

FINAL REPORT
USING LIGHTING AND VISUAL INFORMATION TO ALTER DRIVER BEHAVIOR

by

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16. Abstract Inappropriate traffic speeds are a major cause of traffic fatalities. Since driving is a task with a substantial contribution from vision, the use of lighting and visual information such as signage could assist in providing appropriate cues to encourage appropriate driving speeds. At locations such as sharp roadway curves, an overall reduction in driving speed might be desirable to prevent rollover crashes. At other locations, such as those prone to chronic congestion (exit/entrance ramps, work zones and where posted speed limits change), uniformity of vehicle speeds might be desirable in order to optimize safety and traffic flow. For roadway curves, a method of modifying the size and spacing of traditional chevron signs along a curve was used to convey the perception of increased curvature sharpness. This treatment was field tested in a controlled driving experiment, and then tested in a real-world installation along two highway curves in New York State. Based on the real-world test results, when the perception of curvature sharpness was increased, vehicle speeds were reduced enough to show a statistically significant change. To address the issue of reducing speed variance at congested locations, conditional speed display messages were displayed on a changeable message board based on the speed of oncoming traffic. Under a controlled field experiment, it was found to have the desired impact in terms of driving speed. In a real-world test installation, drivers modified their speeds which reduced speed variance in response to a similar conditional speed display sign. The results of the research project suggest that chevron size and spacing modifications can be readily implemented. Additional limited trials at different types of congested locations should be performed to better understand the impact of conditional speed displays; however, the present results of this research project are promising.			
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ABSTRACT

Inappropriate traffic speeds are a major cause of traffic fatalities. Since driving is a task with a substantial contribution from vision, the use of lighting and visual information such as signage could assist in providing appropriate cues to encourage appropriate driving speeds. At locations such as sharp roadway curves, an overall reduction in driving speed might be desirable to prevent rollover crashes. At other locations, such as those prone to chronic congestion (exit/entrance ramps, work zones and where posted speed limits change), uniformity of vehicle speeds might be desirable in order to optimize safety and traffic flow. For roadway curves, a method of modifying the size and spacing of traditional chevron signs along a curve was used to convey the perception of increased curvature sharpness. This treatment was field tested in a controlled driving experiment, and then tested in a real-world installation along two highway curves in New York State. Based on the real-world test results, when the perception of curvature sharpness was increased, vehicle speeds were reduced enough to show a statistically significant change. To address the issue of reducing speed variance at congested locations, conditional speed display messages were displayed on a changeable message board based on the speed of oncoming traffic. Under a controlled field experiment, it was found to have the desired impact in terms of driving speed. In a real-world test installation, drivers modified their speeds which reduced speed variance in response to a similar conditional speed display sign. The results of the research project suggest that chevron size and spacing modifications can be readily implemented. Additional limited trials at different types of congested locations should be performed to better understand the impact of conditional speed displays; however, the present results of this research project are promising.

1. INTRODUCTION

Inappropriate traffic speeds are a major cause of traffic fatalities. According to the National Center for Statistics and Analysis (2005), speeding alone was a factor in one third of all traffic fatalities in the United States. Such statistics, in part, prompted the New York State Department of Transportation (NYSDOT) to request proposals for alleviating the problems with inappropriate driving speeds. In response, the project team for the present study investigated the use of visual cues to encourage appropriate driving speeds and other positive driving behaviors in potentially hazardous conditions such as speeding along curves and ramps, or where there is a large variance in driving speeds that can lead to traffic congestion and rear end crashes. The present chapter of this report includes summaries of existing research intended to manage speed using various signage and roadway displays.

The ultimate goal of this research is to investigate perceptually based novel delineation and lighting techniques to (a) modify drivers' behavior in such a manner that they negotiate problematic curves more safely, and (b) encourage drivers to adjust their driving speeds and reduce speed variance at locations prone to chronic congestion, in an effort to improve safety and traffic flow.

Delineation for Improving Safety Along Curves

This section will focus on three distinct categories of literature: perception, conventional delineation practice and its effectiveness, and finally prior research on novel approaches to curve delineation.

Perception

Perception, or the manner in which an individual understands his physical environment, has been studied by scientists and artists alike for hundreds of years.

Perception is influenced by cues obtained through inspection of the environment using the senses. Drivers perceive roadway curvature through the use of visual cues almost exclusively. Ittleson (1960) lists important visual cues: size, overlay/inter-position/ superposition, linear perspective, aerial perspective, movement parallax, light and shade, accommodation, convergence, stereoscopic vision, shape, color, brightness, and position in the visual field. Ittleson states that the visual cues function to create differentiation, identification, and location. The relationship of the location of objects in the physical world (which utilizes size, overlay, position, stereopsis, perspective, and perspective as its visual cues) is very important to driver's understanding of roadway geometry.

Ittleson states that visual cues can be manipulated to create equivalent configurations. He describes equivalent configurations as being a "family of physical configurations for which impingement is invariant." He further clarifies this statement in the following manner: "In the absence of other information, or if all other conditions remain constant, equivalent configurations will be perceived as identical, no matter how different they may be physically."

Ittleson also discusses the relationship between physical size and distance which determine the size of the object's image on the retina. The concept of equivalent configurations may be applied to generate a family of shapes that appear to be located at the same distance from an observer through the contraction of the object at closer distances than the reference object, and dilation of the object at further distances than the reference object. This implies that by maintaining the ratio of size to distance, that a family of equivalent configurations can be created. It is important to note, however, that this approach is limited to monocular vision.

The vast majority of the driving population can see with both eyes, and perceive distance binocularly. The ability to judge distances, commonly referred to as depth perception, is treated by Sekuler and Blake (1990). Depth perception exists in two forms: absolute distance perception (which refers to actual distances) and relative distance perception (which refers to the distance of one object to another). In designing to influence drivers' perception, the aim is to influence relative distance perception.

Binocular relative distance perception is known as stereopsis and is formed from retinal image disparity. This disparity arises from the fact that the observer's eyes view an identical scene from slightly different positions. This disparity is translated by the visual system and brain into a perception of depth. The human brain is extraordinarily good at translating these differences into perceived depth, though the manner in which it does is beyond the scope of this research (Sekuler and Blake, 1990).

Allen et al. (1977) investigated the factors which influence drivers' visibility, variables that serve as indicators for curvature perception, and the minimum contrast levels for reliable visibility. Allen et al. used a driving simulator as well as real-world driving tasks to investigate these topics. It was reported that lane position variability, preferred speed, and driver rating were sensitive to delineation configuration and visibility range. Real world testing also revealed that lateral lane position was dependent on delineation contrast and that weather conditions (e.g. presence of rain) effected driver physiological response (EEG variables, heart rate, etc.) indicating an effect on overall driver stress level. Dynamic steering response and time delay are indicators of the severity of drivers' visual impairment. Based on the response of these variables in test subjects the researchers concluded that drivers' ability to control vehicles is dependent on visual range and configuration of delineation treatment, ground speed, and roadway physical geometry.

Allen et al. also investigated the contrast of delineators required for safe vehicular operation. Based on their findings, the researchers recommended a minimum contrast value of 2 for clear night operation. If fog or other visibility limiting conditions exist, higher contrast (with an approximate upper bound of 10) is warranted. Due to the increased cost of maintaining high contrast delineation, the authors suggest that designers perform a cost/benefit analysis before specifying very high contrast levels.

Hagiwara et al. (2001) performed research to determine which factors influence a driver's ability to perceive curvature direction effectively during day and nighttime hours. The researchers selected 32 different curves on a hilly section of Japanese rural roadways. A numeric metric termed "curve detection index" (the ratio of actual detection distance to the maximum detection

distance) was used to evaluate the visibility of roadway curvature. Curves that were evaluated by subjects were treated with various combinations of lighting, chevron signs, cable guide railing, and curvature signs. The test subjects were asked to drive a car up to the curves and to indicate when they were sure whether the road curves to the right or left. The data collected was then analyzed and it was found that for daytime driving the inspection of the landscape provided the largest impact on curve detection, and that other factors were insignificant in comparison. For nighttime driving, it was shown that any electric lighting which was installed at a curve had the largest impact on curvature direction identification. Presumably this finding is due to the fact that subjects are able to see much more of the road's surface than they would with light from only the vehicle headlamps. In curves without lighting at night, the authors reported that signage played a significant role in curve detection.

Some researchers have investigated the physical factors in roadway geometry which influence curve radius perception. Bidulka et al. (2002) studied the impact of vertical curvature (curvature up or down as viewed from the driver's view point) on perceived horizontal curvature (curvature to the left or right from the driver's view point) of two-lane rural roadways. The research was performed using computer created images of a roadway. The test subjects were shown either two still pictures or two animations of the same curve with different levels of vertical curvature applied. The subjects were asked to rate the bottom picture as being "less sharp", "same sharp", or "more sharp". This research showed that overlapping horizontal curvature with a vertical crest curve results in perception of the curve as sharper than it is. The presence of vertical sag curvature causes the curve to be perceived as less sharp or flatter than it actually is. The researchers also identified three factors which increase the likelihood of incorrect curve perception in the presence of vertical curvature: increased sight distance, horizontal radius increases, and length of vertical curvature per 1% change in grade decreases. The authors also showed that there was not a statistical difference between answers obtained from the presentation of still images and those from the presentation of animations.

Conventional Delineation Practice

To augment drivers' understanding of roadway geometry, departments of transportation often install post mounted delineators and chevrons. The installation of such devices is addressed by the Manual of Uniform Traffic Control Devices (MUTCD, 2009), which is accepted as the standard for the application of roadway treatments. The MUTCD's language regarding the installation of such devices is fairly broad, and accordingly, there is wide variation in the way in which individual departments of transportation design their deployment. Post mounted delineators (PMDs) are treated in section 3D of the MUTCD, which describes them as guidance devices and that may be used continuously (along highway sections) or in specific regions (such as curves which warrant their use) at the discretion of the governing department of transportation. The MUTCD recommends that PMDs should be installed "at locations where the alignment might be confusing or unexpected, such as at lane reduction transitions and curves." The MUTCD also recommends their use where visibility is limited by darkness or inclement weather: "An important advantage of [PMDs] in certain locations is that they remain visible when the roadway is wet or snow covered."

The design specification for PMDs is as follows: “Delineators shall be retroreflective devices mounted above the roadway surface and along the side of the roadway in a series to indicate the alignment of the roadway. Delineators shall consist of retroreflector units that are capable of clearly retroreflecting light under normal atmospheric conditions from a distance of 300 m (1,000 ft) when illuminated by the high beams of standard automobile lights. Retroreflective elements for delineators shall have a minimum dimension of 75 mm (3 in).”

The MUTCD calls for placement of PMDs (of color consistent with the edge lines as prescribed in Section 3B.06 of the same) “on the right side of freeways and expressways and on at least one side of interchange ramps” with the following exceptions:

A. On tangent sections of freeways and expressways when all of the following conditions are met:

1. Raised pavement markers are used continuously on lane lines throughout all curves and on all tangents to supplement pavement markings.
2. Where whole routes or substantial portions of routes have large sections of tangent alignment.
3. Roadside delineators are used to lead into all curves.

B. On sections of roadways where continuous lighting is in operation between interchanges.

The MUTCD also calls for the installation of red PMDs to mark truck escape ramps.

In addition to these standard locations, the MUTCD recommends the installation of PMDs on the outside curve of interchange ramps, at median crossovers (for emergency services vehicles), along acceleration/deceleration lanes, and at narrowing lane transitions. It also states that PMDs may be provided on other classes of roadways at the discretion of the governing DOT.

The MUTCD provides guidelines for the spatial parameters of installation. The manual specifies that PMDs are to be mounted no higher than 1.2 meters, and should be mounted between 0.6 and 2.4 meters from the shoulder’s paved edge. The MUTCD specifies that PMDs are to be installed no less than 60 meters and no more than 120 meters apart on main tangent sections of roadway. The spacing of PMDs on curves is specified as a linear distance from post to post along the circumference of the curve. For roadways designed with metric units, the suggested spacing (S) is based on the radius of the curve (R) and is given by the equation:

$$S = 1.7\sqrt{R - 15}$$

The spacing, S , should be no less than 6.1 meters and no more than 90 meters in the curves. The MUTCD also suggests transitioning the spacing of the PMDs both approaching and proceeding away from the curve at $2S$, $3S$, and $6S$, with the more closely spaced delineators closer to the curve.

For chevrons, the MUTCD recommends different spacing than for delineators. MUTCD guidance for chevron spacing is dependent upon either the advisory speed or the curve radius, as follows:

- Less than 15 mph or less than 60 m (200 ft.): 12 m (40 ft.) spacing
- Between 20 and 30 mph or between 60 and 120 m (200 and 400 ft.): 24 m (80 ft.) spacing
- Between 35 and 45 mph or between 120 and 210 m (400 and 700 ft.): 37 m (120 ft.) spacing
- Between 50 and 60 mph or between 210 and 380 m (700 and 1250 ft.): 49 m (160 ft.) spacing
- More than 60 mph or greater than 380 m (1250 ft.): 60 m (200 ft.)

The recommendations of the MUTCD are continuously evolving to incorporate the findings of research as it is published. The following is a summary of research that has been done to investigate the impact of delineation devices (PMDs and chevrons) on driver behavior.

Jennings et al. (1985) evaluated the effectiveness of 3"x 8" PMDs, chevrons (type WI-8, as defined in the 1978 MUTCD), and 6" x 48" striped delineators on Virginia rural roadways. The researchers used vehicle speed upon entry and lateral vehicle location during the curve negotiation as metrics for comparisons. These variables were measured using switch-tapes (linear electronic devices of unspecified length designed to switch state when a vehicle's tire rolls over it) on the roadway surface. The researchers reported that while these delineation devices did not make a statistically significant impact on approach speed, they did have a significant impact on vehicle location in the curve. On the basis of their findings, the researchers recommended the use of PMDs, spaced as recommended in the MUTCD, on gentle curves (defined as less than 7° sweep). It was also reported that the use of chevrons on larger and sharper curves resulted in less centerline encroachment and less vehicle location variation. On this basis, it is recommended that chevrons be installed 6-8 feet from the roadway edge, and have a "top-of-the-sign" height of 4 feet.

Zador et al. (1987) tested the short and long term impact of the application of PMDs, chevrons, and raised pavement markers (RPMs) on rural, two-lane highways in Georgia and New Mexico. The PMDs used were 3" diameter round type and were applied to the outside edges of the roadway in compliance with the MUTCD. The chevrons used measured 18"x 24" and were installed in compliance with the MUTCD specifications. The RPMs used were 4"x 4" type and were installed near the centerlines of the roadway. The researchers used a speed and position measurement system of the same ilk as Jennings et al (1985).

Zador et al. (1987) found that all of the delineation types studied produced change in driver's behavior during the night, that the effects of the different types weren't appreciably different, and that the effects didn't change much over time. On average, all of the delineation types tested resulted in increased speed in the curves. This increase may be attributed to higher driver confidence. The effect of these devices on lateral position depended on the delineation type. The RPMs resulted in a shift away from the centerline, whereas the PMDs and chevrons produced a shift toward the centerline. Despite the findings of increased speed, the authors felt the presence of delineation devices was preferential to the absence of them.

