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16. Abstract

This report presents field studies of in response to horizontal signing applications and a driver comprehension study of route guidance pavement markings. Speed reduction treatments included simple transverse lines, CURVE AHEAD text, CURVE text with advisory speed, and curve arrows with advisory speed. Research showed that warnings with advisory speeds were more effective than those that simply warned of an upcoming curve. Directional arrows on two-way frontage roads to reduce wrong-way movements were also evaluated. One site was evaluated in a before-after study and showed a great reduction of wrong-way movements after installation of directional arrows at the terminus of the freeway exit ramp. Researchers also assessed driver comprehension of an assortment of route guidance shields, text, and curve warnings. Drivers preferred route shields to text for exit lane assignment. Drivers demonstrated good comprehension of curve warning treatments.

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FIELD EVALUATIONS AND DRIVER COMPREHENSION STUDIES OF HORIZONTAL SIGNING

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CHAPTER 1:
LITERATURE REVIEW

In order to gain a better understanding of the issues pertaining to the use of horizontal signing, a review of the literature was conducted. The report organizes this literature review into the following sections:

- a background in the use of signing and pavement markings;
- a review of relevant human factors issues, and
- a review of literature looking at the benefits of using horizontal signing.

A BRIEF BACKGROUND IN THE USE OF SIGNING AND PAVEMENT MARKINGS

The use of pavement markings to convey information to drivers probably dates back to antiquity when markings were used on cart paths to help travelers find their way. Even in the modern era, pavement markings have remained an effective way to convey information to motorists. Around 1900 pavement markings were used to define safety zones and crosswalks in cities. By the 1920s use of edgeline and centerline striping was widespread (*1*). Modern pavement markings such as paints and thermoplastics with retroreflective beads have been in widespread use only since the 1950s (*2*).

By the 1960s traffic speeds rose to the range of speeds seen on roads today. In addition, as the interstate system continued to be completed, engineers began to realize that the methods of relaying information to motorists contained flaws not previously revealed. Schoppert, et al. examined how drivers in California viewed at least one aspect of traffic control – freeway directional signing – and under what conditions drivers were more likely to miss or misinterpret the message that was conveyed (*1*). The researchers concluded that drivers have a certain number of basic assumptions that they use when driving. For example, if a freeway curves to the left and there is an offramp there that proceeds straight, unfamiliar drivers may be inclined to think that the ramp is actually the roadway because of the expectation that the roadway should go straight. It is important to note that in the 1950s and 1960s the use of left-hand freeway exits was more prominent than today, and this could help fool unfamiliar drivers. Adding additional visual miscues can add to the misinterpretation, such as if the freeway loops around a town on the horizon, but the offramp appears to point straight toward it.

This research clearly found that traffic engineers can mislead drivers in certain instances when specific geometric features combine with ambiguous traffic control and other visual cues. Engineers cannot adequately determine some of these problems during the planning stages of a project, and as a result there will always be specific locations where drivers need additional clear information to reduce confusion.

HUMAN FACTORS ISSUES

There are several human factors issues inherent to horizontal signing. These factors include:

- how drivers search their surroundings for information,
- their ability to continue to do this for long periods of time, and
- deficiencies in an individual driver's ability to see and react to information.

Positive Guidance Issues

In the 1970s, the United States Congress requested development of low-cost, short-range methods of reducing accidents at bridges. This impetus resulted in the concept of Positive Guidance, developed by Alexander and Lunenfeld (*2*). This theory has since been broadened to be of use in most traffic situations where driver information needs are studied. This theory states that the driving task consists of three parts: control, guidance, and navigation. Control issues consist of the interactions between the driver and his/her vehicle; such as reading gauges, and manipulating the steering wheel, pedals, and gear shift in order to properly drive the vehicle. Guidance tasks consist of maintaining the proper speed and lane placement to keep the vehicle in the proper lane without hitting surrounding traffic or other objects. The navigation task includes all aspects of planning the route the driver takes to get from point A to point B, including pre-trip planning, reading and interpreting guide signs, and making route changes based on traffic conditions.

The theory of Positive Guidance further states that these levels of the driving task are related in a hierarchy, with the control task in the prime position, and the navigation task in the lowest position of importance. As a result, when the driver is in a stressful driving situation, or has too much information presented at one time, he or she will practice "load shedding" by ignoring the least important information and focusing on the more important tasks (*2*). In other words, when drivers experience high-stress driving situations, or when they are presented with too much information, they may be expected to focus on the more important tasks of control and guidance, and will tend to look at the road more and at side- or overhead-mounted signing less. By understanding these principles, a traffic engineer should be better able to provide information to a driver when and where it is needed.

Target Search

Most information presented to drivers while performing the guidance task is visual. According to Alexander, in the search and detection modes of information processing, "Drivers scan the environment and sample the information in short glances until a potentially needed source is detected" (*3*). Because of the way human beings process information, they are able to only visually gather information from one source at a time. By continuously scanning the visual field, a driver can attend to one visual information source after another in rapid succession.

In order to maximize the likelihood of seeing potential information sources or hazards in the roadway, drivers spend most of their time scanning the roadway directly ahead of their vehicles. In other words, they are already looking at the pavement in their lanes, and are therefore more likely to see the things on the roadway more quickly.

The area of foveal vision – also known as detailed vision – is only 1 to 2 degrees (*4*). Figure 1 shows an example of what area this encompasses in the total field of view. It is this small cone of detailed vision that drivers use to examine signing, vehicle instruments, or other vehicles or potential hazards. All other vision is considered peripheral vision. Because the area of sharp detailed vision is small compared to the entire visual field, target detection usually occurs in the periphery. In order for objects to be detected in peripheral vision, however, the objects must have greater attention-getting characteristics than if the image had fallen in the area of detailed foveal vision. "Other factors being equal, the further from the fovea the image falls, the less likely it is to be detected at any given point in time, and the more likely it is to be overlooked altogether" (*5*).

On a straight, level roadway, the point where the roadway meets the horizon is called the "focus of expansion" (*4*). It is from this area that a new hazard, such as debris in the roadway, would become visible as drivers move forward. It makes sense then that drivers searching for potential hazards would spend a large portion of their available search time focusing on this area.

In a study to see if this is where drivers spend their time looking, Rockwell examined driver eye movements under normal driving conditions (*6*). Since the sharp visual focus of the eye was limited to the fovea, drivers needed to point their foveal vision to what they were trying to see. Rockwell recorded this motion through sensors for analysis. The research indicated that most eye movements were less than six degrees from the focus of expansion. Additionally, the glances away from the focus of expansion were generally less than 350 milliseconds, about 1/3 of a second.

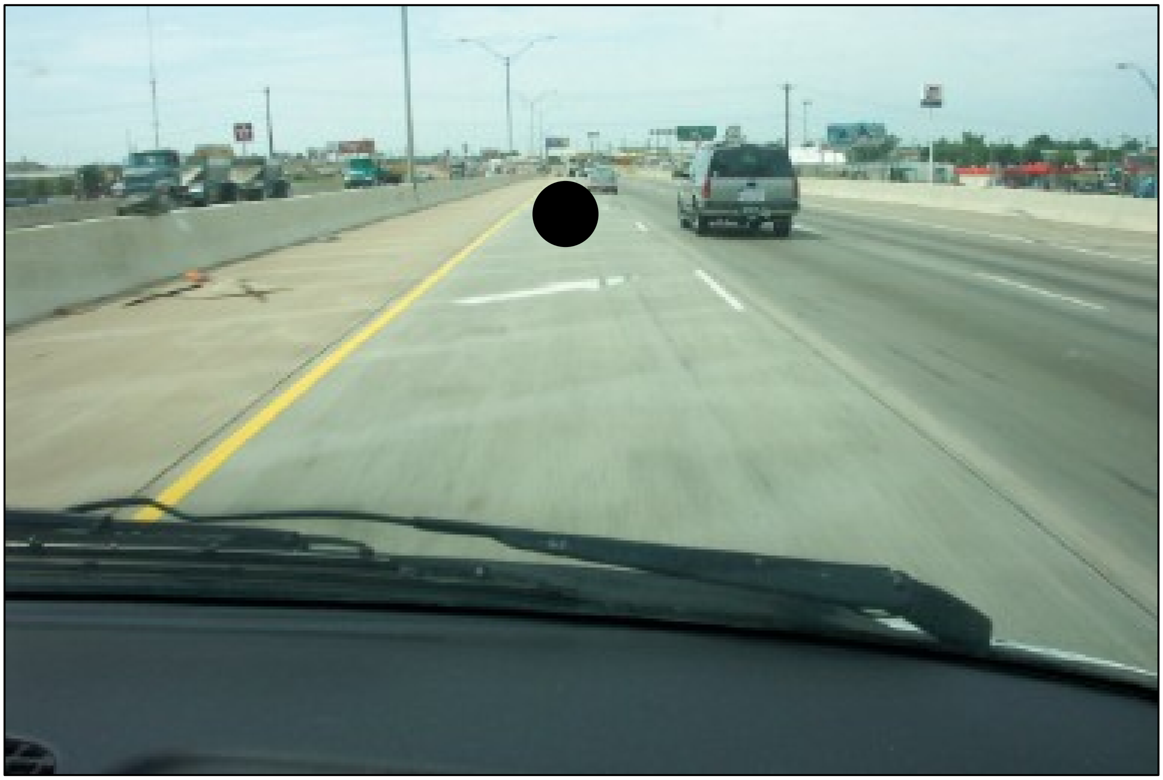


Figure 1. The Area of the Visual Field Scene in the Fovea.

This natural pattern of eye fixations has direct implications for the location of traffic control devices. Normal vertical signage would first appear in a driver's peripheral vision, and once noticed, a driver would attend to the sign by initiating an eye movement to move the sign into foveal vision. Horizontal signing could be expected to initially appear in or near a driver's foveal vision. In other words, placing the information dissemination systems closest to the area where drivers are most likely looking should be more successful in passing information to drivers. By putting warning and guidance information directly on the road where drivers are looking already, the traffic engineer prevents the necessity for an eye movement on the part of the driver.

Degraded Target Search Conditions

Despite the obvious advantage of horizontal signs, the poor durability of materials in the roadway has prevented their widespread use. Instead, most roadway systems rely on shoulder or overhead vertical signs. These signs require drivers to make a visual search in order to locate them. The search for an object has been found to be less successful, in terms of taking longer and being less accurate, when the object is in front of a cluttered background. Akagi, Seo, and Motoda studied the ability of drivers in Japan to detect highway signs in cluttered visual environments (*7*). The researchers limited the study to urban arterial-type streets in Japan that due to less stringent regulations have many more store signs and billboards than typical U.S. cities. By determining the proportion of the visible field that the extraneous signing took up, the researchers developed what they termed the "visual noise ratio." The researchers found that there was a statistically significant negative correlation between the visual noise ratio present in an area and the distance at which a nearby traffic sign was seen. In other words, when more information dissemination devices were present, it was harder for drivers to identify vertically mounted traffic signs. Additionally, the researchers found that women were less sensitive to this phenomenon than men, but that their overall observation distances were less than men's. The researchers gave no explanation as to why the gender differences were present in the data.

Rockwell also examined how drivers scan the driving environment under three different scenarios. The first group of drivers was told to try to look at every sign and every potential hazard to simulate drivers unfamiliar with a particular roadway. The second group was told to only look at signs that pertained to their specific route to simulate drivers with some experience. The third group of drivers was told to ignore all signs except for those deemed important to simulate familiar drivers. As expected, the first group spent the least amount of time fixated on the roadway ahead, while the third group spent most of their time focused on the roadway. A second round of the experiment included a lead car in front of the test vehicle to simulate heavy traffic situations. This version of the experiment led to even more fixation on the area ahead of the test vehicle. In fact, the third group was reported to spend less than 7 percent of their time looking to the side of the highway (*6*).

Other research has been directed at the ability of drivers in the traffic stream to see around other vehicles and see roadside signs. Specifically, researchers found that large trucks can serve as barriers between drivers and signs, limiting the amount of time a driver has to see and read a sign. Several studies have developed models that quantified the probabilities of occlusion based on geometric characteristics, traffic volumes, and the percentage of heavy trucks in the traffic stream (*8*, *9*).

These studies indicate that drivers miss many signs on the side of the roadway or traffic blocks them from view. In these cases, a redundant method of information dissemination would increase the likelihood of the message getting to drivers.

Vigilance and Familiarity

Once a driver masters the basic tasks of driving such as vehicle control and navigation, one of the main tasks of the driver is to continually search for potential hazards and sources of information that provide guidance on the path ahead.

In one study by Summala and Näätänen, drivers were asked to read and explain the meaning of signs along a 160-mile route (*10*). While the drivers were very adept at relating the correct information for individual signs, as the study progressed the subjects were increasingly likely to completely miss signs. At the end of the study, many of the drivers admitted to being fatigued. Indeed, it has been well established in other types of vigilance studies that evidence of fatigue becomes apparent in as little as 30 minutes. Mackworth conducted one of the earliest studies of this type of fatigue research to determine the time that military radar operators could remain optimally vigilant (*11*). Mackworth found that in routine tasks, subjects quickly lost sensitivity to visual stimulus. In other words, subjects would begin to miss information during the experiment. Because of the toll a sustained information search takes on a subject, some researchers refer to a vigilance task as a sustained demand (*12*).

There is another reason that drivers are less likely to glance around during driving: a stressful driving situation. Barbiere, when examining potential physiological indices of stress, tested the relationship between eye movement and stress levels under different non-driving task loadings. The researcher found that as stress levels rose, there was a corresponding decrease in eye movement, and that subjects tended to focus on the one location they deemed most important (*13*). While this experiment was not conducted in a driving environment, it provides an ancillary indication that in a stressful driving situation, drivers are predisposed to spend less time scanning locations other than the road ahead.

In other words, as drivers drive for extended periods of time, or drive for even short periods under high-stress conditions, they become physiologically less likely to notice targets. This means that drivers are even less likely to notice information devices that appear in their peripheral vision. This finding has direct implications for roadway warnings such as alerting drivers to an upcoming hazardous curve or intersection after a long stretch of straight, flat roadway. Horizontal signing applications may be particularly helpful in breaking through this inattention.

Text-Based Signing

Drivers may misinterpret or otherwise not understand a horizontal sign for several reasons. Many of these issues are similar to the problems studied in vertical signing.

For text-based messages, the distance that drivers can read and understand a sign is a function of the letter size (*4*). For drivers who have 20/20 vision, it is generally accepted that drivers can see vertical text from about 50 feet away for each inch of letter height. Font type, letter spacing, and even the individual letters signs use have also been shown to have an impact on legibility (*14*,*15*).

A second issue relating to the legibility distance of a sign is the contrast between the text or symbol and the background, with increased legibility for high-contrast combinations (*14*). Unfortunately, while technicians can engineer vertical signs to provide a desired level or luminance contrast between the letters and the background, this is not possible with horizontal signing. Horizontal signing uses the pavement as the background surface, the luminance of which varies greatly from pavement type to pavement type, and also by age. It could be possible, with alternate materials, to provide a border around a symbol or a rectangular field of a contrasting color to assure good legibility of horizontal signing. Some longitudinal striping products, both tapes and preformed thermoplastics, are available now that provide these contrast stripes. Two of the products tested as part of this project provide contrasting borders.

