	1071	1192	-
Control Point	Mean Speed (mph)	70.77	67.9	-2.9*	67.7	64.4	-3.2*
	85th Speed (mph)	76.8	73.2*	-3.6	73.2	69.2*	-4
	10 mph pace (mph)	66-76	64-74	-2	63-73	59-69	-4
	Percent Exceeding 70 mph	57.9	39.1*	-18.8	35.6	11.1*	-24.5
	Percent Exceeding 55 mph	98.5	96.7*	-1.8	97.5	95.2*	-2.3
	Std. Dev. (mph)	6.6	5.9	-0.7	5.6	5.2	-0.4
Legibility Point	Mean Speed (mph)	72.3	69.4	-2.9*	61.7	61.7	0
	85th Speed (mph)	80.2	76.0*	-4.2	68.2	69.0	0.8
	10 mph pace (mph)	67-77	66-76	-1	56-66	55-65	-1
	Percent Exceeding 70 mph	60.9	44.5*	-16.4	9.5	9.8	0.3
	Percent Exceeding 55 mph	99.4	98.2*	-1.2	85.4	81.5*	-3.9
	Std. Dev. (mph)	7.2	6.5	-0.7	6.3	6.5	0.2
Downstream Point	Mean Speed (mph)	59.8	60.8	1.0*	56.5	57.1	0.5
	85th Speed (mph)	66.9	68.2*	1.3	62.7	63.4*	0.7
	10 mph pace (mph)	53-63	54-64	1	50-60	50-60	0
	Percent Exceeding 70 mph	7.5	8.6	1.1	3.2	3.3	0.1
	Percent Exceeding 55 mph	74.6	79.2*	4.6	55.2	58.5	3.3
	Std. Dev. (mph)	6.7	6.7	0	6.0	6.0	0

* Indicates value is statistically significant at 95% confidence level compared to HI_R.

TABLE A-14 Daytime Results for Treatment Pair MP_R versus HI_R, Heavy Vehicles

Location	Measure of Effectiveness	SH 7 - Marlin			SH 14 - Wortham		
		HI_R	MP_R	MP_R-HI_R	HI_R	MP_R	MP_R-HI_R
	Sample Size	332	269	-	285	275	-
Control Point	Mean Speed (mph)	70.9	67.3	-3.6*	66.3	62.2	-4.1*
	85th Speed (mph)	76.3	73.1*	-3.2	70.8	66.9*	-3.9
	10 mph pace (mph)	66-76	62-72	-4	61-71	56-66	-5
	Percent Exceeding 70 mph	58.1	30.5*	-27.6	20.4	3.3*	-17.1
	Percent Exceeding 55 mph	99.4	97.4*	-2.0	97.9	94.9	-3.0
	Std. Dev. (mph)	5.6	5.8	0.2	5.2	4.7	-0.5
Legibility Point	Mean Speed (mph)	73.6	70.2	-3.4*	61.3	60.5	-0.8
	85th Speed (mph)	80.2	76.0*	-4.2	66.1	66.0	-0.1
	10 mph pace (mph)	70-80	67-77	-3	57-67	55-65	-2
	Percent Exceeding 70 mph	71.4	48.7*	-22.7	2.1	2.9	0.8
	Percent Exceeding 55 mph	99.4	99.3	-0.1	90.5	84.4*	-6.1
	Std. Dev. (mph)	6.4	5.9	-0.5	5.2	5.2	0.0
Downstream Point	Mean Speed (mph)	61.2	61.8	0.6	56.8	57.2	0.3
	85th Speed (mph)	67.9	68.1	0.2	62.0	62.0	0.0
	10 mph pace (mph)	55-65	56-66	1	50-60	50-60	0
	Percent Exceeding 70 mph	9.9	11.2	1.3	1.4	2.2	0.8
	Percent Exceeding 55 mph	85.5	86.6	1.1	63.9	64.4	0.5
	Std. Dev. (mph)	6.3	6.4	0.1	5.0	5.1	0.1

* Indicates value is statistically significant at 95% confidence level compared to HI_R.

TABLE A-15 Daytime Results for Treatment Pair MP_R versus HI_R, All Vehicles

Location	Measure of Effectiveness	SH 7 - Marlin			SH 14 - Wortham		
		HI_R	MP_R	MP_R-HI_R	HI_R	MP_R	MP_R-HI_R
	Sample Size	2027	1981	-	1356	1467	-
Control Point	Mean Speed (mph)	70.8	67.8	-3.0*	67.4	64.0	-3.4*
	85th Speed (mph)	76.8	73.2*	-3.6	72.7	69.0*	-3.7
	10 mph pace (mph)	66-77	64-74	-2	62-72	59-69	-3
	Percent Exceeding 70 mph	57.9	38.0*	-19.9	32.4	9.6*	-22.8
	Percent Exceeding 55 mph	98.6	96.8*	-1.8	97.6	95.2*	-2.4
	Std. Dev. (mph)	6.4	5.9	-0.5	5.6	5.2	-0.4
Legibility Point	Mean Speed (mph)	72.5	69.5	-3.0*	61.6	61.4	-0.1
	85th Speed (mph)	80.2	76.0*	-4.2	67.8	68.0	0.2
	10 mph pace (mph)	67-77	66-76	-1	57-67	55-65	-2
	Percent Exceeding 70 mph	62.7	45.1*	-17.6	8.0	8.5	0.5
	Percent Exceeding 55 mph	99.4	98.4*	-1	86.5	82.1*	-4.4
	Std. Dev. (mph)	7.1	6.4	-0.7	6.1	6.3	0.2
Downstream Point	Mean Speed (mph)	60.0	60.9	0.9*	56.6	57.1	0.5
	85th Speed (mph)	67.3	68.2*	0.9	62.7	63.1	0.4
	10 mph pace (mph)	54-64	54-64	0	50-60	50-60	0
	Percent Exceeding 70 mph	7.9	9.0	1.1	2.8	3.1	0.3
	Percent Exceeding 55 mph	76.4	80.2*	3.8	57.0	59.6	2.6
	Std. Dev. (mph)	6.7	6.7	0	5.8	5.9	0.1

* Indicates value is statistically significant at 95% confidence level compared to HI_R.

TABLE A-16 Nighttime Results for Treatment Pair MP_R versus HI_R, Passenger Vehicles

Location	Measure of Effectiveness	SH 7 - Marlin			SH 14 - Wortham		
		HI_R	MP_R	MP_R-HI_R	HI_R	MP_R	MP_R-HI_R
	Sample Size	371	365	-	275	217	-
Control Point	Mean Speed (mph)	68.1	65.5	-2.6*	64.6	61.7	-2.8*
	85th Speed (mph)	74.5	71.8*	-2.7	70.4	66.1*	-4.3
	10 mph pace (mph)	64-74	61-71	-3	59-69	56-66	-3
	Percent Exceeding 70 mph	70.1	55.3*	-14.8	44.0	24.4*	-19.6
	Percent Exceeding 55 mph	96.2	93.2	-3.0	93.5	90.8	-2.7
	Std. Dev. (mph)	6.9	6.8	-0.1	6.1	5.0	-1.1
Legibility Point	Mean Speed (mph)	68.9	65.9	-3.0*	59.3	57.7	-1.7*
	85th Speed (mph)	77.4	73.0*	-4.4	66.1	63.6	-2.5
	10 mph pace (mph)	62-72	59-69	-3	55-65	55-65	0
	Percent Exceeding 70 mph	68.5	51.2*	-17.3	17.5	10.6*	-6.9
	Percent Exceeding 55 mph	96.2	93.2	-3.0	71.3	60.8*	-10.5
	Std. Dev. (mph)	7.9	7.3	-0.6	6.6	5.9	-0.7
Downstream Point	Mean Speed (mph)	57.5	57.7	0.2	54.8	54.4	-0.4
	85th Speed (mph)	65.3	64.6	-0.7	60.6	59.6	-1.0
	10 mph pace (mph)	50-60	50-60	0	48-58	49-59	1
	Percent Exceeding 70 mph	15.6	14.0	-1.6	7.6	3.2*	-4.4
	Percent Exceeding 55 mph	58.5	63.0	4.5	41.1	38.2	-2.9
	Std. Dev. (mph)	7.3	7.1	-0.2	6.5	5.5	-1.0

* Indicates value is statistically significant at 95% confidence level compared to HI_R.