Krammes et al. (1991) compared the effect of RPMs with that of PMDs on five rural two-lane roadways. For this study, the researchers removed existing PMDs from selected sites and replaced them with RPMs. At these sites, the speeds and lateral positioning of vehicles were monitored. In the short term, drivers of the inside lane of the curve did not alter their behavior significantly. Drivers of the outside lane, on the other hand, increased their mean speed from between 1-3 mph. It was also found that lateral placement improved and fewer drivers crossed the centerline of the roadway after the installation of the new RPMs. In the long term, the data collected suggested that the improvements in lateral placement did not degrade. While it was found that the mean speed through the turn did not change much either, the rate of deceleration entering the curve increased after time. This indicated to the authors that the reflectivity of the RPMs had degraded enough to no longer provide as clear an image of curve geometry from the far-field as new RPMs.

Kallberg (1993) investigated the reasoning for an increase in run-off-the-road accidents following the installation of PMDs on Finnish roadways. The test sites were selected to be roads with 80 km/h and 100 km/h (50 and 62 mph respectively). At the altered sites, delineator posts were installed every 60 meters at a distance of 0.5 meters from the pavement's edge and at a maximum height of 1m. At the control sites, no changes were made. Measurements were made three times, at approximately four month intervals. The maximum lateral shift was observed on 80 km/h roadways in the winter. Less significant shifts were observed on the 100 km/h roadways. The application of delineators to the 80 km/h roadways resulted in an increase in the average nighttime speed (about 5 km/h average magnitude). To explain the fact that speed increases were only significant on roadways with an original speed limit of 80 km/h Kallberg reasoned that Finnish drivers generally prefer to travel at nominally 100 km/h. By applying delineation, drivers feel more comfortable increasing their traveled speed.

Kallberg cites the work of Leibowitz et al. (1982) as an explanation of increased driver comfort. Leibowitz et al. treats the topic of selective visual degradation during dark hours. The theory of selective visual degradation is based on the theory that vision is based on two modes: focal vision (which deals with object discrimination and identification) and ambient vision (which determines spatial orientation). The theory holds that the two modes of vision are both impaired at night, but to different extents. Feelings of confidence and security while driving are generally associated with focal vision, the mode which governs steering of vehicles. Kallberg postulates that the installation of delineation aids the task of focal vision, but does not affect the ambient mode. By doing so, drivers feel more confident about navigating the roadway, despite the fact that their ability to detect hazards (such as pedestrians or animals) on the roadside remains impaired.

Kallberg reported that based on his findings and the work of Leibowitz et al. he could not say that the installation of PMDs significantly reduced daytime accident rates and that such an installation may increase the likelihood of nighttime injury accidents: "reflector posts do not improve a driver's ability to detect potential hazards, such as pedestrians, on the road in low illumination. [...] Improved visual guidance can also increase speeds, which would offset the potential safety benefit or even lead to decreased safety." It should be noted that Kallberg does point out that because the 100 km/h roadways have been designed to be wider and better suited

to higher speed turn negotiation, that the installation of delineators doesn't necessarily increase the likelihood of accidents on these roadways.

Zwahlen et al. (1994) investigated driver's ability to judge curve sharpness based on the number of chevrons in the field of view for both monocular and binocular vision. To perform the experiment, the researchers used 1:50 scale replicas of roadways in an experimental apparatus which is depicted in Figure 1.

The subjects were first shown a reference curve representative of a 150 ft radius curve for two seconds. The subjects then swiveled in their seat and were shown the comparison curve with various chevron treatments and radii (which could be 95%, 97.5%, 100%, 102.5% or 105% of the standard curve radius). The subjects were then given a forced-choice of smaller or larger than the reference curve.

Zwahlen et al. reported that curve radius and number of delineators in view were both statistically significant variables for curve sharpness perception under both monocular and binocular vision. Binocular vision was found to be superior to monocular vision for curve detection. In addition, three to four chevrons in view were found to have optimal curve detection characteristics. The marginal benefit of installing more than four chevrons in the field of view is far outweighed by the additional cost to install them.

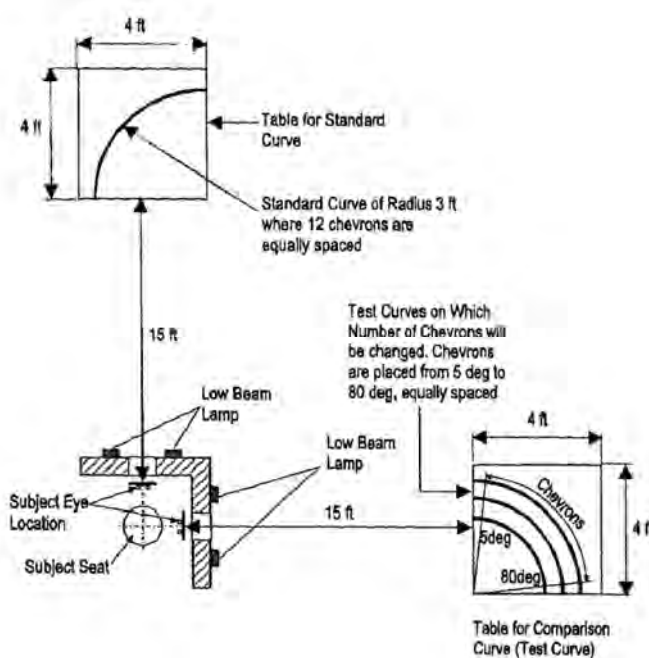


Figure 1-1. Plan view of laboratory experiment. (after Zwahlen et al., 1994)

One of the most recent studies on roadway delineation was performed by Carlson et al. (2004). This research investigated state-of-the-art delineation practice, spacing protocol for PMDs and chevrons, delineator visibility, and delineation color implications. To determine the state-of-the-art practice, the researchers developed a survey which was sent to the departments of transportation in all fifty states of which total of thirty four states responded. From the

information gathered from respondents, the mean threshold radius above which curves are treated as tangent (straight) sections was 6,400 feet (1,950 meters). Also, a majority of states use radius dependent delineator spacing as defined in the MUTCD. Carlson et al. refined and specified two procedures intended to assist in maintenance of existing delineation as well as the installation of new delineation: one based on the advisory speed of a curve and the other based on the radius of the curve as obtained by global positioning satellite receivers.

The visibility study performed by Carlson et al. led to three important conclusions: drivers do not distinguish between double and single PMDs (the benefit of doubling is that delineation will still exist if one of the reflective elements is damaged), there is no effective difference on drivers' behavior based on whether delineators preceding a curve are arranged in at fixed or variable spacing, and drivers do not understand the difference between yellow and white PMDs. The visibility study also found that viewing distance does not significantly impact drivers' perception of curve radius for a given delineation treatment.

Novel Delineation Practices

In addition to conventional delineation practice, a few researchers have investigated certain types of novel delineation methods including novel arrangements of traditional delineation devices, application of unique pavement markings, creation of perceptual illusions by altering specific roadway geometries, etc.

Hungerford et al. (1980) investigated both standard and non-standard delineator types in standard and non-standard geometric arrangements. In a static view experiment, the researchers found that standard PMDs which were placed progressively higher (from ground to 10 feet) and further from the road's edge (0 to 20 feet) throughout the curve resulted in the perception of a sharper curve when compared to standard MUTCD layout. Hungerford et al. also investigated the visual impact of several types and configurations of delineation devices including 3-inch round PMDs, small (standard) chevrons, large chevrons (4' x 4') and carsonite reflectors (3" wide x 72" high). The test subjects were shown photographic slides of the installation in succession to give the impression of motion. The subjects were then polled to subjectively rate how effectively the treatments conveyed the roadway's curvature at 500' intervals from 2000' to 500' from the curve's tangent point.

Based on the findings of the subjective analysis, Hungerford et al. selected four delineation treatments to apply to rural Ohio roadways: standard PMDs configured in the ascending and widening manner, standard PMDs installed in accordance to the MUTCD, carsonite reflectors with a curve warning sign, three large chevrons installed in the standard way, transverse pavement stripes, and the "Life Lite" system used by the Ohio DOT at the time. Of these systems, the large chevrons and carsonite reflectors made no appreciable difference. Standard configurations PMDs positively impacted lateral placement and approach speed. The novel installation of PMDs resulted in significant speed reduction prior to curve entry; a finding which was especially true of high-speed drivers. Transverse stripes were found to reduce approach speeds. Hungerford et al. also concluded that while drivers react positively to the novel delineation methods, they soon adapt and return to their prior behavior. Despite this, the approach would be acceptable for drivers who are unfamiliar with the roadway.

Shinar et al. (1980) also investigated the impact of novel roadway delineation practices. The authors tested four novel curve delineation systems to influence drivers' perception: visual angle manipulation, the Wundt Illusion, parallel cross striping, and the addition of a "Deceptive Curve" sign prior to the curve. The visual angle manipulation was accomplished by repainting the inside edge marking so that it became progressively larger as it approached the apex of the curve. Doing so increased the inside visual angle of the curve. See Figure 2. The parallel cross-stripes were painted on the roadway according to the following relationship: $spacing = 11e^{\frac{x}{179}}$ where x is the distance (in meters) to the tangent point of the curve.

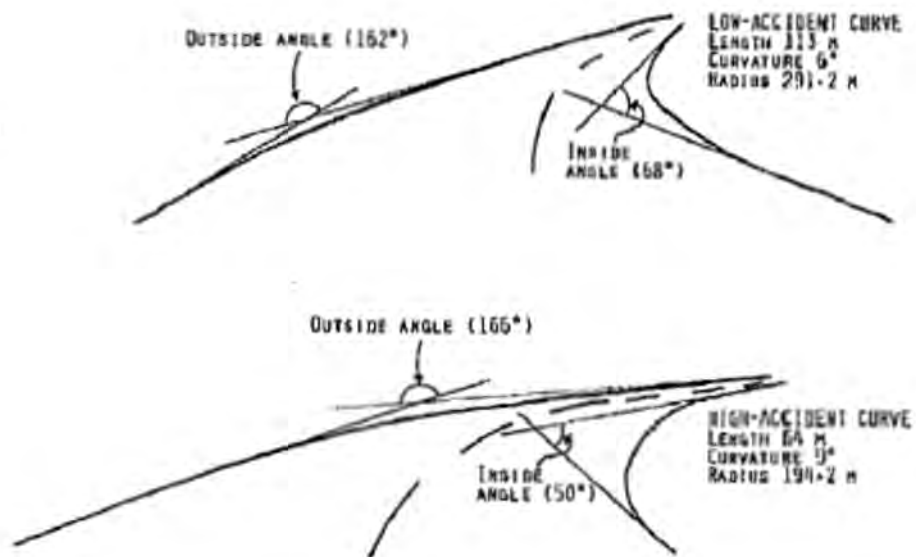


Figure 1-2. Perspective view of high and low accident curves. (after Shinar et al., 1980)

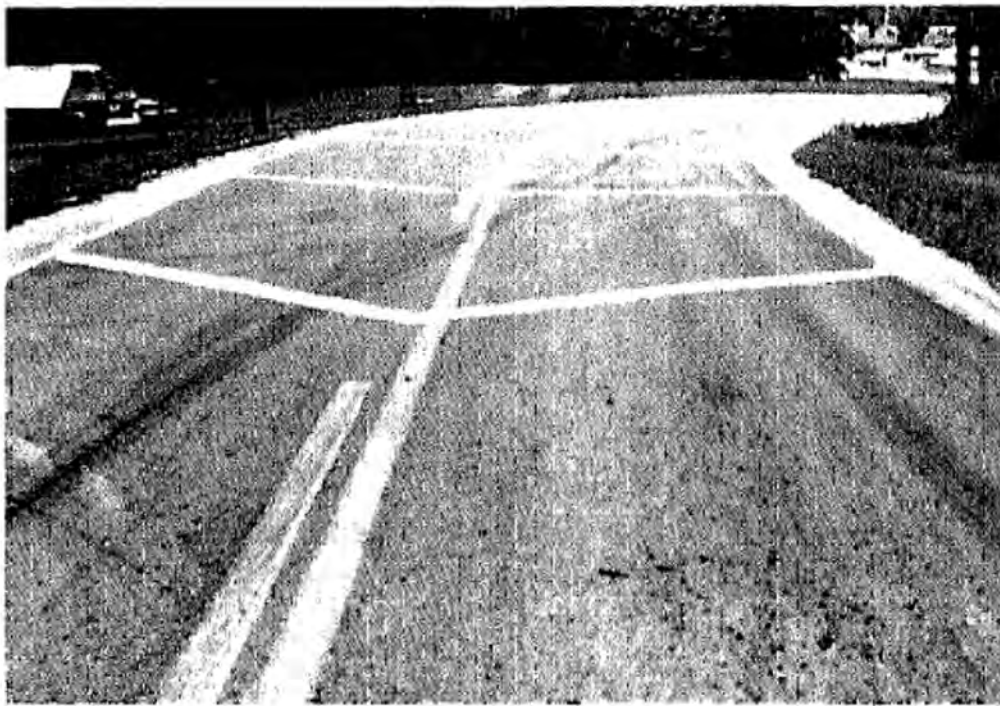


Figure 1-3. Application of Wundt Illusion. (after Shinar et al., 1980)

The Wundt Illusion was intended to create the impression of a narrowing roadway. Figure 3 shows the application of the Wundt Illusion to a test site.

Shinar et al. measured the perceptual effects of the modifications by using speed sensors positioned in the approaches to the treated curves in addition to monitoring eye movements. Visual angle manipulation resulted in an increased visual search pattern, but no significant speed reduction. The Wundt Illusion treatment had limited speed reduction effects, which were seen only in passenger cars. Parallel cross-striping produced statistically significant speed reductions for heavy trucks only. The deceptive curve sign produced no effect at all. The authors also reported that the perceptual effects were highly localized, and also did not persist over time. Despite this, they would still be valid for transient drivers who were unsure of the area.

Helliar-Symons (1981) investigated the effect of the application of transverse yellow stripes applied to selected roadway surfaces. Forty of forty two sites chosen for the addition of the bars were deceleration lanes which enter roundabouts. The remaining two sites were at the end of highways where the roadway made a sharp turn. To investigate the safety impact of the striping, Helliar-Symons performed statistical analyses on the speed related accidents before and after the stripes' application. Overall, the result was the reduction of accidents by 57%. The statistical analyses showed that the stripes were more effective at reducing fatal and serious injury accidents than minor injury accidents, and that the effect was more pronounced during daylight and in wet conditions. It was also found that the yellow stripes' effect at the pilot study sites was still statistically significant even after a period of four years had elapsed.

Agent et al. (1986) compared the effects of on-road delineation devices (paint markings, rumble strips, and raised pavement markers) and off-road delineation devices (PMDs in various configurations and chevrons). Based on a literature survey, the researchers implemented a total of eleven different PMD configurations on a test road. The configurations incorporated variations in mounting height, distance from the shoulder of the road, and spacing. Each configuration was photographed during the night at 500, 300, and 100 feet from the curve's tangent point. A total of 40 subjects (all licensed drivers) were given a survey which polled them as to which treatments made the curve look sharpest and flattest, subjects were asked to report the three sharpest treatments (in order), the three flattest (in order), which element of delineation was most helpful in deciding radius (centerline, edge line, or delineation devices) and their typical driving behavior around curves. On average, the subjects ranked the configuration in which the height of the PMD was increased throughout the curve as being the "sharpest", with the 2nd and 3rd ranked configurations both had increasing height and varying distance from the shoulder. The standard (MUTCD based), IS (constant height, constant distance from shoulder, and increasing spacing), and DOI (decreasing height, decreasing distance from the shoulder, and increasing spacing) configurations were all ranked among the flattest of the curve treatments.