Yet a third issue of text-based signing that relates to horizontal signing is the use of abbreviations. Because the space available to place a horizontal text sign is typically the width of the traveled lane, the urge to use long words may result in abbreviated words placed in signs. While many drivers may readily understand some abbreviations, others tend to provide ambiguity instead of clarity. Previous studies by Dudek, as well as the *Manual on Uniform Traffic Control Devices* (MUTCD), provide information as to the level of abbreviation understanding by drivers, with recommendations as to which abbreviations to accept and which to avoid (*16*, *17*).

The amount of information a sign presents is also an issue that has been researched, as overloading a driver with information tends to reduce the ability of a driver to find, process, and make proper driving decisions. Jacobs and Cole found that as the amount of textual information presented on a vertical sign increased, the amount of reading time also increased (*18*). Smiley et al. also found this relationship, and determined that tourist guide signs should present no more than three locations to prevent overloading the driver (*19*).

Symbolic Signing

Symbolic messages and how they relate to text-based signs have also been extensively studied, at least as they relate to vertical signing. Jacobs, Johnston, and Cole studied the relationship between legibility and the manner the information was presented: textually or symbolically (*20*). These researchers studied sixteen pairs of signs of messages commonly used in Australia (where the study took place). In each pair was a text-based regulatory warning sign, paired with its symbolic equal. In general, they found that drivers could read and comprehend the symbolic signs at greater distances than their text-based counterparts. The most legible symbols (readable from the farthest distances) were symbols with large, simple components, such as the 4-WAY INTERSECTION symbol sign (W2-1), and the RAILWAY CROSSING symbol sign (similar to the "X" in W10-1, but in Australia this is presented on a diamond sign shape). The symbols with the shortest legibility distances were for NO LEFT TURN and NO RIGHT TURN symbol signs. The researchers hypothesized that these signs were harder to understand because the differences between signs were very small.

In a related study, Dewar examined the glance legibility of symbolic signs with a prohibition slash, a partial slash (to make the underlying symbol more apparent), and no slash at all (*21*). The results indicated that legibility of a symbol was best when not obscured with a prohibition slash, and worst when it was. This result seems reasonable, as an obscured symbol has less of its total area visible for observation.

Whitaker researched the extent to which drivers make unconscious errors when processing symbolic sign information (*22*). Whitaker found that because drivers have many demands on their mental processing, they may attend to a sign so quickly that they may misperceive the message. Whitaker found two types of unconscious errors: illusory combinations of display elements and interference from conflicting irrelevant display elements. These problems arise when conflicting information appears on the same sign or on adjacent signs, such as direction arrows pointing in opposite (and unexpected) directions. These errors manifested themselves in the study either with an increased incorrect response rate or a slower response rate by subjects.

From this research, it is evident that the use of symbols is most appropriate when the symbols are clear and unambiguous. Any symbols developed for use as horizontal signs should have large simple components, and be visually unique to the highest possible degree.

CRASH RESEARCH

While the visibility and conspicuity of the horizontal sign are important to help ensure the sign properly alerts drivers, determining their effect on driver performance in the field is valuable to assess the impact of signing on safety in the field. A change in behavior is needed to make sure that the device would be an improvement. In other words, the increased sign information relayed to the driver must translate to a change in motorist behavior in actual driving situations for drivers to realize roadway safety improvements. As such, the objective of the project described in this report was to identify situations in the field where horizontal signing offers traffic operations and safety benefits beyond traditional information devices such as overhead and roadside vertical signing. Therefore, a detailed discussion of surrogate crash research for horizontal signing applications and other related traffic control devices is appropriate.

The reason researchers utilize surrogate crash measures of effectiveness is that crashes are rare events and consequently, improvements in such measures would ultimately correlate to a lower crash frequency. However, although such measures provide a proxy for the direct measurement of crashes, the inability to assign a monetary value to reflect any benefits is the main drawback to this type of analysis. Researchers have performed a number of surrogate measures studies testing the effectiveness of various traffic control devices used in field scenarios such as at horizontal curves and intersections, work zones, and elsewhere, that provided valuable guidance to the work that was performed in this project. In project panel meetings, it was determined that there was not sufficient funding or time available on this project to conduct a crash study. Instead, field installations of horizontal signing during year two of the project will be assessed using surrogate measures.

Krammes et al. studied several types of raised pavement marking designs to see if engineers could use these devices as acceptable substitutes for post-mounted delineators on rural curve locations (*23*). For this study the researchers used speed at the curve midpoint, speed change from the beginning of the curve to the midpoint of the curve, lateral placement of vehicles in the curve, and the number of encroachments into opposing lanes.

In addition, the Institute of Transportation Engineers lists possible surrogate crash measures that researchers more readily measure, as follows:

- speeds,
- acceleration/deceleration,
- initial brake application locations,
- erratic maneuvers,
- traffic conflicts,
- traffic control device compliance,
- lateral placement within lanes, and
- centerline or edgeline encroachment (*24*).

EVALUATION OF HORIZONTAL SIGNING

Horizontal Signing in the *Manual on Uniform Traffic Control Devices*

Modern traffic control devices in the United States are standardized through the application of the *Manual on Uniform Traffic Control Devices* (*17*), and in Texas in the Texas *Manual on Uniform Traffic Control Devices* (TMUTCD) (*25*). These manuals have for decades provided guidance on a wide range of traffic control devices, including pavement markings.

The current version of the MUTCD provides for pavement markings for the purposes of regulatory, warning, and guidance (*17*). Specific types of horizontal signing that the MUTCD cites include provisions for regulatory signing, warning signing, and guide signing. The MUTCD mentions several specific categories of horizontal signing. Examples of each type of category are provided, and the MUTCD stresses that the realm of possible messages is not limited to those presented.

Regulatory messages include:

- STOP,
- Right (left) turn only,
- 40 km/h (25 mph) (or other speed), and
- Arrow Symbols.

Warning messages include:

- Stop Ahead,
- Yield Ahead,
- School Crossing,
- Signal Ahead,
- Pedestrian Crossing,
- Railroad Crossing,
- Bump, and
- Hump.

Horizontal guidance marking examples mentioned in the MUTCD include:

- US 40,
- STATE 135, and
- ROUTE 40 (*17*).

Pavement Markings that Create Optical Illusions

There are currently two types of pavement marking patterns that attempt to promote slower vehicle speeds by tricking drivers into slowing down due to an optical illusion. These two patterns are the converging chevron marking pattern and the transverse bar pavement marking pattern: both patterns are designed to make use of an optical illusion to reduce speeds. By placing chevrons or transverse bars in a repeating pattern on the roadway, and by slowly reducing the spacing between successive markings, a driver moving at a constant speed over the markings would see the markings passing in shorter time headways, and be fooled into thinking that this is due to an increasing vehicular speed. In order to compensate for this, it is theorized that drivers would subconsciously reduce speed and, as a result, would actually drive more slowly through this section than if the markings had not been there.

Zaidel et al. and Jarvis and Jordan, indicated that this may not be the only reason that drivers reduce their speeds (*26*, *27*). They noted that drivers may perceive the markings as warning devices warning them of an upcoming hazard, resulting in lower speeds and increased vigilance.

Chevrons

A horizontal traffic marking innovation that began to appear around the world in the 1970s was the chevron marking. Chevrons marked directly on the traveled lane or on the shoulder of the roadway have been studied to determine any traffic calming effects or safety improvements. Figure 2 shows such an example of these chevron markings in Ohio (photo courtesy of Flint Trading, Inc.).

In 1996 Griffin and Reinhart reviewed these applications in Japan to determine if the theoretical safety benefit actually resulted in the desired speed reductions and if a resulting safety benefit could be observed. A review of traffic and safety data was conducted for five locations in Japan. Data available indicated that crashes were reduced between 14 and 74 percent, with an average crash reduction of 38 percent overall. No data were presented in the review to indicate the degree of speed reduction of traffic, if any (*28*).

Figure 2. Roadway Marked with Chevron Pattern.

Drakopoulos and Vergou studied the use of chevrons to reduce speeds on a two-lane freeway-freeway connector from I-94 to I-894 in Milwaukee County, Wisconsin (*29*). The chevrons were placed in an increasingly close pattern to replicate the illusory effects previously discussed. The patterns covered 610 feet and included 16 individual white chevrons. Based on engineering studies, the desired entering and exiting speed of the ramp was 65 mph and 50 mph, respectively. The researchers found that at the end of the chevron pattern there was a mean speed reduction of 15 mph, from 64 to 49 mph. The 85th percentile speeds were lowered even more, from 70 to 53 mph, a 17 mph reduction. These markings were deemed successful in reducing speeds to desired levels.

Transverse Bars

A similar optical illusion has been determined from a similar pattern of transverse bars that extends across the roadway. The longitudinal spacing of the bars is reduced as the hazard approaches. Also studied for the first time in the 1970s and 1980s, this type of marking pattern appeared to also provide speed and safety benefits. Griffin and Reinhart conducted a critical review of ten previous studies of transverse markings where the study locations included approaches to roundabouts, stop-controlled intersections, prior to interstate construction zones, and rural highways (*28*). The review of this literature provided the following conclusions:

- Speeds were consistently reduced by 1 to 2 mph through the study locations where speeds were recorded.
- Eighty-fifth percentile speeds were reduced by up to 15 mph in studies where this measure was reported.
- Crash reductions at the study locations were lowered due to the presence of the transverse bar pattern.
- Speed reductions were more pronounced during the day than at the night.

Katz studied the use of pavement markings to reduce speeds at problem highway locations in New York, Mississippi, and Texas (*30*). The pavement markings selected for study were peripheral transverse lines, which consisted of white thermoplastic lines in the lanes that extended 18 inches into the lane from both the shoulder and the centerline. The pattern used placed successive lines closer and closer together to provide the optical illusion effect of speed increase as previously discussed. Speed data for free-flowing vehicles were collected far upstream and at the point of curvature of the curves selected for study. Katz compared the data collected from before the marking installation with data collected just after installation and four months after the installation. The Texas site was in advance of a sharp curve on a two lane FM road near Waller in the Houston District.

Katz found that mean speeds were statistically significantly reduced between 1.8 and 4 mph at the New York and Mississippi locations, respectively, but that the Texas site did not have a significant speed change. Interestingly, the study found that overall speed reductions were larger on the interstate and arterial roadway sections tested (those in New York and Mississippi), while speeds on the local roadway (in Texas) were not as great. This seems to indicate that roadways that include larger proportions of unfamiliar drivers may heighten the speed-reducing effects of pavement markings. This research also indicates that a simple, inexpensive marking treatment can be effective in reducing speeds.

Horizontal Signing to Reduce Crashes

Other types of pavement markings have been installed in an attempt to modify driver behavior in other areas. These driver behaviors include rear-end collisions, speeds in sharp curves, and headway distances.

Rear-End Collisions at Mid-Block Driveways

Retting, Greene, and Van Houten researched the safety benefits of placing straight-and-right-turn arrows in advance of busy urban mid-block driveways and intersections (*31*). The locations studied consisted of a post office, a bank, a fast-food restaurant, and an intersection in a busy shopping district. The researchers found that at the mid-block locations there were reductions in the conflicts caused by right-turning vehicles causing following vehicles to brake in response. The researchers concluded that horizontal signing of this type provided drivers with more information about the roadway ahead, and allowed them time to change lanes to avoid having to slow behind a turning vehicle in the right lane. As the researchers used conflicts as a surrogate for rear-end collisions, their contention was that these horizontal pavement markings could be useful in reducing crashes at these kinds of locations.

Speeds in Sharp Curves

Researchers Retting, McGee and Farmer studied the use of horizontal pavement markings to reduce speeds of drivers in a sharp left-hand curve location on a rural two-lane road in Virginia (*32*). The site selected was a near-90º left-hand curve with a minimal sight distance on the approach. The roadway had 10-foot lanes with minimal shoulders, so it was essential that drivers be able to remain in their lane as they passed through the curve. The researchers installed the word SLOW with a left-turn arrow preceded and followed by 18-inch wide lines about 220 feet prior to the curve. The sign was installed with white thermoplastic with glass retroreflective beads.

The sign was successful in reducing the speeds of vehicles from 34.3 to 33.2 mph from the before period to the after period, representing a speed reduction of about 3 percent. This was true even though speeds actually *increased* upstream from the curve and a control site during the same periods.

In a second study, Retting, McGee, and Farmer researched the effects of artificially narrowing the lane width of freeway offramps with pavement markings (*32*). Four freeway offramp locations were studied in Virginia and New York. Researchers hypothesized that by making the lane width of the offramp appear narrower – by widening the painted gore area and moving the outside pavement striping farther into the lane – speeds would be reduced. While the overall mean speeds were not practically affected, the researchers found that the percentage of passenger cars exceeding the speed limit by more than 10 mph was reduced by between -1 percent (a 1 percent increase) and 17 percent. The percentage of large trucks exceeding the posted speed limit by more than 5 mph was also found to be reduced by between 17 and 22 percent.

Headways on High-Speed Roadways

The Pennsylvania Department of Transportation (Penn DOT) installed a series of large white dots in the traveled lane in areas where tailgating has been a problem. Signs were posted in the area explaining that safe headways were obtainable by keeping two of the dots visible between the driver's vehicle and the vehicle they are following. A preliminary study by Patel (*33*), showed that in the locations where this treatment was applied the incidence of crashes dropped by an estimated 60 percent and fatalities were reduced by an estimated 25 percent. These statistics were based on approximately six months of crash data. Figure 3 shows an example of this treatment.

European applications of horizontal signing have been more extensive than in the U.S. The Netherlands has experimented with evenly spaced chevrons on the pavement to instruct motorists about proper vehicle spacing in heavy fog (*34*). This follows the same basic practice as the Pennsylvania DOT treatment. Helliar-Symons et al. also found that the placement of chevrons on the M1 Motorway in England resulted in an increase in the headway gaps between drivers (*35*).

