ASSESSING BENEFITS IN VEHICLE SPEED AND LATERAL POSITION WHEN CHEVRONS WITH FULL RETROREFLECTIVE SIGN POSTS ARE IMPLEMENTED ON RURAL HORIZONTAL CURVES

A Thesis Proposal

by

JONATHAN MICHAEL RÉ

MASTERS OF SCIENCE

February 13, 2009

Major Subject: Civil Engineering
INTRODUCTION

A horizontal curve requires a change in vehicle path alignment and a potential reduction in vehicle speed. The change from tangent alignment may present a challenging task during adverse driving conditions or to inattentive drivers. Delineation devices and horizontal curve treatments aid and assist drivers in safe and efficient horizontal curve negotiation. Delineation treatments provide advanced warning on the approach tangent and positive guidance throughout the curve. Chevron signs are a common type of delineation treatment and are widely utilized. Chevron signs are classified as a warning sign (1) and are placed on the outside of a curve.

Some agencies have been placing supplement retroreflective material on the sign posts to enhance the conspicuity and visibility of the sign. Figure 1 illustrates examples of current uses for the retroreflective material on the sign posts. The additional retroreflective material is applied with either adhesive backing or attached on a flat panel. There are commercial venders that sell such treatments, which are marketed as “Sign Post Covers” or “Reflective Panels.”

![Figure 1. Retroreflective Sign Post Examples (2)](image)

The only regulations or standards that govern the application of retroreflective material on sign posts are contained in the 2003 edition of Manual on Uniform Traffic Control Devices (MUTCD). The MUTCD states in section 2A.21 that “Where engineering judgment indicates a need to draw attention to the sign during nighttime
conditions, a strip of retroreflective material may be used on regulatory and warning sign supports (1).” The MUTCD specifies that the retroreflective material shall be at least 2 inches in width and shall extend from the bottom of the sign to 2 feet above the roadway surface.

The additional retroreflective material is intended to increase the visibility and conspicuity of the treatment. Curve negotiation and driver safety may improve as a result of earlier detection and enhanced guidance within the curve. Placing retroreflective material on the Chevron sign post is relatively inexpensive, easy to install, and requires practically no maintenance cost. The additional retroreflective material may be an attractive option due to its simplicity, low-cost, and practicality.

**PROBLEM STATEMENT**

The purpose of this study is to identify any incremental benefits in vehicle speed and lateral position when supplement retroreflective material is applied to Chevron sign posts on a two-lane rural highway curve. There has been a recent study that analyzed the change in vehicle speed when material was added to Chevron sign posts at one curve (3). This study will evaluate both speed and lateral lane position of vehicles at multiple curves to determine the effects of Chevrons with full retroreflective sign posts (ChevFull). If the current practice of applying supplement retroreflective material is going to continue, then it is a worthy endeavor to investigate the treatment in a more comprehensive study to ascertain if there are additional benefits in both speed and lateral position.

**RESEARCH OBJECTIVES**

This study analyzes three separate evaluation scenarios in a before and after experimental design. A before and after-after design isolates the specific effect of two treatments. The effects of both treatments will be compared to the before or Baseline evaluation. The Baseline evaluation employs no existing vertical delineation, such as Chevron signs and Post-Mounted Delineators (PMD). Data collection in the Baseline
evaluation will occur before the installation of either treatment. The treatment evaluation will be repeated in an identical manner to the Baseline evaluation after one of the treatments has been implemented. Researchers will directly compare the data from the different scenarios to determine any changes or modifications that can be attributed to one of the treatments. The Institute of Transportation Engineers (ITE) Manual of Transportation Engineering Studies has acknowledged that before and after experiments eliminate site-to-site comparisons, reduce the number of sites, and can be easily comprehended by both engineers and non-technical readers (4).

Evaluation scenarios consist of an existing Baseline evaluation (before), a standard Chevron evaluation (after), and an experimental ChevFull treatment evaluation (after). This study will collect vehicle speed and lateral position data on two horizontal curves that do not currently employ vertical delineation. Chevrons will be installed at one site and the ChevFull treatment will be installed at the other site. The first after data collection will replicate the same procedure as in the before or Baseline evaluation. Finally, researchers will remove the ChevFull treatment at one site and install it at the other site for the second after data collection. Statistical analysis techniques will analyze the data from each scenario and conclusions will be put forth. The objective of this study is to determine if the ChevFull treatment produced additional benefits in vehicle speed and lateral position compared to the Baseline and Chevron evaluations.