Based on the findings of their laboratory experiment, Agent et al. implemented several PMD and chevron configurations on two curves, and the researchers also modified an additional four curves with on-road delineation devices (raised pavement markers, rumble strips, and transverse stripes). The researchers reported that on-road delineation was more effective than off-road treatments. Of the on-road type, the installation of raised pavement markers was the most effective. The configuration of off-road delineation recommended by Agent et al. is ascending height with constant spacing and distance from shoulder. Chevrons are recommended over PMDs for sharper curves. The researchers also recommended that transverse stripes and rumble strips only be deployed at high-accident locations.

Summary

No literature was found which investigated the possibility of altering curvature perception through altered sign size and spacing. This approach could potentially be combined with the altered height/lateral placement technique investigated by Hungerford et al. Another potential combination could be the implementation of delineators which have altered size and spacing along with parallel cross-striping like that applied in Shinar et al.'s research.

Lighting and Luminous Displays for Speed Management

In this section, several strategies and technologies for lighting/signal systems designed to influence driver behavior, specifically speed, are reviewed.

Changeable Message Signs

Several researchers have observed that changeable message signs (CMSs) were effective at lowering highway speeds near tapers and work zones. Hanscom et al. (1982) found a speed reduction of 7 to 7.5 mph at tapers, and short-term (over a few hours) effects of a 0 to 5 mph decrease were also found on traffic at work sites in Texas. CMSs were also reported as good

traffic flow moderators (Dudek, 1984) by directing traffic to leave enclosures (Dudek, 1984), and encouraging drivers to change lanes before reaching closures (Pigman and Agent, 1988). Because CMSs have the ability to call attention to drivers, drivers might be more likely to read them and follow their instructions. One disadvantage of using CMSs is that few are utilized and many are fixed on site for prolonged periods. They also require the driver to read textual messages and could serve as distractions. Careless drivers might run into them and damage the effectiveness of these signs.

Flagging

A collection of flagging studies conducted by Richards et al. (1985) showed that flagging following the prescriptions of the Manual on Uniform Traffic Control Devices (MUTCD) and innovative flagging (MUTCD flagging in addition to drawing attention to speed limit signs) both reduced car speeds of up to 3 to 12 mph and 4 to 16 mph, respectively. MUTCD flagging however, was unable to bring speeds down to the desired target range in all six scenarios evaluated by Richards et al. (1985), whereas innovative flagging resulted in a 3 mph lower speed than required in one of the scenarios. Further studies by Noel et al. (1988) also yielded consistently higher speed reductions with innovative flagging methods. Both flagging methods however, were most effective in long-term (two week) and short-term (few days) speed reduction where only one lane out of three was open to traffic (Richards et al., 1985; Noel et al., 1988). Researchers also noted that flaggers provided the added advantage of advance warning for out-of-control vehicles. But being human, flaggers could not work in harsh weather and needed rest every few hours to be continuously effective. Further study of innovative flagging with mechanics (i.e., robotic arms) was urged.

Flashing Beacons

The Department of Engineering at the University of Illinois (Benekahal et al., 1992) also compiled studies evaluating the effect of flashing beacons on vehicle speed control by Goldblatt (1976), Koziol et al. (1979), and Graham et al. (1977). These studies generally concluded that flashing beacons were effective in reducing traffic speeds at intersections, curves, school zones, and when approaching small communities (Koziol et al., 1979). On two-lane work zones, flashing also reduced the erratic behavior of cars defined by sudden maneuvers or stops at transition zones, and increased driver's awareness of roadside conditions (Goldblatt, 1976). Thus, flashing as a warning signal could potentially be used as a speed management indicator, but the effectiveness of the flashing beacons would depend on the intensity and size of flashing used, which may increase costs.

Lighted Guidance Devices

Vercryussen et al. (1995) tested the effectiveness of heads-up displays (HUDs) with speed information and lighted guidance devices (LGDs), rows of red or green lights that pulsed in sequence along the roadway. Studying the effects of these devices on drivers varying in gender and age, Vercryussen et al. (1995) observed the optical flow theory when their participants accelerated with LGDs that pulsed forward while they drove. These results suggested that the LGDs altered velocity perception, causing drivers to speed up. Young males entered the zone

faster for LGD conditions without HUDs, and young females were more varied but were also affected similarly to the young male drivers by this combination of LGDs and HUDs. Finding larger differences between the gender variables than age variables, a second experiment was conducted to further test the effects of LGD pulsing, gender, and light color.

The second study yielded more significant differences in speed and acceleration between genders. Males slowed down faster than females after confronting green backward sequences. The second study also illustrated that different LGD speeds of light pulses can alter the speed of the driver. Flashing LGD lights traveling forward with the driver encouraged the fastest speeds while backward flashing lights correlated with slower driving. Colors also influenced driver acceleration as backward pulsing green encouraged drivers to slow down more so than red. Without explicit signage, participants slowed down or sped up in accordance with the pulsing LGDs. Vercruyssen et al. (1995) however, still conducted all of their experiments in a virtual laboratory; therefore, they suggested that the results of their laboratory test may not be the same as one done in the physical world.

Sequential Flashing Cones

In response to high cone taper collision rates, the Trials Team of the U.K. Highways Agency conducted a six day trial comparing the effectiveness of static lighted cones and sequential flashing cones in encouraging early lane change behavior along a carriageway between two junctions. Using video cameras to track individual vehicle behavior, the authors averaged the data for each type of lamp received across the trial period. Anomalies occurred however when equipment was mislabeled, leading to a cull of some of the data. Comparing the remaining results, the sequential flashing cone lamps had a stronger effect on driver behavior than expected, which was found to be statistically significant ($p < 0.05$). The authors concluded that sequential flashing cones are more effective at encouraging early lane change than static lit cones.

Sequential Warning Light System

Finley et al. (2001) tested the effect of a steady-burn light background and a no-light background on motorist speeds while approaching a night construction zone. “Steady-burn light background” describes a system that continually displays high-intensity synchronized flashes against a lighted background along a taper, while “no-light background” refers to a system with only synchronized flashes with no lighted background. The study took place at the Texas Transportation Institute Proving Ground facility in Texas, utilizing long aircraft runways to simulate freeway conditions. Each system was evaluated at two flash rates: 17 flashes per minute (fpm) and 60 fpm, at two approach speeds: 48 km/h (30 mph) and 105 km/h (65 mph), and with 9 m (30 ft) and 20 m (63 ft) drum spacing (resulting in 7 and 13 drums, respectively). Testing was performed on a 3.6m lane using flat grades in a straight alignment. All individual flashing warning lights used were lens-enclosed arrays of light-emitting diodes (LEDs) in compliance with the “A” specification of the MUTCD.

The study was completed in two parts. The first part included individual evaluations of one random light system by allowing the participant to drive through the course once at a certain speed. In the second part, an administrator drove and participants were asked to evaluate all

systems. Examining the three independent variables of approach speed, treatment, and subject age, Finley et al. (2001) concluded that both warning light systems did not differ in overall performance from each other since both systems did not encourage earlier lane changes while approaching the closure. Some confusion with the warning systems may have also occurred during the study as approximately half of the subjects applied their brakes during the first part of the study. However, the test administrator reported that subjects did not report being confused. Overall, the perceptions of the warning systems were generally positive and the majority favored the “moving” light produced by the steady-burn light background at 60 fpm. Treatments with the no-light background system were rated least favorably in terms of helpfulness, reducing confusion, and making a difference in driving behavior.

A follow-up study compared the steady-burn light background at 60 fpm with a no warning light condition, revealing that the warning system successfully encouraged motorists to change lanes further from the lane enclosure. Lane choice was not affected however, and researchers suggested that the system might be most suitable for short durations where repeat drivers would be infrequent, since frequent drivers became insensitive to the traffic treatment.

Discussion

Given the previous research, several promising approaches such as changeable message signs, flagging and lighting guidance devices (LGDs) to reduce speeding levels, could be feasible. Changeable message signs could be less effective since they generally display textual information that must be read and interpreted by a driver. One aspect of changeable message signs that has not been studied extensively in the literature is the use of graphical information on such signs to provide reinforcing visual cues to drivers to supplement and reinforce textual messages.

Skinner and Bullough (2009) tested the use of curve delineators consisting of plain white rectangles (16" h x 12" w) along a closed test track. The delineators were mounted along curves of 50 m (165 ft.) radii. Two delineator configurations were tested, one with the 16" x 12" delineators mounted at evenly spaced intervals [10 m (33 ft.), according to the published formula for a curve with a 50 m (165 ft.) radius], and one with the delineators increasingly sized and spaced according to a method developed by Skinner (2007) to simulate the appearance of evenly spaced delineators along the radius of an imaginary 33 m (108 ft.) radius curve. Figure 1 illustrates the approach to estimate the necessary spacing of delineators using this method. The equation below refers to the recommended spacing (S) for a delineator from the MUTCD (2009), given a curve radius (R; S and R must be in equivalent units):

$$S = 1.7(R - 15)^{0.5}$$

The result is that the delineators' apparent size and spacing matches that of a 33 m (108 ft.) radius curve rather than that of a 50 m (165 ft.) radius curve.

Skinner and Bullough (2009) confirmed that this method resulted in increased sharpness perception of drivers approaching the curves using a four-point rating scale (1=not at all sharp, 2=not very sharp, 3=somewhat sharp, 4=very sharp). There were also larger speed reductions, between the speed on the straight portion of the test track ahead of the curve and the speed in the beginning of the curve, when the modified delineator size/spacing was used. There was a statistically significant ($p < 0.05$) correlation between the rating of sharpness and the reduction in speed, suggesting that the delineator treatment increased the perception of sharpness and this in turn resulted in reduced speeds.

Because of the promise of the size/spacing modification approach in increasing curve sharpness perception and in reducing speeds in the curves, a study was designed as part of the present project to utilize the same approach with chevron sign panels, along a real-world roadway curve.



Figure 2-2. Satellite map showing the location of the test curve used in the chevron human factors experiment.

Method

Test Conditions

The project team coordinated with the Town of East Greenbush, NY to get permission to install and test chevron sign installations at Temple Lane (a dead-end public road with very little traffic).

Figure 2-2 shows a map of the test location, with an arrow pointing to the curve that was used. This is not a very sharp curve. The recorded curve radius from NYSDOT records is approximately 350 m (1150 ft.). Based on the satellite imagery from Google Maps™, the central portion of the curve appeared to have a central section with a radius of around 200 m. The direction of travel that was used in the experiment was from the northwest toward the southeast. Figure 2-3 shows a view of the curve from the northwest while traveling southeast. There is sufficient curvature that the end of the curve is obscured by vegetation along the roadside.



Figure 2-3. View of test curve.

For the conventional chevron sign treatment, five chevron panels (24" h x 18" w, the minimum size permitted by the MUTCD [2009]) were installed every 18 m (59 ft.) starting at the entrance tangent of the curve. The mounting posts were set so that the height of the bottom edge of the chevron was 1.5 m (5 ft.) off the ground (the MUTCD [2009] requires the bottom edge to be at least 1.2 m (4 ft.) off the ground).

Figure 2-4 shows a photograph of the conventional chevron treatment as installed.

For the modified chevron sign treatment (Figure 2-5), five chevron sign panels were used with the following sizes:

- 24" h x 18" w
- 26" h x 20" w
- 28" h x 22" w
- 32" h x 26" w
- 36" h x 30" w

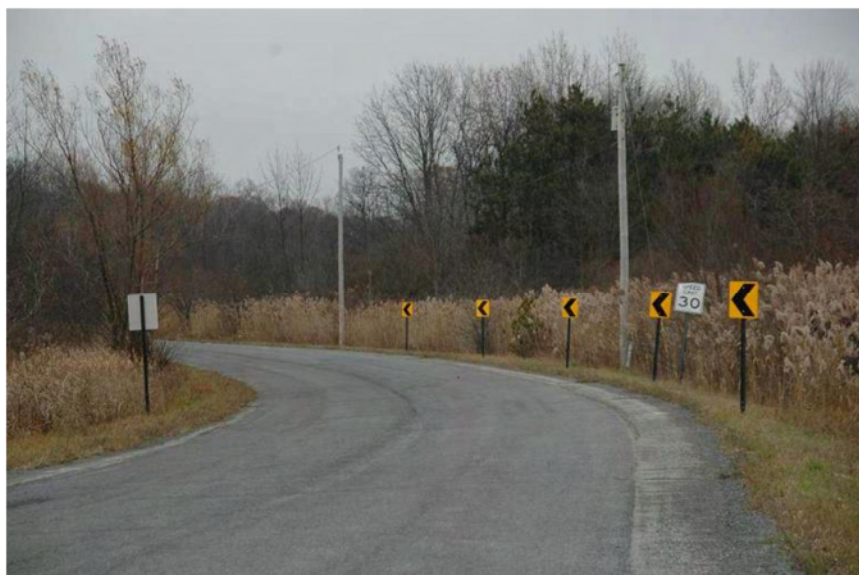


Figure 2-4. Test curve equipped with the conventional chevron treatment.



Figure 2-5. Test curve equipped with the modified chevron treatment.

The first four (with the smallest sizes) were mounted in the same locations as the first four conventional (24" h x 18" w) chevron signs. The last (largest) chevron sign was mounted 8 m past the mounting location of the fourth sign. The sizes and locations were approximations based on the scaling method illustrated in Figure 2-1, to provide the perception of a curvature reduced to two-thirds of the original radius, when viewed from 225 feet away. The first four chevron locations were not changed from the locations of the conventional chevrons because they would not have deviated very much from the initial location; only the fifth chevron would have been substantially removed because for that location, simulating a reduced curve radius would have resulted in a flatter, more perpendicular appearance of the curve with exaggeration of its lateral position. Not having to change the positions of the first four chevron sign posts simplified the execution of the experiment.

Visual observations during a field installation by individuals from the LRC, NYSDOT and Federal Highway Administration (FHWA) confirmed that the installation appeared reasonable and conveyed an impression of sharper curvature with the modified chevron treatment.

Experimental Procedure

Eleven experimental subjects (6 female, 5 male), aged 22 to 64 years (mean age 39) possessing valid driver's licenses participated in the experiment at night during two experimental sessions that started after the end of civil twilight. Approval to conduct the experiment was provided by Rensselaer's Institutional Review Board. The road was closed to public traffic during the experimental sessions per arrangements with the Town of East Greenbush Police Department. During each session, subjects performed three experimental trials in which they drove an instrumented vehicle (a 1999 Ford Contour with automatic transmission equipped with a data logger for throttle, speed, acceleration, and global positioning satellite [GPS] data) through the curve. An LRC experimenter rode with the subjects during all trials.

The first trial for all subjects in both sessions was performed in part to assist subjects in becoming more familiar with the test vehicle and with the overall procedure. For the initial trials, no chevrons were mounted along the curve. For the second and third trials, the order of chevron treatments was counterbalanced between the two nighttime sessions, so that one group experienced the conventional chevron treatment first and the other group experienced the modified chevron treatment first. For all of the chevron treatments, the speed limit sign visible in Figures 2-4 and 2-5 was covered with black fabric with permission from the Town of East Greenbush.

In all three trials, subjects started driving at a location where the curve was not visible in the field of view. They drove around a right-hand curve along a 0.2-mile-long tangent section of road before the curve entrance was reached. They then navigated through the curve. After they passed through the entire curve, they were instructed to stop, turn the vehicle around, and return to the starting location. As they approached the curve along the tangent section, the experimenter riding with the subjects asked them to rate the sharpness of the curve's appearance using the same four-point scale employed by Skinner and Bullough (2009).

After each subject completed three trials, they were dismissed and the experimental session was concluded.

Results

From the data logger, it was possible to use the specialized software that came with the logger to determine the driving speeds when approaching and when navigating through the curves. Figure 2-6 shows a screenshot of the software for a single trial.