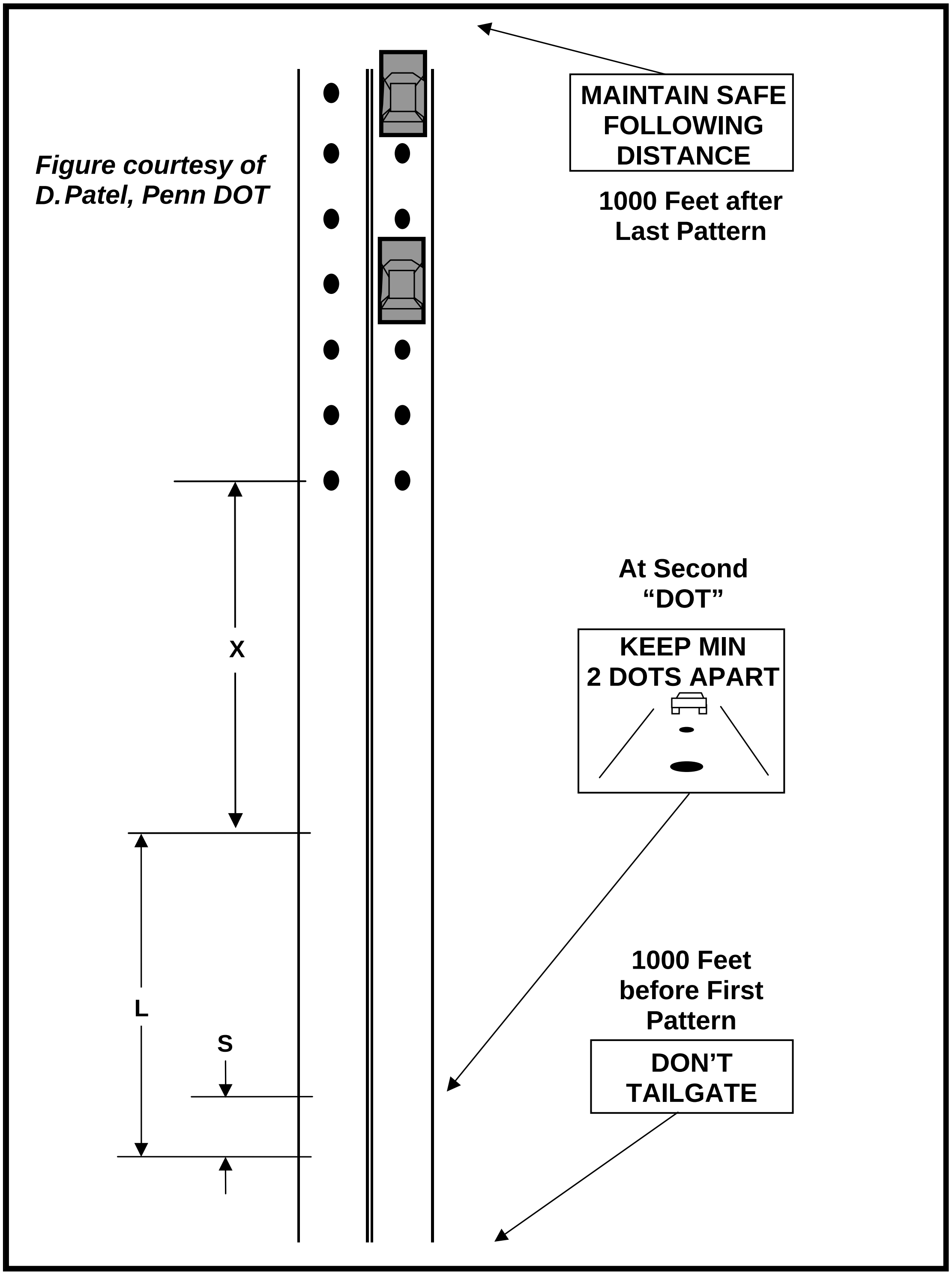


Figure 3. Pennsylvania DOT Treatment to Reduce Tailgating.

Note: Pattern Spacing (X), Pattern Length (L), and Marking Spacing (S) are proscribed in design details as a function of posted speed.

VISUAL ACUITY AND READING DISTANCES FOR HORIZONTAL SIGNING

One problem the current research tried to address is the determination of the proper size of horizontal signing messages. This section presents the researchers' application of sign legibility research to pavement markings. Human factors research has been previously performed to determine how far away a person with "normal" (20/20) vision can just make out letters on a sign. It has been established that subjects can correctly identify objects that encompass about 0.5 minutes of visual arc (*4*). In the case of letters, this relates to the total letter height, as Figure 4 shows. Using this as a limit of the ability of drivers to read signing has allowed the development of the following equation relates the minimum visual angle with the letter height and the viewing distance from a traffic sign:

$$\theta = \arctan\left(\frac{h}{d}\right)$$

where,

θ = visual angle, in degrees;

h = height of character, in feet; and

d = viewing distance, in feet.

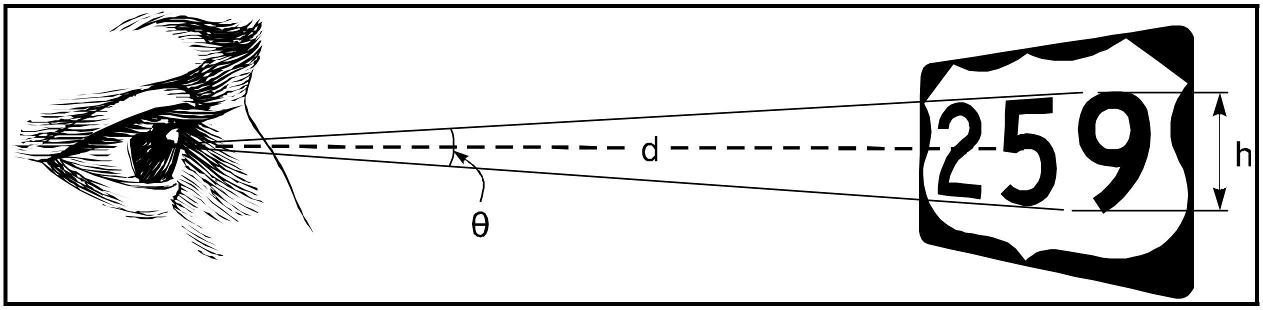


Figure 4. Visual Acuity Measurements for Signing.

Rearranging this basic equation and assuming 20/20 vision, a transportation official can determine the maximum reading distance for a given sign.

$$d = \frac{h}{\tan\theta}$$

For example, a sign with 18 inch (1.5 feet) of letter height should be just discernible to a normal vision driver (visual acuity = 0.5 minutes) from a distance of 1031 feet.

The viewing angle equation requires modification when considering horizontal signing because the viewer would not see the sign straight on perpendicularly. Rather, the sign would be viewed at an angle, as Figure 5 shows. In determining the viewing distance, new variables must be determined, including the height of the horizontal sign (h'), the driver eye height (H) and the horizontal distance from the viewer to the beginning of the sign (D).

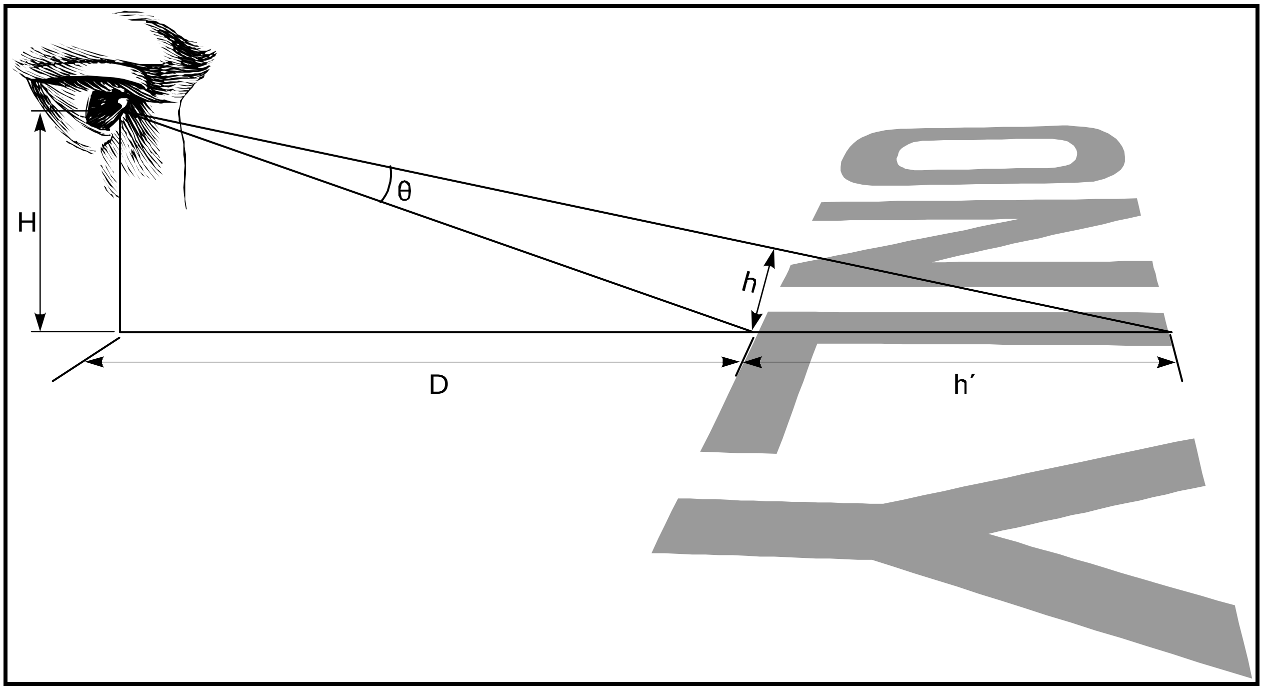


Figure 5. Viewing Distance Calculations for Horizontal Signing.

Relating the triangles that include the driver's eye, the ground point below the driver's eye, and the nearest and farthest edges of the horizontal signing, the following relationships are found:

$$\phi = \arctan\left(\frac{D}{H}\right)$$

$$[\phi + \theta] = \arctan\left(\frac{D + h'}{H}\right)$$

where,

ϕ = angle from point below driver's eye to the leading edge of the horizontal sign,

h' = the letter height of the horizontal signing, and

D = horizontal viewing distance.

Combining these relationships provides an equation that relates the horizontal viewing distance, the viewing angle, the driver eye height, and the letter height of the horizontal message. Due to the trigonometric functions present in the equation, the resulting equation is iterative, requiring a trial-and-error approach to solve for a given viewing distance.

$$\arctan\left(\frac{D}{H}\right) + \theta = \arctan\left(\frac{D + h'}{H}\right)$$

Table 1 shows the predicted viewing distances and associated reading times for several standard horizontal sign letter heights, driver eye heights, and speed limits based on the iterative equation.

Several points seem clear from Table 1. Due to the higher driver eye height, drivers of large trucks should be able to read a horizontal sign with 8-foot letter heights about 67 feet farther away than passenger car drivers, and about 74 feet farther away when 10-foot letters are used. However, the best reading time calculated (large truck driver eye height of 7.67 feet, 50 mph speed limit, 10-foot letter height) only provides 3.05 seconds of reading time. So even under ideal conditions the amount of reading time will always be low when compared to vertical signing. It should be pointed out that the values calculated in Table 1 were calculated assuming a driver with normal or corrected-to-normal vision. Drivers with less than this level of visual acuity would have a smaller viewing distance and a corresponding smaller reading time, all other things being equal.

Nighttime visibility of horizontal signing depends on the reach of vehicle headlamps and the retroreflectivity levels of the pavement marking material. The retroreflectivity of dark colored pavement markings, such as blue or red, is inherently very low. The use of dark colors may need to be limited to areas with overhead roadway lighting.

Table 1. Driver Eye Height, Horizontal Letter Height, and Viewing Distance.

Driver Eye Height, H (ft)	Horizontal Sign Letter Height, h' (ft)	Calculated Viewing Distance, D (ft)	Calculated Reading Time, (sec)
3.5 (assumed for passenger vehicle) (*36*)	8	134	50 mph = 1.82
			55 mph = 1.66
			60 mph = 1.53
			65 mph = 1.41
			70 mph = 1.31
	10	150	50 mph = 2.05
			55 mph = 1.86
			60 mph = 1.70
			65 mph = 1.57
			70 mph = 1.46
7.67 (measured from large trucks) (*37*)	8	201	50 mph = 2.74
			55 mph = 2.49
			60 mph = 2.28
			65 mph = 2.11
			70 mph = 1.96
	10	224	50 mph = 3.05
			55 mph = 2.78
			60 mph = 2.55
			65 mph = 2.35
			70 mph = 2.18

LITERATURE REVIEW SUMMARY

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

- When a driver is experiencing a high-stress driving situation, or when he/she is presented with too much information, he/she may be expected to focus on the more important tasks of control and guidance, and will tend to look at the road and less at side- or overhead-mounted signing.
- Drivers tend to spend most of their time focusing on the roadway in front of them, and drivers will more likely observe an object or sign that appears in this region than a sign appearing in their peripheral vision.
- Drivers can miss roadside signs due to visual clutter (billboards, etc.) or because of other traffic (heavy trucks, etc.). A redundant method of information dissemination would increase the likelihood of the message getting to drivers.
- Any symbols developed for use as horizontal signs should have large simple components, and should be visually unique to the highest possible degree.

Each of these points found in the literature strengthen the potential improvement in information dissemination that horizontal signing can provide. The proper application of horizontal signing messages through either text or symbols can be achieved through:

- minimizing the use of abbreviations,
- keeping symbols simple and legible, and
- limiting their application to critical locations where drivers will recognize them as an added warning or caution.

CHAPTER 2. FIELD TESTS OF HORIZONTAL SIGNING APPLICATIONS TO REDUCE SPEED IN HORIZONTAL CURVES

In preparation for field testing horizontal signing, criteria were developed to determine appropriate characteristics for test sites. Lists of candidate sites for field data collection were prepared for both urban and rural locations. These sites were reviewed, and from these lists several locations were selected for future data collection.

SITE SELECTION CRITERIA

The project team was interested in testing curve locations where speed reduction was considered a positive benefit, and a surrogate for improving curve safety. A review of crash history to develop candidate locations was deemed not useful, as it was expected that hazardous curve locations would have additional safety devices in place, such as flashing lights or other traffic control devices. For the purposes of this project, it was desired that existing curve warning devices be limited to:

- curve warning signs,
- speed advisory plates,
- chevrons, and
- curve direction sign within the curve.

Additional criteria desired for an acceptable data collection site were:

- volumes exceeding 1000 vpd to facilitate data collection;
- no additional geometric features, such as driveways and intersections within the curve;
- pavement markings and signing in acceptable condition;
- long approach tangent; and
- a suitable place to inconspicuously locate data collection equipment and/or personnel.

A list of candidate locations was developed with the assistance of the Abilene District Traffic Engineers Office. The research team then reviewed and evaluated these sites regarding traffic volumes in terms of average daily traffic (ADT) , appropriateness of a curve warning horizontal sign at the location, and the ease of data collection. Table 2 details the candidate locations.

Table 2. Candidate Data Collection Locations for Rural Curve Warning Horizontal Signs.

	Site	**Description**	**Volume (ADT)**
1	US 84 SB & IH20 WB	Ramp	Low
2	TX 70 SB north of Blackwell, TX	Curve	1150
3	FM 1835 south of Old Glory, TX	Curve	150
4	TX 283 west of Sagerton, TX	Curve	530
5	FM 1661 south of Sagerton, TX	Pair of Curves	190
6	FM 707 north of Truby, TX	Curve	560
7	FM 707 South of IH20	Pair of Curves	990
8	FM 1235 northwest of View, TX	Curve	510
9	FM 604 north of Oplin, TX	Pair of Curves	210

Due to low volumes, many of these locations were rejected from consideration. Locations 1, 3, 5, and 9 were removed for this reason. In order to facilitate data collection, only the sites with the highest traffic volumes were evaluated for the appropriateness and the ease of data collection.

Locations 4 and 6 were eliminated because these locations could be safely driven at or very near the 70-mph speed limit, indicating that these would not be appropriate locations to study speed reduction on rural curves. Location 8 was removed from consideration because the roadway had an intersection with a county gravel road in the middle of the curve. Locations 2 and 7 were selected as the best locations for studying speed-reduction effects of horizontal signing at curves. Another candidate location presented itself in the Corpus Christi District during the course of the project. This location was on a divided highway and was slated to have new curve warning signs installed overhead with flashing beacons. The project took advantage of this planned work to install horizontal signing before installing the signs in order to test the contributions of each treatment.

At following project panel meetings, the specific applications for each site were selected. At this point in the project, there were several candidate treatments for these locations:

- the word SLOW with an arrow in advance of the curve;
- a “visual rumble strip” of three transverse lines grouped together, followed by another set of three after a separation; and
- a curve advisory speed with an arrow in advance of the curve.