TABLE A-17 Nighttime Results for Treatment Pair MP_R versus HI_R, Heavy Vehicles

Location	Measure of Effectiveness	SH 7 - Marlin			SH 14 - Wortham		
		HI_R	MP_R	MP_R-HI_R	HI_R	MP_R	MP_R-HI_R
	Sample Size	95	98	-	75	85	-
Control Point	Mean Speed (mph)	68.7	65.8	-2.9*	64.3	60.5	-3.8*
	85th Speed (mph)	73.2	69.7*	-3.5	68.5	64.2*	-4.3
	10 mph pace (mph)	64-74	60-70	-4	57-67	56-66	-1
	Percent Exceeding 70 mph	81.1	59.2*	-21.9	46.7	5.9*	-40.8
	Percent Exceeding 55 mph	98.9	100.0	1.1	97.3	90.6	-6.7
	Std. Dev. (mph)	5.1	4.6	-0.5	5.8	3.8	-2.0
Legibility Point	Mean Speed (mph)	70.6	67.1	-3.4*	59.8	59.1	-0.8
	85th Speed (mph)	76.3	72.0*	-4.3	66.4	65.0	-1.4
	10 mph pace (mph)	66-76	62-72	-4	55-65	55-65	0
	Percent Exceeding 70 mph	78.9	62.2*	-16.7	20.0	8.2*	-11.8
	Percent Exceeding 55 mph	98.9	98.0	-0.9	84.0	70.6*	-13.4
	Std. Dev. (mph)	6.1	5.7	-0.4	5.5	5.0	-0.5
Downstream Point	Mean Speed (mph)	59.0	59.5	0.5	55.7	55.7	0.0
	85th Speed (mph)	64.2	66.5	2.3	61.3	60.6	-0.7
	10 mph pace (mph)	53-63	53-63	0	48-58	50-60	2
	Percent Exceeding 70 mph	10.5	20.4	9.9	8.0	3.5	-4.5
	Percent Exceeding 55 mph	75.8	76.5	0.7	46.7	49.4	2.7
	Std. Dev. (mph)	5.7	6.5	0.8	5.5	4.5	-1.0

* Indicates value is statistically significant at 95% confidence level compared to HI_R.

TABLE A-18 Nighttime Results for Treatment Pair MP_R versus HI_R, All Vehicles

Location	Measure of Effectiveness	SH 7 – Marlin			SH 14 - Wortham		
		HI_R	MP_R	MP_R-HI_R	HI_R	MP_R	MP_R-HI_R
	Sample Size	466	463	-	350	302	-
Control Point	Mean Speed (mph)	68.3	65.5	-2.7*	64.5	61.4	-3.1*
	85th Speed (mph)	74.2	71.3*	-2.9	70.4	66.1*	-4.3
	10 mph pace (mph)	64-74	60-70	-4	59-69	56-66	-3
	Percent Exceeding 70 mph	72.3	56.2*	-16.1	44.6	19.2*	-25.4
	Percent Exceeding 55 mph	96.8	94.6	-2.2	94.3	90.7	-3.6
	Std. Dev. (mph)	6.6	6.4	-0.2	6.1	4.7	-1.4
Legibility Point	Mean Speed (mph)	69.2	66.1	-3.1*	59.4	58.1	-1.4*
	85th Speed (mph)	76.8	73*	-3.8	66.1	65*	-1.1
	10 mph pace (mph)	62-72	62-72	0	55-65	55-65	0
	Percent Exceeding 70 mph	70.6	53.6*	-17.0	18.0	9.9*	-8.1
	Percent Exceeding 55 mph	96.8	94.2	-2.6	74.0	63.6*	-10.4
	Std. Dev. (mph)	7.6	7.0	-0.6	6.4	5.7	-0.7
Downstream Point	Mean Speed (mph)	57.8	58.1	0.3	55.0	54.8	-0.2
	85th Speed (mph)	64.9	65.3	0.4	61.2	59.9	-1.3
	10 mph pace (mph)	50-60	52-62	2	48-58	49-59	1
	Percent Exceeding 70 mph	14.6	15.3	0.7	7.7	3.3*	-4.4
	Percent Exceeding 55 mph	62	65.9	3.9	42.3	41.4	-0.9
	Std. Dev. (mph)	7.1	7.0	-0.1	6.3	5.3	-1.0

* Indicates value is statistically significant at 95% confidence level compared to HI_R.

APPENDIX B

ADDED BORDER STUDY RESULTS

The added border study was completed at three sites to evaluate the short-term and the long-term effects of adding a red border to the standard Speed Limit sign. The speed data were collected at five points for specified sign treatments at each site. The data were analyzed to compute: the mean speeds, 85^{th} percentile speeds, the 10 mph pace values, the percent exceeding upstream and downstream speed limits. The data for daytime and nighttime vehicles were analyzed separately. The results for each lighting condition were further grouped as passenger vehicles, heavy vehicles and all vehicles combined. This appendix presents these detailed results for the added border study. Tables are organized by sites, and for each site, the daytime results are followed by the nighttime results. The daytime and the nighttime results show separate tables for passenger vehicle, heavy vehicle and finally for all vehicles combined. The asterisk (*) next to a value indicates that the values are statistically significantly different at a 95% confidence level compared to the long-term value.

TABLE B-1 Daytime Results for Passenger Vehicles at SH 21

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	1176	1075	2022	-	-
Control Point	Mean Speed (mph)	69.2	70.6	70.7	1.5*	0.1
	85th Speed (mph)	74.0*	75.0	75.0	1.0	0.0
	10 mph pace (mph)	65-75	67-77	65-75	0	-2
	Percent Exceeding 70 mph	40.0*	56.1	56.1	16.1	0
	Percent Exceeding 55 mph	99.4	99.0	99.2	-0.2	0.2
Threshold Point	Mean Speed (mph)	68.6	70.7	65.9	-2.7*	-4.8*
	85th Speed (mph)	74.0*	76.0*	71.0	-3.0	-5.0
	10 mph pace (mph)	65-75	67-77	61-71	-4	-6
	Percent Exceeding 70 mph	38.3*	57.4*	16.3	-22.0	-41.1
	Percent Exceeding 55 mph	98.7*	98.5*	96.2	-2.5	-2.3
Legibility Point	Mean Speed (mph)	-	64.5	65.2	-	0.7*
	85th Speed (mph)	-	70*	71	-	1
	10 mph pace (mph)	-	61-71	61-71	-	0
	Percent Exceeding 70 mph	-	14.5*	18.3	-	3.8
	Percent Exceeding 55 mph	-	90.5*	94.4	-	3.9
Sign Point	Mean Speed (mph)	63.5	64.7	66.1	2.6*	1.4*
	85th Speed (mph)	70*	71*	74	4	3
	10 mph pace (mph)	59-69	61-71	60-70	1	-1
	Percent Exceeding 70 mph	14.5*	18.5*	27	12.5	8.5
	Percent Exceeding 55 mph	87.9*	90.5*	93.8	5.9	3.3
Downstream Point	Mean Speed (mph)	63.1	62.3	59.6	-3.5*	-2.7*
	85th Speed (mph)	71*	69*	67	-4	-2
	10 mph pace (mph)	55-65	55-65	53-63	-2	-2
	Percent Exceeding 70 mph	16.0*	12.3*	4.9	-11.1	-7.4
	Percent Exceeding 55 mph	87.0*	84.1*	70.3	-16.7	-13.8