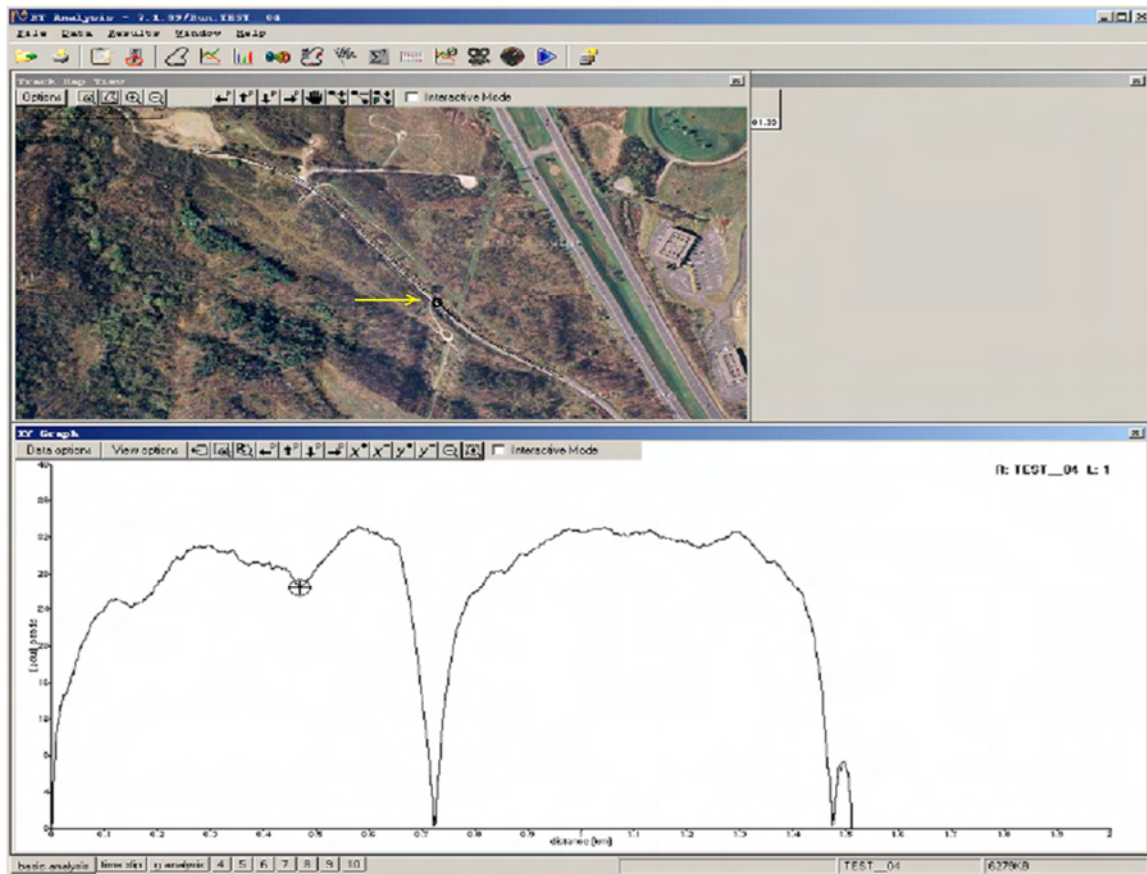


Figure 2-6. Screenshot of data analysis software. The upper panel shows a satellite image of the test location, and the lower panel shows a plot of vehicle speed as a function of distance traveled. The cursor in the lower panel corresponds to the small black circle in the upper panel (denoted by an arrow), with a location near the entrance of the curve.

The upper panel of Figure 2-6 plots the trajectory of the vehicle's course for the trial onto a satellite image based on the recorded GPS coordinates. The bottom panel of Figure 2-6 shows the vehicle speed as a function of the distance traveled. It can be seen that the vehicle in this trial accelerated to a maximum speed of about 31 mph and then decelerated to 27 mph near the entrance of the curve, a driving speed profile that was representative of all of the trials. To assess the impact of chevron treatments on driving speed characteristics, three speed values were evaluated:

- The maximum speed when approaching the curve
- The minimum speed when entering the curve
- The change in speed from approaching to entering the curve

The last speed variable listed above was computed by taking the difference between the maximum and minimum speeds for the curve approach and entrance in each trial.

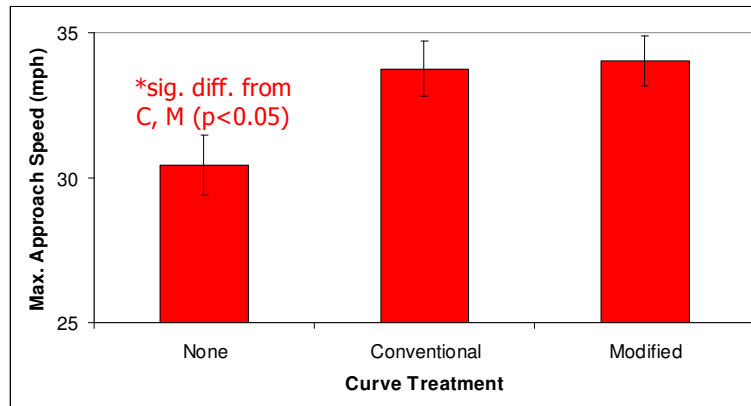


Figure 2-7. Mean maximum approach speeds for each experimental condition.

Figure 2-7 shows the mean maximum approach speeds for all 11 subjects, for each chevron treatment including the no-chevron treatment from the initial trial for each group. The only statistically significant ($p < 0.05$) differences, according to a one-way, repeated-measures analysis of variance (ANOVA) with pairwise comparisons, are between the no-chevron condition and the other two conditions. It is likely that this difference, resulting in lower speeds for the initial trial, is related to the practice/experience effects, which have been observed in other experiments (Skinner, 2007). Therefore it is difficult to interpret whether, or how much, the lack of chevrons might have affected the approach speeds in this experiment. Of interest, the maximum approach speeds for the two subsequent trials, which occurred either second or third during each session, leveled off and were not reliably different from each other, suggesting that any practice effects had stabilized after the first trial, when subjects would have been least familiar with the vehicle and driving course.

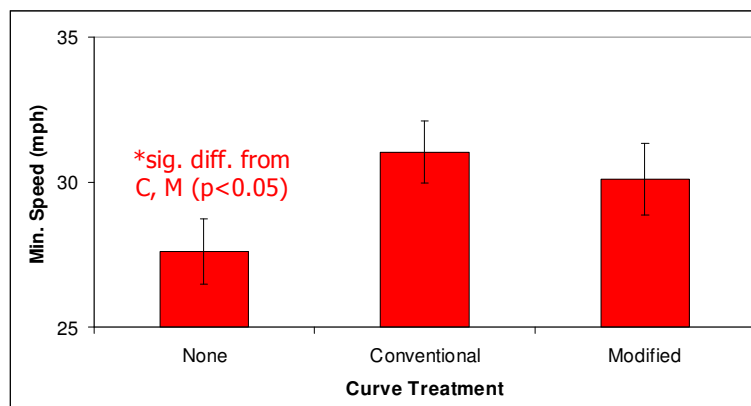


Figure 2-8. Mean minimum curve entrance speeds for each experimental condition.

Figure 2-8 shows the mean minimum speeds for each experimental condition. As with the data in Figure 2-7, the lowest minimum speed is associated with the no-chevron trial, which always occurred first in each session. The lower minimum speed is consistent with the fact that the maximum approach speed was lowest for this condition as well. The minimum curve entrance speed was lower for the modified chevron treatment than for the conventional chevron treatment, suggesting that drivers navigated the curve more slowly with the modified treatment. However, this difference was not statistically significant ($p > 0.05$).

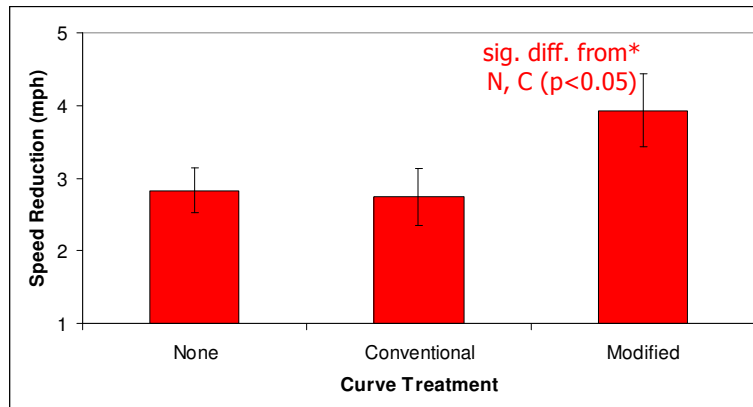


Figure 2-9. Mean speed reductions for each experimental condition.

When the mean speed reductions were compared across the experimental conditions (Figure 2-9), a different pattern was seen than illustrated in Figures 2-7 and 2-8. For the conventional chevron treatment (as well as for the no-chevron treatment), the mean speed reduction was just under 3 mph. For the modified chevron treatment the reduction was larger: about 4 mph, a statistically significant difference between the no- and conventional-chevron conditions.

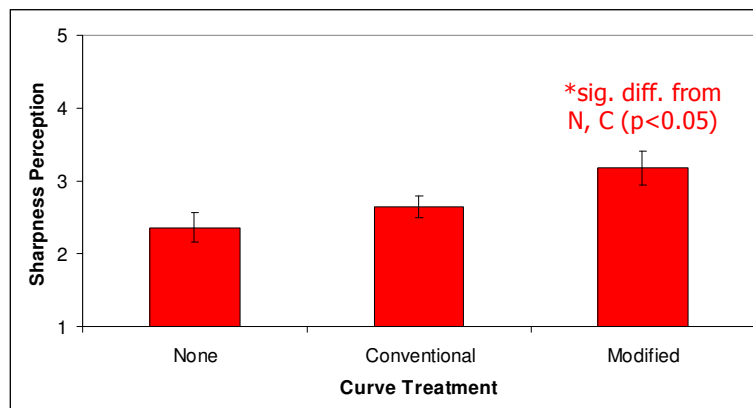


Figure 2-10. Mean curve perception ratings for each experimental condition.

Comparing the speed reduction data in Figure 2-9 to the mean subjective ratings of perceived curve sharpness appearance in Figure 2-10, a similar pattern emerges. Perceptions of curve sharpness along the four-point scale used in this experiment were statistically significantly ($p < 0.05$) higher, by about a half-rating point, for the modified chevron treatment than for the other chevron treatments studied.

The individual curve sharpness perception data and the individual speed reduction data were plotted on a single graph in order to identify whether there was a similar trend as that identified by Skinner and Bullough (2009), whereby higher ratings of perceived sharpness were associated with greater reductions in speed when approaching the curve. Figure 2-11 illustrates this trend, and the best-fitting trends to the entire set of data and to the data corresponding to the chevron conditions only are similar and both exhibit a positive slope, a similar finding as identified by Skinner and Bullough (2009).

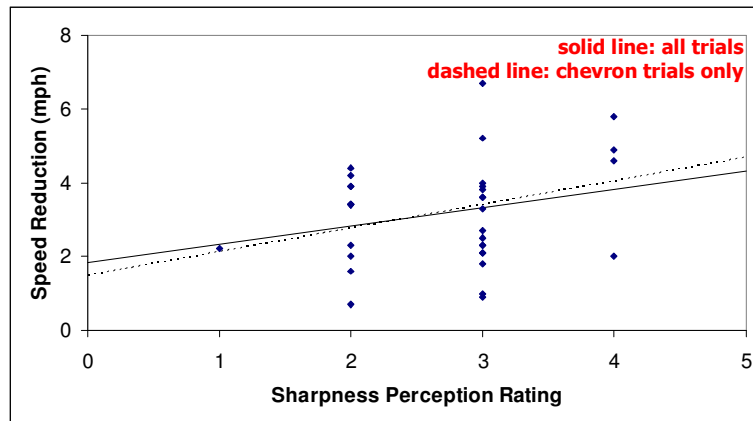


Figure 2-11. Relationship between curve perceived sharpness ratings and measured speed reductions for all trials (solid line) and for the chevron-only trials (dashed line).

Discussion

Based on the findings of the present human factors experiment, in combination with the literature reviewed in the previous chapter of this report and the previous study by Skinner and Bullough (2009), it does appear that modifying the use of chevrons to employ progressively-increasing sizes throughout a curve, and adjusting the spacing of them to provide an appearance consistent with a smaller radius curve (about two-thirds the radius of the original curve) can increase perceptions of sharpness by drivers, and can result in greater speed reductions.

Several important caveats must be discussed in the interpretation of the experimental results. The curve used for the present study was not a very sharp curve and because of this, would not typically have been a candidate for using chevrons. The experimental subjects were driving a largely unfamiliar vehicle, although they had a chance to practice through the first trial in each session, when no chevrons were present. Importantly too, subjects knew that they were navigating through the same curve during each trial. Although they were asked to rate the perceived sharpness of the *appearance* of the curve and not of the curve itself (which all subjects knew was exactly the same in each trial), the resulting driving behavior could have been different had subjects approached each curve in their own vehicles, while experiencing the curve for the first time in each trial.

Nonetheless, the fact that statistically reliable differences in speed reduction were measured despite the fact that the curve itself was identical for each trial could be taken as evidence for the robustness of the visual effect. At any rate, the use of modified chevron size and spacing does not present a dramatically different visual cue to drivers than the conventional treatment (compare Figures 2-4 and 2-5), so the treatment may be a promising one to help encourage reductions in speeds when traversing problematic roadway curves.

3. CURVE TREATMENTS TO REDUCE DRIVING SPEEDS: REAL-WORLD INSTALLATION

Introduction

The present chapter describes the site selection, and real-world installation and evaluation for progressively sized chevron sign panels that were installed along two highway curve locations in New York State.

Site Selection

Through discussions between the project team and NYSDOT, two locations were identified that had existing chevron installations suitable for replacement using the technique described in the Introduction (and summarized in more detail in the Task 2 report for the present project):

- New York State Route 351, Brunswick, Rensselaer County
- New York State Route 43, West Stephentown, Rensselaer County

Coordination and Planning

NYSDOT Region 1 installed the chevron signs at the two locations. The chevron sign panels were drawn from the set used in the human-factors study of driving speed and curve sharpness perception described in the previous chapter of this report. The sign panel sizes (all width by height) for the Route 351 location were as follows:

- 24 x 30 inches
- 26 x 32 inches
- 27 x 33 inches
- 28 x 34 inches
- 30 x 36 inches

At the Route 43 location, the sign panel sizes were:

- 18 x 24 inches (two of these sizes were used in the curve, plus an additional one of this size installed ahead of the curve)
- 20 x 26 inches
- 22 x 28 inches
- 25 x 31 inches

Sign panels were delivered to the Rensselaer County NYSDOT residency in November 2011 and installed in December 2011. Figure 3-1 shows the mounting locations and sizes of the panels proposed for the Route 351 location, which is south of the intersection with White Church Rd. The chevrons on Route 351 in this location face in both traveling directions, but only the chevrons for the northbound traveling direction are proposed to be changed. Figure 3-2 shows the proposed treatment at the Route 43 location. This is a one-way chevron installation with the signs facing traffic only as it approaches from the east.