DATA COLLECTION AND REDUCTION

The traffic counter software automatically classified vehicles into categories of passenger cars and heavy trucks. After extracting data from the counters, researchers were able to compute the headway between vehicles. Vehicles with a five second headway or less were then removed. It was imperative that researchers only examine drivers that were able to make their own decisions in order to properly determine the effect of horizontal signs on speed-related changes in driver behavior. Motorists following too closely to the vehicle in front of them are more likely to make decisions based on what is going on in front of them.

After analyzing the speed data taken from the traffic counters, a number of outliers were clearly visible. It then became necessary to remove these outliers in order to properly identify any significant changes in the before and after results. The first step in determining the values of the extreme outliers was to calculate the 25th and 75th percentiles. The fourth spread (*fs*) is defined as the difference between these numbers and is equivalent to the range of values representing the middle 50 percent of the data. An outlier is considered extreme if it is more than three *fs*s from the nearest quartile. The procedure for trimming outliers is similar to using multiples of standard deviation (σ) for data that are normally distributed; the fourth spread (*fs*) value is similar to the standard deviation. Thus the minimum extreme outlier was obtained by subtracting three *fs*s from the 25th percentile, while the maximum outlier was equal to the 75th percentile plus three *fs*s. This procedure was justified in the fact that it removed instances in which typical driver behavior was not observed. Those traveling below the minimum value were likely a slow-moving vehicle such as a tractor or someone who had pulled out from a driveway just before the counters. As a result they were never up to full speed in time and, therefore, the effect of the advance warning could not be determined. Anyone above the maximum value was traveling extremely fast, with little regard for the posted advisories in the first place. For the rural locations (FM 707 and SH 70) data were collected on individual vehicles at three different points. For the urban location (US 77), which had two travel lanes, it was not possible to track a single vehicle through the three data collection points so the analyses were conducted on the aggregate data at each counter.

TRANSVERSE LINES TREATMENT ON RURAL CURVE

Site Description

The third and fourth data collection sites chosen for studying rural curve warnings were a set of S-curves about one mile south of IH20 on FM 707. The vicinity of the interstate highway made it more likely that unfamiliar drivers may drive on this road, improving the appropriateness of a curve warning device. This location was also determined to be useful for data collection, as there are several parking areas for people to stop and watch Air Force warplanes taking off and landing at the neighboring Dyess Air Force Base. These areas provided locations for data collectors to sit and appear less conspicuous during data collection.

The northbound direction of FM 707 received a treatment of simple transverse lines (see Figure 6). This treatment was selected to represent the lowest cost minimal treatment. Several previous studies that had used elaborate transverse line spacings had speculated that the effect seen may have been due to simply having something in the roadway. The treatments applied here attempted to provide a visual warning, a "visual rumble strip" of sorts, to alert drivers to some upcoming change or hazard.

Results

Speed and traffic volume data were collected using pneumatic tubes at three locations as Figure 6 shows. Before data were collected between 1:00 p.m. November 4 and 11:00 a.m. November 6, 2003, (Tues – Thurs) for a total of 46 hours. The after data were collected between 5:00 p.m. March 1, 2004, and 9:00 a.m. March 4, 2004, (Mon – Thurs) for a total of 64 hours. The number of vehicles collected at this site presented by time of day and vehicle class is shown in Table 3. The difference in sample sizes was significantly different (chi-square = 13.83, $p < 0.05$). A test of homogeneity of variance of the speed variables between the two samples showed no significant difference (Levene statistic (df 1, 2339) = 2.044, p=.153). This test indicates that despite the difference in number of observations, the variance of the two samples is similar enough for valid comparisons.

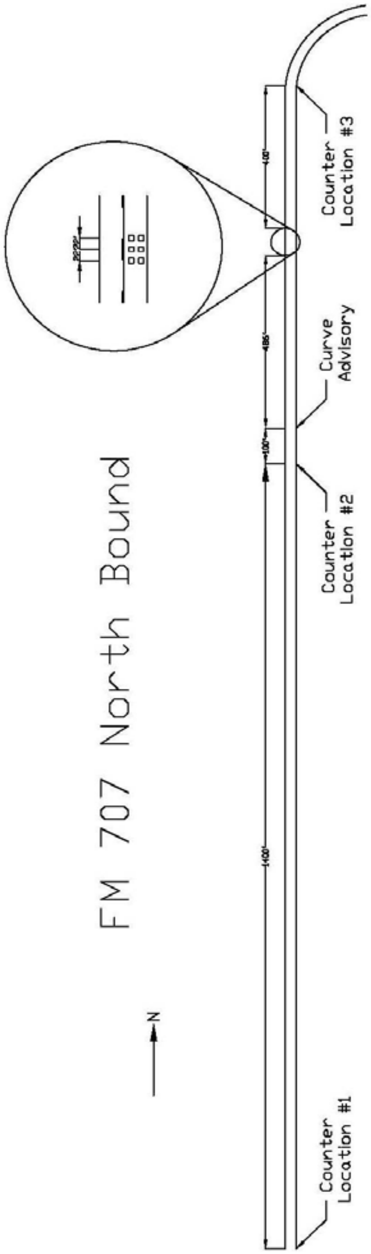


Figure 6. Site Description for Transverse Line Treatment.

Table 3. Vehicle Counts for Transverse Line Treatment.

Before (number of vehicles)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	1082	614	238	230
Cars	995	548	224	223
Heavy Trucks	87	66	14	7
After (number of vehicles)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	1259	754	268	237
Cars	1150	680	244	225
Heavy Trucks	109	74	24	12

The mean speeds for the before and after time periods at each of the counter locations are shown in Figure 7. There was a significant distance at the control point (Counter 1) between the before and after periods ($F_{1,2340} = 121.4$, $p < 0.05$). Because of this difference in control-point speed, further analyses to test for treatment effects were conducted on the speed change for each vehicle calculated by subtracting the speed at Counter 3 from the speed at Counter 1.

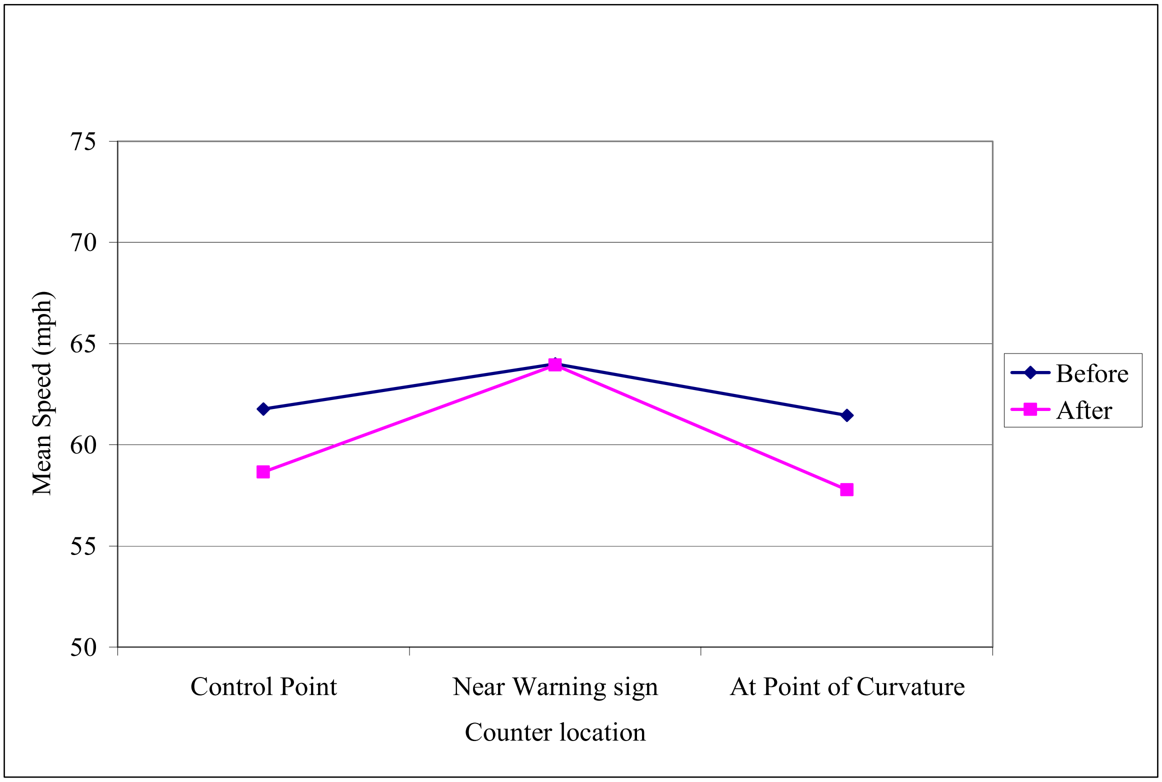


Figure 7. Mean Speeds for Transverse Line Treatment.

Table 4 shows the average of the speed changes from the control point (Counter 3) to the point of curvature (Counter 1). Analysis of variance on this change-in-speed variable revealed no significant differences between the before/after time period, no significant effect of time of day, no differences between cars and heavy trucks, and no significant interactions among the variables.

Table 4. Average Speed Reduction from Control Point to Point of Curvature for Transverse Line Treatment.

Before (mph)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	.3216	.3974	-.1134	.5696
Cars	.3146	.4051	-.0714	.5247
Heavy Trucks	.4023	.3333	-.1161	2.000
After (mph)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	.8825	1.0902	.3705	.8008
Cars	.8739	1.0781	.3498	.8276
Heavy Trucks	.9734	1.2014	.5913	.3000

Note: Positive numbers indicate speed decreases.

Summary and Discussion

The transverse line treatment at this location did not appear to have a measurable effect on speed. The degree of speed change from the control point to the start of the curve was less than one mph for all vehicles at all times of day. The particular size and placement of the transverse lines tested were selected based on a minimum installation. The design was essentially a stop bar and was chosen because it would be a convenient and readily-available material. The results indicate, however, that the materials did not provide a sufficient cue to drivers that they should slow for the approaching curve.

CURVE AHEAD TREATMENT ON RURAL CURVE

Site Description

The southbound direction of FM 707 received a treatment of the text message CURVE AHEAD as shown in Figure 8. The text consisted of 8-foot letters installed as shown in Figure 9.

Figure 8. CURVE AHEAD Treatment.

Results

Data were collected on the southbound section of this same road (FM 707) for the CURVE AHEAD treatment. Due to equipment malfunction, data were only collected for 22 hours during the before period. A sub-set of the after data was identified that corresponded to the same hours of the day in order to provide a comparable sample. The before data were collected between 12:30 p.m. Thursday, November 6, 2003, and 10:30 a.m. Friday, November 7, 2003. The selected after data analyzed were between 12:30 p.m. Tuesday, March 2, 2004, and 10:30 a.m. Wednesday, March 3, 2004. Although the days of the week were different between the two periods, the traffic volumes were comparable as Table 5 shows. A chi-square test confirms that the sample sizes were not statistically different (Chi-square = 0.4, $p > 0.05$)

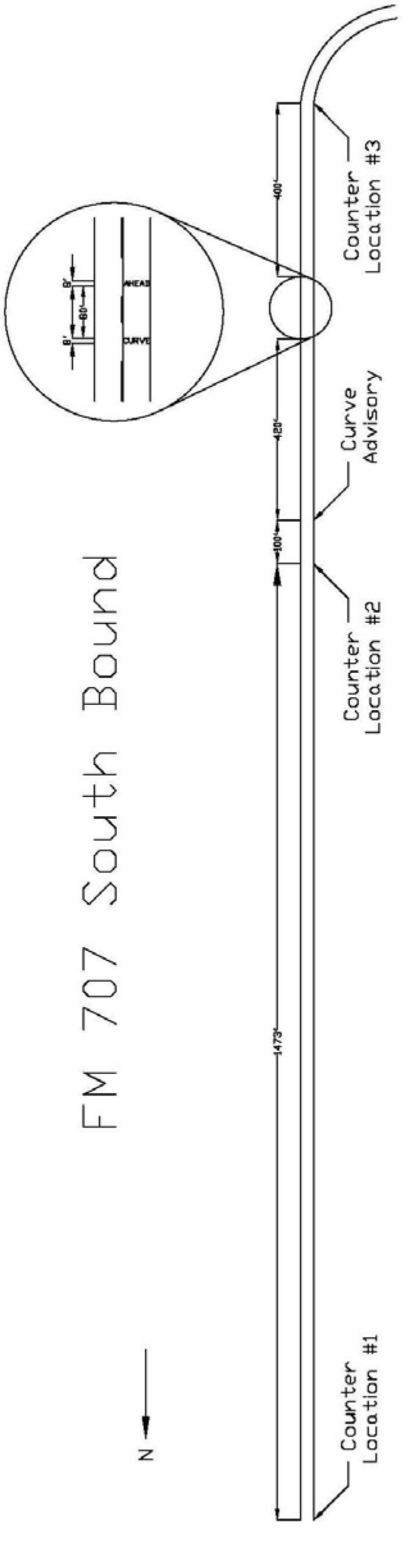


Figure 9. Site Description for CURVE AHEAD Treatment.

Table 5. Vehicle Counts for CURVE AHEAD Treatment.

Before (number of vehicles)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	442	283	91	68
Cars	406	256	87	63
Heavy Trucks	36	27	4	5
After (number of vehicles)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	461	313	94	54
Cars	418	285	81	52
Heavy Trucks	43	28	13	2

The mean speeds for the before and after time periods at each of the counter locations is shown in Figure 10 . There was a statistically significant difference in speeds at the control point between the before and after periods ($F_{1,901} = 4.86$, $p < 0.05$) although the means (before = 59.17, after = 60.25) were very similar.

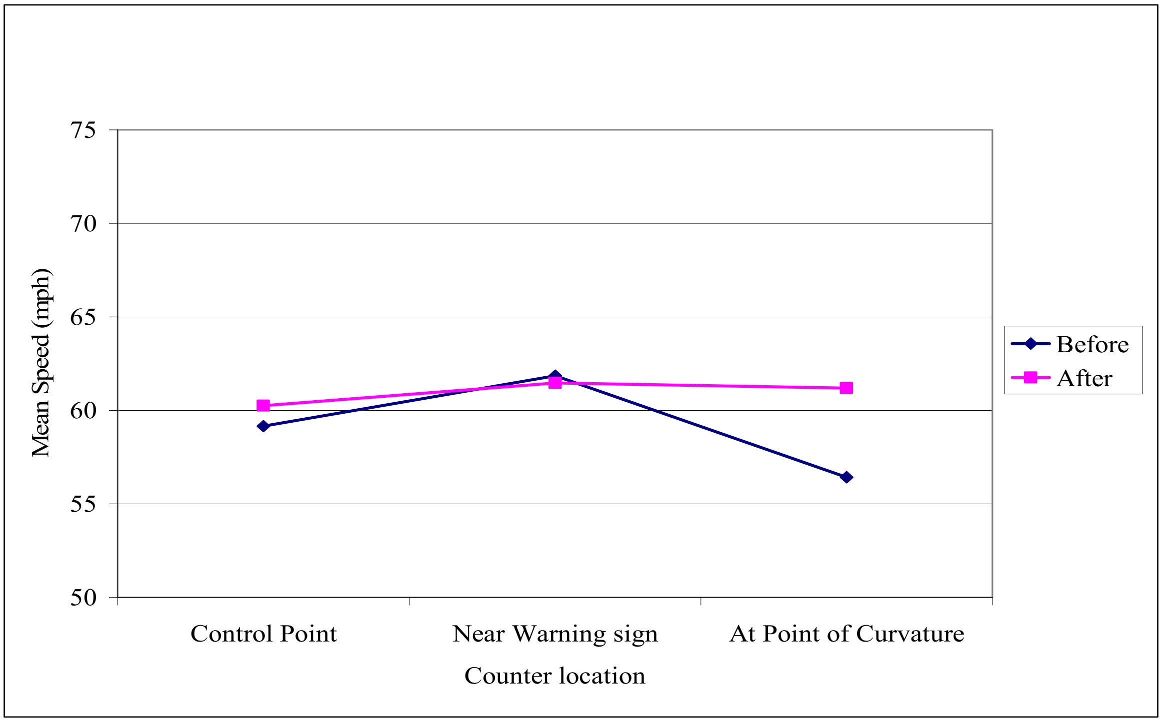


Figure 10. Mean Speeds for CURVE AHEAD Treatment.