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-2 Daytime Results for Heavy Vehicles at SH 21

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	109	107	237	-	-
Control Point	Mean Speed (mph)	66.1	66.3	67.3	1.2	1
	85th Speed (mph)	72	71*	73	1	2
	10 mph pace (mph)	61-71	62-72	63-73	2	1
	Percent Exceeding 70 mph	21.1	22.4	27.4	6.3	5.0
	Percent Exceeding 55 mph	95.4	98.1	95.8	0.4	-2.3
Threshold Point	Mean Speed (mph)	65.7	66.8	63.3	-2.4*	-3.5*
	85th Speed (mph)	72*	72*	69	-3	-3
	10 mph pace (mph)	59-69	61-71	59-69	0	-2
	Percent Exceeding 70 mph	21.1*	24.3*	5.5	-15.6	-18.8
	Percent Exceeding 55 mph	95.4	99.1*	91.1	-4.3	-8.0
Legibility Point	Mean Speed (mph)	-	60.9	62.7	-	1.8*
	85th Speed (mph)	-	67	69	-	2
	10 mph pace (mph)	-	57-67	60-70	-	3
	Percent Exceeding 70 mph	-	3.7	7.6	-	3.9
	Percent Exceeding 55 mph	-	85	89.9	-	4.9
Sign Point	Mean Speed (mph)	61.1	61.2	63.9	2.8*	2.7*
	85th Speed (mph)	68	67*	71	3	4
	10 mph pace (mph)	55-65	57-67	59-69	4	2
	Percent Exceeding 70 mph	8.3*	3.7*	16	7.7	12.3
	Percent Exceeding 55 mph	78.9*	86.9	91.1	12.2	4.2
Downstream Point	Mean Speed (mph)	61	59.3	57.9	-3.1*	-1.4
	85th Speed (mph)	68	66	64	-4	-2
	10 mph pace (mph)	53-63	52-62	51-61	-2	-1
	Percent Exceeding 70 mph	11.0*	1.9	2.1	-8.9	0.2
	Percent Exceeding 55 mph	78.9*	76.6*	60.8	-18.1	-15.8

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-3 Daytime Results for All Vehicles at SH 21

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	1285	1182	2259	-	-
Control Point	Mean Speed (mph)	69	70.2	70.4	1.4*	0.2
	85th Speed (mph)	74*	75	75	1	0
	10 mph pace (mph)	65-75	65-75	65-75	0	0
	Percent Exceeding 70 mph	38.4*	53	53.1	14.7	0.1
	Percent Exceeding 55 mph	99.1	98.9	98.8	-0.3	-0.1
Threshold Point	Mean Speed (mph)	68.4	70.4	65.7	-2.7*	-4.7*
	85th Speed (mph)	74*	76*	71	-3	-5
	10 mph pace (mph)	65-75	67-77	61-71	-4	-6
	Percent Exceeding 70 mph	36.8*	54.4*	15.1	-21.7	-39.3
	Percent Exceeding 55 mph	98.4*	98.6*	95.7	-2.7	-2.9
Legibility Point	Mean Speed (mph)	-	64.2	65	-	0.8*
	85th Speed (mph)	-	70*	71	-	1
	10 mph pace (mph)	-	61-71	61-71	-	0
	Percent Exceeding 70 mph	-	13.5*	17.2	-	3.7
	Percent Exceeding 55 mph	-	90.0*	93.9	-	3.9
Sign Point	Mean Speed (mph)	63.3	64.3	65.8	2.5*	1.5*
	85th Speed (mph)	70*	71*	73	3	2
	10 mph pace (mph)	59-69	60-70	60-70	1	0
	Percent Exceeding 70 mph	14.0*	17.2*	25.9	11.9	8.7
	Percent Exceeding 55 mph	87.2*	90.2*	93.5	6.3	3.3
Downstream Point	Mean Speed (mph)	63	62	59.4	-3.6*	-2.6*
	85th Speed (mph)	71*	69*	67	-4	-2
	10 mph pace (mph)	55-65	55-65	53-63	-2	-2
	Percent Exceeding 70 mph	15.6*	11.3*	4.6	-11	-6.7
	Percent Exceeding 55 mph	86.3*	83.4*	69.3	-17	-14.1

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-4 Nighttime Results for Passenger Vehicles at SH 21

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	335	225	652	-	-
Control Point	Mean Speed (mph)	65.8	66.3	67.7	1.9*	1.4*
	85th Speed (mph)	71	72	73	2	1
	10 mph pace (mph)	59-69	62-72	62-72	-3	0
	Percent Exceeding 65 mph	46.9*	61.8	66.7	19.8	4.9
	Percent Exceeding 55 mph	96.1	95.1*	98.2	2.1	3.1
Threshold Point	Mean Speed (mph)	65	65.7	62.9	-2.1*	-2.8*
	85th Speed (mph)	71*	73*	69	-2	-4
	10 mph pace (mph)	57-67	63-73	59-69	2	-4
	Percent Exceeding 65 mph	46.3*	50.7*	32.2	-14.1	-18.5
	Percent Exceeding 55 mph	94.9*	95.1*	89.7	-5.2	-5.4
Legibility Point	Mean Speed (mph)	-	60.1	62.2	-	2.1*
	85th Speed (mph)	-	68	69	-	1
	10 mph pace (mph)	-	59-69	57-67	-	-2
	Percent Exceeding 65 mph	-	23.6	29.4	-	5.8
	Percent Exceeding 55 mph	-	66.7*	84.7	-	18
Sign Point	Mean Speed (mph)	60.1	60.3	63.1	3*	2.8*
	85th Speed (mph)	67*	68*	70	3	2
	10 mph pace (mph)	55-65	56-66	57-67	2	1
	Percent Exceeding 65 mph	21.2*	25.3*	34	12.8	8.7
	Percent Exceeding 55 mph	75.2*	72.0*	86.8	11.6	14.8
Downstream Point	Mean Speed (mph)	60.2	58.3	57.7	-2.5*	-0.6
	85th Speed (mph)	67*	65	64	-3	-1
	10 mph pace (mph)	55-65	53-63	51-61	-4	-2
	Percent Exceeding 65 mph	19.4*	15.1	11.2	-8.2	-3.9
	Percent Exceeding 55 mph	76.7*	63.1	59	-17.7	-4.1

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-5 Nighttime Results for Heavy Vehicles at SH 21

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	42	28	89	-	-
Control Point	Mean Speed (mph)	64.1	66.2	66.2	2.1*	0
	85th Speed (mph)	68	74	70	2	-4
	10 mph pace (mph)	57-67	65-75	61-71	4	-4
	Percent Exceeding 65 mph	28.6*	60.7	60.7	32.1	0
	Percent Exceeding 55 mph	100	89.3	96.6	-3.4	7.3
Threshold Point	Mean Speed (mph)	65.2	65.9	62.4	-2.8*	-3.5*
	85th Speed (mph)	70	70*	67	-3	-3
	10 mph pace (mph)	57-67	60-70	59-69	2	-1
	Percent Exceeding 65 mph	45.2*	57.1*	24.7	-20.5	-32.4
	Percent Exceeding 55 mph	97.6	92.9	94.4	-3.2	-3.2
Legibility Point	Mean Speed (mph)	-	60.6	61.8	-	1.2
	85th Speed (mph)	-	66	67	-	1
	10 mph pace (mph)	-	55-65	57-67	-	2
	Percent Exceeding 65 mph	-	17.9	21.3	-	3.4
	Percent Exceeding 55 mph	-	67.9*	92.1	-	24.2
Sign Point	Mean Speed (mph)	60.4	61.3	63.5	3.1*	2.2
	85th Speed (mph)	65*	68	69	4	1
	10 mph pace (mph)	55-65	55-65	59-69	4	4
	Percent Exceeding 65 mph	9.5*	21.4	33.7	24.2	24.2
	Percent Exceeding 55 mph	76.2*	75.0*	93.3	17.1	18.3
Downstream Point	Mean Speed (mph)	60.4	59.3	57.7	-2.7*	-1.6
	85th Speed (mph)	64	67*	63	-1	-4
	10 mph pace (mph)	55-65	53-63	54-64	-1	1
	Percent Exceeding 65 mph	9.5	17.9	6.7	-2.8	-11.2
	Percent Exceeding 55 mph	71.4	67.9	65.2	-6.2	-2.7