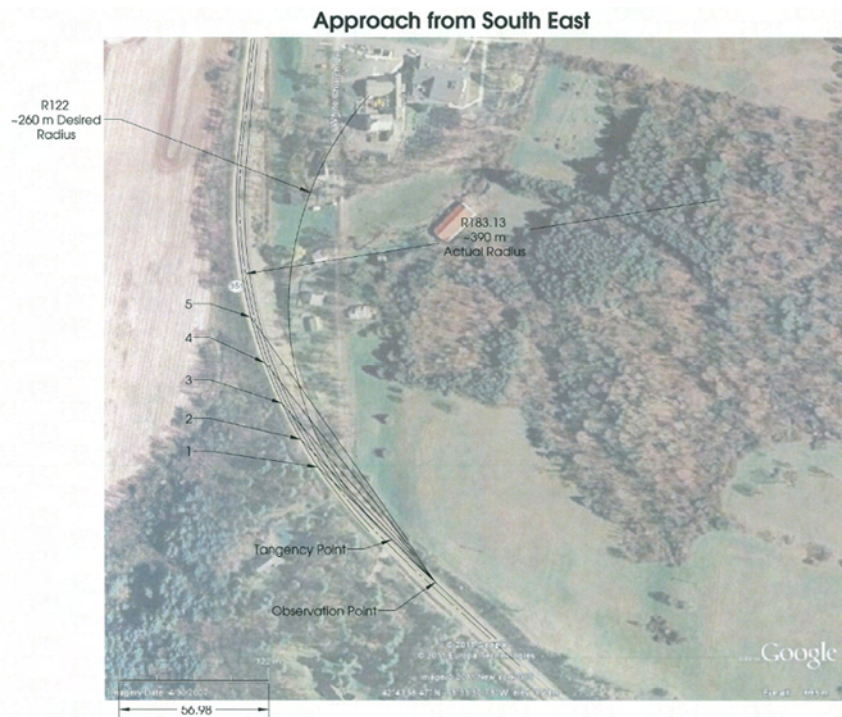


Figure 3-1. Proposed chevron locations as viewed by traffic approaching from the south along Route 351. The sizes of the chevron panels at each location (1-5) are as follows: 1) 24 by 30 inches, 2) 26 by 32 inches, 3) 27 by 33 inches, 4) 28 by 34 inches, 5) 30 by 36 inches.

The chevron signs, as with any roadside sign, would be mounted so that the bottom of the sign were a minimum of 4 feet from the ground level, and be mounted on breakaway posts so that they would yield upon impact by a vehicle.



Figure 3-2. Proposed chevron locations as viewed by traffic approaching from the east along Route 43. The sizes of the chevron panels at each location (1-5) are as follows: 1) 18 by 24 inches, 2) 18 by 24 inches, 3) 20 by 26 inches, 4) 22 by 28 inches, 5) 25 by 31 inches. Following the installation of these signs, an additional 18 by 24 inch chevron panel was installed 20 m ahead of location #1, near the tangency point of the curve.

NYSDOT Region 1 personnel also assisted in contacting property owners near the roadway curves and providing documentation to be used by the project team, providing permission to use nearby driveways and property for subsequent measurements of vehicle speeds. Lighting Research Center personnel verified the correct installation of the signs

Baseline Measurements: Method

Before and after the installation of progressively sized chevron signs along horizontal curves at NYS Route 351 and NYS Route 43 in Rensselaer County, Lighting Research Center (LRC) project team members conducted vehicle speed surveys at the locations in order to identify the baseline vehicle speed conditions.

Measurement Device

The measurement device used was a Bushnell Velocity Speed Gun (#5380A-38006), a handheld radar gun. According to product literature, the gun can be used to measure vehicle speeds from a distance of up to 1500 feet and can measure speeds from 6 to 200 mph with accuracy of +/- 1 mph.

Procedure

A minimum of 100 vehicles were measured at each of the two test locations. Vehicle speeds were measured at the entrance of the curve. At the Route 351 location, an experimenter was located in an off-road location shielded from direct view of oncoming traffic. At the Route 43 location, measurements were made from a parked vehicle in a driveway with permission from the property owner. All vehicle lights were off during measurement. Daytime measurements (made at Route 351 and Route 43) were made in the early afternoon, and evening measurements (made only at Route 43) were made at least 30 minutes after sunset.

When vehicles approached in clusters, only the speed of the lead vehicle was measured and the remaining vehicles were not measured since it is likely that their speeds were not independent of the lead vehicle's speed.

All measurements were made during clear weather with no moisture or ice on the road surface. There was some snow cover on the ground surrounding the road at both locations but the road surface and markings were clearly visible.

Baseline Measurements: Results

Figure 3-3 shows a histogram of the distribution of daytime vehicle speeds at the Route 351 location. The mean vehicle speed was 58 mph and the median speed was 59 mph. The maximum was 68 mph and the minimum speed was 48 mph, with a standard deviation of 4.5 mph. The shape of the histogram is nearly bell shaped, and with similar mean and median speeds, the speeds appeared to be approximately normally distributed.

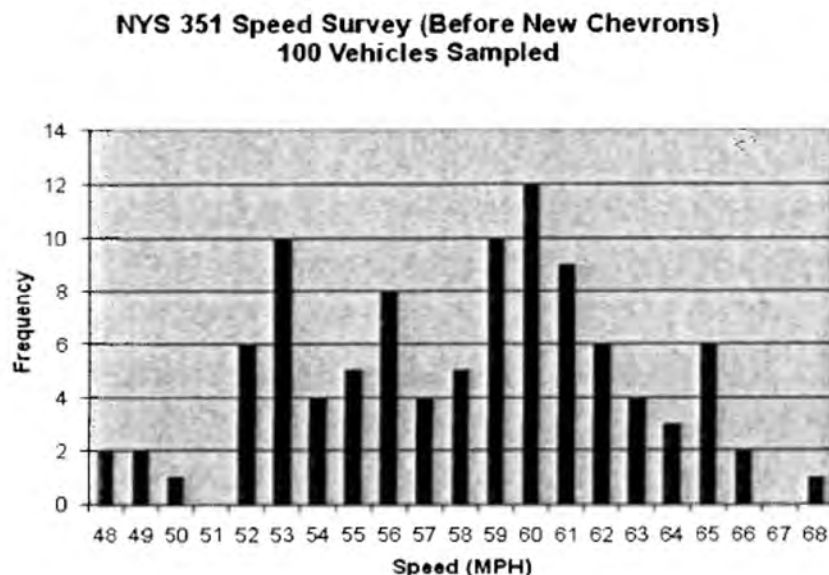


Figure 3-3. Distribution of daytime vehicle speeds at Route 351 before the chevron installation.

Figure 3-4 shows a histogram of the daytime vehicle speeds at the Route 43 location. The mean vehicle speed was 50 mph and the median speed was 51 mph. The maximum was 68 mph and

the minimum speed was 36 mph, with a standard deviation of 5.4 mph. The shape of the histogram is nearly bell shaped, and with similar mean and median speeds, the speeds appeared to be approximately normally distributed.

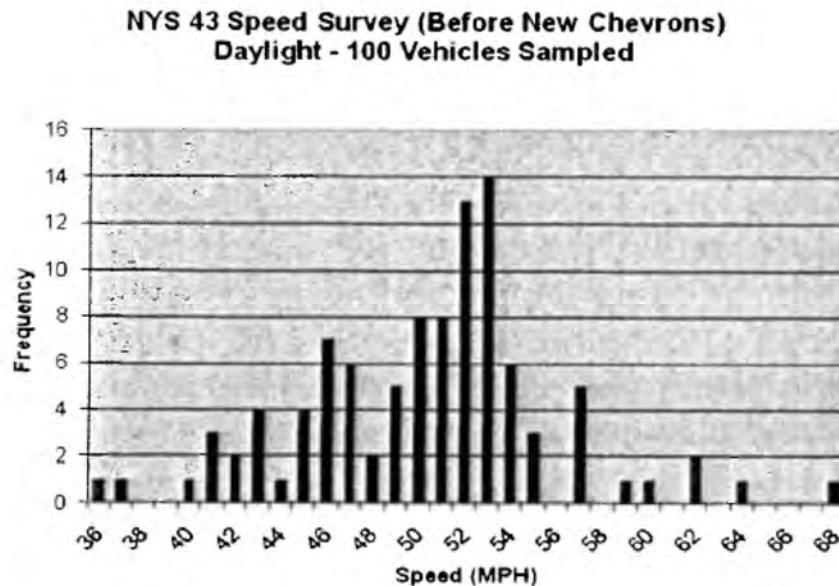


Figure 3-4. Distribution of daytime vehicle speeds at Route 43 before the chevron installation.

Figure 3-5 shows a histogram of the nighttime vehicle speeds at the Route 43 location. The mean vehicle speed was 48 mph and the median speed was 48 mph. The maximum was 61 mph and the minimum speed was 38 mph, with a standard deviation of 4.8 mph. The shape of the histogram is nearly bell shaped, and with similar mean and median speeds, the speeds appeared to be approximately normally distributed.

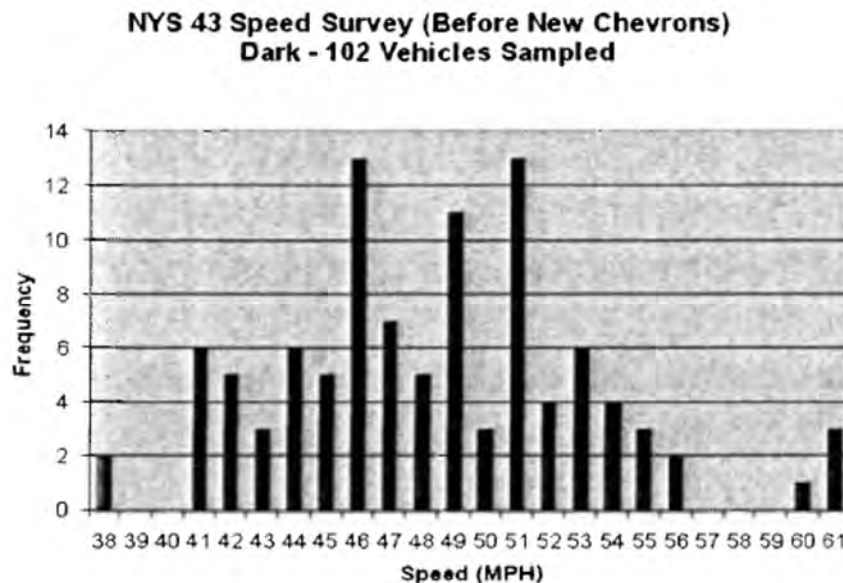


Figure 3-5. Distribution of daytime vehicle speeds at Route 43 before the chevron installation.

Of interest, the data for the Route 43 location for daytime and nighttime vehicle speeds were compared to determine whether there were reliable differences in speed. A two-tailed Student's t-test revealed a statistically significant ($p < 0.05$) difference between the daytime and nighttime mean speeds, with lower mean speeds at night.

Post-Installation Measurements: Method

Before and after the installation of progressively sized chevron signs along horizontal curves at NYS Route 351 and NYS Route 43 in Rensselaer County, project team members conducted vehicle speed surveys at the locations in order to identify the impact of the treatment on vehicle speeds.

The measurement device used was the same as that used for the baseline measurements. A minimum of 100 vehicles were measured at each of the two test locations. All measurements were made during clear weather with no moisture or ice on the road surface. There was some snow cover on the ground surrounding the road at both locations but the road surface and markings were clearly visible.

Post-Installation Measurements: Results

Figures 3-6a and 3-6b show histograms of the distribution of daytime vehicle speeds at the Route 351 location before and after the installation of progressively sized chevrons, respectively. The mean vehicle speed changed from 58 mph to 56 mph, and the median speed changed from 59 mph to 56 mph. The standard deviation changed from 4.5 mph to 5.0 mph. A two-tailed Student's t-test revealed a statistically significant ($p < 0.05$) difference in mean speeds before and after the installation, suggesting that the speeds were lower after the installation of the new chevron signs.

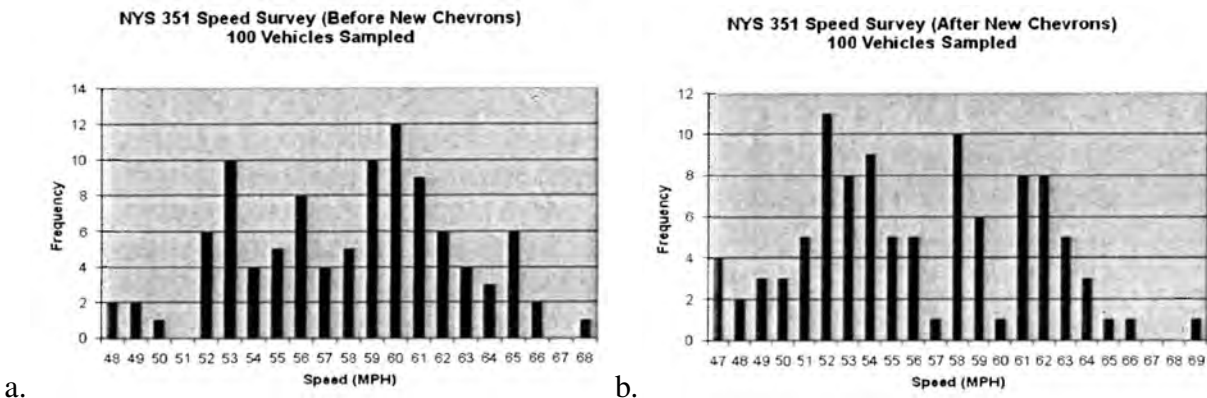


Figure 3-6. Distribution of daytime vehicle speeds at Route 351: a) before the chevron installation, b) after.

Figure 3-7 shows a histogram of the nighttime speeds after the new chevron installation. The mean speed was 55 mph, and the median speed was 54 mph, with a standard deviation of 4.4 mph. Nighttime speeds for the “before” condition were not collected. To determine whether

there was a reliable difference in speeds for the “after” condition between daytime and nighttime, a Student’s t-test was conducted, and a statistically significant ($p < 0.05$) reduction for the nighttime condition was found. This was consistent with the reliable reduction in nighttime speeds found for the Route 43 location’s “before” conditions for day and night.

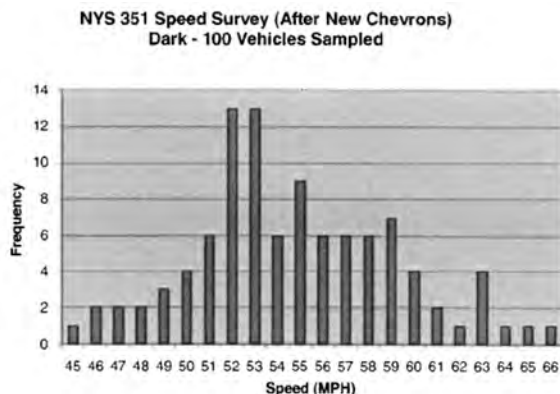


Figure 3-7. Distribution of nighttime vehicle speeds at Route 351 after the chevron installation.

Figure 3-8a shows a histogram of the daytime vehicle speeds at the Route 43 location before the installation of the new chevron signs, and Figure 3-8b shows the corresponding histogram after the installation of the new signs. The mean speed changed from 50 mph before the installation to 49 mph after, and the mean changed from 51 mph to 49 mph. The standard deviation changed from 5.4 mph to 5.0 mph. A two-tailed Student’s t-test showed that although there was a reduction in the mean speed, it was not statistically significant ($p > 0.05$).