As at the previous locations, the measure of change in speed was calculated for further analysis by subtracting the speed at the point of curvature from the speed at the control point for each individual vehicle. The average speed changes for each of the conditions are shown in Table 6. As can be seen in the graph and in the table, there was very little change in speed in the after period. Analysis of Variance on speed change confirmed that there was a statistically significant difference between the before and after periods, in the direction opposite of what was expected. The analysis showed no effect of type of vehicle or time of day and neither of these variables showed significant interactions with other factors.

Table 6. Average Speed Reduction from Control Point to Point of Curvature for CURVE AHEAD Treatment.

Before (mph)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	2.74	2.28	3.88	3.15
Cars	2.81	2.32	4.09	3.05
Heavy Trucks	1.92	1.85	-0.75	4.40
After (mph)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	-0.93	-0.62	-1.76	-1.34
Cars	-0.84	-0.59	-1.36	-1.44
Heavy Trucks	-1.80	-0.90	-4.22	1.35

Note: Positive numbers indicate speed decreases.

Summary and Discussion

The CURVE AHEAD treatment at this location did not have the expected effect on speed selection. Drivers in the before period did slow down between the warning sign and the point of curvature, but did not do so in the after period. The number of observations for this site was smaller than for other sites, but still of sufficient size to draw the conclusion that the CURVE AHEAD text treatment did not succeed in changing driver behavior.

CURVE + ADVISORY SPEED TREATMENT ON RURAL CURVE

Site Description

The first data collection site (location 2 in Table 2) chosen for studying rural curve warning is a left-hand curve on southbound TX 70 (See Figure 12), just at the north end of

Blackwell, Texas. The northbound direction of this curve was not suitable for consideration as reduced city speed limits regulate drivers until just before the curve. When heading southbound on TX 70, a driver would drive an essentially straight roadway for more than 10 miles in advance of the town of Blackwell, providing ample opportunity for drivers to choose their desired speeds. It also has the potential of desensitizing drivers to their surroundings, and may increase the likelihood that drivers will miss the evidence and warning of the impending curve. The use of a horizontal curve warning sign was considered a potential benefit for further study.

The treatment consisted of the words CURVE 55 MPH laid out as shown in Figure 12. The treatment began approximately 400 ft after the standard curve warning sign. A photo of the test site is shown in Figure 11.

Figure 11. CURVE 55 MPH Treatment.

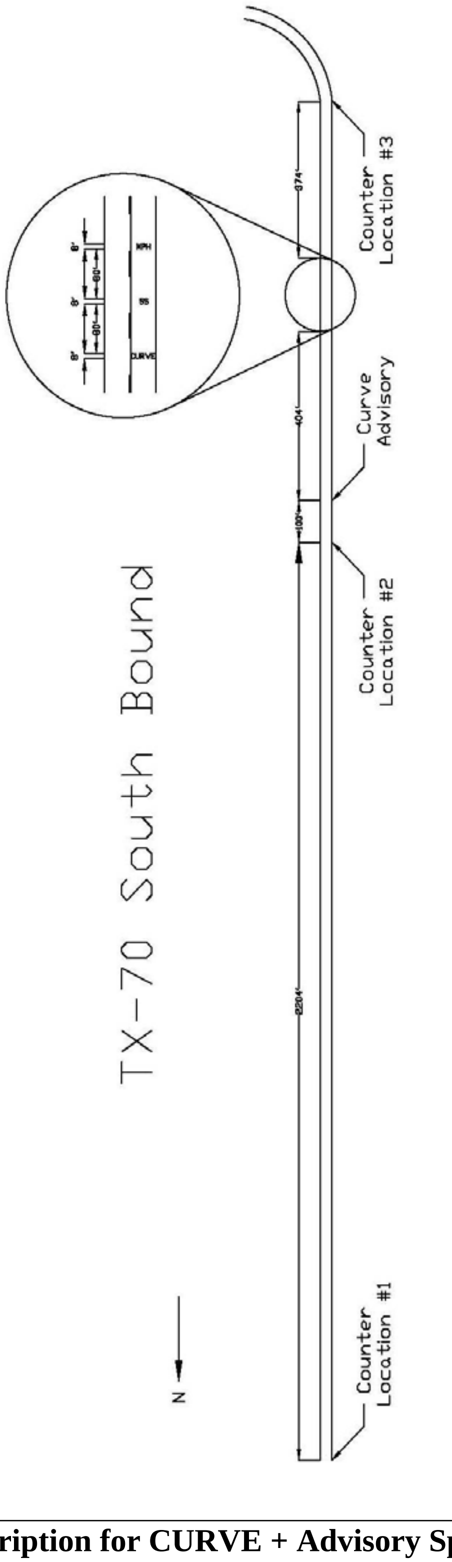


Figure 12. Site Description for CURVE + Advisory Speed Treatment.

Results

Data were collected on TX 70 to assess the text message CURVE 55 MPH. The before data were collected between 10:15 a.m. Tuesday, November 4, 2003, and 9:15 a.m. Friday, November 7, 2003. The after data were between 1:55 p.m. Monday, March 1, 2004, and 10:30 a.m. Wednesday, March 3, 2004. Although the days of the week were different between the two periods, the traffic volumes were comparable as shown in Table 7. A chi-square test confirms that the sample sizes were not statistically different (Chi-square = 0.09, p > 0.05).

Table 7. Vehicle Counts for CURVE 55 MPH Treatment.

Before (number of vehicles)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	933	586	213	134
Cars	819	526	166	127
Heavy Trucks	114	60	47	7
After (number of vehicles)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	946	676	185	85
Cars	738	561	103	74
Heavy Trucks	208	115	82	11

The mean speeds for the before and after time periods at each of the counter locations are shown in Figure 13. The control point mean speed for the before period was 68.88 mph while the comparable speed in the after condition was 71.41 mph. An analysis of variance showed that these two were not statistically different (F = 7.16, p = 0.22), thus allowing direct comparisons of the speeds at the point of curvature. At the point of curvature the mean speed in the before period was 60.71 mph, while during the after period it was 59.31 mph. A test between the before and after conditions at this third counter failed to reach statistical significance (F = 6.72, p = 0.23).

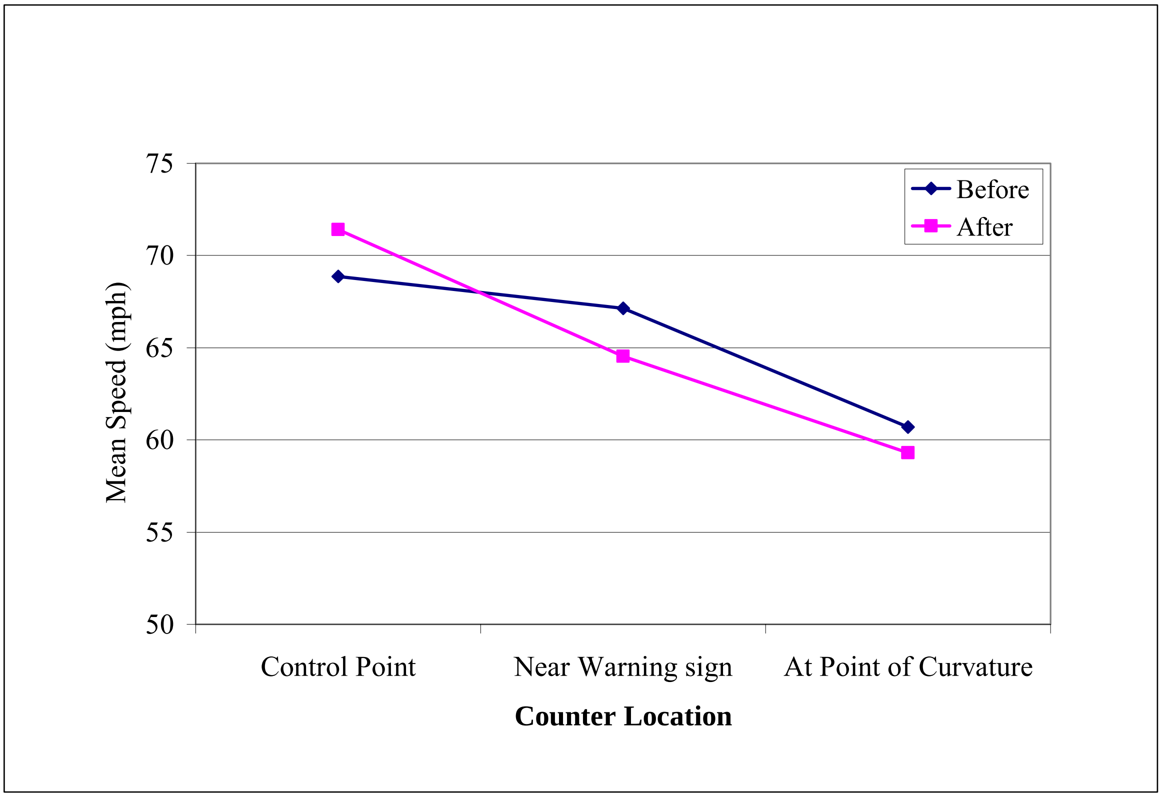


Figure 13. Mean Speeds for CURVE 55 MPH Treatment.

Another way to examine the data is to look at how much individual vehicles slowed down between the control point and the point of curvature. A new variable "speedchange" was calculated for each individual vehicle by subtracting the speed at the point of curvature from the speed at the control point. Table 8 shows the average changes in speed. Analysis of variance on the change in speed variable showed that the difference between the before and after period was not statistically significant ($F_{1, 1867} = 26.34$, $p = .122$).

Table 8. Average Speed Reduction from Control Point to Point of Curvature for CURVE 55 MPH Treatment.

Before (mph)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	8.17	8.26	7.79	8.36
Cars	8.05	8.27	7.10	8.39
Heavy Trucks	8.99	8.13	10.26	7.86
After (mph)				
	Overall	Day	Night	Dawn/Dusk
All Vehicles	12.09	11.59	13.59	12.86
Cars	11.40	11.19	11.60	12.68
Heavy Trucks	14.56	13.52	16.10	14.03

The only significant effect in this analysis was the finding that, for both time periods, trucks slowed down more than cars at nighttime. This interaction was significant ($F_{2,\,1867}$ = 26.02, p = .037) and is shown in Table 9.

Table 9. Speed Reduction (mph) Interaction of Vehicle Type and Time of Day.

	Day	Night	Dawn/Dusk
Cars	9.73	9.35	10.53
Heavy Trucks	10.83	13.18	10.94

Summary and Discussion

In the before period drivers slowed down around 8 mph, while in the after period they slowed down around 12 mph. This difference was not statistically different, but it does suggest a benefit of the horizontal signing treatment that is worthy of further exploration. The finding that heavy trucks decelerate more than passenger cars at night, while not relevant to the treatment studied, does indicate that truck drivers in this corridor are behaving in a safe manner.

CURVE ARROW + ADVISORY SPEED TREATMENT ON URBAN CURVE

Site Description

An urban curve location was selected on US 77 near Robstown in the Corpus Christi District. This location, on a divided four-lane highway, was selected based on a high number of truck rollover accidents in the area as reported by the TxDOT district engineer. In addition, this site was scheduled to have new overhead curve warning signs with flashing beacons installed several months after installing the horizontal signing treatment (see Figure 14). All data reported here are for the horizontal signing treatment only.

Results

The multi-lane freeway test section on US 77 had a much higher volume than the other locations. Because it was a multi-lane facility the data collection method did not allow analysis of individual vehicles. Instead, the data are for aggregate number of vehicles and speeds at each of the three counter locations. Traffic counters were deployed with pairs of pneumatic road tubes to collect the data. The traffic counting devices cannot only collect the number of vehicles passing, but also provide each vehicle's speed and class (i.e., passenger car or large multi-axle truck). The before data were collected beginning Tuesday, January 27, 2004 at 1:00 p.m. through Thursday, January 29 at noon for a total of 47 hours. The after data were collected between Monday, March 29, 2004 at 1:00 p.m. and Friday, April 2 at 10:00 a.m. for a total of 93 hours. The vehicle counts and vehicle mix by time of day for each data collection period are shown in Table 10.

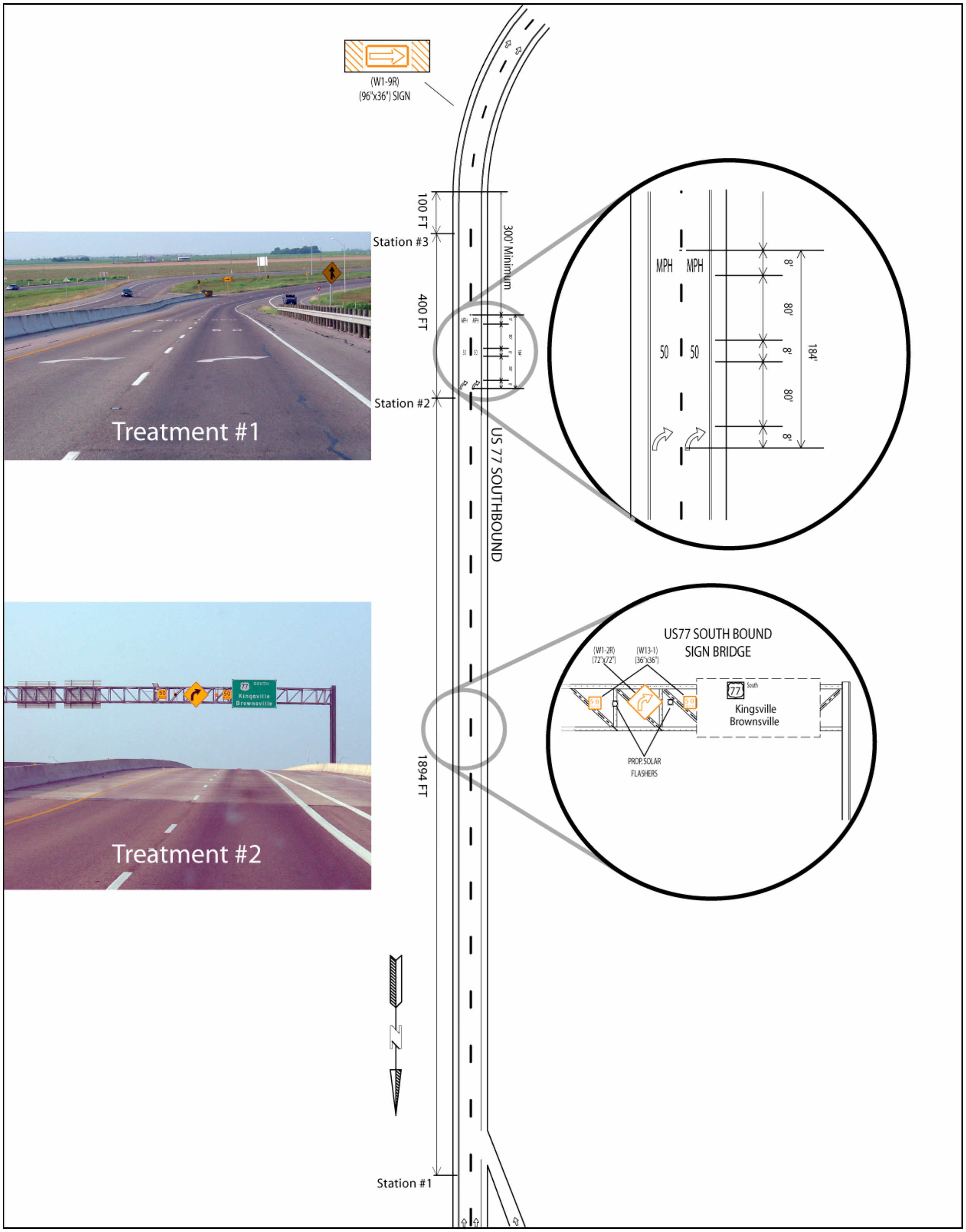


Figure 14. Site Description for CURVE ARROW + Advisory Speed Treatment.