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-6 Nighttime Results for All Vehicles at SH 21

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	377	253	741	-	-
Control Point	Mean Speed (mph)	65.6	66.3	67.5	1.9*	1.2*
	85th Speed (mph)	71	72	72	1	0
	10 mph pace (mph)	61-71	63-73	62-72	1	-1
	Percent Exceeding 65 mph	44.8*	61.7	66	21.2	4.3
	Percent Exceeding 55 mph	96.6	94.5*	98	1.4	3.5
Threshold Point	Mean Speed (mph)	65	65.7	62.9	-2.1*	-2.8*
	85th Speed (mph)	71*	73*	69	-2	-4
	10 mph pace (mph)	57-67	63-73	59-69	2	-4
	Percent Exceeding 65 mph	46.2*	51.4*	31.3	-14.9	-20.1
	Percent Exceeding 55 mph	95.2*	94.9*	90.3	-4.9	-4.6
Legibility Point	Mean Speed (mph)	-	60.1	62.1	-	2*
	85th Speed (mph)	-	68	69	-	1
	10 mph pace (mph)	-	59-69	57-67	-	-2
	Percent Exceeding 65 mph	-	22.9	28.5	-	5.6
	Percent Exceeding 55 mph	-	66.8*	85.6	-	18.8
Sign Point	Mean Speed (mph)	60.1	60.5	63.2	3.1*	2.7*
	85th Speed (mph)	66*	68*	70	4	2
	10 mph pace (mph)	55-65	57-67	57-67	2	0
	Percent Exceeding 65 mph	19.9*	24.9*	34	14.1	9.1
	Percent Exceeding 55 mph	75.3*	72.3*	87.6	12.3	15.3
Downstream Point	Mean Speed (mph)	60.2	58.4	57.7	-2.5*	-0.7
	85th Speed (mph)	67*	66	64	-3	-2
	10 mph pace (mph)	55-65	53-63	52-62	-3	-1
	Percent Exceeding 65 mph	18.3*	15.4*	10.7	-7.6	-4.7
	Percent Exceeding 55 mph	76.1*	66.3	59.8	-16.3	-6.5

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-7 Daytime Results for Passenger Vehicles at FM 60

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	1399	333	1511	-	-
Control Point	Mean Speed (mph)	70.3	70.8	67.4	-2.9*	-3.4*
	85th Speed (mph)	76.0*	76.0*	72.0	-3.8	-3.8
	10 mph pace (mph)	66-76	67-77	62-72	-4	-5
	Percent Exceeding 70 mph	46.6*	54.4*	29.7	-16.9	-24.7
	Percent Exceeding 55 mph	99.0*	98.5	97.3	-1.7	-1.2
Threshold Point	Mean Speed (mph)	68.5	67.6	63.4	-5.1*	-4.2*
	85th Speed (mph)	75.0*	73.0*	69.5	-5.5	-3.5
	10 mph pace (mph)	63-73	63-73	59-69	-4	-4
	Percent Exceeding 70 mph	36.3*	32.7*	12.2	-24.1	-20.5
	Percent Exceeding 55 mph	97.6*	96.1*	91.3	-6.3	-4.8
Legibility Point	Mean Speed (mph)	66.3	66.4	66.4	0.1	0.0
	85th Speed (mph)	72.0*	73.0*	73.2	1.2	0.2
	10 mph pace (mph)	60-70	63-73	62-72	2	-1
	Percent Exceeding 70 mph	20.9*	23.1*	30.6	9.7	7.5
	Percent Exceeding 55 mph	96.5	93.7	95	-1.5	1.3
Sign Point	Mean Speed (mph)	67.2	66.3	60.8	-6.4*	-5.5*
	85th Speed (mph)	73.0*	73.0*	67.3	-5.7	-5.7
	10 mph pace (mph)	63-73	63-73	56-66	-7	-7
	Percent Exceeding 70 mph	28.4*	24.3*	5.6	-22.8	-18.7
	Percent Exceeding 55 mph	96.7*	93.7*	81.8	-14.9	-11.9
Downstream Point	Mean Speed (mph)	65.1	64.7	57.6	-7.5*	-7.1*
	85th Speed (mph)	72.0*	71.0*	63.8	-8.2	-7.2
	10 mph pace (mph)	58-68	58-68	52-62	-6	-6
	Percent Exceeding 70 mph	18.1*	18.0*	1.8	-16.2	-16.2
	Percent Exceeding 55 mph	93.6*	90.7*	63.9	-29.7	-26.8

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-8 Daytime Results for Heavy Vehicles at FM 60

Location	Measure of Effectiveness	Before (B1)	Long-term (A2)	A2-B1
	Sample Size	159	190	-
Control Point	Mean Speed (mph)	68.6	64.2	-4.4*
	85th Speed (mph)	74.5*	70.2	-4.3
	10 mph pace (mph)	63-73	60-70	-3
	Percent Exceeding 70 mph	32.7*	15.3	-17.4
	Percent Exceeding 55 mph	99.4*	93.2	-6.2
Threshold Point	Mean Speed (mph)	67.2	61.5	-5.7*
	85th Speed (mph)	73.0*	67.3	-5.7
	10 mph pace (mph)	60-70	58-68	-2
	Percent Exceeding 70 mph	23.3*	9.5	-13.8
	Percent Exceeding 55 mph	97.5*	84.2	-13.3
Legibility Point	Mean Speed (mph)	65.6	64.6	-1
	85th Speed (mph)	73.0	70.8	-2.2
	10 mph pace (mph)	58-68	59-69	1
	Percent Exceeding 70 mph	15.7	19.5	3.8
	Percent Exceeding 55 mph	96.2*	89.5	-6.7
Sign Point	Mean Speed (mph)	66.1	59.6	-6.5*
	85th Speed (mph)	73.2*	65.3	-7.9
	10 mph pace (mph)	60-70	55-65	-5
	Percent Exceeding 70 mph	20.8*	3.7	-17.1
	Percent Exceeding 55 mph	96.9*	77.9	-19.0
Downstream Point	Mean Speed (mph)	64.5	56.6	-7.9*
	85th Speed (mph)	72.0*	61.9	-10.1
	10 mph pace (mph)	58-68	50-60	-8
	Percent Exceeding 70 mph	14.5*	1.1	-13.4
	Percent Exceeding 55 mph	91.8*	62.1	-29.7

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-9 Daytime Results for All Vehicles at FM 60