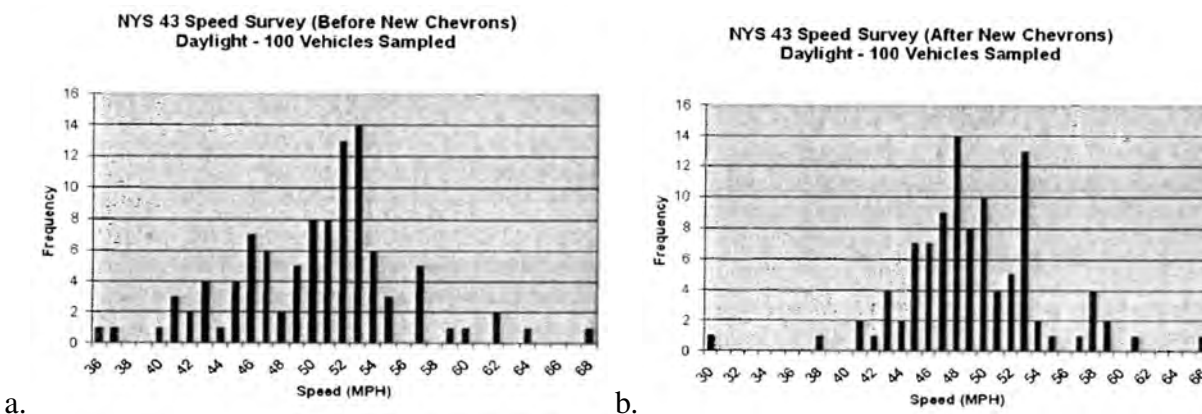


Figure 3-8. Distribution of daytime vehicle speeds at Route 43: a) before the chevron installation, b) after.

Figure 3-9a shows a histogram of the nighttime vehicle speeds at the Route 43 location before installation of the new chevrons, and Figure 3-9b shows the distribution of speeds after the installation. The mean vehicle speed decreased from 48 mph to 45 mph, the median vehicle speed changed from 48 mph to 45 mph, and the standard deviation changed from 4.8 mph to 4.6 mph. There was a statistically significant ($p < 0.05$) difference in mean vehicle speeds, suggesting that speeds were lower after the installation of the new chevron signs.

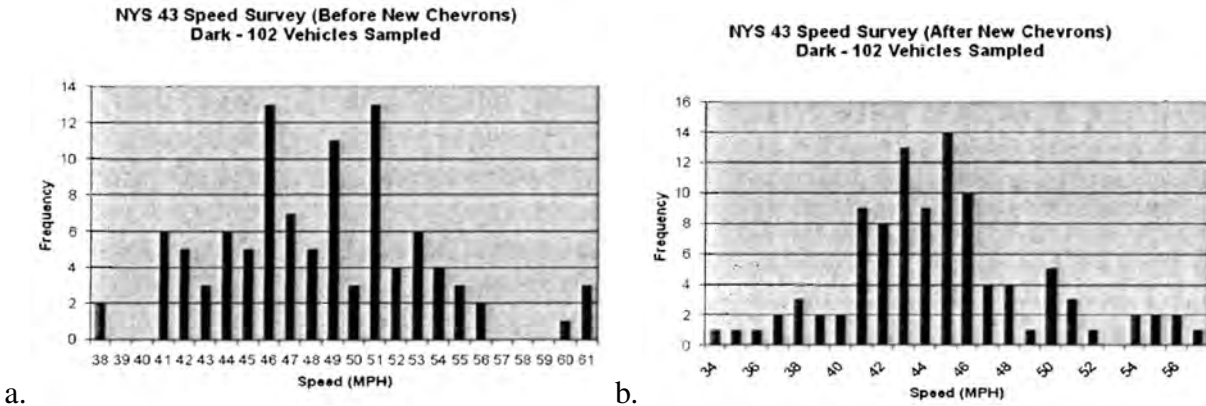


Figure 3-9. Distribution of nighttime vehicle speeds at Route 43: a) before the chevron installation, b) after.

The data for the Route 43 location for daytime and nighttime vehicle speeds after the installation of new chevron signs were compared to determine whether there were reliable differences in speed. A two-tailed Student's t-test revealed a statistically significant ($p < 0.05$) difference between the daytime and nighttime mean speeds, with lower mean speeds at night. This was similar to the previous finding regarding differences between day and night speeds before the installation of the new chevrons.

Discussion

The data summarized in this chapter are consistent with the idea that the progressively sized chevron signs were associated with slightly lower vehicle speeds near the entrance of the curves where they were located. Vehicle speeds were also somewhat lower at night than during the daytime. Figure 3-10 shows a summary of mean vehicle speeds along the Route 351 location, and Figure 3-11 shows the mean speeds at Route 43. Although nighttime speeds were not measure at Route 351 before the installation of new chevron signs, the data for the other three conditions follow similar patterns as for the corresponding conditions at Route 43.

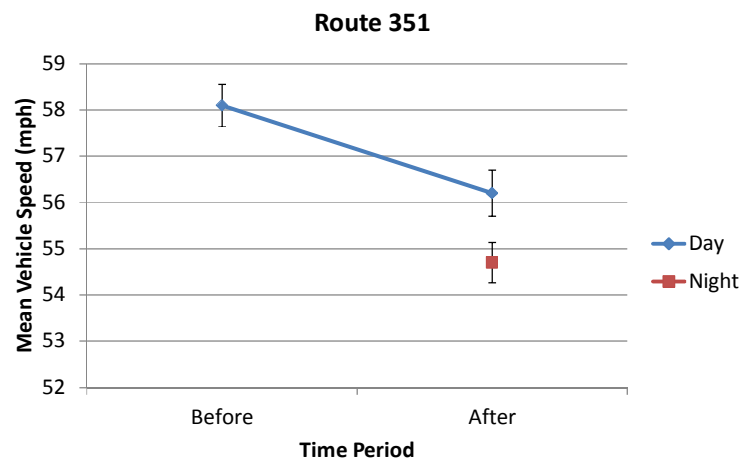


Figure 3-10. Summary of mean vehicle speeds measured at Route 351 before and after installation of the new chevron signs.

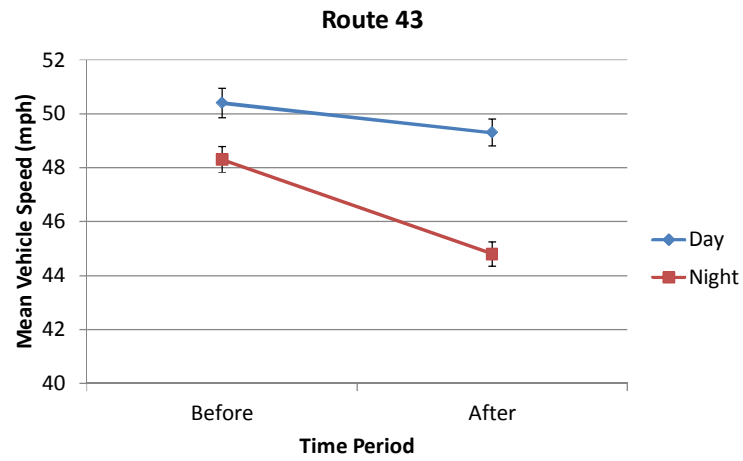


Figure 3-11. Summary of mean vehicle speeds measured at Route 43 before and after installation of the new chevron signs.

4. SPEED DISPLAY TO REDUCE TRAFFIC SPEED VARIABILITY: FIELD EXPERIMENT

Introduction

The present chapter describes a human factors study as part of a New York State Department of Transportation (NYSDOT) project conducted by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute to assess the perceptions and behaviors of drivers approaching a graphical speed display having various configurations. The experiment used naïve study participants who drove their own vehicles along a closed public roadway, and measured drivers' approaching speed and any changes in speed while passing the graphical speed display. Also measured were subjects' subjective ratings of the clarity of the apparent message (if any) provided by the display.

Background

The objective of this study was to determine the effects of a graphical, speed-dependent display sign on driving speed. Traffic congestion along some roadways is caused when some drivers might reduce speeds along the road more than necessary at locations perceived as possible "bottlenecks." In such situations it might be desirable if those drivers did not slow down, but rather, to try to maintain a more uniform speed. In other cases, such as work zones, reduced speeds by all drivers are desired but again, uniformity of behavior is desirable to avoid a large speed variance resulting in congestion and possibly accidents.

The LRC has proposed a graphical speed display sign that is similar to conventional speed limit display signs that also show the speed of the approaching vehicle. The proposed display will also include a graphical element that could appear as an upward- or downward-pointing carat varying in number and position, depending upon the direction and magnitude of a vehicle's speed and the desired speed in a given situation. For example, suppose that the desired prevailing speed is 40 mph, but an approaching vehicle is traveling 50 mph. The sign in this case should provide an intuitive graphical element that would encourage the driver to reduce speed. Similarly, if an approaching vehicle were traveling at 30 mph, the sign should encourage drivers to maintain the desired prevailing speed.

We hypothesized that such a graphical speed display could help to influence drivers to adjust (if necessary) driving speeds along certain roadway locations, which would improve safety and traffic flow. The present experiment was conducted to test this hypothesis.

Method

The experiment was conducted during the months of September and October 2011 along Temple Lane in the Town of East Greenbush, Rensselaer County, New York. Figure 4-1 shows a photograph of the graphical speed display system.



Figure 4-1. View of graphical speed display used in the human factors experiment.

The basic experimental procedure was as follows: The road was closed with traffic cones in cooperation with the Town of East Greenbush and the East Greenbush Police Department, throughout the experimental sessions. Subjects arrived in groups of five at the test location and were provided consent forms approved by Rensselaer's Institutional Review Board (IRB) and after signing the forms, and having their questions answered, they were instructed about the basic process. Driving their own vehicle, each subject was instructed to drive from the initial gathering location to a turnaround location marked with a traffic cone. They were asked to maintain a speed of 20 mph unless instructed otherwise along the way. The graphical speed display was located about a quarter- to a half-mile past the starting location.

During the experiment, five different display messages were utilized, which are illustrated in Figure 4-2. The messages were:

- Maintain 20 mph
- Maintain 15 mph (with a single downward-pointing triangle below the message)
- Maintain 10 mph (with three downward-pointing triangles below the message)
- Maintain 25 mph (with a single upward-pointing triangle above the message)
- Maintain 30 mph (with three upward-pointing triangles above the message)

The messages requiring the largest change in speed from the 20 mph baseline speed had a larger number of triangle symbols. Downward triangles indicated desired reductions in speed, and upward triangles indicated desired increases.

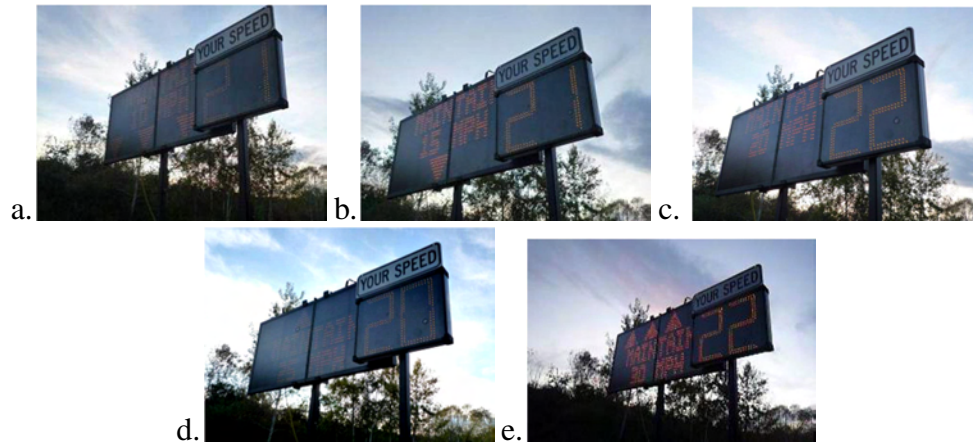


Figure 4-2. Photographs of graphical/text messages from graphical speed display small-scale test installation.

Experimenters located near the graphical speed display recorded oncoming approach speeds as subjects came around a shallow curve to where they could just begin to see the display. The experimenters also recorded driving speeds as subjects passed the sign (approximately 100 ft past the graphical speed display) using a handheld radar speed measurement gun.

Subjects were instructed to maintain a speed of 20 mph, until or unless they saw an indication that they believed was instructing them to change their speeds. During some of the trials, the sign display was intentionally set to a blank display with no message of any kind, to use as a control condition. Subjects were asked to continue driving past the sign for another quarter-mile until they reached a turn-around location marked with a traffic cone. At this point, they were requested to complete a questionnaire asking them to rate the clarity of the meaning of the message they saw (-2: very unclear, -1: somewhat unclear, 0: neither clear nor unclear, +1: somewhat clear, +2: very clear), if any.

The conditions were displayed in randomized order during each experimental session. After all five subjects completed a given trial condition, they all then returned to the starting location in preparation for the next trial. Experimenters communicated to each other with walkie-talkies.

Each subject completed a total of six trials, one for each of the display messages shown in Figure 4-2, plus a control trial with no message displayed. Each experimental session took between 60 and 90 minutes to complete. Both sessions were conducted during the early evening in late daytime, dusk and early nighttime conditions in clear weather. The second session was started but experienced a communications failure due to an improper software setting; for two subjects who completed the first trial during this session and who also participated in the re-scheduled second session, their speeds and ratings for that condition were averaged. Data for those subjects who participated in the incomplete session but who did not participate in the re-scheduled session were discarded.

Results

Approach Speed

Figure 4-3 shows the mean approach speeds for each condition. As expected, since drivers were asked to maintain speeds of 20 mph (unless or until instructed otherwise), the speeds are all close to 20 mph. A repeated-measures analysis of variance (ANOVA) confirmed that there were no statistically significant differences ($p>0.05$) among the conditions in terms of approach speeds.

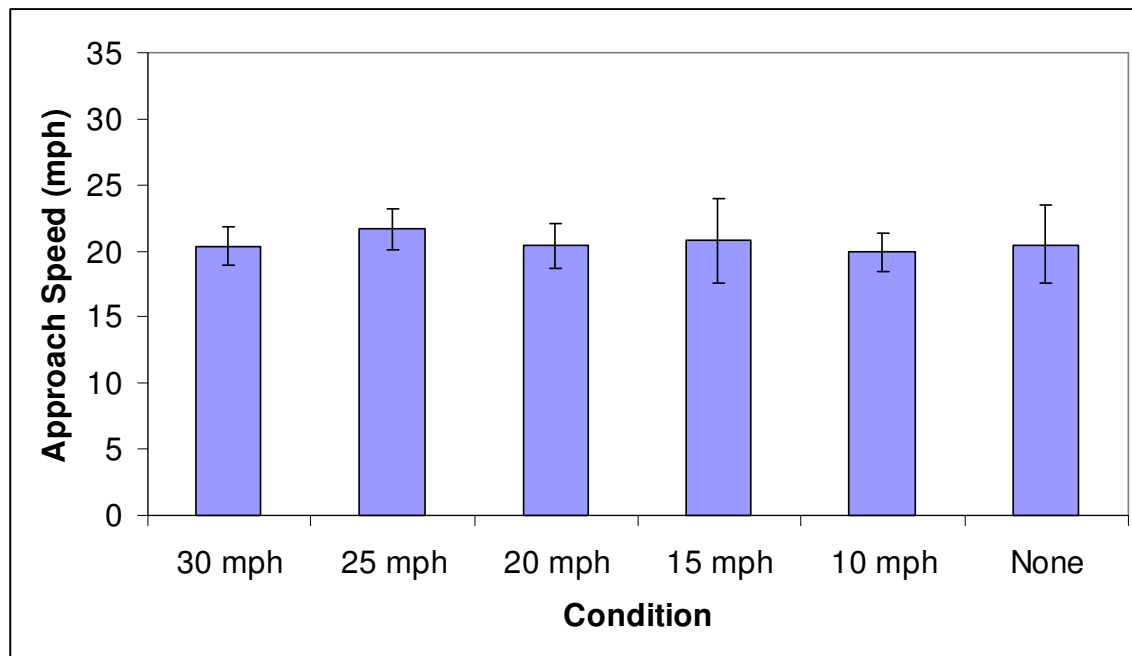


Figure 4-3. Average approach speeds (+/- standard deviation) for each experimental condition.