PRELIMINARY BACKGROUND

The author conducted a preliminary background review of past delineation studies. The reviewed studies focused on traffic safety effects, vehicle operation modifications, and applications of enhanced treatments. The initial review proved to be very beneficial and instrumental in the creation of this proposal.

An early study conducted in 1983 indicated that both PMD and Chevrons improved vehicle safety when implemented individually on analyzed curves (5). The study evaluated curve crashes before and after the installation of delineation treatments. Researchers found that chevrons significantly reduced the overall crash rate and PMD
significantly lowered single-vehicle run-off-the road crashes (5). The study concluded that both Chevron and PMD were adequate devices for delineating horizontal rural curves.

The reduced crash rates may be attributed to improved vehicle operational characteristics, which were identified in an Australian study conducted in 1983. The study used safety surrogates and vehicle operational characteristics to evaluate the benefits of Chevrons and PMD (6). Vehicle operational characteristics consisted of vehicle lateral position, encroachment rates, and speed. The results showed that the curves without delineation treatments were associated with the least desirable vehicle operational characteristics (6). Curves employing Chevron signs achieved significantly superior speed and lateral position results than curves with PMD. Chevrons achieved more uniform lane position and reduced improper vehicle paths. The results determined that the mean speed rose slightly for curves with Chevrons during daytime conditions, which was attributed to enhanced driver confidence and comfort (6). Chevrons still achieved an overall reduction in mean speed during nighttime conditions and the increase in speed during the day was deemed acceptable.

Besides standard delineation, enhanced or modified delineation devices may be beneficial in certain applications. A study on peripheral visual detection concluded that “where there is a need for early detection, the reflectivity of the target should be increased to assure timely recognition, information processing, decision making, and appropriate control actions (7).” Another study that assessed roadway delineation for older drivers also determined that enhanced delineation treatments should be considered in areas with a large population of older drivers and at roadway locations with sharp horizontal curves (8).

A study in 1996 investigated older driver curve perception when standard and enhanced delineation treatments were placed on horizontal curves (9). The objective of the study was to identify effective delineation treatments that increased perception distance and heightened awareness for older drivers. The researchers employed different treatment combinations that consisted of pavement markings, RPM, Chevrons, standard
PMD, PMD with fully retroreflective post, and T-post PMD (9). The T-post PMD treatment was an experimental treatment that employed a thin strip of retroreflective material that ran the length of the post. The PMD with fully retroreflective post had the entire PMD surface covered in retroreflective material. The researchers evaluated treatment effectiveness based on perception distance. The treatment combinations that provided the longest perception distance consisted of the T-post PMD and Chevrons (9). The effective treatments exhibited large retroreflective targets. Researchers also suggested that retroreflective material that extended from the top of the device to the ground aided in the detection task. This study only evaluated enhanced treatments on a closed-course test track when the viewer was stationary, which did not mimic a real-world driving situation.

The effects of retroreflective sheeting applied to Chevron sign posts were assessed in a field study conducted in 2003 (3). This study evaluated a 4 inch wide strip of fluorescent yellow prismatic sheeting that extended the entire length of a Chevron sign post. The treatment was placed on all Chevron signs at one rural horizontal curve. Vehicle speed was measured at two upstream tangent points, at the Point of Curvature (PC), and at the Mid Point (MP). Overall, the treatment achieved a moderate speed reduction. The treatment lowered speeds by 1.7 mph at twilight and by 1.6 mph at nighttime (3). Researchers concluded that the “use of fluorescent yellow microprismatic materials on Chevron posts or other curve delineation is recommended on an as-needed basis at spot locations where additional delineation is desired (3).”

A study at the Texas Transportation Institute (TTI) built upon the previous research by directly comparing the effects of multiple standard and experimental delineation treatments (10). The study tested five different treatments on a close-course track. The treatments consisted of a Baseline condition without any vertical delineation, PMD with standard retroreflective material, PMD with full length retroreflective material (PMD Full), Chevrons, and the ChevFull treatment. Twenty subjects drove ten laps on the track and saw each treatment in both directions. An instrumented vehicle
measured brake pedal and accelerator pedal displacement, lateral acceleration, specific Global Positioning System (GPS) location, and vehicle speed (10).