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	1558	349	1701	-	-
Control Point	Mean Speed (mph)	70.1	70.9	67.1	-3.0*	-3.8*
	85th Speed (mph)	76.0*	76.0*	72.2	-3.8	-3.8
	10 mph pace (mph)	66-76	67-77	62-72	-4	-5
	Percent Exceeding 70 mph	45.2*	54.7*	28.1	-17.1	-17.1
	Percent Exceeding 55 mph	99.0*	98.6	96.8	-2.2	-1.8
Threshold Point	Mean Speed (mph)	68.3	67.7	63.2	-5.1*	-4.5*
	85th Speed (mph)	74.0*	73.0*	69.5	-4.5	-3.5
	10 mph pace (mph)	63-73	63-73	59-69	-4	-4
	Percent Exceeding 70 mph	35.0*	33.8*	11.9	-23.1	-21.9
	Percent Exceeding 55 mph	97.6*	96.3*	90.5	-7.1	-5.8
Legibility Point	Mean Speed (mph)	66.2	66.5	66.2	0.0	-0.3
	85th Speed (mph)	72.0*	73.0*	73.2	1.2	0.2
	10 mph pace (mph)	60-70	63-73	60-70	0	-3
	Percent Exceeding 70 mph	20.3*	24.1*	29.4	9.1	5.3
	Percent Exceeding 55 mph	96.5*	94.0	94.4	-2.1	0.4
Sign Point	Mean Speed (mph)	67.1	66.4	60.7	-6.4*	-5.7*
	85th Speed (mph)	73.0*	73.0*	67.3	-5.7	-5.7
	10 mph pace (mph)	63-73	63-73	56-66	-7	-7
	Percent Exceeding 70 mph	27.7*	25.2*	5.3	-22.4	-19.9
	Percent Exceeding 55 mph	96.7*	94.0*	81.4	-15.3	-12.6
Downstream Point	Mean Speed (mph)	65.0	64.9	57.5	-7.5*	-7.4*
	85th Speed (mph)	72.0*	72.0*	63.8	-8.2	-8.2
	10 mph pace (mph)	58-68	56-66	50-60	-8	-6
	Percent Exceeding 70 mph	17.7*	18.9*	1.7	-16.0	-17.2
	Percent Exceeding 55 mph	93.4*	91.1*	63.7	-29.7	-27.4

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-10 Nighttime Results for Passenger Vehicles at FM 60

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	473	174	623	-	-
Control Point	Mean Speed (mph)	67.0	68.6	65.9	-1.1*	-2.7*
	85th Speed (mph)	73.0	75.0*	71.3	-1.7	-3.7
	10 mph pace (mph)	60-70	66-76	60-70	0	-6
	Percent Exceeding 65 mph	61.1*	70.7*	52.3	-8.8	-18.4
	Percent Exceeding 55 mph	98.1	97.7	96.5	-1.6	-1.2
Threshold Point	Mean Speed (mph)	63.4	63.3	61.2	-2.2*	-2.1*
	85th Speed (mph)	70.0*	69.0	67.8	-2.2	-1.2
	10 mph pace (mph)	58-68	58-68	55-65	-3	-3
	Percent Exceeding 65 mph	35.5*	38.5*	25.5	-10	-13
	Percent Exceeding 55 mph	90.5*	89.7	84.6	-5.9	-5.1
Legibility Point	Mean Speed (mph)	62.2	62.2	64.1	1.9*	1.9*
	85th Speed (mph)	69.0*	68.0*	71.8	2.8	3.8
	10 mph pace (mph)	56-66	58-68	57-67	1	-1
	Percent Exceeding 65 mph	29.8*	31.6*	42.4	12.6	10.8
	Percent Exceeding 55 mph	85.8*	86.2*	91.5	5.7	5.3
Sign Point	Mean Speed (mph)	62.0	61.6	58.9	-3.1*	-2.7*
	85th Speed (mph)	69.0*	68.0*	65.7	-3.3	-2.3
	10 mph pace (mph)	57-67	55-65	55-65	-2	0
	Percent Exceeding 65 mph	32.8*	28.2*	17.5	-15.3	-10.7
	Percent Exceeding 55 mph	81.0*	81.6*	68.5	-12.5	-13.1
Downstream Point	Mean Speed (mph)	60.8	60.3	56.2	-4.6*	-4.1*
	85th Speed (mph)	68.0*	67.0*	62.3	-5.7	-4.7
	10 mph pace (mph)	54-64	54-64	50-60	-4	-4
	Percent Exceeding 65 mph	24.3*	20.7*	8.3	-16.0	-12.4
	Percent Exceeding 55 mph	75.1*	75.9*	52.3	-22.8	-22.8

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-11 Nighttime Results for Heavy Vehicles at FM 60

Location	Measure of Effectiveness	Before (B1)	Long-term (A2)	A2-B1
	Sample Size	25	32	-
Control Point	Mean Speed (mph)	65.2	63.0	-2.2
	85th Speed (mph)	71.0	68.0	-2.8
	10 mph pace (mph)	61-71	57-67	-4
	Percent Exceeding 65 mph	52.0	31.3	-20.7
	Percent Exceeding 55 mph	100.0	93.8	-6.2
Threshold Point	Mean Speed (mph)	62.1	58.3	-3.8*
	85th Speed (mph)	68.0	63.2	-4.8
	10 mph pace (mph)	56-66	55-65	-1
	Percent Exceeding 65 mph	28.0	12.5	-15.5
	Percent Exceeding 55 mph	96.0*	71.9	-24.1
Legibility Point	Mean Speed (mph)	60.7	60.8	0.1
	85th Speed (mph)	66.8	66.4	-0.4
	10 mph pace (mph)	56-66	55-65	-1
	Percent Exceeding 65 mph	20.0	21.9	1.9
	Percent Exceeding 55 mph	76.0	87.5	11.5
Sign Point	Mean Speed (mph)	60.3	56.5	-3.8*
	85th Speed (mph)	66.0	60.0	-5.6
	10 mph pace (mph)	56-66	55-65	-1
	Percent Exceeding 65 mph	24.0*	3.1	-20.9
	Percent Exceeding 55 mph	80.0	65.6	-14.4
Downstream Point	Mean Speed (mph)	60.0	54.4	-5.6*
	85th Speed (mph)	65.0*	59.0	-6.5
	10 mph pace (mph)	56-66	49-59	-7
	Percent Exceeding 65 mph	16.0	3.1	-12.9
	Percent Exceeding 55 mph	80.0*	46.9	-33.1

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-12 Nighttime Results for All Vehicles at FM 60

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	498	189	655	-	-
Control Point	Mean Speed (mph)	66.9	68.3	65.7	-1.2*	-2.6*
	85th Speed (mph)	73.0*	75.0*	71.3	-1.7	-3.7
	10 mph pace (mph)	61-71	66-76	60-70	-1	-6
	Percent Exceeding 65 mph	60.6*	69.3*	51.3	-9.3	-18
	Percent Exceeding 55 mph	98.2	97.9	96.3	-1.9	-1.6
Threshold Point	Mean Speed (mph)	63.4	63.1	61.1	-2.3*	-2*
	85th Speed (mph)	70.0*	69.0*	67.3	-2.7	-1.7
	10 mph pace (mph)	58-68	58-68	55-65	-3	-3
	Percent Exceeding 65 mph	35.1*	36.5*	24.9	-10.2	-11.6
	Percent Exceeding 55 mph	90.8*	89.4	84.0	-5.4	-5.4
Legibility Point	Mean Speed (mph)	62.1	62.1	63.9	1.8*	1.8*
	85th Speed (mph)	68.0*	68.0*	71.8	3.8	3.8
	10 mph pace (mph)	56-66	58-68	57-67	1	-1
	Percent Exceeding 65 mph	29.3*	30.2*	41.4	12.1	11.2
	Percent Exceeding 55 mph	85.3*	86.8	91.3	6.0	4.5
Sign Point	Mean Speed (mph)	62.0	61.5	58.8	-3.2*	-2.7*
	85th Speed (mph)	69.0*	68.0*	65.3	-3.7	-2.7
	10 mph pace (mph)	57-67	55-65	55-65	-2	0
	Percent Exceeding 65 mph	32.3*	27.0*	16.8	-15.5	-10.2
	Percent Exceeding 55 mph	80.9*	82.5*	68.4	-12.5	-14.1
Downstream Point	Mean Speed (mph)	60.8	60.2	56.1	-4.7*	-4.1*
	85th Speed (mph)	68.0*	66.8*	62.3	-5.7	-4.5
	10 mph pace (mph)	54-64	54-64	50-60	-4	-4
	Percent Exceeding 65 mph	23.9*	20.1*	8.1	-15.8	-12.0
	Percent Exceeding 55 mph	75.3*	76.2*	52.1	-23.2	-24.1