Using the condition in which nothing was displayed as a control for statistical comparison purposes, Dunnett's test (Sheskin, 1997) was employed to determine if the approach speeds of any of the test conditions differed reliably from the approach speed with no display (denoted "None" in Figure 4-3). This test revealed that none of the average approach speeds for the graphical display conditions were statistically significantly different ($p>0.05$) from when no display was present.

Downstream Speed

It had been expected that the driving speeds after subjects approached the sign would be influenced by the message displayed on the sign. Figure 4-4 shows the mean downstream speeds measured ~100 feet after passing the sign for each experimental condition. A repeated-measures ANOVA confirmed that there were statistically significant differences ($p<0.05$) among all of the conditions. Dunnett's test (Sheskin, 1997) was employed to compare the downstream speeds under each of the experimental test conditions (with a graphical display present) with the control condition denoted by "None" in Figure 4-4. This test confirmed that the average speeds for all of the experimental test conditions were statistically significantly different ($p<0.05$) from the

control condition, except for the "20 mph" condition. This is not unexpected since the subjects were instructed to maintain a speed of 20 mph and in this condition, the graphical speed display instructed them to maintain this speed, which was the same as the initial starting speed.

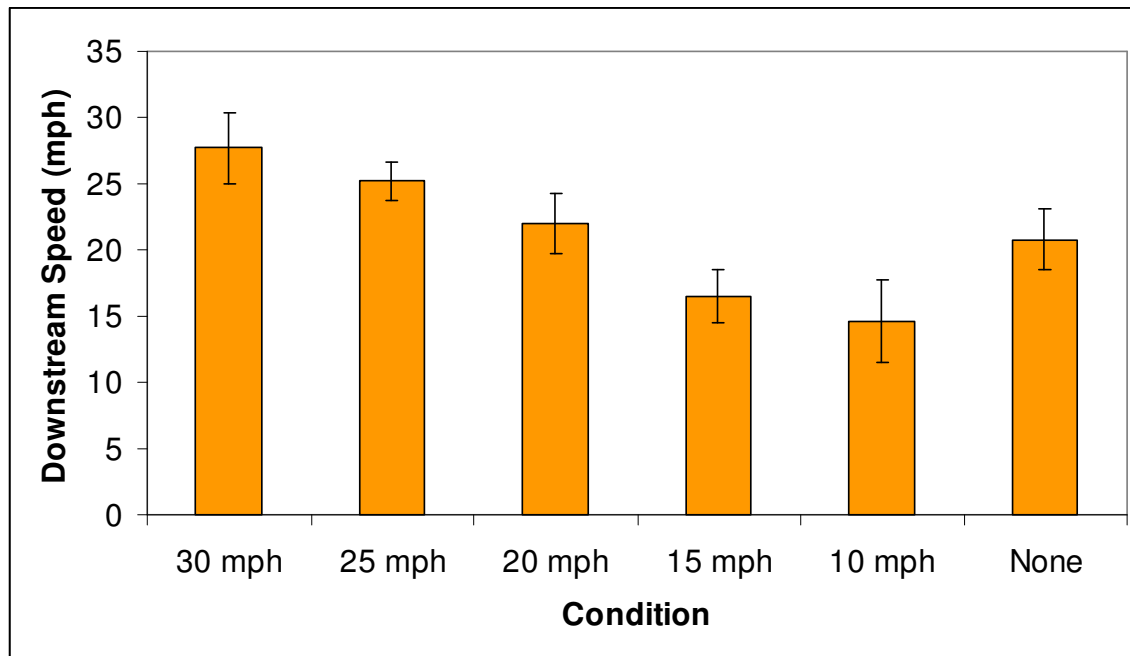


Figure 4-4. Average downstream speeds (+/- standard deviation) for each experimental condition.

Change in Speed

In addition to the absolute downstream speeds, it is also possible to assess the potential impact of the graphical speed display by taking the change in speed for each subjects and each condition, calculated by subtracting each approach speed from the corresponding downstream speed. Figure 4-5 shows these mean values for each experimental condition. Qualitatively, the data in Figure 4-5 appear very similar to those in Figure 4-4.

A repeated-measures ANOVA confirmed that the changes in speed were statistically significantly different ($p < 0.05$) among the experimental conditions. Using Dunnett's test (Sheskin, 1997) to determine whether the speed change values for the experimental test conditions (with a display present) differed from the control condition without a display, the "30 mph", "15 mph" and "10 mph" conditions were statistically significantly different ($p < 0.05$) from the control, and the "20 mph" and "25 mph" conditions were not ($p > 0.05$). For the "25 mph" condition, the difference approached but did not reach statistical significance ($p < 0.07$).

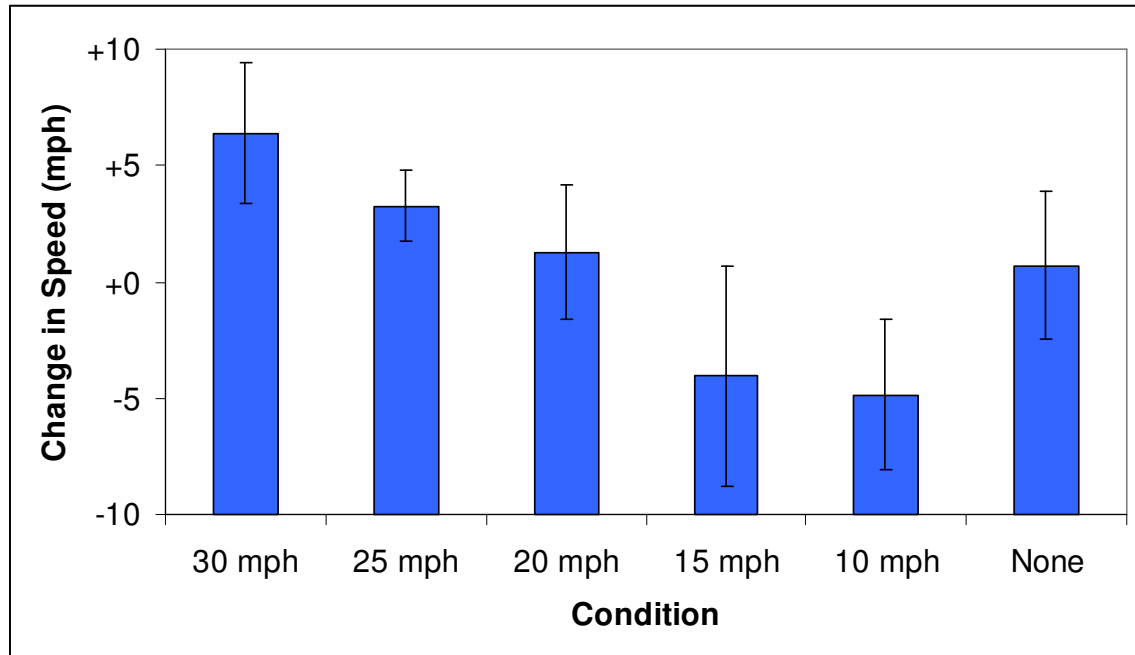


Figure 4-5. Average changes in speed ($\pm$ standard deviation) for each experimental condition.

Ratings of Clarity

Figure 4-6 shows the mean ratings of clarity for each of the conditions.

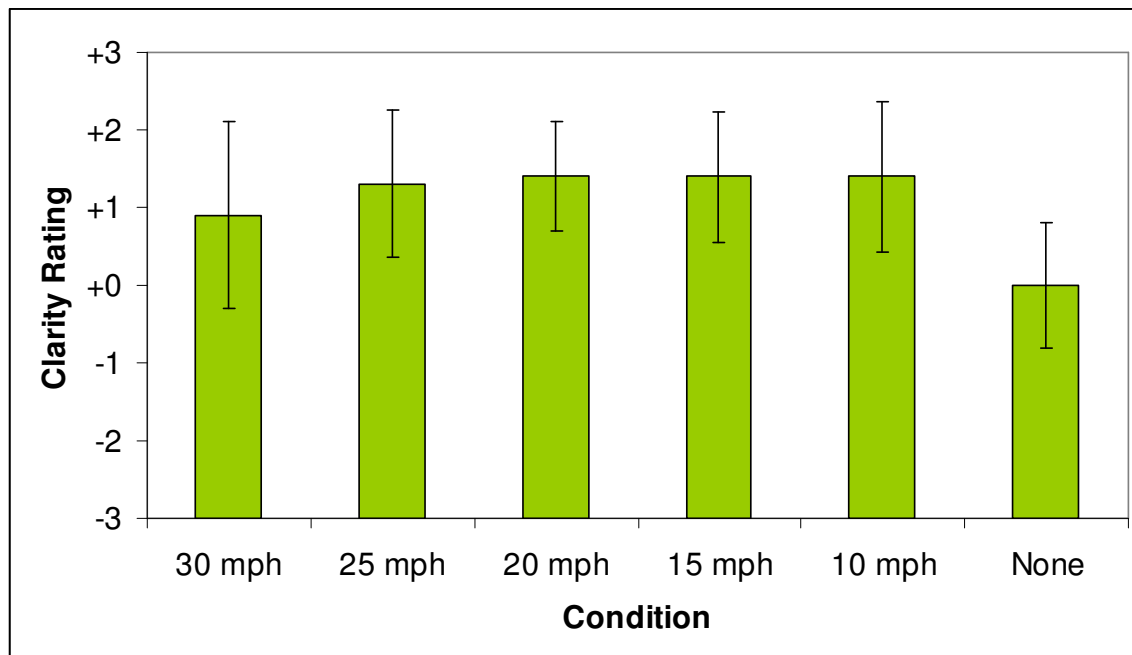


Figure 4-6. Average clarity ratings ($\pm$ standard deviation) for each experimental condition.

For most of the experimental test conditions (excepting "30 mph"), the ratings were very similar. Ratings for the control condition were lowest, averaging near zero, which is not unexpected since nothing was displayed in the control condition. A repeated-measures ANOVA revealed that there were statistically significant differences ($p < 0.05$) among the conditions, and Dunnett's test (Sheskin, 1997) showed that the average ratings for all of the experimental test conditions were statistically significantly different ($p < 0.05$) from the control condition. Using Dunnett's test with the "30 mph" as the control comparison revealed that this condition was not statistically significantly different ($p > 0.05$) from the other experimental test conditions, despite its slightly lower average rating value.

Discussion

The results of this field experiment indicate that subjects were generally able to understand the messages displayed by the graphical speed display sign system (Figure 4-2), and to adjust their speed upward or downward accordingly. Of interest, it is worth noting that based on observations of Figures 4-4 and 4-5, there might have been a ramping off effect of the changes in speed. Assuming a baseline of 20 mph, for the conditions that requested speed changes on the order of 10 mph, the resulting downstream speeds were lower than 30 mph for the "30 mph" condition and higher than 10 mph for the "10 mph" condition. This may be an effect of measuring the downstream speeds 100 feet past the speed display.

Also of interest, the standard deviations in the downstream speeds for the experimental test conditions were lower than for the control (no display) condition when the requested changes in speed (if any) were on the order of 5 mph or less ("15 mph", "20 mph" and "25 mph"). In contrast, the standard deviations were larger for the more extreme requested changes ("10 mph" and "30 mph") than for the control condition. This suggests that subjects may still have been accelerating or decelerating by the time they reached 100 feet past the sign. For the smaller speed adjustments, the results are consistent with the notion that having the graphical speed display present helped to reduce variations in speed relative to the control (no display) condition.

Of course, interpretation of the present results must be somewhat limited. The speeds used in the present field experiment, on the order of 20 mph, are substantially lower than is likely to be found on many highway situations, except perhaps very complex work zone locations with narrow traveling lanes. Subjects, although naïve to the purpose and hypothesis of the experiment, likely gained knowledge throughout the experiment about the types of conditions that they would experience, although this effect was mitigated by balancing the order of experimental conditions between experimental sessions. Overall, the data are promising in that they provide some basis for using such a display, likely with little confusion among drivers, and expecting it to influence driving speeds and perhaps to reduce speed variations among drivers.

5. SPEED DISPLAY TO REDUCE TRAFFIC SPEED VARIABILITY: REAL-WORLD INSTALLATION

Location

The test location was located along Jordan Road, within the Rensselaer Technology Park in the Town of North Greenbush, NY. Figure 5-1 shows a map of the location.



Figure 5-1. Aerial view and map of the test location. The yellow area indicates the portion of Jordan Road that was used for the test.

Coordination

First the installation design was approved by the NYSDOT project manager to ensure that the display was consistent with guidance in the Manual of Uniform Traffic Control Devices (MUTCD).

The project team then contacted the director of the Rensselaer Technology Park to obtain their permission to install the speed display unit along Jordan Road within the Technology Park. Tentative approval and cooperation was given, pending discussions and approval from the Town of North Greenbush as the road is classified as a Town roadway.

The principal investigator met with the Town Supervisor and the Chief of Police at the North Greenbush Town Offices to discuss the installation and planned activities:

- The team would first collect a baseline set of speed data to determine typical vehicle speeds along the untreated road using a speed display sign set to a blank display, which records and stores vehicle speed data.

- Then the team would set up a “speed zone” as follows: the speed display sign would be set up to encourage driving speeds of 25 mph (the posted speed limit at this location is 30 mph); downstream from this display would be the same small blank sign to record speeds within the zone, and further downstream a temporary “30 MPH Speed Limit” sign (provided by the NYSDOT Rensselaer County Residency) would be set up to notify drivers that the speed zone was concluded.

All signs and displays would be located on the grass adjacent to the road, and no activity would take place within the road itself. The Supervisor and Police Chief gave their approval and asked to be notified when the data collection activities would occur.

The Rensselaer Technology Park office staff also requested that the Town Highway Superintendent be notified about the dates of the installation so that the project team could be notified if road work or other Town activities were necessary on the road. The principal investigator contacted the Superintendent’s office as requested.

The project team also acquired documentation from Rensselaer’s Institutional Review Board (IRB) confirming that data collection was exempt from IRB approval (and therefore, speed data could be measured) as long as no personally identifying information about any of the drivers or vehicles would be collected. The speed measurement sign only records speeds and times, with no information about the vehicle or driver, meeting this requirement.

All measurements were planned to be made during daytime hours after 9 a.m. and before 4 p.m. to avoid the bulk of commuter traffic in the Technology Park. Measurements were also only made during clear weather.

Display Functionality

The display to be used is the same one deployed in the small-scale test installation (All Traffic Solutions, Instalert 24, with the Shield 15 used to record driving speeds). The Shield 15 was always used with a blank display only to record vehicle speeds. The larger display (Instalert 24) was programmed to display several conditional messages based on the speed of the approaching vehicle:

- If a vehicle is going faster than 30 mph: "REDUCE SPEED TO 25 MPH"
- If a vehicle is going between 25-30 mph: "25 MPH SPEED ZONE"
- If a vehicle is going between 20-25 mph: (No Message)
- If a vehicle is going less than 20 mph: "25 MPH SPEED ZONE"

When no vehicles are approaching the sign it rests in a blank display.

All display messages were presented in “matrix” format using yellow light emitting diodes (LEDs).