The PMD Full and the ChevFull treatments showed the most promising results and the least desirable vehicle operations were observed for the Baseline condition (10). Subjects released the acceleration pedal and initiated the brake pedal earlier when PMD Full and ChevFull treatments were present (10). The researchers reasoned that the enhanced delineation achieved a greater perception distance, which allowed drivers to decelerate earlier and minimize lateral acceleration on the vehicle.

Past research has indicated that Chevrons signs are effective in providing advanced warning and positive guidance when negotiating a horizontal curve. Chevrons significantly reduced crash rates in a previous study (5). The reduction in crashes could be attributed to improved vehicle operational characteristics (6, 8). Some researchers recommended placing enhanced delineation treatments at locations where early detection and curve warning is critical (6, 7). Placing retroreflective material on the Chevron sign post has obtained promising results (3, 10). These past studies focused on performance measures of detection distance and vehicle speed. Two of the studies both occurred at a close-course test track (8, 10) and one study evaluated enhanced treatments at only one roadway curve (3). The background review determined that there is a need to assess the effects of the ChevFull treatment on both vehicle speed and lateral position in an open-road study with more than one test curve.

RESEARCH METHODOLOGY

This section describes the proposed research methodology that will be implemented to achieve the stated objectives.

Task 1: Literature Review

A comprehensive background and literature review will assess past and ongoing research. The literature review serves as a guide and indicates how this study can contribute knowledge to the current transportation practice. The methodology will build
upon data collection and analysis techniques that have succeeded in past studies and learn from areas where experience and information were missing. Specific areas of interest for the comprehensive literature review are:

- an overview of potential hazards and crash types that are prevalent on horizontal curves,
- driving tasks and human factors that are related to negotiating a horizontal curve,
- vehicle operations that are associated with traffic safety, and
- application of additional retroreflective material to the post of a Chevron sign.

**Task 2: Measures of Effectiveness**

Measures of Effectiveness (MOE) will identify any beneficial effects or modifications in horizontal curve negotiation that are attributed to the ChevFull treatment. Some of the unfavorable vehicle operations that occur on horizontal curves include lane line encroachments, a considerable shift in lateral position between the PC and the MP, and major reduction in speed from the PC to the MP (3, 6, 11). MOE include both longitudinal components (speed) and lateral components (lateral lane position). MOE that will assess vehicle operational characteristics are:

- the mean lateral lane position at the PC and MP,
- the standard deviation in lateral position at the PC and MP,
- the mean change in lateral position from the PC to the MP,
- the lane line encroachment rates at the PC and MP,
- the mean speed at the PC and MP,
- the standard deviation in vehicle speed at the PC and MP, and
- the mean change in vehicle speed from the PC and the MP.

**Task 3: Site Selection**

This study will collect and analyze data from two selected curves. The number of test sites will be based on available time and resources and two sites can yield
acceptable results for recommendations. Knowledgeable Texas Department of Transportation (TxDOT) and TTI staff will assist in the site selection process. Curve candidates will be filmed and researchers will examine the video for a detailed assessment. Basic requirements for the preliminary horizontal curve select list are that:

- roadways shall be classified as a rural highway with a posted speed limit above 50 mph,
- curves shall require a reduction in vehicle speed from the posted speed limit,
- curves shall be located on the TxDOT roadway system, and
- curves should have an Average Daily Traffic (ADT) that is greater than 1,000 vehicles per day.

Selected curves shall have a centerline, edgelines, and Raised Pavement Markers (RPM). The total travel width of the roadway shall be 20 feet or greater. The Curve Warning signs (W1-1 or W1-2) and Advisory Speed signs (W13-1) shall be present on both upstream tangent directions. The curves should experience minimal interference from intersecting roadways or driveways in the surrounding area. It is a goal to minimize outside interference from turning vehicles that could distort vehicle operations. Curves with guardrail, construction, railroad crossing, or other objects are deemed likely to influence vehicle speed and lateral position and will be rejected. Curve candidates should have similar geometric characteristics. Similar curves may have a deflection angle that only differs by about 5 degrees opposed to two curves where the difference is 45 degrees. Selecting similar curves is a necessary step to minimize uncertainty and strengthen the validity of the results by avoiding curves that differ considerably. Isolating two curves with exact geometric characteristics is not an objective of this study.