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-13 Daytime Results for Passenger Vehicles at SH 36

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	361	364	1315	-	-
Control Point	Mean Speed (mph)	71.0	72.8	71.3	0.3	-1.5*
	85th Speed (mph)	76.0	77.0*	75.8	-0.2	-1.2
	10 mph pace (mph)	68-78	68-78	65-75	-3	-3
	Percent Exceeding 70 mph	54.8*	65.7	61.1	6.3	-4.6
	Percent Exceeding 55 mph	100.0	100.0	99.3	-0.7	-0.7
Threshold Point	Mean Speed (mph)	68.7	69.2	68.3	-0.4	-0.9*
	85th Speed (mph)	73.0	74.0	73.7	0.7	-0.3
	10 mph pace (mph)	64-74	64-74	63-73	-1	-1
	Percent Exceeding 70 mph	39.9	38.7	38.7	-1.2	0
	Percent Exceeding 55 mph	96.4*	98.9	98.4	2	-0.5
Legibility Point	Mean Speed (mph)	68.2	68.5	66.4	-1.8*	-2.1*
	85th Speed (mph)	73.0*	74.0*	72.2	-0.8	-1.8
	10 mph pace (mph)	64-74	63-73	62-72	-2	-1
	Percent Exceeding 70 mph	34.9*	34.9*	26.7	-8.2	-8.2
	Percent Exceeding 55 mph	97.0	98.4*	95.9	-1.1	-2.5
Sign Point	Mean Speed (mph)	66.2	65.9	66.7	0.5	0.8
	85th Speed (mph)	72.0*	72.0*	74.2	2.2	2.2
	10 mph pace (mph)	63-73	63-73	63-73	0	0
	Percent Exceeding 70 mph	22.7*	19.0*	33.7	11.0	14.7
	Percent Exceeding 55 mph	94.7	96.4	95.1	0.4	-1.3
Downstream Point	Mean Speed (mph)	66.2	65.3	59.6	-6.6*	-5.7*
	85th Speed (mph)	73.0*	72.0*	66.1	-6.9	-5.9
	10 mph pace (mph)	58-68	59-69	53-63	-5	-6
	Percent Exceeding 70 mph	26.6*	19.8*	4.8	-21.8	-15.0
	Percent Exceeding 55 mph	95.0*	93.4*	74.0	-21.0	-19.4

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-14 Daytime Results for Heavy Vehicles at SH 36

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	157	116	255	-	-
Control Point	Mean Speed (mph)	67.6	70.0	69.2	1.6*	-0.8
	85th Speed (mph)	72.6	73.8*	72.2	-0.4	-1.6
	10 mph pace (mph)	63-73	65-75	63-73	0	-2
	Percent Exceeding 70 mph	25.5*	48.3	39.6	14.1	-8.7
	Percent Exceeding 55 mph	98.1	99.1	99.6	1.5	0.5
Threshold Point	Mean Speed (mph)	63.6	65.6	65.2	1.6*	-0.4
	85th Speed (mph)	68.0*	70.0	70.4	2.4	0.4
	10 mph pace (mph)	58-68	60-70	59-69	1	-1
	Percent Exceeding 70 mph	8.3*	12.9	15.7	7.4	2.8
	Percent Exceeding 55 mph	95.5*	97.4*	100	4.5	2.6
Legibility Point	Mean Speed (mph)	63.6	65.4	64.1	0.5	-1.3
	85th Speed (mph)	68.0	70.0	69.5	1.5	-0.5
	10 mph pace (mph)	56-66	60-70	59-69	3	-1
	Percent Exceeding 70 mph	7.0	14.7	11.0	4.0	-3.7
	Percent Exceeding 55 mph	96.8	97.4	96.9	0.1	-0.5
Sign Point	Mean Speed (mph)	62.1	63.9	64.9	2.8*	1.0
	85th Speed (mph)	66.0*	68.8	69.9	3.9	1.1
	10 mph pace (mph)	56-66	60-70	59-69	3	-1
	Percent Exceeding 70 mph	4.5*	9.5	14.5	10.0	5.0
	Percent Exceeding 55 mph	90.4*	94.8	98.0	7.6	3.2
Downstream Point	Mean Speed (mph)	62.3	63.8	58.5	-3.8*	-5.3*
	85th Speed (mph)	66.0*	69.8*	63.4	-2.6	-6.4
	10 mph pace (mph)	56-66	59-69	52-62	-4	-7
	Percent Exceeding 70 mph	7.6*	7.8*	1.2	-6.4	-6.6
	Percent Exceeding 55 mph	88.5*	93.1*	73.7	-14.8	-19.4

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-15 Daytime Results for All Vehicles at SH 36

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	518	480	1570	-	-
Control Point	Mean Speed (mph)	70.0	72.1	71.0	1.0*	-1.1*
	85th Speed (mph)	75.0	77.0*	75.2	0.2	-1.8
	10 mph pace (mph)	64-74	68-78	65-75	1	-3
	Percent Exceeding 70 mph	45.9*	61.5	57.6	11.7	-3.9
	Percent Exceeding 55 mph	99.4	99.8	99.4	0.0	-0.4
Threshold Point	Mean Speed (mph)	67.1	68.3	67.8	0.7	-0.5
	85th Speed (mph)	73.0*	73.0	73.2	0.2	0.2
	10 mph pace (mph)	63-73	63-73	62-72	-1	-1
	Percent Exceeding 70 mph	30.3	32.5	35.0	4.7	2.5
	Percent Exceeding 55 mph	96.1*	98.5	98.7	2.6	0.2
Legibility Point	Mean Speed (mph)	66.8	67.7	66.0	-0.8*	-1.7*
	85th Speed (mph)	73.0*	73.0*	71.8	-1.2	-1.2
	10 mph pace (mph)	63-73	63-73	62-72	-1	-1
	Percent Exceeding 70 mph	26.4	30.0*	24.1	-2.3	-5.9
	Percent Exceeding 55 mph	96.9	98.1*	96.1	-0.8	-2.0
Sign Point	Mean Speed (mph)	65.0	65.4	66.5	1.5*	1.1*
	85th Speed (mph)	71.0*	71.0*	73.7	2.7	2.7
	10 mph pace (mph)	60-70	63-73	62-72	2	-1
	Percent Exceeding 70 mph	17.2*	16.7*	30.6	13.4	13.9
	Percent Exceeding 55 mph	93.4	96.0	95.5	2.1	-0.5
Downstream Point	Mean Speed (mph)	65.0	64.9	59.4	-5.6*	-5.5*
	85th Speed (mph)	72.0*	71.2*	65.7	-6.3	-5.5
	10 mph pace (mph)	58-68	59-69	53-63	-5	-6
	Percent Exceeding 70 mph	20.8*	16.9*	4.2	-16.6	-12.7
	Percent Exceeding 55 mph	93.1*	93.3*	73.9	-19.2	-19.4

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-16 Nighttime Results for Passenger Vehicles at SH 36