Table 10. Vehicle Counts for CURVE ARROW + Advisory Speed Treatment.

	Overall	**Day**	**Night**	**Dawn/Dusk**
Counter 1 Before				
All Vehicles	9936	6279	3194	463
Cars	6938	4646	1915	377
Heavy Trucks	2998	1633	1279	86
Counter 2 Before				
All Vehicles	10,614	6724	3395	495
Cars	7429	4988	2031	410
Heavy Trucks	3185	1736	1364	85
Counter 3 Before				
All Vehicles	10,424	6471	3445	508
Cars	7804	5114	2253	437
Heavy Trucks	2620	1357	1192	71
All Vehicles	10,424	6471	3445	508
Counter 1 After				
All Vehicles	21,018	14,180	6111	727
Cars	14,699	10,558	3638	503
Heavy Trucks	6319	3622	2473	224
Counter 2 After				
All Vehicles	22,503	15,278	6446	779
Cars	15,482	11,272	3674	536
Heavy Trucks	7021	4006	2772	243
Counter 3 After				
All Vehicles	17705	11,531	5562	612
Cars	11794	8230	3149	415
Heavy Trucks	5911	3301	2413	197

The mean speeds for all vehicles at all times of day are shown in Figure 15. The Analysis of variance on the speed data revealed that there was no difference between the speeds of cars and trucks, nor did type of vehicle interact with any of the other variables. There was a significant effect of time of day with nighttime speeds averaging about 4 mph slower than daytime and dawn/dusk conditions.

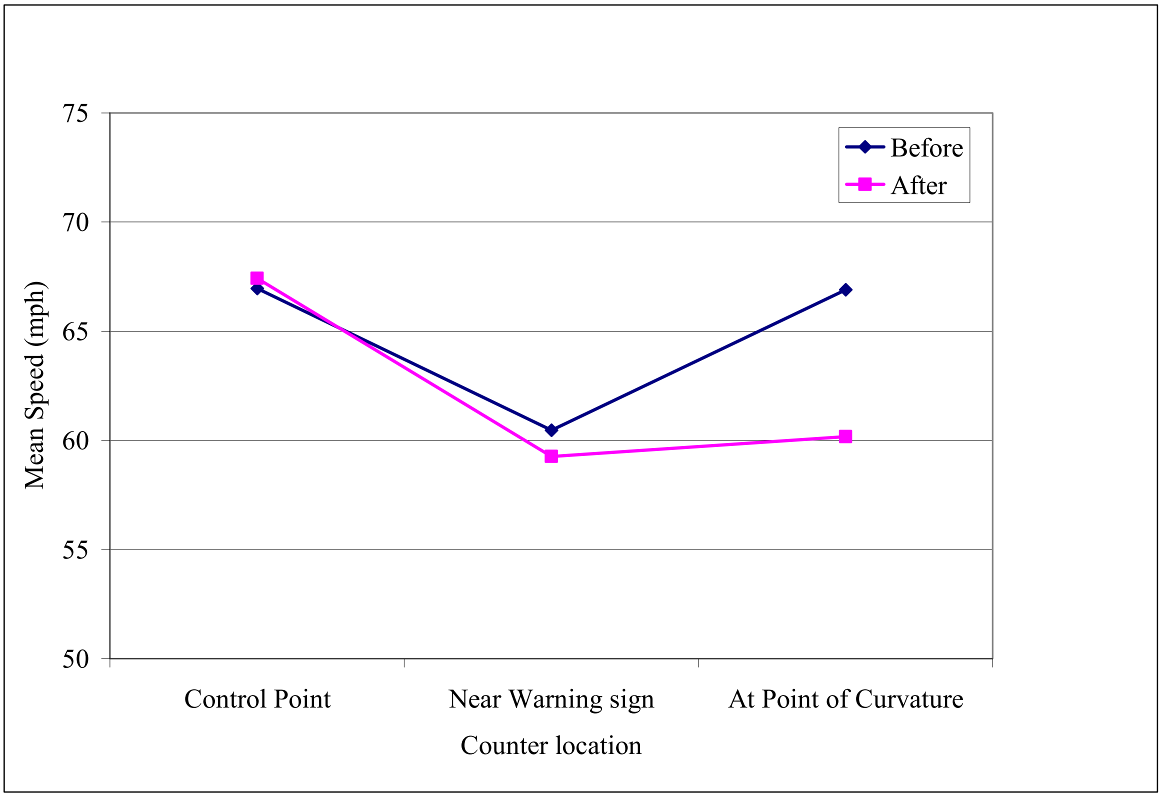


Figure 15. Mean Speeds for CURVE ARROW + Advisory Speed Treatment.

The interaction shown in Figure 15 was significant at the 0.05 level validating that drivers in the after period were driving slower at the point of curvature than drivers in the before period. The difference in speeds at the point of curvature by vehicle type and time of day is shown in Table 11.

Table 11. Difference between before / after in Speed (mph) at the Point of Curvature.

	Overall	Day	Night	Dawn/Dusk
Overall	6.74	7.00	6.53	6.04
Cars	6.43	6.73	6.13	5.53
Trucks	6.81	7.18	6.67	5.62

Another way to view the data is to look at the number of vehicles exceeding the posted speed limit at the point of curvature. Table 12 shows the percentage of vehicles exceeding the posted speed limit in the before and after periods.

Table 12. Percent of Vehicles Exceeding the Posted Speed Limit.

Vehicle Type	Time of Day	Before (%)	After (%)
Cars	Day	97.7	86.8
Trucks	Day	97.0	80.1
Cars	Night	93.2	77.6
Trucks	Night	88.9	69.0

Summary and Discussion

The average speed data show that because of the vertical crest between the control point and the warning sign, vehicles slow down between the first and second counter locations. After passing the warning sign, vehicles accelerate as they go down the overpass. In the after condition, vehicles did not accelerate. The percentage of vehicles exceeding the speed limit also reveals the effectiveness of this treatment. Typical practice involves using an 85th percentile speed limit, which means 85 percent of all vehicles are going the speed limit or slower and only 15 percent are violating the speed limit. The before data show that more than 89 percent of the vehicles were in violation of the posted speed for the curve. The study showed that by implementing the pavement markings, drivers reduced their speeds at the entrance to the curve by 10 percent. The clear positive results shown at this site as compared to the ambiguous results from the rural sites may be a product of sample size. Because US 77 is a freeway, the traffic volume is much higher. It could be the case that, with more observations, the speed patterns at the other sites would become more stable.

CHAPTER 3. TWO-WAY FRONTAGE ROAD TREATMENTS TO REDUCE WRONG-WAY MOVEMENTS

This research effort focuses on the use of lane direction pavement marking arrows as a means of providing an additional cue for drivers to recognize the direction of traffic flow.

PREVIOUS LANE USE ARROW RESEARCH

Pavement markings provide one of the clues that drivers can use to identify the proper direction of traffic flow for a lane. The use of yellow for separating opposing traffic on two-way roadways and as the left edge line on one-way roadways has been well established for over a quarter of a century. A recent *National Cooperative Highway Research Project* (NCHRP) study evaluated the potential for replacing the yellow-white marking system with an all-white one (*38*). The primary focus of the researchers for that effort was a survey of over 800 drivers to assess driver understanding of the existing yellow-white and potential all-white marking systems. These survey results have been described in previous work (*38*). The researchers studied one potential method for improving driver understanding of traffic direction without relying upon pavement marking color. This question asked drivers to describe the meaning of arrows located in the traffic lane.

Lane direction arrows are described in the MUTCD (17). In the U.S., they are commonly used on approaches to intersections to indicate permitted movements from each lane. They are also commonly used in Europe at intersections and other junctions where there is the potential for wrong-way movements. Figure 16 shows a graphic used in the NCHRP study. As had been used in other questions of this survey, the pavement markings used in this image were black to avoid the use of color to indicate lane direction.

A correct response was provided by 93.7 percent of the survey participants. Only 4.3 percent provided an incorrect response or no response. A questionable response was given by 2.1 percent of the survey participants. The responses to this question indicate a very high level of inherent understanding associated with the lane direction arrows. Such arrows might have significant value in locations where drivers may be confused as to the direction of traffic flow.

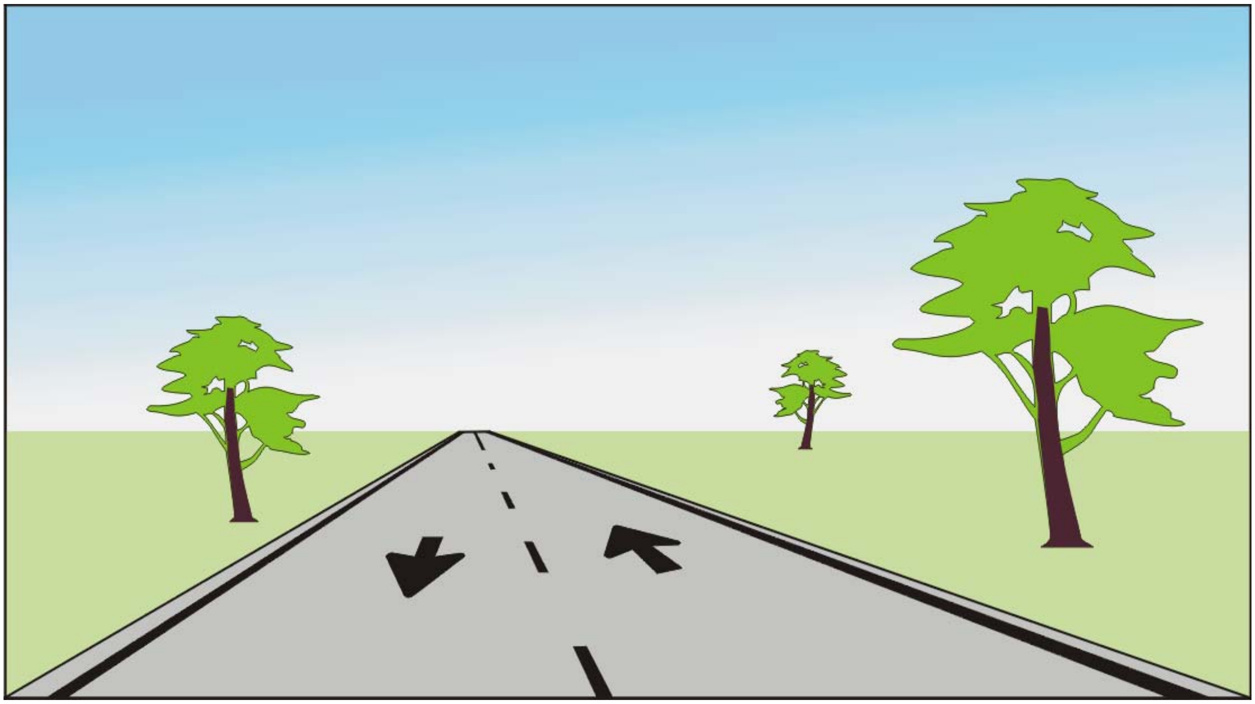


Figure 16. Graphic for Lane Direction Arrow Survey Question.

Opportunity for Further Research

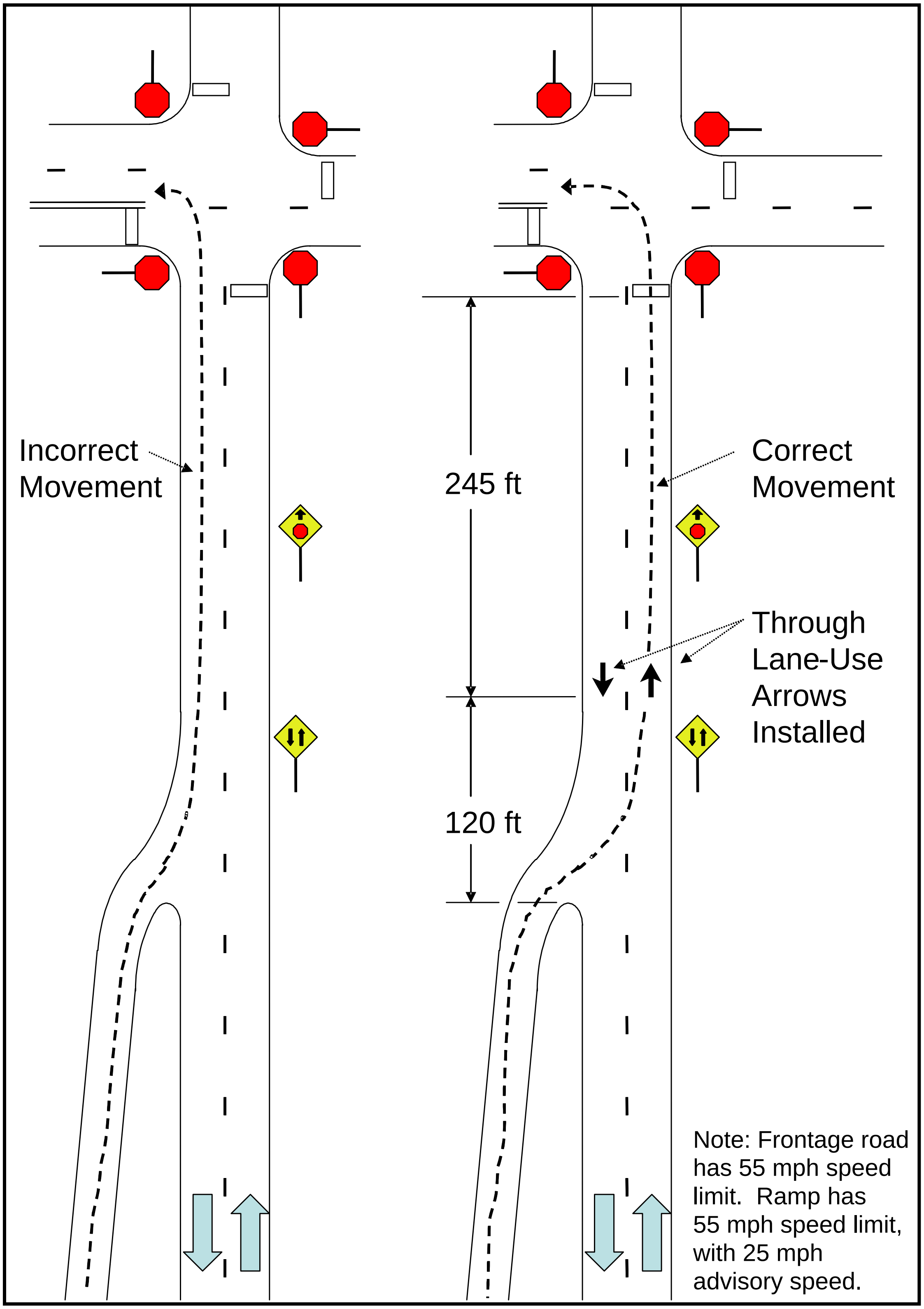
A field evaluation of the effectiveness of the lane direction arrows was not a part of the scope of the NCHRP all-white pavement marking project. However, the results were so positive that TTI researchers believed that opportunity existed to expand on this for this research project. Members of the TTI research team were aware of a location in the College Station, Texas, area with anecdotal evidence of wrong-way movements on a two-way frontage road. The roadway appeared to be a natural location for assessing the potential effectiveness of the lane direction arrows.