**Task 4: Treatment Implementation Schedule**

This study will acquire data in three separate scenarios, which include a Baseline, a Chevron, and a ChevFull treatment evaluation. Table 1 contains the matrix of proposed treatment implementation. Data collection devices will first measure speed
and lateral position data in the Baseline evaluation. TxDOT staff will install the treatments. After installation, there will be a minimum 10-day acclimation period where data will not be measured. This acclimation period allows the novelty or surprise effects of the new treatment to subside. Data collection will resume after the 10-day period. The installation, acclimation, and data collection process will repeat for the final after-after evaluation.

<table>
<thead>
<tr>
<th>Selected Sites</th>
<th>Before</th>
<th>After</th>
<th>After-After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>Baseline</td>
<td>ChevFull</td>
<td>Chevrons</td>
</tr>
<tr>
<td>Site 2</td>
<td>Baseline</td>
<td>Chevrons</td>
<td>ChevFull</td>
</tr>
</tbody>
</table>

**Task 5: Chevron Treatments**

This study will employ the prismatic fluorescent yellow Chevron sign (W1-8). The sign will have dimensions of 24 inches in width by 30 inches in height (12). Figure 2 depicts a standard Chevron sign. A wedge anchor assembly will serve as the post system. Chevron signs will be mounted back-to-back on one sign post and TxDOT staff will orientate the sign as much as possible toward the direction of travel. The ChevFull treatment will be comprised of prismatic fluorescent yellow retroreflective material applied to 4 foot section of PVC pipe. The retroreflective material will completely encircle the PVC pipe from top to bottom. The 2.5 inch diameter PVC pipe will then be placed over the 2 \( \frac{3}{8} \) inch Chevron sign post. The mounting brackets will secure the PVC pipe to the sign post to restrict movement or twisting. The retroreflective material will not be applied directly to the sign post because removing the sheeting may leave adhesive residue that could collect dirt and debris.
Horizontal curve radius and curve advisory speed will determine the spacing requirements for individual Chevron signs. The spacing requirement comes from the Roadway Delineation section of the Texas MUTCD (13). This study will employ the smaller spacing distance for each site and the calculated number of signs will be rounded up to the nearest whole number. There will be a 12 foot offset between the nearest travel lane and the nearest part of the sign (1, 13). All materials utilized for this evaluation will comply with TxDOT and MUTCD standards.

**Task 6: Data Collection**

Data collection devices will collect vehicle speed and lateral position data at the PC and the MP on both curve approaches. The PC and the MP data collection locations were selected because they were easily referenced, they provided uniform locations at both sites, and they have produced favorable results in previous research (3, 6, 11). Figure 3 shows the data collection locations. Control points located approximately one mile upstream from the curve will measure unconstrained free-flow speed. The control points will provide speed data outside of the influence of the treatments, which will indicate if vehicle characteristics and patterns have drastically changed between evaluation periods.
The data collection process will employ traffic classifiers and roadway sensors to measure vehicle data. Roadway sensors layout resembles the letter “Z” and the sensor layout is referred to as the Z-configuration. Figure 4 depicts the Z-configuration, which was adapted from a previous TTI study (14). The parallel sensors measure vehicle speed from the known distance between sensors and the time it takes a vehicle to travel across that distance. All three sensors work simultaneously to yield lateral position data. Lateral position data is a product of known geometric proportions of a right triangle, vehicle speed, and travel time.
Task 7: Data Formatting

The analysis will format and process the raw vehicle data. The researcher will remove constrained vehicles with the intent to isolate the effects of the treatments and minimize vehicle interaction, which may add bias to the results. A previous study identified a headway of 7 seconds as the threshold for determining free-flowing vehicles on rural highways (15). The formatting process will identify free-flowing uninhibited vehicles when there is a headway of 7 seconds or greater between successive vehicles.