A 30 MPH Speed Limit sign would be located after the small blank display in order to delineate the end of the speed zone.

Layout

A schematic view of the installation design is shown in Figure 5-2a. A view of Jordan Road from the approximate location of the programmable sign is given in Figure 5-2b.

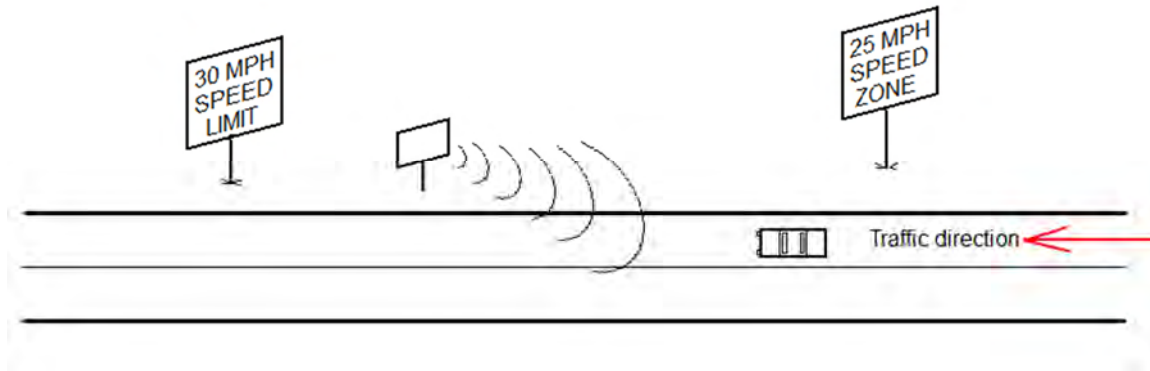


Figure 5-2a. Schematic layout of speed display installation.



Figure 5-2b. View of Jordan Road, traveling northwest (from Google Maps). Approximate speed display location is to the immediate right of this location; the small blank sign to measure downstream speeds and the 30 MPH Speed Limit sign were located ahead of this location.

Installation of Displays

The displays used were mounted to heavy duty tripods with extended bases for stability. They were positioned on the grass along the side of Jordan Road, facing traffic entering the Technology Park and traveling toward the northwest.

Figures 5-3 and 5-4 show the operation of the large speed display, which was programmed to display a “Reduce Speed to 25 MPH” message (Figure 5-3) for vehicle speeds exceeding 30 mph, and “25 MPH Speed Zone” (Figure 5-4) for all other speeds, except for those between 20 and 25 mph, for whom the sign face was blank. In addition, when no vehicles were present the large display was blank.



Figure 5-3. Speed display shown in response to speeds greater than 30 mph.



Figure 5-4. Speed display showing the “25 MPH Speed Zone” message.

Project team members confirmed that the sign was operating properly in response to vehicle speeds through observation.

Approximately 100 m beyond the large display sign (while traveling northwest), a small blank sign was located (Figure 5-5). Just beyond this blank display, a “SPEED LIMIT 30 MPH” sign was located to indicate the end of the speed zone.



Figure 5-5. Appearance of blank speed sign used for measurement.

The system was operated during the daytime from 10 a.m. until 3 p.m.

Baseline Measurements: Method

The method used to measure vehicle speeds was a small two-digit speed display system that was set to a blank display and mounted to a tripod. Measurements were taken on a weekday during clear weather, and only data between 10 a.m. and 3 p.m. were utilized.

Baseline Measurements: Results

Figure 5-6 shows the distribution of vehicle speeds. A total of 663 vehicle speeds were measured between 10 a.m. and 3 p.m.

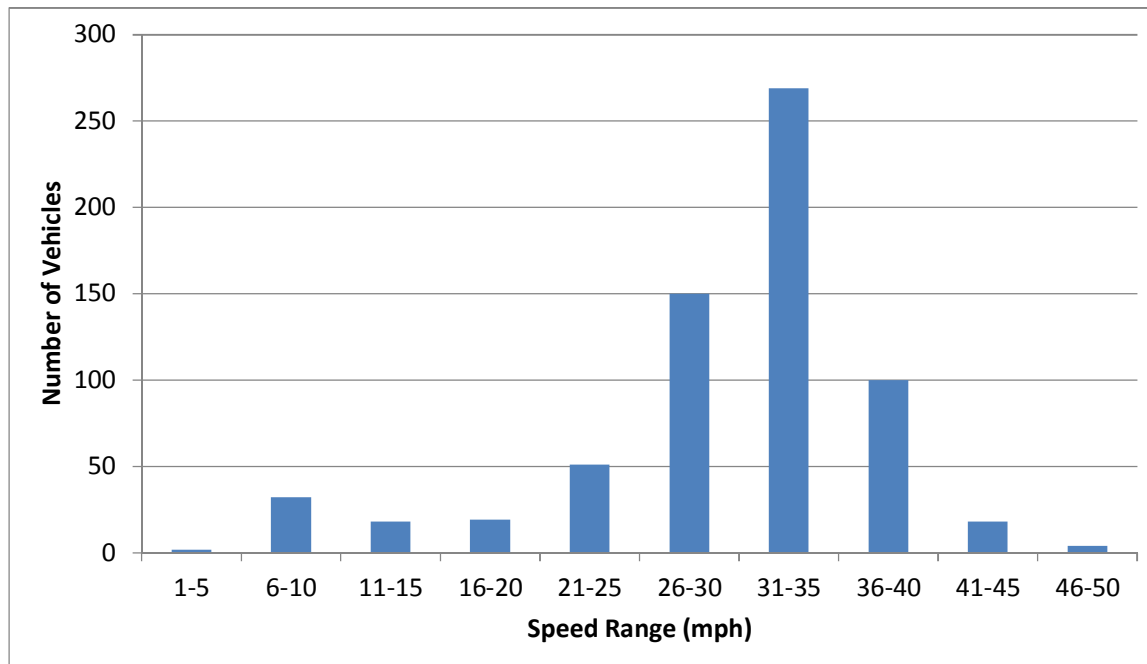


Figure 5-6. Histogram of measured vehicle speeds for the baseline condition.

The mean measured speed was 30 mph, and the median speed was 33 mph. The standard deviation was 7.88 mph. Because there was a driveway located shortly after the measurement location, there is a significant “tail” in Figure 5-6 for low vehicle speeds, primarily drivers preparing to turn into the driveway. The largest “bin” of speeds was from 31 to 35 mph.

Post-Installation Measurements: Method

Following the installation of the speed display system, the project team attempted to measure vehicle speeds using the small blank sign. Although the sign was about 100 m from the larger speed-dependent display, there was cross-talk between the signs so that the data from the blank sign were unreliable.

Therefore, the project team conducted a second installation and evaluation using a hand-held speed radar gun (Velocity, Bushnell). For this installation, the small blank sign was not used, only the larger speed dependent display and the “Speed Limit 30” sign mounted at the end of the speed zone. A member of the project team was positioned among several trees and partially obscured by an electrical junction box with the radar gun. Between approximately 9:45 a.m. and 11:00 a.m., speeds for 108 vehicles were measured. If vehicles were closely spaced, only the speed of the lead vehicle was measured to ensure independent speed measurements.

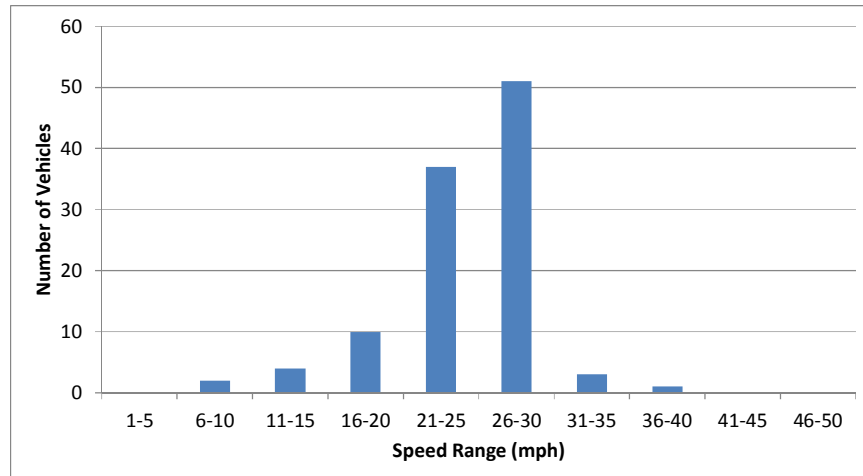


Figure 5-7. Histogram of vehicle speeds during the installation test.

Post-Installation Measurements: Results

Figure 5-7 shows a histogram of the speed data. The mean measured speed was 24 mph, and the median speed was 26 mph. The standard deviation was 4.66 mph. For comparison, the baseline speed measurement histogram is shown in Figure 5-6.

There is a statistically significant ($p < 0.001$) reduction in the mean measured speeds during the installation test compared to the baseline conditions. The speed display messaging appeared to have the intended effect of reducing speeds closer to 25 mph (from a mean of 30 mph and a median of 33 mph), and also reduced the standard deviation of the measured speeds from 7.88 to 4.66 mph.

6. DISCUSSION AND GUIDELINES

Both of the visual information treatments used in the present project appeared to have a favorable influence on driving behavior in terms of speed reductions at curve locations, and in terms of reducing speed variance in locations using a speed display system. The present chapter describes the applicability and preliminary guidelines for using similar approaches in real-world applications by NYSDOT.

Curve Chevron Treatments for Speed Reduction

An advantage of the use of chevron sign panels with modified sizes and spacing distances is that this treatment does not require electrical power or any particular specialized maintenance procedure to implement it. Of course it is necessary to keep documentation about the sizes and locations of chevron signs along each curve where it is used, so that damaged or missing panels can be replaced. To some extent, such documentation is already maintained by NYSDOT so that chevrons placed using the existing standard procedure can be replaced with those of the appropriate size. Panels having non-standard sizes (e.g., 27 by 33 inches) are needed, but precision in size selection is probably not an essential factor. Sign panels with the closest 2-inch interval in size are likely sufficient to convey the visual effect provided by the design method outlined below.

Design Procedure

The present section of this task report describes the calculation procedure for estimating the locations and sizes of sign panels to be located along a curve to simulate the approximate appearance of a virtual curve with a smaller radius.

Figure 6-1 shows an illustration of a drawing of an actual curve with a given radius, and a virtual curve with a smaller radius, illustrating the variables used in the calculation procedure. First, the actual curve onto which the signs are to be installed should be sketched onto a drawing, with the tangent point, or “entrance” of the curve located at (0,0) in Cartesian coordinates. Next, a virtual curve with the desired perceptual radius is sketched tangent to the actual radius at the tangent point of the first curve.

The desired perceptual sign positions are then indicated by placing points along the perceptual radius at a fixed distance determined by the Manual on Uniform Traffic Control Devices table for typical spacing of the chevron alignment sign on horizontal curves. Next, the observer’s position is defined with a point located ahead of the curve. Typically, this is about 25 to 30 m (80 to 100 ft) ahead of the entrance of the curve. Once the observer’s position is defined, sight lines are drawn from it to each sign position on the virtual curve with the desired radius, and then onto the actual curve. This is repeated for all of the sign positions planned for the curve. The Cartesian coordinates of the sight line’s intersection with the actual radius are recorded. These coordinates require no further manipulation and are the positions of the signs installed with the modified spacing. Next, for each sign, the length of the sight line from the observer to the sign location along the virtual curve with the desired radius (L_d), and from the observer to the sign location identified above along the actual curve (L_a) is determined. The size of the chevron sign

along the actual curve is determined by calculating the scaling factor (SF) separately for each individual sign location.

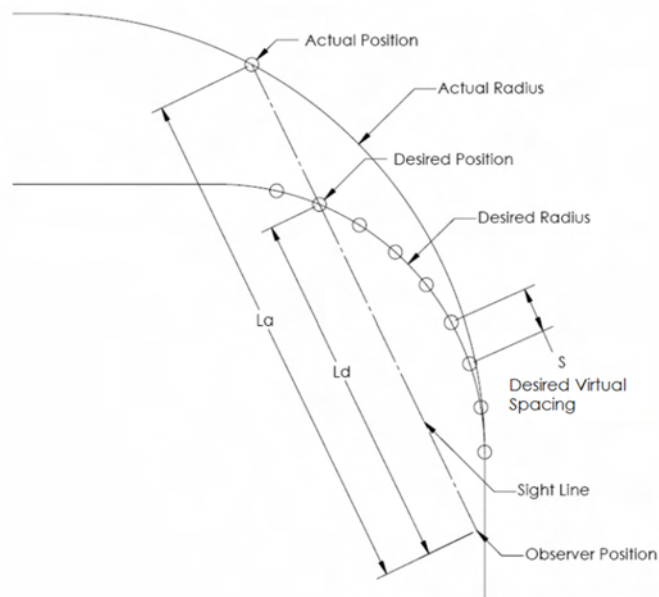


Figure 6-1. Illustration of locations and variables used to determine the modified chevron sign location and size.

The equation for the scaling factor (SF) of each sign is given by:

$$SF = L_a/L_d$$

The height (h) and width (w) of the chevron along the actual curve for each location is given by:

$$h = h_s SF \quad w = w_s SF$$

where h_s and w_s are the height and width of the standard chevron size that would normally be used (e.g., 24 inches and 18 inches).

Speed Display Treatment to Reduce Variability in Traffic Speed

Conclusions regarding the use of the graphical speed display that was evaluated in the field experiment and the display that was tested in real-world conditions are necessarily less firm than conclusions about the chevron treatments. The location for the real-world full scale test was not a state highway but rather a town roadway in an industrial park having a relatively low speed limit (30 mph). The real-world test did not include the triangular elements that were originally part of the display used in the field experiment. The messages used in the real-world test were brief (“25 MPH Speed Zone” for most speeds, and “Reduce Speed to 25 MPH” for those exceeding 30 mph) and so drivers probably did not have much difficulty interpreting them, as indicated by the large change in average speed and speed variability.

Nonetheless, the technique of conveying information about a desired speed to drivers can have measurable short-term impacts on vehicle speeds and importantly, on vehicle speed variance.

The project team did not evaluate situations in which the desired speed might be higher than that driven by a substantial portion of traffic. For example, after leaving a built-up area on a rural state highway, the speed limit might change from 35 mph to 55 mph. Another example is an entrance ramp to a limited access highway, where the advised speed on the ramp differs from the speed limit on the highway. In both situations, if some traffic remains at the lower speed, this could be considered a reduction in safety because a large speed differential might exist among vehicles on the roadway. This large speed differential can lead to rear-end crashes.

NYSDOT may wish to consider a limited deployment of such a system, or possibly even a display message reminding drivers of the increase in a speed limit. This approach would not have the real-time benefit of being able to tailor a message based on the speed of approaching traffic but might still reduce variability. Changeable message signs are sometimes already used in work zones, and real-time conditional messaging based on measured speeds might provide increased credibility to drivers navigating through work zones where such speed displays are installed.

Statement on Implementation

The results of the first part of the present project, on using chevron signs with modified sizes and spacing in order to reduce approaching vehicle speeds along curves, could be readily implemented as long as chevron panels with the necessary sizes were available. The Design Procedure outlined earlier in this chapter provides the necessary information for calculating the required sign panel sizes and spacing. The results of the second part of the project, using a speed display embodied in a changeable message sign, would require additional field trials at different locations, such as work zones, entrance ramp merge areas, or rural highways, before it could be recommended for widespread implementation. The results of the real-world installation described in the present report, however, provide a promising basis for conducting such trials.

7. REFERENCES

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