FIELD EVALUATION

In Texas many freeways exit onto adjacent frontage roads from which drivers access adjacent properties and cross streets. Use of the frontage road system is widespread in Texas and it is common for urban frontage roads to operate as one-way roadways, while rural areas tend to have two-way frontage roads. The presence of both one-way and two-way frontage roads in a given area may create increased potential for wrong-way movements on the two-way frontage roads. The location selected for the field evaluation was such a location. It is a short section of two-way frontage road on the fringe of the College Station, Texas, urban area. Figure 17 illustrates the location where the field study was conducted.

An example of a wrong-way maneuver could include selecting the oncoming lane of a two-way frontage road, as shown in Figure 17. This site was selected because it was believed to have several advantages for this research. It is located at the edge of the Bryan/College Station urban area where the majority of the freeway exit ramps merge into one-way frontage roads, so unfamiliar drivers may be less likely to expect a two-way frontage road at this location. Additionally, traffic volumes are low, especially for traffic traveling in the opposite direction on the frontage road, meaning that drivers could not rely upon the presence of other vehicles to indicate traffic direction. Also, the regional airport is located at this exit and most of the exiting traffic is traveling to the airport. This traffic has to make a left turn at the downstream intersection. Drivers unaware of the two-way traffic flow would be more likely to stay in the left lane approaching the intersection. Existing pavement markings were in fair condition at the time of the study, and could be seen both during the day and at night. Additionally, there was an existing two-way traffic warning sign (W6-3) to the right of the frontage road at the ramp terminus.

The pavement marking treatment that was selected for research was a pair of standard 9 ft white retroreflective thermoplastic pavement marking defined in the MUTCD as a “Through Lane-Use Arrow” (*17*). However, as they are not being used in the immediate vicinity of an intersection they are referred to in this research as lane direction arrows. These were placed approximately 120 ft away from the gore area of the exit ramp, one in each lane of travel, as shown in Figures 17 and 18. This was determined to be close enough to the ramp terminus that drivers would be able to see the arrows as they reached the frontage road, but not so close that a driver choosing the correct right-hand lane would have to drive over the arrow in the left oncoming lane. Typical cost for such an installation is in the range of $300.



Note: Frontage road has 55 mph speed limit. Ramp has 55 mph speed limit, with 25 mph advisory speed.

Figure 17. Possible Wrong-Way Driving Maneuver and Countermeasure Installation.

Figure 18. View of Frontage Road Location after Arrow Installation.

Data Collection and Reduction Procedures

Data were collected using a portable video trailer shown in Figure 19 consisting of a mast-mounted camera system that recorded time-lapse imagery onto VHS tape. The cameras were oriented to view vehicles from the time they entered the frontage road from the exit ramp until they passed through the intersection. Data collection before the installation of the arrows took place from March 1-8, 2004. The lane direction arrows were installed on May 21, 2004, on the frontage road – one in each lane as shown in Figures 17 and 18. Following a two-week acclimation period, another round of data collection occurred. It was desired to collect a full 168-hour week for both the before and after periods. However, due to equipment difficulties only 156 hours of data were collected in the before period and 143 hours during the period after the pavement marking installation. The lost time was typically at night.

Figure 19. Video Camera Trailer Used for Lane Choice Data Collection.

The videotapes were then viewed by TTI staff to determine the lane choice and the direction taken by each vehicle as it left the exit ramp. A conservative designation was made for each vehicle whether the driver made a proper maneuver or not. If the driver drove in the left lane for any time (other than properly crossing the lane at the end of the exit ramp to access the right-hand lane) it was considered a wrong maneuver. Additionally, conflicts that occurred between two or more vehicles were also recorded. These included any time a vehicle moving in the wrong direction was confronted with an oncoming vehicle in the same lane, or when two vehicles from the exit ramp came to the intersection – one in each lane – and both tried to make left turns. While no crashes occurred during the study period, these conflicts were recorded as surrogates for the crash potential at the site due to such improper movements.

Data Analysis

Appropriate statistical tests were selected to analyze the relationship between the dependent and independent variables for this research. The presence of the lane direction arrows and lighting conditions (night and day) were selected as the independent variables, and the proportion of drivers that selected an incorrect path on the frontage road was selected as the dependent variable. The dependent variable was further categorized into the turning movement chosen at the downstream intersection (left turn, straight, or right turn). Researchers performed z-tests for differences in proportions using computerized spreadsheets (*39*). All statistical tests were two-tailed tests, and were performed at a 0.01 level of significance.

Results of Field Installation

Results of the z-tests between the before and after periods showed that the presence of the lane direction arrows had a very beneficial effect on the proportion of wrong-way driving maneuvers. Table 13 shows that there were significant reductions in the overall proportion of drivers that selected the left (incorrect) lane after entering the frontage road from the freeway exit. Overall, incorrect maneuvers were reduced from 7.4 percent to 0.7 percent, a 90-percent reduction of the rate. Stated another way, prior to the installation of the lane direction arrows about one out of every thirteen vehicles that exited the freeway at this location ended up driving in the wrong frontage road lane. After the installation of the arrows, this dropped to about one out of every 150 vehicles.

Table 13. Overall Wrong-Way Driving Maneuvers before and after Treatment.

Number of Vehicles		
	Correct	**Wrong**
Before Installation	4790	385
After Installation	4090	28
Proportions		
	Correct	**Wrong**
Before Installation	0.926	0.074
After Installation	0.993	0.007
Wrong Maneuver Proportion Reductions		0.068
Z Value		15.708 *
P-value		< 0.0001

* Difference is statistically significant at the 0.01 level of significance.

The impact was even greater for the vehicles that turned left at the intersection toward the airport, as shown in Table 14. Prior to the arrow installation, 11.5 percent of vehicles remained in the left (incorrect) lane, but after the installation only 0.9 percent remained in the incorrect lane, or a reduction of 93 percent of wrong-way maneuvers. So in the before case about one out of eight vehicles that were heading to the airport made an incorrect maneuver, while after the installation this had dropped to about one out of 117 vehicles. There were no apparent changes in the driving environment in the study area other than the arrow installation that could have explained a change in this behavior of drivers.

Table 14. Wrong-Way Driving Maneuvers by Traffic Movement.

Number of Vehicles								
	Left Turn			**Through**			**Right Turn**	
	Correct	**Wrong**		**Correct**	**Wrong**		**Correct**	**Wrong**
Before Installation	2714	354		1761	29		315	2
After Installation	2793	24		1067	4		230	0
Proportions								
	Left Turn			**Through**			**Right Turn**	
	Correct	**Wrong**		**Correct**	**Wrong**		**Correct**	**Wrong**
Before Installation	0.885	0.115		0.984	0.016		0.994	0.006
After Installation	0.991	0.009		0.996	0.004		1.000	0.000
Wrong Maneuver Proportion Reductions		0.107			0.012			0.006
Z Value		16.197	*		3.005	*		1.205
P-value		<0.0001			0.0013			0.1141

* Difference is statistically significant at the 0.01 level of significance.

The analysis also found that there was no statistically significant difference between the rates of wrong-way movements when compared by lighting conditions (day and night), as shown in Table 15. Therefore researchers concluded that the presence of the lane direction arrows were equally effective both during the day and at night.

The observations of actual conflicts were also analyzed. During the period of data collection prior to the installation of the pavement markings there were 21 observed conflicts involving two vehicles. Seventeen of these conflicts consisted of two left-turning vehicles that came to the frontage road from the exit ramp arriving at the intersection at the same time but in different lanes – one in the correct right lane, one in the incorrect left lane. These vehicles then had to jockey for position after beginning their left turn in order to avoid a crash. In the after period the total conflicts was reduced to a single instance of such a double left turn. Clearly, it appears consistent that the absolute reduction of wrong-way driving movements would correspond with a reduction of wrong-way driving-related conflicts. However, as Table 16 reveals, the number of conflicts that were observed were virtually eliminated in the data collection period following the installation of the pavement markings, and were statistically significant.

Table 15. Wrong-Way Driving Maneuvers by Time of Day.

Before Number of Vehicles								
	Left Turn			**Through**			**Right Turn**	
	Correct	**Wrong**		**Correct**	**Wrong**		**Correct**	**Wrong**
Daytime Obs.	2032	275		972	20		250	2
Nighttime Obs.	682	79		789	9		65	0
Proportions								
	Left Turn			**Through**			**Right Turn**	
	Correct	**Wrong**		**Correct**	**Wrong**		**Correct**	**Wrong**
Daytime Obs.	0.881	0.119		0.980	0.020		0.992	0.008
Nighttime Obs.	0.896	0.104		0.989	0.011		1.000	0.000
Proportional Difference (Day - Night)		0.015			0.009			0.008
Z Value		1.152			1.480			0.721
P-value		0.1247			0.0694			0.2355
After Number of Vehicles								
	Left Turn			**Through**			**Right Turn**	
	Correct	**Wrong**		**Correct**	**Wrong**		**Correct**	**Wrong**
Daytime Obs.	2209	22		821	2		166	0
Nighttime Obs.	584	2		246	2		64	0
Proportions								
	Left Turn			**Through**			**Right Turn**	
	Correct	**Wrong**		**Correct**	**Wrong**		**Correct**	**Wrong**
Daytime Obs.	0.990	0.010		0.998	0.002		1.000	0.000
Nighttime Obs.	0.997	0.003		0.992	0.008		1.000	0.000
Proportional Difference (Day - Night)		0.006			-0.006			0.000
Z Value		1.511			-1.275			---
P-value		0.0654			0.1012			---

* Difference is statistically significant at the 0.01 level of significance.

Table 16. Reduction in Traffic Conflicts.

	Head-on Conflicts	**Double Left-Turn Conflicts**	**Other Conflicts**	**Total**
Before Installation	2	17	2	21
After Installation	0	1	0	1

Number of Conflicts		
	No Conflicts	**Total Conflicts**
Before Installation	3047	21
After Installation	2817	1
Conflicts as Proportions		
	Correct	**Wrong**
Before Installation	0.993	0.007
After Installation	1.000	0.000
Conflict Proportion Reductions		0.006
Z Value		4.076*
P-value		<0.0001

* Difference is statistically significant at the 0.01 level of significance.

RECOMMENDATIONS

This research provides an indication of the potential effectiveness of low-cost traffic control improvements such as lane direction arrows to improve safety at locations where wrong-way driving occurs. The field evaluation was not of sufficient depth to justify immediate widespread implementation of lane direction arrows. However, the overwhelming reduction in wrong-way driving indicates that the treatment can have a very beneficial safety influence on traffic at locations where drivers may be confused about an appropriate lane selection. To that end, the researchers recommend transportation officials consider this treatment at problem locations.

CHAPTER 4: DRIVER COMPREHENSION AND PREFERENCES

HUMAN FACTORS STUDY

A human factors study was conducted to assess driver understanding of horizontal signing. Video clips and still photos were presented on a laptop computer. The still photos were limited in their presentation time as described below. Participants administered the test themselves and wrote down their answers to the questions.

Research Participants

Forty-nine subjects participated in the laptop survey; 25 completed Version A, and 24 completed Version B. Subject ages ranged from 18 to 61, with an average age of 31.5 years. Seventeen, or 34.7 percent, of the 49 participants were women.

Method

The survey began with the experimenter giving the following instructions:

> "*You're going to look at some video and photographs of different roads and answer some questions by writing on this pad of paper. The questions will be about how you would drive or what you think about some of the features of the roadway scenes. You will control when the pictures appear by pressing the space bar. This is the space bar (points to it). You are not able to go backwards. If you press the bar by mistake, let me know. Once you press the space bar the video or picture will appear, so you need to be watching carefully. The first four questions are videos and the next eight questions are photographs. The photographs will only stay on the screen for a few seconds, to just give you a glance at them just like when you're driving. If you have any questions or aren't sure what a question means don't hesitate to ask me. It's OK to write you don't know to an answer. You can now begin.*"

Participants performed the test alone in a room. The entire test took between 7 and 10 minutes.

Experimental Design

Table 17 displays the counterbalancing, trial order, and timing of the two presentation versions. The various video and roadway scenes will be described in more detail in the results section. The videos were taken at the field test location sites for the frontage road and several of the curve locations.

Table 17. Experimental Design and Timing of Human Factors Study.

Order in Presentation	Version A	Version B	Timing
1	Arrows Present	Arrows Absent	Video
2	Arrows Absent	Arrows Present	Video
3	Transverse Lines	Curve Ahead	Video
4	Curve Ahead	Transverse Lines	Video
5	Curve Arrow	Curve Arrow	4 seconds
6	Hurricane	Hurricane	8 seconds
7	FM 1960 Text in Box	IH 10 Shield	4 seconds
8	TX 288 Text in Box	US 80 Shield	4 seconds
9	IH 10 Text	FM 1960 Text in Box	4 seconds
10	US 80 Text	TX 288 Text in Box	4 seconds
11	BW 8 / Hardy Shield	Hardy Shield / BW 8	Unlimited
12	IH 10 Text / Shield	IH 10 Shield / Text	Unlimited

The participants were randomly assigned to either Version A or Version B of the PowerPoint presentation. Both versions began with four video clips, then six pictures of roadway scenes, and finally two slides showing side-by-side comparisons. The video clips showed a roadway scene in motion from a driver's perspective, and once the clip stopped, the subjects were asked questions about what they saw. The roadway scene pictures consisted of pre-existing or digitally created pavement markings in various settings. The subject was only allowed to view these scenes for a limited amount of time, and then was asked what they thought the markings meant. The final two questions displayed two versions of similar pavement markings on a roadway and asked the participant which they preferred. The subject could take all the time they needed to make these decisions.