Formatting will separate heavy vehicles and passenger vehicles into separate lists for the analysis. A vehicle with 3 or more axles or a vehicle with single axle spacing greater than 15 feet in length will identify a heavy vehicle (16, 17). Data for both passenger vehicles and heavy vehicles will be grouped into two different time classifications of night and day. The night data refers to the hours when there is insufficient natural sunlight and the day data consists of hours with ample sunlight. The formatting process will minimize the effects of twilight, which is the period between ample and insufficient sunlight. Twilight may require drivers to use their headlights and the glare from the lower angle of the sun may also hinder a driver’s vision. To
minimize twilight effects, the formatting process will remove vehicles arriving 30 minutes before and after sunrise and vehicles arriving 30 minutes before and after sunset.

The lateral position data will yield centerline and edgeline encroachment rates. Edgeline encroachment rates are easily established since lateral position measurements are collected from the outside edge of a vehicle’s right tire. Centerline encroachment rates cannot be obtained for each individual vehicle and must be approximated by two aggregated track width values. An 80 inch track width is the maximum value from a list of 45 common sport utility vehicles, vans, and trucks. A larger and more conservative track width accounts for the majority of the possible centerline encroachments. A 61 inch track width is the average width of 14 top selling sedans and represents the average vehicle.

A vehicle tracking technique will follow individual vehicles from the PC to the MP. The vehicle tracking provides an exact account of the change in speed and lateral position from the PC to the MP. This is a more accurate method than directly comparing the means from the PC and the MP locations. The number of axles and axle spacing provides the reference data to correctly match vehicles between the two locations. The change in vehicle speed and lateral position is obtained with the following equation:

\[ \Delta = X_{MP} - X_{PC} \]

Where:

\[ \Delta \] = change in vehicle speed or lateral position from the PC to the MP,

\[ X_{MP} \] = speed or lateral position data point from the MP, and

\[ X_{PC} \] = speed or lateral position data point from the PC.

**Task 8: Statistical Analysis**

The analysis will utilize common statistical techniques to determine if the ChevFull treatment produced a significant difference in the MOE compared to the Baseline and Chevron evaluations. The statistical methods will provide legitimacy and validity to the findings. A Multivariate Analysis of Variance (MANOVA) assesses the
differences between mean values of multiple populations. The analysis of the main effects and the interactions between the independent variables will determine if they produced a significant effect on the dependent variables. If effects are significant, then the test will reject the null hypothesis and accept the alternative hypothesis. This analysis defines the null and alternative hypothesis as:

- Null hypothesis (H₀): the test variable or interaction failed to produce a significant difference between evaluation means, and
- Alternative hypothesis (H₁): the test variable or interaction achieved a significant difference between evaluation means.

Tukey’s Honestly Significant Difference (HSD) post-hoc test will compare the treatment mean of each evaluation scenario. The Tukey’s HSD will determine if the ChevFull treatment means are significantly different from the Chevron and Baseline evaluation. The Z-test will determine significant differences in the encroachment rates or percentages. Speed and lateral position variance can be assessed by the F-test. The independent two-sample T-test will compare the mean speeds at the upstream free-flow control points. The statistical analysis will perform all tests at a confidence interval of 95 percent.

**Task 9: Recommendations**

The author will assess the treatment results to identify meaningful changes in vehicle operational characteristics. Recommendations will derive from both the statistical analysis and engineering judgment. The recommendations address the benefits for both Chevrons and the ChevFull treatment over the Baseline Evaluation. The conclusion of the study determines if the ChevFull treatment did or did not achieve a significant difference in the MOE compared to standard Chevrons.

**RESEARCH BENEFITS**

It is expected that the results from both Chevrons and the ChevFull treatment will be significantly different from the baseline conditions. Standard Chevrons have
achieved beneficial results in previous studies (6, 8, 11) and it is likely that Chevrons will yield similar advantageous results in this study. The author presumes that the additional retroreflective sheeting will produce moderate benefits in both speed and lateral position over the standard Chevrons. Recommendations will be based on the magnitude of the differences between the two Chevron treatments. If one treatment achieves more desirable results, than that treatment will be recommended over the other treatment.
REFERENCES


2. Images from Schoolmasters website.


10. Chrysler, S., J. Re, K. Knapp, D. Funkhouser, and B. Kuhn. Driver Response to Delineation Treatments on Two-Lane Horizontal Curves. FHWA/TX-09/0-5772-1, Texas Transportation Institute, College Station, TX, October 2008.