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	120	63	347	-	-
Control Point	Mean Speed (mph)	68.2	69.2	68.5	0.3	-0.7
	85th Speed (mph)	73.0	75.0	74.0	1.0	-1.0
	10 mph pace (mph)	63-73	63-73	62-72	-1	-1
	Percent Exceeding 65 mph	70.0	84.1	77.8	7.8	-6.3
	Percent Exceeding 55 mph	100.0	98.4	98.6	-1.4	0.2
Threshold Point	Mean Speed (mph)	65.5	64.5	65.5	0.0	1.0
	85th Speed (mph)	71.0	70.0	71.0	0.0	1.0
	10 mph pace (mph)	60-70	60-70	60-70	0	0
	Percent Exceeding 65 mph	58.3	44.4	53.9	-4.4	9.5
	Percent Exceeding 55 mph	96.7	95.2	96.5	-0.2	1.3
Legibility Point	Mean Speed (mph)	64.9	64.1	64.1	-0.8	0.0
	85th Speed (mph)	70.0	69.0	70.0	0.0	1.0
	10 mph pace (mph)	60-70	59-69	59-69	-1	0
	Percent Exceeding 65 mph	51.7	41.3	46.1	-5.6	4.8
	Percent Exceeding 55 mph	95.0	93.7	93.1	-1.9	-0.6
Sign Point	Mean Speed (mph)	62.8	61.9	65.3	2.5*	3.4*
	85th Speed (mph)	69.0*	68.0*	72.0	3.0	4.0
	10 mph pace (mph)	59-69	56-66	59-69	0	3
	Percent Exceeding 65 mph	34.2*	27.0*	50.7	16.5	23.7
	Percent Exceeding 55 mph	89.2*	90.5	94.8	5.6	4.3
Downstream Point	Mean Speed (mph)	63.0	61.5	58.5	-4.5*	-3*
	85th Speed (mph)	70.0*	66.7*	65.0	-5.0	-1.7
	10 mph pace (mph)	56-66	56-66	54-64	-2	-2
	Percent Exceeding 65 mph	36.7*	23.8*	12.1	-24.6	-11.7
	Percent Exceeding 55 mph	90.0*	90.5*	68.6	-21.4	-21.9

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-17 Nighttime Results for Heavy Vehicles at SH 36

Location	Measure of Effectiveness	Before (B1)	Long-term (A2)	A2-B1
	Sample Size	118	116	-
Control Point	Mean Speed (mph)	66.6	65.9	-0.7
	85th Speed (mph)	70.0	70.5	0.5
	10 mph pace (mph)	61-71	60-70	-1
	Percent Exceeding 65 mph	67.8	56.0	-11.8
	Percent Exceeding 55 mph	100.0	100.0	0.0
Threshold Point	Mean Speed (mph)	60.5	60.7	0.2
	85th Speed (mph)	65.0	65.0	0.0
	10 mph pace (mph)	56-66	56-66	0
	Percent Exceeding 65 mph	14.4	17.2	2.8
	Percent Exceeding 55 mph	83.1	88.8	5.7
Legibility Point	Mean Speed (mph)	61.0	60.2	-0.8
	85th Speed (mph)	66.0	65.0	-1.0
	10 mph pace (mph)	55-65	55-65	1
	Percent Exceeding 65 mph	19.5	14.7	-4.8
	Percent Exceeding 55 mph	83.1	87.1	4.0
Sign Point	Mean Speed (mph)	59.6	61.5	1.9*
	85th Speed (mph)	65.0	67.0	2.0
	10 mph pace (mph)	55-65	56-66	1
	Percent Exceeding 65 mph	13.6	22.4	2.0
	Percent Exceeding 55 mph	74.6*	91.4	16.8
Downstream Point	Mean Speed (mph)	60.2	55.6	-4.6*
	85th Speed (mph)	66.0*	60.0	-6.0
	10 mph pace (mph)	54-64	51-61	-3
	Percent Exceeding 65 mph	16.1*	0.9	-15.2
	Percent Exceeding 55 mph	78.8*	54.3	-24.5

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

TABLE B-18 Nighttime Results for All Vehicles at SH 36

Location	Measure of Effectiveness	Before (B1)	Short-term (A1)	Long-term (A2)	A2-B1	A2-A1
	Sample Size	238	71	463	-	-
Control Point	Mean Speed (mph)	67.4	69.1	67.8	0.4	-1.3
	85th Speed (mph)	72.0	75.0	73.0	1.0	-2.0
	10 mph pace (mph)	63-73	63-73	62-72	0	-1
	Percent Exceeding 65 mph	68.9	84.5*	72.4	3.5	-12.1
	Percent Exceeding 55 mph	100.0*	98.6	98.9	-1.1	0.3
Threshold Point	Mean Speed (mph)	63.0	64.3	64.3	1.3*	0.0
	85th Speed (mph)	69.0*	70.0	70.0	1.0	0.0
	10 mph pace (mph)	58-68	60-70	59-69	1	-1
	Percent Exceeding 65 mph	36.6*	43.7	44.7	8.1	1.0
	Percent Exceeding 55 mph	89.9*	93.0	94.6	4.7	1.6
Legibility Point	Mean Speed (mph)	62.9	63.9	63.1	0.2	-0.8
	85th Speed (mph)	69.0	69.0	69.0	0.0	0.0
	10 mph pace (mph)	60-70	58-68	59-69	-1	1
	Percent Exceeding 65 mph	35.7	40.8	38.2	2.5	-2.6
	Percent Exceeding 55 mph	89.1	90.1	91.6	2.5	1.5
Sign Point	Mean Speed (mph)	61.2	61.8	64.3	3.1*	2.5*
	85th Speed (mph)	67.0*	68.0*	71.0	4.0	3.0
	10 mph pace (mph)	58-68	56-66	59-69	1	3
	Percent Exceeding 65 mph	23.9*	26.8*	43.6	19.7	16.8
	Percent Exceeding 55 mph	81.9*	87.3*	94.0	12.1	6.7
Downstream Point	Mean Speed (mph)	61.6	61.5	57.8	-3.8*	-3.7*
	85th Speed (mph)	68.0*	67.0*	64.0	-4.0	-3.0
	10 mph pace (mph)	56-66	56-66	52-62	0	-4
	Percent Exceeding 65 mph	26.5*	25.4*	9.3	-17.2	-16.1
	Percent Exceeding 55 mph	84.5*	87.3*	65.0	-19.5	-22.3

* Indicates value is statistically significant at 95% confidence level in comparison to long-term study.

APPENDIX C

STATISTICAL PROCEDURES

THE BOOTSTRAP PROCEDURE

Traditional parametric procedures are based on several major assumptions about the population(s) from which the data came. For example, common parametric tests, such as the ANOVA, t-test or test of binomial proportions, assume a known distribution of the data. However, our data does not always satisfy these underlying assumptions of normality or equal variances. As such a standard test like the ANOVA might not give us true results about significance between different samples. Another problem is, there are many situations where even with normality, we don't know enough about the statistic we are using to draw the appropriate inferences. For example, the standard error of the mean can be nicely estimated as $S_x = s/\sqrt{n}$. But what is the standard error of the quantiles, or the standard error of the difference between quantiles? For the median we can come pretty close to estimating the standard error if we know the exact distribution of the sample, which is very difficult to determine in most cases. In this particular case, due to large sample sizes, traditional normality tests showed that data were not normally distributed. As such, some other way e.g. the bootstrap procedure was needed to find that standard error or develop confidence intervals to determine significance.

One way to look at bootstrap procedures is as procedures for handling data when we are not willing to make assumptions about the parameters of the populations from which we sampled. The most that we are willing to assume (*and it is an absolutely critical assumption*) is that the data we have are a reasonable representation of the population from which they came. We then resample by replacement from the pool of data that we have, and draw inferences about the corresponding population and its parameters.