RESULTS

Two-Way Frontage Road with or Without Arrows Present

The subjects viewed two video versions of an exit onto a two-way frontage road that approaches a cross street with a stop sign. All subjects viewed both videos, although the order was counterbalanced. In both videos the solid yellow centerlines are visible as well as a yellow diamond warning sign indicating traffic in both directions. There was no oncoming traffic visible in either video. One video did not have any additional pavement markings other than the yellow centerline, but in the other video horizontal pavement arrows indicating the flow of traffic in each lane are visible. The video footage was shot at the frontage road site described in Chapter 3 (with arrows) and another unmarked two-way frontage road with similar geometric design.

The subjects were asked the following questions after viewing each of the videos:

> *"If you wanted to turn left at the intersection the car was approaching before the video stopped, which lane would you choose to approach the intersection (left or right)? What made you decide left or right?"*

Participants freely generated their answers to the "why" question, that is, it was not multiple choice. Table 18 shows the results of the answers to the above questions. Participants correctly chose the right lane the majority of the time regardless of the presence of arrows. These results are slightly contrary to our field observations reported in Chapter 3 that showed a marked decrease in the number of drivers selecting the left lane when directional arrows were present. When asked why they chose the lane, participants noted the presence of yellow centerlines more often when arrows were not present than when they were present. A relatively small number (14 percent) people noted the presence of the arrows had influenced their choice. It is possible that some participants did not notice the arrows in the video, although they were clearly visible.

Table 18. Two-Way Frontage Road Arrows Comprehension Data.

With Arrows Present		Without Arrows Present	
Result	**%**	**Result**	**%**
Left	8	Left	10
Right	92	Right	90
Comments	**%**	**Comments**	**%**
2-Way Traffic	41	2-Way Traffic	41
Yellow Centerlines	11	Yellow Centerlines	25
Sign Indicating 2-Way Traffic	13	Sign Indicating 2-Way Traffic	10
Direction I Want to Turn	7	Direction I Want to Turn	2
Arrows	14	Safer	4
No Comment	9	No Comment	10
Other	5	Other	8

Transverse Line Treatment on Rural Curve

All participants viewed a video of the approach to a rural curve with several transverse line markings before entering the curve. This video footage was shot at the field test location described in Chapter 1 for northbound FM 707 (see Figure 6). There was no other traffic visible in the video. Participants were then asked the following question:

"What do you think the markings in the roadway mean?"

The responses can be seen in Table 19. Nearly one-third of the participants thought the transverse markings were a warning to slow down. Sixteen percent of respondents indicated they did not know what the markings meant. The other responses related to potential hazards downstream, all of which should theoretically cause drivers to slow down.

Table 19. Transverse Line Treatment on Rural Curve Comprehension Data.

Comments	%
Slow Down	33.87
Don't Know	16.13
Possible Stop Sign Ahead	17.74
Possible Intersection Ahead	8.06
Alert You to What's Coming Up Ahead	6.45
Rumble Strips	6.45
Two-Way Traffic	3.23
Curve Ahead	1.61
Other	6.45

CURVE AHEAD Treatment on Rural Curve

All participants viewed a video of the approach to a rural curve with the text message CURVE AHEAD before entering the curve. This video footage was shot at the field test location described in Chapter 1 for southbound FM 707 (see Figure 9). There was no other traffic visible in the video.

After viewing the video the following question was asked of the participants:

"What do you think the markings in the roadway mean?"

The participants' responses to the preceding question after watching the video are contained in Table 20. All of the responses indicated that drivers were able to read the markings and interpreted them to mean something related to a curve ahead. Some responses (63 percent) simply repeated the message "curve ahead" while others indicated further action such as slowing down or not passing. These responses indicate unambiguous interpretation of the text message.

Table 20. CURVE AHEAD Treatment on Rural Curve Comprehension Data.

Comments	%
Curve Ahead	63.27
Slow Down, Curve Ahead	28.57
Do Not Pass, Curve Ahead	6.12
Don't Know	2.04

CURVE ARROW + Advisory Speed Treatment on Urban Curve

After subjects viewed the video clips, they were shown a series of still photos for limited amounts of time. All participants in the comprehension study were shown the picture in Figure 20 for four seconds before being asked the following question, *"What do you think the markings in the roadway mean?"*

Their responses can be found in Table 21 [AUTHOR: Should this be Table 21?]. Note that in the photo it is difficult to make out the speed advisory numerals so it is safe to assume participants based their responses on the curve arrows alone. Responses were varied, with 48 percent interpreting the arrows to mean something related to a curve ahead. Misinterpretations included traffic merging (15 percent) and split ahead (15 percent).

Figure 20. CURVE ARROW + Advisory Speed on Urban Curve Treatment.

Table 21. CURVE ARROW + Advisory Speed Comprehension Data.

Comments	%
Curve to Right	28.85
Slow Down for Upcoming Curve	19.23
Traffic Merges	15.38
Road Splits	15.38
Don't Know	9.62
Other	11.54

Hurricane Evacuation Symbol

Another potential application for pavement marking symbols is for emergency management. In order to aid another ongoing TxDOT research project on hurricane evacuation traffic control, a test of a symbol for this purpose was included in this project. This symbol (see Figure 21) is designed to be placed on the shoulder of a roadway on a designated evacuation route to indicate that driving on the shoulder is allowed during an official evacuation. This symbol was also shown to all participants in the comprehension study for an eight-second viewing time. Because of the novelty of the symbol, the viewing time was increased. It should also be noted that participants were all from the College Station area which does not typically have hurricane evacuations, so most respondents were likely unfamiliar with the practice of marking of evacuation routes. The answers to the question *"What do you think this marking along the shoulder means?"* are found in Table 22. Despite the novelty of the marking, 25 percent of responses mentioned something about a hurricane. These responses included "hurricane route," "hurricane evacuation," "hurricane parking," and "hurricane lane." The majority of responses (45 percent) indicated ignorance of the meaning. When applied in conjunction with traditional vertical signs, it is likely that the meaning of the lane symbol will be more apparent.

Figure 21. Hurricane Evacuation Symbol.

Table 22. Hurricane Evacuation Comprehension Data.

Comments	%
Hurricane	26.53
No Parking	4.08
Emergency Parking	4.08
Don't Know	44.90
Other	20.41

Route Markers

Participants viewed multiple versions of route markers applied to the pavement intended to indicate the route served by an upcoming exit. The three variations included text only markings, text in a box, and route shield markings. Some of the following markings were viewed by all of the participants while some comparable versions were split amongst the participants.

FM Route Text Box

For route guidance in advance of an interchange or intersection with an FM road, it may be desirable to indicate the FM route number in the lane, particularly for a lane drop situation.

Such a marking has gone through preliminary design in the Houston District and consists of a solid white field with black letters. This marking would provide consistently good contrast between the text and the background. An alternative would be to use white markings directly applied to the roadway surface to indicate the route number.

Participants were shown a text box marking for a route number likely familiar to most participants (see Figure 22). The image was displayed for four seconds. Their responses to the question *"What do you think this marking in the right hand lane means?"* are shown in Table 23. While the majority of participants (61 percent) correctly interpreted the marking to indicate an upcoming exit, a large portion (29 percent) misinterpreted the marking to mean that it was indicating the route number of the road they were currently on.

Figure 22. FM Route Text Box.

Table 23. FM Route Text Box Comprehension Data.

Comments	%
This Lane or Exit To FM 1960	60.78
You Are On FM 1960	29.41
Other/Don't Know	9.80

State Highway Route Shield

In the same fashion, an interchange or intersection with a state highway may utilize a text box. In this case, the symbol is nearly identical to the traditional route marker sign for Texas state highways.

Participants were shown a text box marking for a route number likely familiar to most participants (see Figure 23). The image was displayed for four seconds. Their responses to the question *"What do you think this marking in the right hand lane means?"* are shown in Table 24. Again, the majority of participants (56 percent) correctly interpreted the marking to indicate an upcoming exit. As with the FM route marker, a large portion (36 percent) misinterpreted the marking to mean that it was indicating the route number of the road they were currently on.

Figure 23. State Highway Route Shield.

Table 24. State Highway Route Shield Comprehension Data.

Comments	%
This Lane or Exit To TX 288	56.00
You Are On TX 288	36.00
Passing Under TX 288	2.00
Don't Know	4.00
Other	2.00

Interstate Highway Route Shield vs. Text

In order to directly compare comprehension of text directly applied to the pavement to comprehension of distinct route shield, participants viewed two versions of the same message at different points in the experiment. The photos were not shown side-by-side at this point in the study; half the participants saw the shield version and half saw the text version (see Figure 24). Later in the study, the participants were shown the two versions next to each other and asked to indicate a preference. For the individual photos, the question was *"What do you think this marking in the right hand lane means?"* Responses are shown in Table 25 and once again indicate that many people misinterpret these symbols to mean that they are currently on the marked route.

Figure 24. Two Versions of an Interstate Highway Route Marker.

Table 25. Interstate Highway Marking Comprehension Data.

IH-10 Shield		**IH-10 Text**	
Comments	**%**	**Comments**	**%**
This Lane or Exit To IH-10	51.85	This Lane or Exit To IH-10	40.00
You Are On IH-10	44.44	You Are On IH-10	32.00
Don't Know	3.70	Don't Know	20.00
		Other	8.00
Note: Half the participants viewed the Shield and half viewed the text version.			

U.S. Highway Route Shield vs. Text

Route shields for U.S. highways were also tested. Participants viewed a text version and a route shield version of the same route number at different points in the experiment. The photos were not shown side-by-side at this point in the study; half the participants saw the shield version and half saw the text version (see Figure 25). For the individual photos, the question was *"What do you think this marking in the right hand lane means?"* The percentage of responses by category is shown in Table 26 and once again indicate that many people misinterpret these symbols to mean that they are currently on the marked route.

Figure 25. Two Versions of a U.S. Route Marker.

Table 26. U.S. Route Marker Comprehension Data.

US 80 Shield		**US 80 Text**	
This Lane or Exit To US 80	57.69	This Lane or Exit To US 80	48.00
You Are on US 80	38.46	You are on US 80	48.00
Other	3.85	Other	4.00

It was clear from each of these individual items that a significant number of participants were misinterpreting the meaning of the route markers. Table 27 presents a summary of the responses for all the route markers tested. The percentage of responses indicated improper interpretation ranges from 29 to 48 percent. In practice, drivers would view route markers such as those tested in context of other cues to an upcoming exit including overhead- and ground-mounted signs and visible roadway geometry. It is safe to assume the number of people misunderstanding the route markers may be lower in actual practice, although this has not been empirically tested.

Table 27. Summary of Route Marker Comprehension Data.

	FM 1960 Box (%)	Texas 288 Box (%)	IH -10 Shield (%)	IH -10 Text (%)	US 80 Shield (%)	US 80 Text (%)
Upcoming Exit	60.78	56.00	51.85	40.00	48.00	48.00
Currently on Route	29.41	36.00	44.44	32.00	48.00	48.00
Other/Don't Know	9.80	8.00	3.70	28.00	4.00	4.00

Lane Drop Preference Questions

At the end of the PowerPoint presentation, the participants were asked two preferential questions concerning various lane drop pavement markings. The first one asked the participants to choose between and text lane drop pavement marking and a shield pavement marking (see Figure 24, photos were shown side by side). The results to the following question can be seen in Table 28, *"Which version, the symbol shown on the left or the text shown on the right, do you think most drivers would be able to see and understand better?"* The vast majority (94 percent) of participants preferred the shield symbol to the text version of the route marker.

Table 28. Interstate Route Shield Preference Data.

Result	**%**
IH -10 Text	4
IH -10 Shield	94
No preference	2

A second preferential question asked the participants to choose between two varying pavement symbols indicating a toll road (Figure 26). Table 29 contains the results of this question, *"Which version, the symbol shown on the left or the text shown on the right, do you think most drivers would be able to see and understand better?"* For this application, the majority (59 percent) preferred the text version. This may be due to the difficulty in legibility and symbol recognition for the toll road route marker (common on signs in the Houston area).

Another concern with the application of this particular route marker is the prominence of the yellow arrow in the graphic design of the symbol. When placed on the roadway the large yellow arrow is the most prominent feature of the symbol and drivers may misinterpret this to be a one-way arrow pointing in the wrong direction. This is particular concern at night, when the low retroreflectivity of the purple marking compared to the high retroreflectivity of the yellow portion would make the yellow arrow even more prominent.

Figure 26. Two Versions of a Toll Road Route Marker.

Table 29. Toll Road Route Marker Preference Data.

Result	**%**
BW8	59
Hardy Shield	39
No preference	2

CHAPTER 5: SUMMARY AND CONCLUSIONS

The review of the literature showed many potential applications of pavement marking text and symbols to affect driver behavior. The results of the previous field studies have been mixed with some showing large reductions in speed while others found relatively modest changes. Likewise, the current project showed substantial reductions in speed for the multi-lane freeway location marked with a curve arrow and an advisory speed. The rural curve marked with the word CURVE and the advisory speed showed modest reductions in speed. Both treatments that included a specific advisory speed produced more clear cut results than the treatments that simply warned of an upcoming curve through words and transverse lines. In addition, the use of the curve arrow provides drivers with information about the direction of the curve that can be particularly useful on a blind approach like the one created by the vertical crest of the overpass at out test location.

Overall, the results of our rural location field studies were fairly inconclusive. None of the three locations produced statistically significant changes in speed following the application of a horizontal signing treatment. Despite efforts to select locations with good traffic volumes, no intervening driveways, and no vertical alignment changes, some of our sites may have suffered from problems due to these factors. Some equipment malfunctions limited our data collection efforts at FM 707 southbound where the CURVE AHEAD message was tested. The data that were collected there, though, indicated that drivers increased their speed as they approached the curve. A reasonable explanation of this behavior cannot be provided. The presence of the Air Force Base, and its visible runways, near the FM 707 locations may have distracted drivers' visual attention to the point that many drivers did not notice the pavement marking treatments there.

The lane direction arrows applied to two-way frontage roads showed a clear positive effect on wrong-way movements. Though only tested at one location, this treatment shows promise as a way to reinforce the message to drivers that traffic flow is two-way.

The use of horizontal signing for route guidance information was evaluated through a laboratory driver comprehension study. One desired application of route markers, either text or shields, is to mark dedicated lane drop exit lanes. When photographs of these applications were shown to the research participants, a large portion of them misunderstood the route markers to mean that they were currently traveling on the marked route, not that the lane was exiting to that route.   It could be that in the context of accompanying signs the meaning of these route markers would be more apparent. The drivers tested showed a clear preference for recognizable route marker shields over simple text markings for this application.

As materials continue to improve in terms of durability, retroreflectivity, and color fastness, the use of pavement markings to supplement warning and guide signs could increase. A concurrent phase of this project is examining the durability of pavement marking materials on three different pavement surfaces. The results of this three-year durability test will be presented in a separate research report in late 2005.

The Houston District has recently installed full-color route marker shields as supplemental lane assignment markings in advance of major interchanges. Their experience with these applications, in terms of durability and driver behavior, should also be considered when establishing standards and guidance for horizontal signing.

In summary, treatments which provide a clear message to drivers as to a specific action to take showed the most positive effects in this research. Lane direction arrows clearly indicate to drivers the correct direction of travel for each lane. Speed limits applied in advance of curves inform drivers of the safe advisory speed. Horizontal signing should be used a key locations where a clear message can be transmitted. If horizontal signing is applied broadly with poor or ambiguous messages, the efficacy and safety benefit may be diminished.

CHAPTER 6: REFERENCES

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