This procedure is described in work by Efron and Tibshirani (*20*). Simply defined a non-parametric bootstrap is a simulation method based upon resampling of existing data. For the purpose of this study, bootstrap confidence intervals were developed for mean speeds and 85th percentile speeds for each sign treatment. The confidence intervals were then compared to test for significance between various sign conditions. The step by step procedure for a two sample comparison is described below:

1. Let $x_1, x_2, \ldots\ldots\ldots x_n$ be our sample 1 of size n and $y_1, y_2, \ldots\ldots\ldots y_m$ be our sample 2 of size m. Assume our sample 1 is our entire population 1 and sample 2 is our entire population 2.
2. First consider sample 1 only.
3. Let our parameter/statistic of interest be 85th percentile.
4. Draw 'B' random samples of size n from our sample 1 with replacement. (B = 1000 was used for this study. However, B = 200 is usually considered sufficient.)
5. Calculate the 85th percentile value for each of the 'B' resamples. This is referred to as the bootstrap estimate of our parameter/statistic of interest.
6. Order the B bootstrap estimates of 85th percentile from smallest to largest. Identify the $(\frac{\alpha}{2} * 100 * B)^{th}$ and the $((1-\frac{\alpha}{2}) * 100 * B)^{th}$ values of the ordered values for the statistic i.e. 85th percentile. These values represent the lower and upper limits for the $(1-\alpha)*100$ % confidence interval for the 85th percentile.
7. Repeat steps 4 through 6 for sample 2.
8. Compare the confidence intervals for the two samples for the 85th percentile. If the two intervals intersect each other, the treatment has not resulted in a significant change and both our samples are assumed to have come from the same population.
9. Repeat steps 2 through 8 for the means of the samples or any other parameter of interest.

The above procedure was coded in statistical analysis software SAS and confidence intervals developed. Table C-1 shows the confidence intervals developed for 85th percentile speeds at SH 21 for the before and the long-term study using the Bootstrap procedure. Similar tables were developed for all seven sites for all pairs of study conditions.

TABLE C-1 Bootstrap Confidence Intervals (95 Percent) for 85th percentile Speeds at SH 21 for Before and Long-Term Study

Light Condition	Point	Vehicle Group	B	Before Study		Long-term Study		Significant
				95% C.I.		95% C.I.		
				P_2.5	P_97.5	P_2.5	P_97.5	
Day	P1	ALL	1000	74	74	75	75	Y
		PV	1000	74	75	75	76	Y
		HV	1000	70	74	72	73	N
	P2	ALL	1000	74	75	70	71	Y
		PV	1000	74	75	70	71	Y
		HV	1000	69	74	67	69	Y
	P3	ALL	1000	x	x	71	71	N
		PV	1000	x	x	71	72	N
		HV	1000	x	x	67	70	N
	P4	ALL	1000	70	71	73	74	Y
		PV	1000	70	71	73	74	Y
		HV	1000	66	70	69	73	N
	P5	ALL	1000	70	71	66	67	Y
		PV	1000	70	72	66	67	Y
		HV	1000	66	71	63	67	N
Night	P1	ALL	1000	70	73	72	73	N
		PV	1000	70	73	72	74	N
		HV	1000	65	73	69	72	N
	P2	ALL	1000	70	72	68	69	Y
		PV	1000	70	72	68	69	Y
		HV	1000	67	75	66	68	N
	P3	ALL	1000	x	x	68	69	N
		PV	1000	x	x	68	69	N
		HV	1000	x	x	65	68	N
	P4	ALL	1000	66	68	69	71	Y
		PV	1000	66	69	70	71	Y
		HV	1000	63	68	68	71	Y
	P5	ALL	1000	65	68	63	65	Y
		PV	1000	65.5	68	63	65	Y
		HV	1000	62.5	69	62	64	N

UNI-VARIATE ANALYSIS OF VARIANCE

The General Linear Model Uni-variate procedure was used to test for differences in mean speeds for different sets of data collected at a site. This procedure provides regression analysis and analysis of variance for one dependent variable (speed in this case) by one or more factors and/or variables. The factor variables divide the population into groups, e.g., passenger vehicles, heavy vehicles. Sign design and/or sheeting material was used as an independent variable. Tukey's LSD and Tamhane's T2 was used to test for differences in mean speeds for various sign treatments at a site. Tukey's LSD is used where variances are not significantly different, and Tamhane's T2 is used where variances between the samples are significantly different. An example output from SPSS is presented in the following section.

Example SPSS Output

Table C-1 to C-6 show the SPSS output for downstream point 5 at SH 21. The output is for the daytime passenger vehicle group. Description of the terms in output is as follows:

Light = 0 indicates day time,
Vehclass = 2 means passenger vehicle group,
Study = 0 stands for before conditions,
Study = 1 stands for short-term condition, and
Study = 2 stands for long-term condition.

Table C-1 shows the descriptive statistics for different study conditions. Levene's test was used to test the null hypothesis that the error variance of the dependent variable (speed at downstream point 5 in this example) is equal across groups. The model used for this test was:

Model Design: Intercept + Study

Table C-2 shows results for this test. Table C-3 shows results for between-subjects effects for the regression analysis. Table C-4 shows the estimated marginal means and Table C-5 shows the results of the post-hoc tests for different study conditions respectively. Table C-6 displays the means for groups in homogeneous subsets based on Type III sum of squares.

TABLE C-2 Descriptive Statistics For Speed At Downstream Point 5

Study	Light	VehClass	Mean	Std Deviation	Sample Size N
0	0	2	63.14	6.79	1176
1	0	2	62.27	6.61	1075
2	0	2	59.59	6.32	2022
Total	0	2	61.24	6.72	4273

TABLE C-3 Levene's Test of Equality of Error Variances

F-value	Df1	Df2	Significance
4.206	2	4270	0.015

TABLE C-4 Results for Tests of Between-Subjects Effects

Source	Type III Sum of Squares	Degree of Freedom df	Mean Square	F	Significance
Corrected Model	10879.985	2	5439.993	127.665	0.000
Intercept	15042568.5	1	15042569	353017.4	0.000
Study	10879.985	2	5439.993	127.665	0.000
Error	181950.698	4270	42.611		
Total	16218327	4273			
Corrected Total	192830.683	4272			

R Squared = 0.056 (R Squared Adjusted = 0.056)

TABLE C-5 Estimated Marginal Means For Different Study Conditions

Study	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
0	63.14	0.19	62.767	63.513
1	62.266	0.199	61.876	62.656
2	59.59	0.145	59.306	59.875

TABLE C-6 Post Hoc Tests for Different Study Conditions

Test	Study (I)	Study (J)	Mean Difference (I-J)	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
LSD	0	1	0.8743*	0.2755	0.3342	1.4143
		2	3.5498*	0.2394	3.0805	4.0191
	1	0	-0.8743*	0.2755	-1.4143	-0.3342
		2	2.6755*	0.2464	2.1925	3.1586
	2	0	-3.5498*	0.2394	-4.0191	-3.0805
		1	-2.6755*	0.2464	-3.1586	-2.1925
Tamhane	0	1	0.8743*	0.2755	0.1985	1.55
		2	3.5498*	0.2394	2.9695	4.1301
	1	0	-0.8743*	0.2755	-1.55	-0.1985
		2	2.6755*	0.2464	2.0878	3.2633
	2	0	-3.5498*	0.2394	-4.1301	-2.9695
		1	-2.6755*	0.2464	-3.2633	-2.0878

* The mean difference is significant at the 0.05 level.

TABLE C-7 Homogeneous Subsets for Means

Study	Sample Size N	Subset		
		1	2	3
2	2022	59.5905		
1	1075		62.266	
0	1176			63.1403

The error term is mean square (error) = 42.611.

a. Uses harmonic mean sample size = 1318.605.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

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